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16. Abstract

This study describes rapid transit system implementation, design, and construction procedures. The relationships and responsibilities of governmental, private, and public groups involved in planning and implementing an urban rapid transit system are discussed. In this report, techniques and processes of cut-and-cover and tunnel construction are discussed in detail. Environmental impacts of this construction as well as safety and insurance aspects are presented. Physical and institutional controls (sensitivities) on construction are identified. Physical controls include such factors as utility density, traffic conditions, maintaining existing structure integrity, ground conditions, and weather. Institutional controls include the project schedule, right-of-way acquisition, material and equipment supply, and labor agreement and productivity.

Three San Francisco Bay Area Rapid Transit (BART) projects and two Washington Metropolitan Area Transit Authority (WMATA) projects are analyzed herein with respect to time schedules, costs, and sensitivity to physical and institutional controls. These data are utilized in developing generalized models of four specific types of underground construction: cut-and-cover station, cut-and-cover line, free-air-driven tunnel, and compressed-air-driven tunnel. The models presented herein are a planning tool for evaluation of the alternative types of underground construction in a transit system with respect to local costs and physical and institutional controls. Possible future tunneling cost-reduction techniques and recommendations for further research are made. +

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SYSTEMS ANALYSIS OF RAPID TRANSIT UNDERGROUND CONSTRUCTION
Volume II: Sections 6-9 and Appendixes

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DECEMBER 1974

FINAL REPORT

Prepared for
U.S. DEPARTMENT OF TRANSPORTATION
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Section 6

STUDY PROJECTS

INTRODUCTION

The study projects selected from the BART and WMATA Transit Systems formed the cornerstones on which the study as a whole was based. A detailed analysis of these projects accomplished the following:

- Established the appropriate classifications of the various work events
- Determined how these work events could be quantified
- Assigned costs to the work events
- Determined the physical controls that influenced the costs of the work events
- Determined the actual cost effects of these physical controls on the work events
- Provided a formulation for an appraisal of construction schedules
- Provided a formulation for the evaluation of institutional controls

The three BART projects had been completed at the time of study, and documented construction histories existed for two of these projects; the third (a cut-and-cover line section) had not been documented, though most of the data required could be established. Because the projects from the WMATA system were still under construction at the time of the study, they lacked complete cost and schedule information; nevertheless, they provided a great deal of useful information on the different geographical and productivity factors and on owner philosophies.

Owing to the importance of the relative costs of the work events, the summary of project bid prices for each project is included in the Appendix. The Appendix also contains the change order records, where they were available, and data concerning system-wide labor agreements and insurances.

SELECTION OF THE PROJECTS FOR STUDY

Three criteria governed the selection of the projects. These stipulated that (1) typical present-day downtown underground transit structures were to be represented (this was the most important criterion); (2) that the locations reflect the typical construction conditions that might be encountered in systems to be built in other parts of the country; and (3) that the cost and schedule records, historic data, and key engineering and construction personnel who would be able to provide supplementary information on the many facets of the work undertaken should be available.

The project structures selected, together with the methods of construction, were:

- Passenger stations in reinforced concrete constructed in cut-and-cover
- Line structures (connecting the stations) in reinforced concrete constructed in cut-and-cover
- Line structures constructed by tunneling with segmented steel linings, in free air or in compressed air
- Line structures constructed with sets and lagging followed by reinforced concrete linings in free air

Candidate projects representing these structures were screened within the BART and the WMATA systems, and a final selection was made of five projects as follows:

Stations	BART Project K0016 WMATA Project C0021
Cut-and-Cover Lines	BART Project S0031 BART Project K0016 WMATA Project C0021
Tunnel Line - Free Air	BART Project K0016 WMATA Project C0041
Tunnel Line - Compressed Air	BART Project S0022

The selection of projects involving similar types of construction from the two different transportation systems - BART in San Francisco, and WMATA in Washington, D. C. - provides a comparison of productivity between different areas of the country and highlights the differences in the basic contracting procedures. The engineering designs for the stations in the two cut-and-cover station contracts are basically different: the BART Station K0016 is an orthodox beam-and-slab and column structure, with structural separation between mezzanine and station platforms the WMATA Station C0021 is a clear span arch structure, which embraces both mezzanine and station platforms.

Contracts from the BART system were essentially complete, and full construction reports were available for Projects K0016 and S0022. The contracts from the WMATA system were still in progress, but were sufficiently advanced to provide a complete picture of all phases of the construction. In the following discussion, each of the study projects is described in detail.

DESCRIPTION OF PROJECTS

The entire San Francisco Bay Area Rapid Transit System is shown in Figure 6-1. Locations of the three projects from the Bay Area Rapid Transit System (BART) are shown in Figures 6-1a and 6-1b. The locations of the two projects from the Washington Metropolitan Area Transit Authority (WMATA) are shown in Figure 6-2.

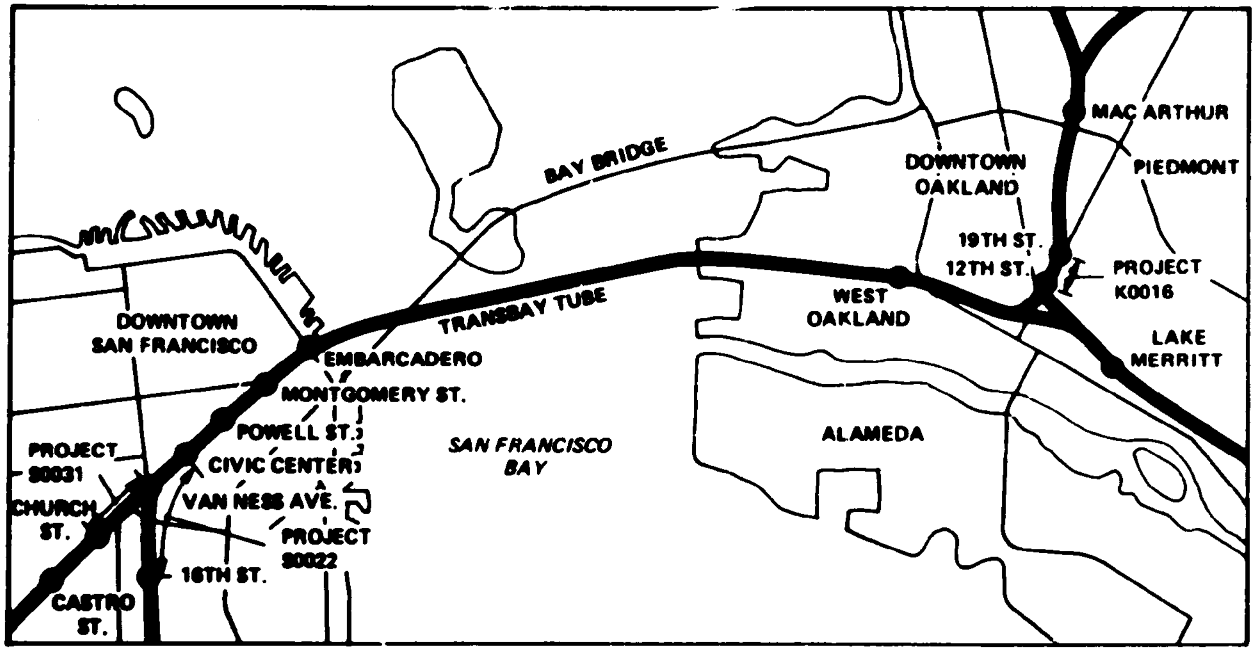


Figure 6-1. San Francisco Bay Area

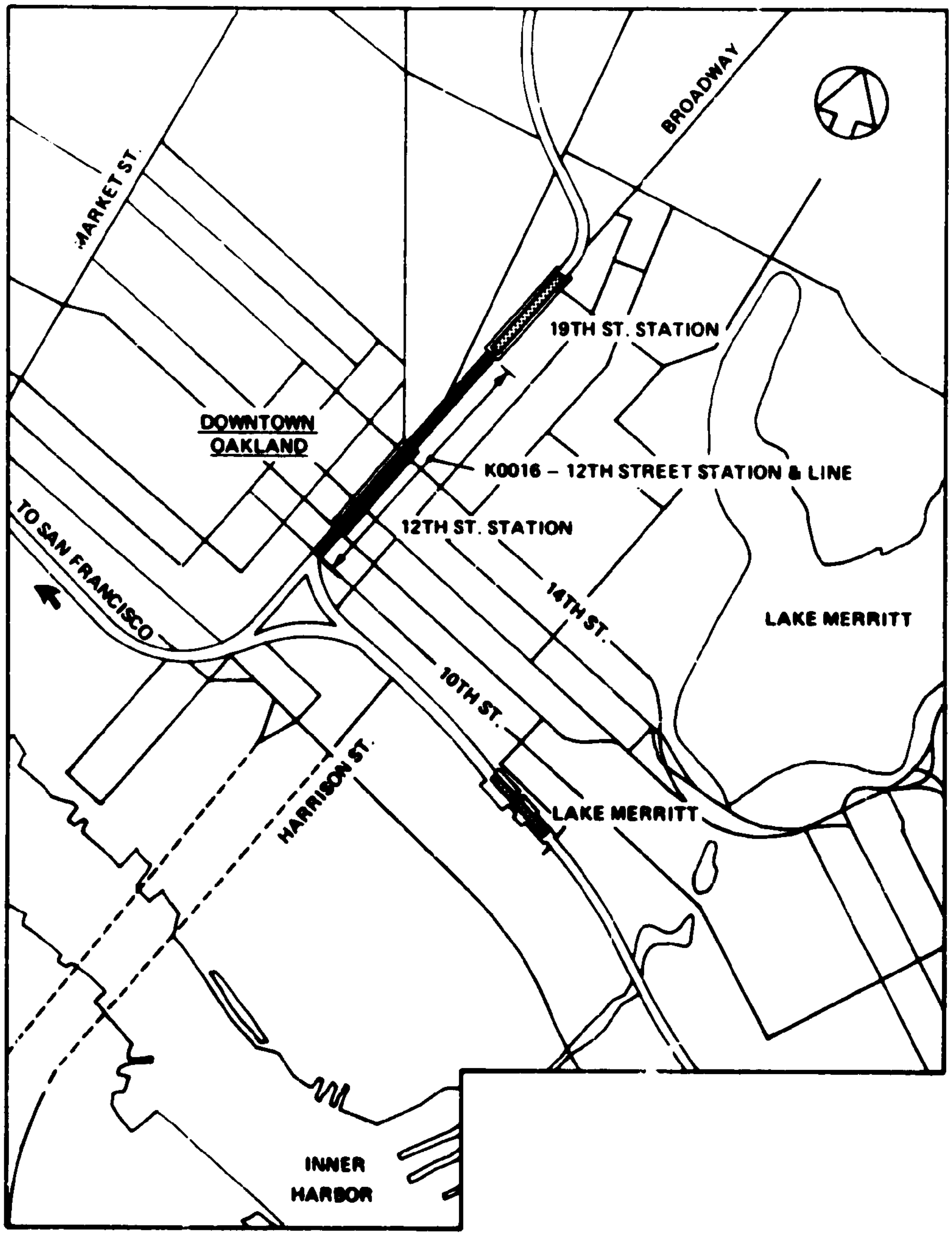


Figure 6-1a. Location of BART Project K0016 in Oakland

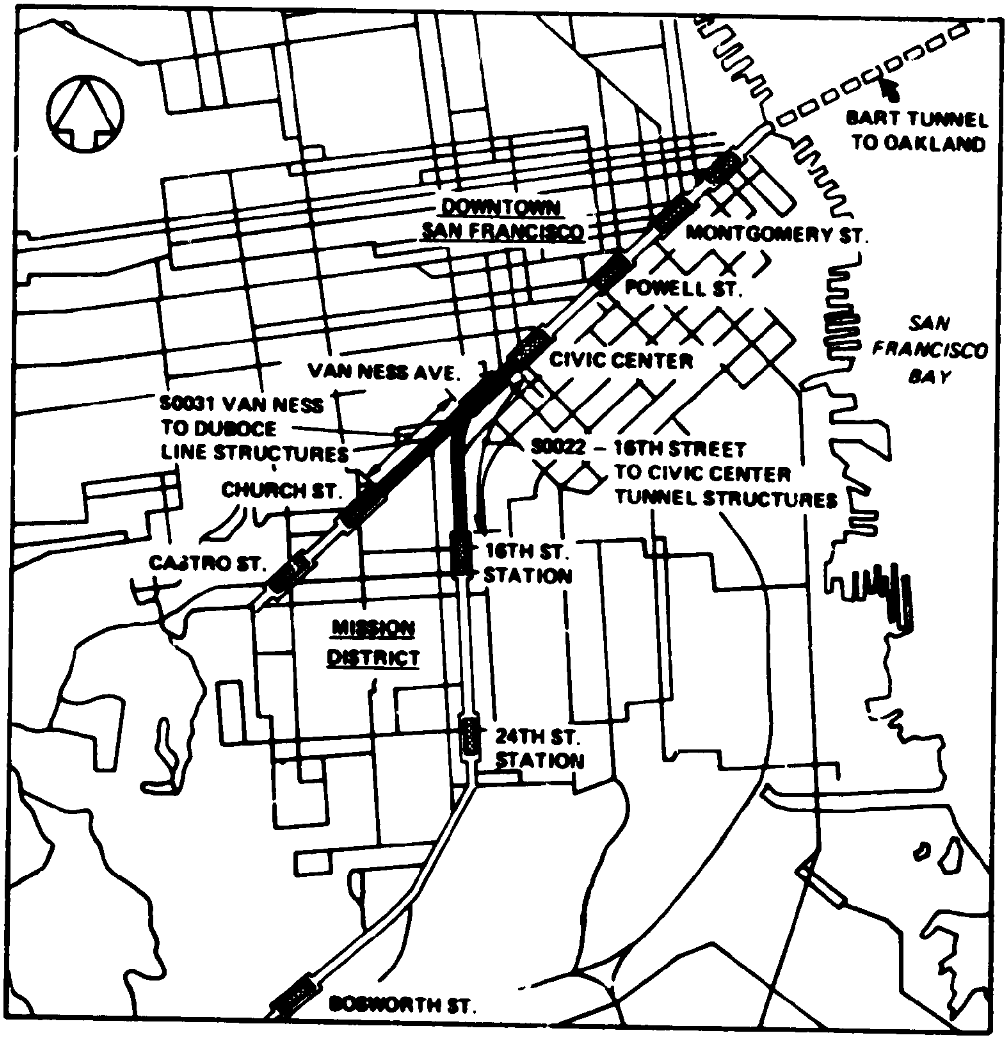


Figure 6-1b. Location of BART Projects S0022 and S0031 in San Francisco

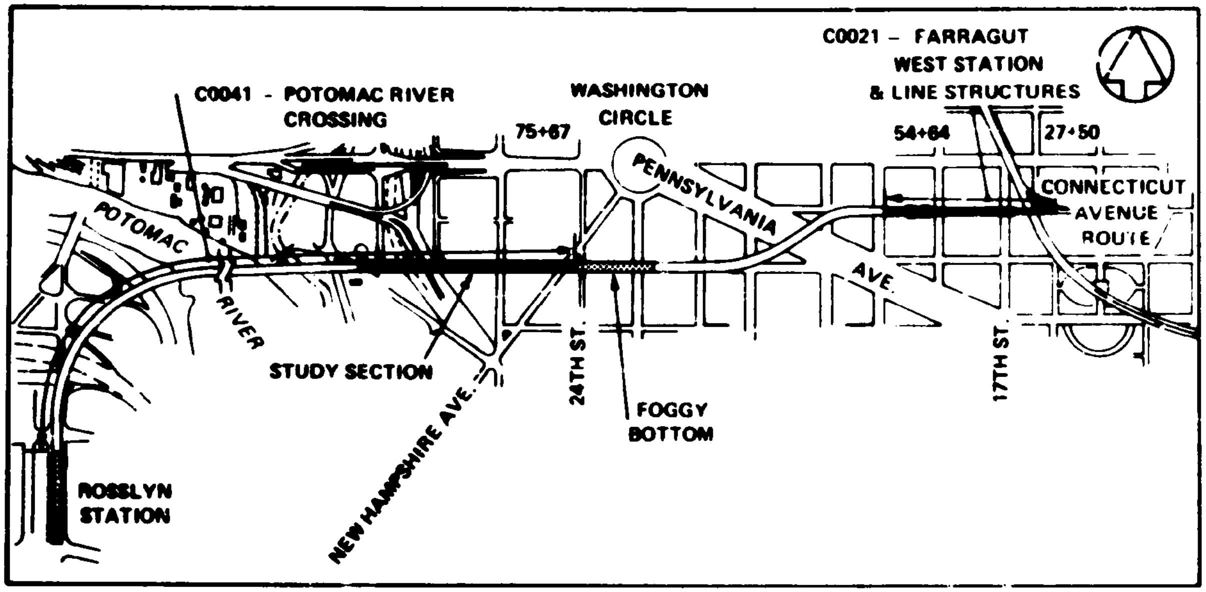


Figure 6-2. Location of WMATA Projects C0021 and C0041 in Washington, D.C.

A general dimensional and functional description is provided for each project, together with a brief discussion of the principal construction features.

The cost information included in the Appendix represents the actual construction costs of the projects and has not been escalated to those tabulated in Table 6-2 and Table 6-3.

A discussion of the schedule histories and the causes and effects of any delays encountered is included in this section.

<u>BART Project K0016 - Station and Tunneled Line Structures - Oakland</u>

The project, illustrated in Figure 6-3, consisted of a station structure with three 700-ft platforms, on two levels, with a 700-ft-long mezzanine area on an upper (third) level; a cut-and-cover line structure 200 ft in length on the south end; three 1,200-ft tunneled line structures on the north end; and other structures, including ventilation structures to the surface at each end of the station, fan and pump rooms, electrical service rooms, entrances to the station stairs, and provisions for escalators. The station structure was about 70 ft deep, the top being about 15 ft below ground.

Not included in the contract were station finishes and mechanical and electrical equipment, except for owner-furnished fans and pumps. The station (60 ft wide except at the entrances) and line structures were located almost in the center of Broadway, Oakland, and the construction intercepted several cross streets.

Numerous utilities, including gas, water, sewer, and electricity, had to be rerouted or supported during the construction. The ground was generally dense sand clay or clay/sand stratum with a high water table that

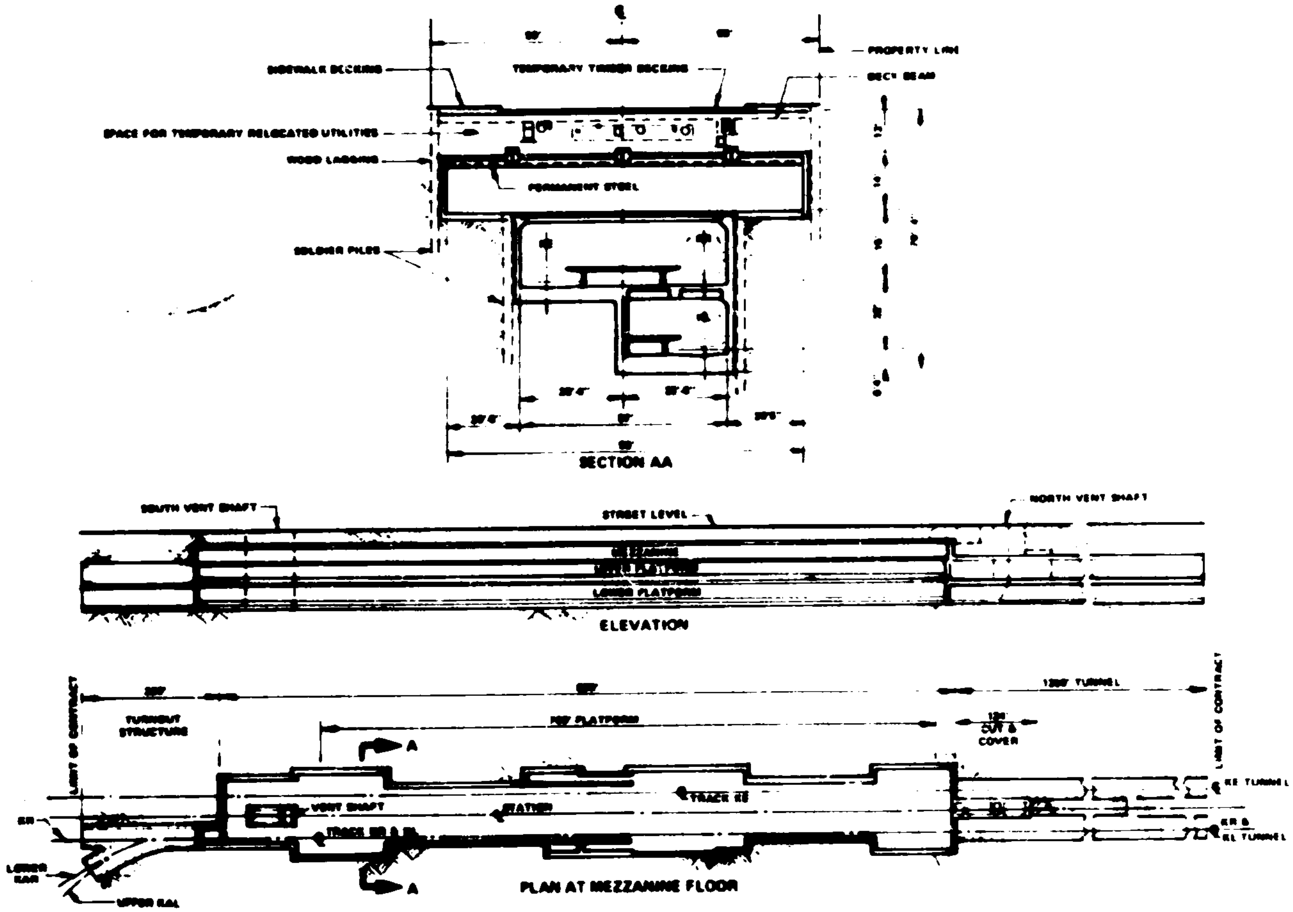


Figure 6-3. BART Project K001b, Twelfth Street Station and Line, Oakland

necessitated dewatering. Traffic was heavy, and maintenance of all the traffic by decking over the construction was required, with the exception of one lane which was set aside as the contractor's working area. Selected buildings on either side of the street required underpinning.

The bidders were given two alternative structural systems for pricing:

- Installation of soldier-pile, slurry concrete walls to be incorporated as a part of the permanent walls of the station
- Installation of soldier piles, and lagging and construction of the station walls as separate entities

The successful contractor elected to use the second system. Since the specifications required that the tunnels be driven under compressed air, the contractor installed a compressed air plant and installed air locks in one tunnel. However, because the ground conditions along the tunnel routes were better than originally expected, neither air plant nor locks were used, and the tunnels were constructed in free air. This resulted in a cost savings to both the owner and contractor.

Figures 6-4 and 6-5 show the tunnel workshafts and initial assembly of shields at the north end of the station.

The bid price for the construction was $19,429,000, not including $755,000 in precontract utility relocation costs. Changes in the work and construction conditions increased the cost by 4 percent ($765,000) to $20,194,000. The original time of construction was extended by 198 days from 795 days to 993 days. The starting date was February 1967, and the schedule date of completion was April 1969. The project was completed in November 1969.

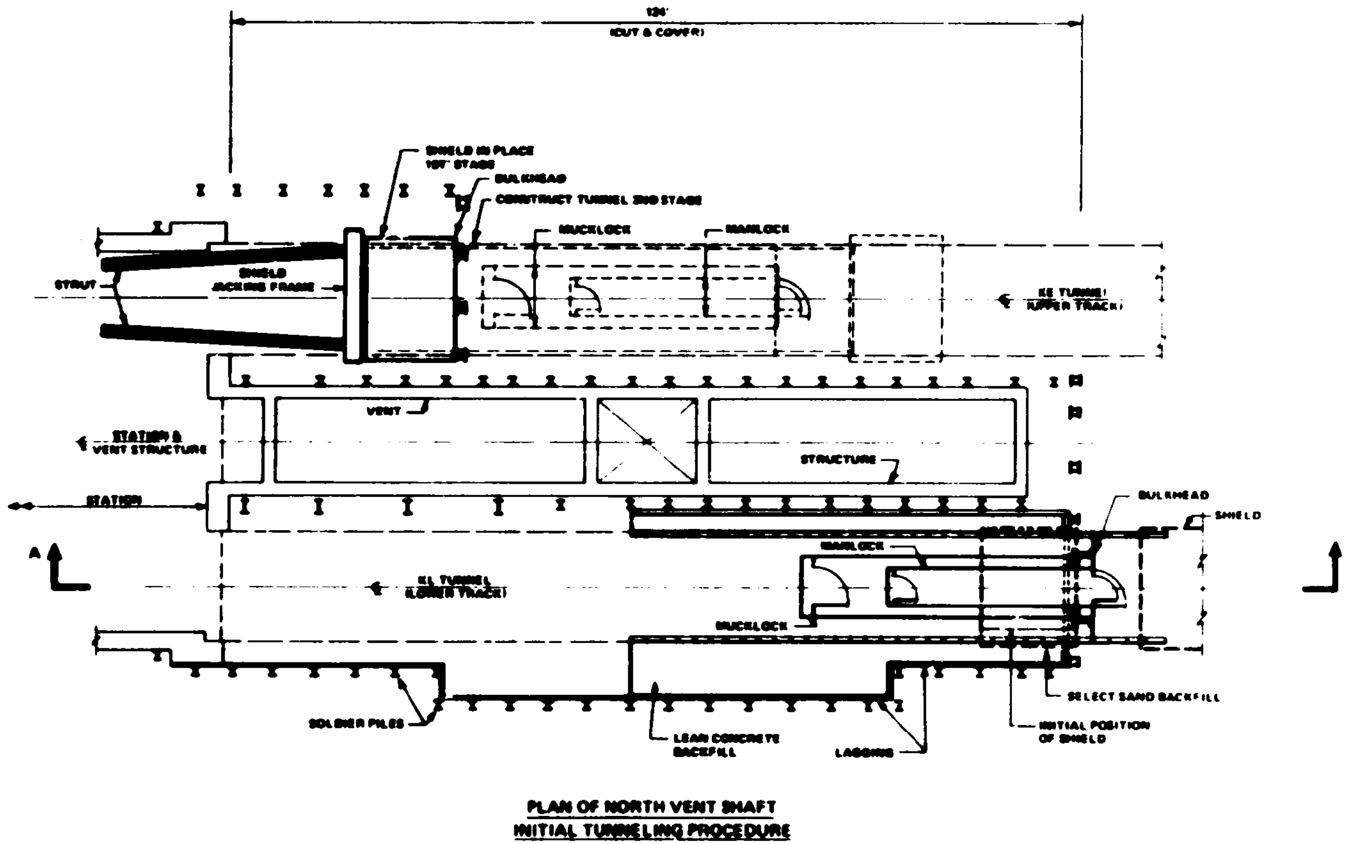
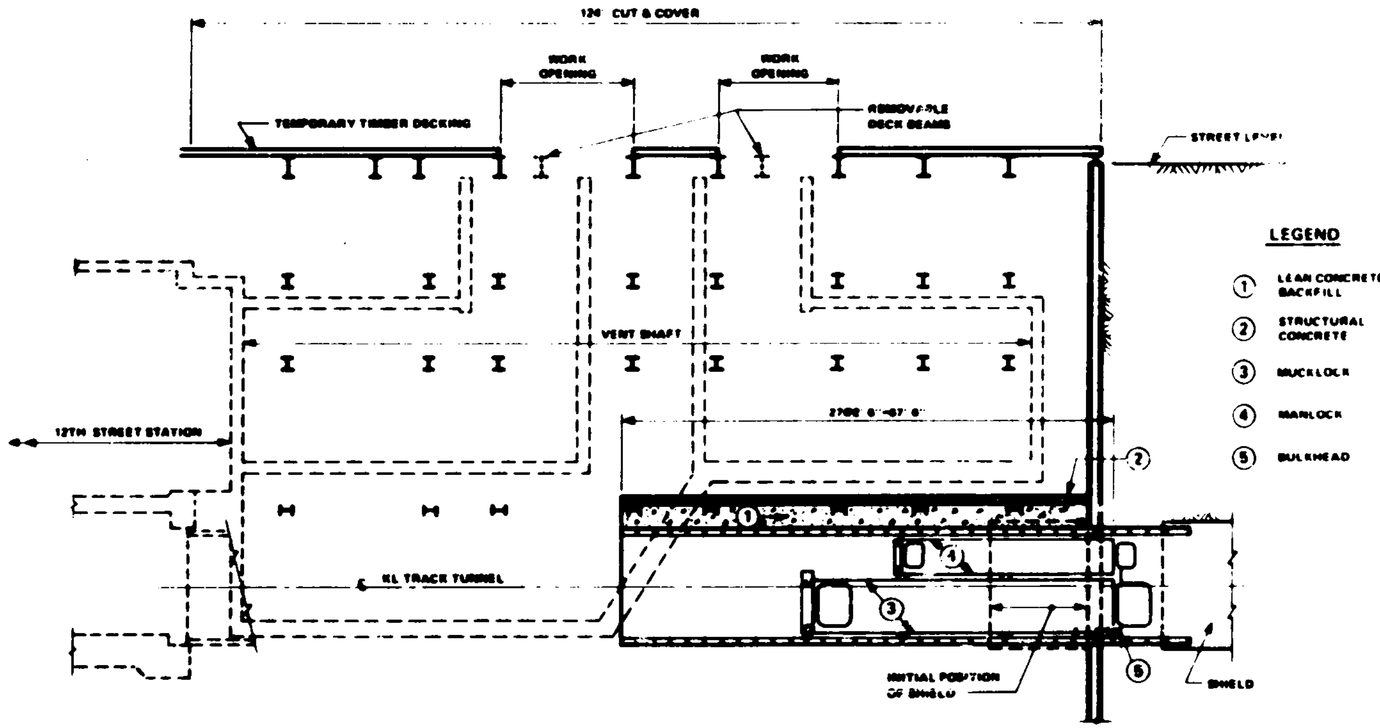


Figure 6-4. BART Project K0016, Twelfth Street Station and Line, Oakland – Tunnel Workshaft Plan



SECTION A-A

Figure 6-5. BART Project K0014. Twelfth Street Station and Line, Oakland – Tunnel Workshaft Section

BART Project S0022 - Sixteenth Street to Civic Center Tunnel Structures-San Francisco

This project, depicted in Figure 6-6, called for the construction of two 5,120-ft tunnels, 16.5 ft inside diameter, with one vertical ventilation shaft and several horizontal cross passages. The tunnels were lined with the BART standard 16-25 and 16-40 welded steel segmented rings. The work was planned on the assumption that the contractor would wish to use the ventilation shaft (which was about midway along the tunnels and provided a good working area at the surface) as a workshaft from which to tunnel in both directions. However, the successful contractor elected to construct, at his own expense, a workshaft at one end of the project so that a tunnel could be driven full length — a shield to each tunnel. The workshaft is shown in Figure 6-7.

The tunneling was through water-bearing sands and silts, and compressed air was used in addition to dewatering to maintain the stability of the tunnel face. There were numerous utilities of various degrees of importance along the tunnel route, but none of these was modified or relocated except around the tunnel workshaft. The ground in the vicinity of the tunnel route contained compressible lenses. To minimize ground settlements which could adversely affect utilities and nearby buildings, dewatering was limited to 30 ft above the top of the tunnels, and particular care was exercised in the tunneling operations.

The natural groundwater was about 10 ft below the surface with the tunnel inverts up to 80 ft below the surface. The contractor installed deep wells 20" in diameter, from 80 ft to 140 ft in length along the tunnel route for partial dewatering of the ground to about 30 ft above the tops of the tunnels. The tunnels were then driven under compressed air at 12-15 psi in order to control the remaining water.

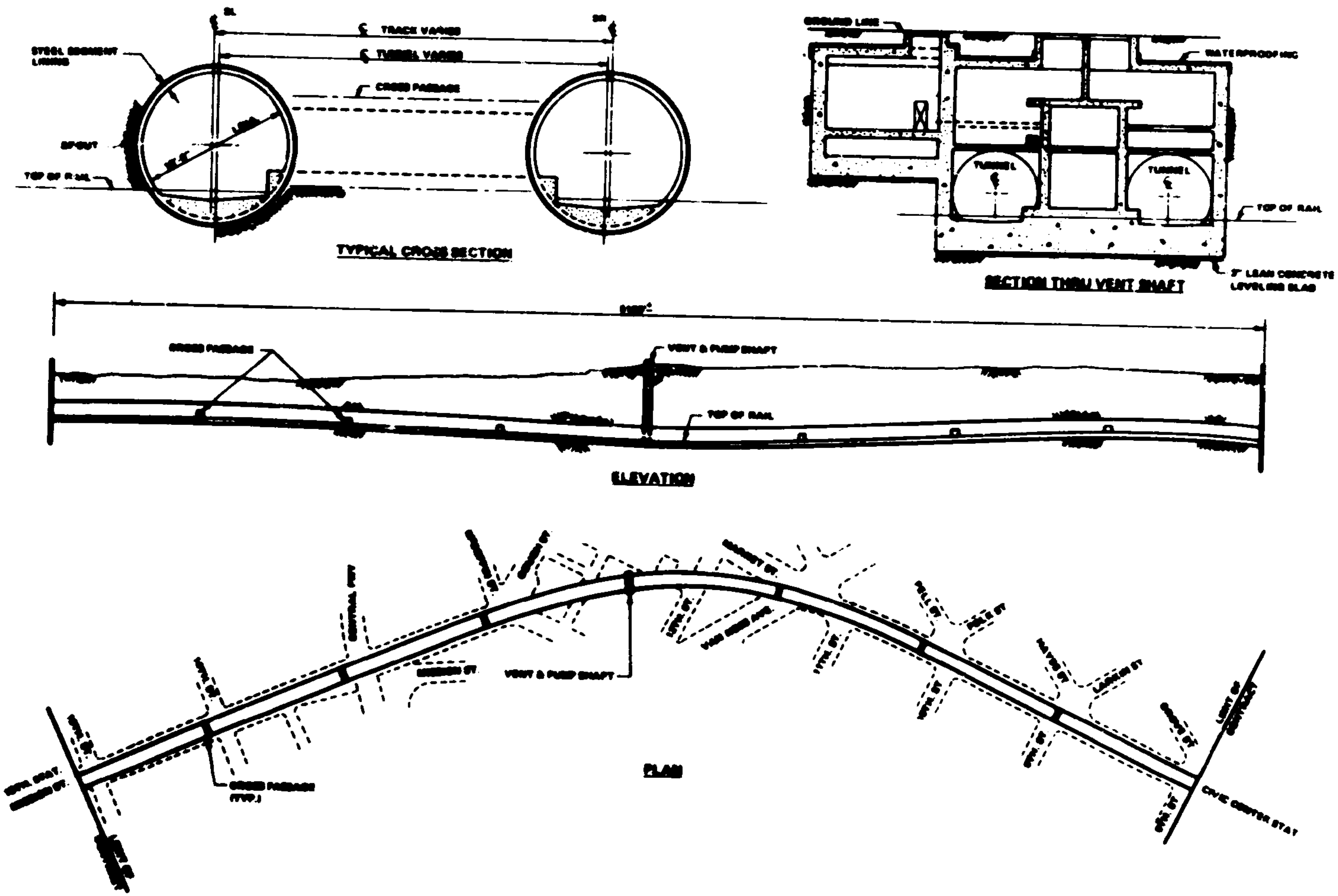


Figure 6-6. BART Project S0022, Sixteenth Street Station to Civic Center, San Francisco

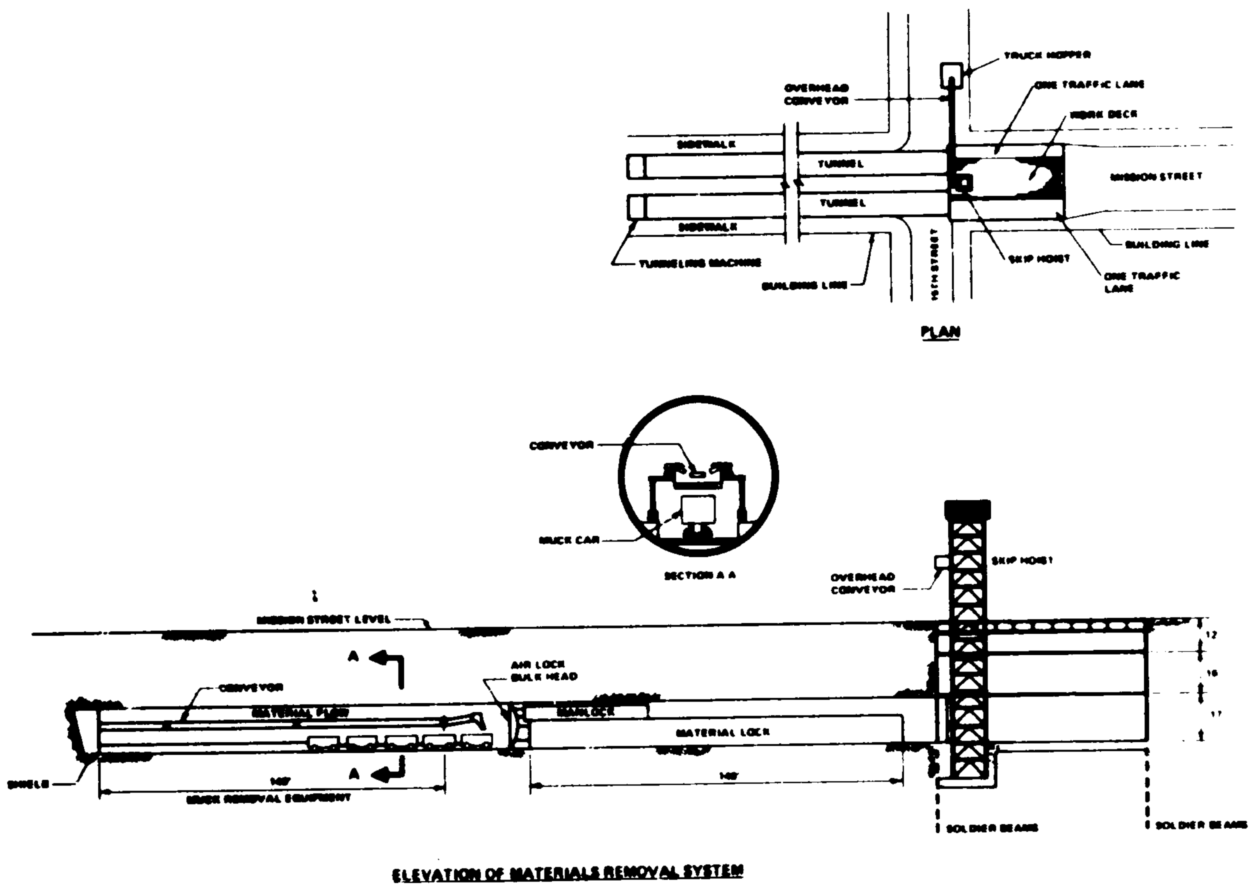


Figure 6-7. BART Project S0022, Sixteenth Street Station to Civic Center, San Francisco – Tunnel Workshaft

The tunnels passed close to or beneath several major structures. Underpinning of these structures, although contemplated, was not undertaken since it was felt that with the groundwater control described, coupled with the contractor-selected rotating-breast-board tunneling machine, ground settlements would be minimal and the resulting damage to buildings small. The ventilation shaft, 98 ft deep and 63 ft by 28 ft in plan, was constructed by the slurry wall technique, thereby avoiding underpinning of the adjacent buildings. Ground settlements typically were 0.5" from deep-well dewatering and 0.5" from the tunneling operations, and no damage claims were made by any of the building owners.

Except for the area around the workshaft where decking was installed, the tunnel construction did not conflict with the surface traffic. Tunnel excavation was performed with a MEMCO tunneling machine, and the muck was removed by conveyor and rail to a skip hoist in the workshaft.

Change orders, including those for the delays mentioned, increased the original contract price from $17,764,000 to $18,371,000, or about 3.4 percent. Construction was started on November 26, 1966, and the schedule called for completion in 850 days. This had to be extended to 1,170 days for several reasons, including the terminal interface with an adjoining project that was not ready to receive the tunnels. The project was completed in December 1969.

BART Project S0031 - Van Ness to Duboce Street Line Structures - San Francisco

As shown in Figure 6-8, this project required the construction of 2,591 ft of twin-box and 910 ft of single-box cross-section, including two 700-ft tunnels, one ventilation shaft, and one portal structure. The contract also called for the relocation and restoration of the Muni streetcar tracks and electrical facilities, as well as the normal street utilities. Originally, the entire contract was designed for cut-and-cover construction, but

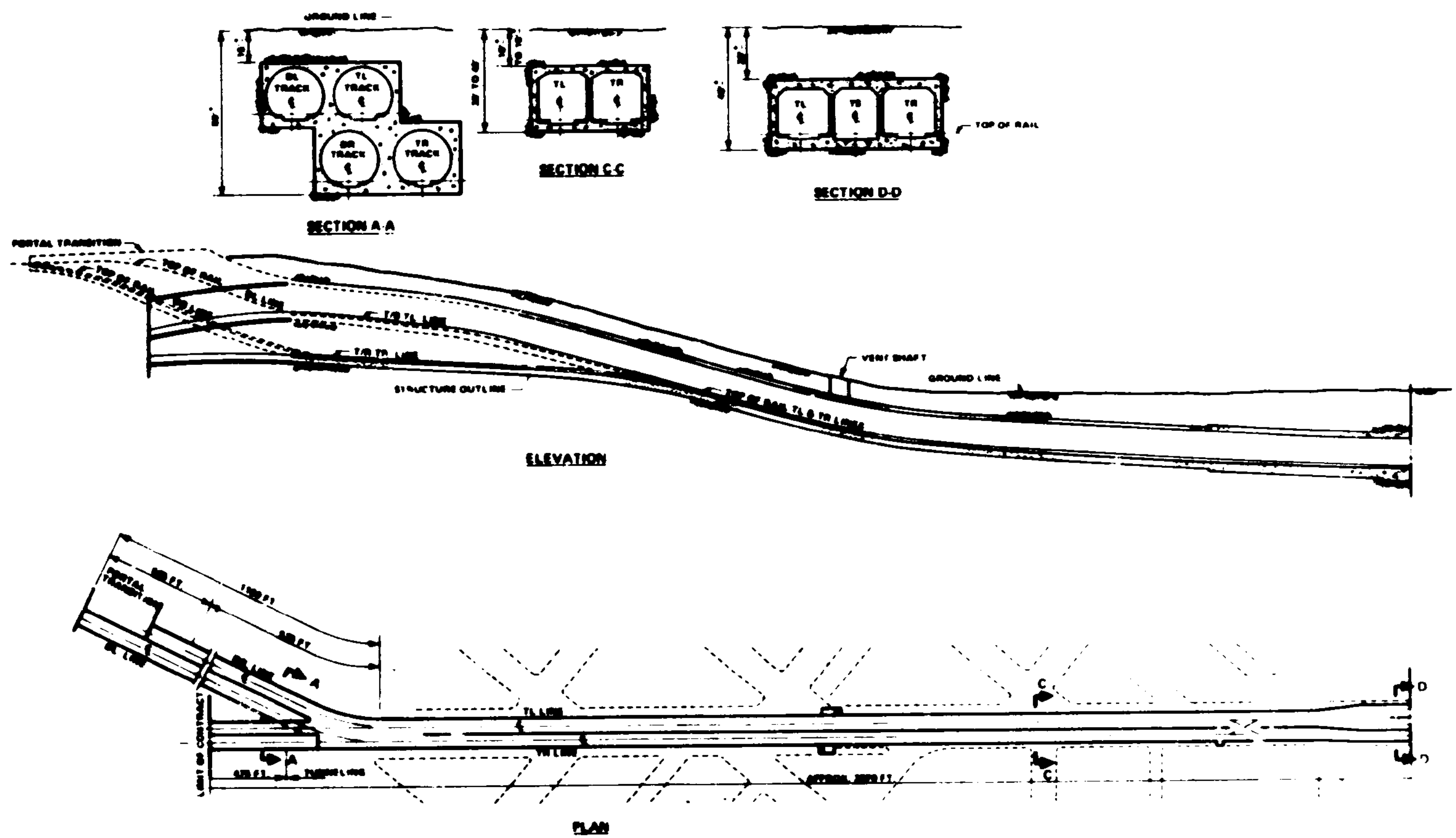


Figure 6-8. BART Project S0031, Van Ness to Duboce Line Structure, San Francisco

the contractor undertook a value-engineering study which indicated an economic advantage in substituting tunnel construction for some 700 ft of cut-and-cover box structure. The contractor's proposal was accepted, and both the owner and contractor shared in the related cost savings. The tunnels were at one end of the project, and the cost and other effects of this portion of the work were deleted from the study.

The ground was generally dense clayey sand, or dense medium-fine silty sand stratum, with fractured sandstone outcropping above the bottom of the excavation. The water table was on top of the rock, and dewatering was accomplished from within the excavation.

Numerous utilities, including the Muni streetcar system, gas, water, sewer, and electricity, had to be rerouted or supported during construction and restored to the center of the street at the completion of the work. Heavy traffic had to be maintained on a vehicular lane in each direction on Market Street, and decking had to be provided at street intersections. No underpinning of existing structures was required. Excavation was performed by bulldozer working within the excavation, with a crane and clamshell bucket loading the muck directly onto trucks at street level. Impact tools and blasting were used, as necessary, when rock was encountered.

The bid price for the construction was $10,967,444. Changes in the work and exclusion of the cost for the tunneled portion of the contract reduced the original contract price to $10,815,700. Construction started July 13, 1970, with a scheduled completion date of December 9, 1972. An extension of 282 days was granted, which resulted in a final completion date of September 26, 1973.

WMATA Project C0021 Farragut West Station and Line Structures - Washington, D.C.

Project C0021 (see Figure 6-9) consisted of single-track-level, cut-and-cover station structure, 770 ft long, with side platforms 600 ft long and mezzanine booking areas at either end. There were also two cut-and-cover line sections at either end of the station with a combined length of 1,944 ft and 435 ft of turnout structure. The total route length of station and line structure was 3,149 ft. Other structures included ventilation structures to the surface at each end of the station, fan and pump rooms, entrances to the station, stairs, and provisions for escalators. The station structure was 50 ft deep, with the top 8 ft below ground surface. The ground – for the most part a sandy, silty clay overlying rock, which outcropped into the excavation – was readily drainable and there were no problems due to the water. Controlled blasting was used in the rock excavation, and numerous utilities had to be rerouted or supported, particularly at the cross streets. The construction generally occupied the full width of the heavily trafficked street. Decking was required over the excavation and was installed one block at a time, with the blocks closed to traffic during the installation. Numerous 10- to 12-story buildings on either side of the construction required underpinning.

The awarded low bid for the contract was $31,078,000. At the present time, the additional costs incurred as a result of recent changes are not known. The work started November 1971, and the contract time was about 30 months, giving a scheduled completion date of May 1974. It appears at this time that the date may be extended to mid-1975.

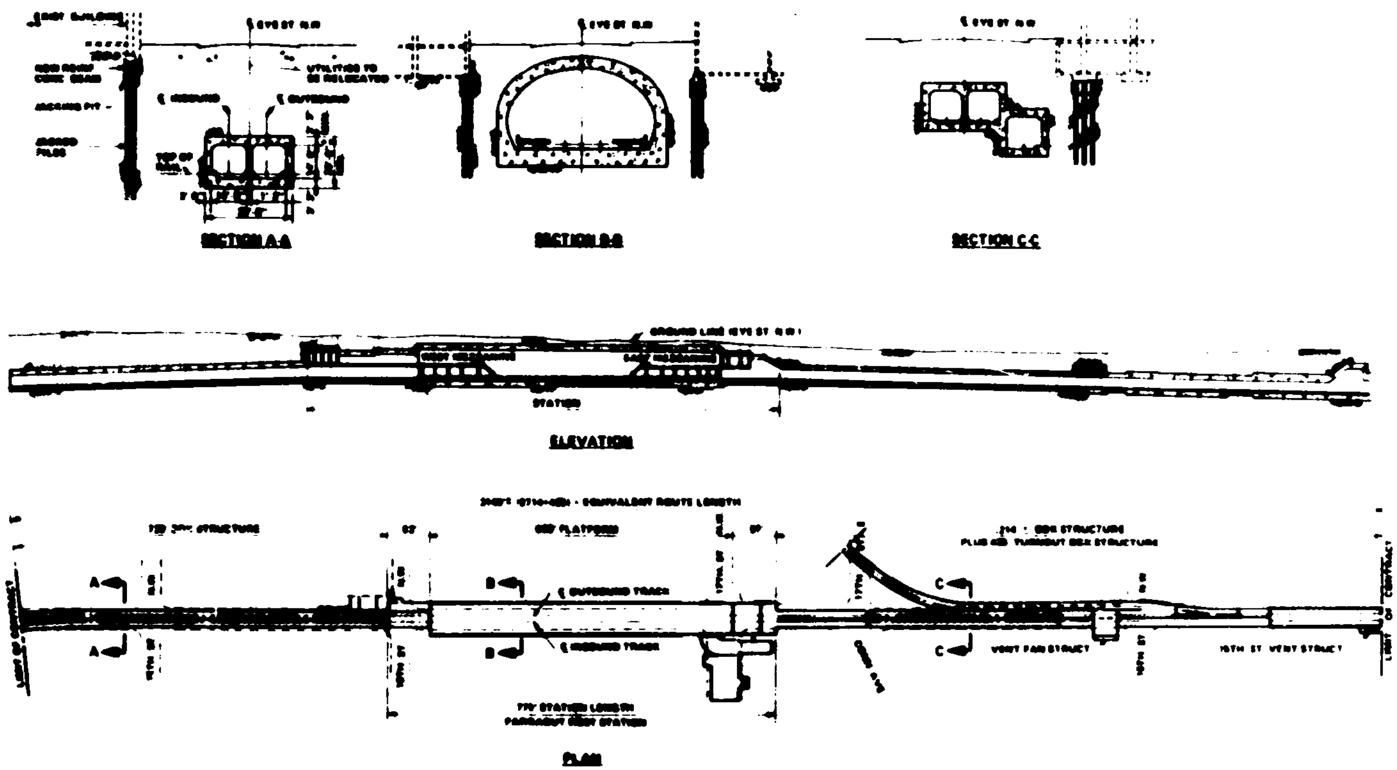


Figure 6-9. WMATA Project C0021, Farragut West Station and Line Structures, Washington, D. C.

WMATA Project C0041 - Potomac River Crossing Extension - Washington, D. C.

As shown in Figure 6-10, Project C0041 involved 1,370 ft of twin tunnels driven in a mixed face and soft ground. (This was part of a project that included 8,300 ft of rock tunnel.) The tunnel excavations were supported with steel sets at 4-ft centers and timber lagging, and the final lining consisted of 12"-thick reinforced concrete.

The ground was a mixture of sandy, silty, clay overlying rock, which outcropped at intervals into the tunnel excavations. In some areas, there was a considerable amount of water, which was controlled at times with cement grouting; the drainage was accomplished directly from within the tunnel. Since the workshafts were located off the street, construction did not interfere with utilities or traffic. One structure required protection from ground movements, and to provide this protection, a slurry concrete wall was constructed between the tunnels and the structure.

For the tunneling, open face shields were used, and breast boards supported the ground at the face when needed. Blasting was employed where rock was encountered. Muck removal was performed by an 8-yd rubber-tired face shovel, which transported the material from the face to the vertical hoist at the workshaft.

The cost for this part of the total construction contract was $2,700,000, according to the bid document. However, since this portion of the work was only part of a very much larger project, the above figure is not likely to be representative of the real cost of the work. The data from this project were, therefore, not used as part of the input in the generalized tunnel models.

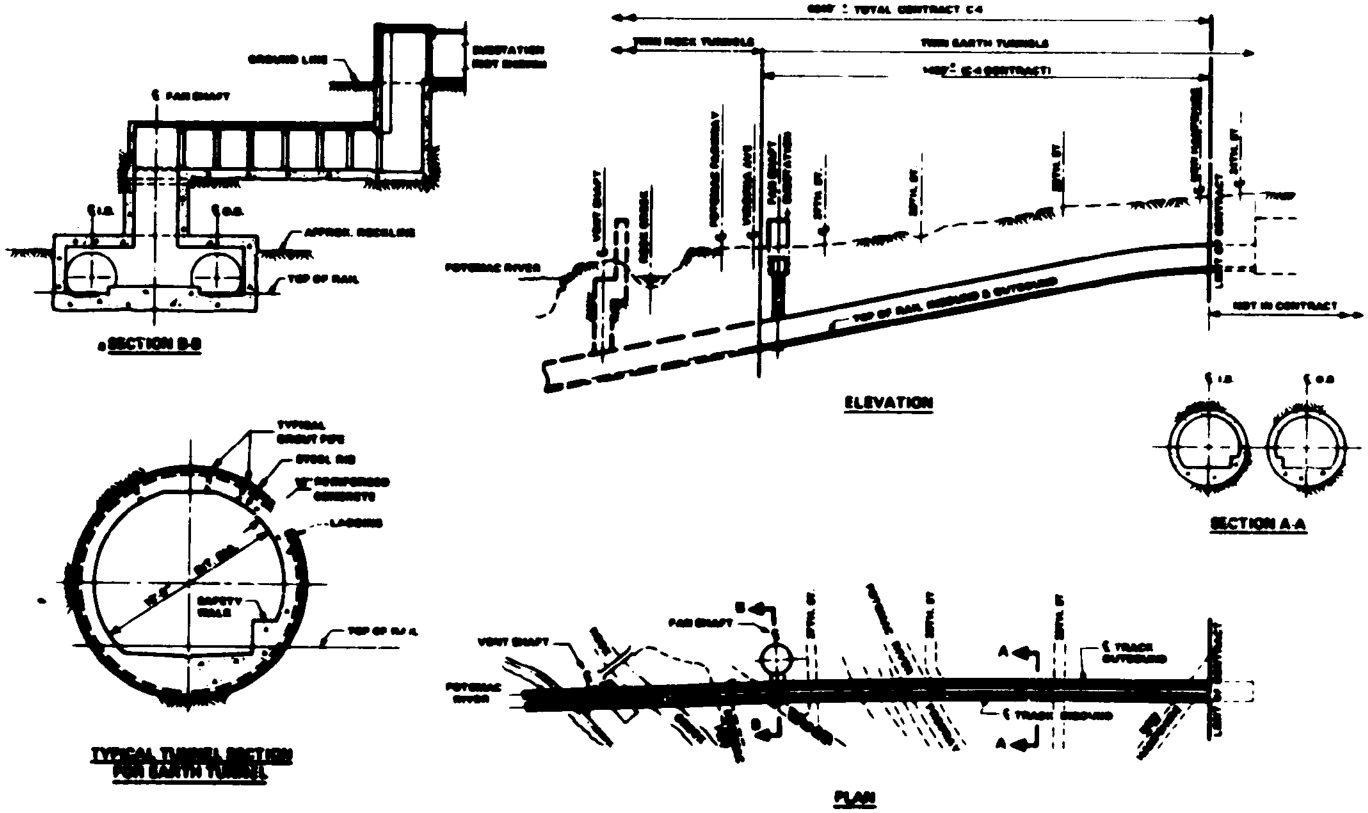


Figure 6-10. WMATA Project C0041, Potomac River Crossing Extension, Washington, D. C.

STUDY PROCEDURES

Introduction

In the analysis of the project costs, three major cost components which constitute the total cost of the projects will be identified.

- The cost of the work events of the project, without any external influences
- The cost of the physical controls, such as utility density, the traffic conditions, etc., which add to the cost of the work event
- The cost of the institutional controls, such as financing, productivity, etc., which add to or otherwise influence the cost of all the work events or the project as a whole

The components are indicated in model form in Figure 6-11.

A detailed description and discussion of the work events and the physical and institutional controls are presented in Sections 3 and 5, respectively.

Scope of the Study

The project study scope was limited to the actual construction contract costs for the primary structures, together with the precontract costs of utility relocation. Construction of the projects was basically in ground, with mixed faces of rock and ground being encountered in one tunnel and one cut-and-cover project. Five items not included in the cost of construction were:

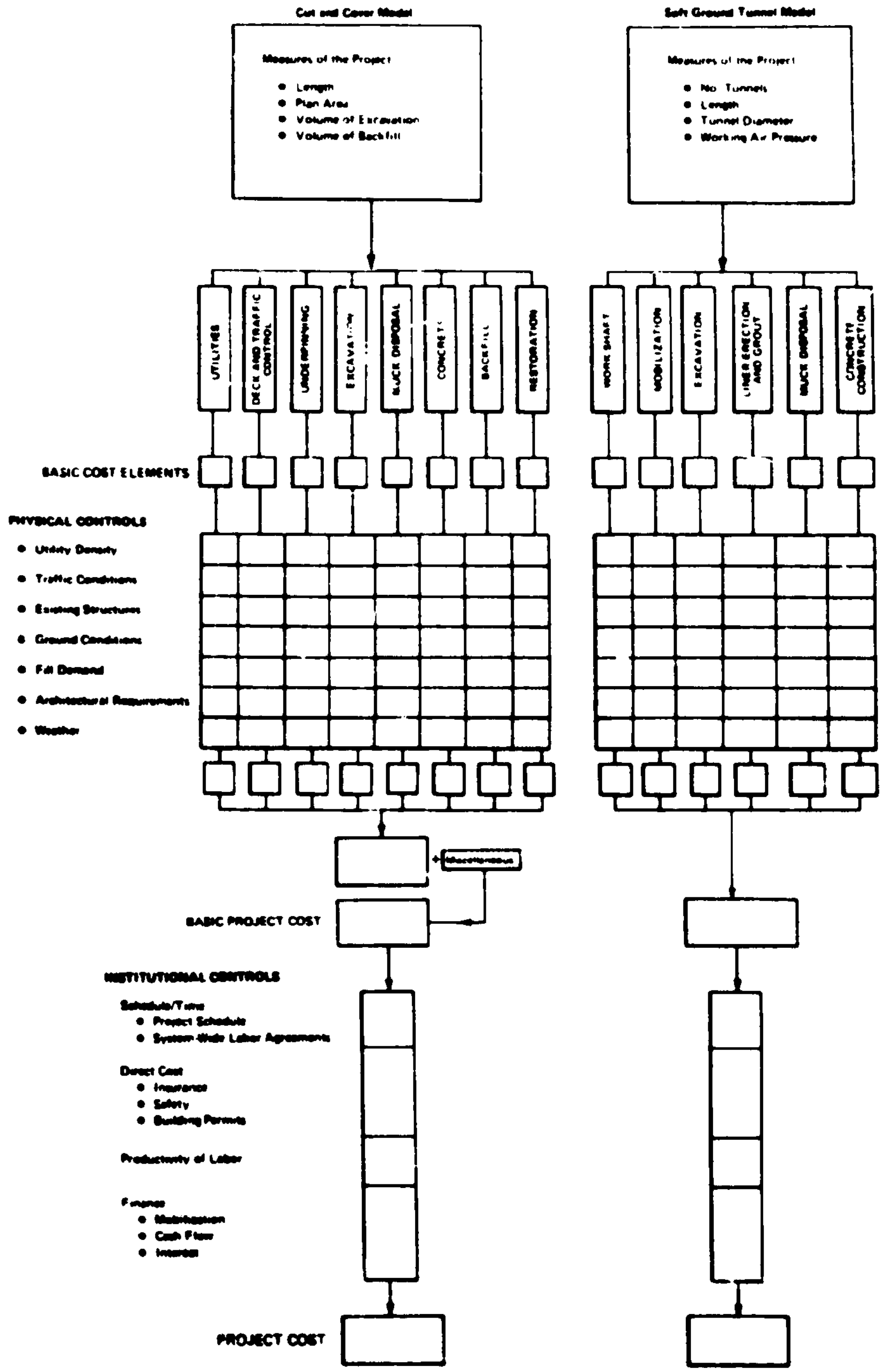


Figure 6-11. Rapid Transit Tunneling Cost Model

- Track and control equipment
- Ventilation fans and motors
- Electrical switch gear
- Architectural finishes for stations and line structures
- Escalators, elevators, and other equipment in the mezzanine and booking areas of the stations

TIME/COST ANALYSIS

Introduction

In the following pages, data sources are presented and the techniques used in analyzing the cost in the five contract case studies are described. It should be noted that the five case studies involved eight separate structures, which in the course of this study were analyzed individually. Of these eight, two were cut-and-cover stations, three were cut-and-cover line sections, and three were soft-gound tunnels, one of which was driven under air pressure.

Data Sources

The primary sources of data for the study of cost and schedules in the five study projects are summarized in Table 6-1. Data for the basic costs came from published summaries of bids submitted by each contractor for the work items in the contract specification. For the BART system, the data were derived from the Daily Construction Service; for the WMATA contracts, bid data were derived from computer printouts of the bid summaries. Both of these data sources for the five study contracts are included in the Appendix.

Table 6-1

SOURCES OF DATA CONCERNING STUDY CONTRACTS

	BART			WMATA	
	K0016	S0031	S0022	C0021	C0041
Basic Costs (average of the three lowest bids)	1	1	1	2	2
Change Order Costs	3	4	4	contracts	not complete
Precontract Utility Relocation Costs	5	5	none	none	none
Construction Schedules	3	3	3	6	6

Key	Data Source*
1	Daily Construction Service
2	Engineers bid summaries for WMATA
3	Historical construction reports
4	Historical cost reports
5	Analysis of the precontract utility relocation contracts
6	Ongoing construction schedules

* Copies of this material are included in the Appendix.

Significant costs of precontract utility relocation were incurred in two of the BART contracts, and these cost data were derived from contract historical records. Data on the construction schedules for the three BART project construction schedules were obtained from construction reports and from historical records. Construction schedule data for the two WMATA contracts were obtained from the field engineers' offices on each project.

Cost Analysis

In the analysis, individual bid items were grouped according to the work events to which they applied. The work events used in the study contract analysis were:

Cut-and-Cover Construction

- Utilities
- Decking and traffic control
- Underpinning
- Excavation
- Concrete
- Backfill
- Restoration

Soft-Ground Tunnel Construction

- Tunnel construction
- Tunnel linings
- Concrete invert and walkway
- Underpinning
- Workshaft, vent shaft, and cross passages

Considerable variation was found among the bids submitted by the contractors. For the purposes of this study, the three contractors with the lowest bids were selected, and the average of their bid prices for each bid item was used. Such a method produced a statistically better representation of the costs. This averaging technique is standard practice in the construction industry for bid analysis and for projecting the cost of future work.

The average price for each item was then multiplied by the construction quantity of that item to arrive at the item's cost. The sum of all bid items within a work event was the total cost for that work event. Additional contract change order costs, wherever available, were added to the appropriate work items, and the precontract costs of utility relocation were added to the utility work category.

When preparing a bid, a contractor escalates his bid construction costs to the projected midpoint date of the construction. In most bidding procedures, the labor and material costs are escalated at different rates, depending upon the projected trend in these two cost elements. All of the five contract studies had different midpoint completion dates. In the course of the analysis, the aggregate costs for each work item were escalated from the midpoint date of the original contract to January 1974 in order to put all case studies on an equal basis. Because the individual work items in the bid summaries (see the Appendix) did not include breakdowns for labor and materials, a bulk overall escalation factor was calculated for each work item on the basis of estimates of the proportions of labor and material and the cost escalation factors summarized in the Appendix.

Table 6-2 summarizes (1) the work event costs and the total project costs for the two cut-and-cover stations and three cut-and-cover line structures within the five case study contracts and (2) the significant measures of the constructions. Table 6-3 summarizes the project measures and costs for the three tunnel projects within the five case study contracts.

The next step in the analysis was the estimation of the cost sensitivity of each work item to each of the physical controls. The techniques used in this analysis and the results of the sensitivity analysis are presented in Section 5.

Table 6-2

SUMMARY OF MEASURES AND COSTS FOR CASE STUDIES, CUT-AND-COVER STRUCTURES

Average of Three Lowest Bids, January 1974 Costs

MEASURES AND COSTS	K0016 (BART) Oakland Station	C0021 (WMATA) Farragut Station	C0021 (WMATA) Farragut Line	S0031 (BART) Muni Line	K0016 (BART) Oakland Line
Length (LF)	838	770	2,365	3,040	216
Plan Area (yd^2)	8,670	8,740	8,590	11,700	663
Deck Area (yd^2)	11,300	8,422	9,457	2,000	1,000
Excavation Volume (yd^3)	135,000	91,720	151,108	152,000	16,000
Net Volume (yd^3)	111,475	76,313	77,896	101,000	11,500
COSTS	EF(1) = 1.344	EF = 1.070	EF = 1.070	EF = 1.105	EF = 1.344
Utilities	2,004,748	1,210,550	1,674,058	4,171,442	599,616
Deck & Traffic Control	1,216,817	1,383,911	1,793,725	260,984	148,613
Underpin	751,360	2,767,559	2,940,779	0	43,211
Excavate	5,733,106	4,700,052	6,961,365	3,504,283	844,216
Concrete	6,595,388	5,204,869	5,267,402	3,318,729	631,661
Backfill	321,115	184,805	785,842	262,005	47,557
Restore	243,788	365,677	505,695	623,440	62,857
Miscellaneous	812,086	601,696	832,085	48,950	129,877
	17,678,408	16,419,119	20,760,951	12,189,833	2,507,608

(1) EF = Escalation factor from contract midpoint to January 1974

Table 6-3

SUMMARY OF MEASURES AND COSTS
FOR CASE STUDIES, SOFT-GROUND TUNNELS

Average of Three Lowest Bids, January 1974 Costs

MEASURES AND COSTS	K0016 BART Oakland	S0022 BART Market Street	C0041 WMATA Potomac River
Tube Length (LF)	1,085 (three tunnels)	5,100 5,128	1,370 (two tunnels)
Total Length (LF)	3,255	10,228	2,740
COSTS EF [(1)]	1,344	1,345	1,070
Tunnel Construction – excavation, linear erection, grouting, caulking, and clean-up	$ 7,410,780	$22,383,810	$4,167,090
Tunnel Liners	1,445,880	4,127,000	0
Tunnel Concrete Invert	192,610	1,177,530	142,930
Underpinning	732,370	0	509,640
Workshaft, Vent Shaft, and Cross Passages	292,710	3,232,950	279,480
TOTAL	$10,074,350	$30,921,290	$5,099,140

(1) EF = Escalation factor from contract midpoint to January 1974

In addition to the above costs, there are other costs incurred by the owner that result from changes in schedule time. These include:

- Site supervision costs, i.e., costs related to field office and support engineering services
- The cost of the owner's contract management service
- Costs due to the change in time of possession of the completed work

Schedule (Time) Analysis

The time required for the completion of an individual contract is established by the engineer from a consideration of (1) the overall schedule for completion of the rapid transit system, (2) an estimate of the economic construction time for each project, and (3) a determination of the schedule of interfaces between contracts for contiguous segments of the system. The starting time for the contract specified in the contract document usually is initiated by a "notice to proceed" within about 30 days of the date of the contract award.

The contractor establishes a detailed construction schedule best suited to his proposed method of working within the starting and ending dates, and any other specified requirement of contiguous contracts. Scheduled changes that extend or accelerate the completion date will influence the cost of the contract. If the contract time is extended, certain fixed costs (e.g., overhead and financing charges, leased equipment charges, and engineering and supervision labor costs) that are proportional to the length of the extension will be incurred. If the contract time is reduced, overtime working or additional marginally productive labor may be required, either of which increases the contractor's costs.

Cost changes due to contract changes requested by the owner are clearly outside of the contractor's control. If actions by the owner cause a delay, the contractor is usually reimbursed, and the total contract price for these costs is increased correspondingly. If the delay is not caused by the owner, the contractor is usually not compensated for the effects of the extension.

These three costs are not included in this study. After the award of the contract, delays in the schedules can be a responsibility of the owner or of the contractor.

Schedule delays that are the responsibility of the owner include:

- Interfaces with other contracts, i.e., when the work at the interfaces of adjacent contracts are not completed on the dates scheduled
- Changes of the scope of work
- Delays in delivery of owner-furnished material
- Delays in obtaining right-of-way work areas or accesses to buildings
- Delays in providing the design drawings and approving the contractors' work drawings

Schedule delays that may be the responsibility of, or be borne by, the contractor include:

- Labor disputes and strikes (outside a system-wide labor agreement)
- Strikes off the job (these affect material supply)
- Organization and execution of work
- Inclement weather

The schedule of a project is sensitive to the above factors. In the detailed construction schedule which the contractor formulates, it is assumed that none of the factors under the control of the owner will occur, though he may include a time allowance for those factors within his responsibility.

The actual "as-constructed" bar schedules for the project work events for each of the five study projects are defined in Figures 6-12 through 6-16. Noted on each of the schedules is the completion date specified in the bid document and the actual completion date.

BART Project K0016 (See Figure 6-12.). The date of notice to proceed was February 1967, and the time for completion of the project according to contract was 795 calendar days (completion date, April 1969). The total time for completion of the contract, including all extensions, was 993 calendar days. The causes of the 198-day delay are given in Table 6-4.

Table 6-4

SCHEDULE TIME EXTENSION
BART Project K0016

Cause	Number of Days	% of Time Extension
Severe weather	27	14
Mat[illegible]ial shortages due to strikes of refinery workers, a supplier's plant, and a concrete supplier	61	31
Material shortages delays	56	28
Additional work due to changed conditions	54	27
	198	100

The contractor had to bear the costs of his fixed charges for the increase in the construction time from the first three items. For the costs of the additional work, he received compensation in which fixed charges were included.

BART Project S0022 (See Figure 6-13.). The date of notice to proceed was late November 1966, and the time for completion of the contract according to specifications was 850 calendar days, or approximately 28 months. The work was substantially completed in 36 months, but because of a delay in completing the work at the interfacing project, where the tunnels were to be terminated, there was an additional 2-month delay in the actual completion of the tunnels. The causes of the 10-month delay are given in Table 6-5.

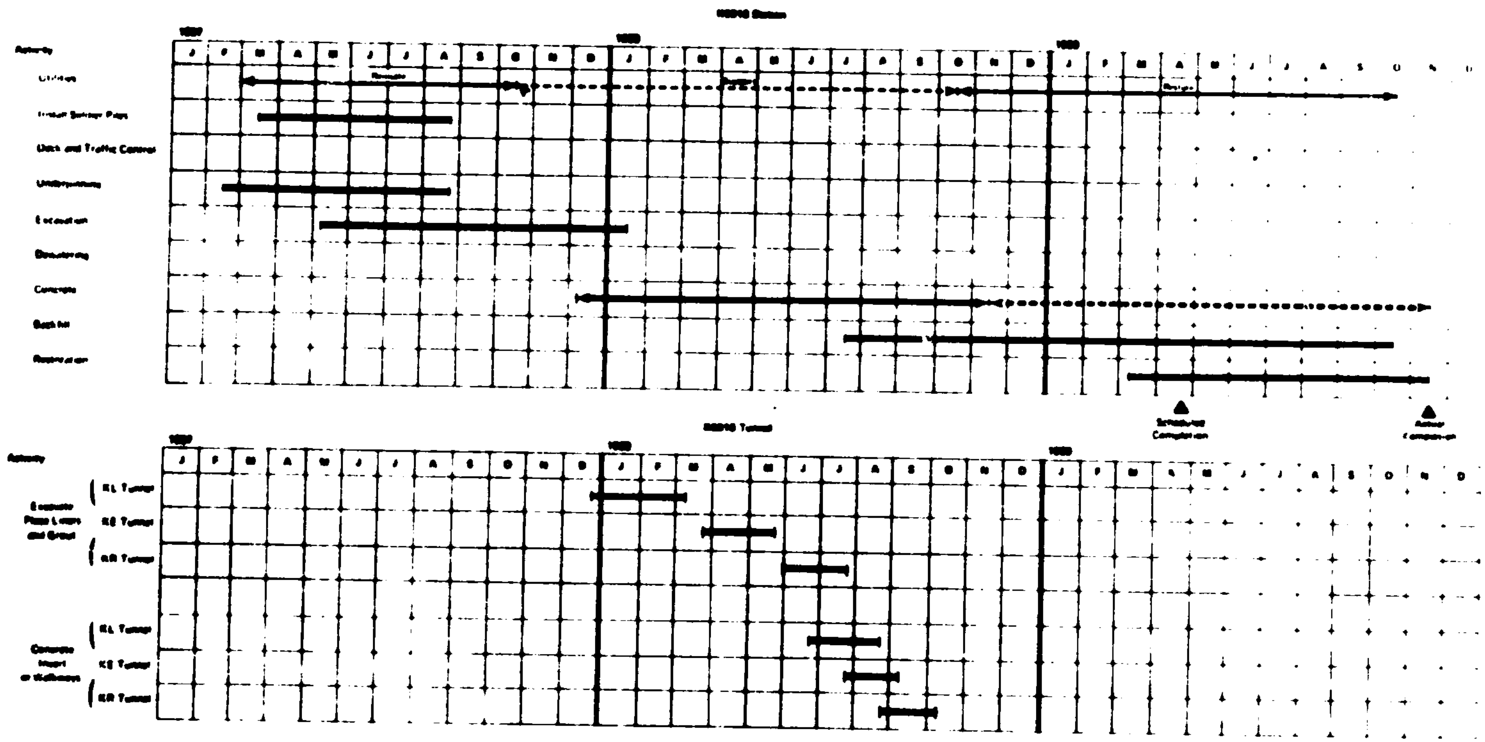


Figure 6-12. Construction Schedule – BART Project K0016, Twelfth Street Station and Line, Oakland

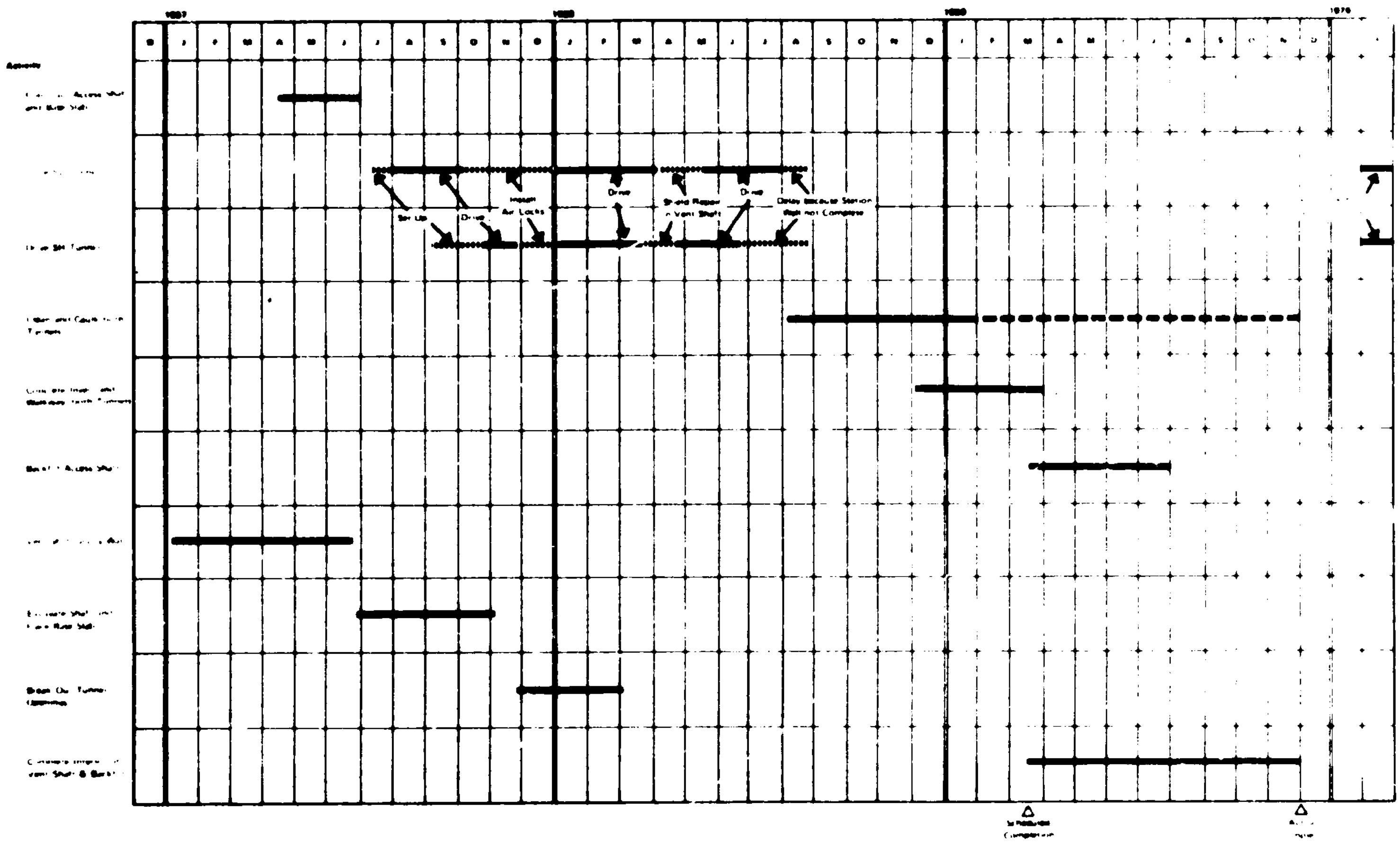


Figure 6-13. Construction Schedule – BART Project S0022, Sixteenth Street to Civic Center, San Francisco

Table 6-5

SCHEDULE TIME EXTENSION
BART Project S0022

Cause	Number of Days	% of Time Extension
Machine breakdown or related causes	92	31
Bad ground conditions (water)	118	39
Other causes	32	10
Delay at interface contract	60	20
	302	100

The delay of 8 months in achieving substantial completion was occasioned both by problems encountered in controlling the groundwater and by repairs of mechanical breakdowns of the newly developed tunneling machines. As a consequence of the very arduous service conditions, such problems are inherent in any new kind of tunneling machine. In this particular case, the problems were usually solved by modifying components and strengthening structural elements. Presumably, the machines will perform with greater efficiency in any future projects in which they will be used. The difficulties caused by the groundwater illustrate the problems that can arise in working the type of variable ground encountered. It was not possible to determine the effectiveness of the measures taken to lower the groundwater ahead of the tunnel excavation, and hence, heavy inflows of water into the tunnel face occurred at various times, delaying the progress of the work.

The contractor bore the costs caused by the time delays due to machine breakdowns and bad ground conditions. For other factors, such as interface problems, he was reimbursed for the delays.

BART Project S0031 (See Figure 6-14.). The date of notice to proceed was mid-July 1970, and the required time of completion of the project was 880 days or about 29 months. The work was completed in 38-1/2 months. The causes of the 9-1/2-month delay are given in Table 6-6.

Table 6-6

SCHEDULE TIME EXTENSION
BART Project S0031

Cause	Number of Days	% of Time Extension
Additional traffic detours	9	3
Changed work conditions	97	35
Strikes by the Teamsters	99	35
Strikes on the job	77	27
	282	100

The 3-month delay due to changed work conditions could be attributed chiefly to unforeseen utility conflicts and the unexpectedly bad condition of the existing utilities. The strikes by the Teamsters Union and others, which were responsible for most of the delays, occurred at a stage in the project when the system-wide labor agreement had ceased to operate. This demonstrates the value of such an agreement.

The contractor had to bear the cost of the delays, except for items involving changed conditions of extra work, for which he was reimbursed. All the BART project contracts contained a liquidated damages provision for late completion of the projects. In none of the projects discussed was the clause invoked, as the delays which occurred were judged outside the contractor's control.

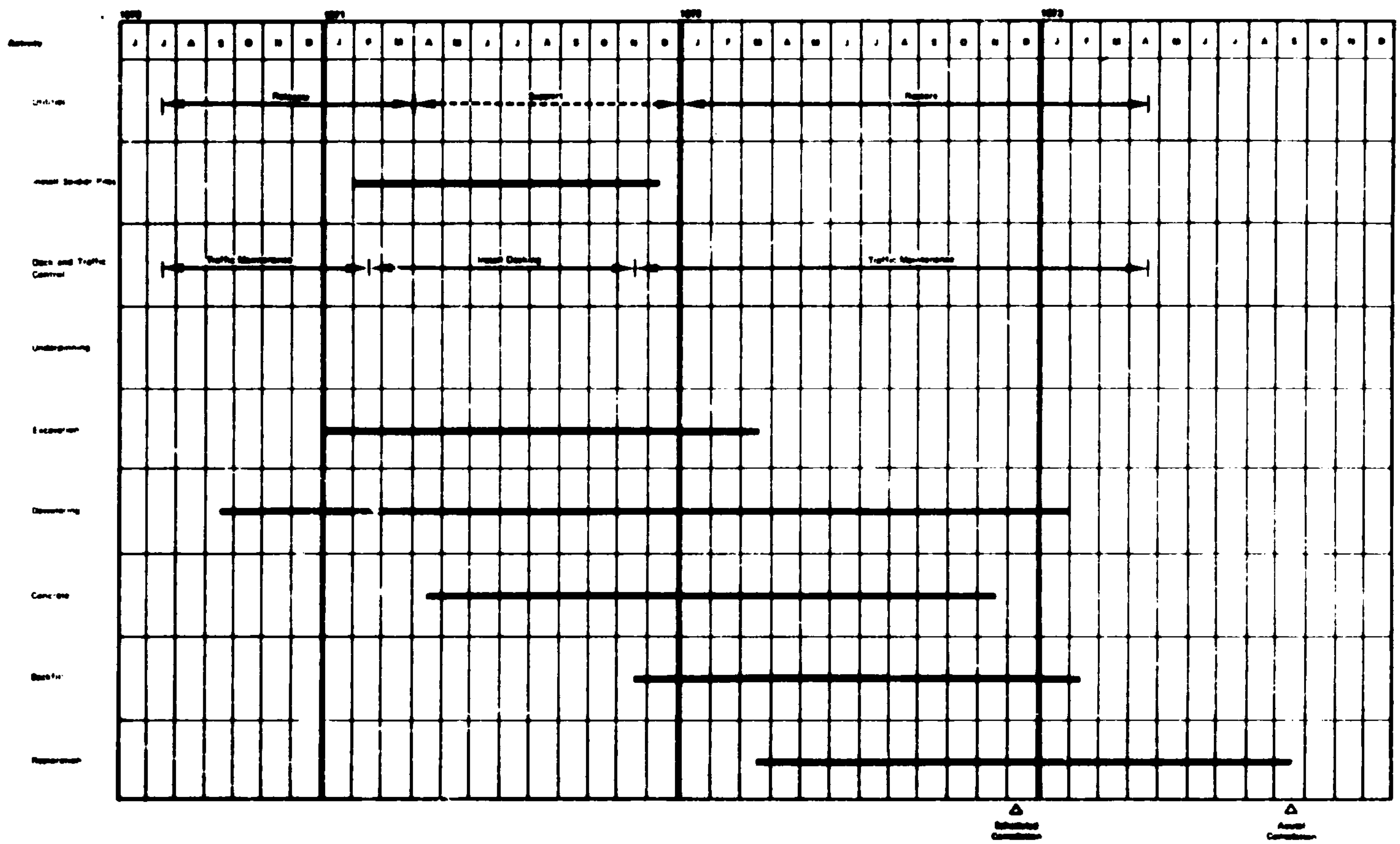


Figure 6-14. Construction Schedule — BART Project S0031, Market Street, Van Ness to Duboce Portal, San Francisco

WMATA Project C0021 (See Figure 6-15.). The date of notice to proceed was mid-November 1971. The scheduled date of completion was mid-May 1974, which provided a schedule time of about 30 months. The project is still under construction; the forecast date of substantial completion is January 1975, and that for final completion, May 1975. The causes of delay are given in Table 6-7.

Table 6-7

SCHEDULE TIME EXTENSION
WMATA Project C0021

Cause	Number of Days
Changed conditions (utilities)	Information unavailable
Extra work (elevator for handicapped)	110
Underpinning difficulties	Information unavailable
Strikes, Teamsters and others	90

Information was not available to complete the present forecast dates of completion of the work events in the schedule.

The 7-1/2-month discrepancy between scheduled completion and forecasted completion was due principally to the last three items in Table 6-7. The changed utility conditions arose from the utility companies' changed restoration requirements.

It appears that the contractor will be reimbursed for most of his delay-related costs, except for those caused by strikes, and will be fully reimbursed for the extra changed conditions and the extra work item.

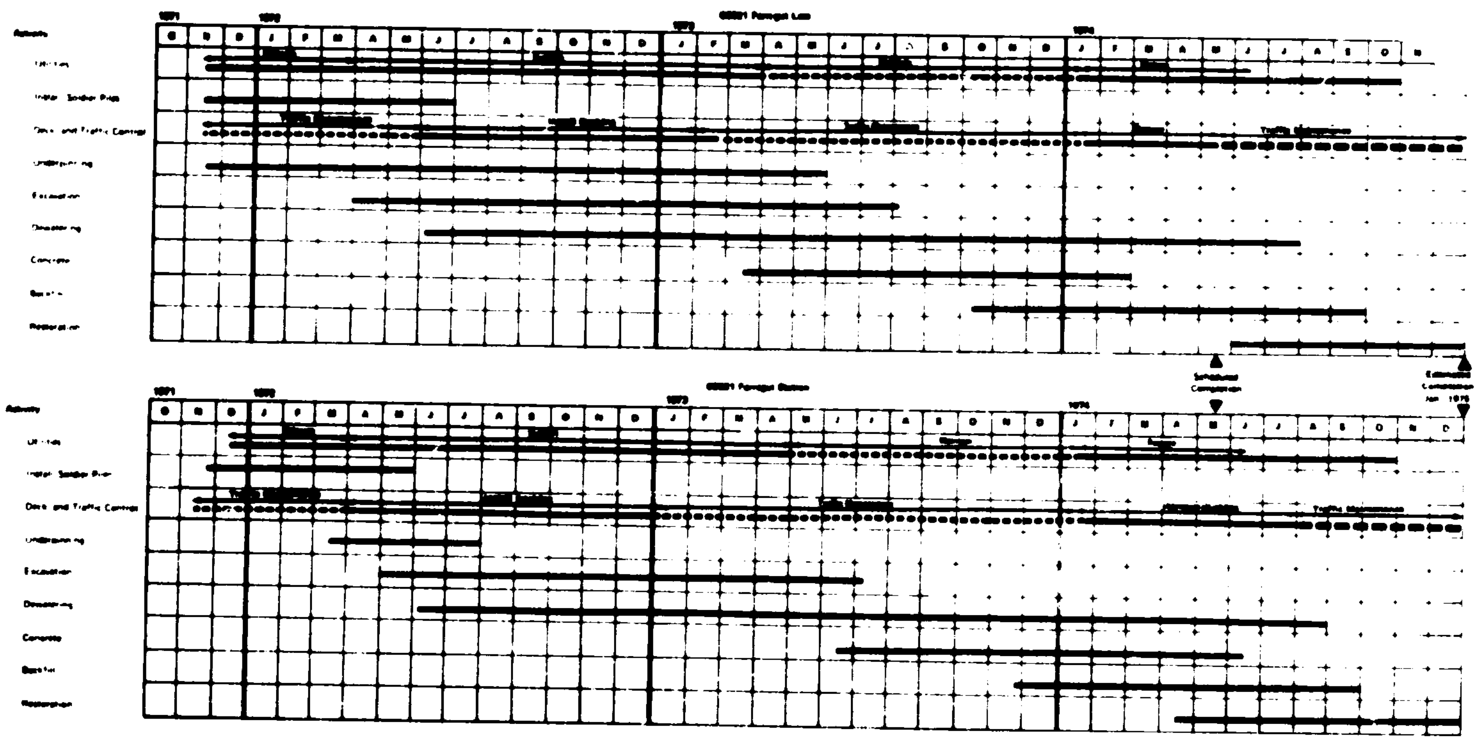


Figure 6-15. Construction Schedule — WMATA Project C0021, Farragut Station West and Line, Washington, D.C.

WMATA Project C0041 (See Figure 6-16.). As noted previously, this study project is the mixed face (ground) portion of a tunnel project, the majority of which was in rock. Because the contractor elected to construct the ground tunnel section after the rock section, this determined the starting date of the ground tunnels (January 1972). Although this date was later than originally scheduled, the ground tunnel was completed within the initially scheduled time span.

Some difficulties were encountered during excavation owing to the rock outcropping above the invert at a higher elevation than was indicated in the geological information provided in the contract documents. This occasioned some delays at various stages in this event, but the time was eventually made up.

No schedule extension was requested for this or any other event, but the contractor requested consideration for reinbursement of extra cost due to changed ground conditions.

Analysis of Study Project Schedule

In four of the five study projects, there were substantial delays. The major causes were:

- Changed work conditions, particularly in the cut-and-cover projects. These accounted for about 30 percent of the total time delays.
- Strikes by material suppliers who were not under the control of system-wide labor agreements. These strikes accounted for another 30 percent of the delays.
- Strikes on the projects where system-wide labor agreements were not in force or had expired. These strikes contributed about 35 percent to the delays.

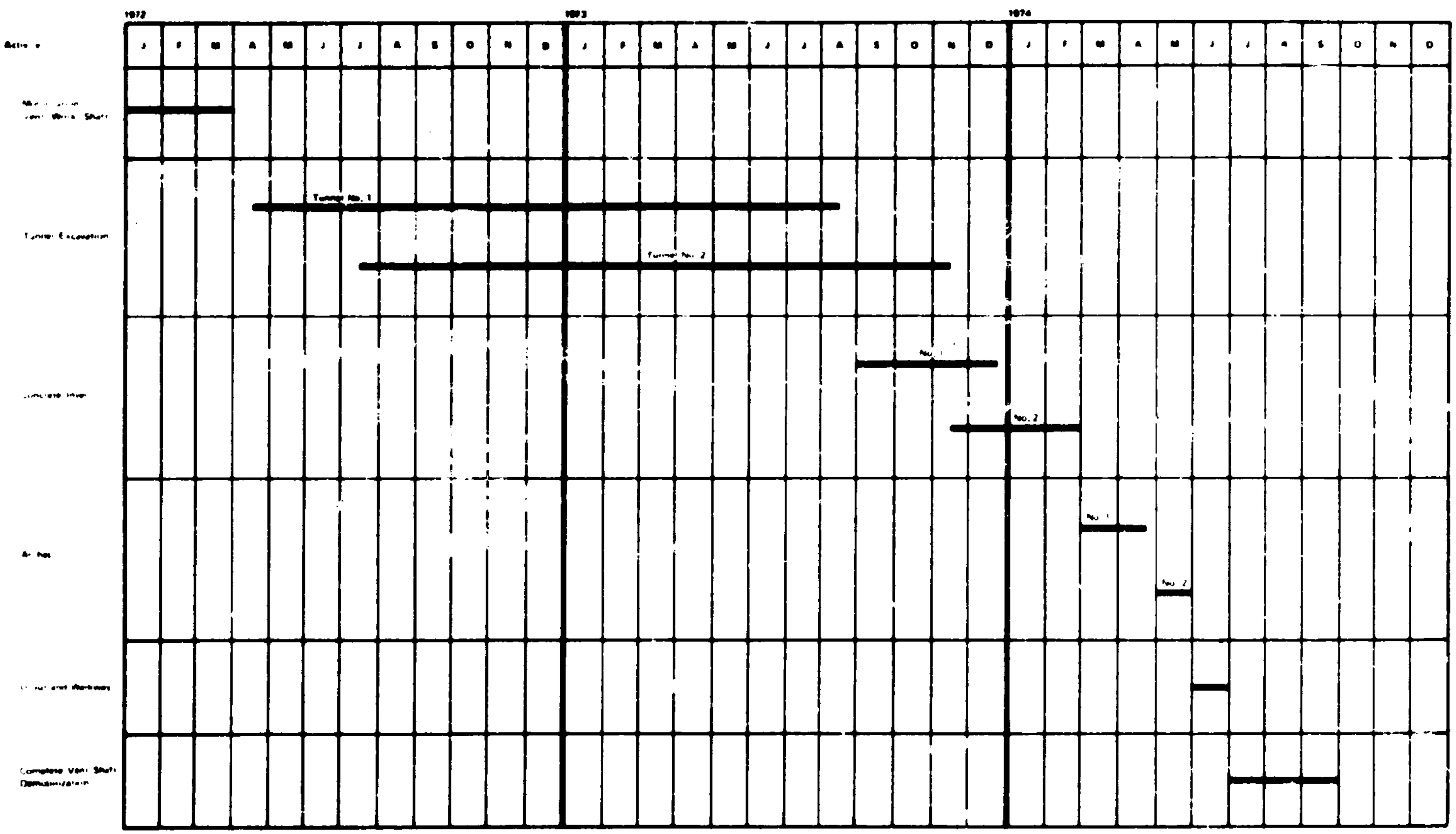


Figure 6-16. Construction Schedule — WMATA Project C0041, Potomac River Crossing Extension, Washington, D.C.

None of the contractors absorbed the added costs due to the construction time increase engendered by changed work conditions; however, they did absorb costs associated with delays caused by severe weather, strikes, bad ground, and machine breakdowns. Reimbursement of contractors for change work conditions that resulted in schedule delays included fixed costs for the additional time spent and costs for the additional work.

Despite the fact that the completion dates for most projects were appreciably extended beyond those originally scheduled, these delays did not cause delays to interfacing contracts. This was because the interfacing contracts were scheduled so that their matching structure faces were all completed ahead of time. In addition, none of the study projects were on the critical path of any subsequent contracts for related components of the transit systems, such as the rails, electrification, architectural finishes, or rail cars.

STUDY PROJECT SENSITIVITY ANALYSIS

Physical Controls

In the analysis of the sensitivity of work events to the physical controls, the starting point was the total cost per linear foot of the structure for each work item as determined from the average of the three lowest bids for each study contract. The methodology for the determination of the cost for work items is discussed previously in this section under "Cost Analysis." These total costs per linear foot for each work event of the five study projects are presented on the bottom row of Tables 6-8 through 6-15. Included with the total costs per linear foot are the percentages of the overall total cost per linear foot of the particular project segment, which is shown in the lower right-hand corner of each table.

Table 6-8

INFLUENCE OF PHYSICAL CONTROLS ON WORK EVENTS – BART CONTRACT K0016, TWELFTH STREET STATION, OAKLAND

Physical Control Elements	Cost for Work Events – $ Per Linear Ft (% of Total)								
	Utilities	Deck and Traffic Control	Underpinning	Excavation	Concrete	Backfill	Restoration	Miscellaneous	Total
Basic Cost Without Influence of Any Physical Controls	1,793 (75)	943 (65)	718 (80)	4,106 (60)	7,086 (90)	231 (60)	203 (70)	969 (100)	10,949 (76)
Utility Density		145 (10)		513 (7.5)		95 (25)			753 (4)
Traffic Conditions	478 (20)	290 (20)		513 (7.5)	394 (5)	38 (10)	73 (25)		1,786 (8)
Existing Structures		73 (5.0)		1,025 (15)					1,098 (5)
Ground Conditions			179 (20)	684 (10)					863 (4)
Architectural Requirements					394 (5)				394 (2)
Weather	120 (5)					19 (5)	15 (5)		154 (1)
TOTALS $ Per Linear Ft % of Total	2,391 (11.3)	1,451 (6.9)	897 (4.3)	6,841 (32.4)	7,874 (37.3)	383 (1.8)	291 (1.4)	969 (4.6)	21,097 (100.0)

NOTE: Costs given include an escalation factor of 1.344 to cover the period from June 1968 to January 1974.

Table 6-9

INFLUENCE OF PHYSICAL CONTROLS ON WORK EVENTS – WMATA CONTRACT C0021, FARRAGUT STATION

Physical Control Elements	Cost for Work Events – $ Per Linear Ft (% of Total)								
	Utilities	Deck and Traffic Control	Underpinning	Excavation	Concrete	Backfill	Restoration	Miscellaneous	Total
Basic Cost Without Influence of Any Physical Controls	1,150 (73.2)	1,240 (69.0)	2,875 (80.0)	1,826 (29.9)	3,718 (55.0)	177 (73.7)	379 (80.0)	781 (100)	12,148 (57.0)
Utility Density		90 (5.0)		305 (5.0)		12 (4.7)			407 (1.9)
Traffic Conditions	315 (20.0)	270 (15.0)		920 (15.1)	338 (5.0)	24 (9.8)	71 (14.7)		1,938 (9.1)
Existing Structures		90 (5.0)		916 (15.0)					1,006 (4.7)
Ground Conditions			719 (20.0)	1,220 (20.0)					1,939 (9.1)
Architectural Requirements				610 (10.0)	2,365 (35.0)	11 (4.9)			2,986 (14.0)
Weather	107 (6.8)	107 (6.8)		305 (5.0)	337 (5.0)	16 (6.7)	24 (5.0)		896 (4.2)
TOTALS $ Per Linear Ft % of Total	1,572 (7.4)	1,797 (8.4)	3,594 (16.9)	6,102 (28.6)	6,758 (31.7)	240 (1.1)	474 (2.2)	781 (3.7)	21,318 (100.0)

NOTE: Costs given include an escalation factor of 1.070 to cover the period from June 1968 to January 1974.

Table 6-10

INFLUENCE OF PHYSICAL CONTROLS ON WORK EVENTS – WMATA CONTRACT C0021, FARRAGUT LINE

Physical Control Elements	Cost for Work Events – $ Per Linear Ft (% of Total)								
	Utilities	Deck and Traffic Control	Underpinning	Excavation	Concrete	Backfill	Restoration	Miscellaneous	Total
Basic Cost Without Influence of Any Physical Controls	519 (73.2)	553 (73.0)	993 (80)	1,473 (50.0)	2,001 (89.9)	258 (78.0)	170 (80.2)	351 (100)	6,318 (72.0)
Utility Density		38 (5.1)		147 (5.0)		17 (5.1)			202 (2.3)
Traffic Conditions	141 (19.8)	114 (15.0)		441 (15.0)	110 (4.7)	33 (9.8)	31 (14.7)		870 (9.9)
Existing Structures				150 (5.0)					150 (1.7)
Ground Conditions			249 (20)	589 (20.0)					838 (9.5)
Architectural Requirements									
Weather	49 (6.9)	52 (6.9)		147 (5.0)	116 (5.2)	23 (7.1)	11 (5.1)		398 (4.6)
TOTALS $ Per Linear Ft % of Total	709 (8.1)	757 (8.6)	1,242 (14.1)	2,947 (33.6)	2,227 (25.4)	331 (3.8)	212 (2.4)	351 (4.0)	8,776 (100.0)

NOTE: Costs given include an escalation factor of 1.070 to cover the period from January 1973 to January 1974.

Table 6-11

INFLUENCE OF PHYSICAL CONTROLS ON WORK EVENTS – BART CONTRACT S0031, MUNI LINE

Physical Control Elements	Cost for Work Events – $ Per Linear Ft (% of Total)								
	Utilities	Deck and Traffic Control	Underpinning	Excavation	Concrete	Backfill	Restoration	Miscellaneous	Total
Basic Cost Without Influence of Any Physical Controls	1,097 (80.0)	73 (84.9)		980 (85.2)	1,092 (100)	71 (82.5)	175 (85.0)	17 (100)	3,505 (87.4)
Utility Density		4 (4.6)		58 (5.0)					62 (1.6)
Traffic Conditions	206 (15.0)	[illegible] (10.5)		57 (4.9)		9 (10.5)	21 (10.2)		302 (7.5)
Existing Structures									
Ground Conditions				57 (4.9)					57 (1.4)
Architectural Requirements									
Weather	68 (5.0)					6 (7.6)	10 (4.8)		84 (2.1)
TOTALS $ Per Linear Ft % of Total	1,371 (34.2)	86 (2.2)		1,152 (28.7)	1,092 (27.2)	[illegible] (2.2)	206 (5.1)	17 (0.4)	4,010 (100.0)

NOTE: Costs given include an escalation factor of 1.105 to cover the period from December 1972 to January 1974.

Table 6-12

INFLUENCE OF PHYSICAL CONTROLS ON WORK EVENTS – BART CONTRACT K0016, OAKLAND LINE

Physical Control Elements	Cost for Work Events – $ Per Linear Ft (% of Total)								
	Utilities	Deck and Traffic Control	Underpinning	Excavation	Concrete	Backfill	Restoration	Miscellaneous	Total
Basic Cost Without Influence of Any Physical Controls	2,082 (75)	477 (65)	160 (80)	2,345 (60)	2,778 (95)	132 (60)	204 (70)	601 (100)	8,749 (75.4)
Utility Density		69 (10)		293 (7.5)					362 (3.1)
Traffic Conditions	550 (20)	138 (20)		293 (7.5)	146 (5)	55 (25)	73 (25)		1,260 (10.9)
Existing Structures		34 (5)		586 (15)		22 (10)			642 (5.5)
Ground Conditions			40 (20)	391 (10)					431 (3.7)
Architectural Requirements									
Weather	139 (5)					11 (5)	14 (5)		164 (4.1)
TOTALS $ Per Linear Ft % of Total	2,776 (23.9)	688 (5.9)	200 (1.7)	3,908 (33.7)	2,924 (25.2)	220 (1.9)	291 (2.5)	601 (5.2)	11,608 (100.0)

NOTE: Costs given include an escalation factor of 1.344 to cover the period from June 1968 to January 1974.

Table 6-13

INFLUENCE OF PHYSICAL CONTROLS ON WORK EVENTS – BART CONTRACT K0016, OAKLAND TUNNELS

Physical Control Elements	Cost for Work Events – $ Per Linear Ft (% of Total)					
	Tunnel Construction	Liners	Workshaft, Vent Shaft, and Cross Passages	Concrete Invert	Underpinning	Total
Basic Cost Without Influence of Any Physical Controls	1,753 (77.0)	444 (100)	90 (100)	59 (100)	112 (50)	2,458 (79.4)
Utility Density						
Traffic Conditions	114 (5.0)					454 (3.7)
Existing Structures	68 (3.0)					68 (2.2)
Ground Conditions	342 (15.0)				112 (50)	454 (14.7)
Architectural Requirements						
Weather						
TOTALS $ Per Linear Ft % of Total	2,277 (73.6)	444 (14.3)	90 (2.9)	59 (1.9)	224 (7.3)	3,094 (100.0)

NOTE: Costs given include an escalation factor of 1.344 to cover the period from June 1968 to January 1974.

Table 6-14

INFLUENCE OF PHYSICAL CONTROLS ON WORK EVENTS – BART CONTRACT S0022, MARKET STREET TUNNEL

Physical Control Elements	Cost for Work Events – $ Per Linear Ft (% of Total)					
	Tunnel Construction	Liners	Workshaft, Vent Shaft, and Cross Passages	Concrete Invert	Underpinning	Total
Basic Cost Without Influence of Any Physical Controls	1,591 (75)	470 (100)	190 (60)	115 (100)	0	2,366 (78.3)
Utility Density						
Traffic Conditions						
Existing Structures						
Ground Conditions	530 (25)		126 (40)			656 (21.7)
Architectural Requirements						
Weather						
TOTALS $ Per Linear Ft % of Total	2,121 (70.2)	470 (15.6)	316 (10.4)	115 (3.8)	0	3,022 (100.0)

NOTE: Costs given include an escalation factor of 1.345 to cover the period from October 1968 to January 1974.

Table 6-15

INFLUENCE OF PHYSICAL CONTROLS ON WORK EVENTS – WMATA CONTRACT C0041, POTOMAC RIVER CROSSING

Physical Control Elements	Cost for Work Events – $ Per Linear Ft (% of Total)					
	Tunnel Construction	Liners	Workshaft, Vent Shaft, and Cross Passages	Concrete Invert	Underpinning	Total
Basic Cost Without Influence of Any Physical Controls	1,015 (66.7)	0	77 (75)	52 (100)	93 (50)	1,237 (66.5)
Utility Density						
Traffic Conditions	76 (5.0)					76 (4.1)
Existing Structures	50 (3.3)					50 (2.7)
Ground Conditions	380 (25.0)		25 (25)		93 (50)	498 (26.7)
Architectural Requirements						
Weather						
TOTALS $ Per Linear Ft % of Total	1,521 (81.7)	0	102 (5.5)	52 (2.8)	186 (10.0)	1,861 (100.0)

NOTE: Costs given include an escalation factor of 1.070 to cover the period from January 1973 to January 1974.

To determine the values of the physical controls, consideration was given to the fact that the interaction of each of the controls on each of the work events varied according to the project construction type and location. Therefore, the incremental influences of the same physical controls on the same work events in many cases varied between the projects and in all cases had a different total effect on the project. It should be noted that the physical controls were not contract bid items and therefore had to be established on the bases of rapid transit underground construction experience. An indication of the estimating process which developed the actual incremental influence values for the more important physical controls are the typical examples discussed below.

Utility Density. As can be seen in Tables 6-8 and Tables 6-9 (BART Project K0016 and WMATA Project C0021), the influence values of Project K0016 are appreciably higher than those of the Project C0021. The principal difference is due to the much larger number of utilities left in place and supported in Project K0016. In Project K0016, the major proportion of the 10 percent was assigned to the decking work event because the utilities, being close to the surface, required raising of the decking above the general street elevation. This necessitated approach ramps and structures and other cost-generating items.

This situation applied to a much lesser degree in Project C0021. With respect to the excavation work event, the numerous utilities left in place during the construction of Project K0016 increased the cost of excavating the upper 10 ft to the extent that the total excavation, down to 70 ft, was increased by 7.5 percent. Utilities in the C0021 Contract were considerably less, and the cost influence on the total shallower excavation (50 ft) was estimated at 5 percent.

Traffic Conditions. As can be seen in Tables 6-8 and 6-9, the traffic conditions had a major effect on work events close to the surface, i.e., utilities and deck and traffic control. The traffic conditions in WMATA Project C0021 were heavier over a larger area surrounding the construction than in BART Project K0016. This affected the cost of muck removal and haulage (15 percent of the excavation cost). The influence on deck and traffic control however was less in the Project C0021 because of an agreement with the traffic authorities to close the street, block by block, as the decking was installed. This was not possible in Project K0016; the decking had to be installed two lanes at a time.

Ground Conditions. The ground in Project K0016 was variable and somewhat difficult to dewater, requiring numerous deep wells with submersible pumps. The cost of providing and operating the pumping system was assigned as an influence to the excavation work event and to the underpinning work event, as applicable. Other aspects of the soils condition assigned to both the events were related to problems in support of the ground and the lack of suitability of much of it for use as fill.

The ground in Project C0021 presented no dewatering difficulties but the presence of rock, which outcropped into the excavation, increased the cost in two ways. The first was the additional effort required for its removal and its lack of suitability as a fill material. The second evolved from the increased difficulties in drilling and installing the soldier piles for the excavation shoring.

As can be noted in Table 6-13 (Project K0016), Table 6-14 (Project S0022) and Table 6-15 (Project C0041), the ground condition in the study tunnel projects had major effects on the tunnel construction and other work events. In Project K0016, the ground condition effect on the tunnel construction was assessed on the same basis as for the station portion of the project; e.g., it was variable, it required rather elaborate dewatering equipment, and it was difficult to dispose of. In addition, owing to its variability and unknown excavation characteristics prior to project construction, a compressed air plant had to be provided as insurance against tunneling difficulties. A proportion of the cost of the compressed air plant (which was not used) was included in the ground condition influence factor.

The 50 percent ground condition factor applied against the work event of underpinning was based again on the fact that fairly elaborate underpinning was undertaken as a precaution because of the variability and unknown character of the ground, and some compressible lenses. Had the ground condition been more predictable, underpinning costs probably would have been reduced appreciably.

In Project S0022, the ground condition was very bad over some lengths of the tunnels, even after the application of compressed air. Tunnel driving was halted on more than one occasion so the tunnel face could be stabilized with grouting. Extensive dewatering was undertaken as a supplement to the compressed air control. The construction of the ventilation shaft, midway in the tunnel length, required expensive soldier-pile, slurry concrete construction and dewatering due to severe ground water conditions — hence the 40 percent ground condition factor against its construction cost.

Although the ground in tunnel Project C0041 did not present difficulties in dewatering, the tunnel face encountered extensive rock outcropping which slowed the excavation progress and added to its cost. Some cement grouting had to be undertaken to stabilize the face of the excavation. Ground disturbance during tunneling was considerable, resulting in extensive (though minor in cost) property damage.

A review of the influence of physical controls on the work events shown in Tables 6-8 through 6-15 reveals the cost sensitivity of and transit construction to physical controls.

Cut-and-Cover Stations. In the two cut-and-cover station projects, (Tables 6-8 and 6-9), it is interesting to note that the total basic cost is between 57 and 76 percent of the total project cost without the influence of physical controls (see the upper right-hand corner of the tables). The work events and their percentage contribution to the total cost in descending order of importance are as follows:

Work Event	Percent of Project Cost
Concrete	32-37
Excavation	29-32
Underpinning	4.3-17
Utilities	7.4-11
Decking and traffic control	6.9-8.[illegible]
Restoration	1.4-2.2
Backfill	1.1-1.8
Miscellaneous	3.7-4.6

The important physical control elements and their percentage contribution to the total project costs are summarized in the right-hand columns of Tables 6-8 and 6-9. In descending order of importance they are as follows:

Physical Control Element	Percent Contribution to Project Costs
Architectural requirements	2-14
Traffic conditions	8-9.1
Ground conditions	4-9.1
Existing structures	4.7-5
Weather	1-4.2
Utility density	1.9-4

The above figures reveal that the upper limit of 14 percent for archi tectural requirements demonstrate the effect of using a special structural form for architectural purposes in the WMATA station. Table 6-9 indicates details of the effect this control has upon the work events. The effect may not be representative for many stations in the transit system, but it does indicate the degree of cost involved in harmonizing architectural design between a station constructed in cut-and-cover and the majority of the WMATA stations, which were tunneled in rock.

There is a reduction of 35 to 45 percent in the total project cost when costs for the peripheral work events — utilities, decking and traffic control, and underpinning — and the physical controls related thereto (i.e., utility density, traffic conditions, and existing structures) are subtracted from the total project costs, as shown in Tables 6-8 and 6-9. This cost reduction demonstrates the large effect that these work events and physical controls have on cut-and-cover station construction. They also reveal the potential savings that might be offset against the costs of alternative construction techniques, such as mining or tunneling of stations.

Cut-and-Cover Line Sections. The cost of construction and the influence of physical controls on the three cut-and-cover line sections are presented in Tables 6-10, 6-11, and 6-12. The data in Table 6-12 for the BART Contract K0016, Oakland Line, cannot be regarded as typical for this type of construction because the structure was only about 200 ft long and consisted of two levels with three trackways, one of which was a wye. Therefore these data are not considered further in this discussion. For the remaining two study projects (see Tables 6-10 and 6-11) the basic cost for constructing line sections, without the influence of any physical controls, was between 72 and 87 percent of the actual total cost. In cut-and-cover line sections, the work events and their percentage cost contribution in approximate descending order of importance are as follows:

Work Event	Percent of Total Project Cost
Excavation	29-34
Concrete	25-27
Utilities	8.1-34
Underpinning	0-14
Decking and traffic control	2.2-8.6
Restoration	2.4-5.1
Backfill	2.2-3.8
Miscellaneous	0.4-4.0

The physical control elements and their percentage contribution to the total project cost are summarized in the right-hand columns of Tables 6-10 and 6-11. In descending order of importance they are as follows:

Physical Control Element	Percent Contribution to Project Cost
Traffic conditions	8-10
Ground conditions	1-10
Weather	2.1-4.6
Utility density	1.6-2.3
Existing structures	0-1.7

There is a reduction of 40 percent in the total project cost when costs from the peripheral work events — utilities, decking and traffic control, and underpinning — and the physical controls related thereto (i.e., utility density, traffic conditions, and existing structures) are subtracted from the total project costs, as shown in Tables 6-10 and 6-11. This cost reduction again demonstrates the large effect that these work events and physical controls have on cut-and-cover construction and points out the extent of the potential savings which can be offset against the cost of tunnel construction in high-density urban areas.

Tunnels. For the study-project tunnels (Tables 6-13, 6-14, and 6-15), costs for the following five work events were considered:

- Tunnel construction, which included excavation, muck haul, liner erection, grouting, caulking, and cleanup
- Liner costs
- Workshaft, vent shaft, and cross-passage construction
- Concrete invert and walkway placement
- Underpinning of adjacent structures

These work events and their percentage contribution to the total project costs in descending order of importance are as follows:

Work Event	Percent of Project Cost
Tunnel Construction	70-82
Liners (if applicable)	14-15
Workshaft, vent shafts, and cross passages	2.9-10
Underpinning	0-10
Concrete invert	1.9-3.8

In the above values, the major cost item is the tunnel construction, which includes excavation and related equipment, the erection of the tunnel liners, and ancillary items. The availability of tunnel liners is also a significant cost item.

These items represent areas where improvements in technology and alternative technologies can produce significant reductions in cost. In some instances, underpinning can become a significant cost, particularly in unstable ground when the tunnel alignment is close to or passes under structures with high-level foundations.

The important physical controls and their contribution to total tunneling costs are summarized in the right-hand columns of Tables 6-13, 6-14, and 6-15 and are summarized below in descending order of importance.

Physical Control Elements	Percent Contribution to Project Costs
Ground conditions	15-27
Traffic conditions	0-24
Existing structures	0-2.7
Utility density	0
Architectural requirements	0
Weather	0

It is of interest to note that the basic costs for tunneling, without the influence of any physical controls, constitute between 67 and 79 percent of the total project costs. By far the most influential physical control is the ground conditions. In the case of the three tunneling projects within the five study projects, this parameter consisted of bad ground and water conditions (the S0022 Market Street tunnel had to be driven under compressed air) or the mixed face conditions (such as those encountered in the C0041 Potomac River tunnel).

Institutional Controls

Listed below are the policies adopted by BART and WMATA on the major institutional controls that formed the basis for evaluating the sensitivities described elsewhere in this chapter.

Institutional Controls	BART	WMATA
System-wide labor agreement	Yes	No
Owner acquisition of work areas	Yes	Yes
Entry to buildings	Yes	Yes
Building permits	All major permits	No

Institutional Controls	BART	WMATA
Owner-purchased materials	Tunnel liners (other material and equipment not in study projects)	No
Owner-purchased insurance	Yes	Not for study projects
Owner-implemented safety programs	Yes	Yes
Advance payment	Yes	Yes

The above information was obtained from discussions with key engineering and other personnel engaged in system-wide engineering and managerial functions.

Discussion of Study Project Sensitivities

The sensitivity controls, both physical and institutional, were described in detail and evaluated for the five study projects and the generalized model. In addition, work event sensitivities were investigated for the generalized model.

The study project sensitivity analysis revealed these important points:

- The total basic cost without the influence of any physical controls for the types of construction are as follows:

Construction	Basic Costs as a Percent of Total Costs
Cut-and-cover stations	57-76
Cut-and-cover lines	72-87
Soft-ground tunnels	66-79

- The costs for the work events — utilities, decking and traffic control, and underpinning of existing structures, and the physical controls related thereto (i.e., utility density, traffic conditions, and existing structures) make up between 35 and 45 percent of the total project costs for the cut-and-cover stations and line sections in the study projects. These costs demonstrate the potential savings which might be offset against the costs of alternate construction techniques.

The physical controls in the study projects were a major input in developing the physical sensitivities incorporated into the generalized tunnel models. To establish the average project cost in the generalized tunnel models, a medium value for the physical controls was used for the influence of each physical control on each work event. Values were also established for both low and high influences of physical controls for each work event.

The influences on total project costs of institutional controls were determined from studying the overall contract .g philosophies and approaches for both the BART and WMATA systems and from estimating the values for the major institutional controls. To establish the average project cost in the generalized tunnel models, values for optimal institutional controls were used because there is no compelling reason to operate under less than optimal institutional control.

<u>Mathematical Analysis for Scale Effects and Influence of Physical Controls</u>

Early in the program for the analysis of study contract data, a mathematical analysis was made of the basic unit costs for all work events (i.e., costs for work events without the influence of physical controls). The analysis indicated no significant scale effects in the unit costs for each work event (e.g., no cost savings for the added work in larger projects). Furthermore, for almost all segments of a rapid transit system, there are two natural limits to the size of any one project. The first limit is the distance between stations; the second is the contract dollar size that a contractor is capable of handling. Both of these limitations govern the scale of all rapid transit constructions.

A multiple linear regression analysis was made of the physical control costs to determine mathematically the cost influence on each work item in the study contracts for low, medium, and high effects of each physical control. Inconsistencies in the data base, and the differences in the cost per unit of work for each work element, produced inconsistent influence factors for each physical control.

Bounds of the Model

Figure 6-11 reveals that the framework of the model for both cut-and-cover and tunnel construction is determined by the cost of the individual work events and the cost effects of the physical and institutional controls components. The sum of these three components is the final cost of the project.

In the analysis of the study projects, the starting point was the actual construction costs, and the process for evaluating the component costs required working back from the basic project cost to establish the values of the physical and institutional controls, and hence the cost elements of the work events. This process is described in Section 7.

SUMMARY

The analysis of five study projects from the two rapid transit systems did not yield sufficient data for the direct formulation of generalized cost models for construction of segments of rapid transit systems. It did, however, yield a methodology for the construction of this model by:

- Establishing the major types of downtown underground construction; cut-and-cover stations, line structures, and line tunnels
- Providing the definition of the construction work events for purposes of modeling and for setting the bounds of the model
- Providing the definition of the construction work events for purposes of modeling and for setting the bounds of the model
- Providing a basis for the formulation of the four generalized tunneling models:
  - cut-and-cover station
  - cut-and-cover line
  - driven tunnel under free air
  - driven tunnel under compressed air
- Providing cost/time input data to the generalized models
- Identifying the influence of both physical and institutional controls in the process of underground urban rapid transit construction
  - The effects of physical controls on the work events were established with an acceptable degree of accuracy.
  - The influence of institutional controls could not be identified from the data base of the study projects and will be assessed in a study of a system-wide approach in Section 7.
- Pointing out the interdependence among many of the physical and institutional parameters in determining the cost of work elements

Section 7

GENERALIZED TUNNEL MODELS

INTRODUCTION

The generalized tunnel models provide a basic framework for the codification of:

- Underground construction costs by project work event
- The effects on these costs of site-related project characteristics and of the nature of the relationship between the owner, engineer, and project contractor

The inputs to these models are descriptions of these physical and institutional characteristics and basic measures of project size; the outputs are parameters or trends of project cost.

Costs can also be adjusted for geographically related productivity of labor and for time-dependent escalation of labor and material costs.

For the planning and implementing of the future urban rail rapid transportation system in this country, such models can be used to:

- Determine the sensitivity of overall project costs to each construction work event and to the physical and institutional controls
- Determine the inefficient areas of tunneling in which changes in either technology or institutional influences may reduce project costs and/or reduce the time for construction

- Evaluate cost trends for the urban rapid transit systems that will be built during the next decade
- Evaluate the savings in overall project cost and construction time that may accrue when proposed new tunneling technologies are introduced into the construction process

BASIS OF THE MODELS

The models were formulated to represent structures that are likely to be in demand in the foreseeable future by rapid transit systems across the nation. The basis of the structures used for the four models is described below.

Cut-and-Cover Station

This model is based on an underground station similar in size and layout to the K0016 Station of the BART system, with the nontypical provision for the lower third track being deleted. The resulting structure for the model station is shown in Figure 7-1. The station serves two tracks from a center platform 700 ft in length. The station is 838 ft in total length, 47 ft deep, 100 ft wide, and is covered with 10 ft of fill. Provision is made for connection to the twin tunnel line structures serving the station and also for ventilation shafts at each end of the station.

Cut-and-Cover Line

This model is based on a twin-cell line structure 3,225 ft in total length, as shown in Figure 7-2. The structure cross-section is approximately 35 ft wide by 20 ft high and is covered by 15 ft of fill. Provision is made for transition from twin cells to single cells at one end, as is required when a line structure joins with a station. The design includes one pump station for structure drainage.

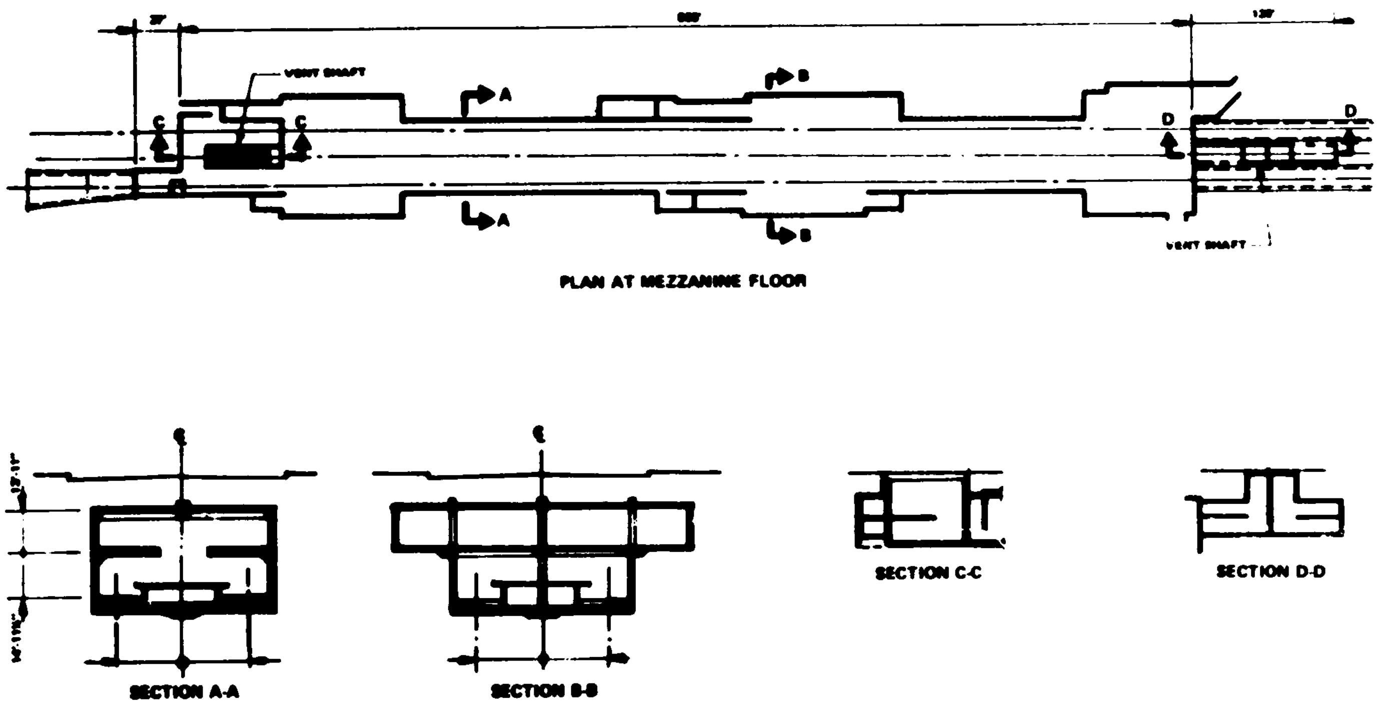


Figure 7-1. Plan and Elevation for the Model Station Similar in Size and Layout to the K0016 Station of the BART System

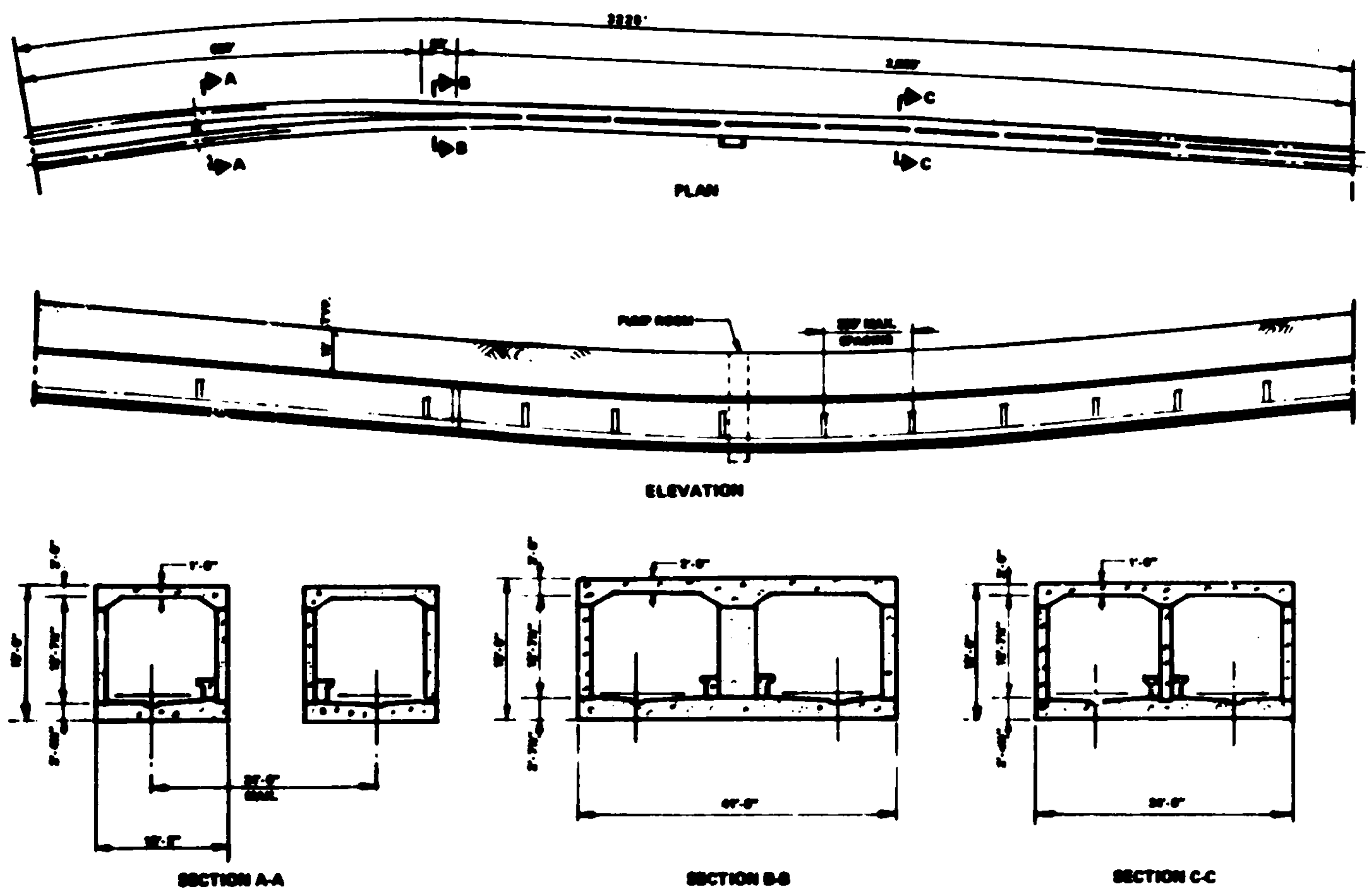


Figure 7-2. Plan and Elevation for the Model Cut-and-Cover Line Based on a Twin-Cell Line Structure

Free-Air-Driven Tunnel

This model is based on 3,000 ft of twin tunnel, each tunnel having a 16-ft i.d. Tunneling is assumed to occur under 30 ft of cover, with groundwater conditions allowing the tunnel site to be constructed in free air. The construction includes the concrete invert and walkway in each tunnel and cross passages between tunnels at 500-ft intervals. Plan and elevation of the model tunnel are shown in Figure 7-3.

Compressed-Air-Driven Tunnel

The basis for this model is the same as for the free-air-driven tunnel, except that the excavation is accomplished under compressed air in order to control water seepage.

Work Events

The cut-and-cover station and line structure work events are the same as those established by the project studies, with the exception of one additional event — muck disposal. Although in construction contracts this item is included within the excavation work event, in many urban areas the environmental aspects and the cost of muck disposal are becoming matters of considerable concern. Therefore, muck disposal, with the related physical control of fill demand, has been included as a separate work event in both cut-and-cover and the tunnel models.

The tunnel structure work events were increased by two from those established in the study projects to provide more flexibility in the model. The first — muck disposal — was added for the reasons discussed for the cut-and-cover models. The second — mobilization — is not generally a separately priced item in the contracts documents, as it is an element of the whole tunnel construction process. Mobilization includes the cost of providing (prior to shaft excavation and tunneling) and dismantling most of the surface site support facilities, such as the yard shops,

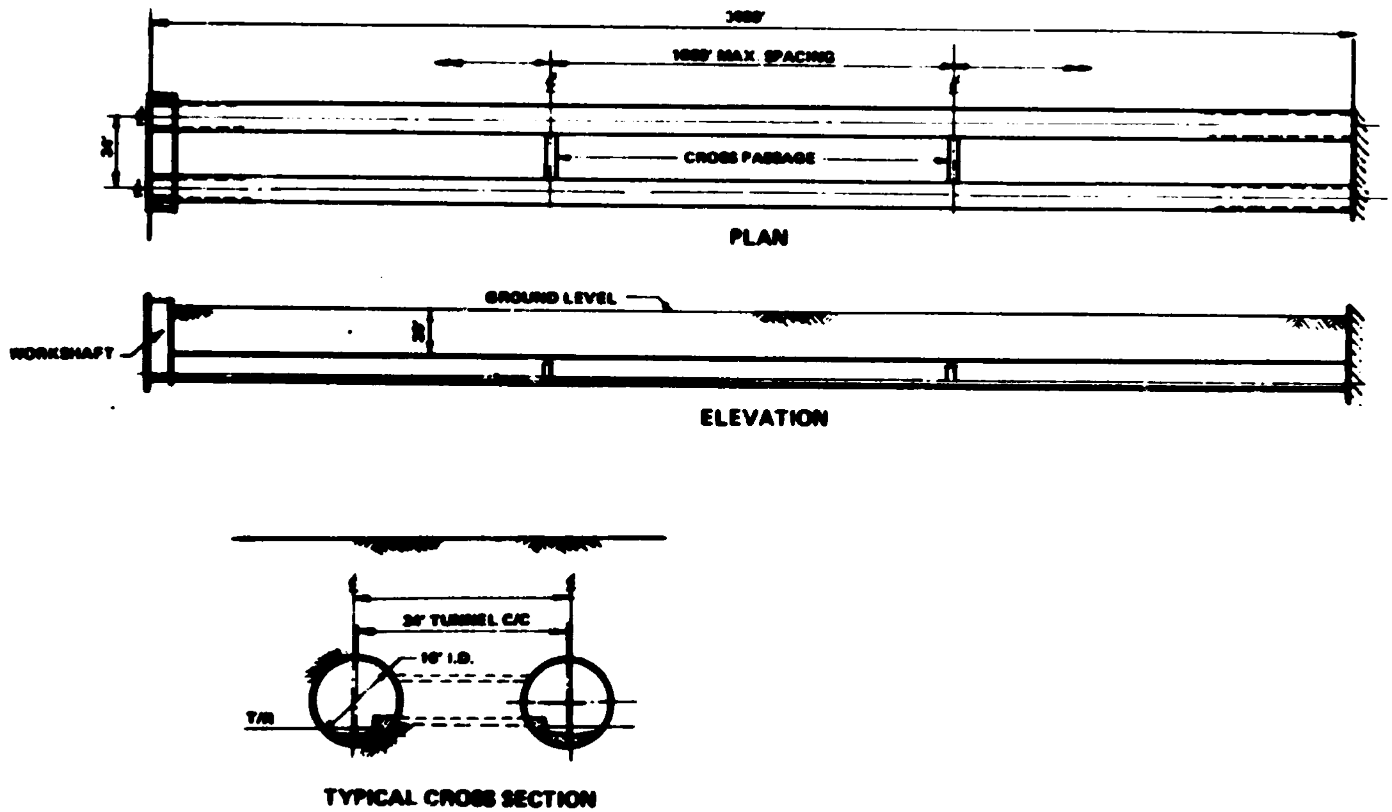


Figure 7-3. Plan and Elevation for the Model Free-Air-Driven Tunnel Based on 3,000 Ft of Twin Tunnel

electrical substations, some mobile and mechanical equipment, and low-pressure air equipment in the case of compressed air equipment. Such items are not influenced to a definable extent by any of the physical controls. Therefore, they do not appear in the model. The separate identification of the cost of mobilization permits a more accurate sensitivity study to be made of the work events directly relating to the actual tunnel construction process.

Basic Costs

Basic costs were derived for each work event from a study of as many similar structures as were available within the BART system and the WMATA system. The number of structures used for each model was:

Station — Cut-and-Cover	3
Line — Cut-and-Cover	5
Tunnel in Free Air	2
Tunnel in Compressed Air	2

Costs for the unit work events were obtained for each project by averaging the unit prices of the three low bidders and multiplying by the unit quantities. In the determination of the appropriate cost to be used, non-typical situations, which would influence the cost of a work event, were evaluated and modifications were made accordingly.

Controls

Physical and institutional control factors were obtained from a study of the appropriate structures in both transit systems, emphasis being placed on determining the representative average for each control.

Model Structure

The structure of the generalized models is based on one central fact and one general premise. The fact is that the cost of tunneling depends in complicated ways on a myriad of physical characteristics of the site, owner-engineer-contractor interactions, and the history, if any, of similar work in the area. The premise is that the model will be used in a general way to estimate the effects on project cost of new technology and new institutional arrangements, and in a more specific way to estimate the cost trends of specific projects before detailed engineering designs are completed.

The premise requires that the model be operable with a minimum of specification related to technical design, site characteristics, and institutional arrangements. Because of the complexity of the effects of the numerous items contained in the specifications of an actual project, detailed cost effects cannot be accounted for in general models. Hence, the models show only the main events of the tunneling technology and physical and institutional controls.

DESCRIPTION OF THE MODELS

The Three Parts of Each Model

Based on the philosophy stated above, the generalized models consist of three major parts. For each project type, a representative project is defined.

The First Part of the Model. This part gives the basic costs of each work event for the representative project under "average" physical conditions and optimal institutional controls. The definition of the project as to scope and design and the basic costs are quite firmly based in fact. Given a limited set of data for a complex multivariable situation, it is always easier to arrive at broad averages than to specify the deviation from these averages occasioned by a change in this or that variable. For flexibility in model use, these basic work event costs are expressed as unit costs based on relevant project measures (i.e., dollars per foot, or dollars per cubic yard). The work with the study projects showed that these unit costs do not vary significantly with project scale over the anticipated range of projects. The unit-cost approach allows the model to be used to estimate the basis of the cost of projects simiiar in type to the representative project but with reasonable differences in scope (i.e., the lengths of the construction may vary ± 30 percent without greatly affecting the unit costs).

The Second Part of the Model. This part deals with the effects of physical controls on the average. While the factors that influence the cost can be broadly defined and described (see Section 6), quantification of the effects in detail is impossible. For example, the difference in the cost of a cut-and-cover construction between a project in which there are essentially no utilities in the way and one in which there is a normal mix of water pipes, sewers, and telephone and electric lines can be quantitatively estimated. On the other hand, the cost difference due to the addition of one extra set of telegraph lines to the normal mix cannot be quantitatively estimated without detailed engineering study and cost estimates specific to the case of interest.

It was therefore decided to describe the effects of physical controls in three levels rather than in a continuous range of values. The latter could not be adequately defined without extensive and detailed study, and, if defined, could not be evaluated from the data at hand. The three levels are "significantly more favorable than average," "average," and "significantly less favorable than average."

The Third Part of the Model. This part is concerned with the effect on project cost of institutional controls. Some of these effects can be estimated quite accurately; others cannot. The ones that can, tend to be "yes-no"-type situations — either the owner makes an advance payment to the contractor to finance project mobilization or he does not. The cost difference between these cases is clear-cut. In the first case, the owner bears the interest cost at the prime rate generally accorded to stable public agencies with a guaranteed tax base; in the second case, the contractor must bear the interest cost at a higher rate of interest, and this cost will be reflected in the contractor's bid and hence in the cost of the project to the owner.

The effects of some institutional controls are uncertain. For example, if the owner does not supply tunnel liners, the delay in project start-up caused by the lead time to fill the contractor's order depends on the state of business in the area and could be as little as 1 month or as much as 6 months or more.

To take these uncertainties into account, the model has three levels of institutional controls. The first level corresponds to the application of optimal institutional control (i.e., making an advance payment to the contractor, or ordering tunnel liners far enough in advance to ensure their availability when the contractor needs them). The second and third levels both correspond to the absence of the optimal control, with "average minimum" and "average maximum" effects specified, respectively, for the two levels.

Basic Model Structure

The basic structure of the four models is quite similar. There are only minor differences between the two cut-and-cover models on the one hand and the two tunneling models on the other. A flow diagram of the basic model structure is shown in Figure 7-4. In this figure, data incorporated in the program are identified, as are the required inputs for the cost estimations of a specific project. The four flow diagram blocks are described below.

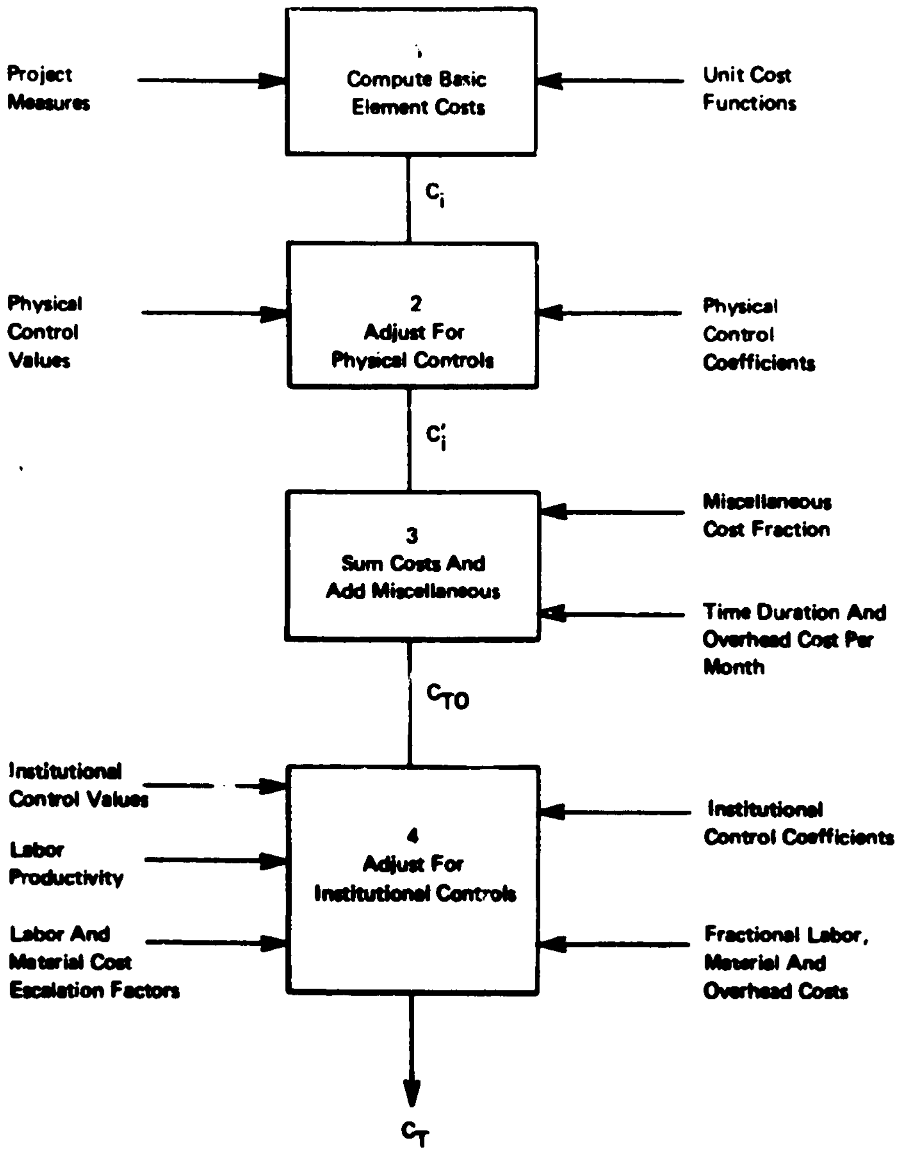


Figure 7-4. Basic Model Structure

Block 1 — Project Work Event. In Block 1, the basic costs associated with each project work element are computed from stored values of element unit costs and the measures that describe the size of the project. For cut-and cover projects, the work events, the unit costs, and the associated project measures are given in Table 7-1.

Table 7-1

MEASURES AND COSTS FOR CUT-AND-COVER WORK EVENTS

(1) Project Work Event	(2) Relevant Project Measure	(3) Unit Cost Expressed as	(4) Total Element Cost ($)
Utilities	M_1 — Length of Project (LF)	c_1($/LF)	$C_1 = c_1 M_1$
Deck and Traffic Control	M_2 — Plan Area (yd^2)	c_2($/$yd^2$)	$C_2 = c_2 M_2$
Underpinning	M_1 — Length of Project (LF)	c_3($/LF)	$C_3 = c_3 M_1$
Excavation	M_3 — Volume Excavated (yd^3)	c_4($/$yd^3$)	$C_4 = c_4 M_3$
Backfill	M_4 — Volume Backfilled (yd^3)	c_6($/$yd^3$)	$C_6 = c_6 M_4$
Concrete*	(M_3-M_4) — Net Volume (yd^3)	c_6($/$yd^3$)	$C_6 = c_6(M_3-M_4)$
Restoration	M_1 — Length of Project (ft)	c_7($/LF)	$C_7 = c_7 M_1$
Muck Disposal	(M_3-M_4) — Net Volume (yd^3)	c_8($/$yd^3$)	$C_8 = c_8(M_3-M_4)$

*The relevant measure is taken to be the net size of the excavation rather than the actual volume of concrete used. See the "Cost and Sensitivity Data" part of this section for further discussion.

For tunnel projects, there are fewer work events and relevant project measures, but the form of the model and the computation of the basic work element costs are similar as shown in Table 7-2.

Table 7-2

MEASURES AND COSTS FOR TUNNELING WORK EVENTS

(1) Project Work Event	(2) Relevant Project Measure	(3) Unit Cost Expressed as	(4) Total Element Cost ($)
Mobilization	Lump-Sum		C_1
Shaft Construction	Lump-Sum		C_2
Underpinning	M_1 – Length of tunnel (LF)	c_3($/LF)	$C_3 = c_3M_1$
Line, Grout, and Caulk	M_1 – Length of tunnel (LF)	c_4($/LF)	$C_4 = c_4M_1$
Excavation	M_1 – Length of tunnel (LF)	c_5($/LF)	$C_5 = c_5M_1$
Muck Disposal	M_1 – Length of tunnel (LF)	c_6($/LF)	$C_6 = c_6M_1$
Concrete and Clean-Up	M_1 – Length of tunnel (LF)	c_7($/LF)	$C_7 = c_7M_1$

The total basic element cost is computed from the unit cost multiplied by the relevant measure, as shown in column (4) in each table. Unit costs are part of the program data, but the values of the project measures must be supplied for each specific case of interest.

Block 2 – Relevant Project Measure. In Block 2, the basic element costs are adjusted for the effects of physical site characteristics. The important characteristics are:

- Utility density
- Traffic conditions

- Existing structures (size and age)
- Ground conditions
- Architectural requirements
- Weather
- Fill demand

For each specific case, each of these characteristics must be rated as low, medium, or high, depending on whether the characteristic has an insignificant, average, or important effect on the performance of the project and hence its cost. The basic work element costs are adjusted for low, medium, or high effects by the addition of a specified percentage to these basic costs.

In principle, each of the seven physical characteristics could affect each of the eight (cut-and-cover) or seven (tunnel) work element costs. For the ith work element, the adjusted cost is

$$C_i\left(1+\sum_{j=1} \beta_{ijk}\right)\left(1+\gamma_{in}\right)$$

where β_{ijk} is the appropriate cost correction coefficient by which the jth physical characteristic affects the cost of the ith work element. Subscript k denotes whether the value of the physical characteristic is low (k=1), medium (k=2), or high (k=3). All coefficients are positive fractions. The required data inputs for Block 2 are the values (low, medium, high) for each of the seven physical controls. Program data required are three coefficient matrices (β_{ij1}, β_{ij2}, and β_{ij3}) and two coefficient vectors (γ_{i1} and γ_{i3}). Values of γ_{i1} are either negative or zero; values of γ_{i3} are either positive or zero; values of γ_{i2} are all zero. In addition, subscript n is equal to the value of k when i=j.

Block 3 — Unit Cost. In Block 3, the adjusted project element costs are summed, and the sum is multiplied by the factor $(1 + \delta_M)$ to account for miscellaneous project costs not included under any work element.

The total cost thus computed (C_T) is further corrected to account for the overhead costs associated with the change in work time required if the scope of the work element changes (as indicated by the coefficient γ_{in}). These changes are possible only in the first three work events in the cut-and-cover models and in the third work event in the tunnel models, since only these work events are subject to scope change. The fractional time increase in total project duration is taken to be one-half the fractional change in total project cost due to the change in scope. This fractional time increase is multiplied by the basic project duration (T) to give the change in project time (δ_T), and then by the overhead rate per month (Z) to give the added cost (C_D).

$$C_D = \delta_T Z$$

$$= \frac{1}{2C_T}\left[\sum_{i=1}^{3}\left(c_i \cdot M_i\right) \cdot \left(1 + \sum_{j=1}^{J} \beta_{ijk}\right)\gamma_{in}\right] TZ$$

The result of Block 3 operations is an estimate of the total basic project cost adjusted for the physical characteristics of the site. No input data are required in this block, and the only pieces of program data needed are the values of δ_M, T, and Z.

The operations carried out in Blocks 1 through 3 can be summarized in one equation :

$$C_{To} = \left[\sum_{i=1}^{I}\left(c_i \cdot M_i\right)\cdot\left(1 + \sum_{j=1}^{J} \beta_{ijk}\right)\left(1 + \gamma_{in}\right)\right]\left(1 + \delta_M\right) + C_D$$

where

- i = project work event ($I = 8$ for cut-and-cover; $I = 7$ for tunnels)
- j = physical characteristic ($J = 7$ for all projects)
- k, n = value of physical characteristic
- M = project measure

Block 4 — Total Element Cost. In Block 4, the project cost is adjusted for the influences of the owner-engineer relationship and for cost escalation. Costs in the basic model are derived on the assumption that an optimal relationship exists. To the degree that elements of this relationship are missing, costs must be added. The elements of the owner-engineer-contractor relationship are:

- Optimal project schedule
- System-wide labor agreement
- Owner-acquired work areas
- Owner-acquired rights-of-way
- Owner-acquired entry permits
- Owner-acquired building permits
- Owner-supplied material
- Owner-purchased insurance
- Owner-enforced environmental requirements
- Advance payments
- Safety
- Efficient cash flow

For each of these controls, three effects are estimated: (1) the delay (in months), (2) a lump-sum addition to the cost, and (3) an increase in total cost by a given percentage. The effects under each category are calculated according to the following formulas:

Months delay	$\alpha 1T = \sum_{i=1}^{12} \alpha 1_{ij}$
Lump-sum	$\alpha 2T = \sum_{i=1}^{12} \alpha 2_{ij}$
Fraction of cost	$\alpha 3T = (\sum_{i=1}^{12} \alpha 3_{ij}) + \alpha 3L$

In the above equations, i denotes the institutional control, and the value of j denotes whether the optimal control is present (j=1), absent with moderate effect (j=2), or absent with large effect (j=3). The values of $\alpha 1_{i,j}$, $\alpha 2_{i,j}$, and $\alpha 3_{i,j}$ are all zero for j=1 and may be positive or zero for other values of j. The value $\alpha 3L$ is a specific factor relating to labor productivity and must be calculated from a separate labor productivity input value (p), which defines labor productivity in terms of work units performed per man-hour relative to the San Francisco area. The equation for this factor is

$$\alpha 3L = \epsilon_L\left(\frac{1}{p} - 1\right)$$

where ϵ_L is the fraction of the total cost attributed to labor (a piece of program data).

The delays associated with owner-acquired building permits, material, and rights-of-way and entry permits are not strictly additive, since the efforts necessary to obtain each can be concurrent to a degree. To account for this concurrence, the sum of the delay (in months) associated with these four controls is reduced by 20 percent if at least three controls, each having moderate effect, are absent; or if at least two controls, each having a major effect, are absent.

The cost is then computed from

$$C_{T_1} = C_{TO}(1 + \alpha 3T) + \alpha 2T + \alpha 1TZ$$

where Z is the overhead cost per month (a piece of program data).

Finally, the cost is corrected for escalation in labor and materials costs relative to January 1974 in San Francisco. The final cost estimate is

$$C_T = C_{T_1}\left[\epsilon_L f_L + \epsilon_M f_M + \epsilon_o\right]$$

where ϵ_L, ϵ_M, and ϵ_o are the fractional labor, materials, and overhead cost (program data), respectively, and f_L and f_M are cost escalation factors which must be entered as data.

The total project duration (T_T) is computed by adding the basic project duration (T_1), a piece of program data, to the delays caused by changes in scope due to physical controls (δ_T) and to the delays caused by absence of optimal organizational controls ($\alpha 1T$).

$$T_T = T + \delta_T + \alpha 1T$$

As described earlier, the basic cost data were generated by cost estimators and engineers connected with this work and represent their best estimates of the costs of representative projects. The sensitivity data are also the result of a distillation of the material developed in this manner. Sensitivities to physical controls are expressed in terms of fractions of the basic work element costs. Those associated with institutional controls are also expressed in terms of months of delay and direct cost in order to account in optimal fashion for all significant effects.

A complete FORTRAN listing of the computer program and instructions for use of the model are given in the Appendix .

COST AND SENSITIVITY DATA

The basic cost and sensitivity data used in formulating the generalized tunneling models were provided from the experience of cost personnel and other engineering personnel and are based for the most part on the analysis of data from BART and, in some cases, from WMATA. Care was taken to distill this experience into estimates consistent with the representative nature of the generalized projects modeled.

Tables 7-3 through 7-5 show the basic cost data, by work event, for the four model projects. For each event, the quantities, units, and unit costs used in developing the cost estimate are shown. The total for each event is the product of the quantity multiplied by the unit cost.

The units and unit costs used in the computerized models of cut-and-cover models are shown in the last two columns of Tables 7-3 and 7-4. These differ from the units and unit costs used to generate the estimate in one work element — concrete — for which the model unit is taken as the cubic yards of net excavation (excavation less backfill) rather than cubic yards of concrete, since the former is more readily available to the potential future user of the model.

In each model, the cost of miscellaneous items is expressed as a percentage of the total project cost.

In Tables 7-5 and 7-6, which describe the free-air-driven and compressed-air-driven tunnels, respectively, all but two of the work event costs were estimated and expressed in the model in terms of linear feet of twin-bore tunnel. The first two items — shaft construction and mobilization — treated as lump-sum amounts.

Physical Control Sensitivity Data

Table 7-7 shows the sensitivities of the work event costs to the physical controls for the cut-and-cover station model. The bottom line gives the unit costs for each work event taken from Table 7-3. The fractional effect

Table 7-3

COST SUMMARY FOR GENERALIZED MODEL FOR 838-FT CUT-AND-COVER STATION

Work Event	Costs*						
	Quantity	Unit	Unit Cost ($)	Amount	Totals	Model Unit	Unit Cost
Utilities	838	LF	1990.13		$1,667,727	838 LF	1990.13
Decking and Traffic Control							
Decking Area = 100% Plan Area Traffic Control	9,500	yd^2	98.29	933,755 226,761	1,160,516	9,500 yd^2	122.16
Underpinning					500,000	838 LF	596.6[illegible]
Excavation (Including Settlement Monitoring)	113,218	yd^3	45.02		5,096,865	113,218 yd^3	45.02
Muck Disposal	89,514	yd^3	4.36		390,508	89,514 yd^3	4.36
Concrete	29,538	yd^3	180.00		5,316,928	89,514 yd^3	59.40
Backfilling	23,704	yd^3	11.60		274,966	23,704 yd^3	11.60
Street Restoration	838	LF	212.00		177,656	838 LF	212.00
Miscellaneous+					768,863	% of total cost	5.0%
TOTAL					$15,354,023		

NOTE: The construction schedule is 24 months.

*All costs reflect a January 1974 midpoint.

+This event includes miscellaneous steel and iron, steel and iron doors, and installation of district furnished fans.

Table 7-4

COST SUMMARY FOR GENERALIZED MODEL FOR 3,225-FT CUT-AND-COVER LINE

Work Event	Costs*						
	Quantity	Unit	Unit Cost ($)	Amount	Totals	Model Unit	Unit Cost
Utilities	3,225	LF	804.38		$2,594,119	3,225 LF	804.38
Decking and Traffic Control							
Decking Area = 50% Plan Area Traffic Control	6,665	yd^2	86.82	578,655 352,894	931,549	6,665 yd^2	139.76
Underpinning					322,500	3,225 LF	100.00
Excavation (Including Settlement Monitoring)	146,126	yd^3	23.17		3,385,294	146,126 yd^3	23.17
Muck Disposal	76,871	yd^3	4.36		335,400	76,871 yd^3	4.36
Concrete	25,935	yd^3	118.41		3,070,963	76,871 net excavation	39.95
Backfilling	69,255	yd^3	7.78		538,804	69,225 yd	7.78
Street Restoration	3,225	LF	107.70		347,335	3,225 LF	107.70
Miscellaneous[+]					329,004	% of total cost	2.77%
TOTAL					$11,854,968		

NOTE: The construction schedule is 21 months.

*All costs reflect a January 1974 midpoint.

+This event includes miscellaneous steel and iron, and owner-furnished pumps.

Table 7-5

COST SUMMARY FOR GENERALIZED MODEL FOR 3,000-FT FREE-AIR-DRIVEN TUNNEL

Work Event	Unit	nit Costs $/System Ft	Amount
Shaft Construction	L. S.		$ 815,000
Mobilization	L. S.		500,000
Underpinning	LF	100	300,000
Tunnel Driving Costs			
Liner, Erection, and Caulking	LF	$ 300/LF	
Grouting	LF	$ 240/LF } 1800	5,400,000
Tunnel Liners	LF	$1260/LF	
Excavation	LF	2000	6,000,000
Disposal	LF	80	240,000
Concrete Construction	LF	170	510,000
TOTAL		4588	$13,765,000

Labor = 37%

Equipment and Materials = 63%

*All costs reflect a January 1, 1974 midpoint.

Table 7-6

COST SUMMARY FOR GENERALIZED MODEL FOR 3,000-FT TWIN-BORE COMPRESSED-AIR-DRIVEN TUNNEL

Work Event	Unit	Unit Costs* $/System Ft	Amount
Shaft Construction	L. S.		$ 978,000
Mobilization, Staff E&M	L. S.		700,000
Underpinning	LF	100	300,000
Tunnel Driving Costs			
Liner Erection, Caulking	LF	$ 400/LF	
Grouting		$ 290/LF } 1950	5,850,000
Tunnel Liners		$1260/LF	
Excavation	LF	2950	8,850,000
Disposal	LF	80	240,000
Concrete Construction	LF	170	510,000
TOTAL		5809	$17,428,000

Labor = 43%

Equipment and Materials = 57%

*All costs reflect a January 1, 1974 midpoint.

Table 7-7

PHYSICAL CONTROL EFFECTS, CUT-AND-COVER STATION

	Utilities	Decking and Traffic Control	Under-pinning	Excavation	Concrete	Backfill	Restoration	Muck Disposal	Misc.
Basic Costs ($/LF)	1493	73.20	478	22.51	59.40	8.12	180	1.96	
Utility Density	.50 | 0 0 | 0 -.50 | 0	0.42 0.25 0.08		0.30 0.20 0.10		0.43 0.29 0.14			
Traffic Conditions	0.39 0.26 0.07	0 | .51 0 | .34 -.50 | .09		0.40 0.20 0.10		0.14 0.07 0	0.24 0.12 0.06	0.22 0.11 0	
Existing Structures			5.00 | 0 0 | 0 -0.50 | 0	0.40 0.20 0					
Ground Conditions	0.13 0 0		0.38 0.25 0.13	0.50 0.30 0.10				0.44 0 0	
Architectural Requirements				0.20 0 0	0.35 0 0	0.07 0 0			
Weather	0.14 0.07 0	0.16 0.08 0		0.20 0.10 0	0.10 0 0	0.14 0.07 0	0.12 0.06 0		
Fill Demand								2.22 1.11 0	
TOTALS	1990 $/LF	122 $/yd^2	597 $/LF	45.02 $/yd^3	59.40 $/net yd^3	11.60 $/yd^3	212 $/LF	4.36 $/yd^3	5.3%

Length 838 LF
Plan Area 9500 yd^2
Backfill 23,704
Excavation 113,218 yd^3
Overhead $59,000/mo
Duration 24 mo

of each physical control (listed vertically on Table 7-7) on the cost of each work event was estimated. These values are given in the box in Table 7-7, in which the work event of interest intersects the physical control of interest.

For example, consider the effect of ground conditions on excavation. The three numbers listed in the intersecting box in Table 7-7 are 0.50, 0.30, and 0.10, indicating that if the ground conditions are poor (high level of the physical control), 50 percent should be added to the basic work event cost. Similarly, if the ground conditions are moderate (medium level of the physical control) or good (low level of the control), 30 percent and 10 percent, respectively, should be added to the basic work event cost.

For these values, which give the fractional effects of each physical control on each work event, the basic costs shown on the top line of Table 7-7 were derived from the total work event costs shown on the bottom line of Table 7-7 and taken from Table 7-3. Since the estimated work event costs shown in Table 7-3 were derived assuming medium levels for each physical control, the basic costs on the top line were computed by adding unity to the sum of the middle numbers in all boxes under the work event of interest and dividing the result into the total cost on the bottom line. For example, the estimated unit cost for excavation is shown on the bottom line of Table 7-7 to be $\$45.02/yd^3$. The sum of the middle fractions in all boxes above this cost is (0.10 + 0.30 + 0.20 + 0.20 + 0.20) = 1.00. Adding this sum to unity gives 2.00, and dividing the result into \$45.02 gives the basic cost, shown in the top line, of \$22.51.

In most cases, the physical control modifies the degree of difficulty of performing the work event without changing the scope of the work event. For example, poor ground conditions make excavation more difficult, but do not increase the amount of material that must be excavated.

In three specific cases, the level of the physical control modifies the scope of the work event. These cases are:

Physical Control	Work Event
Utility Complexity	Utilities
Traffic Conditions	Decking and Traffic Control
Existing Structures	Underpinning

In each case, an increasing level of the control (e.g., more utilities to be relocated) means an increased scope of the work event. These effects are shown in the left-hand side of the three relevant boxes on Table 7-7. For example, the three values shown for the utility density/utilities effect are +0.50, 0, and -0.50, signifying the effect of a high, medium, and low level of the control, respectively.

The adjusted work event cost is computed by first adjusting the basic cost (top line) for the effects of other controls as described above. This cost is then multiplied by the sum of the scope factor and unity. For example, if all physical controls are at the low level, the adjusted basic cost is 1,493 x (1.00 + 0.07) = 1,598, and the cost adjusted for scope is 1,598 x (1.00 - 0.50) = 799.

The basic cost values and the fractional coefficients shown in Table 7-7 are incorporated directly into the computerized cut-and-cover station model. Tables 7-8 through 7-10 show the comparable costs and coefficients for the cut-and-cover line model and the two tunneling models.

Institutional Control Sensitivity Data

The basic data showing the sensitivity of project cost to institutional controls are shown in Table 7-11 for the cut-and-cover station model. The institutional controls are listed under four headings: (1) Schedule-Time, showing the potential project delay associated with the absence of optimal control; (2) Direct Cost, showing direct additions to project cost;

Table 7-8

PHYSICAL CONTROL EFFECTS, CUT-AND-COVER LINE

	Utilities	Decking and Traffic Control	Under-pinning	Excavation	Concrete	Backfill	Restoration	Muck Disposal	Misc.
Basic Costs ($\$/LF$)	683	112	90	17.38	35.96	6.22	97.20	1.96	
Utility Density	1.50, 0 0, 0 -0.50	0.12 0.06 0.02		0.13 0.07 0.03		0.12 0.06 0.02			
Traffic Conditions	0.24 0.12 0.06	1.00, 0.18 0, 0.12 -0.70, 0.06		0.19 0.13 0.06	0.12 0.06 0	0.18 0.12 0.05	0.16 0.11 0.05	0.22 0.11 0	
Existing Structures			5.00, 0 0, 0 -1.00, 0	0.07 0 0					
Ground Conditions	0.12 0 0		0.22 0.11 0	0.35 0.07 0				0.44 0 0	
Architectural Requirements									
Weather	0.12 0.06 0	0.12 0.06 0		0.13 0.07 0	0.12 0.06 0	0.12 0.06 0	0.11 0 0		
Fill Demand								2.22 1.11 0	
TOTALS	804 $\$/LF$	140 $\$/yd^2$	100 $\$/LF$	23.17 $\$/yd^3$	39.95 $\$/net\ yd^3$	7.78 $\$/yd^3$	108 $\$/LF$	4.36 $\$/yd^3$	2.8%

Length 3225 LF
Plan Area 6665 yd^2
Excavation 141,126 yd^3
Backfill 69,255 yd^3
Overhead $\$56,000/mo$
Duration 21 mo

Table 7-9

PHYSICAL CONTROL EFFECTS, FREE AIR TUNNEL

	Mobilization	Workshaft	Under-pinning	Excavation	Liner Erection, etc.	Muck Disposal	Concrete
Basic Costs (L.S. or $/LF)	500,000 L.S.	570,000 L.S.	70	1600	1800	36	170
Utility Density				0.12 0.06 0			
Traffic Conditions						0.22 0.11 0	
Existing Structures			2.00 0 0 0 -1.00 0	0.12 0.06 0			
Ground Conditions		0.86 0.43 0.21	0.86 0.43 0.21	0.26 0.13 0		0.44 0 0	
Fill Demand						2.22 1.11 0	
TOTALS	500,000 L.S.	815,000 L.S.	100 $/system ft	2000 $/system ft	1800 $/system ft	80 $/system ft	170 $/system ft

Length of Twin Bore	3000 LF
Labor	37%
E&M	63%
Overhead	$160,000/mo
Duration	13 mo

Table 7-10

PHYSICAL CONTROL EFFECTS, COMPRESSED AIR TUNNEL

	Mobilization	Work Shaft	Under-pinning	Excavation	Liner Erection, etc.	Muck Disposal	Concrete
Basic Costs (L.S. or $/LF)	700,000 L.S.	683,000 L.S.	70	2360	1950	36	170
Utility Density				.12 .06 0			
Traffic Conditions						0.22 0.11 0	
Existing Structures			2.0[illegible] 0 0 0 -1.00 0	0.12 0.06 0			
Ground Conditions		0.86 0.43 0.21	0.86 0.43 0.21	0.26 0.13 0		0.44 0 0	
Fill Demand						2.22 1.11 0	
Totals	700,000 L.S.	978,000 L.S.	100 $/system ft	2950 $/system ft	1950 $/system ft	80 $/system ft	170 $/system ft

Length	3000 LF
Labor	43%
E&M	57%
Overhead	$200,000/mo
Duration	21 mo

Table 7-11

COSTS ASSOCIATED WITH CONTROLS– CUT-AND-COVER STATION

	Added Cost Trend Optimal Control Absent			
	Moderate Effect		Major Effect	
Schedule/Time		Time Assumed		Time Assumed
Project Schedules	$ 59,000	1.0 mo	$ 118,000	2.0 mo
System-Wide Labor Agreement	59,000	1.0 mo	88,500	1.5 mo
Owner Lease/Purchase, Work Areas	59,000	1.0 mo	59,000	1.0 mo
Right-of-Way	59,000	1.0 mo	354,000	6.0 mo
Entry to Existing Buildings	29,500	0.5 mo	118,000	2.0 mo
Building Permits	29,500	0.5 mo	29,500	0.5 mo
Owner Purchase/Material and Equipment	NIL	–	NIL	–
(Deduct 20% for concurrence.)	S. T. 236,000		613,000	
Direct Cost		**Basis**		**Basis**
Building Permits	3,500	2 man-mo	7,000	4 man-mo
Owner-Purchased Material and Equipment	NIL	–	NIL	–
Owner Purchased Insurance	176,000	Workmen's compensation handback	211,200	Workmen's compensation handback, 20% increment
Safety Programs	-62,000	Safety engineers 1.5 men, 24 mo	-93,000	Safety engineers 54 man-mo
Environmental Requirements	50,000	Soldier piles drilled @ $42/LF	100,000	Soldier piles drilled @ $84/LF
	S. T. 167,500		225,200	
Productivity				
Owner-Purchased Insurance	254,000	5% of labor	1,524,000	30% of labor
Safety Programs				
Geographical Area	508,000	10% of labor	2,540,000	50% of labor
	S. T. 762,000		4,064,000	
Interest				
Mobilization Advance Payment	30,000	$1,000,000 @ 3%, 1 yr	45,000	$1,000,000 @ 3%, 1.5 yr
Cash Flow	39,000	$15,300,000 @ 3%, 1 mo	234,000	$15,300,000 @ 3%, 6 mo
Owner-Purchased Material and Equipment	NIL	–	NIL	–
Owner-Purchased Insurance	16,000	$540,000 @ 3%/yr	16,000	$540,000 @ 3%/yr
	S. T. 85,000		295,000	
TOTAL	$1,250,500		$5,197,800	

(3) Productivity, showing the effects on labor productivity, and hence on cost, and (4) Interest, showing the added costs associated with contractor financing of project elements compared with owner financing of those elements. Some institutional controls appear under several headings, since they produce multiple effects.

The first column lists the costs to be added to the project cost if the specific optimal institutional control is absent and the effect is moderate. The second column lists the basic estimated assumptions to provide the dollar values in the first column. The third column lists the costs to be added if the specific optimal institutional control is absent and there is a major effect. Column four explains these values.

Under the Schedule/Time heading, the costs associated with delays in the project are shown, with the overhead rate at $59,000 per month. As shown in the third column, if acquisition of rights-of-way is not started sufficiently in advance of construction, and a stop of 6 months occurs, the cost could be $354,000.

Under the Direct Cost heading, the major item is the potential added cost if the owner does not supply the insurance. The assumed added cost of $176,000 is attributed to handback of workmen's compensation premiums which would accrue to the owner if he provided the insurance. Otherwise, any handback goes to the contractor. Lack of an owner-sponsored safety program results in a saving of direct cost, since it is assumed that the contractor will devote less in the way of resources to the safety program than would the owner. The added cost for meeting environmental regulations is based on the assumption that soldier piles protecting the excavation will have to be drilled, rather than driven, at an added cost of $42 per linear system foot.

Productivity can be significantly affected by institutional controls. It is estimated that labor costs can increase from 5 percent ($254,000) to 30 percent ($1,524,000) if the owner does not supply the insurance and monitor the safety programs and the project is very accident-prone. These costs are attributed to loss of productivity due to accidents. The second item under the Productivity heading relates to the productivity of the labor available in the local market and is not under the control of the owner. The lack of skilled labor in some geographical areas can raise labor costs by an estimated 10 percent ($508,000) to 50 percent ($2,540,000) because of inefficiency and the necessity of extensive training programs.

The Interest heading shows the added costs accruing if the owner does not provide optimal financing. The 3 percent figure on which these cost estimates are based is the estimated differential between what the owner must pay for money (say, 9 percent) and what the less financially stable contractor must pay (say, 12 percent). This differential percentage operates on the mobilization payment and on the insurance premium, if not supplied at project start-up by the owner. The cash flow effect shows the added cost if the owner delays from 1 to 6 extra months in making partial payments to the contractor during the course of the project. During this period, the contractor must borrow the money at the higher interest rate. The entire project cost ($15,300,000) is subject to this delay over the life of the project at the differential interest rate of 3 percent.

The subtotals and totals shown on Table 7-11 set the maximum limit on the cost that institutional controls can add to project cost. It is unlikely that all institutional controls will be simultaneously absent, and even more unlikely that all will be absent with major effect.

Tables 7-12 through 7-14 show the institutional control sensitivity data for the other three generalized models. The basic information in these tables is similar to that for the cut-and-cover station discussed above. The potential effect of owner-purchased materials (tunnel liners) on the costs of the tunneling projects deserves special mention. Owner acquisition of these liners prior to project start-up eliminates a potentially significant delay, makes possible a "quantity-buy" saving if ordered for more than one project, and keeps the financing of this major quantity of material with the owner. Failure to do this can result in significant added costs, as summarized below (using data taken from Table 7-13).

	Moderate Effect	Major Effect
Delay	160,000	960,000
Loss of Quantity Saving	378,000	756,000
Added Interest Cost	114,000	114,000
	$652,000	$1,830,000

The basic institutional control data shown in Tables 7-11 through 7-14 were transformed into coefficients for the computerized model. Three sets of coefficients were derived for each of the 12 organizational controls, as shown for the cut-and-cover station model in Table 7-15.

The $\alpha 1$ coefficients show the potential delay (in months) associated with each control at each level (low — optimal control; medium — optimal control absent, moderate effect; high — optimal control absent, major effect). The medium and high values are taken directly from Table 7-11.

The $\alpha 2$ coefficients (Table 7-15) show the direct cost effects. Only the direct costs associated with building permits and safety programs and the interest cost associated with the advance payment were included in the computer model as direct costs, since they are relatively independent of project size. These costs were taken directly from Table 7-11.

Table 7-12

COSTS ASSOCIATED WITH CONTROLS – CUT-AND-COVER LINE

	Added Cost Trend Optimal Control Absent			
	Moderate Effect		Major Effect	
Schedule/Time		Time Assumed		Time Assumed
Project Schedules	$ 56,000	1.0 mo	$ 112,000	2.0 mo
System-Wide Labor Agreement	56,000	1.0 mo	84,000	1.5 mo
Owner Lease/Purchase, Work Areas	56,000	1.0 mo	56,000	1.0 mo
Right-of-Way	56,000	1.0 mo	336,000	6.0 mo
Entry to Existing Buildings	28,000	0.5 mo	98,000	1.75 mo
Building Permits	28,000	0.5 mo	28,000	0.5 mo
Owner-Purchased Material and Equipment	NIL	–	NIL	–
(Deduct 20% for concurrence.)	S.T. 224,000		571,200	
Direct Cost		Basis		Basis
Building Permits	3,500	2 man-mo	7,000	4 man-mo
Owner-Purchased Material and Equipment	NIL	–	NIL	–
Owner-Purchased Insurance	130,000	Workmen's compensation handback	156,000	Workmen's compensation handback, 20% increment
Safety Programs	-54,000	Safety engineers 1.5 men, 21 mo	-81,000	Safety engineers 47.25 man-mo
Environmental Requirements	136,000	Soldier piles drilled @ $42/LF	204,000	Soldier piles drilled @ $63/LF
	S.T. 215,500		286,000	
Productivity				
Owner-Purchased Insurance	185,000	5% of labor	1,100,000	30% of labor
Safety Programs				
Geographical Areas	370,000	10% of labor	1,850,000	50% of labor
	S.T. 555,000		2,960,000	
Interest				
Mobilization Advance Payment	13,000	$500,000 @ 3%, 1 yr	19,500	$500,000 @ 3%, 1.5 yr
Cash Flow	29,000	$11,500,000 @ 3%, 1 mo	174,000	$11,500,000 @ 3%, 6 mo
Owner-Purchased Material and Equipment	NIL	–	NIL	–
Owner-Purchased Insurance	10,000	$310,000 @ 3%, 1 yr	10,000	$310,000 @ 3%, 1 yr
	S.T. 52,000		203,500	
TOTAL	$1,046,500		$4,020,700	

Table 7-13

COSTS ASSOCIATED WITH CONTROLS — FREE-AIR-DRIVEN TUNNEL

	Added Cost Trend Optimal Control Absent			
	Moderate Effect		Major Effect	
Schedule/Time		Time Assumed		Time Assumed
Project Schedule	160,000	1.0 mo	$ 400,000	2.5 mo
System-Wide Labor Agreement	160,000	1.0 mo	240,000	1.5 mo
Owner Lease/Purchase, Work Areas	160,000	1.0 mo	320,000	2.0 mo
Right-of-Way	160,000	1.0 mo	640,000	4.0 mo
Entry Permits	80,000	0.5 mo	280,000	1.75 mo
Building Permits	80,000	0.5 mo	80,000	0.5 mo
Owner-Purchased Material and Equipment	160,000	1.0 mo	960,000	6.0 mo
(Deduct 20% for concurrence.)	S.T. 768,000		2,336,000	
Direct Cost		Basis		Basis
Building Permits	3,500	2 man-mo	7,000	4 man-mo
Owner-Purchased Material and Equipment	378,000	10% saving	756,000	20% saving
Owner-Purchased Insurance	300,000	Workmen's compensation handback	300,000	Workmen's compensation handback, 20% increment
Safety	-54,000	Safety engineers 1.5 men - 21 mo	-64,800	Safety engineers 37.8 man-mo
Environmental Requirements	NIL	—	NIL	—
	S.T. 627,500		1,058,200	
Productivity				
Owner-Purchased Insurance Safety	128,000	2.5% of labor	1,408,000	27.5% of labor
Labor Productivity	256,000	5% of labor	1,280,000	25% of labor
	S.T. 384,000		2,688,000	
Interest				
Advance Payments	15,000	$500,000 @3%, 1 yr	22,500	$500,000 @ 3%, 1.5 yr
Cash Flow	34,000	$13,500,000 @ 3%, 1 mo	206,400	$13,500,000 @ 3%, 6 mo
Owner-Purchased Material and Equipment	114,000	$3,780,000 @ 3%/1 yr	114,000	$3,780,000 @ 3%/1 yr
Owner-Purchased Insurance	27,000	$900,000 @ 3%, 1 yr	27,000	$900,000 @ 3%, 1 yr
	S.T. 190,400		369,000	
TOTAL	$1,969,900		$6,452,100	

Table 7-14

COSTS ASSOCIATED WITH CONTROLS – COMPRESSED-AIR-DRIVEN TUNNEL

	Added Cost Trend Optimal Control Absent			
	Moderate Effect		Major Effect	
Schedule/Time		Time Assumed		Time Assumed
Project Schedule	$200,000	1.0 mo	$ 500,000	2.5 mo
System-Wide Labor Agreement	200,000	1.0 mo	300,000	1.5 mo
Owner Lease/Purchase, Work Area	200,000	1.0 mo	500,000	2.5 mo
Right-of-Way	200,000	1.0 mo	800,000	4.0 mo
Entry Permits	100,000	0.5 mo	350,000	1.75 mo
Building Permits	100,000	0.5 mo	100,000	0.5 mo
Owner-Purchased Material and Equipment	100,000	1.0 mo	1,200,000	6.0 mo
(Deduct 20% for concurrence.)	S. T. 880,000		3,000,000	
Direct Cost		Basis		Basis
Building Permits	3,500	2 man-mo	7,000	4 man-mo
Owner-Purchased Material and Equipment	378,000	10% saving	756,000	20% saving
Owner-Purchased Insurance	375,000	Workmen's compensation handback	450,000	Workmen's compensation handback - 20% increment
Safety	-54,000	Safety engineers 1.2 men - 21 mo	-64,800	Safety engineers 37.8 man-mo
Environmental Requirements	136,000	Quiet compressors	170,000	Quiet compressors, 25% increment
	S. T. 838,500		1,318,200	
Productivity				
Owner-Purchased Insurance Safety	188,000	2.5% of labor	2,068,000	27.5% of labor
Labor Productivity	376,000	5% of labor	1,880,000	25% of labor
	S. T. 564,000		3,948,000	
Interest				
Advance Payments	24,000	$800,000 @ 3%, 1 yr	36,000	$800,000 @ 3%, 1.5 yr
Cash Flow	43,600	$17,500,000 @ 3%, 1 mo	258,000	$17,500,000 @ 3%, 6 mo
Owner-Purchased Material and Equipment	114,000	$3,780,000 @ 3%	114,000	$3,780,000 @ 3%, 1 yr
Owner-Purchased Insurance	35,500	$1,118,000 @ 3%	33,500	$1,118,000 @ 3%, 1 yr
	S. T. 193,600		$ 441,500	
TOTAL	$2,476,100		$8,707,700	

Table 7-15

INSTITUTIONAL CONTROL EFFECTS, CUT-AND-COVER STATION

	α1 (Months)			α2 (Direct Cost $'s)			α3 (Fraction of Total Project Cost)		
	Lo	Mod	Maj	Lo	Mod	Maj	Lo	Mod	Maj
Optional Project Schedule	0	1.0	2.0	–	–	–	–	–	–
System-Wide Labor Agreement	0	1.0	1.5	–	–	–	–	–	–
Owner-Acquired Work Area	0	1.0	1.0	–	–	–	–	–	–
Owner-Acquired Right-of-Way	0	1.0	6.0	–	–	–	–	–	–
Owner-Acquired Entry Permit	0	0.5	2.0	–	–	–	–	–	–
Owner-Acquired Building Permit	0	0.5	0.5	0	3500	7000	–	–	–
Owner-Supplied Materials	–	–	–	–	–	–	–	–	–
Owner-Purchased Insurance	–	–	–	–	–	–	0	.0126	.0149
Owner-Enforced Environmental Regulations	–	–	–	–	–	–	0	.0033	.0066
Advance Payment	–	–	–	0	30,000	45,000	–	–	–
Efficient Cash Flow	–	–	–	–	–	–	0	.0025	.0150
Safety Programs	–	–	–	0	-62,000	-93,000	0	.0166	.0993

β (Overhead) = $59,000/mo

Labor = 33%

E&M = 67%

Labor productivity associated with geographical area is handled in the computer model through the direct introduction of a labor productivity factor. This factor is defined as the units of work produced per man hour in the geographical area of interest, divided by that in the San Francisco area. Therefore, geographical area does not appear in the coefficient matrix (Table 7-15).

All other costs associated with institutional controls are included in the α_3 coefficients in Table 7-15 as a fraction of total project cost. This treatment is based on the fact that these costs are directly related to project scope (and total cost). Working with these costs as fractions should provide better extrapolation of these effects when the computer model is exercised for a project of somewhat different scope than that on which the model is based. The fractional costs were derived by dividing the specific cost figures on Table 7-11 by the total project cost.

Tables 7-16 through 7-18 show the same information for the other three models. The coefficients were computed from the basic sensitivity data as discussed above, except for the case of the compressed-air-driven tunnel (Table 7-18), in which the added cost of meeting environmental regulations is treated as a direct cost, rather than as a fraction of total cost.

GENERALIZED MODEL SENSITIVITIES

Sensitivity Analysis

The four general models were exercised in order to show the sensitivity of project costs to changes in the basic work event costs and to the nature of the physical and institutional controls relevant to the project. The physical controls describe the physical characteristics of the specific job site and hence are project-specific. The insitutional controls

Table 7-16

INSTITUTIONAL CONTROL EFFECTS, CUT-AND-COVER LINE

	$\alpha 1$ (Months)			$\alpha 2$ (Direct Cost $'s)			$\alpha 3$ (Fraction of Total Project Cost)		
	Lo	Mod	Maj	Lo	Mod	Maj	Lo	Mod	Maj
Optimal Project Schedule	0	1.0	2.0	–	–	–	–	–	–
System-Wide Labor Agreement	0	1.0	1.5	–	–	–	–	–	–
Owner-Acquired Work Area	0	1.0	1.0	–	–	–	–	–	–
Owner-Acquired Right-of-Way	0	1.0	6.0	–	–	–	–	–	–
Owner-Acquired Entry Permit	0	0.5	1.75	–	–	–	–	–	–
Owner-Acquired Building Permit	0	0.5	0.5	0	3,500	7,000	–	–	–
Owner-Supplied Materials	–	–	–	–	–	–	–	–	–
Owner-Purchased Insurance	–	–	–	–	–	–	0	.0124	.0147
Owner-Enforced Environmental Regulations	–	–	–	–	–	–	0	.0118	.0177
Advance Payment	–	–	–	0	15,000	22,500	–	–	–
Efficient Cash Flow	–	–	–	–	–	–	0	.0025	.0150
Safety	–	–	–	0	-54,000	-81,000	0	.0161	.0966

θ (Overhead) = $56,000/mo

Labor = 32%

E&M = 68%

Table 7-17

INSTITUTIONAL CONTROL EFFECTS, FREE AIR TUNNEL

	α1 (Months)			α2 (Direct Cost $'s)			α3 (Fraction of Total Project Cost)		
	Lo	Mod	Maj	Lo	Mod	Maj	Lo	Mod	Maj
Optimal Project Schedule	0	1.0	2.5	–	–	–	–	–	–
System-Wide Labor Agreement	0	1.0	1.5	–	–	–	–	–	–
Owner-Acquired Work Area	0	1.0	2.0	–	–	–	–	–	–
Owner-Acquired Right-of-Way	0	1.0	2.0	–	–	–	–	–	–
Owner-Acquired Entry Permit	0	0.5	1.75	–	–	–	–	–	–
Owner-Acquired Building Permit	0	0.5	0.5	0	3,500	7,000	–	–	–
Owner-Supplied Materials	0	1.0	6.0	–	–	–	0	.036	.064
Owner-Purchased Insurance	–	–	–	–	–	–	0	.0242	.0282
Owner-Enforced Environmental Regulations	–	–	–	–	–	–	–	–	–
Advance Payment	–	–	–	0	15,000	22,500	–	–	–
Efficient Cash Flow	–	–	–	–	–	–	0	.0025	.0150
Safety	–	–	–	0	-54,000	-64,800	0	.0093	.1023

£ (Overhead) = $160,000/mo

Labor = 37%

E&M = 63%

Table 7-18

INSTITUTIONAL CONTROL EFFECTS, COMPRESSED AIR TUNNEL

	$\alpha 1$ (Months)			$\alpha 2$ (Direct Cost $'s)			$\alpha 3$ (Fraction of Total Project Cost)		
	Lo	Mod	Maj	Lo	Mod	Maj	Lo	Mod	Maj
Optimal Project Schedule	0	1.0	2.5	–	–	–	–	–	–
System-Wide Labor Agreement	0	1.0	1.5	–	–	–	–	–	–
Owner-Acquired Work Area	0	1.0	2.5	–	–	–	–	–	–
Owner-Acquired Right-of-Way	0	1.0	2.0	–	–	–	–	–	–
Owner-Acquired Entry Permit	0	0.5	1.75	–	–	–	–	–	–
Owner-Acquired Building Permit	0	0.5	0.5	0	3,500	7,000	–	–	–
Owner-Supplied Materials	0	1.0	6.0	–	–	–	0	.0281	.0497
Owner-Purchased Insurance	–	–	–	–	–	–	–	–	–
Owner-enforced Environmental Regulations	–	–	–	0	136,000	170,000	–	–	–
Advance Payment	–	–	–	0	24,000	36,000	–	–	–
Efficient Cash Flow	–	–	–	–	–	–	0	.0025	.0150
Safety	–	–	–	0	-54,000	-64,800	0	.0108	.1188

β (Overhead) = $200,000/mo

Labor = 43%

E&M = 57%

describe the relationships between the owner, engineer, and contractor and are therefore system-specific.

In the determination of the generalized model sensitivities, the first step was to establish, for each model project, a construction cost based upon average conditions for all components (work events, physical controls, and institutional controls). The next step was to perturbate each component, while keeping all others at their average value. In this sensitivity analysis in the generalized model, each work event was perturbated by a conservative amount (±10 percent), the physical controls were perturbated for maxima and minima (low and high effects), and the institutional controls were perturbated for medium and major effects.

The results of these sensitivity analyses are summarized in Figure 7-5, which shows the basic project cost for each of the four types of projects modeled, along with the maxima and minima achieved with extreme values of the physical and institutional controls. Variations due to physical and institutional controls are shown separately. Each is the composite of a number of individual effects, not all of which are likely to be present in any specific project.

The average project cost was estimated assuming average physical controls and optimal institutional controls. The rationale behind this choice is that there is no compelling reason to choose to operate under less than optimal institutional controls even though one has little control over the physical characteristics of the project site. Therefore, both positive and negative variations around the average are shown on Figure 7-5 for the physical controls, and only positive variations are shown for the institutional controls.

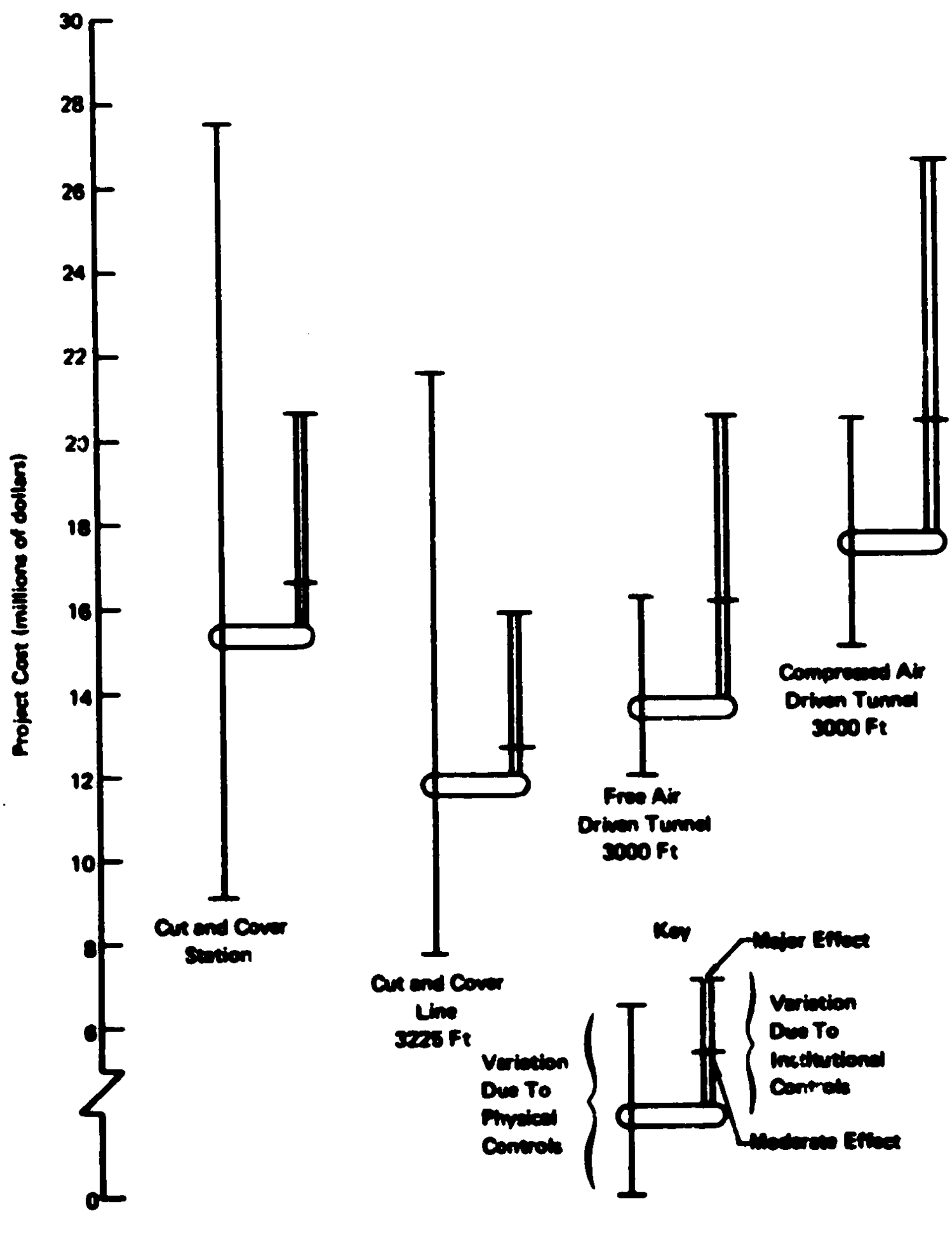


Figure 7-5. Summary of Effect of Controls on Project Cost

The important points shown in Figure 7-5 are:

- Costs for cut-and-cover construction are more dependent on physical controls than costs for tunneling.
- Institutional controls have a somewhat larger effect on tunnel construction than on cut-and-cover work, principally because of the effect of the cost of the tunnel liner item, i.e., owner- or contractor-purchased.
- Overall, costs for cut-and-cover construction are more variable than tunneling costs.
- For favorable values of physical controls and the height of ground cover assumed in the models, line structures can be constructed more cheaply by cut-and-cover techniques than by tunneling. However, for unfavorable physical controls (i.e., existing structures requiring extensive underpinning, or high utility complexity), tunneling is less expensive provided that institutional controls are optimal.

The data on the basis of which these sensitivity analyses were developed are derived from the experience of site and other engineering personnel connected with rapid transit engineering. The effects represent their best judgment of the "average maximum" to be encountered in representative underground structure projects. More extreme effects can occur in specific situations, but these were discounted as nontypical. The basic sensitivity data are presented in detail and discussed at greater length in Sections 5 and 6.

Significant Results

The sensitivities of each of the models to the physical and institutional controls are discussed below, and the points summarized above are explained in terms of these sensitivities.

Cut-and-Cover Station. Table 7-19 and Figure 7-6 show the results of the sensitivity analysis for the cut-and-cover station model. The work events show the effect on cost of assumed changes of ±10 percent in the basic work element costs.

Changes of ±10 percent in the basic work event costs were selected as being representative of what migh accrue from a loss of efficiency (+) or an improvement (-) in technology. Of course, radical changes in technology might introduce larger cost effects.

Of particular interest here is the degree of dilution of cost changes originating in one work element when expressed in terms of the total project cost. Excavation and concrete are the most important work elements, and changes in costs of these elements of 10 percent result in changes in total project cost of 3.3 percent and 3.5 percent, respectively.

The physical controls in Table 7-19 show that the nature of existing structures and special architectural requirements have a major influence on project cost. The presence of structures that require extensive underpinning can raise the total project cost by as much as 24 percent, and architectural requirements can add as much as 19 percent. Other physical controls that can significantly influence the cost include:

- Traffic conditions (8.8 percent) — affect excavation, utility relocation, and decking and traffic control
- Utility density (9.9 percent) — affect utility relocation
- Ground conditions (8.5 percent) — affect excavation
- Weather (7.9 percent) — affect most work elements

The total effect of physical controls can increase the model project cost by as much as 79 percent or reduce it by 41 percent.

Table 7-19

SENSITIVITY ANALYSIS FOR CUT-AND-COVER STATION MODEL

Sensitivity Parameters	Program Input Values at Medium Physical and Optimal Institutional Control ($/LF)	Change in Value of Input		Resulting Change in Total Project Cost ($/LF)		Resulting Percentage Change in Total Project Cost (%)	
Work Events							
Utilities	1,990	±10%		±199		±1.09	
Decking and Traffic Control	1,385			±139		±0.76	
Underpinning	597			± 60		0.33	
Excavation	6,082			±608		±3.32	
Muck Disposal	466			± 47		±0.26	
Concrete	6,345			±635		±3.47	
Backfilling	328			± 33		±0.18	
Restoration	212			± 21		0.11	
Miscellaneous	917			± 92		±0.50	
	18,322						
Physical Controls		Low	High				
Utility Density				-1,823	+1,623	- 9.95	+ 9.95
Traffic Conditions				-1,873	+1,612	-10.22	+ 8.80
Existing Structures				-1,529	+4,339	- 8.34	+23.68
Ground Conditions				-1,276	+1,562	- 6.96	+ 8.55
Fill Demand				- 232	+ 232	- 1.77	+ 1.27
Architectural Requirements				- 0	+3,453	- 0	+18.85
Weather				- 806	+1,441	- 4.40	+ 7.86
						-41.14	+78.94
Institutional Controls		Med	High				
Optimal Project Schedule				+ 70.41	+140.82	+ 0.38	+ 0.77
System-Wide Labor Agreement				+ 70.41	+105.62	+ 0.38	+ 0.58
Owner-Acquired Work Areas				+ 70.41	+ 70.41	+ 0.38	+ 0.38
Owner-Acquired Right-of-Way				+ 70.41	+422.46	+ 0.38	+ 2.31
Owner-Acquired Entry Permit				+ 35.20	+140.82	+ 0.19	+ 0.77
Owner-Acquired Building Permit				+ 39.38	+ 43.55	+ 0.21	+ 0.24
Owner-Supplied Material							
Owner-Purchased Insurance				+230.86	+273.00	+ 1.26	+ 1.49
Owner-Enforced Environmental Regulations				+ 60.46	+ 120.93	+ 0.33	+ 0.66
Safety				+230.16	+1708.40	+ 1.26	+ 9.32
Labor Productivity				+606.20	+3031.03	+ 3.31	+16.54
Advance Payment				+ 35.80	+ 53.70	+ 0.20	+ 0.29
Efficient Cash Flow				+ 45.81	+ 274.83	+ 0.25	+ 1.50
						+ 8.53	+34.85

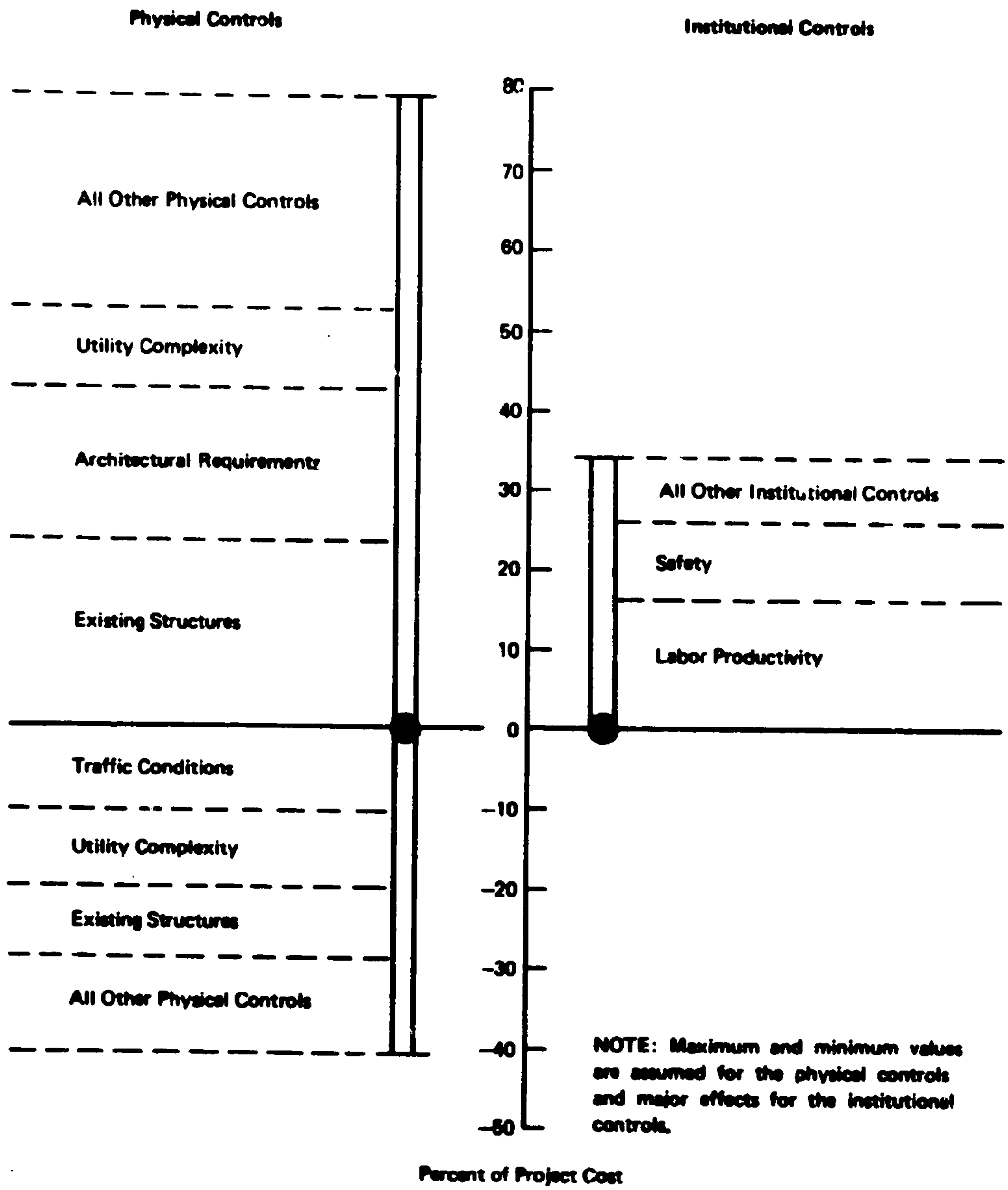


Figure 7-6. Cut-and-Cover Station Sensitivity of Cost to Controls

The total effect of physical controls can increase the model project cost by as much as 79 percent or reduce it by 41 percent.

The influence of institutional controls on total project cost can be significant (35 percent) and is shown in Table 7-19. The greatest effect (16.5 percent) is from labor productivity, assumed at worst to be 50 percent lower than the optimum. The lack of safety programs, with a resulting decrease in labor productivity due to accidents, can add as much as 9.3 percent to the total project cost.

Cut-and-Cover Line. The cost sensitivities for cut-and-cover line construction, shown in Table 7-20 and Figure 7-7, are similar to the cost sensitivities for station construction. Under work events, the utilities item assumes equal importance with excavation and concrete.

The principal effect under physical controls, as shown in Table 7-20, is that of utility density on the cost of relocating utilities. As can be seen, utility density can increase total project cost by as much as 36 percent. Existing structures, traffic conditions, and ground conditions are also important for the same reasons as were discussed for the stations.

The nature of the site-specific physical controls can increase total project cost by as much as 81 percent or decrease it by as much as 34 percent.

As with station construction, labor productivity is the most important institutional control, amounting to as much as 15.6 percent of the total cost increase for a 50 percent decrease in labor productivity. The total effect of institutional controls can be as much as 35.5 percent, which is comparable to the value found for station construction.

Table 7-20

SENSITIVITY ANALYSIS FOR CUT-AND-COVER LINE MODEL

Sensitivity Parameters	Program Input Values at Medium Physical and Optimal Institutional Control ($/LF)	Change in Value of Input	Resulting Change in Total Project Cost ($/LF)		Resulting Percentage Change in Total Project Cost (%)	
Work Events						
Utilities	804	±10%	- 80.4	+ 80.4	- 2.19	+ 2.19
Deck and Traffic Control	289		- 28.9	+ 28.9	- 0.79	+ 0.79
Underpinning	100		- 10.0	+ 10.0	- 0.27	+ 0.27
Excavation	1,050		-105.0	+105.0	- 2.86	+ 2.86
Muck Disposal	104		- 10.4	+ 10.4	- 0.28	+ 0.28
Concrete	952		- 95.2	+ 95.2	- 2.59	+ 2.59
Backfilling	67		- 16.7	+ 16.7	- 0.45	+ 0.45
Restoration	108		- 10.8	+ 10.8	- 0.29	+ 0.29
Miscellaneous	102		- 10.2	+ 10.2	- 0.27	+ 0.27
	3,675					
Physical Controls						
Utility Density		Low High	-478	+1,335	-12.73	+36.32
Traffic Conditions			-394	+ 517	-10.72	+14.06
Existing Structures			-105	+ 580	- 2.86	+15.78
Ground Conditions			- 65	+ 333	- 1.77	+ 9.06
Fill Demand			- 52	+ 52	- 1.41	+ 1.41
Architectural Requirements			0	0	0	0
Weather			-170	+ 172	- 4.62	+ 4.68
					-34.11	+81.31
Institutional Controls						
Optimal Project Schedule		Med High	+ 17.4	+ 34.8	+ 0.47	+ 0.95
System-Wide Labor Agreement			+ 17.4	+ 26.1	+ 0.47	+ 0.71
Owner-Acquired Work Areas			+ 17.4	+ 17.4	+ 0.47	+ 0.47
Owner-Acquired Right-of-Way			+ 17.4	+104.4	+ 0.47	+ 2.84
Owner-Acquired Entry Permit			+ 8.7	+ 30.5	+ 0.24	+ 0.83
Owner-Acquired Building Permit			+ 8.7	+ 8.7	+ 0.24	+ 0.24
Owner-Supplied Material			0	0	0	0
Owner-Purchased Insurance			+ 45.6	+ 54.0	+ 1.24	+ 1.47
Owner-Enforced Environmental Regulations						
Safety			+ 43.4	+ 65.1	+ 1.18	+ 1.77
Labor Productivity			+ 75.9	+330.0	+ 2.06	+ 8.98
Advance Payment			+114.7	+573.5	+ 3.12	+15.60
Efficient Cash Flow			+ 4.7	+ 7.0	+ 0.13	+ 0.19
			+ 9.2	+ 55.1	+ 0.25	+ 1.50
					+10.34	+35.55

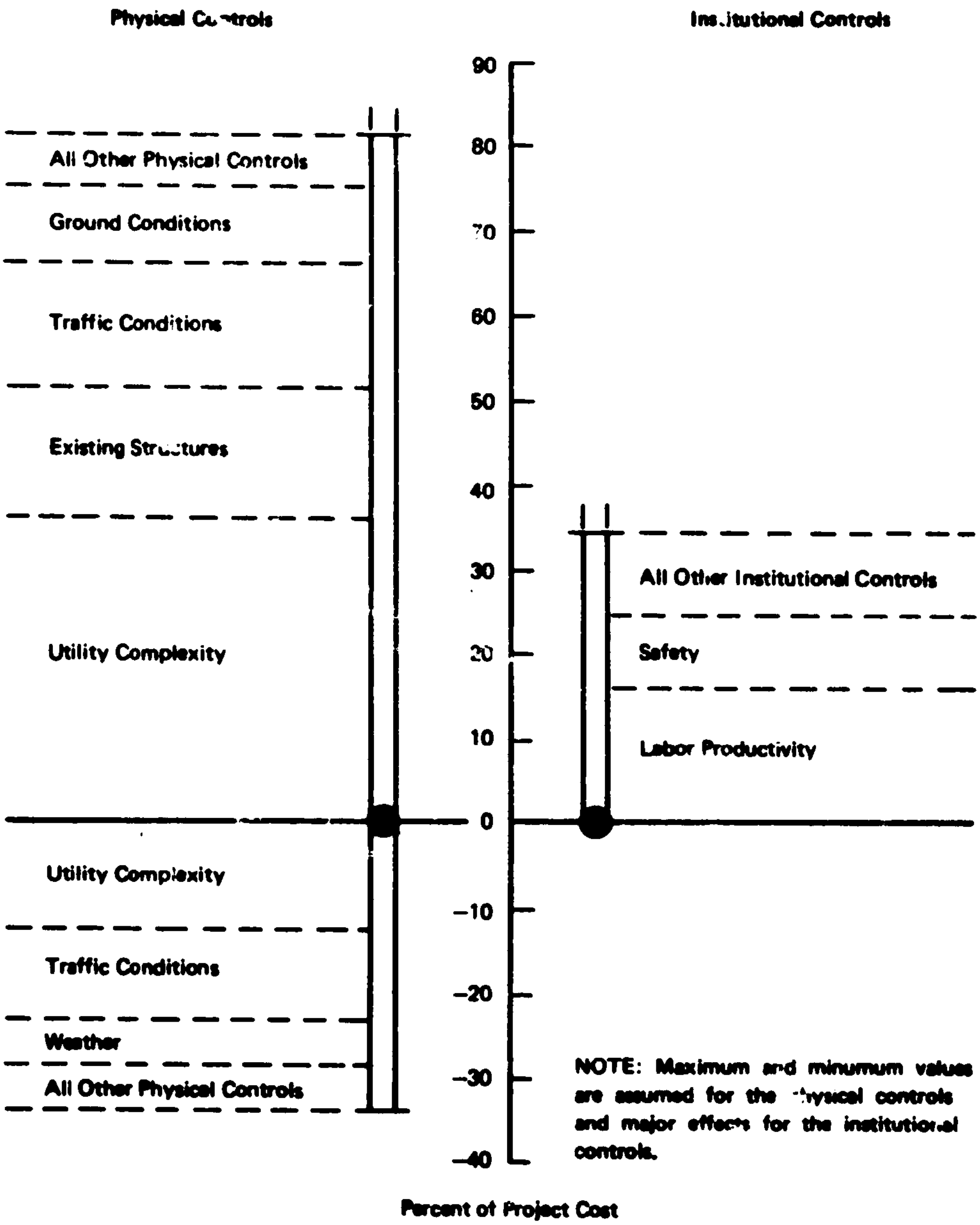


Figure 7-7. Cut-and-Cover Line Sensitivity of Cost to Controls

Free-Air-Driven Tunnel. The most important work events in tunnel construction are excavation and liner erection (see Table 7-21 and Figure 7-8). Changes of 10 percent in these basic costs change the total project cost by 4.4 percent and 4.0 percent, respectively.

Table 7-21 and Figure 7-8 show the effect of controls. As long as tunneling can be performed in free air, physical controls appear to have a relatively minor effect on total tunnel costs, with the effects of ground conditions on excavation (7.3 percent) and of existing structures on underpinning requirement (6.8 percent) predominating. Cumulative physical effects can raise total project cost by as much as 17 percent or decrease it by as much as 13 percent.

Institutional controls are quite important, having a maximum potential of adding 49 percent to total cost. The effect of owner-supplied materials (i.e., tunnel liners) is most important. If these materials are not furnished, the total project costs can increase by as much as 13.4 percent. This effect comes from increased direct cost of materials and from delay in the project. Labor productivity and safety are next in importance (over 9 percent each). The remaining institutional controls have larger effects on total tunneling cost than on cut-and-cover cost, primarily because of the equipment-intensive nature of tunneling work. (Compare the influence of institutional controls in Tables 7-19 and 7-20 with those in Table 7-21). Schedule delays, which keep equipment tied up unproductively, are proportionately more expensive in tunneling than in cut-and-cover. Labor productivity as such appears less important in tunneling because of the equipment-intensive nature of the work, but it can assume importance if it materially affects the progress of the tunneling operation.

Table 7-21

SENSITIVITY ANALYSIS FOR FREE-AIR-DRIVEN TUNNEL MODEL

Sensitivity Parameters	Program Input Values at Medium Physical & Optimal Institutional Control ($/LF)	Change in Value of Input	Resulting Change in Total Project Cost ($/LF)		Resulting Percentages Change in Total Project Cost (%)	
Work Events						
Mobilization	167	±10%	± 16.7		±0.36	
Workshaft	272		± 27.2		±0.59	
Underpinning	100		± 10.0		±0.22	
Excavation	2,000		±200.0		±4.36	
Muck Disposal	80		± 8.0		±0.17	
Liner, Grouting	1,800		±180.0		±3.92	
Concrete	170		± 17.0		±0.37	
	4,589					
Physical Controls						
Utility Density		Low High	- 96.0	+ 96.0	- 2.09	+ 2.09
Traffic Conditions			- 4.0	+ 4.0	- 0.09	+ 09
Existing Structures			-204.7	+313.4	- 4.46	+ 6.83
Ground Conditions			-265.2	+335.6	- 5.78	+ 7.31
Fill Demand			- 40.0	+ 40.0	- 0.87	+ 0.87
					-13.29	+17.19
Institutional Controls						
Optimal Project Schedule		Med High	+ 53.33	+133.33	+ 1.16	+ 2.91
System-Wide Labor Agreement			+ 53.33	+ 80.00	+ 1.16	+ 1.74
Owner-Acquired Work Areas			+ 53.33	+106.67	+ 1.16	+ 2.32
Owner-Acquired Right-of-Way			+ 53.33	+106.67	+ 1.16	+ 2.32
Owner-Acquired Entry Permit			+ 26.67	+ 93.33	+ 0.58	+ 2.03
Owner-Acquired Building Permit			+ 27.84	+ 29.00	+ 0.61	+ 0.64
Owner-Supplied Material			+218.53	+613.68	+ 4.76	+13.37
Owner-Purchased Insurance			+111.05	+129.41	+ 2.42	+ 2.82
Owner-Enforced Environmental Regulations			0	0	--	—
Safety			+ 24.67	+447.85	+ 0.54	+ 9.76
Labor Productivity			+ 85.33	+426.67	+ 1.86	+ 9.30
Advance Payment			+ 5.00	+ 7.50	+ 0.11	+ 0.16
Efficient Cash Flow			+ 11.47	+ 68.84	+ 0.25	+ 1.50
					+15.77	+48.87

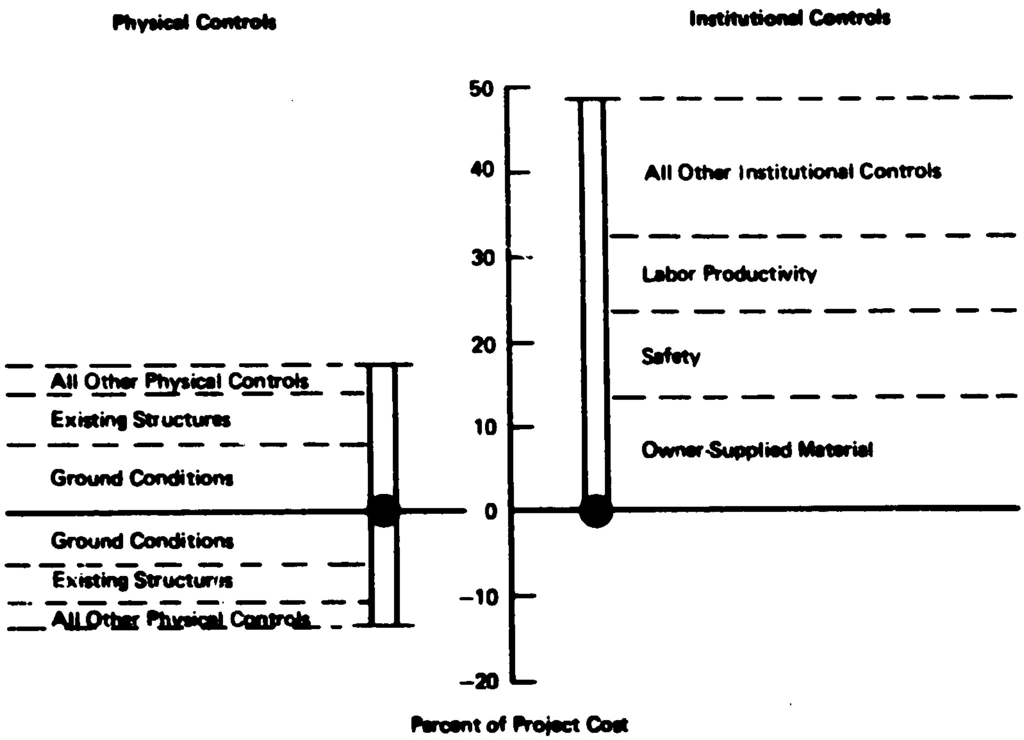


Figure 7-8. Free-Air-Driven Tunnel Sensitivity of Cost to Controls

Compressed-Air-Driven Tunnel. The effects on compressed-air-driven tunnels (Table 7-22 and Figure 7-9) are comparable to those described in the previous sections, and for the same reasons. While the total cost of driving under compressed air is greater than driving under free air, the percentage effects of the physical and institutional controls are nearly the same.

Discussion of Generalized Model Sensitivities

In the construction of stations and line segments of rapid transit systems, there are basic costs associated with the work events that constitute each project. These costs are sensitive to a set of physical influences (physical controls) over which the owner, the engineer, and the contractor have little control. The project as a whole is sensitive to another set of influences (institutional controls) which the owner-engineer can, to a large extent, minimize.

The generalized model sensitivity analysis revealed these important points:

- The sensitivity of all work events were determined by assuming a change in cost for each event of +10 percent (work event less efficient than average) and -10 percent (work event more efficient than average). For the generalized models, the most sensitive work events and their percent effect on total project costs are:

Most Sensitive Work Events	Percent Change in Total Project Cost
Cut-and-cover	
Excavation	3.3
Concrete	3.5
Cut-and-cover line	
Excavation	2.9
Concrete	2.6
Utilities	2.2

Table 7-22

SENSITIVITY ANALYSIS FOR COMPRESSED-AIR-DRIVEN TUNNEL MODEL

Sensitivity Parameters	Program Input Values at Medium Physical & Optimal Institutional Control ($/LF)	Change in Value of Input	Resulting Change in Total Project Cost ($/LF)		Resulting Percentage Change in Total Project Cost (%)	
Work Events						
Mobilization	233	± 10%	± 23.5		± 0.40	
Workshaft	326		± 32.6		± 0.56	
Underpinning	100		± 10.0		± 0.17	
Excavation	2,950		± 295.0		± 5.08	
Muck Disposal	80		± 8.0		± 0.14	
Liner, Grouting	1,950		± 195.0		± 3.36	
Concrete	170		± 17.0		± 0.29	
	5,809					
Physical Controls						
Utility Density		Low High	-141.6	+141.6	- 2.44	+ 2.44
Traffic Conditions			- 4.0	+ 4.0	- 0.07	+ 0.07
Existing Structures			-253.7	+365.7	- 4.37	+ 6.30
Ground Conditions			-372.4	+450.8	- 6.41	+ 7.76
Fill Demand			- 40.0	+ 40.0	- 0.69	+ 0.69
					-13.98	+17.26
Institutional Controls						
Optimal Project Schedule		Med High	+ 66.67	+166.67	+ 1.15	+ 2.87
System-Wide Labor Agreement			+ 66.67	+100.00	+ 1.15	1.72
Owner-Acquired Work Areas			+ 66.67	+166.67	+ 1.15	+ 2.87
Owner-Acquired Right-of-Way			+ 66.67	+133.34	+ 1.15	+ 2.30
Owner-Acquired Entry Permit			+ 33.33	+116.67	+ 0.51	+ 2.01
Owner-Acquired Building Permit			+ 34.50	+ 34.50	+ 0.59	+ 0.59
Owner-Supplied Material			+229.90	+688.71	+ 3.96	+11.86
Owner-Purchased Insurance			+135.35	+160.33	+ 2.33	+ 2.76
Owner-Enforced Environmental Regulations			+ 45.33	+ 56.67	+ 0.78	+ 0.98
Safety			+ 44.74	+668.51	+ 0.77	+11.51
Labor Productivity			+125.33	+626.67	+ 2.16	+10.79
Advance Payment			+ 8.00	+ 12.00	+ 0.14	+ 0.21
Efficient Cash Flow			+ 14.52	+ 87.14	+ 0.25	+ 1.50
					+16.15	+51.97

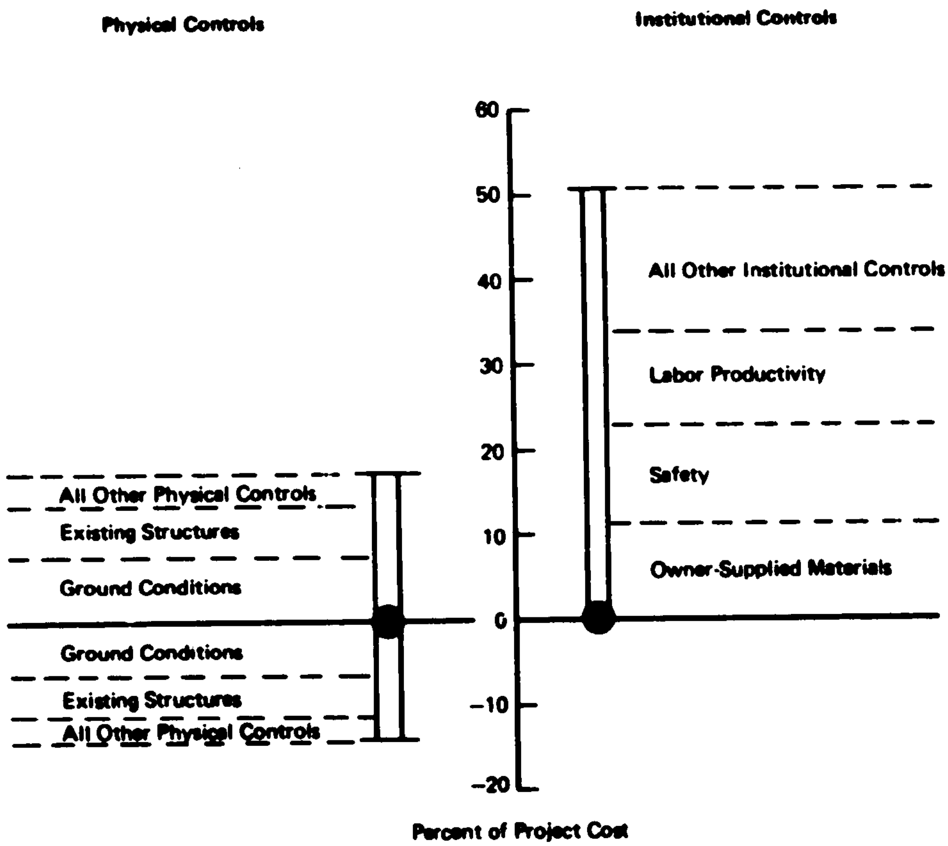


Figure 7-9. Compressed-Air-Driven Tunnel Sensitivity of Cost tc Controls

Tunnel in free air	
Excavation	4.4
Liner, erection, and grouting	3.9
Tunnel in compressed air	
Excavation	5.1
Liner, erection, and grouting	3.4

- Costs for cut-and cover construction are more sensitive to physical controls (especially existing structures, utility density, and traffic conditions) than are costs for tunneling.
- Institutional controls have a larger effect on tunneling than on a cut-and-cover construction— principally because of the tunnel liner purchase item.
- A cost increase of about 25 percent is incurred when ground conditions require that soft-ground tunnels be driven under compressed air.
- Total costs for cut-and-cover construction are more sensitive to physical controls than are total costs for tunneling.
- For favorable values of physical controls (i.e., when traffic, adjacent structures, and utilities are of minor importance), line structures constructed by cut-and-cover methods for the depth of ground cover considered are less expensive than soft-ground-driven tunnels.

EXAMPLE OF MODEL UTILIZATION

A sample of the computer output obtained from the generalized model for a cut-and-cover line section is shown in Table 7-23 (for a complete description of the computer model, see the Appendix). For completeness, the output shows all input data as well as values computed by the model. The input data are of two types: program data, which give the basic cost and sensitivity information associated with the type of project of interest (in this case, the cut-and-cover line); and input data, which give the characteristics of the specific project of interest. Details as to how these data are put into the computer are given in the Appendix. In the following paragraphs, each block of numbers shown in Table 7-23 is identified.

Table 7-23

SAMPLE OF THE OUTPUT OBTAINED FROM THE GENERALIZED MODEL FOR A CUT-AND-COVER LINE SECTION

CUT AND COVER LINE

PROJECT WORK EVENT	RELEVANT PROJECT MEASURE	A	B UNIT COST	C TOTAL EVENT COST
1. UTILITIES	LENGTH OF PROJECT	3220. FT	663.00/FT	2400075.00
2. DECK AND TRAFFIC CNTRL	PLAN AREA	6666. SQ YD	112.00/SQ YD	746400.00
3. UNDERPINNING	LENGTH OF PROJECT	3220. FT	90.00/FT	290000.00
4. EXCAVATION	VOLUME EXCAVATED	146130. CU YD	17.30/CU YD	2530000.70
5. BACKFILL	VOLUME BACKFILLED	66200. CU YD	6.22/CU YD	430766.00
6. CONCRETE	NET VOLUME	70071. CU YD	38.00/CU YD	2704201.00
7. RESTORATION	LENGTH OF PROJECT	3220. FT	97.30/FT	313470.00
8. MUCK DISPOSAL	NET VOLUME	70071. CU YD	1.00/CU YD	190007.10

PROJECT WORK EVENT NUMBER

	1.	2.	3.	4.	5.	6.	7.	8.	E
UTILITY COMPLEXITY	0.000	0.000	0.000	0.070	0.000	0.000	0.000	0.000	2
TRAFFIC CONDITIONS	0.120	0.120	0.000	0.130	0.120	0.000	0.110	0.110	2
EXISTING STRUCTURES	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	2
GROUND CONDITIONS	0.000	0.000	0.110	0.070	0.000	0.000	0.000	0.000	2
ARCHITECTURAL REQUIREMENTS	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	2
WEATHER	0.000	0.000	0.000	0.070	0.000	0.000	0.000	0.000	2
FILL DEMAND	0.000	0.000	0.000	0.000	0.000	0.000	0.000	1.110	2

PROJECT WORK EVENT	GAMMA VALUE	N
1. UTILITIES	0.000	2
2. DECK AND TRAFFIC CNTRL	0.000	2
3. UNDERPINNING	0.000	2

MISCELLANEOUS FRACTIONS 0.000

EVENT	ADJUSTED EVENT COST
1. UTILITIES	2990150.00
2. DECK AND TRAFFIC CNTRL	990030.11
3. UNDERPINNING	322177.00
4. EXCAVATION	3403107.00
5. BACKFILL	536140.00
6. CONCRETE	3000004.70
7. RESTORATION	347901.70
8. MUCK DISPOSAL	234401.00
TOTAL ADJUSTED EVENT COSTS	11000004.00

(INCLUDES MISCELLANEOUS FRACTIONS AND ADJUSTMENT FOR DELAY)

INSTITUTIONAL CONTROLS	MO. DELAY	J	LUMP SUM	J	FRACTION TOTAL COST	J
[illegible]	1.00	2	0.	2	0.0000	2
[illegible]	1.00	2	0.	2	0.0000	2
[illegible]	1.00	2	0.	2	0.0000	2
[illegible]	1.00	2	0.	2	0.0000	2
[illegible]	0.00	2	0.	2	0.0000	2
[illegible]	0.00	2	3000.	2	0.0000	2
[illegible]	0.00	2	0.	2	0.0000	4
[illegible]	0.00	2	0.	2	0.0124	4
[illegible]	0.00	2	0.	2	0.0110	4
[illegible]	0.00	2	10000.	2	0.0000	2
[illegible]	0.00	2	0.	2	0.0029	4
[illegible]	0.00	2	-60000.	2	0.0101	4

LABOR PRODUCTIVITY 1.00

FRACTION OF TOTAL COST ATTRIBUTED TO LABOR	0.40
OVERHEAD COST PER MONTH	50000.

TOTAL COST(EXCLUDING ESCALATION) 18010190.00

LABOR ESCALATION FACTOR	1.0
MATERIALS ESCALATION FACTOR	1.0

FRACTIONAL COST ATTRIBUTED TO MATERIALS	0.00
FRACTIONAL COST ATTRIBUTED TO OVERHEAD	0.00

TOTAL PROJECT COST	18010190.00	
TOTAL TIME	29.0	MONTHS

Block A shows the specific project measures (input data). Only four independent values need be supplied: (1) project length (ft), (2) volume excavated (yd^3), (3) volume backfill (yd^3), and (4) plan area (yd^2). The other measure – net structure volume (yd^3) – is computed by the program.

Block B shows the unit costs associated with cut-and-cover line work. These values are put in as program data, and all eight must be supplied.

Block C gives the basic work event costs computed by the program for each event as the product of the relevant project measures and the unit cost.

Block D gives the cost sensitivity coefficients, which show the influence of the physical controls on the project work events. The numbers "1" through "8" refer to the eight project work events listed above. These values are program data.

Block E shows the level of each physical control, the value "2" signifying the medium level, entered as input data.

Block F repeats the levels of the first three physical controls.

Block G lists the scope-influence coefficients of the first three physical controls on the first three project work elements. These value, entered as program data, are all zero in this example, since the level of each physical control is medium.

Block H shows the work event costs based on those shown in Block C and adjusted by the computer for the effects of the physical controls (Blocks D through G).

Block I shows the cost sensitivity coefficients (program data) relating to the institutional controls. The three columns show, respectively, (1) the delay in months, (2) the lump-sum addition to the total cost, and (3) the fractional addition to the total cost. Values shown correspond to the intermediate level of institutional control (optimal control absent-moderate effect), denoted for each control in Block J by the number "2". These values are input data.

Item K and Block N show additional input data, specifically the labor productivity factor and cost escalation factors for labor and materials, each based on the San Francisco area in January 1974.

Blocks L and O show additional program data related to the breakdown of project costs into labor, materials, and overhead.

Blocks M and P show computer-adjusted values of total project cost. In Block M, the adjusted cost is based on that given in Block H and includes the effects of the institutional controls. This cost is adjusted further in Block P to include the effects of cost escalation on labor and materials. Block P also shows the total project time, including the effects associated with changes in project scope caused by the physical controls, and delays associated with the institutional controls.

HOW TO USE THE MODELS

The introduction to this section emphasizes the value of the models in determining relative cost trends of project sections with respect to variations or sensitivities. In this application, if the cost units given in the models and their relative proportions remain constant, then variations in the absolute values of the costs of work events are relatively unimportant. However, when costs of material, equipment, and labor are escalating rapidly at nonuniform rates (as they are at present doing), the relative proportions of the various work event costs will change and must be reestimated. The procedures needed to undertake such cost adjustments and to handle other basic input data are described below.

Basic Cost Data

The generalized models were formulated using data that were developed principally from the five study cases and similar projects from the BART system. The quantities of the various work events and the prices (escalated to an assumed midpoint of January 1974) are considered average for the design types represented by the models. Therefore, the amounts in the Model Cost Summaries are only for these particular conditions.

In order to apply the model to sections within a transit system that is being planned, the following data must be developed:

- Preliminary design drawings and quantity estimates of the work events, i.e., quantities of utilities, excavation, concrete, etc.
- Cost unit to apply to the work events. Account must be taken of the geographic location of the work to obtain a factual cost representation. Costs should be escalated to the midpoint of the expected construction schedules.

Escalation. Traditionally, the estimation of the escalation costs of labor, material, and equipment to be applied to a projected midpoint construction expenditure date has been based on the projection of historical inflation records of previous years. With respect to the project studies, the project costs were escalated to a common January 1974, construction-midpoint base for comparative purposes. Historical records indicated that during the period from 1966 to 1973 the average annual combined escalation rate was about 11 percent for total construction costs. Individual component escalation averaged about 4 percent for materials and equipment and 10 percent for labor.

Towards the end of the recording period, there was a noticeable increase in the escalation rates, with the rate of increase for materials and equipment being steeper than that for labor. The problem of historical record projection information to future dates with good accuracy is therefore difficult.

Bidding Climate and Productivity. These items have a major effect upon the bid costs of projects. Both of them are mainly dependent upon the ratio of heavy civil engineering construction underway or immediately projected to the available contracting capacity on more or less a national basis. When there is much construction work being undertaken, available contracting capacity will be limited, competition will be low, and bid costs will be high. As the amount of construction work decreases, the competition becomes keener and the bid costs decrease. Productivity is related to the availability of trained labor, which in turn is dependent upon the volume of ongoing construction.

Therefore, in determining the cost units, account must be taken of the probable bidding climate and related productivity factors existing at the midpoint of the construction schedule for the project section to be modeled.

Estimation of Basic Cost Data. A study has recently been concluded in the southeast United States which assesses the escalation and bidding climate factors relative to estimating costs of future construction work. The study includes an historical survey of Government and National Construction Indices and other construction indices, as well as a survey of the current approaches of the local contractors in evaluating these factors.

The results of this study can be found in the Appendix.

Assessment of Physical Controls

In the generalized models, three designs of influence (or density) for the physical controls have been established: low, medium, and high. The first three physical controls listed in the models — utility density, traffic conditions, and existing structures — are particularly difficult to quantify prior to final design, as they are very dependent upon the specific location and conditions where the work is to be undertaken. Only experience gained in the construction of similar work in comparable situations will permit the influence of these items on the costs associated with the various work events to be accurately assessed. However, in the sensitivity trend analysis contemplated by the models, reasonably broad assumptions as to the density and the sensitivity factors of these three controls should be satisfactory.

Utilities. As far as the modeling is concerned, the utility cost element involves only those utilities that are within the general construction contract; i.e., the preconstruction utility contracts are omitted.

A utility plan from the construction contract documents of BART Project K0016 is indicated in Figure 7-10 and may be considered representative of medium utility density for a downtown station. It will be noted that although the utilities are numerous on both sides of the streets and most of the usual utility services are present, none is of major size.

As can be seen from the dotted outline, the station is wide enough to conflict with nearly all of the utilities, which is one factor to be taken into account when accessing utility density; another is the frequency of cross streets within the station limits and the number of utilities they contain.

Low utility density would be appropriate if, for instance, the utilities were reduced appreciably in number or if the structure was sufficiently narrow (as in the case of cut-and-cover line structure) to avoid many of the utilities indicated.

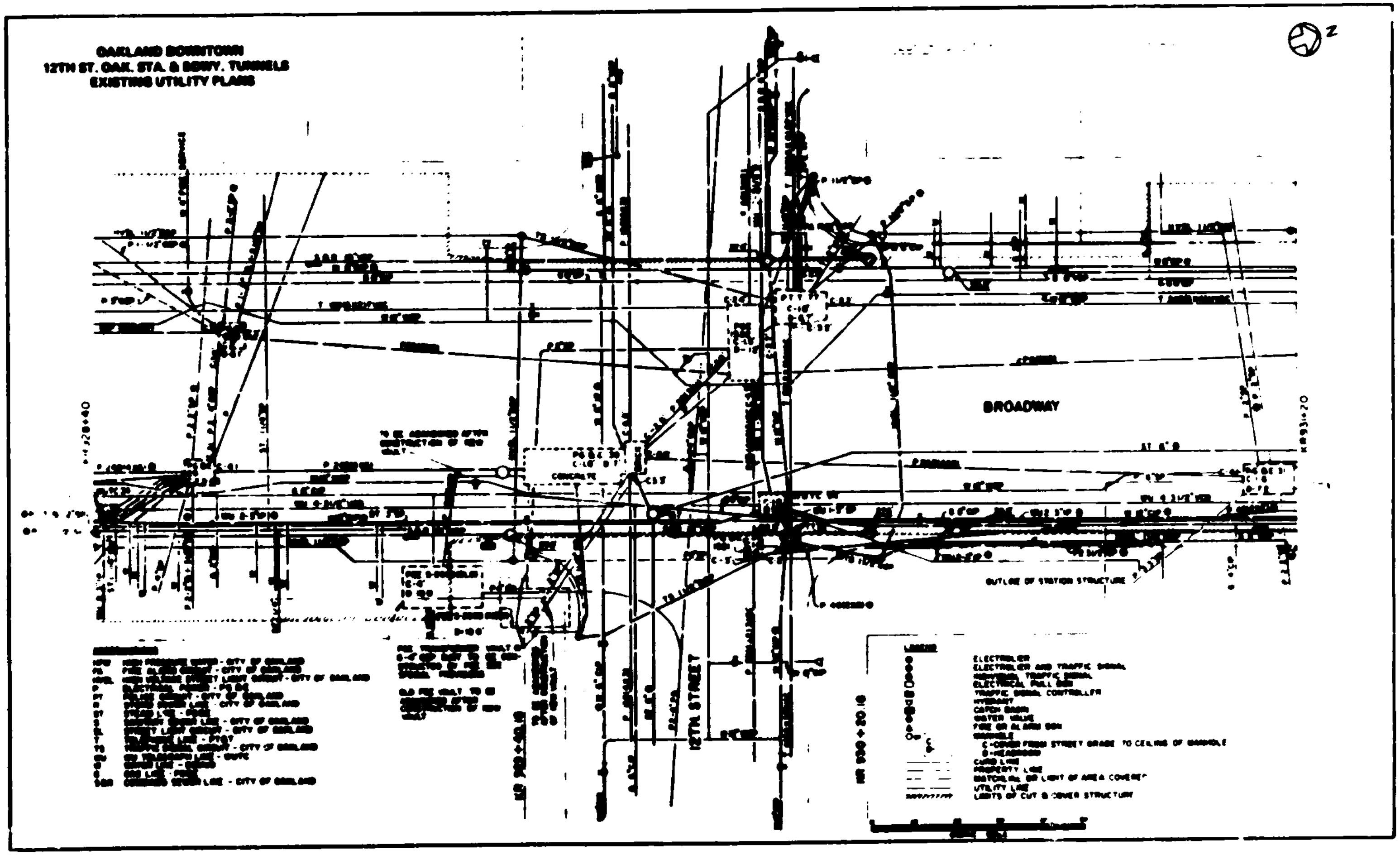


Figure 7-10. Utility Plan, BART Project K0016

In a more densely developed street, such as lower Market Street, San Francisco, the size of the various utilities is much greater (e.g., sewers up to 60" in diameter), conflict at cross streets increases sharply, construction problems increase, and the utility density is rated as high.

Traffic Conditions. Owing to the traffic conditions in downtown city areas, cut-and-cover construction involves a degree of decking. For stations, which are normally located in areas of dense traffic, the model assumes fully decked excavation for the "medium and high traffic conditions." For line sections, which are generally located in less dense traffic areas, 50 percent decking is assumed for the medium and 100 percent for the high. In both cases, a percentage less than the medium case as indicated in the Physical Control Effects tables in assumed.

The effect of such degrees of decking upon the construction work events is one element of the influence factors. The other element is the restrictive effect of the traffic itself upon the performance of the work events. Therefore, in order to evaluate the effects of traffic conditions on the work events for a construction section to be modeled, the following information must be estimated:

- Extent of decking required
- Number of traffic lanes, if any, which can be closed for the contractor's use
- The degree of restriction the traffic will exert on the performance of the work events
- The degree of restriction the traffic will exert upon the ingress and egress of construction materials

In the case of tunnel construction, the last of the items listed above is generally the only item of consequence.

Existing Structures. It will be noted from the Physical Control Effects tables that, apart from the large variation in the cost of the item itself, existing structures influence only the cost of the excavation. For the cut-and-cover station and the tunnel models, it is assumed that in the medium case the existing structures will require some additional precautions in support of the excavation. Since a cut-and-cover line structure is normally narrow and is generally constructed in less densely built-up areas, the medium condition is assumed as zero effect.

To evaluate the effects of existing structures upon the excavation process beyond the medium condition, the extent of (and the cost of) additional excavation support and the time to perform the excavation must be known.

Ground Conditions. Excavation is the major work event affected by the condition and character of the ground, but it also has a considerable influence on the underpinning and utility work events.

For the medium value in cut-and-cover construction, the ground is assumed to have a high water table, but to be readily dewatered; to be somewhat variable, but fairly easily excavated.

For the high value, the ground might contain some rock might be squeezing or compressible, and/or might be difficult to dewater.

For the low value, there may be little water, and the ground may be easy to support, excavate, and dispose of. The type of ground and the condition of the ground determine whether the tunnel model is to be used in free air or in compressed air. After this determination is made, the medium, high, or low assessment of the ground condition is assigned on the same basis as for the cut-and-cover models.

Architectural Requirements. This control is applied to the cut-and-cover station model only. The medium and low values are generally the most functional and economic structural forms indicated in the model structure. Architectural requirements that increase the volume of the station or the shape, such as the need to use free-spanning arches or configurations that create difficulties in forming, excavation, support, or backfilling, must be evaluated according to the effect on the cost of these work events.

Weather. The San Francisco Bay Area has been assumed as the medium base for the control. The effect of weather upon the various physical controls is discussed in considerable detail in Section 5. In general, areas with greater or lesser extremes of high and low temperatures and greater or lesser precipitation than the Bay Area must be assessed as having a higher or lesser degree of influence on the various work events, respectively.

Fill Demand. The type of material being excavated and the demand for fill determine the cost of excavation disposal. The model medium values assume moderate distances to the disposal point and no charge for the disposal.

If distances to disposal are long and cost is incurred in the actual disposal, this control would be assessed as high. Correspondingly, if fill was salable within a short haulage distance from the construction site, the factor would be rated low.

Assessment of Institutional Controls

Details of institutional control determination for the model are described in Tables 7-11 through 7-18 and the accompanying text. The lack of institutional controls in a project have the effect of adding time and therefore cost to a project. When the models are used, the costs of the various institutional controls must be reestimated accordingly.

SUMMARY

It is important that users of the models understand the philosophy behind the model structure outlined above, since this philosophy bears importantly on the way in which the numerical results of the models must be viewed. The models show main effects, not fine detail. They are computerized, and their structure and use are completely documented to allow for future application and updating as the introduction of improved technology reduces basic project costs. It should be understood that these are not cost-estimating models; they should be used only to arrive at an "index" of probable relative costs between project alternatives.

Section 8

POTENTIAL COST REDUCTION TECHNIQUES AND NEW TECHNOLOGIES

INTRODUCTION

Throughout the development of this study, certain ways of improving project schedules, costs, and safety became apparent. These improvements, discussed in this section, include proposed methods of changing the owner-engineer-contractor relationships and improvements in existing cut-and-cover and tunneling methods. New technology in tunneling is also presented.

A report of a study conducted by Standing Subcommittee No. 4, Contracting Practices, of the U. S. National Committee on Tunneling Technology for the National Academy of Sciences, is very pertinent to the subject of changing the O-E-C relationships. The advance draft of the report, which is entitled "Better Contracting for Underground Construction," reviews most of the major items concerning O-E-C constructional practices (covered in Section 2 of this report) and makes recommendations to improve these practices. Some of the recommendations, such as those relating to the form of contract, call for far-reaching changes in present contracting approaches, and implementing these changes would require the coordinated efforts of several organizations, probably over a considerable time period. Other recommendations, such as those concerning "wrap-up insurance" and "alternative bids," have not yet received full approval of the committee responsible for the report. Thus, at the present time, there are many difficulties involved in changing O-E-C relations. Some of these proposed changes are discussed below.

PROPOSED METHODS OF CHANGING O-E-C RELATIONS

Because of the complexities of underground transit construction and the uncertainties regarding the physical conditions that have a major bearing on the construction costs, present-day construction contracts and specification are justifiably open to criticism. Implementation of the changes suggested in this section should lead to the removal of some of the undesirable features and reduce costs and construction time.

Contractual Changes

In the first approach, the contractor subcontracts most of the construction vide input to the engineering design and specifications. The first time he sees the contract documents specification and construction drawings is when they are issued for bidding, and it is only then that he can tell whether they will permit him to use his existing construction organization and equipment to the best advantage.

The bidding period of 6 weeks for the many items that have to be evaluated in pricing underground construction work does not permit serious study of the use of truly innovative construction techniques, which may result in modifications in the design. An even greater restriction is imposed upon the possible use of innovative equipment, which not only may require the design to be modified, but may also require some period for development and testing. The bidder's conference, which usually is scheduled 3 weeks before the date the bid is due, is the first opportunity the contractor has to meet with the engineer. Obviously, such a meeting is not the place where design changes to permit innovative approaches, with the related competitive implications, can be discussed openly. Nor is there enough time to make any of the probable design changes that an innovative approach might necessitate.

The shortcomings of current contractual relations may be summed up as follows:

- The use of innovative approaches and equipment is severely restricted.
- During the design phase, there is no engineer-contractor dialogue and no opportunity for contractor input; during the bidding, there is very little engineer-contractor dialogue.
- An adversary climate is established which permits provisions of the specifications to be challenged up until the final acceptance of the project.

It is to the advantage of all parties concerned to have the contractor's input in both the design and the contract documents and specification. Since such an input demands the contractor's time and money, reimbursement should be made accordingly. If the rules of competitive bidding are to be observed, the inputs of all selected prequalified bidders must be obtained. Innovative approaches devised by the contractor must be treated with the utmost confidentiality to preserve the contractor's competitive position. Unfortunately, confidentiality of this sort is difficult to guarantee.

Four approaches that incorporate the contractor's input in the design stage of heavy civil engineering projects bear discussion.

In the first approach, the contractor subcontracts most of the construction work and thereafter manages the subcontractors. In this approach, the contractor is selected from a prequalification list through a comparative evaluation of the following:

- Performance records, experience, quality of work, punctuality, ability to work within a budget, etc.

- Descriptions of potential contributions during the design stage and estimates of the cost of such contributions
- Fees for managing the subcontractors
- Estimates of the costs of any construction work performed by the contractor

Upon completion of the design, subcontract bids are obtained for the work, and the managing contractor then guarantees a price for the total work. Until this point, the parties are not committed to the entire contract. Upon acceptance by the owner, construction begins.

This approach was developed by James F. Abbott, formerly Manager of Construction of the University of California, and works well without violating any of the laws on public bidding, which usually require acceptance of the low bid. One of the reasons for its success is that a large percentage of the work is subcontracted.

A second possible way of incorporating contractor input during the design period is a two-stage bid approach. In this approach, the prequalified contractors make written proposals on the preliminary design documents, specifications, and drawings on all details except price. Each contractor describes how he wishes to do the work and has an opportunity of discussing proposed modifications of the design, specifications, or contract with the engineer. Following the discussion, the bidder is notified if his proposed construction methods are acceptable. At the end of the discussions with all the bidders, an addendum is issued to finalize the documents. This addendum covers the changes necessary to accommodate the various construction methods. Bid prices are then taken in the normal manner, the low bidder receiving the contract. To motivate the contractors, it is desirable and reasonable to reimburse the bidders for their first-stage participation. This procedure produces a highly construction-oriented and responsible input to design, which is often lacking in present-day practices. It also gives the contractor time and opportunity to make a thorough study and interpretation of the subsurface exploratory data, which under current practices he does not have.

To minimize the probability that the contractor will include substantial contingency sums for unforeseen or difficult-to-evaluate conditions, the contract documents should make provisions for adjustment of prices on an equitable basis if the scope is changed or if the actual conditions differ appreciably from those indicated in the bid documents. Such conditions relate mainly to utilities, ground conditions, existing structures, and (to a lesser degree) traffic conditions.

Neither of the approaches discussed appears to conflict with any of the public works contractor selection procedures with which public-owned rapid transit authority must comply, and the adoption of either one could result in attractive cost services for a single-contractor project construction arrangement. However, because of the complexities of planning and engineering design, rapid transit construction in the present state of the art involves the awarding of many multimillion dollar contracts over a time period of several years, and the practicability of selecting and incorporating, in one form or another, numerous contractors within the engineering design teams is in serious question. It appears that at least the next generation of rapid transit systems will continue to be implemented using the same general principles as exist today, and that a procedure whereby direct input from the contractor can be incorporated into the engineering design must be deferred until the day when structural planning can avoid head-on conflicts with the peripheral work events and when structural systems become more standardized.

A third method of incorporating contractor input during the design period is a compromise approach which provides some of the desired balance between sound engineering design and economical construction practice.

This approach involves the creation of a contractors' panel during the preliminary planning and throughout the engineering design stages. The panel is composed of, say, three prominent contractors from the area of the proposed rapid transit implementation. Ideally, these contractors should be experienced in heavy civil engineering construction in the general geographical area of the proposed transit system.

During the engineering planning and design process, the panel is consulted at all key decision points including: discussion and agreements with authorities and agents; specification and contract document formulation; and scheduling and project size determination. The panel is available as a source of both information and advice to contractors interested in bidding on the contract work. Members (and their companies) of the panel are not eligible for bidding on and undertaking the construction of the system, but are reimbursed for their efforts.

A fourth approach of incorporating contractor input makes use of construction management. Construction management can be an important vehicle for providing construction-oriented input for engineering design, specifications, schedules, and the like, and can also become a source of information to contractors interested in bidding for the construction. In this respect, it performs a function similar to that performed by the contractors' panel, but its impact is not as great as that of the panel. Construction management can also provide the engineers with feedback about problems encountered during the construction of the various projects, particularly the early ones. A proper and creative analysis of such problems can lead to substantial improvements in the formulation of engineering and contractual documents for the subsequent project. The BART organization was illustrative of this philosophy, and construction management made important contributions to the engineering design and construction process.

In conclusion, it is recommended that the basic principles upon which the BART and WMATA construction documents were formulated should not be changed at this time. Maximum effort should be concentrated on developing construction-oriented engineering designs and contract documents, particularly with respect to the peripheral works. The most promising approach for achieving this is through an appointed and salaried panel of contractors or construction consultants who would not only provide input to the design engineering and contract documents from the contractor's point of view, but would also be a source of both information and advice to contractors bidding on the construction projects. The panel could serve as the needed bridge between the contractor and engineer, and might prove to be the catalyst for removing the often present adversary relationship that exists between the two parties.

Contractual Changes and Comprehensive Site Investigation

Scope changes caused by unforeseen conditions, and the problems arising therefrom, can be reduced considerably by instituting more detailed site exploration, particularly in conjunction with the aforementioned contractual changes. One of the shortcomings in the present system of gathering data on utilities, ground exploration, existing structures, and traffic conditions for inclusion in the bid documents has been the lack of contractor's input to the criteria for the data.

The specifics of locating utilities in relation to the underground structures, the decisions on which structures to support and how to support them, and the scheduling and sequencing of the work are of vital concern to utility owners and contractors alike. If the contractor could participate at the utility company/engineering planning meetings, he could inform the other parties of his plans and gain information that will enable him to optimize his construction details and schedule. In these meetings, each party can become better acquainted with the problems of the other. This might result in a better spirit of cooperation and lead to a resolution of most of the unknowns, which the contractor would otherwise price as contingencies. Moreover, definitions of what constitutes "as-bid conditions" and what constitutes "changed conditions" for additional payment can be more readily determined. The result of all of this should be reduced construction costs.

The soil data required for excavation in cut-and-cover and tunnel construction differ somewhat from those required for engineering design. The designer needs to know the criteria for establishing soils values for final loading, distortion, and settlement, and he needs to know maximum groundwater elevations. The contractor must be aware of the excavation characteristics of the soil, the way it handles during removal, its suitability for backfill, the drainage parameters, and the quantities of water involved in dewatering operatings. For cut-and-cover construction, he has to know the time of standup during excavation and whether or not the ground will run. (If during the excavation process the ground outside the excavation subsides, existing structures in the excavation area will have to be supported.)

Such ground information is even more important to the contractor for his tunneling process, and the accuracy of cost estimates for groundwater control (including the requirement for compressed air), rate of progress, excavation, muck handling, and removal, all of which are major cost items, depends upon the reliability and extent of the ground information available. Therefore, prior to bidding, the contractor, as well as the engineer, should provide input on the extent and form of soil testing required.

A typical soils investigation program might include:

- Thorough research of available information from engineers, contractors, and public agencies that have worked in the contiguous area

- The use of closely spaced bores or probes in areas where soil formations change to determine the location of formation interfaces and mixed face conditions, to obtain an accurate rock profile, and to determine the rock quality and the structural capacity of the rock formations
- Rigorous pumping tests in some situations to determine groundwater control requirements
- Test pits to establish ground behavior during excavation procedures and groundwater control
- Pilot shafts and tunnels in difficult ground situations to establish tunnel construction techniques
- More testing, including additional borings, to determine the volume and quantity of excavated material suitable for fill. Where rock is encountered, crushing tests may be required to establish its suitability as aggregate
- Examination of the geological structure of the area

The measures required to protect existing structures (or utilities) from ground disturbance resulting from nearby excavations are dependent upon several considerations, most of which are interrelated. Such considerations include:

- Structure. The size of the structure and the importance of its function, the sensitivity of the structure to settlements, the type of foundations, the horizontal and vertical proximity of the foundations to the excavation, and the problems of access to the structure for the construction support operations
- Ground. Sensitivity to settlement during the excavation and dewatering processes
- Construction Techniques. As an alternative to directly supporting structures, support excavation that can reduce ground movements to acceptable limits, using the following methods:

  For cut-and-cover — slurry wall construction, recharging groundwater, tie back wall construction, preloaded bracing struts, soils grouting

For tunnel — continuous support of excavated face, compressed air working, "one shot" grouting of tail space

The interrelationships of the above factors are uppermost in the engineer's mind when he attempts to evaluate probable economic construction approaches to the existing structure support problem, and he establishes the design and specifications accordingly. The contractor's input at this stage is of considerable value. Ground and construction techniques are intimately related to the output data from ground exploration, and the contractor's input to the latter is useful to the engineer's evaluation of alternative approaches to the support of the existing structure.

Modern high-rise (over eight stories) buildings, unless on very good soil or rock, are usually supported on piles or caissons that are founded below the bottom of the transit construction and are therefore not affected by it. It is the low- or medium-height structures on spread footings that usually cause trouble, particularly if the buildings are old and the drawings are scanty, if indeed they exist at all. In these cases, exploratory investigations to determine position, type, and condition of the foundations permit more economical design and bidding procedures. A large proportion of traffic decking installation and removal may stem from restrictive sequences and schedules imposed by the City Traffic and Streets Departments. The presence of the contractor at engineer/department discussions during the design stage provides opportunities for restrictions to be examined and possible alternatives to be worked out to best suit the contractor's preferred methods, sequences, and schedules. During the course of the construction work, the contractor liaises constantly with the Traffic Departments on matters of traffic rerouting and control, and a clear understanding by both sides of the requirements prior to bidding cannot help but reduce the project cost.

A comprehensive traffic decking/detour plan covering the entire construction period and phases would be a great asset in minimizing traffic problems.

Contractual Changes, Comprehensive Site Investigation, and Field Testing

There are two groups of field testing objectives that may be undertaken during construction. The first is concerned with the monitoring of criteria (established in the specifications) that are designed to safeguard life and property during certain of the construction operations. The second deals with research and development, with the objective of improving the implementation of future rapid transit construction.

Testing items in the first group include periodic measurements for the following: movements of existing structures and ground surfaces adjacent to the construction during the process of excavation, stress and deflection of the horizontal and vertical bracing elements supporting the excavation, and groundwater elevations during dewatering and the various construction stages. Other routine testing is performed to determine the quality of materials and workmanship. Items covered include concrete welding, grading, and selection and compaction of fill material.

Additional second group field measurements that may produce substantial economic benefits for the implementation of future rapid transit construction are:

- The lateral movement of vertical excavation support, such as soldier piles and cast-in-place slurry concrete walls, and ground movements outside the construction
- Stress build-up in horizontal members
- Recording of the soils profile as actually encountered, and in some situations, soils testing in situ

A comprehensive program for assembling such data over a wide range of conditions will greatly aid in establishing design criteria and excavation procedures and techniques.

Stress and strain measurements in various elements of the cut-and-cover structure should be made at periodic intervals during backfilling and the restoration of the groundwater table. Such measurements should continue until the increase in stress and strain ceases or until they are no longer practical. The information obtained from all these measurements may well advance the economic design of cut-and-cover structures.

In tunnel construction, the following procedures should be undertaken:

- Instrumentation should be installed in tunnel linings to measure stresses and strains in the various elements at periodic time-intervals until all changes in tunnel geometry cease, or as long as practical after the construction.
- Pressure cells should be installed to determine actual soil pressures on the lining.
- Soils profiles as actually encountered should be recorded during the excavation, and, in certain situations, in-place soil testing should be performed.
- Both shallow and deep settlement reference points over and around the tunnel profiles should be established. Ground settlement readings should be taken at intervals during and after construction until all settlements cease.
- Devices should be installed in the soil outside the lining to verify, at periodic intervals during the operation of the system, the occurrence of any corrosive action of the soil on the lining.

The data from these tests and measurements are of inestimable value in advancing the state of the art of present-day tunnel liner design.

Preliminary Plans for Demonstrating the Effectiveness of the Changes Proposed

All three groups in the O-E-C organization, as well as various legislatures, are vitally interested in any actions that can reduce the time and cost of implementing the transit construction.

Of the three groups in the O-E-C organization, the engineer probably has the most influence in initiating contractual and technical changes. It is upon him that the owner chiefly relies for guidance in establishing the bases for such changes, and at the present time, the engineer largely determines the contractor's bidding policies and construction approach. Therefore, engineers concerned with rapid transit implementation should be the principal targets to which information about the effects of the changes proposed in this study should be directed.

This study should also be of great interest to contractors and representative organizations concerned with rapid transit construction. As a group, contractors are particularly alert to any changes that (1) result in better information at the bidding stage and (2) produce engineering designs and contracts that facilitate the introduction of innovative construction approaches. Various construction organizations are at present actively exploring the possibility of such approaches for heavy civil engineering projects, and some of the results may be applicable to rapid transit projects.

Specific Approaches for Implementation

It seems obvious that changes in practices to conform with the conclusions of the study will not become effective immediately; a continuing organized effort will be required and will be directed on a broad front at all segments of the tunneling industry. To assist in bringing about these desired changes, a document that provides concise statements of recommended procedures should be prepared for circulation. This document should be directed at engineers, contractors, owners, and legislatures, and should accomplish the following:

For engineers:

- Promote the presentation of papers at meetings of professional societies of national, state, and local levels and promote the publication of such papers in the professional literature.
- Supply appropriate educational material to engineering departments of universities and colleges.
- Furnish information to professional societies, such as ASCE, CEC, SAME, NSPE, AIA, and others in related fields of accounting, cost engineering, law, contract administration, environmental protection, et al.

For contractors:

- Keep contractor organizations, such as the Associated General Contractors (AGC) and the National Constructors Association (NCA), informed of the latest developments.
- Promote study recommendations by the AGC and NCA.

For owners and legislatures:

- Supply information to federal agencies (primarily DOT), Transit Districts and Authorities, state legislatures, state transportation departments, Congress, and city governments in cities where rapid transit programs are underway or contemplated.
- Promote changes in regulations for administration of planning, research, and capital grant programs that will discourage the growing tendency on the part of grantors to impose rigorous controls,

which all too often develop into virtual project management.

- Promote legislation for local, state, and federal government to implement study recommendations where necessary.
- Identify legislative bodies, public works bodies, and leading citizen's groups, and promote political activity to inform them of the study recommendations.

A study of contracting practices for tunneling and underground construction is being conducted by the U.S. National Committee on Tunneling Technology (USNC/TT) of the National Research Council. Standing Subcommittee No. 4 has investigated many elements of the foregoing discussion, particularly with respect to the precontract data on soils information, underpinning, design specifications, and contract details. The final recommendations of the study undoubtedly will prove a valuable contribution to improvement of O-E-C relations.

IMPROVEMENTS OF CUT-AND-COVER TECHNOLOGY

An analysis of the costs of the construction events in the study projects indicates that new technology may bring about the following improvements in the time/cost factor.

Utilities

Although this is a prime cost event in underground construction, few technological advances for improving the current methods of relocating, supporting, or restoring utilities can be expected. The best way of dealing with utilities is to avoid them, if possible.

Decking for Traffic

The present system of temporary timber decking leaves much to be desired. The deck is potentially dangerous to traffic and pedestrian alike because of its poor surface skid characteristics and the often abrupt changes of grades at the decking approaches make it hazardous to users. As the cost of lumber continues to rise, its use in the future will become increasingly less economical. Possible alternatives to lumber are ductile iron deck units and permanent road support deck.

Ductile Iron Deck Units. The Japanese appear to have pioneered the manufacture and use of these units, which are available in various standard dimensions. Their abrasive surface provides good traction; they seem to be economical and easy to install and remove; and they have a longevity far greater than that of timber. Their initial cost, however, may be appreciably higher than the initial cost of timber, even at present-day timber prices.

The adoption of these units will depend on the number of repetitive uses that may be obtained and on the increase in the amount of standardization of deck-supporting structures. Such deck units appear to be future candidates for owner-furnished material.

Permanent Road Support Deck. In conjunction with slurry-tremie concrete walls, a permanent deck appears to be an attractive alternative to the temporary deck in a number of situations. The benefits to traffic and adjacent businesses of installing the deck and restoring most of the roadway at one time are immediately obvious. Permanent decks have been used with success in many instances outside the United States. The cost of installing the deck is partly offset by the savings realized from not having to pay for (1) the cost of backfill, and (2) the additional station structural costs needed for the support of the 8 ft or so of backfill.

Figure 8-1 shows a typical installation for a station. The sequence of the principal installation is outlined.

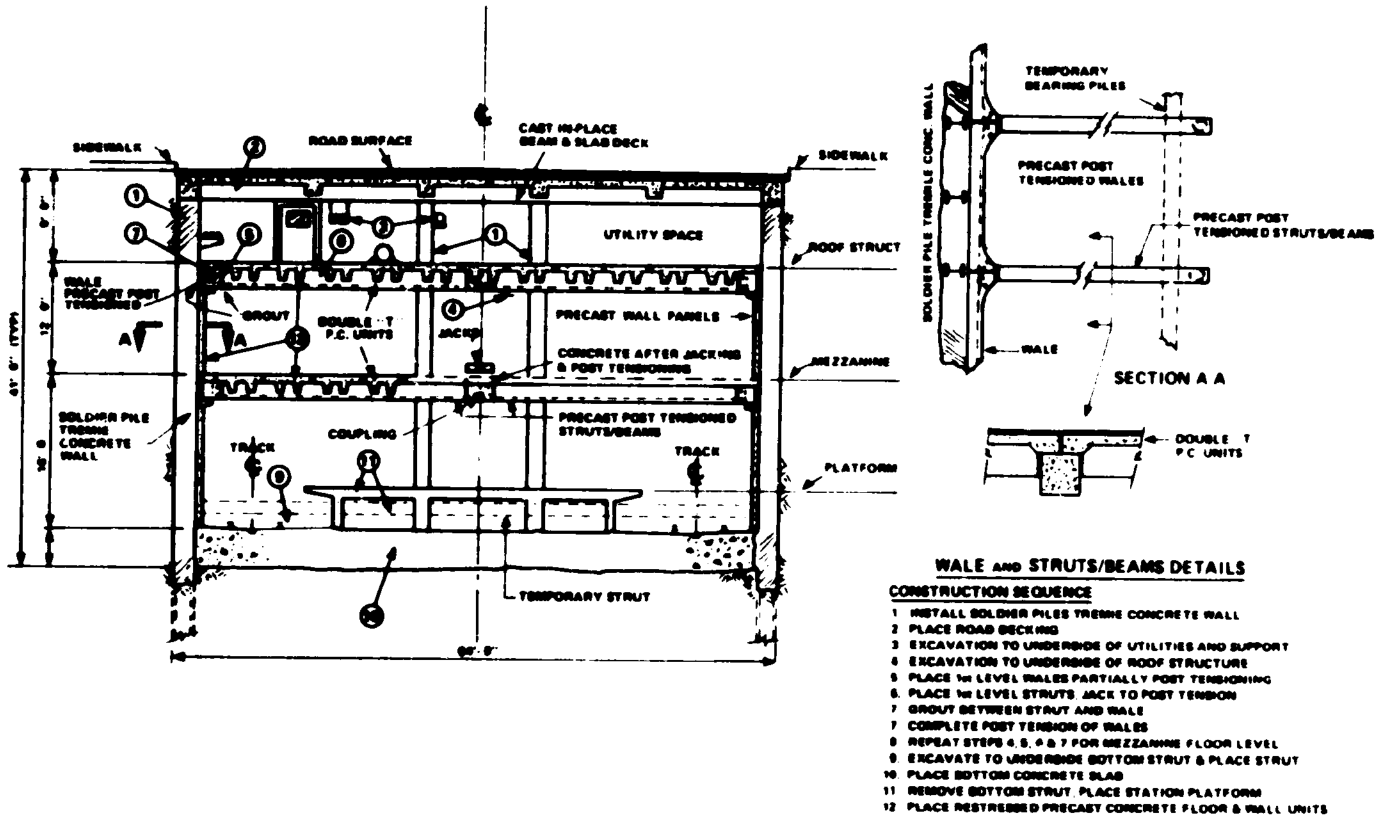


Figure 8-1. Cut-and-Cover Station – Permanent Road Deck, Precast Concrete Unit Construction

The concept of having the utilities located in an open space above the station roof is not new, and the space is no more than a short utilidor. However, before this concept can be adopted. certain problems with the utility companies must be resolved. These include:

- Separation of gas and electric services
- Protection of exposed utilities
- Possible space congestion problems, particularly at intersections
- Control and maintenance of the utilidor

Underpinning of Existing Structures

Since this work requires considerable labor in restricted working spaces, underpinning and other methods of supporting the foundations of existing structures are likely to remain an expensive operation. However, the time/cost aspects of the work can be improved in the future by the methods described below.

Obtaining More Precise Soils Information and Improving the Art of Soils Disturbances Prediction. This is particularly critical where the parameters of foundation type, depth, and distance, relative to the excavation, and the soil characteristics are borderline. With the present state-of-the-art methods of determining these parameters, a prudent designer will of necessity take the conservative approach and when in doubt will elect to underpin. In many cases, such costs can be avoided by better ground and design information.

Mud Jacking. This is a system whereby grout is injected under a foundation with sufficient pressure to cause the foundation to rise. Mud jacking thus restores a foundation that has settled from its original elevation.

For a square or rectangular footing, the approach is to drill and sleeve grouting holes at an inclined angle under and below the footing around the perimeter of the footing. Grout (a mixture of various clays and cements) is successively injected under controlled pressure at each hole, thereby consolidating the soil under the foundation. Continued grouting eventually raises the foundation to the required level.

During one of the BART construction projects, this method was used to raise a footing of a freeway which supported several hundred kips. The footing was raised several inches but not to the full amount desired. This lack of complete success was due partly to the inexperience of the contractor, but the method seems to have considerable future promise.

Excavation Bracing

Where the horizontal bracing steel was used as a permanent component of the station structure in the BART system, the result indicated a good potential for cost savings.

This principle is illustrated and described in Figure 8-1. In this example, precast post-tensioned concrete was employed. The increase in time in installing the walings and struts appears to be more than offset by the time saved in the construction sequence by not having to remove temporary bracing. Figure 8-1 also indicates the use of precast concrete wall units as final surface finish and prestressed concrete floor units placed directly on the precast concrete strut/beams. With a certain degree of standardization, both of these items could be economically attractive.

IMPROVEMENTS IN EXISTING TUNNELING TECHNOLOGY

It may be assumed that most rapid transit tunnel structures in downtown areas will be constructed in various types of ground and that the ground will usually have a relatively high water table. Improvements in existing lining systems and excavation techniques, which are discussed below, should be attainable without extensive modifications of present planning and design concepts and existing construction techniques, and should result in increased efficiency of the tunneling process, with corresponding economic benefits.

Segmented Linings

A standardized design (such as that adopted in the BART system), together with the advantages of bulk purchasing of the linings by the owner, does appear to give appreciable cost savings in lining purchase costs. The adoption of national standards would produce yet lower costs in future systems. Such standards ought to include the ring diameters (preferably the outside diameters), the width of the rings, and the ring tapers. It should be noted that these standards depend upon the adoption of standard transit car dimensions and springing characteristics.

In the interests of both lining manufacture economy and operation and maintenance of the system, consideration should be given during the layout of the system to keeping the radius of track curvature above a certain minimum. For example, in the case of the BART tunnels, the minimum radius of track curvature was 500 ft, which required that the base design tunnel inside diameter, designed for a track radius of 1500 ft, be increased from 16.5 ft to 17 ft. The lining for the tunnel with the 16.5-ft i.d. (1500-ft radius of curvature) was 7 percent less expensive than that for the tunnel with the 17-ft i.d. (500-ft radius of curvature).

More important, small-radius tunnels restrict the advance of the shield owing to the tendency of the shield tail, as it changes direction, to bind on the ring. This, in turn, imposes a limit on the width of the segments, as well as requiring the increased use of tapered rings. Both these factors increase the cost of the linings.

In summary, restricting the radius of curvatures of tunnels to, say, 1500 ft and greater will lower the cost of linings by reducing the tunnel diameter, reducing the number of tapered rings, and permitting the use of a wider ring for many soil conditions. In addition, such a restriction will increase the rate of tunnel advance.

Gaskets in neoprene, or a similar material, could be used to provide watertightness around the perimeters of the segments, either as a complete or as a partial substitute for present-day methods of caulking. This would eliminate not only the caulking, but also the cleaning of the caulking grooves, which sometimes get packed with mud and grout; and both caulking and cleaning are laborious and expensive. Current estimates indicate that the caulking and the preparation of the caulking average $120 per tunnel foot. In firm ground, additional savings could accrue from reducing the number of segment bolts, whose main function is to hold the segment faces together in order to maintain the integrity of the caulking.

Excavation Methods

For the BART system tunnels, approximately 35,000 ft was constructed with tunneling machines, and approximately 31,000 ft was constructed with shields using manual excavation.

In Table 8-1, production rates for two different methods of tunnel construction are compared for a single tunnel, 5,200 ft long, in free air.

There are three facts revealed in Table 8-1 that are of particular interest:

1) At 1974 labor rates, it is less expensive to use tunneling machines than manual shields.

2) The time it takes to erect a ring lining is the same for both methods.

3) The downtime for the tunneling machine is substantial.

Table 8-1

PRODUCTION RATES FOR TUNNEL CONSTRUCTION USING TUNNELING MACHINES AND TUNNEL CONSTRUCTION USING MANUAL SHIELDS

	Machine	Manual
AVERAGE RATE OF RING ADVANCE		
Time to excavate and advance shield	20 min	85 min
Time to erect lining ring and grout tail space	45 min	45 min
Time cycle for on 2-1/2-ft-wide ring advance (no equipment downtime)	65 min	130 min
Equivalent advance per day	55 ft	28 ft
Average equipment downtime over project	27 %	10 %
Average advance per day over project	40 ft	25 ft
AVERAGE LABOR IN HEADING AND SHAFT		
Labor per day, three shifts @ 8 hr per shift	122 men	102 men
Labor per foot of tunnel	24.5 man-hours	32.5 man-hours
AVERAGE COSTS		
Labor cost per foot tunnel @ $17.55/hr	$430	$790
Equipment & plant (incl. muck handling)	211	116
Equipment operation, maintenance, and power	30	27
Direct cost per foot — single tunnel	578	882
Indirect cost — 45% of direct cost	260	398
Per foot — single tunnel	838	1280
Per system foot — two tunnels	$1676*	$2560*

*Costs are estimated using 1974 as a base and include costs due to shaft crew, lining erection, grouting, excavation, and indirect costs such as overhead and profit. Costs not included are those due to muck disposal, shaft construction, mobilization, invert concrete, tunnel liners, and underpinning.

The major element in the rate of tunnel construction is seen to be the placing of the lining, which accounts for 70 percent of the production time in machine-driven tunnels and 35 percent of the production time for manual shields. (No allowance for breakdowns is made in either case.)

In recent years, there has been no major technical development for appreciably accelerating the present methods of building segmented rings. Present-day ring segments are manufactured with considerable precision in order to minimize bolting fit-up delays and to improve watertightness. Precast concrete segments are sometimes more difficult to erect owing to the long bolts required and the problems of matching the holes.

The BART welded steel rings, which are typical in many designs, required from 51 to 72 high-tensile bolts, and in a 17-ft-dia. tunnel, it takes an appreciable amount of time to torque these bolts to the specified tension.

Without changing the current erector arm methods of placing the segments, the rate of tunnel construction could be accelerated by wider segments, fewer segments, and less equipment downtime.

- Wider Segments. In reasonable ground, the normal standard could be increased from 2-1/2 ft to 4 ft. Although the weight would be increased, the segments would not take appreciably longer to erect. If the number of bolts per segments remained constant, the time required for installing lining erection per foot of tunnel might be reduced approximately in proportion to the two widths, or about 40 percent.

  Wide segments would require compatible tunnel geometrics (see the discussion in "Segmented Linings"), or alternatively, two segment widths within one system.

  Wide segments are not suitable for use in loose or squeezing ground. Ground of this sort will drop or close in around the ring as the shield advances and before the tail space grout can be placed, thus increasing the ground displacements and surface settlements. This situation might be improved by better grouting techniques. In addition, with manual excavation, the greater excavation length in front of the shield, the more hazardous is the support of the face. This danger, however, may be lessened by the use of a full face support tunneling machine.

Another factor to be considered with the use of wider segments is the effect on the corresponding lengthened shield shove jacks during horizontal alignment changes. That is, the shield assumes a different line than the erected lining. This produces bending moments on the jack pistons, causes excessive wear on the seals, and thereby increases the amount of maintenance required. Both better design of the jack mountings and restriction of the use of wide segments to the larger-radius tunnels would minimize this problem.

- Fewer Segments. If the segments were longer, there would be fewer segments in a ring, and ring erection might proceed faster. The length of the segment is to some degree limited by both the material used and the method of manufacture, but the main limitation is the diameter of the tunnel and the feasibility of maneuvering the segments into position in a crowded tunnel heading. Six-segment rings appear to be fairly standard, with four used occasionally in a 18-ft-dia. ring. There is at least one example of a three-segment ring in a 20-ft-dia. tunnel. Optimizing studies, which take into account the tunnel construction equipment, the segment-handling and erection methods, and segment design, are required to determine the most economic segment length.
- Equipment Downtime. As can be seen in Table 8-1, the 27 percent average for the tunnel machine was apportioned as follows:

Tunneling machine	14%
Muck trains	3%
Unspecified	7%
Nondelivery tunnel rings (owner-controlled delay)	3%

Some of the causes of machine downtime were: failures of motors, bearings, rollers, and hydraulic lines; and distortion or cracking of complete components, such as oscillation cutter arms or cutting wheels.

For every hour of machine production time lost, 21 man-hours were lost at the tunnel heading. (Additional man-hours were lost in the shaft and surface.) This is equivalent to the labor required to construct a 1.65 ft length of tunnel. Reducing the downtime to 10 percent, as for manual shield driving, would increase the production rate of machine tunnel driving from 40 ft/day to about 50 ft/day, and would reduce the labor per foot in the heading and beyond from 12.5 man-hours to 10 man-hours. The results would be an 11 percent lower tunneling cost.

Both machine and other equipment manufacturers and tunnel contractors are aware of deficiencies of the performance of the machines and equipment under the arduous conditions imposed by the underground work. The experience gained in the BART projects should go a long way toward decreasing downtime in future projects.

Grouting

Grout injection into the space between the lining and ground accounts for about 20 percent of the labor in the tunnel heading. The success of the grouting operation depends upon the skill and judgment of the grouting crew (and sometimes the results are less than satisfactory).

Problems are often experienced in sealing the space between the inside of the shield tail and the outside of the tunnel ring. This sealing process is required to prevent the grout from running back into the tunnel. The contractors of some of the latest BART tunnel projects fitted the tail of the tunneling machines with various types of neoprene skirt seals. Some of these seals performed fairly satisfactorily, but most had to be replaced frequently. This need for replacement was partly due to drag when the shield tail bound on the segments, and partly due to the grout cement setting up around the seal during machine downtime and dragging the seal off when the advance resumed.

There are three major grout requirements: it must be easy to place: it must be able to fill all voids; and it must have a reasonably rapid setup time at initial low strength. Grout strength is not as important a requirement. Improved grouts have been developed recently in Europe, but so far these grouts do not appear to have been used in the United States.

Ideally, grout should be placed from several grouting points in the tail of the shield, with continuous injection during the advance of the shield, thereby filling the tail space as it develops.

Caulking

In addition to incorporating segment face gaskets, discussed in "Segmented Linings," caulking systems other than the one that employs lead should be considered. In 1968, BART undertook a research and test program to determine the possibilities of such alternatives. Two systems appeared promising.

The first used a neoprene hollow teardrop extension which was forced into the 1/4" wide x 3/4" deep caulking groove. The groove had previously been treated with an epoxy adhesive or else it was applied directly to the extrusion.

The second system employed a caulking yarn, called "Sealite," which expanded when in contact with water. Two layers were placed in the segment caulking groove to a depth of about 3/8", and the remaining space was filled with epoxy adhesive.

The epoxy adhesive in both systems was formulated to provide good bond to wet and dirty surfaces.

A test installation in a BART tunnel of both systems was made, and both showed considerable promise.

It was concluded that both systems produced satisfactory watertightness in the segments, and that some development work should be undertaken to automate the placing of the caulking material and the epoxy adhesive.

NEW TECHNOLOGY

The preceding discussion on tunneling technology was based upon existing cut-and-cover planning concepts and current cut-and-cover and tunneling construction techniques. New technology for cut-and-cover tunnel installation, alternative approaches to station planning, the probable impacts upon tunneling installation techniques, and the effect upon the installation of the combined underground structural system will be described in this subsection.

Driving Tunnels Through Several Contiguous Station Locations

In most rapid transit systems in downtown areas, the principal barrier to faster and more economic tunneling is the close spacing of the cut-and-cover stations, which limits tunnel projects to lengths ranging from 1000 ft to 5000 ft. To maximize the potentials of present-day tunneling machines and to spur the development of automated and continuous tunnel-building equipment, it is mandatory to increase the tunnel lengths, and to achieve this, it will be necessary to drive the tunnels through several contiguous stations. The structural systems and the resulting station arrangements that will result from these concepts are discussed below.

Tunneled Trackway, Cut-and-Cover Station. Figures 8-2 and 8-3 illustrate the sequence involved in tunneling through the station location and constructing the station later, either in cut-and-cover or by mining techniques. In both cases, the three major construction stages required are in principle the same and involve the work tasks indicated below.

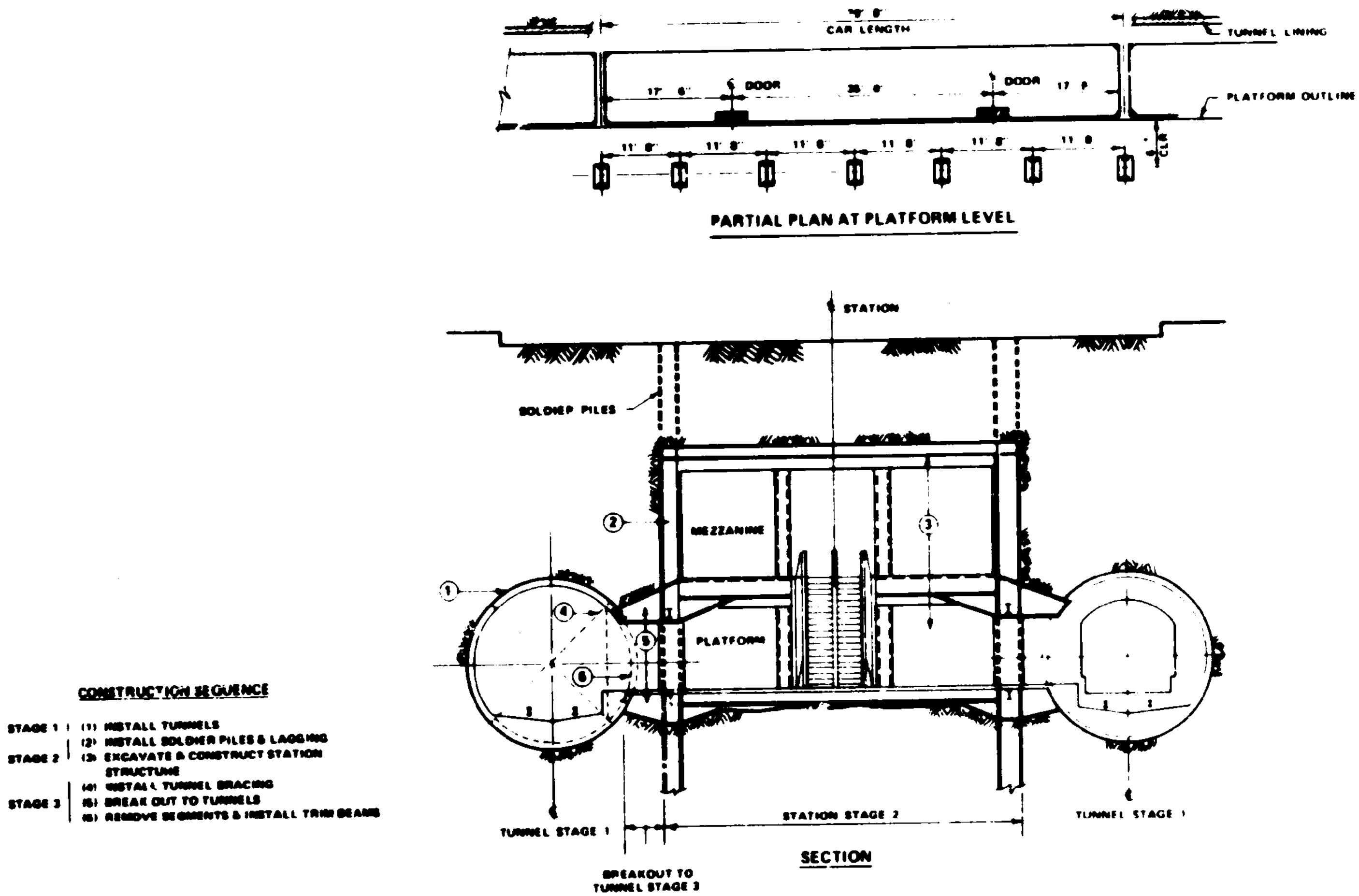


Figure 8-2. Cut-and-Cover Station Construction, Tunneled Trackway

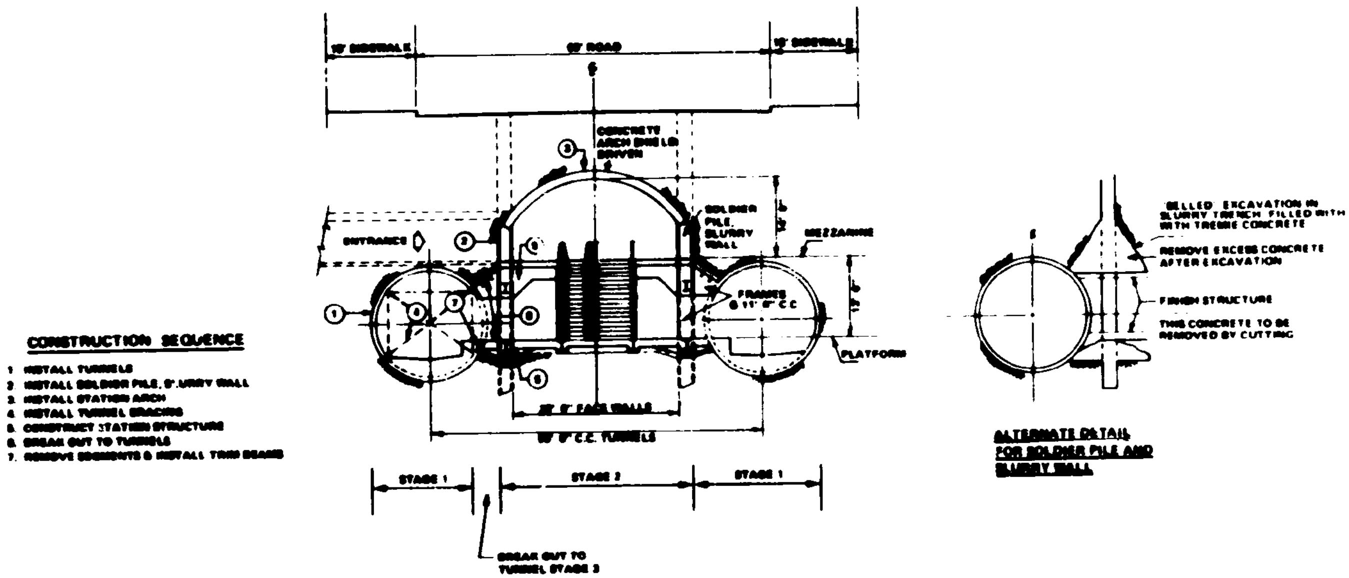


Figure 8-3. Mined Station Construction, Tunneled Trackway

Stage 1. The tunnels are driven to whatever economic length may be determined. At the station platform areas with segment-lined tunnels, half segments and keys are provided, as necessary, to facilitate the removal of segments and permit a straight interface with the trimming girders.

Stage 2. The station is installed. Figure 8-2 indicates a relatively orthodox-type cut-and-cover installation of decking, soldier piles, and lagging. Figure 8-3 shows a mined station installation which takes advantage of soldier-pile slurry-wall construction.

In both concepts, the mezzanine and platform structure are designed to accommodate the thrusts and bending moments from the cantilevers supporting the tunnel opening. In addition, the supporting columns, which may be installed initially as soldier piles, are spaced to minimize obstruction to the train doorways. About 6 ft clear is provided from the column face to the platform edge. This distance could be increased with more expenditure in the supporting steel structure.

Stage 3. The tunnels are suitably braced to prevent movements arising from soil disturbance during the station excavation and during the removal of the soil and the segments in the tunnel "break-out" operations. In this stage, the following is done.

- Main platform cantilevers are mined and cantilevers and other steelwork are installed.
- Mining is done between the platform cantilevers and the roof, and floor beams with lagging are installed.
- Tunnel liner segments are removed, trimmer beams are installed, and connections are made to cantilevers.

The structural work is completed by removing the tunnel bracing and concreting the platform roof, the platform floor, and the tunnel inverts.

In Figure 8-3, the alternate detail indicates a technique for facilitating the tunnel breakout work, particularly in bad ground. As shown, the slurry wall is "belled" with a special tool so that the concrete may be placed close to the tunnel lining.

Tunneled Trackway, Tunneled Station. Figure 8-4 indicates the concept of tunneling through the station location and subsequently tunneling the station platform and the stair and escalator accesses. The mezzanine is shown constructed in cut-and-cover, but of course it can also be mined, as indicated in Figure 8-3. This system has been used extensively in London and was also used in compressed air construction for a section of the Toronto subway.

There are five stages in the construction sequence:

Stage 1. The trackway tunnels are driven.

Stage 2. From the trackway tunnels, station shield chambers approximately 30 ft in diameter are mined. The station tunnels are driven using shields of the required size around the tunning tunnels, and trackway tunnel lining is recovered in the process. At the platform access points, half segments and keys are employed to facilitate making the openings.

Stage 3. The station access breakouts are made by removing segments at the portal positions and supporting the openings with steel posts and lintels. The cross passages are mined in preparation for the stair and escalator shafts.

Stage 4. The stair escalator shafts are mined, and the lining is erected manually and bulkheaded at the top.

Stage 5. The mezzanine is constructed in cut-and-cover.

In good ground, Stages 4 and 5 may be done in reverse order.

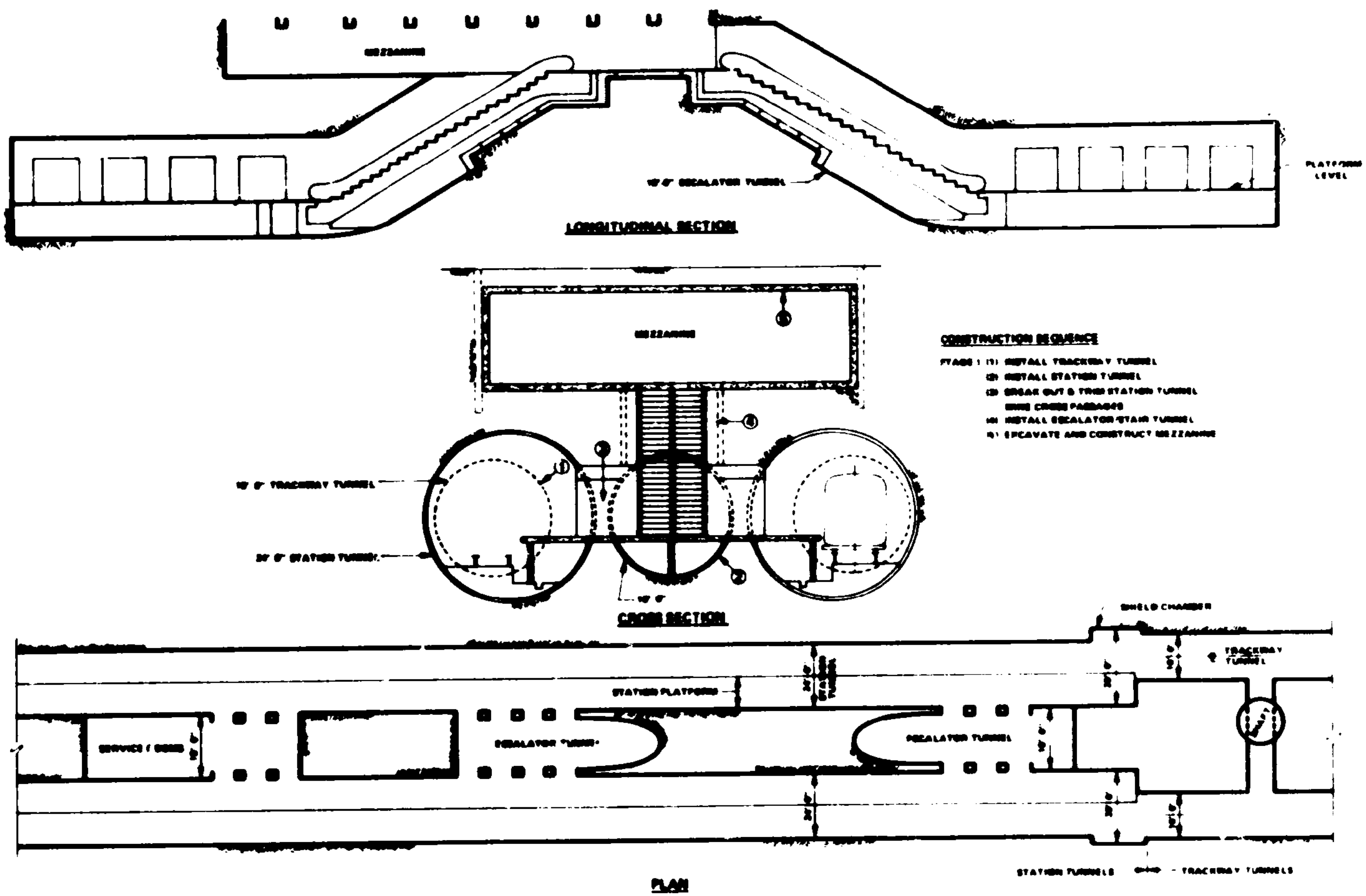


Figure 8-4. Tunneled Station Construction, Tunneled Trackway

The station shield chambers may become blast fan shafts by linking them to the surface by means of a vertical, or inclined shaft.

The arrangements and construction of the stair and escalator shafts and mezzanine can be varied considerably. For instance, the stair and escalator shafts can be constructed in cut-and-cover and can be located for a side platform arrangement, and the mezzanine can be mined to reduce traffic and utility interference.

Further Advantages of the New Techniques. Apart from permitting the construction of the running tunnels in economically long lengths, the three station concepts illustrated in Figures 8-2, 8-3, and 8-4 permit the size of the mezzanine to be reduced to the width required for its function rather than the width set by the trainway, as in present-day cut-and-cover construction.

The concept illustrated in Figure 8-2 reduces the surface and utility disruption to an extent proportional to the street excavation eliminated.

The concept of Figure 8-3 limits surface and utility disruption to that occasioned by installing the two slurry concrete walls. In addition, as the street surface does not have to be opened up over the plan of the station, the mezzanine need only be as long as required for its function.

The concept of Figure 8-4 provides the potential for reducing the street and utility disruption even further, particularly if the mezzanine is being mined or tunneled.

The concepts of Figure 8-3 and 8-4 both lend themselves to planning arrangements that remove the mezzanines from the streets altogether and place them at the surface within the property lines. The underground station work is limited to the station platforms and their accesses.

The actual underground construction, particularly when mined, is considerably more costly and time-consuming than construction undertaken in the open. However, as noted previously, these costs are offset by the savings due to: the practical elimination of time and cost peripheral items (such as utilities and street traffic) on the installation of the cut-and-cover construction; the decreased volume of structure; and the reduced environmental impacts.

In addition to the reduction of tunneling costs that can accrue from the improvements suggested in "Improvements in Tunneling Technology," there can be cost reductions that stem from the use of more economical lengths. Moreover, in addition to the incentive for contractors to introduce more efficient mechanization of excavation and muck handling, there are many incentives for the development of more innovative approaches for tunnel design and construction. Three such developments will now be examined: continuous tunneling, the helical segmented lining, and the slip-form concrete system.

Continuous Tunneling

The System Work Flow 3 diagram (page 3-45), discussed previously, indicates all the basic tunneling operations that are being performed continuously and simultaneously, including the placing of the lining and the performing of the excavation. Current tunneling machines and muck-handling equipment have that capability, and any shortcomings in reliability can certainly be remedied. The tunnel lining is presently the bottleneck to a continuous tunneling operation, and the two systems of helical segments and slip-form cast-in-place concrete (described in "Improvements in Existing Tunnel Technology") appear to offer possibilities of providing a solution.

Helical Segmented Lining. The normal "straight" segmented lining is composed of rings with the circle faces normal to the longitudinal axis of the tunnel. The segments constituting the ring cannot be placed until the tunneling machine has advanced the width of the segment (or ring), which is normally 30" to 36". Unless the shoving jacks and the shield tail are long enough to permit the machine to advance continuously during the erection of all the ring segments, the machine must be stopped during the ring-building period. In most cases, the jacks and the shield tail cannot be made long enough (and hence the machine must be stopped), since jack design, jack maintenance, and construction problems increase proportionally with increase of jack and shield tail length.

In an approach to continuous tunneling machine advance that increases the jack and shield tail length only slightly, the segments in the ring are arranged in the form of a helix, the lead of the helix being the width of a segment. The advance of the machine (for each segment erected), therefore, is the segment width divided by the number of segments in a ring. For example, for a ring composed of four segments and a segment width of 30", the advance for one segment is 7-1/2".

There are two systems of helical segments:

In the first system (see Figure 8-5, Type 1), the circle faces are normal to the line of the tunnel, and the radial faces are normal to the lead of the helix. The advance of the ring is obtained by stepping the adjacent segments. This system was used in the construction of some parts of the Munich, Germany, Rapid Transit System.

In the second system (see Figure 8-5, Type 2), the circle faces are inclined (to the degree of the helix) to the line of the tunnel, and the radial faces are normal to them. The circle faces are flush, one with another, but the rate of advance for each segment is the same as in the first system.

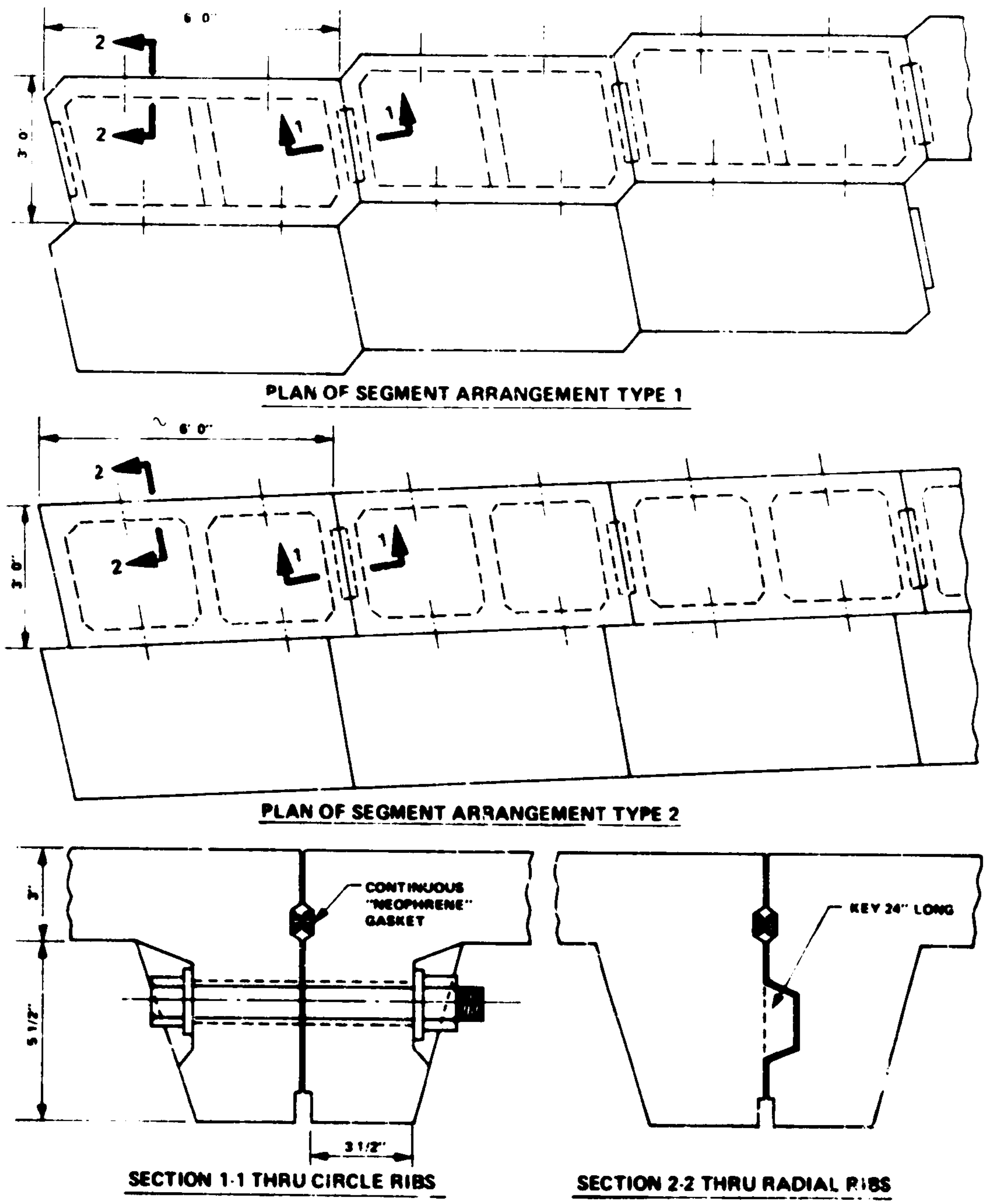
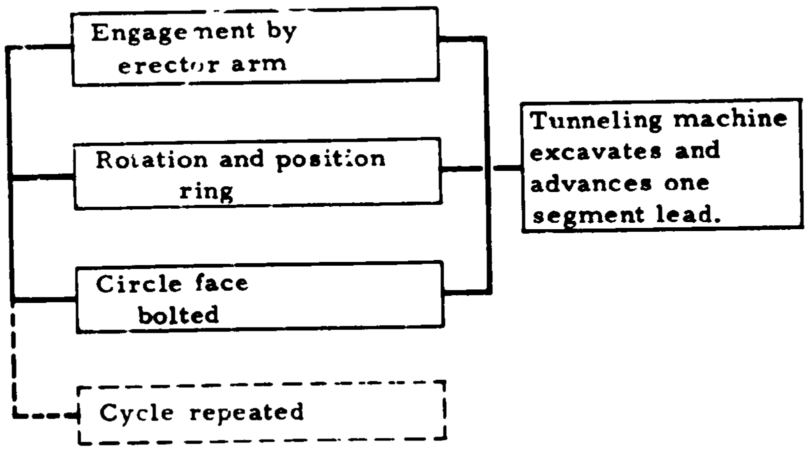


Figure 8-5. Helical Segmented Tunnel Lining

The faying faces and bolt details are the same for both systems. From Figure 8-5, the following can be seen: continuous gaskets are provided in rebates in each segment; the design is such that the compressibility pressure of the gaskets exceeds the external groundwater pressure; a caulking groove in the segment toes serves as a backup water-sealing system; and the radial faces are keyed to each other (not bolted), but the circumferential joints are bolted one to another.

For a continuous-construction operation, the segments should not be so long that their placing requires the retraction of two or three shield shove jacks. This results in 8 to 10 segments in a ring. The cycle for segment erection is as follows:



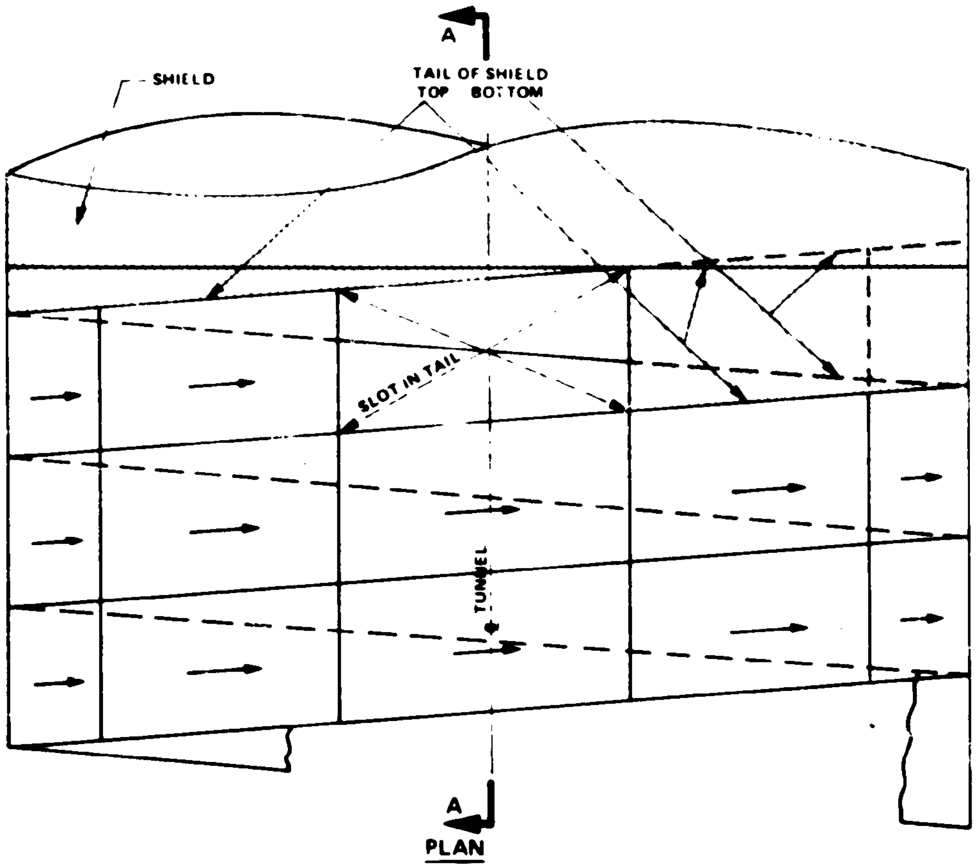
The system has the possibility of becoming automatic to a large degree. If it did, the following processes would be included:

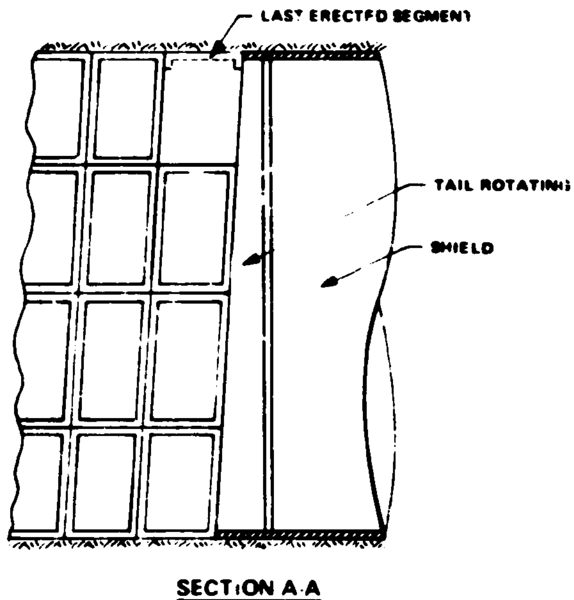
- Each straight and tapered segment would be coded in accordance with the geometry of the tunnel.
- According to the coding, the segments would be conveyed continuously to the tunnel heading.
- Tunneling machine advance, shove jack retraction at the position of the segment being erected, and pickup and placement of the segment by the erector arm would be synchronized and automated.

- The steering of the tunneling machine would be programmed and automated.
- Grout would be injected continuously into the tail space, concurrently with the advance of the tunneling machine, with continuous grout mixing and continuous operation of the delivery equipment.
- Bolting of the circle joints might be accomplished by the development of a "press stud" fastener principle. Alternatively, bolts could be placed manually by personnel who might be required in the heading for monitoring purposes anyway.

As discussed in this section and elsewhere in the report, grouting the tail space when the shield advances is a somewhat difficult and expensive, but necessary task. In homogeneous ground with good stand-up properties, the shield can cut a neat, clean circle, which makes it possible to dispense with the tail of the shield and erect the lining directly against the ground. This was done frequently in the tunnel construction of the London Transport System whenever the blue clay (which is predominant in the area) was encountered. Because the clay is free from water, it is possible to use nonbolted, expandable segmented linings in cast iron or in precast concrete. The expansion of the linings is performed with jacks inserted in slots in the lagging at the spring lines and produces a tight interface between the lining and the soil.

The development of a helical lining system offers an intriguing possibility of placing the segments directly against the ground, with the use of the rotating tail unit depicted in Figure 8-6. The tail piece would support the ground around the perimeter of the erected lining, except for the area in which the next segment would be placed. Here the ground would be exposed to an area which, in a 10-segment ring, would be about 6 ft x 3 ft. After the segment has been placed, the tail would rotate and the succeeding segment placed. The fact that only a relatively small area of ground would be exposed at any time makes good homogeneous ground less of a requirement.





SECTION A-A

Figure 8-6. Helical Segmented Tunnel Lining Erection of Segments Directly Against Excavation

Slip-Form Concrete Lining. Theoretically, for the continuous tunneling process, there is no better lining system than slip-formed, cast-in-place concrete. For some time, tunnel designers, contractors, and research engineers have expressed a great deal of interest in this system, and it appears that some of the major problems preventing its application may be solved in the near future.

The two initial requirements of lining a tunnel in ground are:

- Support of the shield shove jack reactions
- Almost immediate support of the ground as soon as it is excavated

In the slip-forming of concrete structures such as bins and silos, the rate of travel of the form is relatively slow (about 1 ft per hour), and the reactions on the placed concrete are low because the forms react on steel rods incorporated within the concrete. As a result, normal time-set portland cement is satisfactory in these applications.

For a tunnel, however, the progress can be as great as 10 ft per hour, the reactions of the tunneling machine may be on the order of 120 kips per foot of circumference (which for an 8" thick lining is about 1250 psi), and the lining must support the ground pressure shortly after being placed. Thus, any slip-form system for tunnel linings requires a concrete of high early strength, which is the factor that determines the length of the slip form.

The four basic elements of slip-form tunneling equipment are indicated in Figure 8-7. These are:

- A steel cylinder or slip-form (whose outside diameter is equal to the tunnel inside diameter) fixed to the shield

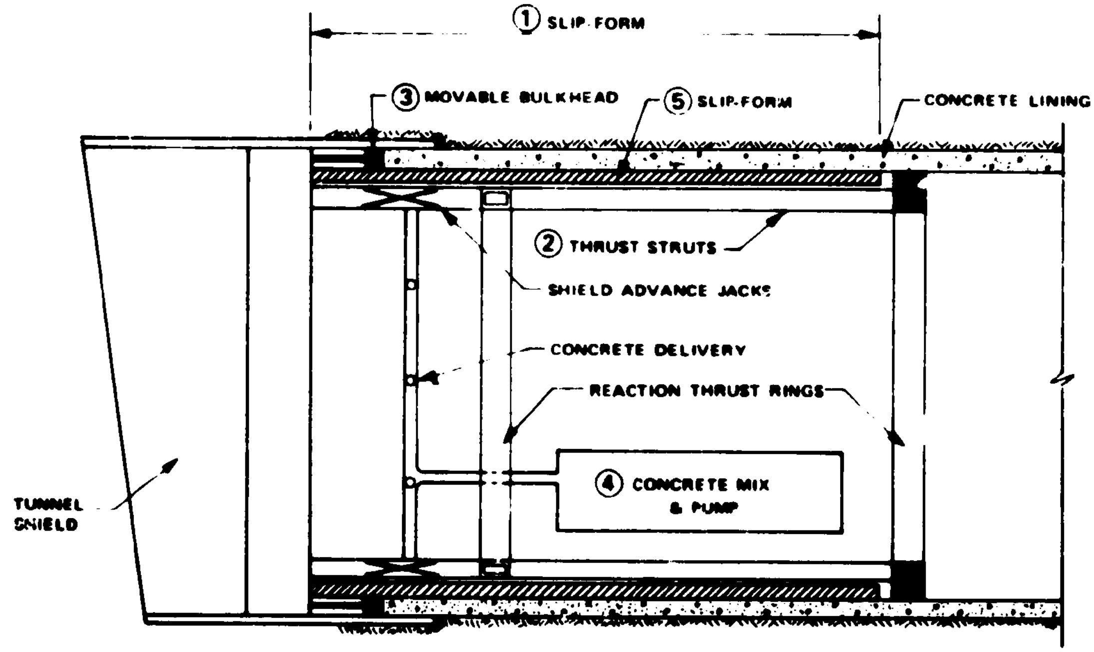


Figure 8-[illegible]. Slip-Form Concrete Tunneling Concept

- Two thrust reaction rings and struts. The rear ring, which grips the set concrete behind the slip-form, is released periodically when the shield jacks reach the end of the slip-form. The front ring stabilizes the struts to the reactions of the shoring jacks.
- The movable bulkhead between the shield tail and the slip-form. This provides additional control of the pressure of the concrete as it is being placed ahead of the bulkhead.
- The concrete mixing and the delivery equipment from which the concrete is placed at several points through the slip-forms

Several portland cement companies have Regulated-Set cement under development, and at least one company manufactures it commercially. Typical concrete strengths attainable appear to be 1000 psi after 1 hour, with a slower rate of increase of strength thereafter. Literature from the Research and Development Laboratories, Portland Cement Association, Skokie, Illinois, describes the characteristics of this cement, and it appears that a concrete could be produced from this cement with the desired high early strength properties that would allow a slip-form length of about 25 to 30 ft — a practical length.

In the Portland Cement Association paper, mention is made of steam curing in conjunction with Regulated-Set cement. This process no doubt would speed the rate of increase of strength and consequently shorten the slip-form.

Placing reinforcement in a slip-form tunnel system would be difficult owing to the congested space at the head of the slip-form and the desirability of making the tunnel process as continuous as possible. The question arises: Does a tunnel constructed by the methods suggested above require reinforcement for structural purposes at all? If modern machine-driving techniques are used, if the concrete is placed directly against the ground, and if the ground is reasonably good, movements after the concrete sets up are likely to be slight. Radial planes of the linings would be under compression, and any cracks developing in the circumferential direction would tend to be small. Cracks in the longitudinal direction would develop, and although they would have little effect on the structural performance of the lining, they could be troublesome in water-bearing ground. A gunited internal skin, applied after the completion of the lining, would prevent leakage.

A second course of action would be to incorporate short steel fibers in the concrete mix, which, according to current research, provides the concrete with considerable tensile strength. Although this would distribute cracks, it is doubtful whether they would be eliminated altogether, and internal waterproofing skin might still be required.

Pressurized Slurry-Face Tunneling Machine

The need for such machines is the result of: (1) the high cost of labor or productivity resulting from the limitation of working hours in compressed air, which is imposed by most compressed air regulations (see Figures 3-10 and 3-11); and (2) the fact that some ground and tunnel situations make the use of compressed air working unsafe or impractical. An example of the latter situation is tunneling in very soft, water-breaking silts or muds, which are difficult to stabilize by chemical or other means. The pressure of the ground and water across the shield face will vary more or less hydrostatically in the vertical direction, while the pressure of the air will be constant. If the air pressure is made equal to the ground pressure at the bottom, the air will escape at the top and can cause a blowout and a subsequent collapse; if the air pressure is made equal to the ground pressure at the top, the ground and water may not be controlled at the bottom, with the same dire results.

A pressurized slurry-face tunneling machine is illustrated in Figure 8-8. This machine permits the tunneling of bad ground in free air and consists of:

- A watertight bulkhead behind the rotating cutter head
- A slurry pipe for the muck removal and a return pipe for slurry makeup
- Shield tail seals to permit the slurry and the groundwater to flow into the tunnel (which is in free air) from the space between the shield tail and the tunnel lining

Two countries, Japan and England, have slurry-face tunneling machines under active development. The Japanese tunneling machine, illustrated in Figure 8-8, is presently owned and manufactured by the Mitsubishi Company. A detailed description of its principles of operation is given in the Appendix. During the course of a number of projects in which this machine was used, some major problems were encountered and solved. It appears that further development work is required to improve its reliability, particularly with respect to the seals, bearings, and slurry system. This is not brought out fully in the paper in the Appendix.

The English pressurized slurry-face tunneling machine — called "the bentonite shield" — is similar in operating principle to the Japanese machine. Most of the development costs of about $1,000,000 were underwritten by the National Research and Development Corporation — a British Government Agency. The ground in which the machine was tested — water-bearing gravel, grading from 10" cobbles to fine sands — presented a different, and in some respects more difficult, set of conditions than did the silts and sands encountered by the Japanese machines, and in this type of ground, the English system seems to solve most of the major problems of tunneling. At the present time, it is ready for more extensive testing in differing ground conditions. A description of the machine and muck-handling system is given in the Appendix.

In summary, both the Japanese and English systems give considerable promise of providing alternatives to compressed air working and solutions for tunneling in heretofore impossible situations.

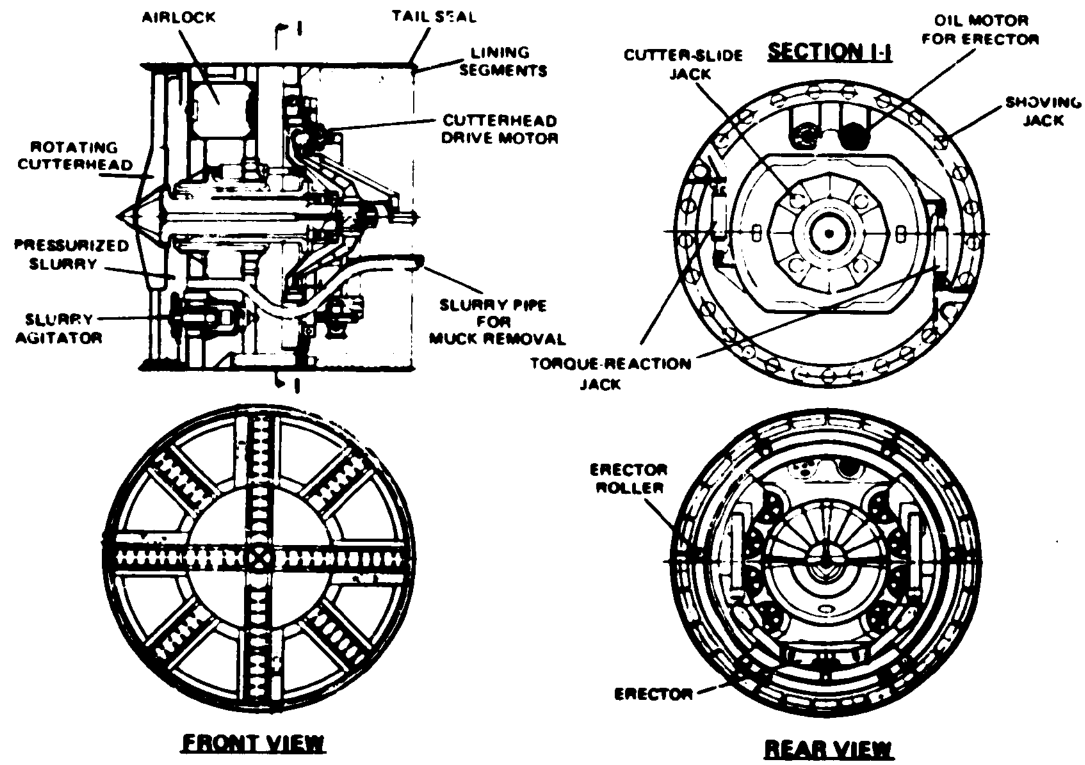


Figure 8-8. Tunneling Machine with Pressurized Slurry-Face

Section 9

CONCLUSIONS AND RECOMMENDATIONS

Many conclusions can be drawn from a review of the many subjects in the preceding sections. In this section, however, the discussion is limited to major conclusions only, in order not to confuse, but to highlight, the major aspects of the report. In line with the conclusions, recommendations for further research and development are presented.

CONCLUSIONS

System Modeling

By the process of separating several projects of rapid transit underground structures into their principal construction components (or work events) and pricing the components, it has been possible to determine the relative importance of these components within the projects. From the analysis of the project contract data and other related material, the various factors that affect the costs of the components were identified and evaluated. This resulted in a determination of component sensitivity factors with acceptable degrees of accuracy.

The sensitivity factors were further developed and refined from an in-depth study of rapid transit technology, contractual procedures, and environmental effects. Structural models were synthesized for use with sensitivities.

These systems models are for typical underground transit structures in average downtown situations. The models were formulated so they could be used with a minimum of specifications relative to technical design, site, characteristics, and institutional arrangements.

With respect to the different types of transit structures, the models can be used for:

- Determining project cost sensitivity to any or all of the site physical controls and the institutional controls
- Demonstrating the inefficient areas of current approaches to the design and construction
- Evaluating the effects on project time and cost of changed technology and contractual approaches

It is expected that such application will provide a much better understanding of the many variable factors which influence the cost/time framework of rapid transit construction.

Contracts

The inherent complexity of underground transit construction requires that a continuing effort be made to improve the contractual interface between the owner-engineer and the contractor. The need for construction-oriented engineering design and other contract documents is self-evident; there is also a need for improved informational sources to contractors interested in bidding on the work.

Both these needs might be served by a panel of contractor or construction consultants who would (1) function in an advisory and informational capacity to the engineer; (2) solicit technical and contractual suggestions from; and (3) generally act as a sounding board for interested contractors.

One shortcoming in the present contractual system relates to inadequate definition of work items, such as utilities, traffic conditions, and underpinning requirements. Here, members of the panel might participate in the engineering planning meetings with the municipal authorities and the utility and building owners, and in this way, an expression of contractor's opinions could be obtained.

The establishment of continuing communication between the panel and major construction contractors in the states would be a source of valuable input to the engineering design and contract documents. In return, the contractors would gain early information concerning the probable scope and contract requirements of the projects on which they might be interested in bidding. This would allow a more orderly planning of the contractors' resources, and hence an improved bidding climate. Procedures would have to be established to allow this information to be openly disseminated. This would preclude certain contractors from gaining an unfair advantage over others.

Technical Considerations

A review of the interrelationships between planning design and construction indicated some areas which have an overriding effect on the cost/time framework of the transit system as a whole.

The principal area of concern is the present cut-and-cover station concept. Inordinate construction costs and schedule restraints result from constructing this type of station in heavily trafficked streets and in the generally dense complex of utilities encountered therein. The cut-and-cover station also impacts upon the cost of the adjacent tunneled line projects. The stations, which are normally less than 1 mile appart in the central business district, create physical barriers to tunneling the line structures in economic lengths, and this in turn stifles more innovative approaches by the tunneling contractor.

Several modified station planning approaches and construction techniques can be used to permit tunneling through the stations and to reduce, or virtually eliminate, street disruptions. Such modifications include reducing the mezzanine areas, divorcing the mezzanine from the station, and incorporating slurry wall design with partial or fully mined construction techniques. An examination of existing tunneling technology indicates that substantial potential economic benefits can accrue from increased mechanization of the tunneling process. This would be generated from longer tunnel projects, improved tunnel lining design, and the development of continuous lining and tunneling systems.

<u>Environment</u>

Environmental conditions within the construction site and safety and insurance programs are two factors that can have a considerable effect on construction economics and that are likely to assume more importance in the future. With respect to unifying and monitoring safety programs, system-wide insurance coverage has definite advantages, and it can also provide economic benefits to the owner.

Although accident and injury reporting forms give some useful information, they should be expanded to provide comprehensive data as to the cause of the accident/injury and the type of work that resulted in the accident/injury. This would allow statistical evaluation which would indicate the necessary corrective procedures in work approaches and organization and the type of worker training needed to reduce the accident/injury incidence. The degree to which productivity is affected by accidents and worker/injuries could therefore be established. Both owner and contractor would share in improved safety-oriented construction.

RECOMMENDATIONS FOR RESEARCH AND DEVELOPMENT

Improved technology can be readily attained by applying already developed and tested construction techniques or materials. New technology requires research and development to demonstrate effectiveness and worth. The subjects listed below suggested for further study or for research and development are derived, in general, from a review of the analyses of the study projects.

Optimizing Rapid Transit Station Design

It will be noted in Tables 6-8 and 6-9 that the study project stations cost about $21,000 per system foot (1974 costs). Part of the stations' costs can be attributed to the large mezzanine booking halls, which are apparently much in excess of passenger requirements.

The mezzanine could be constructed, either in cut-and-cover or in tunnel, to the optimum size for predicted passenger loads by tunneling the trackway through the stations and "breaking out" to the platforms. Alternatively, the platforms could be constructed by enlarging the trackway tunnels. Study programs could establish the optimum mezzanine sizes for: various passenger loads; the economic benefits from the lessened surface traffic dislocation, utility disturbance, and street reconstruction during construction; the effect on the cost of the actual station structure; and the effect of reduced operating and maintenance costs of the station.

In addition, the scope of such investigations should include concepts which remove mezzanine/booking halls from the street to within private rights-of-way. This is primarily an economic determination which trades construction costs for right-of-way, with a possible additional cost offsetting factor in the commercial value of air rights. The effect on construction, operation, and maintenance costs of the station with a "no fare" system (i.e., one with no mezzanine, in which passengers enter and exit directly, sidewalk to platform) should also be included.

Lining Systems for Optimizing the Tunneling Process

As indicated in Tables 6-13 and 6-14 (BART tunnels), the cost of tunnel liners is about 15 percent of tunnel construction cost. The liner erection is a substantial percentage of tunnel construction, a major work event, as indicated in Table 8-1. The two lining systems that appear to offer attractive possibilities in reducing both these cost items are discussed below.

Helical Tunnel Lining Systems. The advantages of such systems are:

- The elimination of the key and the special segment necessary in "straight" ring systems. That is, only one segment type need be produced (plus modification for tapers)
- The possibility of continuous lining erection and tunnel excavation

A research program is needed to determine the required design and field testing of such systems. The scope of the program would include the bolting or other fastening needed for the segments and the requirements for manufacture and testing of segment joint water barriers. Such barriers could be a substitute for caulking against water seepage.

Slip-Form Concrete Tunnel Lining Systems. The development of such systems enhances the possibility of performing continuous tunneling, thus reducing the manual labor content in present-day tunnel construction. The research program would not only include development and laboratory testing, but also the associated tunneling and concrete placing component. In this respect, it should be noted that a program of research on concrete mixes appropriate to the application of slip-form tunnel lining is already being conducted by the University of Illinois for the Federal Railroad Administration.

Tunneling Machine with Pressurized Slurry Face

With the current emphasis being placed on more and deeper tunnels for rapid transit, methods that avoid the use of compressed air for construction in bad ground have assumed great importance. Compressed air working, even at moderate pressures, substantially increases the costs of tunneling. Reference to the generalized model sensitivity (Tables 7-5 and 7-6) indicates that compressed air tunnels (in about 14 psi pressure) cost $5,809.00 LF or about 27 percent above those constructed in free air ($4,588.00 LF). Tunnel machines with pressurized slurry faces present a promising alternative to compressed air working, and both England and Japan appear to have demonstrated the feasibility of such machines. A research program could be set up to report on the state of the art in both these countries and recommend the course of action needed to develop the machine for use in the United States.

Geology/Soils Information Bank

The importance of subsurface information relative to rapid transit underground construction is widely recognized. In the BART system, substantial time and effort were spent in gathering historical soils data, much of which were incomplete. The effort needed would have been considerably less if a soils information bank had been in existence. In most cities where a rapid transit system is being considered, there is a wealth of geological/soils information that has been generated by private construction interests. This information, however, may not be readily available to the builders of rapid transit systems and other public works. A geology/soils information bank, containing records of all soils investigations in a metropolitan area and available to the public, would save everyone time and money.

Environmental Impacts of Underground Construction

Detailed investigation of environmental impacts and costs were outside the scope of this study. However, a great deal of data are needed as additional input for the evaluation of construction alternatives in conjunction with the use of the model. Also, research needs to be done in assessing impacts of the surface/underground construction interface, with particular reference to traffic dislocation and business disruption.

Both these items are interdependent; they are generally rather localized; and they are both short- and long-term factors that are difficult to quantify with believable accuracy.

It would appear that a statistical method would be the most promising approach for any research program to be undertaken on the subject. As a guideline to such an effort, the following is suggested:

- Historical data would be gathered from systems (or parts of systems) recently implemented or currently under construction. Such systems might include those in San Francisco*, Washington, D.C., New York, Chicago, and Toronto.
- In conjuction with the gathering of historical data, a program would be established to monitor systems yet to be constructed. Such systems might include Atlanta and Baltimore, as well as Washington, D.C., New York, and Chicago.

The data gathered should be oriented toward both cut-and-cover and tunnel construction and should include information on:

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* A current impact study, "The BART Impact Study," is a comprehensive assessment of the impacts of the San Francisco Bay Area Rapid Transit System. The study is being conducted by the Metropolitan Transportation Commission with participation of the U.S. Department of Transportation, the U.S. Department of Housing and Urban Development, and the California Department of Transportation.

- The number and type of vehicles delayed by the construction, and the duration and frequency of the delays
- The elimination of vehicular trips
- The effect of rerouting traffic on contiguous streets
- The number and types of businesses affected by the construction
- The degree to which construction affects each type of business, i.e., reduction in profits, loss of productivity, etc.
- The number of businesses that have relocated (or have ceased to operate) during construction
- The effect on businesses and traffic after construction is completed

Quantification of these data might permit a "total cost to the public" to be approximated during and after construction. Such costs would be set against construction costs established by the models for the evaluation of alternative construction methods.

Improved Accident Reporting

Investigation of accident and injury reports from the BART and WMATA study projects revealed that in some cases the information requested on the forms was omitted. Consequently, realistic evaluation of accident/injury aspects of the projects was not possible.

Injury reporting should have a high priority in any safety program. The information needed should be systematized to include all of the following:

- Type of accident
- Number of accidents
- Types of injuries
- Number of injuries
- Cause of accidents/injuries
- Type of work being performed when injury accident occurred

- Location on job site of accident/injury
- Severity rates
- Frequency rates
- Length of occupational experience and age of employee
- Lost time injury reporting
- Compliance or lack of compliance with safety regulations at time of accident
- Type of training program given to employee, by whom, (union, etc.)
- Follow-up safety supervisor/meetings, subsequent to job accident/injury (i.e., action taken to prevent similar accidents from occurring)
- Some indication of fault by safety supervisor (or by insurance company on insurance forms)

These data can then be interpreted by the contractor and the owner-engineer to show various weaknesses in the safety program, relationships of occupational injuries to productivity, and other vital conclusions such as:

- The phases of tunnel construction most hazardous to employees
- Relationship of occupational experience and age to severity and frequency rates
- Relation of type of accident to type of injury
- Number of lost time injuries relative to type of accident/injuries
- Frequency of minor accidents (little or no lost time) due to job carelessness
- Total decreases in productivity due to occupational injuries/accidents
- The group of employees that needs special attention from the safety supervisor (young, inexperienced employees, general laborer vs. skilled workers, etc.)

- The need for the contractor to take extra precautions in problem areas such as maintaining equipment, supervising clean-up crews, enforcing rules regarding wearing of safety goggles, gloves, and other safety gear, etc.
- An evaluation of the strengths and weaknesses of job training by unions, etc., prior to hire by contractor

APPENDIXES
A THROUGH F

CONTENTS

Appendix A

COST INFORMATION

D A I L Y   C O N S T R U C T I O N   S E R V I C E

TUNNEL CONSTRUCTION — PAGE 1

12-6-66(BARTD-12TH ST.OAKLAND STA.,BROADWAY TNLS.CONTR.#1K0016)

SAN FRANCISCO,CALIF.(UNIT AND TOTAL BIDS RECEIVED,TAKEN UNDER ADVISEMENT)

PERINI CORP.,MORRISON-KNUDSEN CO,INC(JV)255 CALIFORNIA ST.,S.F.,$19,428,625(OPTION II) LOW TO S.F.BAY AREA RAPID TRANSIT DIST.,814 MISSION ST.,S.F.,FOR CONST.THE 12TH ST. OAKLAND STA.&BROADWAY TUNNELS ON THE DIST'S OAKLAND DOWNTOWN LINE IN THE CITY OF OAKLAND, CONTR.#1K0016.

	OPTION 1	OPTION 2
(1)PERINI CORP.,MORRISON-KNUDSEN CO.,INC.(JV) S.F. - LOW	-	$19,428,625
(2)WINSTON BROS.,FRED J.EARLY,JR.CO.,INC.,DONALD M.DRAKE CO., S & M.KEMPER CONST.CO. (JV) SAN FRANCISCO	-	$20,227,092
(3)ROTHSCHILD, RAFFIN & WEIRICK,INC., PIOMBO CONST.CO. & P&Z CO.,INC.(JV), SAN FRANCISCO	-	$21,353,700
ENGINEER'S ESTIMATE	$19,389,930	$18,972,855

	(1)	(2)	(3)
L.S.,TRAFFIC CONTROL & MAINT.	$200,000	$145,000	$220,000
PER LFT. ADD UNDERPINNING PILES	55.00	55.00	55.00
PER LFT. DEDUCT UNDERPINNING PILES	30.00	30.00	30.00
PER CU.FT. ADD CONC.PIER UNDERPINNING	6.00	6.00	6.00
PER CU.FT. DEDUCT CONC.PIER UNDERPINNING	4.00	4.00	4.00
OPTION 2			
L.S. MOBILIZ.&PREPARATORY WORK	$970,000	$970,000	$970,000
1 PARCEL UNDERPIN &SUPPORT CAT.A 0-K348	$85,000	$126,000	$180,000
135,200 CY.SUBWAY STA.CUT-&-COVER EXCAV.&FULL SUPPORT EXC.	35.00	39.50	27.00
10,080 CY. CL.4000 CONC.WALL,SUBWAY STA.	80.00	83.50	120.00
11,400 CY. CL.4000 CONC.SLABS ON GRADE,SUBWY.STA.	40.00	43.00	35.00
23,725 CY. CUT-&-CVR.SUBWAY STA.BKFL.	8.40	10.40	7.00
5,620,000 LB.BAR REINF.STL.,SUBWAY STA.	.13	.12	.12
TOTAL OPTION 2	$7,979,290	$8,648,020	$7,249,475
1 PARCEL UNDERPINNING &SUPPORT.CAT.A 0-K053	$15,000	$10,100	$17,000
1 PARCEL UNDERPINNING &SUPPORT.CAT.A 0-K054	$18,800	$15,000	$20,000
1 PARCEL UNDERPINNING &SUPPORT.CAT.A 0-K055	$15,500	$11,500	$19,000
1 PARCEL UNDERPINNING &SUPPORT.CAT.A 0-K056	$6,000	$4,900	$7,000
1 PARCEL UNDERPINNING &SUPPORT.CAT.A 0-K057	$7,300	$8,400	$10,000
1 PARCEL UNDERPINNING &SUPPORT.CAT.A 0-K060	$16,800	$6,400	$20,000
1 PARCEL UNDERPINNING &SUPPORT.CAT.A 0-K339	$14,700	$6,800	$20,000
1 PARCEL UNDERPINNING &SUPPORT.CAT.A 0-K340	$5,100	$6,400	$7,000
1 PARCEL UNDERPINNING &SUPPORT.CAT.A 0-K342	$74,000	$82,000	$130,000
1 PARCEL UNDERPINNING &SUPPORT.CAT.A 0-K349	$24,500	$33,500	$40,000
1 PARCEL UNDERPINNING &SUPPORT.CAT.A 0-K352	$4,500	$4,500	$7,000
1 PARCEL UNDERPINNING &SUPPORT.CAT.A 0-K363	$15,500	$17,900	$20,000
1 PARCEL UNDERPINNING &SUPPORT.CAT.A 0-K411	$17,300	$23,000	$35,000
1 PARCEL UNDERPINNING CATEGORY B 0-K050	$5,200	$5,200	$5,200
1 PARCEL SUPPORT CATEGORY B 0-K050	$5,700	$3,400	$6,000
1 PARCEL UNDERPINNING CATEGORY B 0-K326	$2,500	$2,500	$2,500
1 PARCEL SUPPORT CATEGORY B 0-K326	$4,200	$1,800	$7,000
1 PARCEL UNDERPINNING CATEGORY B 0-K361	$64,000	$64,000	$64,000
1 PARCEL SUPPORT CATEGORY B 0-K361	$11,900	$1,600	$35,000
1 PARCEL UNDERPINNING CATEGORY B 0-K362	$83,000	$83,000	$83,000
1 PARCEL SUPPORT CATEGORY B 0-K362	$21,000	$3,900	$50,000
1 PARCEL UNDERPINNING CATEGORY B 0-K382	$65,000	$65,000	$65,000
1 PARCEL SUPPORTING CATEGORY B 0-K382	$18,000	$2,700	$40,000
1 PARCEL UNDERPINNING CATEGORY B 0-K383	$22,000	$22,000	$22,000
1 PARCEL SUPPORTING CATEGORY B 0-K[illegible]	$14,700	$1,400	$30,000
1 PARCEL UNDERPINNING CATEGORY B 0-K[illegible]	$3,400	$3,400	$3,400
1 PARCEL SUPPORTING CATEGORY B 0-K[illegible]	$2,800	$1,100	$5,000
1 PARCEL UNDERPINNING CATEGORY B 0-K397	$31,000	$31,000	$31,000
1 PARCEL SUPPORTING CATEGORY B 0-K397	$46,400	$4,100	$40,000
L.S.SUPPORT ALL CATEGORY C PARCELS	$35,000	$21,900	$2,000
120 PAIR STRAIN GAUGES	[illegible]	780.00	700.00
2,100 LFT.OBSERVATION WELLS, INSTLN.TY.I	8.30	6.80	7.00

-CONTINUED ON NEXT PAGE-

TUNNEL CONSTRUCTION Page 2

12-6-66 (SAN FRANCISCO, CALIF-BARTD-12TH ST. OAKLAND STA, BROADWAY TNLS, #1K0016) CONT'D.

	(1)	(2)	(3)
2,800 LFT. OBERV. WELLS INSTALLN., TY. II	9.90	6.10	7.00
1,410 LFT. INCLINOMETER CASINGS	10.50	7.00	5.00
50 EA. MAINTAIN. OBSERVATION WELLS	490.00	255.00	100.00
50 EA. REMOVE OBSERVATION WELLS	67.00	510.00	200.00
16,000 CY. SUBWAY LINE CUT&CVR. EXCAV.	37.00	27.20	40.00
4,500 CY. CUT&CVR. SUBWAY LINE BACKFILL	8.40	5.80	[illegible]
11,300 SY STREET DECK., SUBWAY STA.	40.00	54.70	100.00
1,000 SY STREET DECK., SUBWAY LINE	40.00	63.00	100.00
7,910 CY. CL. 4000 CONC, SUPPTS. SLABS&BMS, SUBWAY STA	130.00	119.00	100.00
1,500 CY. SAME, PLATFORMS&PLATFORM SUPPTS, SAME	215.00	122.00	100.00
2,000 CY. "2500" CONC, UPR. TRACKWAY. INVERT, SAME	60.00	58.00	35.00
300 CY. "4000" CONC. STAIRS, ETC, SAME	175.00	173.00	140.00
700 CY. "2000" CONC. LEVEL. SLABS&FILL, SAME	70.00	76.00	75.00
230 CY. "4000" NONSHRINK CONCRETE, SAME	90.00	64.00	110.00
1,000 CY. SAME, CONC. SLABS ON GRADE, SUBWAY LINE	30.00	40.00	50.00
1,600 CY. SAME, SUPPTD. SLABS, SUBWAY LINE	56.00	66.00	35.00
1,800 CY. SAME, WALLS, SUBWAY LINE	66.00	99.00	70.00
100 CY. "2000" CONC. LEVEL. SLABS&FILL, SAME	90.00	79.00	75.00
160 CY. SAME, WALKWAY, SUBWAY LINE	100.00	131.00	100.00
6,700 SF "3000" LGTWGT. CONC, PRECAST SLABS, SUBWY. STA	3.50	7.80	4.00
3,260 LFT. 16'6" SUBWAY TUNNEL	$1,200	$1,356	$1,016
PER LFT. 16'6" SUBWAY TNL. ADD FOR COMPRSD. AIR, 1-18 PSIG	150.00	150.00	150.00
PER LFT. SAME, ADD FOR COMPRESSED AIR, OVR. 18 PSIG	250.00	250.00	250.00
L.S., CROSS PASSAGE No. 2	$23,000	$31,000	$40,000
750,000 LB. BAR REINF. STEEL, SUBWAY LINE	.13	.12	.12
19,300 LFT. WATERSTOPS	3.00	3.40	3.00
8,500 SY WATERPROOFING	6.50	6.00	7.00
3,788,000 LB. STRUC. STEEL, A36	.30	.283	.33
800,000 LB. STRUC. STEEL, A441	.30	.375	.33
31,000 LB. STRUC. STEEL, A242	.35	.303	.33
108,000 LB. MISC. STL. &IRON, ZINC COATED	1.00	.88	1.00
80,000 LB. MISC. STL. &IRON, NONZINC COATED	1.00	.75	.70
30,000 EA. WELD. STUDS FOR ROOF BMS., SUBWAY STA.	.75	1.83	1.00
11,000 SY WELDED WIRE FABRIC, 6"x6" #10x10	1.25	.50	1.00
22 EA. STEEL DOOR, TYPE A	450.00	599.00	400.00
2 EA. STEEL DOOR, TYPE B	850.00	960.00	450.00
383 CY. CL. 3000 CONC. CURBS&GUTTERS	50.00	32.00	32.00
425 CY. SAME, SIDEWALKS & DRIVEWAYS	60.00	30.00	32.00
3,800 SY ADDL. COST-SDWKS. &DRVWYS. IN SPCL. DIST.	11.00	6.10	6.50
1,767 CY. AGGR. SUBBASE, CL. 2	9.00	8.00	8.00
3,658 T CL. B AGGR. FOR CEM. TRTD. BASE	6.00	7.00	5.00
876 BBL. P.C. FOR CEM. TRTD. BASE	6.00	5.50	5.00
7 T LIQ. ASPH. CURING SEAL	75.00	60.00	110.00
4 T ASPHAL. EMULSION PAINT BINDER	75.00	60.00	110.00
1,830 T AGGR. FOR TY. B, ASPH. CONCRETE	12.00	9.50	9.50
128 T PAV. ASPH. FOR ASPH. CONCRETE	12.00	9.50	10.00
L.S., PAINTING	$12,500	$11,798	$10,000
112 CY. CL. 3000 CONC., MINOR STRUCS.	*$17,920	*$16,576	*$44,800
29 CY. CL. 3600 CONC., STRUCTURES	225.00	149.00	400.00
L.S., SUPPT&MAINT. CITY OF OAKLAND ELEC. FACILS.	$52,000	$95,000	$28,000
L.S., SAME, EXIST. PG&E, GAS FACILITIES	$13,000	$6,000	$12,000
L.S., SAME, EIXST. PG&E STEAM FACILITIES	$8,200	$14,000	$25,000
L.S., SAME, EXIST. PG&E ELEC. FACILITIES	$120,000	$60,000	$435,000
L.S., SAME, EXIST. PG&T TELEPH. FACILITIES	$30,000	$20,000	$160,000
L.S., SAME, EXIST. EBMUD WATER FACILITIES	$13,600	$10,000	$85,000
L.S., SAME, RELOC. CITY OF OAKLAND FACILS, 11, ETC.	1.00	$2,000	$50,000
L.S., SAME, PG&E GAS FACILS. 11TH, 12TH, 13TH&14TH STS.	1.00	$11,000	$14,000

* — SUBTOTAL

-CONTINUED ON NEXT PAGE-

TUNNEL CONSTRUCTION

12-6-66 (SAN FRANCISCO, CALIF-BARTD-12TH ST. OAKLAND STA, BROADWAY TNLS, #1K0016) CONT'D.

	(1)	(2)	(3)
L.S., RELOC. TRANSV. PG&E STEAM FACILS., 11TH&14TH	1.00	$6,000	$29,000
L.S., SAME, ELEC. FACILS, 12TH, 13TH&14TH STREETS	1.00	$18,000	$25,000
L.S., SAME, PT&T TELPH. FACILS. 11TH, 12TH, 13TH&14TH STS.	1.00	$5.000	$7,500
L.S., SAME, WUTC TELEGRAPH FACILS., SAME	1.00	$1,000	$5,000
90 LFT. 21"R.C.P., CLASS III	21.00	14.00	16.00
730 LFT. 15"R.C.P., CLASS III	11.00	12.00	14.00
27 LFT. 15" PLAIN CONCRETE PIPE	22.00	12.00	13.00
485 LFT. 12"R.C.P., CLASS III	11.00	11.00	12.00
103 LFT. 15"V.C.P., EX. STRENGTH	13.00	16.00	18.00
120 LFT. 12" SAME, WITH CONC. BACKFILL	16.00	14.00	18.00
90 LFT. 10"V.C.P., EX. STRENGTH	44.00	13.00	15.00
2,025 LFT. 8"V.C.P., EX. STRENGTH	13.00	12.00	14.00
350 LFT. 6"V.C.P., EX. STRENGTH, BLDG. SWR.	20.00	10.00	11.00
50 LFT. 4"VCP, EX. STRENGTH, BLDG. SWR.	23.00	8.00	9.00
160 LFT. 6"C.I. EX. HVY. WEIGHT BLDG. SWR.	23.00	20.00	22.00
60 LFT. 4"C.I. EX. HVY. WEIGHT BLDG. SWR.	16.00	18.00	20.00
23 EA. SEWER MANHOLE, TYPE 1	575.00	700.00	750.00
23 EA. MANHOLE FR.&COVER, TY. H	310.00	80.00	90.00
4 EA. CLEANOUT	270.00	160.00	170.00
1 EA. LAMPHOLE	250.00	160.00	160.00
14 EA. INLET, TYPE B	700.00	330.00	700.00
1,700 LFT. 2" BLACK OR GALV. WROUGHT STL. CONDUIT	4.30	4.45	5.50
115 LFT. 1½" BLACK OR GALV. WROUGHT STL. CONDUIT	11.00	6.00	6.00
218 TR. FT. 4-WAY DUCT OF 4" ABS COND. W/CONC. ENC	30.00	11.00	14.00
8,200 LFT. #8-5KV ST. LGT. CABLE, CITY OF OAKLAND, ELEC	.35	.55	.50
36 EA. CURB BOX, CITY OF OAKLAND ELEC.	110.00	60.00	70.00
44 LFT. 2" STL. PIPE, GAS, PG&E TEMP.	15.00	10.00	12.00
69 LFT. 3" STL. PIPE, GAS, PG&E TEMP.	14.00	11.00	13.00
892 LFT. 4" STL. PIPE, GAS, PG&E TEMP.	14.00	12.00	13.00
98 LFT. 2" STL. PIPE, GAS, PG&E, PERMANENT	19.00	4.00	5.00
85 LFT. 6" STL. PIPE, GAS, PG&E, PERMANENT	24.00	6.00	8.00
1,804 LFT. 8" STL. PIPE, GAS, PG&E, PERMANENT	14.00	7.00	8.00
167 LFT. 3" SAME, STEAM MAIN, INSUL'N&JKT, PG&E TEMP	25.00	22.00	24.00
317 LFT. SAME PG&E PERMANENT	30.00	22.00	24.00
30 LFT. 3/4" STL. PIPE, REDWD. BOX INSULN&JKT. STEAM SERVICE, PG&E	36.00	30.00	32.00
25 LFT. 1¼" SAME, PG&E	21.00	35.00	38.00
2,976 LFT. 4" FIBER CONDUIT, PG&E	2.50	3.00	2.50
3,912 LFT. 4" SPLIT FIBER CONDUIT, PG&E	3.00	4.00	4.50
340 TR. FT. CONC. ENCASEMENT FOR 1-WAY DUCT PG&E	7.00	1.00	2.00
25 TR. FT. SAME, FOR 2-WAY DUCT PG&E	10.00	1.40	2.00
185 TR. FT. SAME, FOR 3-WAY DUCT PG&E	7.00	1.60	3.00
150 TR. FT. SAME, FOR 4-WAY DUCT PG&E	10.00	2.00	3.00
75 TR. FT. SAME, FOR 5-WAY DUCT PG&E	12.00	2.40	3.00
600 TR. FT. SAME, FOR 6-WAY DUCT PG&E	10.00	2.50	3.00
690 TR. FT. SAME, FOR 8-WAY DUCT, PG&E	11.00	3.00	4.00
35 TR. FT. SAME, FOR 12-WAY DUCT, PG&E	24.00	4.00	5.00
246 TR. FT. SAME, FOR 24-WAY DUCT, PG&E	29.00	8.00	10.00
6 EA. M.H. FRAME & COVER, PG&E	240.00	200.00	25[illegible].00
700 LFT. 2" GALV. STEEL PIPE PG&E	7.00	1.60	3.00
650 LFT. 3" GALV. STEEL PIPE PG&E	12.00	2.50	4.00
810 TR. FT. 6-WAY MULTIPLE TILE DUCT, PT&T	9.00	16.00	10.00
50 TR. FT. 6-WAY SPLIT SAME, PG&T	9.60	18.00	12.00
35 TR. FT. 8-WAY SAME, PT&T	11.00	20.00	23.00
75 TR. FT. 24-WAY SPLIT MULTIPLE TILE DUCT, PT&T	45.00	30.00	26.00
15 TR. FT. 36-WAY SAME, PT&T	82.00	40.00	37.00
90 LFT. 3" A.C. CONDUIT PT&T	3.40	4.00	5.00

-CONTINUED ON NEXT PAGE-

DAILY CONSTRUCTION SERVICE

TUNNEL CONSTRUCTION

12-6-66 (SAN FRANCISCO, CALIF-BARTD-12TH ST. OAKLAND STA., BROADWAY TNLS, #1K0016) CONT'D.

	(1)	(2)	(3)
30 LFT. 3½" A.C. CONDUIT, PT&T	4.00	5.00	6.00
670 LFT. 3½" SPLIT A.C. CONDUIT, PT&T	4.00	6.00	4.00
750 LFT. 3½" A.C. CONDUIT, WUTC	4.00	2.00	3.00
1,250 LFT. 3½" SPLIT A.C. CONDUIT, WUTC	4.00	3.00	3.00
35 TR.FT. CONC. ENC. FOR 1-WAY AC DUCT, WUTC	3.00	1.00	1.00
335 TR.FT. SAME, FOR 4-WAY VC DUCT, WUTC	8.00	8.00	9.00
165 TR.FT. SAME, FOR 4-WAY AC DUCT, WUTC	8.00	8.00	9.00
35 TR.FT. SAME, FOR 6-WAY VC DUCT, WUTC	4.00	9.00	10.00
L.S. MECH. WK. SUBWAY LINE STRUCS, STA. KAR 915+59.592	$1,400	$1,000	$1,100
L.S., SAME, SUBWAY STA. FRM. STA. KR927+39	$142,000	$120,500	$129,000
L.S., SAME, SUBWAY LINE STRUCS. FRM. STA. KR935+77	$28,000	$25,000	$27,500
8 EA. SAME, INSTALLN. DIST. FURN. LN. SECT. FAN UNITS	$20,000	$16,300	$2,200
1 PARCEL BLDG. SWR. REARRANGEMENT, PARCEL 0-K050	$5,000	$5,000	$5,000
1 PARCEL SAME, PARCEL 0-K054	$2,000	$1,900	$2,100
1 PARCEL SAME, PARCEL 0-K055	$5,000	$5,000	$5,000
1 PARCEL SAME, PARCEL 0-K056	$10,900	$5,200	$5,700
1 PARCEL SAME, PARCEL 0-K057	$5,000	$5,000	$5,000
1 PARCEL SAME, PARCEL 0-K058	$13,500	$6,100	$6,700
1 PARCEL SAME, PARCEL 0-K059	$9,100	$3,600	$4,000
1 PARCEL SAME, PARCEL 0-K060	$5,000	$5,000	$5,000
1 PARCEL SAME, PARCEL 0-K339	$11,300	$7,300	$8,000
1 PARCEL SAME, PARCEL 0-K341	$5,000	$5,000	$5,000
1 PARCEL SAME, PARCEL 0-K344	$5,000	$5,000	$5,000
1 PARCEL SAME, PARCEL 0-K348	$3,700	$4,900	$5,500
1 PARCEL SAME, PARCEL 0-K349	$8,000	$5,400	$6,000
1 PARCEL SAME, PARCEL 0-K352	$13,100	$4,900	$5,500
1 PARCEL SAME, PARCEL 0-K363	$5,000	$5,000	$5,000
L.S., ELEC. WK. SUBWAY LN. STRUCS. STA. KAR915+59.592	$40,000	$34,000	$2,100
L.S., SAME, SUBWAY STA. FRM. STA. KR927+39-KR935+77	$186,000	$180,000	$200,000
L.S., SAME, SUBWAY LINE STRUCS. FRM. STA. KR935+77	$17,000	$14,000	$26,000
L.S., AUX. SUB. BACK-UP TRANSFORMER	$14,000	$12,000	$18,000
L.S., INSTALLN. SWGEAR & PWR. DISTRIB. PANELS	$4,000	$3,000	$7,000
22,600 LFT. 4" NONMETALLIC ELEC. CONDUIT	1.00	.90	1.00
21,000 LFT. 4" METALLIC ELEC. CONDUIT	5.00	4.00	6.00
3 EA. TUNNEL CONNECTS. TO VENT SHAFT	$20,000	$12,600	$25,000
L.S., CLOSURE WALLS	$75,000	$75,000	$75,000
L.S., SUPPT. & MAINT. SANIT. SWRS. & STORM SWRS.	$52,000	$132,000	$156,000
L.S., SAME, EXIST. WUTC FACILITIES	$41,000	$20,000	$100,000

TUNNEL CONSTRUCTION

5-12-70(BARTD-SUBWAY STRUC., VAN NESS STA.TO DUBOCE PORTAL,NO.1S0031)

SAN FRANCISCO,CALIF.(UNIT AND TOTAL BIDS RECEIVED,TAKEN UNDER ADVISEMENT)

Fruin-Colnon Corp.,Dravo Corp.,(JV), Box 3704,Hayward $10,967,444 low to S.F.BARTD, Recept.Rm.5th Flr.,814 Mission St.,S.F.,for const.subway struc.betw. Van Ness Sta.&Duboce Portal on the Dist's Outer Market St.line. Contr.#1S0031.

(1)Fruin-Colnon Corp.,Dravo Corp.(JV) Hayward - LOW $10,967,444
(2)J.F.Shea Co.,Inc.P&Z Co.,Inc.(JV) Oakland $11,373,505
(3)Massman Const.Co.,S.Leandro $11,551,105
(4)Gordon H.Ball,Inc.,Homer J.Olsen,Homer J.Olsen,Inc.(JV)Danville $11,911,875
-continued in next column-
(5)Perini Corp., S.F. $12,139,322
(6)Peter Kiewit Sons Co.,Omaha $12,289,277
(7)Morrison-Knudsen Co.,Inc.Boise12,676,450
(8)Fred J.Early,Jr.Co.,Inc.,Winston Bros. Co.,Donald M.Drake Co.,S.F.13,275,750
(9)Granite Const.Co.,Watsonville$13,322,140
(10)MacLean Grove&Co.Inc.New Yrk$19,371,710
Engineer's Estimate $12,148,105

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
L.S.,mobiliz.&prep. work	250000	250000	250000	250000	250000	250000	250000	250000	250000	250000
L.S.traf.maint.&cntrl	180000	200000	200000	500000	124600	76,505	145000	160000	150000	75,000
L.S.bulkhead E.end	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000
L.S.same,W.end	20,000	10,000	20,000	30,000	36,000	12,000	24,000	10,000	5[illegible],000	30,000
L.S.Muni.Railway track facil.	1,080,264	914342	80,000	350000	600000	500000	880000	700000	750,000	750000
L.S.same,perm.	230000	200000	493370	250000	320000	706307	350000	150000	250000	750000
2,000 SY decking	98.00	150.00	100.00	75.00	264.00	125.00	200.00	200.00	200.00	150.00
152,100 cy.excav.	20.00	19.38	20.00	20.00	22.00	21.50	24.00	28.00	34.00	38.00
51,100 cy.bkfl.	6.00	5.50	8.00	4.00	9.25	6.80	5.00	10.00	6.00	15.00
6 ea.incl.casings	600.00	$1,500	600.00	$2,000	750.00	$1,200	$1,800	$2,000	650.00	$1,500
60 ea.bracing instr.	375.00	500.00	375.00	270.00	500.00	310.00	650.00	600.00	400.00	$1,500
1,500 lft.observ.wells installation type I	4.25	5.00	5.00	5.00	5.00	25.00	8.00	9.00	5.00	7.00
650 lft.same,ty.II	4.70	6.00	10.00	6.00	6.00	30.00	9.00	10.00	6.00	8.00
1,000 well mo.maint.observ. wells	8.50	10.00	15.00	1.00	63.00	25.00	30.00	10.00	15.00	10.00
44 ea.rmv.wells	130.00	20.00	100.00	1.00	60.00	50.00	130.00	100.00	50.00	10.00
178 cy.crb.gtrs.isl	60.00	70.00	60.00	75.00	75.00	140.00	75.00	80.00	70.00	70.00
260 cy.sdwlk.drvwy	60.00	80.00	60.00	80.00	75.00	140.00	75.00	80.00	70.00	60.00
1,570 cy.aggr.base	17.00	17.00	17.00	20.00	21.00	21.00	20.00	15.00	20.00	20.00
23,460 SY Cl.3000 conc.base 8" thick	10.00	9.00	10.00	10.00	8.00	13.00	12.00	10.00	10.00	10.00
21 T liq.asph.	200.00	150.00	200.00	100.00	240.00	300.00	250.00	200.00	200.00	200.00
21 T asph.emuls.	200.00	100.00	200.00	150.00	240.00	300.00	250.00	200.00	200.00	200.00
3,020 T aggr.	15.00	16.00	16.00	16.00	20.00	40.00	20.00	15.00	16.00	17.00
180 T pav.asph.	15.00	16.00	16.00	16.00	20.00	40.00	20.00	15.00	16.00	17.00
5,250,000 lb. bar reinforcing steel	.13	.13	.13	.13	.17	.14	.14	.14	.13	.15
13,850 cy.Class 4000 conc.,subway,struc., grade slab	54.00	55.00	50.00	50.00	40.00	65.00	50.00	80.00	45.00	100.00
9,000 cy.same, exterior walls	54.00	55.00	80.00	50.00	76.00	95.00	65.00	80.00	60.00	150.00
1,250 cy.same,interior walls	54.00	55.00	80.00	50.00	134.00	130.00	110.00	80.00	60.00	150.00
12,650 cy.same, supptd.slabs & beams	54.00	55.00	80.00	50.00	56.00	65.00	40.00	80.00	50.00	150.00
27,000 lft.waterstops	1.70	.50	1.00	1.00	2.[illegible]	2.00	2.00	5.00	3.00	2.00
43,100 lb.misc.steel&iron & struc. steel	1.00	1.50	1.00	1.00	1.12	1.80	.90	1.50	1.20	1.00
760 lft.parapet rail,Duboce Portal	7.00	8.50	10.00	15.00	15.00	16.00	12.00	20.00	20.00	50.00
5 ea.stl.door	485.00	500.00	750.00	450.00	460.00	600.00	500.00	800.00	500.00	500.00
10 ea.same,ty.D	625.00	850.00	750.00	600.00	846.00	$1,000	500.00	$1,000	700.00	$1,000

-continued on next page-

TUNNEL CONSTRUCTION

5-12-70 SAN FRANCISCO,CALIF.(BARTD-SUBWY.STRUCS.,VAN NESS STA.TO DUBOCE PORTAL #1SO031)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
L.S.painting	$1,100	$5,000	$10000	$5,000	$1,300	[illegible]	$6,000	$5,000	$10000	$20000
L.S.drnge.fire prot.	$80,000	$40000	$73450	$50000	$96500	$75000	$40000	[illegible]	$30000	$40000
L.S.elec.work	$113,000	$75000	$72500	$30000	$89200	$90000	$125000	$80000	$100000	$100000
L.S.PT&Tfacils.	$28,000	$40000	$28000	$30000	$34400	$120000	$30000	$40000	$35000	$40000
L.S.undrgrd.facil.	$60,000	$100000	$60000	$100000	$73800	$250000	$60000	$40000	$75000	$70000
L.S.traf.sig.	$77,000	$120000	$117000	$120000	$144000	$140000	$120000	$120000	$75000	$120000
L.S.street ltg.	$138,000	$40000	$25000	$30000	$28300	$30000	$30000	$50000	$40000	$50000
L.S.restor.work	$11,000	$15000	$10000	$20000	$12900	$110000	$25000	$20000	$25000	$50000
L.S.Muni.Railwy.pwr	$106,000	$110000	$60000	$70000	$92000	$30000	$400000	$65000	$100000	$500000
L.S.restor.work	$44,000	$50000	$40000	$50000	$50000	$60000	$150000	$35000	$75000	$200000
L.S.AWSS facils.	$300,000	$600000	$345000	$1000000	$424000	$300000	$400000	$300000	$400000	$445000
180 cy.prot.enc.,ducts	220.00	80.00	220.00	200.00	270.00	360.00	250.00	[illegible]50.00	250.00	220.00
860 tr.ft.WU conduit	8.00	16.00	8.00	25.00	10.00	24.00	25.00	10.00	10.00	10.00
2 ea.WU manhole	$3,200	$1,500	$3,200	$3,000	$4,000	180.00	$2,500	$3,000	$3,600	$3,200
2,400 lft.16"bell&spigot push-on	65.00	50.00	65.00	50.00	80.00	43.00	125.00	70.00	80.00	100.00
150 lft.12"same	55.00	50.00	55.00	50.00	68.00	50.00	100.00	60.00	70.00	90.00
500 lft.8" same	50.00	30.00	50.00	50.00	60.00	34.00	100.00	40.00	60.00	85.00
500 lft.4"D.I.pipe	40.00	28.00	40.00	50.00	50.00	60.00	60.00	30.00	50.00	80.00
400 lft.1"svc.pipe	25.00	20.00	25.00	25.00	30.00	30.00	12.00	25.00	30.00	70.00
30 ea.screw tap	15.00	80.00	15.00	75.00	18.00	24.00	150.00	100.00	20.00	50.00
40,000 lb.fittings	.20	.30	20	1.00	.25	.30	.60	.50	25	.50
L.S.swr.facils.	$60,000	$90000	$75000	$193406	$73800	$75000	$80000	$100000	$100000	$90000
937 lft.42" RCP	110.00	80.00	110.00	150.00	135.00	90.00	180.00	120.00	130.00	220.00
177 lft.same w/enc.	120.00	90.00	120.00	250.00	148.00	138.00	200.00	130.00	140.00	240.00
256 lft.24"VCP	100.00	130.00	100.00	200.00	123.00	96.00	125.00	110.00	120.00	200.00
257 lft.21"VCP	95.00	120.00	95.00	200.00	117.00	72.00	100.00	100.00	110.00	190.00
2,750 lft.same,encsm.	85.00	180.00	85.00	200.00	105.00	66.00	100.00	90.00	100.00	170.00
154 lft.same,conc.base	120.00	160.00	120.00	200.00	148.00	48.00	60.00	100.00	150.00	240.00
1,364 lft.12"VCP	90.00	150.00	90.00	175.00	110.00	58.00	90.00	100.00	110.00	180.00
450 lft.10"VCP	65.00	130.00	65.00	150.00	80.00	78.00	60.00	60.00	75.00	130.00
260 lft.10"RCP culv.	60.00	120.00	60.00	100.00	74.00	60.00	50.00	55.00	70.00	120.00
37 ea.4'swr.MH	$1,000	$2,200	$1,000	$1,500	$1,230	$1,300	$1,200	$1,200	$1,200	$2,000
4 ea.box MH	$2,000	$1,500	$2,000	$2,000	$2,460	$2,000	$3,000	$2,500	$2,500	$4,000
5 ea.modif.box MH	$2,200	$1,800	$2,200	$2,500	$2,700	$2,200	$3,600	$3,000	$3,000	$4,400
1 ea.junct.MH struc	$3,000	$2,500	$3,000	$3,000	$3,700	$2,400	$3,500	$4,000	$4,000	$6,000
3 ea.angle swr.MH	$2,500	$1,500	$2,500	$2,500	$3,100	$2,100	$3,000	$2,500	$3,500	$5,000
1 ea.modif.same	$3,000	$2,000	$3,000	$3,000	$3,700	$2,200	$3,500	$3,000	$4,000	$6,000
49 ea.swr.MH frame and cover	180.00	250.00	180.00	200.00	220.00	160.00	180.00	200.00	210.00	360.00
19 ea.swr.connect.	400.00	300.00	400.00	750.00	500.00	480.00	600.00	300.00	500.00	600.00
11 ea.wtr.inlet	700.00	450.00	700.00	$1,000	860.00	360.00	350.00	500.00	800.00	900.00
7 ea.same,w/grate	700.00	475.00	700.00	$1,000	860.00	420.00	900.00	650.00	850.00	900.00
445 lft.4"gas pipe	45.00	40.00	45.00	50.00	55.00	35.00	35.00	60.00	55.00	90.00
125 lft.4"same perm.	75.00	30.00	75.00	75.00	92.00	36.00	30.00	70.00	90.00	150.00
185 lft.6" same	80.00	60.00	80.00	100.00	100.00	38.00	35.00	80.00	95.00	160.00
60 lft. 8" same	80.00	80.00	80.00	100.00	10[illegible].00	42.00	50.00	85.00	100.00	160.00
3,180 lft.12"same	55.00	60.00	55.00	100.00	68.00	48.00	78.00	60.00	65.00	110.00
2,590 lft.16"same	60.00	65.00	60.00	100.00	74.00	60.00	97.00	65.00	75.00	120.00
510 lft.24"same	70.00	70.00	70.00	125.00	85.00	66.00	90.00	75.00	85.00	140.00
30 lft.6"same,HP at Duboce and Market	100.00	60.00	100.00	100.00	123.00	96.00	40.00	80.00	120.00	200.00
150 lft.stl.pipe PG&E	40.00	50.00	40.00	50.00	50.00	36.00	60.00	40.00	50.00	80.00
10,000 points per mo.,settlement measuremnt.pts.	5.00	1.00	9.00	1.25	1.40	1.00	2.00	5.00	2.00	2.00
1 ea. sidewalk exit door	$3,200	$5,000	$[illegible],000	$5,000	$1,550	$3,000	$3,500	$10000	$1,000	$5,000

TUNNEL CONSTRUCTION

9-23-66(BARTO-SUBWAY&STRUCS., MARKET ST. LINE, CONTR.NO. 1S0022)
SAN FRANCISCO, CALIF. (UNIT & TOTAL BIDS RECEIVED, TAKEN UNDER ADVISEMENT)

MORRISON-KNUDSEN CO., INC., BROWN&ROOT, INC. &PERINI CORP. (JV), 8610 ATLANTIC AVENUE, SOUTH GATE, $17,763,825 LOW TO S.F. BAY AREA RAPID TRANSIT DIST., 814 MISSION STREET, S.F., FOR CONST. SUBWAY STRUCS., 8TH ST. TO 15TH ST. ON THE DIST'S. S.F. MARKET STREET LINE IN S.F. CONTRACT NO. 1S0022.

(1)MORRISON-KNUDSEN CO, INC., BROWN&ROOT INC., &PERINI CORP(JV)-LOW- $17,763,825

-CONTINUED IN NEXT COLUMN-

'2)WINSTON BROS, FRED J. EARLY JR. CO, INC., &S&M CONST. CO, KEMPER CONST. CO., L.A. $19,703,247

(3)MCLEAN-GROVE&SHEPHRED, N.Y. $20,755,420

ENGINEER'S ESTIMATE $20,341,517

	(1)	(2)	(3)
L.S., MOBILIZ. & PREP. WORK	$1,000,000	$1,000,000	$1,000,000
500 EA. SETTLEM'T. MEAS. POINTS	200.00	38.00	10.00
L.S., PROTECTIVE WORK	$5,000	$3,500	$10,000
L.S., SUPPT. WORK EQUI	10,000	$7,000	$10,000
OPTION A			
2,330 CY. EX. EXTERIOR	[illegible]5.00	130.00	200.00
3,820 CY. STRUC. EX.	[illegible].00	10.00	150.00
2,220 CY. CL. 3000 CONC.	[illegible].00	132.00	250.00
440 CY. "4000" CONC.	70.00	100.00	100.00
262,000 LB. FAB. JT. MBRS.	.40	.61	.50
61,300 LB. STL. STRUTS	.60	1.00	.50
343,000 LB. REINF. STL.	.25	.50	.25
170 CY. CONC, PUMP&VENT SHAFT WALLS	250.00	135.00	200.00
180 CY. CONC. SAME SUPPTD. SLABS & BEAMS	250.00	75.00	200.00
73,500 LB. STEEL	.25	.33	.25
SUBTOTAL OPTION A	$784,785	$1,131,465	$1,973,775
2,800 LFT. OBSVN. WELLS	10.00	6.70	10.00
30 EA. MAINTAIN SAME	$3,000	490.00	100.00
30 EA. REMOVE SAME	200.00	92.00	30.00
3 CY. "3000" CONC.	300.00	170.00	300.00
10,228 LFT. "2500" CONC.	60.00	58.50	125.00
10,228 LFT. SUBWAY TNL.	$1365	$1,577	$1,480
L.S., CROSS PASSAGE, STA. SR403+76	$45,000	$45,000	$70,000
LS, SAME, SR410+04	$45,000	$45,000	$70,000
L.S., CROSS PASSAGE, STA. SR416+32	$45,000	$45,000	$70,000
L.S., SAME, SR428+55	$45,000	$50,000	$90,000
L.S., SAME, SR435+58	$45,000	$60,000	$90,000
L.S., SAME, SR442+07	$45,000	$60,000	$90,000
2 EA. TERMINAT. TUNNELS, 8TH STREET	$120,000	$7,350	$75,000
2 EA. SAME, 15TH ST.	$60,000	$8,430	$75,000
8 EA. TUNNEL SEALS	$4,000	$4,530	$10,000
47,200 LB. MISC. STEEL & IRON	1.50	1.04	1.25
1 EA. MANHOLE FRAMES & COVERS	300.00	430.00	500.00
L.S., FIRE PROTECT. SYSTEMS	$50,000	$46,900	$25,000
L.S., DRAINAGE SYSTEMS	$20,000	$17,000	$35,000
L.S., VENTILATION SYSTEMS	$12,000	$9,900	$15,000
61,650 LFT. 4" EMBED. NON-MTL. CONDUIT	1.00	.80	.70
40 EA. WALKWAY PULL-BOXES	$1,000	900.00	500.00
L.S., ELECTRICAL WORK	$150,000	$140890	$170000
7 EA. METAL DOORS, TYPE A	700.00	660.00	250.00
14 EA. METAL DOORS, TYPE B	900.00	765.00	250.00
L.S., 1ST AID FACILS.	$80,000	$40,000	$75,000

WASHINGTON METROPOLITAN AREA TRANSIT AUTHORITY.
BID TABULATION

CONTRACT DESCRIPTION FOR THE CONSTRUCTION OF SECTION C-2, HUNTINGTON ROUTE

CONTRACT NUMBER 1C0021 WMATA ESTIMATE- $ 31,301,690.52

BID OPENING DATE 08/31/71

ITEM NO	APPROXIMATE QUANTITY	UNIT	WASHINGTON METROPOLITAN AREA TRANSIT AUTHORITY UNIT PRICE	UNIT AMOUNT	MORRISON-KNUDSEN CO., INC. BOISE, IDAHO UNIT PRICE	UNIT AMOUNT	LAPORA CONTRACTING CO. & SQUARE CONSTRUCTION CO. A JOINT VENTURE UNIT PRICE	UNIT AMOUNT	CONDUIT & FOUNDATION CORP INTERCOUNTY CONSTRUCTION BUCKLEY & COMPANY A JOINT VENTURE UNIT PRICE	UNIT AMOUNT	FRED J. EARLY, JR. KIEWIT-MASSMAN A JOINT VENTURE UNIT PRICE	UNIT AMOUNT	GORDON H. BALL, INC. UNIT PRICE	UNIT AMOUNT
1	MOBILIZATION & PREPARATORY WORK 1.00	FP	950,000.00	950,000.00	950,000.00	95C,000.00	950,000.00	950,000.00	950,000.00	950,000.00	950,000.00	950,000.00	950,000.00	950,000.00
2	MAINTENANCE OF TRAFFIC 1.00	LS	440,000.00	440,000.00	600,000.00	600,000.00	220,000.00	220,000.00	900,000.00	900,000.00	150,000.00	150,000.00	1,200,000.00	1,200,000.00
3	UNDERPINNING & SUPPORT, CATEGORY I - 916 - 16TH ST. NORTHWEST 1.00	LS	57,000.00	57,000.00	100,000.00	100,000.00	119,000.00	119,000.00	200,000.00	200,000.00	200,000.00	200,000.00	300,000.00	300,000.00
4	UNDERPINNING & SUPPORT, CATEGORY I - 1625 EYE ST., NORTHWEST 1.00	LS	142,000.00	142,000.00	200,000.00	200,000.00	220,000.00	220,000.00	300,000.00	300,000.00	300,000.00	300,000.00	50C,000.00	500,000.00
5	UNDERPINNING & SUPPORT, CATEGORY I - 1627 EYE ST., NORTHWEST 1.00	LS	671,000.00	671,000.00	600,000.00	600,000.00	1,110,000.00	1,110,000.00	1,400,000.00	1,400,000.00	2,000,000.00	2,000,000.00	2,500,000.00	2,500,000.00
6	UNDERPINNING & SUPPORT, CATEGORY I - 830 - 17TH ST., NORTHWEST (POINT 100 ADJACENT TO TRACTION POWER SUBSTA.) 1.00	LS	130,000.00	130,000.00	100,000.00	100,000.00	110,000.00	110,000.00	200,000.00	200,000.00	1,000,000.00	1,000,000.00	300,000.00	300,000.00
7	UNDERPINNING & SUPPORT, CATEGORY I - 1719 EYE ST., NORTHWEST 1.00	LS	40,000.00	40,000.00	50,000.00	50,000.00	36,000.00	36,000.00	50,000.00	50,000.00	40,000.00	40,000.00	200,000.00	200,000.00
8	UNDERPINNING & SUPPORT, CATEGORY I - 1722 EYE ST., NORTHWEST 1.00	LS	20,000.00	20,000.00	100,000.00	100,000.00	66,000.00	66,000.00	150,000.00	150,000.00	100,000.00	100,000.00	200,000.00	200,000.00
9	UNDERPINNING & SUPPORT, CATEGORY I - 1725 EYE ST., NORTHWEST 1.00	LS	74,000.00	74,000.00	100,000.00	100,000.00	179,000.00	179,000.00	250,000.00	250,000.00	250,000.00	250,000.00	450,000.00	450,000.00
10	UNDERPINNING & SUPPORT, CATEGORY I - 1720 EYE ST., NORTHWEST 1.00	LS	71,000.00	71,000.00	70,000.00	70,000.00	92,000.00	92,000.00	250,000.00	250,000.00	120,000.00	120,000.00	300,000.00	300,000.00
11	UNDERPINNING & SUPPORT, CATEGORY I - 808 - 19TH ST., NORTHWEST 1.00	LS	97,000.00	97,000.00	120,000.00	120,000.00	90,000.00	90,000.00	250,000.00	250,000.00	80,000.00	80,000.00	300,000.00	300,000.00
12	UNDERPINNING & SUPPORT - CATEGORY II 1.00	LS	775,000.00	775,000.00	400,000.00	400,000.00	325,000.00	325,000.00	1,000,000.00	1,000,000.00	100,000.00	100,000.00	400,000.00	400,000.00
13	COMMON EXCAVATION - LINE 148,248.00	CY	14.00	2,075,472.00	14.00	2,075,472.00	[illegible]	1,482,480.00	8.00	1,185,984.00	8.00	1,185,984.00	20.00	2,964,960.00
14	COMMON EXCAVATION - STATION 83,719.00	CY	14.00	1,172,066.00	14.00	1,172,066.00	10.00	837,190.00	12.00	1,004,628.00	16.00	1,339,504.00	20.00	1,674,380.00
15	COMMON EXCAVATION - CHILLED WATER PLANT 992.00	CY	14.00	13,888.00	14.00	13,888.00	10.00	9,920.00	12.00	11,904.00	8.00	7,936.00	20.00	19,840.00
16	COMMON EXCAVATION - TRACTION POWER SUBSTATION 7,009.00	CY	14.00	98,126.00	14.00	98,126.00	10.00	70,090.00	12.00	84,108.00	8.00	56,072.00	20.00	140,180.00
17	ROCK EXCAVATION - LINE 2,860.00	CY	25.00	71,500.00	30.00	85,800.00	30.00	85,800.00	50.00	143,000.00	40.00	114,400.00	40.00	114,400.00
18	BACKFILL - LINE 73,212.00	CY	9.00	658,908.00	12.00	878,544.00	9.00	658,908.00	8.60	629,623.20	6.00	439,272.00	15.00	1,098,180.00
19	BACKFILL - STATION 13,491.00	CY	9.00	121,419.00	12.00	161,892.00	9.00	121,419.00	12.00	161,892.00	16.00	215,856.00	15.00	202,365.00
20	BACKFILL - CHILLED WATER PLANT 328.00	CY	9.00	2,952.00	12.00	3,936.00	10.00	3,280.00	12.00	3,936.00	6.00	1,968.00	20.00	6,560.00
21	BACKFILL - TRACTION POWER SUBSTATION 1,588.00	CY	9.00	14,292.00	12.00	19,056.00	10.00	15,880.00	12.00	19,056.00	6.00	9,528.00	20.00	31,760.00

ITEM NO	APPROXIMATE QUANTITY	UNIT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT
22	REMOVAL OF ROAD PAVEMENTS AND DRIVEWAYS													
	16,350.00	SY	13.00	212,550.00	8.00	130,800.00	7.00	114,450.00	8.00	130,800.00	12.00	196,200.00	10.00	163,500.00
23	REMOVAL OF SIDEWALK PAVEMENTS													
	8,435.00	SY	6.00	50,610.00	3.00	25,305.00	5.00	42,175.00	3.00	25,305.00	8.00	67,480.00	10.00	84,350.00
24	CONSTRUCT TEMPORARY BULKHEAD AT STATION 27+50													
	1.00	LS	15,000.00	15,000.00	34,000.00	34,000.00	20,000.00	20,000.00	12,000.00	12,000.00	2,000.00	2,000.00	50,000.00	50,000.00
25	NOT USED													
	0.00													
26	REMOVE TEMPORARY BULKHEAD AT CONNECTION TRACK													
	1.00	LS	5,000.00	5,000.00	4,500.00	4,500.00	3,500.00	3,500.00	5,000.00	5,000.00	10,000.00	10,000.00	6,000.00	6,000.00
27	REMOVE CONCRETE CURBING													
	1,634.00	LF	6.00	9,804.00	3.50	5,719.00	3.00	4,902.00	3.00	4,902.00	4.00	6,536.00	35.00	57,190.00
28	GROUNDWATER CONTROL - LINE													
	1.00	LS	690,000.00	690,000.00	250,000.00	250,000.00	400,000.00	400,000.00	400,000.00	400,000.00	600,000.00	600,000.00	500,000.00	500,000.00
29	GROUNDWATER CONTROL - STATION													
	1.00	LS	250,000.00	250,000.00	100,000.00	100,000.00	200,000.00	200,000.00	350,000.00	350,000.00	350,000.00	350,000.00	280,000.00	280,000.00
30	GROUNDWATER CONTROL-TRACTION POWER SUBSTATION													
	1.00	LS	21,000.00	21,000.00	20,000.00	20,000.00	120,000.00	120,000.00	10,000.00	10,000.00	50,000.00	50,000.00	60,000.00	60,000.00
31	SUPPORT OF EXCAVATION-LINE													
	1.00	LS	2,470,000.00	2,470,000.00	2,500,000.00	2,500,000.00	5,000,000.00	5,000,000.00	5,150,000.00	5,150,000.00	7,000,000.00	7,000,000.00	2,435,700.00	2,435,700.00
32	SUPPORT OF EXCAVATION-STATION													
	1.00	LS	1,023,000.00	1,023,000.00	1,250,000.00	1,250,000.00	2,300,000.00	2,300,000.00	4,020,000.00	4,020,000.00	4,200,000.00	4,200,000.00	5,000,000.00	5,000,000.00
33	SUPPORT OF EXCAVATION-TRACTION POWER SUBSTATION													
	1.00	LS	11,000.00	11,000.00	200,000.00	200,000.00	500,000.00	500,000.00	150,000.00	150,000.00	200,000.00	200,000.00	400,000.00	400,000.00
34	SUPPORT OF EXCAVATION-CHILLED WATER PLANT													
	1.00	LS	21,000.00	21,000.00	60,000.00	60,000.00	44,000.00	44,000.00	150,000.00	150,000.00	50,000.00	50, 00.00	250,000.00	250,000.00
35	TELEPHONE & TELEGRAPH DUCT LINE-1 DUCT CONCRETE ENCASED, 4" FIBER, 8 WALL													
	12.00	LF	40.00	480.00	40.00	480.00	30.00	360.00	30.00	360.00	35.00	420.00	40.00	480.00
36	TELEPHONE & TELEGRAPH DUCT LINE - 2 DUCT CONCRETE ENCASED, 4" FIBER, 8 WALL													
	90.00	LF	29.00	2,610.00	40.00	3,600.00	35.00	3,150.00	75.00	6,750.00	36.00	3,240.00	40.00	3,600.00
37	TELEPHONE & TELEGRAPH DUCT LINE-4 DUCT, CONCRETE ENCASED, 4" FIBER, 8 WALL													
	300.00	LF	40.00	12,000.00	45.00	13,500.00	40.00	12,000.00	80.00	24,000.00	40.00	12,000.00	60.00	18,000.00
38	TELEPHONE & TELEGRAPH DUCT LINE-9 DUCT CONCRETE ENCASED, 4" FIBER, 8 WALL													
	215.00	LF	57.00	12,255.00	60.00	12,900.00	50.00	10,750.00	100.00	21,500.00	65.00	13,975.00	60.00	12,900.00
39	TELEPHONE & TELEGRAPH DUCT LINE-15 DUCT CONCRETE ENCASED, 4" FIBER, 8 WALL													
	70.00	LF	86.00	6,020.00	70.00	4,900.00	65.00	4,550.00	140.00	9,800.00	70.00	4,900.00	70.00	4,900.00
40	TELEPHONE & TELEGRAPH MANHOLE - 5'-0" X 7'-0"													
	1.00	EA	5,700.00	5,700.00	5,000.00	5,000.00	5,000.00	5,000.00	5,000.00	5,000.00	5,000.00	5,000.00	6,500.00	6,500.00
41	TELEPHONE & TELEGRAPH MANHOLE-5'-0" X 9'-0"													
	2.00	EA	6,900.00	13,800.00	7,000.00	14,000.00	6,000.00	12,000.00	8,000.00	16,000.00	6,000.00	12,000.00	9,000.00	18,000.00
42	MAINTAIN AND SUPPORT POLICE AND FIRE LINES													
	1.00	LS	17,000.00	17,000.00	24,000.00	24,000.00	35,000.00	35,000.00	30,000.00	30,000.00	4,000.00	4,000.00	30,000.00	30,000.00
43	MAINTAIN AND RESTORE - TRAFFIC SIGNALS													
	1.00	LS	11,000.00	11,000.00	20,000.00	20,000.00	36,000.00	36,000.00	35,000.00	35,000.00	6,000.00	6,000.00	60,000.00	60,000.00
44	MAINTAIN AND RESTORE - STREET LIGHTS													
	1.00	LS	[illegible]	[illegible]	35,000.00	[illegible]	40,000.00	40,000.00	30,000.00	30,000.00	7,000.00	7,000.00	50,000.00	50,000.00
45	MAINTAIN AND SUPPORT - ELECTRIC UTILITIES													
	1.00	LS	397,000.00	397,000.00	850,000.00	850,000.00	150,000.00	150,000.00	900,000.00	900,000.00	650,000.00	650,000.00	700,000.00	700,000.00
46	MAINTAIN AND SUPPORT - TELEPHONE UTILITIES													
	1.00	LS	49,000.00	49,000.00	31,000.00	31,000.00	150,000.00	150,000.00	160,000.00	160,000.00	69,000.00	69,000.00	100,000.00	100,000.00
47	MAINTAIN AND SUPPORT - TELEGRAPH UTILITIES													
	1.00	LS	11,000.00	11,000.00	5,000.00	5,000.00	30,000.00	30,000.00	5,000.00	5,000.00	4,000.00	4,000.00	75,000.00	75,000.00

ITEM NO	APPROXIMATE QUANTITY	UNIT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT
48	MAINTAIN AND SUPPORT-WATER UTILITIES 1.00	LS	91,000.00	91,000.00	100,000.00	100,000.00	100,000.00	100,000.00	250,000.00	250,000.00	70,000.00	70,000.00	330,000.00	330,000.00
49	MAINTAIN AND SUPPORT-SEWER UTILITIES 1.00	LS	102,000.00	102,000.00	367,401.00	367,401.00	200,000.00	200,000.00	350,000.00	350,000.00	125,000.00	125,000.00	200,000.00	200,000.00
50	MAINTAIN AND SUPPORT-GAS UTILITIES 1.00	LS	33,000.00	33,000.00	50,000.00	50,000.00	40,000.00	40,000.00	100,000.00	100,000.00	9,000.00	9,000.00	90,000.00	90,000.00
51	REMOVE, STORE & REPLACE PARKING METERS POSTS 1.00	LS	800.00	800.00	15,000.00	15,000.00	2,000.00	2,000.00	3,000.00	3,000.00	2,300.00	2,300.00	2,000.25	2,000.25
52	REMOVE, MAINTAIN & REINSTALL SIGNS-BUS, STREET & TRAFFIC 1.00	LS	1,000.00	1,000.00	6,000.00	6,000.00	2,000.00	2,000.00	3,000.00	3,000.00	4,000.00	4,000.00	10,000.50	10,000.50
53	DECKING OF STREETS - LINE 8,609.00	SY	124.00	1,067,516.00	175.00	1,506,575.00	170.00	1,463,530.00	110.00	946,990.00	100.00	860,900.00	300.00	2,582,700.00
54	DECKING OF STREETS - STATION 4,341.00	SY	124.00	538,284.00	175.00	759,675.00	170.00	737,970.00	110.00	477,510.00	100.00	434,100.00	300.00	1,302,300.00
55	DECKING OF STREETS-CHILLED WATER PLANT 288.00	SY	124.00	35,712.00	175.00	50,400.00	150.00	43,200.00	110.00	31,680.00	100.00	28,800.00	250.00	72,000.00
56	DECKING OF STREETS-TRACTION POWER SUBSTATION 712.00	SY	124.00	88,288.00	175.00	124,600.00	150.00	106,800.00	110.00	78,320.00	100.00	71,200.00	250.00	178,000.00
57	DECKING OF SIDEWALKS-LINE 848.00	SY	124.00	105,152.00	130.00	110,240.00	90.00	76,320.00	50.00	42,400.00	10.00	8,480.00	250.00	212,000.00
58	DECKING OF SIDEWALKS-STATION 2,902.00	SY	124.00	359,848.00	130.00	377,260.00	90.00	261,180.00	50.00	145,100.00	10.00	29,020.00	250.00	725,500.00
59	DECKING OF SIDEWALKS-CHILLED WATER PLANT 108.00	SY	124.00	13,392.00	130.00	14,040.00	90.00	9,720.00	50.00	5,400.00	10.00	1,080.00	250.00	27,000.00
60	DECKING OF SIDEWALKS-TRACTION POWER SUBSTATION 71.00	SY	124.00	8,804.00	130.00	9,230.00	90.00	6,390.00	50.00	3,550.00	10.00	710.00	250.00	17,750.00
61	REINFORCING STEEL BARS-LINE 4,176,111.00	LBS	25	1,044,027.75	25	1,044,027.75	25	1,044,027.75	25	1,044,027.75	20	835,222.20	25	1,044,027.75
62	REINFORCING STEEL BARS-STATION 3,990,782.00	LBS	25	997,695.50	25	997,695.50	25	997,695.50	25	997,695.50	20	798,156.40	25	997,695.50
63	REINFORCING STEEL BARS-CHILLED WATER PLANT 111,474.00	LBS	25	27,868.50	25	27,868.50	25	27,868.50	25	27,868.50	25	27,868.50	50	55,737.00
64	REINFORCING STEEL BARS-TRACTION POWER SUBSTATION 253,735.00	LBS	25	63,433.75	25	63,433.75	25	63,433.75	25	63,433.75	25	63,433.75	40	101,494.00
65	WIRE MESH - STATION 87.00	SY	5.00	435.00	2.00	174.00	3.00	261.00	2.00	174.00	2.00	174.00	10.00	870.00
66	ELECTRICAL BONDING-LINE 1.00	LS	24,000.00	24,000.00	10,000.00	10,000.00	30,000.00	30,000.00	10,000.00	10,000.00	15,000.00	15,000.00	60,000.00	60,000.00
67	ELECTRICAL BONDING-STATION 1.00	LS	23,000.00	23,000.00	15,000.00	15,000.00	25,000.00	25,000.00	5,000.00	5,000.00	10,000.00	10,000.00	40,000.00	40,000.00
68	ELECTRICAL BONDING-CHILLED WATER PLANT 1.00	LS	6,400.00	6,400.00	3,000.00	3,000.00	5,000.00	5,000.00	500.00	500.00	5,000.00	5,000.00	5,000.00	5,000.00
69	ELECTRICAL BONDING - TRACTION POWER SUBSTATION 1.00	LS	1,500.00	1,500.00	4,000.00	4,000.00	7,000.00	7,000.00	500.00	500.00	3,000.00	3,000.00	30,000.00	30,000.00
70	CONCRETE FOR SLAB ON GRADE-LINE 11,718.00	CY	75.00	878,850.00	65.00	761,670.00	85.00	996,030.00	70.00	820,260.00	100.00	1,171,800.00	80.00	937,440.00
71	CONCRETE FOR EXTERIOR WALLS-LINE 8,591.00	CY	115.00	987,965.00	75.00	644,325.00	130.00	1,116,830.00	70.00	601,370.00	100.00	859,100.00	80.00	687,280.00
72	CONCRETE FOR INTERIOR WALLS-LINE 1,722.00	CY	115.00	198,030.00	150.00	258,300.00	200.00	344,400.00	100.00	172,200.00	100.00	172,200.00	200.00	344,400.00
73	CONCRETE FOR COLUMNS-LINE 11.00	CY	138.00	1,518.00	500.00	5,500.00	300.00	3,300.00	450.00	4,950.00	100.00	1,100.00	500.00	5,500.00

ITEM NO	APPROXIMATE QUANTITY	UNIT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT
74	CONCRETE FOR ROOF SLAB-LINE 11,494.00	CY	126.00	1,448,244.00	65.00	747,110.00	125.00	1,436,750.00	100.00	1,149,400.00	100.00	1,149,400.00	80.00	919,520.00
75	CONCRETE FOR PRECAST CONCRETE BEAMS-VENT STRUCTURES 25.00	CY	310.00	7,750.00	600.00	15,000.00	305.00	7,625.00	300.00	7,500.00	200.00	5,000.00	250.00	6,250.00
76	CONCRETE FOR INVERT SLAB-STATION 11,706.00	CY	75.00	877,950.00	50.00	585,300.00	85.00	995,010.00	45.00	526,770.00	100.00	1,170,600.00	50.00	585,300.00
77	CONCRETE FROM INVERT JOINT TO FIRST CONSTRUCTION JOINT-STATION 5,740.00	CY	207.00	1,188,180.00	75.00	430,500.00	90.00	516,600.00	70.00	401,800.00	100.00	574,000.00	100.00	574,000.00
78	CONCRETE FOR ARCH VAULT ABOVE FIRST CONSTRUCTION JOINT-STATION 6,750.00	CY	230.00	1,552,500.00	100.00	675,000.00	125.00	843,750.00	120.00	810,000.00	100.00	675,000.00	100.00	675,000.00
79	CONCRETE FOR END WALLS-STATION 217.00	CY	138.00	29,946.00	160.00	34,720.00	205.00	44,485.00	250.00	54,250.00	100.00	21,700.00	240.00	52,080.00
80	CONCRETE FOR INTERIOR WALLS BELOW PLATFORMS-STATION 450.00	CY	115.00	51,750.00	500.00	225,000.00	400.00	180,000.00	400.00	180,000.00	200.00	90,000.00	200.00	90,000.00
81	CONCRETE FOR PLATFORM DECK-STATION 366.00	CY	115.00	42,090.00	250.00	91,500.00	105.00	38,430.00	240.00	87,840.00	200.00	73,200.00	300.00	109,800.00
82	CONCRETE FOR COLUMNS ABOVE TOP OF PLATFORM - STATION 55.00	CY	138.00	7,590.00	450.00	24,750.00	280.00	15,400.00	400.00	22,000.00	200.00	11,000.00	500.00	27,500.00
83	CONCRETE FOR MEZZANINE FLOOR SLAB STATION 516.00	CY	115.00	59,340.00	175.00	90,300.00	140.00	72,240.00	180.00	92,880.00	200.00	103,200.00	250.00	129,000.00
84	CONCRETE FOR DOME RELIEF VENTS-STATION 124.00	CY	115.00	14,260.00	225.00	27,900.00	355.00	44,020.00	250.00	31,000.00	200.00	24,800.00	300.00	37,200.00
85	CONCRETE FOR FLOOR SLABS-BOX SECTION-PASSAGES ENTRANCE & SERVICE AREAS 1,627.00	CY	75.00	122,025.00	85.00	138,295.00	110.00	178,970.00	130.00	211,510.00	100.00	162,700.00	120.00	195,240.00
86	CONCRETE FOR EXTERIOR WALLS - BOX SECTION - PASSAGES, ENTRANCE & SERVICE AREAS 1,561.00	CY	115.00	179,515.00	150.00	234,150.00	140.00	218,540.00	100.00	156,100.00	100.00	156,100.00	120.00	187,320.00
87	CONCRETE FOR INTERIOR WALLS - BOX SECTION - PASSAGES, ENTRANCE & SERVICE AREAS 112.00	CY	115.00	12,880.00	300.00	33,600.00	225.00	25,200.00	350.00	39,200.00	100.00	11,200.00	300.00	33,600.00
88	CONCRETE FOR ROOF SLABS - BOX SECTION - PASSAGES ENTRANCE & SERVICE AREAS 2,879.00	CY	115.00	331,085.00	75.00	215,925.00	105.00	302,295.00	80.00	230,320.00	100.00	287,900.00	100.00	287,900.00
89	CONCRETE - CHILLED WATER PLANT 740.00	CY	126.00	93,240.00	110.00	81,400.00	125.00	92,500.00	120.00	88,800.00	100.00	74,000.00	150.00	111,000.00
90	CONCRETE-TRACTION POWER SUBSTATION 2,271.00	CY	126.00	286,146.00	75.00	170,325.00	125.00	283,875.00	80.00	181,680.00	100.00	227,100.00	100.00	227,100.00
91	PVC WATERSTOP-LINE 5,413.00	LF	3.50	18,945.50	3.00	16,239.00	5.00	27,065.00	4.00	21,652.00	5.00	27,065.00	5.00	27,065.00
92	PVC WATERSTOP-STATION 3,763.00	LF	3.50	13,170.50	3.00	11,289.00	5.00	18,815.00	4.00	15,052.00	5.00	18,815.00	5.00	18,815.00
93	PVC WATERSTOP-CHILLED WATER PLANT 132.00	LF	3.50	462.00	3.00	396.00	5.00	660.00	4.00	528.00	5.00	660.00	5.00	660.00
94	PVC WATERSTOP-TRACTION POWER SUBSTATION 684.00	LF	3.50	2,394.00	3.00	2,052.00	5.00	3,420.00	4.00	2,736.00	5.00	3,420.00	5.00	3,420.00
95	STRUCTURAL STEEL 313,718.00	LBS	.69	216,465.42	.50	156,859.00	.50	156,859.00	.60	188,230.00	.50	156,859.00	.50	156,859.00
96	ZINC-COATED MISC. IRON AND STEEL 56,801.00	LBS	1.15	65,321.15	1.00	56,801.00	2.00	113,602.00	1.00	56,801.00	2.00	113,602.00	2.00	113,602.00
97	NON-ZINC-COATED MISC. IRON AND STEEL 270.00	LBS	.86	232.20	1.00	400.00	1.00	270.00	.90	243.00	2.00	540.00	5.00	1,350.00
98	ASBESTOS CEMENT PIPE-8 INCH DIAMETER 2,261.00	LF	21.00	47,481.00	15.00	33,915.00	6.00	13,566.00	45.00	101,745.00	60.06	135,660.03	[illegible]	[illegible]
99	CAST IRON PIPE-2 INCH DIAMETER 90.00	LF	5.00	450.00	25.00	2,250.00	15.00	1,350.00	10.00	900.00	6.00	540.00	25.00	2,250.00

ITEM NO	APPROXIMATE QUANTITY	UNIT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT
100	CAST IRON PIPE-3 INCH DIAMETER 228.00	LF	9.00	1,624.00	25.00	5,700.00	17.00	3,876.00	11.30	2,500.00	6.50	1,482.00	30.00	6,840.00
101	CAST IRON PIPE-4 INCH DIAMETER 2,548.00	LF	12.00	30,576.00	21.00	53,508.00	20.00	50,960.00	16.00	40,768.00	12.00	30,576.00	6.00	15,288.00
102	TRACK MANHOLE-TYPE 1 14.00	EA	920.00	12,880.00	530.00	7,420.00	500.00	7,000.00	400.00	5,600.00	800.00	11,200.00	750.00	10,500.00
103	TRACK MANHOLE FRAME AND COVER 14.00	EA	250.00	3,500.00	280.00	3,920.00	130.00	1,820.00	60.00	840.00	300.00	4,200.00	400.00	5,600.00
104	CLEANOUT-TYPE 1 31.00	EA	86.00	2,666.00	100.00	3,100.00	50.00	1,550.00	40.00	1,240.00	60.00	1,860.00	40.00	1,240.00
105	CLEANOUT-TYPE 2 5.00	EA	86.00	430.00	120.00	600.00	65.00	325.00	100.00	500.00	80.00	400.00	100.00	500.00
106	CLEANOUT-TYPE 3 24.00	EA	86.00	2,064.00	130.00	3,120.00	75.00	1,800.00	100.00	2,400.00	70.00	1,680.00	100.00	2,400.00
107	TRACK DRAIN INLET-TYPE 1 1.00	EA	320.00	320.00	350.00	350.00	100.00	130.00	300.00	300.00	250.00	250.00	300.00	300.00
108	TRACK DRAIN INLET-TYPE 2 30.00	EA	260.00	7,800.00	150.00	4,500.00	100.00	3,000.00	100.00	3,000.00	250.00	7,500.00	100.00	3,000.00
109	TRACK DRAIN INLET-TYPE 3 2.00	EA	140.00	280.00	200.00	400.00	100.00	200.00	110.00	220.00	275.00	550.00	120.00	240.00
110	DRAIN INLET-TYPE 1 3.00	EA	320.00	960.00	370.00	1,110.00	75.00	225.00	300.00	900.00	250.00	750.00	300.00	900.00
111	DRAIN INLET-TYPE 2 7.00	EA	260.00	1,820.00	150.00	1,050.00	75.00	525.00	100.00	700.00	250.00	1,750.00	100.00	700.00
112	DRAIN INLET-TYPE 3 1.00	EA	140.00	140.00	200.00	200.00	[illegible]	100.00	40.00	40.00	90.00	90.00	80.00	80.00
113	FLOOR DRAIN-TYPE 3 1.00	EA	120.00	120.00	125.00	125.00	75.00	75.00	70.00	70.00	75.00	75.00	90.00	90.00
114	FLOOR DRAIN-TYPE 4 12.00	EA	160.00	1,920.00	110.00	1,320.00	75.00	900.00	40.00	480.00	100.00	1,200.00	60.00	720.00
115	FLOOR DRAIN-TYPE 6 3.00	EA	200.00	600.00	200.00	600.00	75.00	225.00	200.00	600.00	150.00	450.00	200.00	600.00
116	FLOOR DRAIN-TYPE 7 10.00	EA	210.00	2,100.00	200.00	2,000.00	100.00	1,000.00	200.00	2,000.00	200.00	2,000.00	200.00	2,000.00
117	FLOOR DRAIN-TYPE 8 9.00	EA	220.00	1,980.00	200.00	1,800.00	100.00	900.00	140.00	1,260.00	150.00	1,350.00	140.00	1,260.00
118	FLOOR DRAIN-TYPE 9 2.00	EA	120.00	240.00	100.00	200.00	100.00	200.00	60.00	120.00	70.00	140.00	60.00	120.00
119	FLOOR DRAIN COVER-TYPE 3 1.00	EA	20.00	20.00	25.00	25.00	100.00	100.00	4.00	4.00	40.00	40.00	10.00	10.00
120	FLOOR DRAIN COVER-TYPE 4 12.00	EA	30.00	360.00	35.00	420.00	100.00	1,200.00	8.00	96.00	50.00	600.00	10.00	120.00
121	FLOOR DRAIN COVER-TYPE 6 3.00	EA	30.00	90.00	60.00	180.00	100.00	300.00	50.00	150.00	50.00	150.00	60.00	180.00
122	FLOOR DRAIN COVER-TYPE 7 10.00	EA	40.00	400.00	30.00	300.00	100.00	1,000.00	14.00	140.00	50.00	500.00	20.00	200.00
123	FLOOR DRAIN COVER-TYPE 8 9.00	EA	40.00	360.00	30.00	270.00	100.00	900.00	12.00	108.00	40.00	360.00	20.00	180.00
124	FLOOR DRAIN COVER-TYPE 9 2.00	EA	20.00	40.00	25.00	50.00	100.00	200.00	10.00	20.00	40.00	80.00	15.00	30.00
125	ROOF DRAIN-TYPE 1 7.00	EA	200.00	1,400.00	150.00	1,050.00	100.00	700.00	120.00	840.00	220.00	1,540.00	130.00	910.00

ITEM NO	APPROXIMATE QUANTITY	UNIT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT
126	ROOF DRAIN-TYPE 4 6.00	EA	200.00	1,200.00	150.00	900.00	100.00	600.00	140.00	840.00	230.00	1,380.00	300.00	1,800.00
127	ROOF DRAIN COVER-TYPE [illegible] 7.00	EA	30.00	210.00	50.00	350.00	100.00	700.00	20.00	140.00	60.00	420.00	200.00	1,400.00
128	ROOF DRAIN COVER-TYPE 4 6.00	EA	30.00	180.00	50.00	300.00	100.00	600.00	20.00	120.00	70.00	420.00	200.00	1,200.00
129	SCUPPER DRAIN-TYPE 2 13.00	EA	150.00	1,950.00	125.00	1,625.00	100.00	1,300.00	60.00	780.00	150.00	1,950.00	300.00	3,900.00
130	SCUPPER DRAIN COVER-TYPE 2 13.00	EA	20.00	260.00	50.00	650.00	100.00	1,300.00	20.00	260.00	70.00	910.00	250.00	3,250.00
131	REINFORCED CONCRETE PIPE-15 INCH DIAMETER, CLASS III SEWER 456.00	LF	29.00	13,224.00	30.00	13,680.00	40.00	18,240.00	80.00	36,480.00	46.00	20,976.00	70.00	31,920.00
132	REINFORCED CONCRETE PIPE - 18 INCH DIAMETER, CLASS III, SEWER 244.00	LF	32.00	7,808.00	35.00	8,540.00	50.00	12,200.00	85.00	20,740.00	52.00	12,688.00	75.00	18,300.00
133	REINFORCED CONCRETE PIPE 24 INCH DIAMETER, CLASS III, SEWER 309.00	LF	37.00	11,433.00	45.00	13,905.00	60.00	18,540.00	110.00	33,990.00	63.00	19,467.00	95.00	29,355.00
134	REINFORCED CONCRETE PIPE-36 INCH DIAMETER, CLASS III SEWER 536.00	LF	41.00	21,976.00	45.00	24,120.00	80.00	42,880.00	80.00	42,880.00	90.00	48,240.00	30.00	16,080.00
135	CAST IRON SOIL PIPE-4 INCH DIAMETER, CLASS SV 15.00	LF	29.00	435.00	30.00	450.00	30.00	450.00	100.00	1,500.00	30.00	450.00	50.00	750.00
136	VITRIFIED CLAY PIPE-10 INCH DIAMETER, EXTRA STRENGTH, SEWER 30.00	LF	29.00	870.00	25.00	750.00	50.00	1,500.00	70.00	2,100.00	35.00	1,050.00	70.00	2,100.00
137	VITRIFIED CLAY PIPE-12 INCH DIAMETER, EXTRA STRENGTH, SEWER 1,886.00	LF	24.00	45,264.00	20.00	37,720.00	60.00	113,160.00	80.00	150,880.00	37.00	69,782.00	80.00	150,880.00
138	VITRIFIED CLAY PIPE-15 INCH DIAMETER, EXTRA STRENGTH, SEWER 1,066.00	LF	32.00	34,112.00	25.00	26,650.00	80.00	85,280.00	100.00	106,600.00	50.00	53,300.00	80.00	85,280.00
139	VITRIFIED CLAY PIPE-18 INCH DIAMETER, EXTRA STRENGTH, SEWER 275.00	LF	41.00	11,275.00	35.00	9,625.00	100.00	27,500.00	105.00	28,875.00	72.00	19,800.00	90.00	24,750.00
140	VITRIFIED CLAY PIPE-21 INCH DIAMETER, EXTRA STRENGTH, SEWER 75.00	LF	52.00	3,900.00	50.00	3,750.00	110.00	8,250.00	140.00	10,500.00	82.00	6,150.00	100.00	7,500.00
141	STANDARD MANHOLE-30" OR LESS TO 12'-0" 76.00	VF	86.00	6,536.00	100.00	7,600.00	120.00	9,120.00	70.00	5,320.00	125.00	9,500.00	120.00	9,120.00
142	STANDARD MANHOLE-30" OR LESS, 12'-1" - 15'-0" 261.00	VF	[illegible]	34,015.00	110.00	28,710.00	140.00	36,540.00	75.00	19,575.00	132.00	34,452.00	125.00	32,625.00
143	STANDARD MANHOLE - 30" OR LESS 15'-1" - 20'-0" 184.00	VF	155.00	28,520.00	120.00	22,080.00	165.00	30,360.00	85.00	15,640.00	140.00	25,760.00	140.00	25,760.00
144	MANHOLE FRAME AND COVER-CAST IRON, 24 INCH DIAMETER 37.00	EA	144.00	5,328.00	200.00	7,400.00	70.00	2,590.00	70.00	2,590.00	175.00	6,475.00	215.00	7,955.00
145	MANHOLE FRAME AND COVER-CAST IRON, 30 INCH DIAMETER 3.00	EA	287.00	861.00	260.00	780.00	150.00	450.00	200.00	600.00	200.00	600.00	280.00	840.00
146	CONNECTION OR RECONNECTION OF HOUSE SEWERS 35.00	EA	400.00	14,000.00	300.00	10,500.00	300.00	10,500.00	1,200.00	42,000.00	350.00	12,250.00	425.00	14,875.00
147	CATCH BASIN-SHALLOW 2.00	EA	1,150.00	2,300.00	650.00	1,300.00	1,000.00	2,000.00	600.00	1,200.00	1,200.00	2,400.00	900.00	1,800.00
148	CATCH BASIN-ELONGATION NO. 1 2.00	EA	1,380.00	2,760.00	450.00	900.00	1,500.00	3,000.00	1,000.00	2,000.00	1,700.00	3,400.00	1,100.00	2,200.00
149	CATCH BASIN CONNECTIONS-15 INCH REINFORCED CONCRETE PIPE, CLASS II 155.00	LF	35.00	5,425.00	30.00	4,650.00	100.00	15,500.00	50.00	7,750.00	75.00	11,625.00	90.00	13,950.00
150	ABANDONMENT OF CATCH BASINS 4.00	EA	460.00	1,840.00	150.00	600.00	400.00	1,600.00	200.00	800.00	800.00	3,200.00	600.00	2,400.00
151	DUCTILE IRON PIPE-6 INCH DIAMETER, WATER MAIN 95.00	LF	23.00	2,185.00	60.00	5,700.00	80.00	7,600.00	80.00	7,600.00	82.00	7,790.00	85.00	8,075.00

ITEM NO	APPROXIMATE QUANTITY	UNIT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT
152	DUCTILE IRON PIPE-8 INCH DIAMETER, WATER MAIN													
	3,377.00	LF	32.00	108,064.00	65.00	219,505.00	85.03	287,045.00	70.00	236,390.00	71.00	239,767.00	110.00	371,470.00
153	DUCTILE IRON PIPE-12 INCH DIAMETER, WATER MAIN													
	1,819.00	LF	48.00	87,312.00	100.00	181,900.00	100.00	181,900.00	90.00	163,710.00	130.00	236,470.00	150.00	272,850.00
154	DUCTILE IRON PIPE-20 INCH DIAMETER, WATER MAIN													
	251.00	LF	69.00	17,319.00	210.00	52,710.00	120.00	30,120.00	120.00	30,120.00	200.00	50,200.00	270.00	67,770.00
155	FIRE HYDRANTS-REMOVE & REINSTALL													
	6.00	EA	630.00	3,780.00	1,500.00	9,000.00	700.00	4,200.00	800.00	4,800.00	1,000.00	6,000.00	3,250.00	19,500.00
156	CONNECTION OR RECONNECTION OF WATER SERVICES													
	1.00	LS	24,000.00	24,000.00	15,000.00	15,000.00	30,000.00	30,000.00	100,000.00	100,000.00	24,000.00	24,000.00	21,500.00	21,500.00
157	VALVE MANHOLE													
	54.00	EA	550.00	29,700.00	500.00	27,000.00	500.00	27,000.00	400.00	21,600.00	600.00	32,400.00	430.00	23,220.00
158	MANHOLE FRAME AND COVER-CAST IRON, WATER													
	54.00	EA	170.00	9,180.00	200.00	10,800.00	100.00	5,400.00	70.00	3,780.00	175.00	9,450.00	105.00	5,670.00
159	UTILITY EXCAVATION													
	6,574.00	CY	32.00	210,368.00	25.00	164,350.00	20.00	131,480.00	20.00	131,480.00	25.00	164,350.00	26.00	170,924.00
160	UTILITY BACKFILL													
	5,723.00	CY	13.00	74,399.00	20.00	114,460.00	12.00	68,676.00	12.00	68,676.00	25.00	143,075.00	20.00	114,460.00
161	AGGREGATE FOR SUBGRADE FOUNDATION													
	100.00	CY	14.00	1,400.00	30.00	3,000.00	20.00	2,000.00	20.00	2,000.00	22.00	2,200.00	25.00	2,500.00
162	METALLIC ELECTRICAL CONDUIT-ALLOY RIGID STEEL, 3/4 INCH DIAMETER													
	2,600.00	LF	2.30	5,980.00	3.00	7,800.00	4.00	10,400.00	2.00	5,200.00	2.00	5,200.00	3.00	7,800.00
163	METALLIC ELECTRICAL CONDUIT-ALLOY RIGID STEEL, 1 INCH DIAMETER													
	16,100.00	LF	3.10	49,910.00	3.00	48,300.00	5.00	80,500.00	3.00	48,300.00	3.00	48,300.00	3.00	48,300.00
164	METALLIC ELECTRICAL CONDUIT-ALLOY RIGID STEEL, 1-1/2" DIAMETER													
	4,500.00	LF	4.50	20,250.00	4.00	18,000.00	5.00	22,500.00	4.00	18,000.00	4.00	18,000.00	3.00	13,500.00
165	METALLIC ELECTRICAL CONDUIT-ALLOY RIGID STEEL, 2" DIAMETER													
	1,000.00	LF	5.70	5,700.00	6.00	6,000.00	6.00	6,000.00	7.00	7,000.00	6.00	6,000.00	4.00	4,000.00
166	METALLIC ELECTRICAL CONDUIT-ALLOY RIGID STEEL, 3" DIAMETER													
	600.00	LF	10.00	6,000.00	10.00	6,000.00	10.00	6,000.00	11.00	6,600.00	15.00	9,000.00	10.50	6,300.00
167	METALLIC ELECTRICAL CONDUIT-ALLOY RIGID STEEL, 4" DIAMETER													
	3,100.00	LF	16.00	49,600.00	15.00	46,500.00	15.00	46,500.00	15.00	46,500.00	20.00	62,000.00	12.00	37,200.00
168	NON-METALLIC ELECTRICAL CONDUIT-POLYVINYL CHLORIDE, 3/4" DIAMETER													
	200.00	LF	1.70	340.00	4.00	800.00	4.00	800.00	1.50	300.00	1.00	200.00	3.00	600.00
169	NON-METALLIC ELECTRICAL CONDUIT-POLYVINYL CHLORIDE, 1 1/2" DIAMETER													
	100.00	LF	3.40	340.00	6.00	600.00	5.00	500.00	3.00	300.00	2.00	200.00	4.00	400.00
170	NON-METALLIC ELECTRICAL CONDUIT-POLYVINYL CHLORIDE, 2" DIAMETER													
	600.00	LF	4.00	2,400.00	6.00	3,600.00	6.00	3,600.00	3.00	1,800.00	3.00	1,800.00	5.00	3,000.00
171	NON-METALLIC ELECTRICAL CONDUIT-POLYVINYL CHLORIDE, 3" DIAMETER													
	2,600.00	LF	7.30	18,980.00	8.00	20,800.00	7.00	18,200.00	12.00	31,200.00	20.00	52,000.00	10.00	26,000.00
172	ELECTRICAL BONDS													
	1.00	LS	11,000.00	11,000.00	20,000.00	20,000.00	15,000.00	15,000.00	6,000.00	6,000.00	10,000.00	10,000.00	3,000.00	3,000.00
173	ELECTRICAL EMBEDDED DUCTS													
	12.00	LF	72.00	864.00	30.00	360.00	100.00	1,200.00	25.00	300.00	50.00	600.00	12.00	144.00
174	CHANNEL INSERTS													
	17,420.00	LF	5.20	90,584.00	4.00	69,680.00	5.00	87,100.00	4.00	69,680.00	8.00	139,360.00	4.00	69,680.00
175	GROUND RODS-1" DIA. X 10 FT. LONG AND ACCESS MANHOLES													
	42.00	EA	142.00	5,964.00	200.00	8,400.00	100.00	4,200.00	150.00	6,300.00	100.00	4,200.00	125.00	5,250.00
176	4/0 CABLE-STRANDED COPPER, 600 VOLT, TYPE RR-USE													
	1,100.00	LF	4.60	5,060.00	7.00	7,700.00	15.00	16,500.00	2.00	2,200.00	3.00	3,300.00	3.00	3,300.00
177	INTERIM ELECTRICAL PLANT-LEFT IN PLACE													
	1.00	LS	50,000.00	50,000.00	60,000.00	60,000.00	72,000.00	72,000.00	50,000.00	50,000.00	20,000.00	20,000.00	90,000.00	90,000.00

ITEM NO	APPROXIMATE QUANTITY	UNIT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT
178	MECHANICAL WORK 1.00	LS	100,000.00	100,000.00	300,000.00	300,000.00	350,000.00	350,000.00	500,000.00	500,000.00	280,000.00	280,000.00	350,000.00	350,000.00
179	TEN INCH PORTLAND CEMENT CONCRETE BASE (UNREINFORCED) 14,516.00	SY	16.10	233,707.60	25.00	362,900.00	18.00	261,288.00	20.00	290,320.00	20.00	290,320.00	20.00	290,320.00
180	PORTLAND CEMENT CONCRETE ALLEY ENTRANCE AND ALLEY PAVEMENT 712.00	SY	11.50	8,188.00	30.00	21,360.00	20.00	14,240.00	27.00	19,224.00	25.00	17,800.00	35.00	24,920.00
181	REINFORCED PORTLAND CEMENT CONCRETE PAVING 494.00	SY	17.20	8,496.80	30.00	14,820.00	20.00	9,880.00	27.00	13,338.00	30.00	14,820.00	25.00	12,350.00
182	MODIFIED ASPHALT CONCRETE BINDER COURSE 14,516.00	SY	1.70	24,677.20	5.00	72,580.00	3.00	43,548.00	2.50	36,290.00	2.00	29,032.00	2.25	32,661.00
183	SHEET ASPHALT SURFACE COURSE 14,516.00	SY	2.30	33,386.80	6.00	87,096.00	5.00	72,580.00	3.00	43,548.00	3.00	43,548.00	2.50	36,290.00
184	ASPHALT FOR TACK COAT 363.00	GALS	.45	163.35	1.00	363.00	1.00	363.00	2.00	726.00	2.00	726.00	5.00	1,815.00
185	TEMPORARY PAVING-UTILITY EXCAVATIONS 200.00	SY	20.60	4,120.00	10.00	2,000.00	15.00	3,000.00	7.00	1,400.00	50.00	10,000.00	15.00	3,000.00
186	FIVE PLY BUILT-UP MEMBRANE-LINE 430.00	SY	15.50	6,665.00	4.00	1,720.00	8.00	3,440.00	18.00	7,740.00	6.00	2,580.00	8.50	3,655.00
187	FIVE PLY BUILT-UP MEMBRANE-STATION 6,780.00	SY	15.50	105,090.00	4.00	27,120.00	8.00	54,240.00	10.00	67,800.00	6.00	40,680.00	4.50	30,510.00
188	FIVE PLY BUILT-UP MEMBRANE-CHILLED WATER PLANT 432.00	SY	15.50	6,696.00	4.00	1,728.00	8.00	3,456.00	10.00	4,320.00	6.00	2,592.00	8.50	3,672.00
189	FIVE PLY BUILT-UP MEMBRANE-TRACTION POWER SUBSTATION 707.00	SY	15.50	10,958.50	4.00	2,828.00	8.00	5,656.00	10.00	7,070.00	6.00	4,242.00	8.00	5,656.00
190	BENTONITE PANEL WATERPROOFING-STATION 4,700.00	SY	13.00	61,100.00	11.00	51,700.00	6.00	28,200.00	9.00	42,300.00	8.00	37,600.00	11.50	54,050.00
191	LIQUID APPLIED WATERPROOFING - 64.00	SY	8.00	512.00	5.00	320.00	10.00	640.00	10.00	640.00	15.00	960.00	15.00	960.00
192	JOINT SEALING-LINE 4,090.00	LF	4.00	16,360.00	4.00	16,360.00	3.00	12,270.00	2.00	8,180.00	9.00	36,810.00	3.00	12,270.00
193	JOINT SEALING-STATION 2,345.00	LF	4.00	9,380.00	4.00	9,380.00	3.00	7,035.00	2.00	4,690.00	9.00	21,105.00	3.00	7,035.00
194	JOINT SEALING-CHILLED WATER PLANT 98.00	LF	4.00	392.00	4.00	392.00	3.00	294.00	2.00	196.00	9.00	882.00	7.50	735.00
195	JOINT SEALING-TRACTION POWER SUBSTATION 114.00	LF	4.00	456.00	4.00	456.00	3.00	342.00	2.00	228.00	9.00	1,026.00	7.50	855.00
196	THREE INCH CONCRETE PROTECTION COURSE-LINE 500.00	SY	8.00	4,000.00	7.00	3,500.00	10.00	5,000.00	10.00	5,000.00	3.00	1,500.00	10.00	5,000.00
197	THREE INCH CONCRETE PROTECTION COURSE-STATION 6,505.00	SY	8.00	52,040.00	7.00	45,535.00	10.00	65,050.00	12.00	78,060.00	10.00	65,050.00	10.00	65,050.00
198	THREE INCH CONCRETE PROTECTION COURSE-CHILLED WATER PLANT 348.00	SY	8.00	2,784.00	7.00	2,436.00	10.00	3,480.00	10.00	3,480.00	3.00	1,044.00	10.00	3,480.00
199	THREE INCH CONCRETE PROTECTION COURSE-TRACTION POWER SUBSTATION 708.00	SY	8.00	5,664.00	7.00	4,956.00	10.00	7,080.00	10.00	7,080.00	6.00	4,248.00	10.00	7,080.00
200	PROTECTION BOARD-LINE 2,027.00	LF	12.00	24,324.00	3.00	6,081.00	20.00	40,540.00	5.00	10,135.00	4.00	8,108.00	3.00	6,081.00
201	PROTECTION BOARD-STATION 792.00	LF	25.00	19,800.00	3.00	2,376.00	20.00	15,840.00	6.00	4,752.00	4.00	3,168.00	5.00	3,960.00
202	PROTECTION BOARD-CHILLED WATER PLANT 49.00	LF	17.00	833.00	3.00	147.00	20.00	980.00	6.00	294.00	4.00	196.00	10.00	490.00
203	PROTECTION BOARD-TRACTION POWER SUBSTATION 60.00	LF	14.00	840.00	3.00	180.00	20.00	1,200.00	6.00	360.00	4.00	240.00	10.00	600.00

ITEM NO	APPROXIMATE QUANTITY UNIT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT
204	BASE FOR PAVEMENTS 3,292.00 CY	13.00	42,796.00	18.00	59,256.00	25.00	82,300.00	17.00	55,964.00	17.00	55,964.00	20.00	65,840.00
205	GRANITE CURB 1,634.00 LF	11.90	10,791.00	25.00	40,850.00	22.00	35,948.00	23.00	37,582.00	20.00	32,680.00	24.00	39,216.00
206	RESET EXISTING GRANITE 3,530.00 LF	9.20	32,476.00	16.00	56,480.00	10.00	35,300.00	14.00	49,420.00	11.00	38,830.00	15.00	52,950.00
207	REMOVAL OF GRANITE CURB 3,530.00 LF	11.50	40,595.00	13.00	45,890.00	5.00	17,650.00	10.00	35,300.00	4.00	14,120.00	11.00	38,830.00
208	ADJUST GRANITE CURB 200.00 LF	10.30	2,060.00	16.00	3,200.00	15.00	3,000.00	14.00	2,800.00	12.00	2,400.00	11.00	2,200.00
209	PORTLAND CEMENT CONCRETE SIDEWALK 8,435.00 SF	15.00	150,402.00	16.00	134,960.00	15.00	126,525.00	16.50	139,177.50	15.00	126,525.00	17.00	143,395.00
210	BRICK SIDEWALK PAVING 364.00 SY	40.00	14,560.00	20.00	7,280.00	20.00	7,280.00	40.00	14,560.00	40.00	14,560.00	50.00	18,200.00
211	REPLACE TREES 74.00 EA	86.00	6,364.00	400.00	29,600.00	200.00	14,800.00	100.00	7,400.00	100.00	7,400.00	200.00	14,800.00
212	UNDERPINNING PILES - 10 3/4 INCH DIAMETER 1,632.00 LF	138.00	225,216.00	200.00	326,400.00	230.00	375,360.00	70.00	114,240.00	42.00	68,544.00	50.00	81,600.00
213	UNDERPINNING PILES - 12 3/4 INCH DIAMETER 7,405.00 LF	144.00	1,066,320.00	200.00	1,481,000.00	230.00	1,703,150.00	70.00	518,350.00	62.00	459,110.00	50.00	370,250.00
214	PAVEMENT MARKING AND STRIPING 3,034.00 SF	2.50	7,585.00	1.00	3,034.00	.50	1,517.00	2.00	6,068.00	1.00	3,034.00	2.00	6,068.00
215	BONDING OF UNDERPINNING AND SOLDIER PILES 1.00 LS	11,000.00	11,000.00	50,000.00	50,000.00	5,000.00	5,000.00	50,000.00	50,000.00	20,000.00	20,000.00	6,000.00	6,000.00
216	FOUNDATION CAISSONS- 18 3/4 INCH DIAMETER 40.00 LF	150.00	6,000.00	200.00	8,000.00	240.00	9,600.00	175.00	7,000.00	200.00	8,000.00	600.00	24,000.00
217	FOUNDATION CAISSONS- 30 INCH DIAMETER 1,072.00 LF	225.00	241,200.00	150.00	160,800.00	330.00	353,760.00	175.00	187,600.00	300.00	321,600.00	600.00	643,200.00
218	FOUNDATION CAISSONS- 36 INCH DIAMETER 543.00 LF	200.00	108,600.00	130.00	70,590.00	325.00	176,475.00	175.00	95,025.00	50.00	27,150.00	600.00	325,800.00
219	FOUNDATION CAISSONS- 42 INCH DIAMETER 200.00 LF	225.00	45,000.00	180.00	36,000.00	430.00	86,000.00	175.00	35,000.00	300.00	60,000.00	600.00	120,000.00
220	FLOATING SLABS-TYPE 1 6,100.00 SF	20.00	122,000.00	20.00	122,000.00	20.00	122,000.00	15.00	91,500.00	20.00	122,000.00	23.00	140,300.00
221	FLOATING SLABS-TYPE 2 31,700.00 SF	20.00	634,000.00	20.00	634,000.00	20.00	634,000.00	15.00	475,500.00	20.00	634,000.00	23.00	729,100.00
222	MILL BUILDING MODIFICATIONS 1.00 LS	150,000.00	150,000.00	300,000.00	300,000.00	150,000.00	150,000.00	400,000.00	400,000.00	250,000.00	250,000.00	800,000.00	800,000.00
223	ELECTRIC DUCT 1-WAY CONC ENCASED 770.00 LF	16.00	12,320.00	35.00	26,950.00	16.00	12,320.00	65.00	50,050.00	10.00	7,700.00	50.00	38,500.00
224	ELECTRIC DUCT 2-WAY CONC ENCASED 90.00 LF	18.00	1,620.00	40.00	3,600.00	22.00	1,980.00	80.00	7,200.00	20.00	1,800.00	54.00	4,860.00
225	ELECTRIC DUCT 4-WAY CONC ENCASED 60.00 LF	21.00	1,260.00	45.00	2,700.00	36.00	2,160.00	140.00	8,400.00	25.00	1,500.00	60.00	3,600.00
226	ELECTRIC DUCT 6-WAY CONC ENCASED 175.00 LF	26.00	4,550.00	50.00	9,750.00	40.00	7,000.00	100.00	17,500.00	40.00	7,000.00	65.00	11,375.00
227	ELECTRIC DUCT 7-WAY CONC ENCASED 20.00 LF	30.00	600.00	60.00	1,200.00	66.00	1,320.00	140.00	2,800.00	100.00	2,000.00	65.00	1,300.00
228	ELECTRIC DUCT 8-WAY CONC ENCASED 400.00 LF	33.00	13,200.00	65.00	26,000.00	46.00	18,400.00	110.00	44,000.00	50.00	20,000.00	70.00	28,000.00
229	ELECTRIC DUCT 9-WAY CONC ENCASED 65.00 LF	37.00	2,405.00	70.00	4,550.00	61.00	3,965.00	130.00	8,450.00	60.00	3,900.00	70.00	4,550.00

ITEM NO	APPROXIMATE QUANTITY	UNIT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT
230	ELECTRIC DUCT 10-WAY CONC ENCASED 215.00	LF	41.00	8,815.00	70.00	15,050.00	63.00	13,545.00	135.00	29,025.00	70.00	15,050.00	92.00	19,780.00
231	ELECTRIC DUCT 12-WAY CONC ENCASED 1,190.00	LF	46.00	54,740.00	80.00	95,200.00	64.00	76,160.00	140.00	156,600.00	80.00	95,200.00	100.00	119,000.00
232	ELECTRIC DUCT 16-WAY CONC ENCASED 50.00	LF	52.00	2,600.00	95.00	4,750.00	104.00	5,200.00	160.00	8,000.00	100.00	5,000.00	100.00	5,000.00
233	ELECTRIC DUCT 22-WAY CONC ENCASED 175.00	LF	57.00	9,975.00	100.00	17,500.00	93.00	16,275.00	165.00	28,875.00	160.00	28,000.00	110.00	19,250.00
234	ELECTRIC DUCT 24-WAY CONC ENCASED 60.00	LF	64.00	3,840.00	105.00	6,300.00	112.00	6,720.00	200.00	12,000.00	180.00	10,800.00	120.00	7,200.00
235	ELECTRIC DUCT 25-WAY CONC ENCASED 10.00	LF	69.00	690.00	110.00	1,100.00	118.00	1,180.00	240.00	2,400.00	190.00	1,900.00	130.00	1,300.00
236	ELECTRIC MH 5'6" X 8'0" 4.00	EA	4,600.00	18,400.00	5,000.00	20,000.00	2,500.00	10,000.00	5,000.00	20,000.00	7,000.00	28,000.00	7,200.00	28,800.00
237	ELECTRIC MH 3'0" X 3'0" 6.00	EA	800.00	4,800.00	1,000.00	6,000.00	1,000.00	6,000.00	1,500.00	9,000.00	900.00	5,400.00	900.00	5,400.00
238	ELECTRIC MH 5'6" X 17'0" 5.00	EA	8,000.00	40,000.00	10,000.00	50,000.00	5,000.00	25,000.00	10,000.00	50,000.00	10,000.00	50,000.00	18,300.00	91,500.00
239	ELECTRIC MH 4'6" X 6'0" DBL ACT FGC 2.00	EA	3,500.00	7,000.00	3,500.00	7,000.00	2,000.00	4,000.00	3,500.00	7,000.00	4,000.00	8,000.00	4,300.00	8,600.00
240	ELECTRIC MH 5'0" X 10'0" DBL ACT FGC 2.00	EA	5,000.00	10,000.00	5,000.00	10,000.00	4,000.00	8,000.00	4,000.00	8,000.00	7,000.00	14,000.00	7,600.00	15,200.00
241	ELECTRIC MH 5'6" X 12'0" DBL ACT FGC 1.00	EA	5,500.00	5,500.00	6,000.00	6,000.00	4,000.00	4,000.00	4,500.00	4,500.00	6,000.00	6,000.00	7,200.00	7,200.00
242	ELECTRIC MH 6'0" X 9'0" DBL ACT FGC 1.00	EA	5,500.00	5,500.00	9,000.00	9,000.00	4,000.00	4,000.00	5,000.00	5,000.00	9,000.00	9,000.00	14,000.00	14,000.00
243	ELECTRIC MH 6'0" X 10'0" DBL ACT FGC 5.00	EA	6,000.00	30,000.00	7,000.00	35,000.00	4,000.00	20,000.00	5,000.00	25,000.00	9,000.00	45,000.00	10,000.00	50,000.00
244	VIBRATION ISOLATION MATERIAL 6,300.00	SF	40.00	252,000.00	4.00	25,200.00	.50	3,150.00	4.00	25,200.00	5.00	31,500.00	25.00	157,500.00
	SUB TOTAL ITEMS 1 THROUGH 244			31,381,650.52		31,343,383.50 (043 written above)		35,888,501.50		37,326,973.00		37,979,200.85		45,678,900.00
301	REMOVE STREETCAR TRACKS 200.00	LF	40.00	8,000.00	50.00	10,000.00	50.00	10,000.00	50.00	10,000.00	100.00	20,000.00	50.00	10,000.00
401	REMOVE TEMPORARY BULKHEAD AT STATION 54+64 1.00	LS	6,000.00	6,000.00	25,000.00	25,000.00	3,500.00	3,500.00	20,000.00	20,000.00	10,000.00	10,000.00	6,000.00	6,000.00
	TOTAL ITEMS 1 THROUGH 401			31,395,650.52		31,078,383.50		35,902,001.50		37,356,973.00		38,009,200.85		45,694,900.00

WASHINGTON METROPOLITAN AREA TRANSIT AUTHORITY,
BID TABULATION

CONTRACT DESCRIPTION FOR THE CONSTRUCTION OF EARTH & ROCK TUNNELS, VENT SHAFTS, SUBSTATIONS, UNDERPINNING, OF

CONTRACT NUMBER 1C0041 SECTION C-4, HUNTINGTON ROUTE.

BID OPENING DATE 3-03-71

ITEM NO	APPROXIMATE QUANTITY	UNIT	WASHINGTON METROPOLITAN AREA TRANSIT AUTHORITY UNIT PRICE	UNIT AMOUNT	JOINT VENTURE OF SHEA-BALL-S&M UNIT PRICE	UNIT AMOUNT	JOINT VENTURE OF S.J. GROVES & SONS CO. & GRANITE CONSTRUCTION CO. UNIT PRICE	UNIT AMOUNT	PETER KIEWIT SONS' CO. UNIT PRICE	UNIT AMOUNT
1	MAINTENANCE AND PROTECTION OF TRAFFIC 1.00	LS	150,000.00	150,000.00	50,000.00	50,000.00	150,000.00	150,000.00	200,000.00	200,000.00
2	NOT USED 0.00									
3	MOBILIZATION AND PREPARATORY WORK 1.00	LS	1,500,000.00	1,500,000.00	1,500,000.00	1,500,000.00	1,500,000.00	1,500,000.00	1,530,000.00	[illegible]
4	CLEARING AND GRUBBING 1.00	LS	4,750.00	4,750.00	200,000.00	200,000.00	25,000.00	25,000.00	303.00	303.00
5	EDWARD JOHNSON HOTEL, UNDERPINNING, SUPPORT AND RESTORATION - CATEGORY I 1.00	LS	700,000.00	700,000.00	200,000.00	200,000.00	430,000.00	430,000.00	93,330.00	400,000.00
6	UNDERPINNING, SUPPORT AND RESTORATION OF STRUCTURES - CATEGORY II 1.00	LS	50,000.00	50,000.00	5,000.00	5,000.00	100,000.00	150,000.00	15,073.33	10,007.00
7	FURNISHING 12" DIAMETER PIPE PILES FOR CATEGORY - I UNDERPINNING 100.00	LF	10.00	1,000.00	10.00	1,000.00	70.00	7,000.00	23.50	2,350.00
8	INSTALLING 12" DIAMETER PIPE PILES FOR CATEGORY - I UNDERPINNING 100.00	LF	200.00	20,000.00	100.00	10,000.00	555.55	55,555.00	412.00	41,235.00
9	REMOVE CONCRETE PAVEMENT 700.00	SY	10.30	9,000.00	12.00	8,400.00	6.33	2,400.00	7.50	5,250.00
10	REMOVE ASPHALT CONCRETE PAVEMENT 300.00	SY	5.00	1,700.00	10.00	3,000.00	2.33	643.00	4.33	1,364.30
11	REMOVE CONCRETE SIDEWALK AND DRIVEWAY 840.00	SY	6.00	5,040.00	6.00	5,040.00	4.03	3,300.00	4.50	3,743.00
12	REMOVE CONCRETE CURB AND GUTTER AND CONCRETE CURB 605.00	LF	10.00	6,050.00	5.00	3,025.00	3.33	1,965.00	2.70	1,636.00
13	REMOVE AND STORE GRANITE CURBING 1,070.00	LF	12.00	12,840.00	12.00	12,840.00	6.03	6,400.00	5.50	5,340.00
14	REMOVE ASPHALT CONCRETE CURB 130.00	LF	3.00	390.00	5.00	650.00	1.33	173.33	1.43	172.00
15	REMOVE AND STORE STONE BLOCK PAVING 67.00	SY	20.00	1,340.00	15.00	1,005.00	3.33	223.33	26.05	1,745.00
16	ABANDON STORM DRAINAGE SYSTEM, SHAFT C4-1 1.00	LS	1,000.00	1,000.00	2,500.00	2,500.00	1,333.33	1,333.30	17,700.33	17,730.00
17	ABANDON STORM DRAINAGE SYSTEM, SHAFT C4-3 1.00	LS	2,000.00	2,000.00	2,500.00	2,830.00	300.33	300.33	15,033.30	15,030.00
18	ABANDON SANITARY SEWER, SHAFT C4-2 1.00	LS	1,000.00	1,000.00	2,500.00	2,503.00	403.33	403.33	[illegible]	[illegible]
19	SUPPORT AND MAINTAIN EXISTING 90" AND 30" SEWERS AT APPROXIMATE STATION 75+20 (NEW HAMPSHIRE AVE. CROSSING) 1.00	LS	30,000.00	30,000.00	10,250.00	10,250.00	25,000.33	25,003.00	10,930.33	10,309.00
20	MAINTAIN AND SUPPORT NEW WATER LINE AT SHAFT C4-1 AND ADJUST AND RESTORE EXISTING 20" W.M. 1.00	LS	5,000.00	5,000.00	2,500.00	2,500.00	1,000.33	1,003.00	2,033.00	2,030.03
21	REMOVE, ADJUST, MAINTAIN AND RESTORE SEWER STRUCTURES AND LINES, SHAFT C4-3 1.00	LS	10,000.00	10,000.00	3,000.00	3,030.00	1,703.33	1,700.03	1,733.33	3,330.00
22	MAINTAIN AND SUPPORT NEW WATER AND SEWER LINES AT SHAFT C4-2 1.00	LS	12,000.00	12,000.00	4,000.00	4,000.00	1,500.33	1,503.03	2,733.00	2,730.00
23	10" WATER LINE MAINTENANCE AND SUPPORT, SHAFT C4-3 1.00	LS	10,000.00	10,000.00	3,500.00	3,500.00	1,500.33	1,503.00	2,433.33	2,400.00
24	TELEPHONE M.H., STANDARD TYPE I, 6'-0" X 6'-0" X 6'-0" 1.00	EA	1,500.00	1,500.00	1,500.30	1,533.00	[illegible]	[illegible]	[illegible]	[illegible]
25	SUPPORT AND MAINTAIN EXISTING TEL. FAC., SHAFT C4-1 1.00	LS	8,000.00	8,000.00	3,500.00	3,500.00	2,500.00	2,533.03	11,033.03	11,033.00
26	REMOVE AND BULKHEAD 12" SEWER, REMOVE 30" STORM SEWER AND MAINTAIN ELECTRIC LINES AND VAULT 1.00	LS	15,000.00	15,000.00	2,000.00	2,000.03	2,130.33	2,100.30	51,530.33	51,530.33
27	6" ASBESTOS CEMENT DUCT, CONCRETE ENCASED 65.00	LF	10.00	650.00	30.00	1,950.00	15.03	955.33	17.33	740.00

ITEM NO	JOINT VENTURE OF MCLEAN GRADING INC AND GROW SHEEHAN WILSON & TUGE, INC. UNIT PRICE	UNIT AMOUNT	JOINT VENTURE OF PERINI CORPORATION, KENNY-DIST AND MORRISON-KNUDSEN CO., INC UNIT PRICE	UNIT AMOUNT	JOINT VENTURE OF SQUARE CONSTRUCTION CO., LAFERA CONTRACTING CO. AND C. SALVATORE & SONS UNIT PRICE	UNIT AMOUNT	S.A. HEALY CO., WASHINGTON, D.C. UNIT PRICE	UNIT AMOUNT
1	200,000.00	200,000.00	125,000.00	125,000.00	400,000.00	400,000.00	300,000.00	300,000.00
2								
3	1,500,000.00	1,500,000.00	1,500,000.00	1,503,000.00	1,500,000.00	1,500,000.00	1,500,000.00	1,500,000.00
4	5,000.00	5,000.00	10,000.30	13,033.03	10,000.00	30,000.00	50,000.00	50,000.00
5	500,000.00	490,000.00	550,000.00	550,003.03	300,000.03	300,000.00	800,000.00	800,000.00
6	1,000.00	1,000.00	85,200.00	93,003.33	10,000.33	50,000.00	100,000.00	100,000.00
7	15.00	1,500.00	10.00	1,000.00	20.03	2,000.00	80.00	8,000.00
8	403.00	40,000.30	160.00	16,003.00	223.03	22,000.00	150.00	15,000.00
9	5.00	3,500.00	20.00	14,030.00	8.03	5,600.00	20.00	14,000.00
10	5.00	1,700.00	10.33	3,000.00	8.33	2,780.05	10.00	5,100.00
11	5.00	4,200.00	13.00	10,920.00	7.00	5,880.00	25.00	21,000.00
12	2.00	1,210.00	5.00	3,025.03	5.33	3,025.00	15.00	9,075.00
13	10.00	10,700.00	10.00	13,750.03	10.03	10,700.00	15.00	16,140.00
14	2.00	260.00	3.00	390.00	2.00	260.00	4.00	520.00
15	10.00	670.00	20.00	1,342.05	15.30	1,005.00	30.00	2,010.00
16	5,000.00	5,000.00	10,000.30	13,003.00	20,000.00	20,000.00	15,000.00	17,000.00
17	2,003.03	2,000.00	15,003.00	15,038.00	15,000.03	15,000.00	5,000.00	5,000.00
18	2,033.03	2,000.00	1,503.00	1,033.00	15,000.33	15,000.00	10,000.00	10,000.00
19	1,003.00	1,000.30	5,000.00	5,033.00	155,030.03	155,000.00	100,000.00	100,000.00
20	1,003.03	1,000.33	2,000.00	2,030.03	10,000.30	10,000.00	20,000.00	20,000.00
21	4,003.03	4,000.00	5,003.33	5,033.33	30,000.00	30,000.03	10,000.00	10,000.00
22	3,003.33	3,000.00	2,000.30	2,033.00	25,000.00	25,030.03	10,000.00	10,000.00
23	1,000.00	1,000.00	2,003.30	2,033.07	8,000.03	8,000.03	10,000.00	10,000.00
24	7,533.03	[illegible]	[illegible]	[illegible]	10,333.33	[illegible]	12,000.00	12,033.00
25	2,000.33	2,000.00	13,033.30	10,003.00	15,300.33	15,000.00	25,000.00	[illegible]
26	10,000.90	13,000.90	15,033.03	15,033.03	52,000.31	50,300.00	25,000.00	25,000.00
27	30.03	1,953.00	53.70	3,453.33	25.33	1,675.03	50.00	3,250.00

ITEM NO	DESCRIPTION	APPROXIMATE QUANTITY	UNIT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT
28	SUPPORT AND MAINTAIN EXISTING ELECT. FAC., AND ADJUST AND RESTORE MANHOLES AT SHAFT CO-1	1.00	LS	8,000.00	8,000.00	10,000.00	10,000.00	7,000.00	7,000.00	14,020.00	14,020.00	6,000.00	7,000.00	10,000.00	10,000.00	15,000.00	15,000.00	15,000.00	15,000.00
29	10" RCP PIPE CLASS IV	315.00	LF	18.00	5,670.00	20.00	6,300.00	18.00	5,940.00	15.00	4,725.00	14.00	4,410.00	21.00	6,615.00	50.00	15,750.00	10.00	3,150.00
30	24" RCP PIPE CLASS IV	204.00	LF	40.00	8,160.00	25.00	5,100.00	18.00	3,672.00	24.00	4,896.00	25.00	5,100.00	45.00	9,180.00	75.00	15,300.00	20.0	4,080.00
31	30" RCP PIPE CLASS IV	190.00	LF	50.00	9,500.00	35.00	6,650.00	23.00	4,370.00	38.00	7,220.00	50.00	9,500.00	62.50	11,875.00	100.00	19,000.00	25.00	4,750.00
32	STANDARD MANHOLE, TYPE I, 30" OR LESS TO 12' DEEP	60.00	VF	100.00	6,000.00	70.00	4,200.00	95.00	5,700.00	162.00	9,720.00	40.00	2,400.00	150.00	9,000.00	125.00	7,500.00	400.00	24,000.00
33	STANDARD MANHOLE, TYPE II, 30"-90" TO 12' DEEP	14.00	VF	150.00	2,100.00	80.00	1,120.00	125.00	1,750.00	162.00	2,268.00	75.00	1,050.00	253.00	3,542.00	150.00	2,100.00	450.00	6,300.00
34	STANDARD DROP MANHOLE, TYPE III, 30"-90" TO 12' DEEP	9.00	VF	170.00	1,530.00	90.00	810.00	180.00	1,620.00	182.00	1,638.00	50.00	450.00	150.00	1,350.00	220.00	1,980.00	350.00	3,150.00
35	STANDARD MANHOLE, TYPE IV, 30" OR LESS TO 12' DEEP	8.00	VF	120.00	960.00	90.00	720.00	160.00	1,280.00	162.00	1,296.00	60.00	480.00	153.00	1,224.00	200.00	1,600.00	400.00	3,200.00
36	MANHOLE FRAMES AND COVERS, CAST IRON, 2' TYPE	9.00	EA	100.00	900.00	80.00	720.00	160.00	1,440.00	156.00	1,404.00	153.00	1,377.00	150.00	1,350.00	200.00	1,800.00	750.00	6,750.00
37	MANHOLE FRAMES AND COVERS, CAST IRON, 3' TYPE	1.00	EA	175.00	175.00	100.00	100.00	210.00	210.00	310.00	310.00	250.00	250.00	250.00	250.00	200.00	200.00	1,000.00	1,000.00
38	MANHOLE FRAMES AND COVERS, CAST IRON 2' TYPE I	1.00	EA	125.00	125.00	100.00	100.00	160.00	160.00	310.00	310.00	200.00	200.00	230.00	230.00	200.00	200.00	800.00	800.00
39	CATCH BASINS, STANDARD TYPE I	2.00	EA	900.00	1,800.00	900.00	1,800.00	900.00	1,800.00	1,620.00	3,240.00	450.00	900.00	1,450.00	2,900.00	1,000.00	2,000.00	3,000.00	6,000.00
40	STANDARD CO-1 CATCH BASIN, TYPE II	1.00	EA	750.00	750.00	400.00	400.00	900.00	900.00	800.00	800.00	500.00	500.00	1,500.00	1,500.00	1,000.00	1,000.00	2,500.00	2,500.00
41	REMOVE AND RELOCATE EXISTING FRAMES & COVERS	3.00	EA	200.00	600.00	50.00	150.00	150.00	450.00	200.00	600.00	1,000.00	3,000.00	100.00	300.00	200.00	600.00	300.00	900.00
42	8" DIA. V.C. PIPE, EXTRA STRENGTH	325.00	LF	15.00	4,875.00	10.00	3,250.00	9.00	2,925.00	18.00	5,850.00	10.00	3,250.00	10.00	3,250.00	25.00	8,125.00	75.00	24,375.00
43	TRENCH EXCAVATION AND BACKFILL	740.00	CY	18.00	13,320.00	20.00	14,800.00	16.00	11,840.00	54.00	39,960.00	30.00	22,200.00	30.00	22,200.00	20.00	14,800.00	50.00	37,000.00
44	GRAVEL BEDDING FOR UTILITIES	90.00	CY	15.00	1,350.00	10.00	900.00	11.00	990.00	16.00	1,440.00	15.00	1,350.00	23.00	2,070.00	20.00	1,800.00	75.00	6,750.00
45	RELOCATE EXISTING WATER METER AND VAULT	1.00	LS	2,500.00	2,500.00	1,000.00	1,000.00	2,000.00	2,000.00	2,000.00	2,000.00	2,000.00	2,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,500.00	1,500.00
46	3/4" DIA. COPPER WATER SERVICE	1.00	LS	1,000.00	1,000.00	2,000.00	2,000.00	3,000.00	3,000.00	2,000.00	2,000.00	2,500.00	2,500.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00	1,000.00
47	6" DIA. DUCTILE IRON PIPE	120.00	LF	15.00	1,800.00	25.00	3,000.00	11.00	1,320.00	36.00	4,320.00	40.00	4,800.00	3.00	360.00	30.00	3,600.00	60.00	7,200.00
48	8" DIA. DUCTILE IRON PIPE	73.00	LF	25.00	1,825.00	30.00	2,190.00	21.00	1,533.00	40.00	2,920.00	45.00	[illegible]	4.00	292.00	35.00	2,555.00	70.00	5,110.00
49	INTERIM ELECTRICAL SERVICE, SUBSTATION	1.00	LS	10,000.00	10,000.00	10,000.00	10,000.00	11,000.00	11,000.00	9,130.00	9,130.00	20,000.00	[illegible]	27,000.00	27,000.00	12,000.00	12,000.00	75,000.00	75,000.00
50	PCC (UNREINFORCED) BASE, 10" DEPTH	327.00	SY	25.00	8,175.00	35.00	11,445.00	37.00	12,099.00	35.00	11,445.00	30.00	9,810.00	16.00	5,232.00	40.00	13,080.00	50.00	16,350.00
51	PCC (UNREINFORCED) BASE, 8" DEPTH	349.00	SY	22.00	7,678.00	25.00	8,725.00	26.00	9,074.00	25.00	8,725.00	19.00	6,631.00	14.00	4,886.00	35.00	12,215.00	25.00	8,725.00
52	REINFORCED PCC PAVEMENT, 7" DEPTH	184.00	SY	30.00	5,520.00	30.00	5,520.00	30.00	5,520.00	29.00	5,336.00	25.00	4,600.00	14.00	2,576.00	40.00	7,360.00	29.00	5,336.00
53	MODIFIED ASPHALTIC CONCRETE BINDER COURSE	64.00	TON	25.00	1,600.00	35.00	2,240.00	32.00	2,048.00	30.00	1,920.00	30.00	1,422.50	22.00	1,408.00	40.00	2,560.00	30.00	1,920.00
54	HOT ASPHALTIC CONCRETE SURFACE COURSE	37.00	TON	45.00	1,665.00	40.00	1,480.00	32.00	1,184.00	30.00	1,110.00	30.00	1,110.00	36.00	1,332.00	45.00	1,665.00	30.00	1,110.00
55	SHEET ASPHALT SURFACE COURSE, 1" THICK	665.00	SY	4.00	2,660.00	3.00	1,995.00	3.00	1,995.00	2.00	1,720.00	2.00	1,330.00	3.00	1,995.00	2.00	1,330.00	3.00	1,995.00
56	ASPHALT CONCRETE CURB	85.00	LF	5.00	425.00	4.00	340.00	4.00	340.00	3.00	255.00	3.00	255.00	8.00	680.00	5.00	425.00	5.00	425.00
57	SHELL AGGREGATE BASE, TYPE I	435.00	CY	12.00	5,220.00	20.00	8,700.00	18.00	7,830.00	17.00	7,395.00	20.00	8,700.00	6.00	2,610.00	20.00	8,700.00	20.00	8,700.00
58	CURB, CONCRETE	300.00	LF	10.00	3,000.00	8.00	2,400.00	8.00	2,400.00	7.50	2,250.00	7.00	2,100.00	9.10	2,730.00	10.00	3,000.00	10.00	3,000.00
59	CURB AND GUTTER, CONCRETE	300.00	LF	12.00	3,600.00	11.00	3,300.00	10.00	3,000.00	9.00	2,700.00	9.00	2,700.00	11.00	3,300.00	15.00	4,500.00	19.90	5,970.00

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ITEM NO	APPROXIMATE QUANTITY / UNIT	DESCRIPTION	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT
60	1,075.00 LF	RESET EXISTING GRANITE CURB	15.00	16,125.00	20.00	21,503.00	19.33	20,675.63	15.03	16,150.00	20.00	21,500.30	22.33	23,650.30	10.03	10,750.00	20.00	21,500.00
61	110.00 LF	FURNISH AND INSTALL GRANITE CURB	23.00	2,530.00	25.00	2,750.00	26.33	2,900.00	25.00	2,750.00	20.03	2,200.00	30.33	3,300.00	20.03	2,200.00	[illegible]	5,500.00
62	67.00 SY	RESET STONE BLOCK PAVING	30.00	2,010.00	30.00	2,010.00	32.00	2,144.00	30.03	2,010.00	30.00	2,010.00	30.00	2,010.00	20.03	1,340.00	50.00	3,350.00
63	10.00 SY	FURNISH AND INSTALL STONE BLOCK PAVING	80.00	800.00	50.00	500.00	52.00	520.00	50.00	500.00	50.00	500.00	35.03	350.30	70.00	700.00	100.00	1,000.00
64	5.00 CY	SAND [illegible]	200.00	1,000.00	180.00	900.00	210.03	1,053.30	150.00	750.00	50.00	250.30	103.30	503.30	200.33	1,000.00	200.00	1,000.00
65	700.00 SF	CONCRETE SIDEWALK, 4"	12.00	8,730.00	20.00	14,560.03	16.03	11,665.03	14.00	10,144.00	20.00	14,500.00	16.30	11,661.33	12.03	8,730.00	20.00	14,000.00
66	1,120.00 LF	FURNISHING PILES, CAST-IN-PLACE, 12" DIA.	5.00	5,600.00	10.00	11,200.00	10.03	11,200.93	2.75	3,080.00	4.00	4,493.00	10.10	11,230.30	10.03	11,200.00	40.00	50,400.00
67	1,120.00 LF	DRIVING PILES, CAST-IN-PLACE, 12" DIA.	12.00	13,440.00	15.00	16,800.00	10.30	11,200.00	15.00	17,300.00	13.00	11,703.30	5.33	5,773.00	5.03	5,600.00	50.00	56,000.00
68	1.00 LS	CONSTRUCTION OF SURFACE SUBSTATION AT SHAFT C6-1	300,000.00	300,000.00	300,000.33	300,003.03	200,000.03	200,030.03	233,333.00	200,003.00	250,000.00	250,000.00	553,300.33	553,033.30	180,000.33	180,000.00	180,000.00	180,000.00
69	1.00 LS	CONSTRUCTION, REMOVAL AND RESTORATION OF TEMPORARY RETURN FAN, FAN AND [illegible]	200,000.00	200,000.00	150,000.00	150,003.00	100,000.00	100,000.33	75,303.00	75,000.00	75,000.00	75,000.00	125,000.33	123,033.00	150,000.03	150,000.00	150,000.00	150,000.00
70	1.00 LS	RESTORATION OF SEAWALL	20,000.00	20,000.00	5,000.00	5,000.00	5,000.30	5,000.00	22,030.30	20,030.00	15,003.09	13,003.30	5,300.33	5,300.33	15,030.03	15,000.00	10,000.00	10,000.00
71	1.00 LS	SHAFT C6-1 AND ADIT	1,800,000.00	1,800,000.00	2,202,000.00	2,202,000.00	1,333,000.00	1,330,303.03	1,133,300.33	1,100,030.30	1,370,030.03	1,300,033.30	2,603,303.33	2,673,003.23	1,755,000.03	1,765,000.00	3,503,000.00	3,000,003.00
72	1.00 LS	SHAFT C6-2 AND ADIT	1,700,000.00	1,700,000.00	1,910,250.00	1,910,250.00	1,510,000.00	1,510,200.03	1,033,033.00	1,030,000.00	1,000,003.30	1,300,333.30	2,533,003.03	2,510,330.00	2,301,400.03	2,301,000.03	2,700,000.00	2,700,000.00
73	1.00 LS	SHAFT C6-3 AND ADIT	1,300,000.00	1,300,000.00	1,400,000.00	1,400,000.00	1,200,000.03	1,200,030.33	1,103,303.00	1,100,000.00	1,300,003.33	1,330,003.30	1,933,033.33	1,403,033.33	2,032,000.00	2,372,000.30	2,000,000.00	2,000,000.00
74	1.00 LS	[illegible] RIVER PUMPING STATION	300,000.00	300,000.00	200,000.00	200,000.00	200,003.33	220,000.03	235,000.00	200,030.00	150,000.30	153,[illegible]	400,000.00	430,003.33	250,300.33	250,000.03	200,000.00	800,000.00
75	500.00 M/GALS	PUMPING FROM TUNNELS DURING CONSTRUCTION	100.00	50,000.00	25.00	12,500.00	1,500.03	750,333.33	733.30	350,030.00	103.30	53,000.00	133.33	53,330.30	450.33	225,000.00	1,500.00	750,000.00
76	1,000.00 LF	OBSERVATION WELLS - INSTALL AND READ	20.00	20,000.00	10.00	10,000.00	40.03	37,403.00	4.00	12,900.00	13.30	10,333.03	33.30	37,333.03	20.33	20,000.00	50.00	70,000.00
77	10.00 EA	OBSERVATION WELLS - REMOVE	200.00	2,000.00	100.00	1,003.33	50.03	900.00	150.00	2,730.30	203.03	3,633.33	333.03	3,303.00	300.30	5,000.00	600.00	10,000.00
78	1.00 LS	SUBWAY DRAINAGE SYSTEM	100,000.00	100,000.00	50,000.00	50,000.03	50,000.03	60,003.30	150,300.00	150,300.00	75,000.33	75,333.33	133,333.33	133,333.30	133,000.33	130,000.00	400,000.00	400,000.00
79	1.00 LS	SUBWAY FORCE MAIN OUTLET	75,000.00	75,000.00	40,000.00	40,000.00	30,000.00	30,300.30	63,000.00	60,030.00	100,003.33	130,333.33	33,333.33	3,333.33	33,000.00	50,000.00	200,000.00	200,000.00
80	1.00 LS	INTERIM DRAINAGE PUMPS LEFT IN PLACE	20,000.00	20,000.00	10,000.00	10,000.00	20,000.03	20,003.30	35,003.30	35,030.30	60,000.03	33,333.33	13,333.33	10,333.33	50,000.00	50,000.00	75,000.00	75,000.00
81	1.00 LS	INTERIM LIGHTING AND POWER SYSTEM LEFT IN PLACE	25,000.00	25,000.00	10,000.00	13,003.30	10,000.03	10,000.33	133,000.00	100,003.30	75,000.30	75,333.33	5,033.33	5,333.33	53,033.33	50,000.00	200,000.00	200,000.00
82	200.00 LF	ROCK TRENCH FOR MAIN TRACK DRAIN, INCLUDING CONCRETE BACKFILL	100.00	20,000.00	75.00	15,000.00	30.33	6,000.00	100.00	20,003.30	300.00	60,033.30	33.33	6,033.33	100.33	20,000.03	135.00	27,000.00
83	10,000.00 LB	SURPLUS STEEL RIB SUPPORTS FOR DIRECT ROCK SUPPORT	.1?	1,030.00	.17	1,030.00	.17	1,930.03	.17	1,030.00	100,000.33	100,303.30	133,303.33	133,333.03	50,000.00	50,000.00	100,000.00	100,000.00
84A	30,000.00 LF	DRILLING PROBE HOLES	10.00	300,000.00	3.00	90,300.03	3.03	90,000.00	1.00	30,003.00	1.33	3,333.30	1.33	33,303.33	0.03	20,000.00	10.00	90,000.00
84B	150.00 LF	DRILLING HOLES FOR EXTENSOMETERS	10.00	1,500.00	3.00	450.00	10.03	1,500.00	10.00	1,500.00	100.33	15,000.10	53.33	12,533.33	100.50	15,000.00	100.00	15,000.00
85	1.00 LS	[illegible] RIVER PUMPING STATION POWER FEEDER	125,000.00	125,000.00	25,000.00	25,000.30	7,500.33	7,503.33	70,100.30	70,100.00	1.03	[illegible]	[illegible]	[illegible]	13.33	10,333.03	5.00	8,300.03
86	5,000.00 LF	DRILLING GROUT HOLES	2.50	12,750.00	15.03	75,000.00	10.33	50,333.33	[illegible]	[illegible]	23.30	200,303.33	13.33	13,333.33	60.33	450,000.00	15.00	100,000.00
87	250.00 EA	CONNECTIONS FOR GROUTING	10.00	2,500.00	50.00	12,500.00	15.33	3,750.30	20.30	5,330.00	3.00	3,333.33	7.33	10,333.33	30.03	72,000.30	1.00	2,000.00
88	1,000.00 LF	GROUT PIPES	7.50	4,000.00	4.00	8,403.00	1.33	1,500.33	5.33	9,330.00		8,333,333.33		11,656,095.93		11,300,377.03		10,950,917.00
89	10,000.00 SACK	CEMENT	10.00	100,000.00	5.00	50,000.00	4.33	96,600.00	23.33	233,333.30	2,000.00	3,050,333.33	1,033.33	3,350,003.33	2,100.33	5,750,003.30	1,253.03	3,070,000.00

ITEM NO	APPROXIMATE QUANTITY	UNIT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT	UNIT PRICE	UNIT AMOUNT
90	SAND 2,000.00	CF	2.50	6,000.00	5.00	12,500.00	2.33	4,662.03	20.00	40,000.00								
	SUB TOTAL ITEMS 1 THROUGH 90			9,085,170.00		9,700,907.03		7,063,045.00		6,722,520.00								
01A	TUNNEL CONSTRUCTION 2,700.00	LF	1,000.00	6,370,000.00	750.00	2,040,000.00			1,551.00	4,259,220.00								
010	TUNNEL CONSTRUCTION 2,700.00	LF	2,210.00	6,000,000.00			2,400.03	6,570,000.03										
020	CONCRETE SAFETY WALK, INCLUDING REINFORCING STEEL AND LAGGING 2,700.00	LF	25.00	50,500.00	10.00	17,400.00			20.00	100,000.00	20.00	54,400.00	35.00	95,900.00	40.3	109,000.00	25.00	40,000.00
030	CONCRETE SAFETY WALK, INCLUDING REINFORCING STEEL AND LAGGING 2,700.00	LF	25.00	60,500.00			20.03	54,000.09										
040	GRAVEL PACKING 50,000.00	CF	2.75	140,500.00	20	10,000.00			2.40	120,000.00	1.50	81,000.00	63	13,203.00	2.03	100,000.00	80	3,000.00
050	CORROSION CONTROL FOR STEEL LINING 1.00	LS	150,000.00	150,000.00			20,000.03	20,300.00										
06A	CEMENT 20,450.00	SACK	10.50	400,000.00	1.00	60,720.00			7.30	277,104.00	2.30	60,700.30	7.20	227,103.03	6.33	120,920.00	6.00	160,640.90
060	GRAVEL PACKING 44,000.00	CF	2.75	121,000.00			33	13,203.00										
06A	SAND 10,000.00	CF	2.50	27,400.00	1.50	10,440.00			7.30	93,000.00	2.00	21,920.00	5.33	55,750.30	5.33	50,000.00	80	8,100.00
060	CEMENT 20,000.00	SACK	12.50	275,000.00			0.33	10,000.07										
06A	GROUT PIPES 1,100.00	LF	2.50	2,750.00	4.00	4,400.00			7.63	8,300.00	1.00	1,103.00	5.30	5,603.03	10.33	11,000.30	6.00	6,600.00
060	SAND 1,000.00	CF	2.50	2,500.00			1.00	1,003.07										
07A	DRILLING GROUT HOLES 2,200.00	LF	3.00	6,600.00	1.00	3,300.00			5.40	10,400.00								
070	CONNECTIONS FOR GROUTING 13,200.00	EA	10.00	132,000.00			5.03	66,000.00			1.00	3,133.00	5.33	16,570.30	1.00	13,200.00	6.00	13,200.00
08A	CONNECTIONS FOR GROUTING 270.00	EA	10.00	2,700.00	20.00	5,030.00			20.33	5,040.00								
90	CONTROL OF GROUNDWATER 1.00	LS	750,000.00	750,000.00	100,000.00	100,000.00	400,000.03	400,000.33	73,000.00	70,000.00	10.00	2,748.03	53.33	13,733.03	100.03	27,400.00	20.00	5,400.00
100	TEMPORARY BULKHEADS 2.00	EA	7,000.00	8,000.00	500.00	1,000.00	2,000.03	4,000.33	4,350.90	14,330.00	500,000.00	502,033.30	333,003.33	333,300.03	32,003.33	32,000.00	1,000,000.00	1,000,000.00
101A	TUNNEL CONSTRUCTION 1,000.00	LF	1,290.00	1,370,010.00	2,500.00	2,072,500.00			2,290.03	2,025,250.00	2,000.00	6,033.30	5,003.33	13,033.00	6,003.33	8,000.00	1,000.00	2,000.00
1010	TUNNEL CONSTRUCTION 1,000.00	LF	2,000.00	2,001,010.00			1,900.03	1,920,200.10			2,000.00	2,130,003.30	2,133.33	2,200,090.33	1,900.00	2,031,100.00	1,290.00	1,320,200.00
1004	STEEL RIB SETS (CIRCULAR OR HORSESHOE) INCLUDING LAGGING, FOR DIRECT EARTH SUPPORT 130.00	SET	1,170.00	150,000.00	1,005.00	162,713.00			500.00	75,000.33								
1020	CONCRETE SAFETY WALK INCLUDING REINFORCING STEEL AND LAGGING 1,000.00	LF	25.00	20,720.00			15.33	10,035.30			1,000.00	170,033.30	1,033.33	110,033.00	403.00	53,000.00	1,000.00	130,000.00
102A	STRUCTURAL STEEL RIB SUPPORTS (CIRCULAR OR HORSESHOE) INCLUDING LAGGING, FOR DIRECT ROCK SUPPORT 170.00	EA	1,170.00	151,200.00	1,005.03	163,775.00			900.00	70,413.00								
1030	CORROSION CONTROL FOR STEEL LINING 1.00	LS	50,000.00	50,000.00			10,000.33	10,000.00			1,000.33	135,033.30	1,333.33	135,003.00	400.33	50,000.00	1,000.00	130,000.00
1004	SURPLUS STEEL RIB SETS FOR DIRECT EARTH SUPPORT 10,000.00	LB	17	1,030.00	17	1,030.03			17	1,030.00								
1040	GRAVEL PACKING 27,000.00	CF	2.75	70,700.00			33	6,700.03			17	1,030.30	17	1,030.33	17	1,010.00	17	1,030.00
1004	ROCK BOLTS, TYPE B 1,000.00	LF	5.73	5,000.00	3.33	3,033.03			5.73	5,733.30								
1050	CEMENT 15,000.00	SACK	12.50	187,500.00			6.33	50,300.30			5.00	5,033.30	5.33	5,303.30	7.05	7,000.00	3.00	3,000.00
1004	WELDED WIRE FABRIC, HEAVY GAUGE FOR ROCK REINFORCEMENT 400.00	SF	4.03	1,000.00	5.00	2,003.00			5.73	2,200.00								
1040	SAND 500.00	CF	2.50	1,250.00			1.33	503.30			1.03	631.30	3.50	1,203.00	5.33	2,000.00	3.00	800.00

ITEM NO	APPROX. QUANTITY / UNIT	UNIT PRICE	AMOUNT	UNIT PRICE	AMOUNT	UNIT PRICE	AMOUNT	UNIT PRICE	AMOUNT	UNIT PRICE	AMOUNT	UNIT PRICE	AMOUNT	UNIT PRICE	AMOUNT	UNIT PRICE	AMOUNT (PAGE 6)
1070	MISCELLANEOUS STEEL FOR ROCK REINFORCEMENT 20,900.00 LB	1.00	20,900.00	.50	10,450.00			.50	10,450.00	.20	4,180.00	.50	10,450.	5.00	104,500.00	3.00	62,700.00
[illegible]	CONNECTIONS FOR GROUTING 5,000.00 EA	10.00	50,000.00			5.00	25,000.00										
[illegible]	CONCRETE SAFETY WALK, INCLUDING REINFORCING STEEL AND LADDERS [illegible] LF	[illegible]	[illegible]	10.00	10,003.00			104.00	115,432.00	20.00	21,300.00	35.00	37,015.00	45.00	47,700.00	20.63	[illegible]
[illegible]	GRAVEL PACKING 10,300.00 CY	[illegible]	[illegible]	1.00	10,300.00			1.00	10,300.00	1.50	15,450.00	.80	8,240.00	2.00	20,600.00	.85	[illegible]
[illegible]	CEMENT 5,000.00 SK	12.00	[illegible]	10.00	50,003.00			1.25	6,250.00	2.00	10,000.00	7.00	35,000.00	4.00	20,000.00	5.00	[illegible]
[illegible]	SAND [illegible] CF	[illegible]	1,100.00	10.00	[illegible]			1.25	550.00	2.00	880.00	6.00	[illegible]	5.00	2,200.00	.20	[illegible]
[illegible]	GROUT PIPES [illegible] LF	[illegible]	[illegible]	4.00	10,000.00			7.60	19,000.00	1.00	2,500.00	6.00	15,000.00	10.00	25,000.00	4.00	10,000.00
[illegible]	DRILLING GROUT HOLES [illegible] LF	[illegible]	[illegible]	1.00	2,500.00			1.00	2,500.00	1.00	2,500.00	5.00	12,500.00	4.00	10,000.00	4.00	10,000.00
[illegible]	CONNECTIONS FOR GROUTING [illegible] EA	10.00	5,000.00	10.00	5,000.00			4.67	2,335.00	10.00	5,000.00	50.00	25,000.00	100.00	50,000.00	20.00	10,000.00
[illegible]	EXCAVATION (OPTIONAL [illegible] SECTION [illegible]) [illegible] LF	[illegible]	[illegible]													[illegible]	[illegible]
[illegible]	ROCK BOLTS, TYPE 2 [illegible] LF	[illegible]	[illegible]													[illegible]	[illegible]
[illegible]	MISCELLANEOUS STEEL FOR ROCK REINFORCEMENT [illegible] LB	1.00	[illegible]													[illegible]	[illegible]
[illegible]	STRUCTURAL STEEL SET SUPPORTS [illegible] INCLUDING LAGGING [illegible] [illegible]	[illegible]	[illegible]													1,000.00	[illegible]
[illegible]	CAST-IN-PLACE CONCRETE LINING, INCLUDING REINFORCING STEEL AND CHANNEL INSERTS [illegible] LF	[illegible]	[illegible]													[illegible]	[illegible]
[illegible]	CONCRETE INVERT, INCLUDING REINFORCING STEEL [illegible] LF	170.00	[illegible]													[illegible]	[illegible]
[illegible]	CONCRETE SAFETY WALK INCLUDING REINFORCING STEEL AND LADDERS [illegible] LF	[illegible]	[illegible]													[illegible]	[illegible]
[illegible]	CEMENT [illegible]	10.00	[illegible]													[illegible]	[illegible]
[illegible]	SAND [illegible] CF	[illegible]	[illegible]													[illegible]	[illegible]
[illegible]	GROUT PIPES [illegible] LF	[illegible]	[illegible]													[illegible]	[illegible]
[illegible]	DRILLING GROUT HOLES [illegible] LF	[illegible]	[illegible]													10.00	[illegible]
[illegible]	CONNECTIONS FOR GROUTING [illegible] EA	10.00	[illegible]													10.00	[illegible]
[illegible]	EXCAVATION (OPTIONAL CIRCULAR SECTION [illegible]) [illegible] LF	[illegible]	[illegible]	[illegible]	[illegible]	750.00	[illegible]	1,020.00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100.00	[illegible]
[illegible]	[illegible] ROCK BOLTS, TYPE 1 [illegible] LF	[illegible]	[illegible]	7.00	[illegible]	4.50	225,000.00	11.00	[illegible]	10.00	[illegible]	10.00	[illegible]	15.50	775,000.00		
[illegible]	MISCELLANEOUS STEEL FOR ROCK REINFORCEMENT [illegible] LB	1.00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	27,000.00	[illegible]	[illegible]	1.00	[illegible]	[illegible]	172,500.00		
[illegible]	STRUCTURAL STEEL SET SUPPORTS [illegible] INCLUDING LAGGING AND REINFORCING STEEL [illegible]	1,150.00	[illegible]	1,000.00	[illegible]	[illegible]	[illegible]	1,500.00	[illegible]	1,500.00	[illegible]	1,000.00	277,000.00	[illegible]	[illegible]		
[illegible]	[illegible] AND SUPPORTS [illegible]																
[illegible]	WELDED WIRE FABRIC [illegible] FOR SHOTCRETE REINFORCEMENT [illegible]	[illegible]	[illegible]	2.50	[illegible]	1.00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	4.00	[illegible]	[illegible]	[illegible]		
[illegible]	SHOTCRETE, CLASS I (MINED TUNNEL) [illegible] CY	[illegible]	[illegible]	153.00	612,000.00	75.00	321,000.00			100.00	[illegible]	200.00	[illegible]	170.00	727,000.00		
[illegible]	SHOTCRETE, CLASS II (MINED TUNNEL) [illegible] CY	[illegible]	[illegible]	153.00	[illegible]	150.00	757,500.00			100.00	[illegible]	200.00	1,010,000.00	100.00	[illegible]		
[illegible]	SHOTCRETE, CLASS II ([illegible] TUNNEL) [illegible] CY	[illegible]	[illegible]					130.00	[illegible]								
[illegible]	CEMENT FOR SHOTCRETE [illegible] SACK	2.00	[illegible]	4.00	272,400.00	[illegible]	[illegible]	1.50	[illegible]	2.00	[illegible]	[illegible]	[illegible]	.15	[illegible]		
[illegible]	ACCELERATING ADDITIVE FOR SHOTCRETE [illegible] LB	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	123,100.00	[illegible]	[illegible]		
[illegible]	CONCRETE INVERT, INCLUDING REINFORCING STEEL [illegible] LF	125.00	[illegible]	[illegible]	[illegible]	75.00	[illegible]	91.00	[illegible]	100.00	[illegible]	100.00	[illegible]	160.00	[illegible]		
[illegible]	CONCRETE SAFETY WALK INCLUDING [illegible] REINFORCING STEEL AND LADDERS [illegible] LF	[illegible]	[illegible]	10.00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	100,000.00	[illegible]	[illegible]	[illegible]	[illegible]		
[illegible]	CHANNEL INSERTS [illegible] EA	[illegible]	[illegible]	10.00	[illegible]	[illegible]	[illegible]	[illegible]	100,000.00	[illegible]	[illegible]	[illegible]	100,000.00	[illegible]	[illegible]		
	TOTAL				[illegible]		[illegible]		[illegible]		[illegible]		[illegible]		[illegible]		[illegible]
	[illegible]				[illegible]		[illegible]		[illegible]		[illegible]		[illegible]		[illegible]		[illegible]

HISTORICAL COST REPORTS

Direct Cost

			Percent
Labor	$ 4,300,977		
Repair Labor	199,279		
		4,500,256	30.4
Equipment		515,112	3.5
Job Materials		2,296,144	15.5
Perm. Materials		816,207	5.5
Subcontract		5,357,741	36.2
Other		1,323,400	8.9
Total Direct Cost		$14,808,860	100%
Job Overhead		1,765,820	11.9
Total Contractor's Cost		$16,574,680	
Contractor's Markup		2,065,595	12.5
Adjustment		332,580	2.0
TOTAL ENG. EST.		$18,972,855	

PARAMETER PRICES

Tunnels

Category	Low Bid %	Low Bid $/LF	High Bid %	High Bid $/LF	Eng. Est. %	Eng. Est. $/LF
Mobilization	--	--	--	--	--	--
Traffic Control & Maint.	--	--	--	--	--	--
Instrumentation	2.1	95.59	1.8	84.96	1.9	90.38
Underpinning	8.8	395.43	6.0	289.10	10.1	487.48
Tunnel Excav., Lining, Conc., Resteel, Cross Passage & Connections	86.2	3876.20	90.0	4343.97	84.4	4061.25
Mechanical Work	0.6	27.16	0.5	24.20	0.3	16.03
Electrical Work	2.0	88.10	1.5	71.02	3.0	143.22
Misc. Steel & Iron	0.3	14.59	0.2	12.00	0.3	17.13
Street Restoration	--	--	--	--	--	--
TOTAL	100%	$4496.20	100%	$4827.90	100%	$4815.50

Notes: Tunnel liners are District-furnished material.
Costs for utilities work and street restoration are included in cost for line and station.

PARAMETER PRICES

Subway Line

Category	Low Bid %	Low Bid $/LF	High Bid %	High Bid $/LF	Eng. Est. %	Eng. Est. $/LF
Mobilization	--	--	--	--	--	--
Traffic Control & Maint.	2.9	199.77	2.2	144.54	1.9	132.04
Instrumentation	1.4	95.65	1.3	85.00	1.3	90.42
Underpinning	1.0	70.37	0.8	52.55	0.9	67.13
Cut-&-Cover Excav. & Sup't	42.2	2884.63	35.3	2272.18	35.6	2545.23
Decking	2.9	194.91	4.8	306.39	4.5	317.18
Backfill	2.7	184.17	2.0	128.01	2.4	171.30
Concrete	20.8	1420.92	28.8	1852.22	24.8	1764.63
Bar Reinf. Steel	7.0	475.09	6.8	437.68	6.7	475.74
Misc. Steel & Iron	2.4	164.91	2.1	135.74	2.7	193.56
Mechanical Work	0.1	6.80	0.1	4.86	--	3.42
Electrical Work	3.9	266.53	3.5	222.82	5.8	410.92
Utilities: Support, Maintain, Restore	10.3	707.22	10.4	670.42	11.1	788.57
Street Restoration	2.4	166.20	1.9	123.42	2.3	161.80
TOTAL		$6,837.18		$6,435.83		$7,121.94
	100%		100%		100%	

PARAMETER PRICES

Underground Station

Category	Low bid %	Low bid $/LF	High Bid %	High Bid $/LF	Eng. Est. %	Eng. Est. $/LF
Mobilization	--	--	--	--	--	--
Traffic Control & Maint.	1.3	199.70	0.9	144.51	0.9	131.99
Instrumentation	0.6	95.69	0.5	85.06	0.6	90.46
Underpinning	2.7	419.14	2.9	475.85	4.2	615.69
Cut-&-Cover Excav. & Sup't	38.1	5943.23	41.2	6694.62	30.6	4455.27
Decking	3.6	567.70	4.8	774.84	5.5	810.12
Backfill	1.6	250.30	1.9	309.31	2.1	298.14
Concrete	24.1	3753.13	22.0	3577.18	23.2	3371.47
Bar Reinforcing Steel	6.0	934.88	5.3	852.30	6.4	932.76
Structural Steel	11.4	1770.60	11.1	1800.51	14.0	2041.13
Misc. Steel & Iron	1.1	174.73	0.9	143.82	1.4	205.14
Mechanical Work	1.3	203.46	1.1	182.77	1.5	218.85
Electrical Work	1.9	305.30	1.8	283.72	2.3	338.88
Utilities: Support, Maintain, Restore	4.5	706.87	4.1	670.13	5	788.23
Street Relocation	1.1	166.12	0.8	123.38	1.9	161.75
Other	0.7	108.77	0.7	112.95	0.8	110.05
TOTAL		$15,599.62		$16,230.95		$14,570.21
	100%		100%		100%	

CONTRACT COST

Total Bid Price	$19,429,000
Change Orders	$ 528,690
Other Changes	$
Actual Cost	$19,957,690 (as of June, 1972)

COMMENTS:

There are 75 contract changes (as of October, 1969). Some of them deal with time extension.

Changes are related to: Closure walls, sewer rearrangements, underpinning modifications, demolition, relocations, modifications to soldier piles, failure to receive tunnel rings, details to sidewalks, emergency bypass. The range of a change order is from $112 to $70,414.

SOIL CONDITION: The upper 25-30 LF consists of sandy soils (sand, clayey sand and gravelly sand). Utilities are located in these materials.

The lower part consists of clayey soils, gravelly soils (silty clay, sandy clay, gravelly clay; clayey gravel, sandy gravel, gravel).

One large lense of organic silty clay is present, too.

UNDERGROUND WATER: Underground water table is 20 to 25 below the surface.

BIDS RECEIVED: December 6, 1966

CONSTRUCTION SCHEDULE: 795 calendar days

NOTICE TO PROCEED: February 1, 1967

CONTRACT ACCEPTED: October 20, 1969

EXTENSION OF TIME: 184 calendar days

LIQUIDATED DAMAGES:

LOW BID: $ 19,428,625

ENGINEER'S ESTIMATE: $ 18,972,855

30% ESTIMATE:

85% ESTIMATE:

RE-ESTIMATE: $ 18,523,000 (July, 1966)

COMPOSITE REPORT: $ 9,446,000

HISTORICAL COST REPORT

CONTRACT:	1K0016
ENGINEER:	Parsons Brinckerhoff, Quade & Douglas and Bechtel
TITLE OF CONTRACT:	Subway structures, 12th Street Oakland Station and Broadway tunnels, Oakland downtown line.
DESCRIPTION OF WORK:	The work includes the construction of the 12th St. Oakland Station--a three level station. L = 838 LF Subway line structure: L = 216 LF. Triple bored tunneled subway: L = 1085 LF. Both the station and line section are constructed by cut-and-cover method. Construction is principally of reinforced concrete with structural steel framing for the subway station. Tunnels are driven by using a shield method and protected by District-furnished segmented steel tunnel rings. The work also includes earthwork, underpinning of existing buildings and structures, utility relocation, temporary decking, protection of existing facilities, electrical and mechanical work and street restoration.
GENERAL TYPE OF AREA:	Project is located in Oakland downtown area. The construction extends from a point approximately midway between 10th and 11th Streets and continues to Broadway to the north of 17th Street.
WORK AREA:	Entire right-of-way of Broadway and off street area between 9th and 10th Streets and Broadway and Franklin Streets.
TRAFFIC CONTROL & MAINTENANCE:	During the construction time all bus and other traffic was maintained on minimum three 10' lines open at all times between the hours 6:00 am and 10:00 pm. At other times, Broadway may be closed to traffic but not more than one block. Traffic control, detour signs, sidewalks and access and cross streets were provided and maintained at all times.

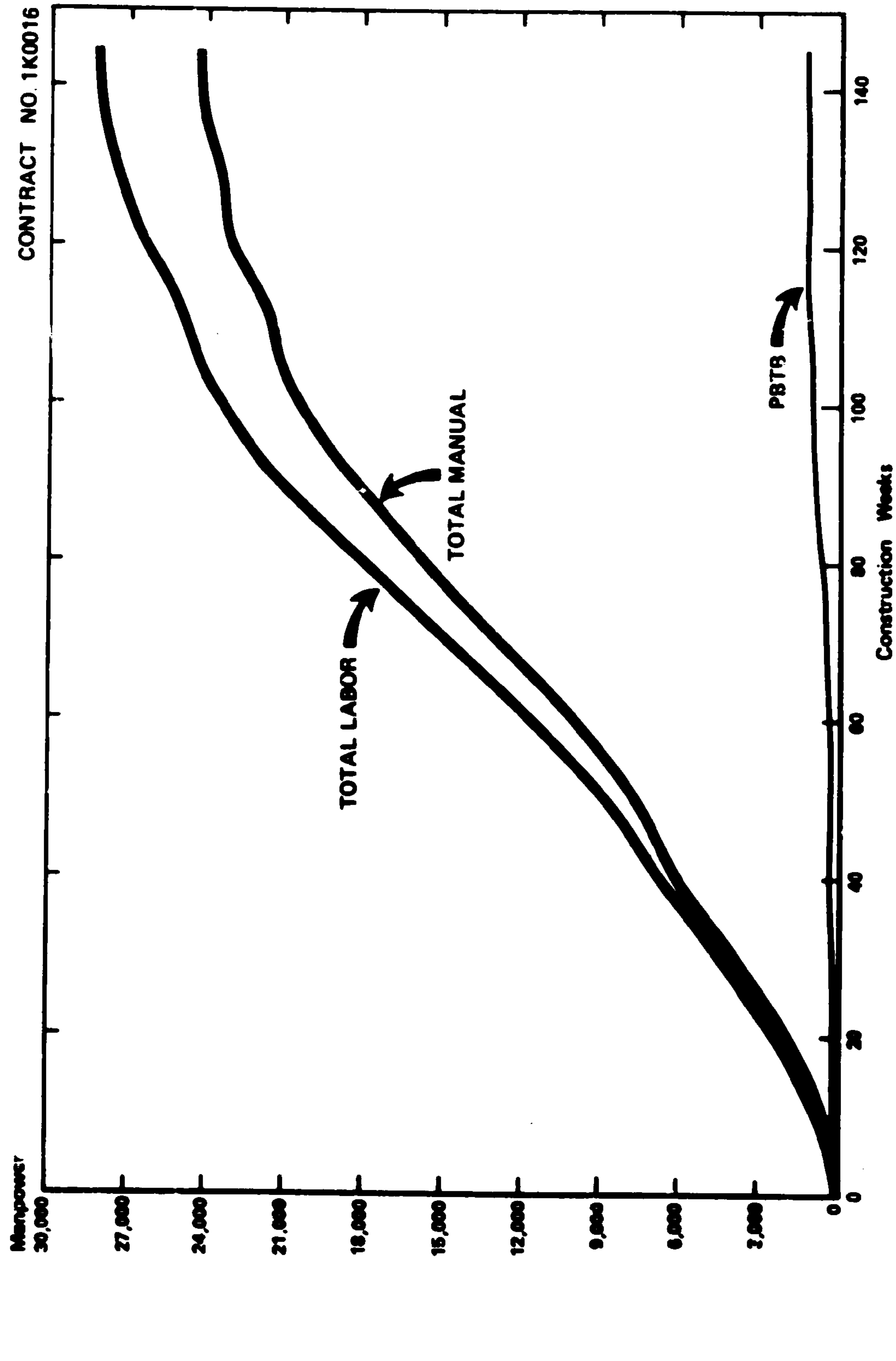
DESIGNATION OF SUBCONTRACTORS

In compliance with the provisions of Sections 4100-4113, inclusive, of the Government Code of the State of California, which provisions are hereby incorporated herein, and any amendments thereof, each Bidder shall set forth below: (a) The name and the location of the place of business of each subcontractor whom the Bidder proposes to have perform work or labor or render service to him in or about the construction of the work in an amount in excess of one-half of one per cent of the Bidder's total bid; and (b) the portion of the work which will be done by each such subcontractor.

LIST BELOW THE NAME AND LOCATION OF THE PLACE OF BUSINESS OF EACH SUBCONTRACTOR AND THE PORTION OF THE WORK TO BE DONE BY EACH SUBCONTRACTOR:

	Name of Subcontractor	Location of Place of Business	Portion of the Work
(1)	Judson Steel Company	Berkeley, California	Reinforcing Steel
(2)	Del Monte Electrical Corp.	Hayward, California	Electrical
(3)	Monterey Mechanical Co.	Oakland, California	Mechanical
(4)			
(5)			
(6)			
(7)			
(8)			
(9)			
(10)			
(11)			
(12)			
(13)			
(14)			
(15)			
(16)			
(17)			
(18)			
(19)			

MANPOWER GRAPH



HISTORICAL COST REPORT

CONTRACT: 1S0022

ENGINEER: Bechtel Corporation.

PRIME CONTRACTOR: Morrison Knudsen, Brown & Root and Perini Co. (Joint Venture)

TITLE OF CONTRACT: Subway structures, 8th Street to 15th Street, San Francisco Market Street Line.

DESCRIPTION OF WORK: This contract is part of the District's San Francisco Downtown Subway System, extending from Station 397+44.367 on the SR line, at a point just south of 15th St. at Mission St., and continuing along Mission and Otis Sts. on tangent and then on a curve to Market St. and along Market St. on tangent to the end of the contract at Station 448+64.167 just east of 8th St. The work includes construction of subway line tunnels of approximately 5,100 LF of SR line and 5,130 LF of SL line; placing of tunnel invert and walkway concrete; construction of a vent and pump shaft; mechanical and electrical work; and installation of District-furnished fans and pumps.

GENERAL TYPE OF SOIL & WATER CONDITIONS: Brown clayey to brown fine sand and red brown to grey to black sandy clay, ranging from medium to very dense. Water was encountered at depths between 10' to 20'.

BIDS RECEIVED: September 23, 1966

NOTICE TO PROCEED: January 9, 1967

SCHEDULED COMPLETION: March 28, 1969

SUBSTANTIAL COMPLETION: April 10, 1970

CONTRACT ACCEPTED: April 27, 1970

EXTENSION OF TIME Yes

TUNNEL CONSTRUCTION

9-23-66(BARTD-SUBWAY&STRUCS.,MARKET ST. LINE,CONTR.NO. 1S0022)
SAN FRANCISCO,CALIF.(UNIT & TOTAL BIDS RECEIVED,TAKEN UNDER ADVISEMENT)

MORRISON-KNUDSEN CO.,INC.,BROWN&ROOT,INC.&PERINI CORP.(JV),8610 ATLANTIC AVENUE, SOUTH GATE,$17,763,825 LOW TO S.F.BAY AREA RAPID TRANSIT DIST.,814 MISSION STREET, S.F.,FOR CONST.SUBWAY STRUCS.,8TH ST.TO 15TH ST.ON THE DIST'S.S.F. MARKET STREET LINE IN S.F. CONTRACT NO. 1S0022.

(1)MORRISON-KNUDSEN CO,INC.,BROWN&ROOT INC.,&PERINI CORP(JV)-LOW- $17,763,825

(2)WINSTON BROS,FRED J.EARLY JR.CO,INC., &S&M CONST.CO,KEMPER CONST.CO., L.A. $19,703,247

(3)MCLEAN-GROVE&SHEPHRED,N.Y. $20,755,420

ENGINEER'S ESTIMATE $20,341,517

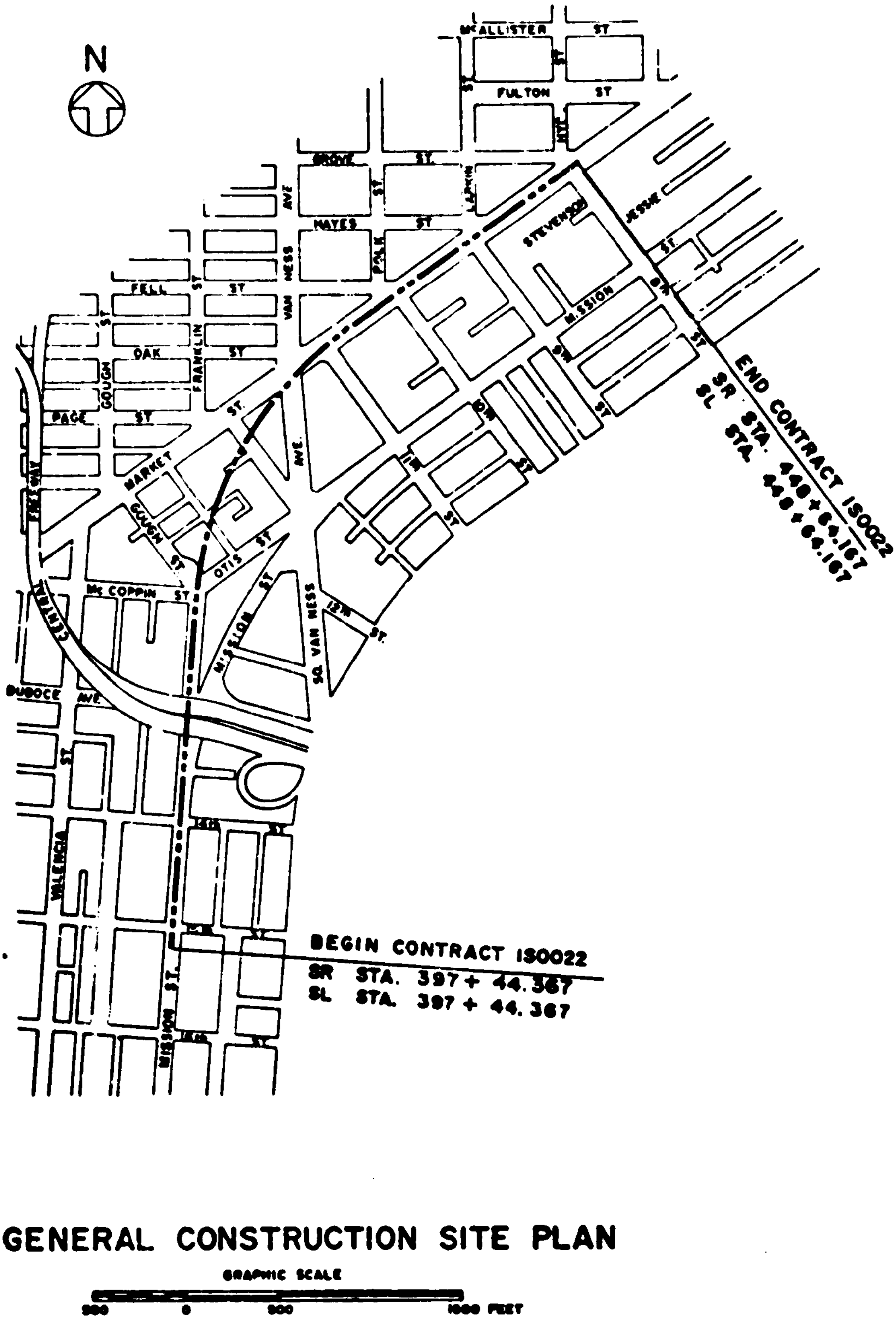
-CONTINUED IN NEXT COLUMN-

	(1)	(2)	(3)
L.S.,MOBILIZ.& PREP.WORK	$1,000,000	$1,000,000	$1,000,000
500 EA.SETTLEMT.MEAS. POINTS	200.00	38.00	10.00
L.S.,PROTECTIVE WORK	$5,000	$3,500	$10,000
L.S.,SUPPT.WORK EQUIP	10,000	$7,000	$10,000
OPTION A			
2,330 CY.EX.EXTERIOR	85.00	130.00	200.00
3,820 CY.STRUC.EX.	6.00	10.00	150.00
2,220 CY.CL.3000 CONC.	90.00	132.00	250.00
440 CY."4000"CONC.	70.00	100.00	100.00
262,000 LB.FAB.JT.MBRS.	.40	.61	.50
61,300 LB.STL.STRUTS	.60	1.00	.50
343,000 LB.REINF.STL.	.25	.50	.25
170 CY.CONC,PUMP&VENT SHAFT WALLS	250.00	135.00	200.00
180 CY.CONC.SAME SUPPTG.SLABS & BEAMS	250.00	75.00	200.00
73,500 LB.STEEL	.25	.33	.25
SUBTOTAL OPTION A	$784,785	$1,131,465	$1,973,775
2,800 LFT.OBSVN.WELLS	10.00	6.70	10.00
30 EA.MAINTAIN SAME	$3,000	490.00	100.00
30 EA.REMOVE SAME	200.00	92.00	30.00
3 CY."3000"CONC.	300.00	170.00	300.00
10,228 LFT."2500"CONC.	60.00	58.50	125.00
10,228 LFT.SUBWAY TNL.	$1365	$1,577	$1,480
L.S.,CROSS PASSAGE, STA.SR403+76	$45,000	$45,000	$70,000
LS,SAME,SR410+04	$45,000	$45,000	$70,000
L.S.,CROSS PASSAGE, STA.SR416+32	$45,000	$45,000	$70,000
L.S,SAME,SR428+55	$45,000	$50,000	$90,000
L.S.,SAME,SR435+58	$45,000	$60,000	$90,000
L.S.,SAME,SR442+07	$45,000	$60,000	$90,000
2 EA.TERMINAT.TUNNELS, 8TH STREET	$120,000	$7,350	$75,000
2 EA.SAME,15TH ST.	$60,000	$8,430	$75,000
8 EA.TUNNEL SEALS	$4,000	$4,530	$10,000
47,200 LB.MISC.STEEL & IRON	1.50	1.04	1.25
1 EA.MANHOLE FRAMES & COVERS	300.00	430.00	500.00
L.S.,FIRE PROTECT. SYSTEMS	$50,000	$46,900	$25,000
L.S.,DRAINAGE SYSTEMS	$20,000	$17,000	$35,000
L.S.,VENTILATION SYSTEMS	$12,000	$9,900	$15,000
61,650 LFT.4"EMBED.NON-MTL.CONDUIT	1.00	.80	.70
40 EA.WALKWAY PULL-BOXES	$1,000	900.00	500.00
L.S.,ELECTRICAL WORK	$150,000	$140890	$170000
7 EA.METAL DOORS, TYPE A	700.00	660.00	250.00
14 EA.METAL DOORS, TYPE B	900.00	765.00	250.00
L.S.,1ST AID FACILS.	$80,000	$40,000	$75,000

CHANGE ORDERS
BART PROJECT 1S0022

No.	Description	Amount $
1	Delete Bid Item #40, Medical & First Aid Facilities	(80,000)
2	Furnishing, installation and reading	33,710
3	Furnish and install boxes for train control	10,200
4	Miscellaneous	217,255
5	Miscellaneous architectural and electrical work	16,830
6	Construct 4 cross passages & provide misc. equipt.	(89,894)
7	Furnish and install metal doors and frames	(2,633)
8	Providing sealing around cross passage framing	4,433
9	Relocate temporary electrical work	806
10	Provide bonding bars in steel lined tunnel	5,750
11	Install guy pole and support sign	162
12	Install 2 additional soldier beams	6,965
13	Remove underground storage tank	710
14	Sample test and removal of solvent	4,683.73
15	Drive a portion of tunnels in free air	(7,178)
16	Repair street surface	631.54
17	Furnish and install rubber gasket	298
18	Modify electrical installation	4,448
19	Repair and redrill improperly drilled tunnel ring segments	121
20	Relocate pump discharge pipe and modify gratings	262
21	Split dry standpipe inlet box covers	949
	TOTAL	$607,572.27

Note: Figures in brackets are credits (deductions).



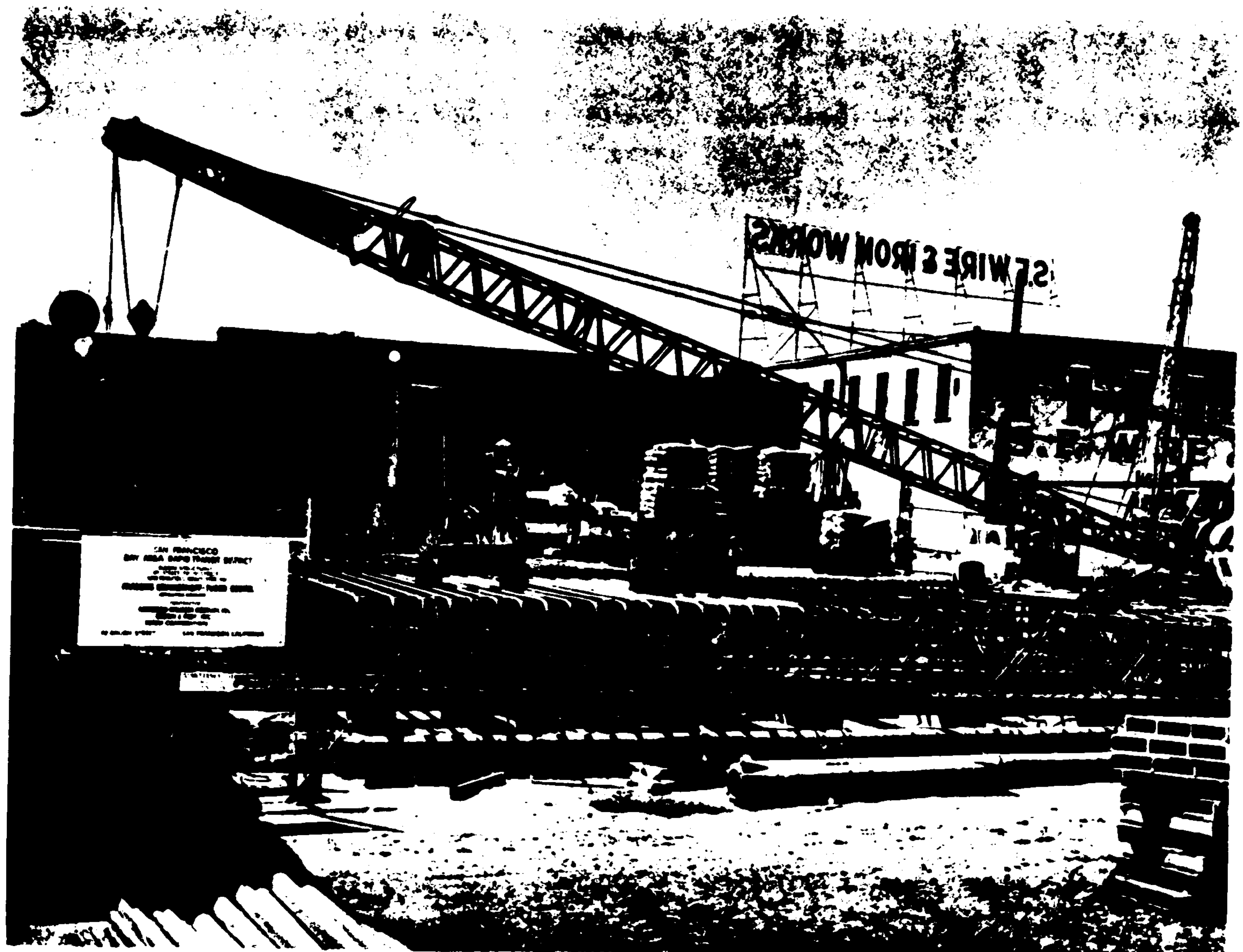
GENERAL CONSTRUCTION SITE PLAN

GRAPHIC SCALE

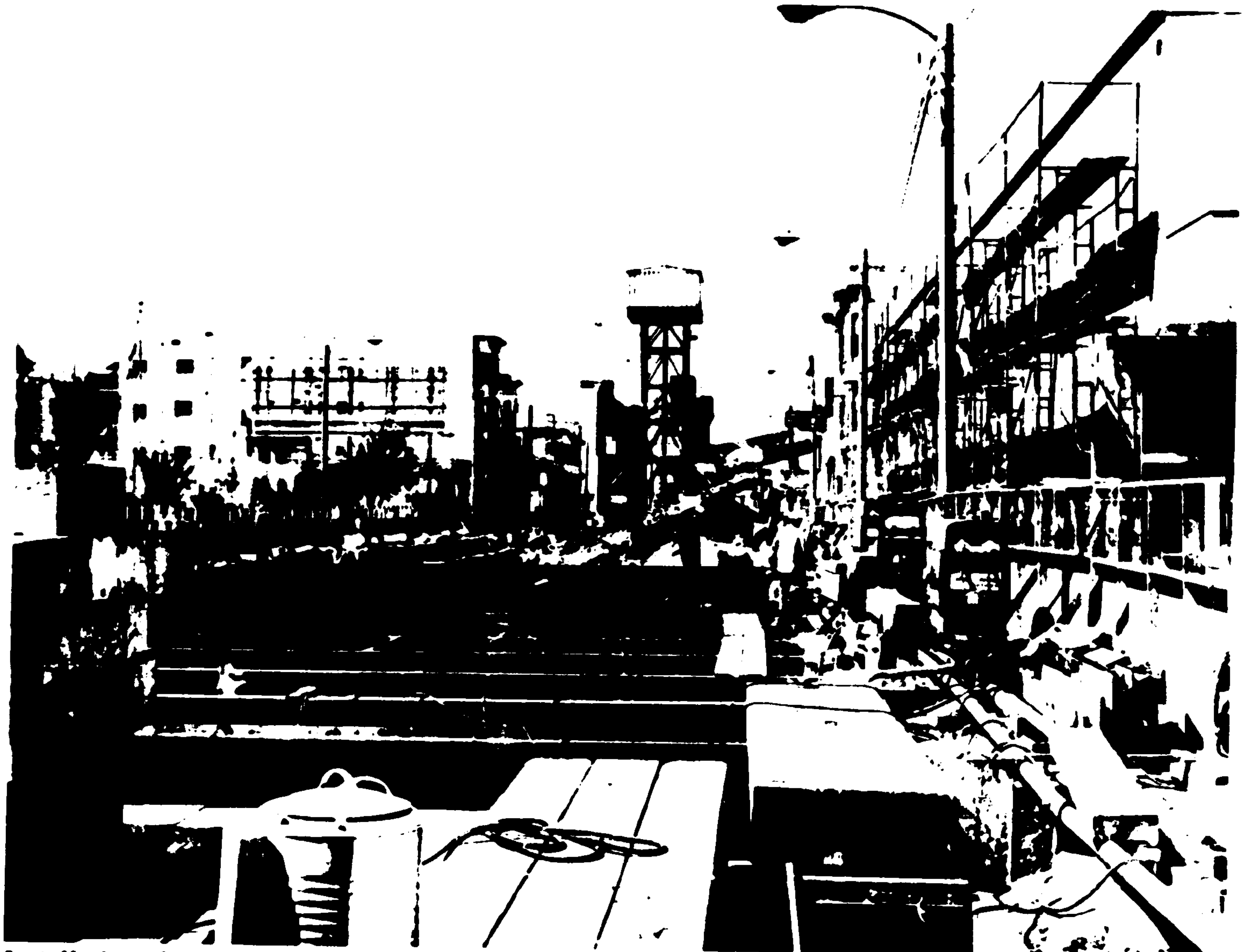
View looking into tunnel portals from 15th Street access shaft, showing airlock installation on left. Access to the manlock is above the materials lock. Contract 1S0022, Subway Structures, 8th to 15th Street.

Dashed line indicates route of rapid transit subway as it leaves Market Street and progresses toward Mission Street. Crane boom at center of picture is on the vent shaft construction site. Contract 1S0022, Subway Structures, 8th to 15th Street.

Site of the Vent Structure being constructed by the slurry-wall method. Contract 1S0022, Subway Structures, 8th to 15th Streets.

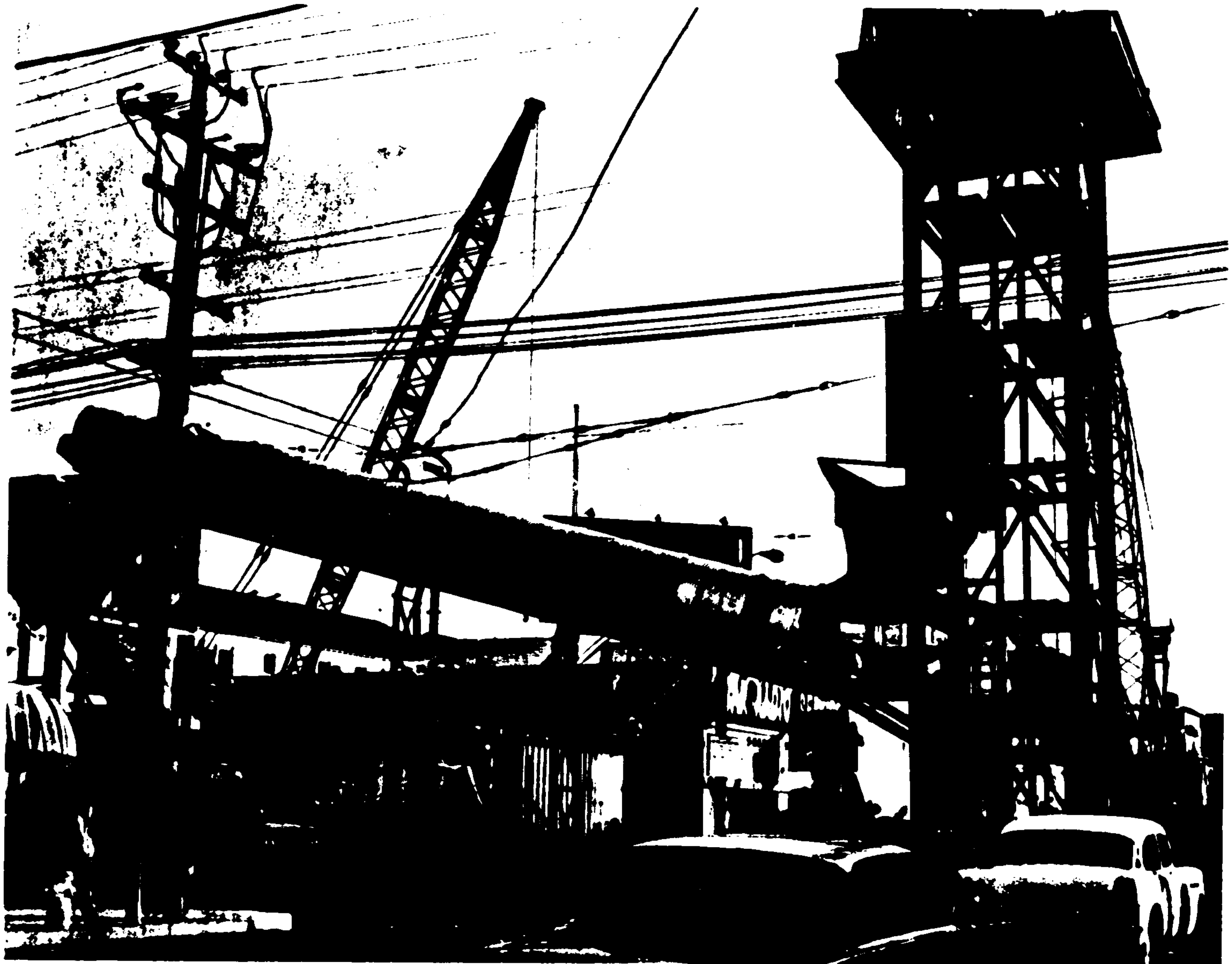


Reinforcing steel cages for construction of slurry-wall vent structure. Contract 1S0022, Subway Structures, 8th to 15th Streets.



Installation of street decking at the site of the contractor's access shaft, located at 15th and Mission Streets. Contract 1S0022, Subway Structures, 8th to 15th Streets.

Fabricated-steel tunnel-liner segments are temporarily stored in the center of Mission Street near the contractor's tunnel access shaft. Contract 1S0022, Subway Structures, 8th and Market to 15th and Mission Streets.



Tunnel muck is hoisted to the surface and stored in a 100-ton bin at the contractor's access shaft at 15th and Mission. Contract 1S0022, Subway Structures, 8th and Market to 15th and Mission.

Revised as of 6/30/72

HISTORICAL COST REPORT

CONTRACT:	1S0031
ENGINEER:	Bechtel Corporation
TITLE OF CONTRACT:	San Francisco-Outer Market Street Line; Van Ness Avenue Station to Duboce Portal.
DESCRIPTION OF WORK:	This contract is a part of the District's system to house the San Francisco Municipal Railway located within the City and County of San Francisco, and lying in Market St. between approximately Duboce Ave. and Van Ness Avenue. The contract consists of 3,516 LF of cut-and-cover subway structures located between the west wall of Van Ness Ave. Station and just west of Duboce Ave. turnout, and a ramp connection approximately 900' in length in Duboce Ave. for transition of streetcars from surface to underground operations.
BIDS OPENED:	May 12, 1970
NOTICE TO PROCEED:	June, 1970
SCHEDULED TIME:	1,040 Calendar days
EXTENSION:	54 Calendar days
LOW BID:	$10,967,444
NO. OF BIDDERS:	10
NAME OF CONTRACTOR:	Fruin-Colnon Corporation, Dravo Corporation.
ENGINEER'S ESTIMATE:	$12,148,105
DISTRICT TARGET:	$ 8,545,000
COMPOSIT REPORT:	$ 9,917,000 (1962)
PROJECT ESTIMATE:	$ 9,408,000
85% ESTIMATE:	$12,853,000
PRE-FINAL ESTIMATE:	$12,760,000
TOTAL CHANGE ORDERS:	$ 920,840
ACTUAL COST:	$11,888,284 (As of June 30, 1972)

TUNNEL CONSTRUCTION

5-12-70(BARTD-SUBWAY STRUC., VAN NESS STA.TO DUBOCE PORTAL, NO.1S0031)
SAN FRANCISCO, CALIF. (UNIT AND TOTAL BIDS RECEIVED, TAKEN UNDER ADVISEMENT)

Fruin-Colnon Corp., Dravo Corp., (Jv), Box 3704, Hayward $10,967,444 low to S.F.BARTD, Recept.Rm.5th Flr., 814 Mission St., S.F., for const.subway struc.betw. Van Ness Sta.&Duboce Portal on the Dist's Outer Market St.line. Contr.#1S0031.

(1)Fruin-Colnon Corp., Dravo Corp.(Jv) Hayward - LOW $10,967,444
(2)J.F.Shea Co., Inc.P&Z Co., Inc.(Jv) Oakland $11,373,505
(3)Massman Const.Co., S.Leandro $11,551,105
(4)Gordon H.Ball, Inc., Homer J.Olsen, Homer J.Olsen, Inc.(Jv)Danville $11,911,875
-continued in next column-
(5)Perini Corp., S.F. $12,139,322
(6)Peter Kiewit Sons Co., Omaha $12,289,277
(7)Morrison-Knudsen Co., Inc.Boise12,676,450
(8)Fred J.Early, Jr.Co., Inc., Winston Bros. Co., Donald M.Drake Co., S.F.13,275,750
(9)Granite Const.Co., Watsonville$13,322,140
(10)MacLean Grove&Co.Inc.New Yrk$19,371,710
Engineer's Estimate $12,148,105

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
L.S., mobiliz &prep. work	250000	250000	250000	250000	250000	250000	250000	250000	250000	250000
L.S.traf.maint.&cntrl	180000	200000	200000	500000	124600	76,505	145000	160000	150000	75,000
L.S.bulkhead E.end	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000	30,000
L.S.same, W.end	20,000	10,000	20,000	30,000	36,000	12,000	24,000	10,000	50,000	30,000
L.S.Muni.Railway) track facil.)	1,080,264	914342	80,000	250000	600000	500000	880000	700000	780000	750000
L.S.same, perm.	230000	200000	493370	250000	320000	706307	350000	150000	250000	750000
2,000 SY decking	98 00	150 00	100 00	75 00	264 00	125 00	200 00	200 00	200 00	150 00
152,100 cy.excav.	20.00	19 38	20.00	20 00	22 00	21 50	24 00	28 00	34.00	38 00
51,100 cy.bkfl.	6 00	5 50	8 00	4.00	9 25	6 80	5 00	10 00	6 00	15.00
6 ea.incl.casings	600.00	$1,500	600.00	$2,000	750 00	$1,200	$1,800	$2,000	650 00	$1,500
60 ea.bracing instr.	375 00	500 00	375.00	270 00	500 00	310 00	650 00	600.00	400.00	$1,500
1,500 lft.observ.wells installation type I	4 25	5 00	5 00	5.00	5 00	25 00	8 00	9.00	5 00	7.00
650 lft.same, ty.II	4 70	6 00	10 00	6 00	6 00	30 00	9 00	10 00	6.00	8.00
1,000 well mo.maint.observ. wells	8 50	10 00	15 00	1 00	63 00	25 00	30 00	10 00	15 00	10.00
44 ea.rmv.wells	130 00	20 00	100 00	1 00	60 00	50 00	130 00	100 00	50.00	10.00
178 cy.crb.gtrs.isl	60.00	70 00	60 00	75.00	75 00	140 00	75 00	80 00	70.00	70.00
260 cy.sdwlk.drvwy	60 00	80 00	60 00	80 00	75 00	140 00	75 00	80 00	70 00	60.00
1,570 cy.aggr.base	17 00	17 00	17 00	20 00	21 00	21 00	20 00	15 00	20 00	20.00
23,460 SY Cl.3000 conc.base 8" thick	10 00	9 00	10 00	10 00	8 00	13 00	12 00	10 00	10 00	10 00
21 T liq.asph.	200 00	150 00	200 00	100 00	240.00	300 00	250 00	200.00	200 00	200.00
21 T asph.emuls	200.00	100 00	200 00	150 00	240.00	300 00	250 00	200.00	200 00	200 00
3,020 T aggr.	15 00	16 00	16 00	16 00	20 00	40 00	20 00	15 00	16 00	17 00
180 T pav.asph.	15 00	16 00	16 00	16 00	20 00	40 00	20.00	15 00	16.00	17.00
5,250,000 lb. bar reinforcing steel	13	13	13	13	17	14	14	.14	13	15
13,850 cy.Class 4000 conc., subway, struc., grade slab	54.00	55 00	50 00	50 00	40 00	65 00	50 00	80 00	45 00	100.00
9,000 cy.same, exterior walls	54 00	55 00	80.00	50 00	76 00	95.00	65 00	80 00	60.00	150.00
1,250 cy.same, interior walls	54 00	55.00	80 00	50 00	134 00	130 00	110.00	80 00	60 00	150 00
12,650 cy.same, supptd.slabs & beams	54.00	55 00	80.00	50 00	56 00	65 00	40 00	80.00	50 00	150.00
27,000 lft.watersteps	1 70	.50	1 00	1 00	2 20	2.00	2.00	5 00	3.00	2.00
43,100 lb.misc.steel&iron & struc. steel	1.00	1.50	1.00	1.00	1 12	1 80	90	1.50	1 20	1 00
760 lft.parapet rail, Duboce Portal	7.00	8 50	10.00	15 00	15 00	16 00	12 00	20 00	20 00	50.00
5 ea.stl.door	485.00	500 00	750.00	450.00	460 00	600 00	500.00	800.00	500.00	500.00
10 ea.same, ty.D	625.00	850.00	750 00	600 00	846 00	$1,000	500.00	$1,000	700.00	$1,000

-continued on next page-

DAILY CONSTRUCTION SERVICE

TUNNEL CONSTRUCTION

Page 2

5-12-70 SAN FRANCISCO,CALIF.(BARTD-SUBWY.STRUCS.,VAN NESS STA.TO DUBOCE PORTAL #1S0031)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
L.S.painting	$1,[illegible]00	$5,000	$10000	$5,000	$1,[illegible]	[illegible]	$6,000	$5,000	$10000	$20000
L.S.drnge.fire prot	$80[illegible]00	$40000	$73450	$50000	$96500	$[illegible]5000	$40000	$5[illegible]000	$30000	$40000
L.S.elec.work	$113,000	$75000	$72500	$[illegible]0000	$89200	$90000	$125000	$80000	$100000	$100000
L.S.PT&T facils.	$[illegible]8,000	$40000	$28000	$30000	$34400	$120000	$30000	$40000	$35000	$40000
L.S.undrgrd.facil.	$60,000	$100000	$60000	$100000	$73800	$250000	$60000	$400[illegible]	$75000	$70000
L.S.traf.sig.	$77,000	$120000	$117000	$120000	$144000	$140000	$120000	[illegible]	$[illegible]5000	$120000
L.S.street ltg.	$138,000	$40000	$25000	$30000	$28300	$[illegible]0000	$30000	$50000	$40000	$50000
L.S.restor.work	$11,000	$15000	$10000	$20000	$12900	$110000	$25000	$20000	$25000	$50000
L.S.Muni.Railwy.pwr	$106,000	$110000	$60000	$70000	$92000	$80000	$400000	$65000	$100000	$500000
L.S.restor.work	$44,000	$50000	$40000	$50000	$50000	$60000	$150000	$35000	$75000	$200000
L.S.AWSS facils	$300,000	$600000	$345000	$1000000	$424000	$300000	$400000	$300000	$400000	$445000
180 cy.prot.enc.,ducts	220 00	80 00	220 00	200 00	270 00	360 00	250.00	250.00	250.00	220.00
860 tr.ft.WU conduit	8 00	16.00	8.00	25.00	10 00	24 00	25.00	[illegible]0.00	[illegible]0.00	10.00
2 ea.WU manhole	$3,200	$1,500	$3,200	$3,000	$4,000	180 00	$2,500	$3,000	$3,500	$3,200
2,400 lft.16"bell&spigot push-on	65 00	50.00	65 00	50 00	80 00	43 00	125 00	70.00	80.00	100.00
150 lft.12"same	55.00	50 00	55.00	50 00	6[illegible]	50.00	100.00	60.00	70.00	[illegible].00
500 lft.8" same	50.00	30.00	50.00	50 00	[illegible]	34.00	100.00	40 00	60.00	85.00
500 lft.4"D.I.pipe	40.00	28.00	40.00	50.00	50 00	60 00	60 00	30.00	50 00	80.00
400 lft.1"svc.pipe	25 00	20.00	25.00	25.00	30 00	30.00	12.00	25.00	30.00	70.00
30 ea.screw tap	15.00	80.00	15 00	75 00	18 00	24.00	150.00	100.00	20.00	50.00
40,000 lb.fittings	.20	.30	20	1 00	.25	.30	.60	.50	.25	.50
L.S.swr.facils.	$60,000	$90000	$75000	$193406	$73800	$75000	$80000	$100000	$100000	$90000
937 lft.42" RCP	110 00	80.00	110.00	1[illegible]0.00	135 00	90 00	180 00	120.00	130.00	220.00
177 lft.same w/enc.	120 00	90.00	120 00	250 00	148 00	138 00	200 00	130 00	140.00	240.00
256 lft.24"VCP	100.00	130.00	100.00	200.00	123.00	96.00	125.00	110.00	120.00	200.00
257 lft.21"VCP	95.00	120.00	95.00	200 00	117.00	72.00	100 00	100 00	110.00	190.00
2,750 lft.same,encsm	85.00	180.00	85.00	200 00	105.00	66.00	100.00	90.00	100.00	170.00
154 lft same,conc.base	120.00	160.00	120 00	200.00	148 00	48.00	60 00	100.00	1[illegible]0.00	240.00
1,364 lft.12"VCP	90.00	150 00	90.00	175 00	110.00	58 00	90 00	100 00	[illegible]0 00	180.00
450 lft.10"VCP	65.00	130.00	65.00	150 00	80 00	78.00	60 00	60 00	75.00	130.00
260 lft.10"RCP culv.	60.00	120.00	60.00	100.00	74 00	60 00	50 00	55 00	7[illegible] 00	120.00
37 ea.4'swr.MH	$1,000	$2,200	$1,000	$[illegible],500	$1,230	$1,300	$1,200	$1,200	$[illegible],200	$2,000
4 ea.box MH	$2,000	$1,500	$2,000	$[illegible],000	$2,460	$2,000	$3,000	[illegible]2,500	$2,500	$4,000
5 ea.modif.box MH	$2,200	$1,800	$2,200	$2,5[illegible]	$2,700	$2,200	$3,500	$3,000	$3.000	$4,400
1 ea.junct.MH struc	$3,000	$2,500	$3,000	$[illegible],000	$3,[illegible]00	$2,400	$3,500	$4,000	$4,000	$6,0[illegible]0
3 ea.angle swr.MH	$2,500	$1,500	$2,500	$2,500	$3,100	$2,100	$3,000	$2,500	$3,500	$5,0[illegible]0
1 ea.modif.same	$3,000	$2,000	$3,000	$3 000	$3,700	$2,200	$3,500	$3,[illegible]00	$4,000	$6,000
49 ea.swr.MH frame and cover	180.00	250.00	180.00	200 00	220 00	160 00	180.00	2[illegible]0.00	210.00	360.00
19 ea.swr.connect.	400.00	300.00	400.00	750.00	500 00	480 00	600.00	300.00	500.00	600.00
11 ea.wtr.inlet	700.00	450.00	700 00	$1,000	860 00	360 00	350.00	500.00	800.00	900.00
7 ea.same,w/grate	700.00	475.00	700.00	$1,000	860 00	420.00	[illegible]00.00	650.00	850 00	900.00
445 lft.4"gas pipe	45.00	40.00	45.00	50 00	55 00	35 00	35.00	60.00	55.00	90 00
125 lft.4"same perm.	75 00	30.00	75.00	7[illegible] 00	92.00	36.00	30 00	70.00	90.00	150.00
185 lft.6" same	80.00	60.00	80.00	100.00	100 00	38.00	35.00	80.00	95.00	160.00
60 lft. 8" same	80 00	80.00	80.00	100 00	100.00	42.00	50.00	85.00	100.00	160.00
3,180 lft.12"same	55.00	60.00	55.00	100.00	68 00	48.00	78.00	60.00	65.00	110.00
2,590 lft.16"same	60 00	65.00	60 00	100 00	74 00	60.00	97 00	65.00	75.00	120.00
510 lft.24"same	70.00	70.00	70.00	125 00	86.00	66 00	90.00	75.00	85 00	140.00
30 lft.6"same,HP at Duboce and Market	100.00	60.00	100.00	100 00	123 00	96.00	40 00	80.00	120.00	200.00
150 lft.stl.pipe PG&E	40.00	50.00	40.00	50 00	50 00	36.00	60.00	40.00	50.00	80.00
10,000 points per mo.,settlement measuremnt pts.	5 00	1.00	9.00	1 25	1 40	1 00	2 00	5.00	2 00	2.00
1 ea. sidewalk exit door	$3,200	$5,000	$7,000	$5,000	$1,550	$3,000	$3,500	$10000	$1,000	$5,000

SAN FRANCISCO BAY AREA RAPID TRANSIT DISTRICT

CONTRACT CHANGE

CONTRACT NO. 1S0031
CONTRACT CHANGE NO. 6

CONTRACT TITLE: Subway Structures
Van Ness Station to Duboce Portal
S. F. Outer Market Street Line

TO. Fruin-Colnon Corporation
and Dravo Corporation
P. O. Box 688

RE: Contractor's Letters C-13 dated 8/31/70
C-15 dated 9/23/70, C-36 dated 10/14/70
and PB-1-B Letter Serial 18 dated
10/22/70

The following changes shall be made to the contract:

In accordance with your revised Value Engineering Proposal of September 23, 1970, you are hereby authorized to construct tunnels in lieu of a portion of the originally specified subway structure.

Work under this contract change will be accomplished as follows:

1) Tunnels shall be constructed as specified by the tunnel specifications and drawings which were issued under Change Notice D-4, Revision 1.

2) Contractor shall construct the cross passage originally located at Station TR401+00 as relocated within contract limits and detailed by Change Notice D-3, all at no addtional cost to the District.

3) Contractor shall support open-cut slopes on Duboce Street, including the use of rock bolts, as required by the Engineer.

4) Excavation, placing of concrete lining and necessary backfill grouting will be completed in each tunnel prior to starting excavation of adjoining tunnels.

5) Shoo-fly track layouts, support systems, traffic patterns and detours shall be revised to complement this contract change in accordance with the applicable provisions of the contract documents.

6) Contractor will provide new track material for all restored MUNI track, and all original materials removed from Market Street and Duboce Street following shoo-flying the MUNI to the sides of the cut-and-cover excavation will become the Contractor's property except for special items, such as switches, mates and frogs which will be delivered to MUNI storage yards.

(CONTINUED ON PAGE 2)

You may proceed with this contract change. By reason of this contract change, the contract time of completion will be unchanged.

All other terms and conditions of the contract remain unchanged and in full force and effect.

If you disagree with the above terms and conditions, you must act in accordance with the Protest Procedures of the contract documents.

Submitted: /s/ E W Peterson — Date 5-10-71
PB-T-B MANAGER OF CONSTRUCTION

Approved: /s/ L A Kimball — Date JUN 2 1971
GENERAL MANAGER

The undersigned Contractor agrees to the above terms and conditions.

FRUIN-COLNON CORPORATION AND DRAVO CORPORATION — Date 6/4/71
CONTRACTOR

By: /s/ S H Bartholomew — Title Proj. Manager

... 3-174

CONTRACT CHANGE

CONTRACT NO. 1S0031 CONTRACT TITLE: Subway Structures
CONTRACT CHANGE NO. 6 Van Ness Station to Duboce Portal
S. F. Outer Market Street Line

TO: Fruin-Colnon Corporation
and Dravo Corporation

7) It is understood and agreed that, in the event the Contractor encounters changed conditions within the meaning of Article GP4.5, the District's liability thereunder shall in no event exceed that to which it was exposed prior to the execution of this contract change.

Compensation for this contract change and determination of the total savings to be shared equally between the District and the Contractor shall be as follows:

Delete the following bid items from the contract book:

Bid Item #2:	Traffic Maintenance and Control.	$ (180,000.00)
Bid Item #4:	West End Transverse Bulkhead – 1S0032 Interface.	(20,000.00)
Bid Item #5:	MUNI Railway Track Facilities Tempo[illegible]ry.	$(1,080,264.00)
Bid Item #7:	Street Decking Installation and Removal.	(196,000.00)
Bid Item #8:	Cut-and-Cover Excavation.	(3,042,000.00)
Bid Item #9:	Cut-and-Cover Backfill.	(306,600.00)
Bid Item #25:	Class 4000 Concrete, Subway Structure Grade Slab	(747,900.00)
Bid Item #26:	Class 4000 Concrete, Subway Structure Exterior Walls	(486,000.00)
Bid Item #27:	Class 4000 Concrete, Subway Structure Interior Walls.	(67,500.00)
Bid Item #28:	Class 4000 Concrete, Subway Structure Supported Slabs and Beams.	(683,100.00)
Bid Item #38:	Supporting and Maintaining PT&T Telephone Facilities.	(28,000.00)
Bid Item #39:	Supporting and Maintaining Underground Utility Facilities.	(60,000.00)
Bid Item #43:	MUNI Power Facilities Temporary Work.	(106,000.00)

As a result of this contract change and for arriving at the agreed upon cost reduction base, the estimated quantities for the following bid items are reduced by the following agreed to amounts:

CONTRACT CHANGE

CONTRACT NO. 1S0031 CONTRACT TITLE: Subway Structures
CONTRACT CHANGE NO. 6 Van Ness Station to Duboce Portal
S. F. Outer Market Street Line

TO: Fruin-Colnon Corporation
and Dravo Corporation

Bid Item #16:	Class 3000 Concrete Curbs, Gutters & Islands. 15 cubic yards @ $60.00 per cubic yard.	$	(900.00)
Bid Item #17:	Class 3000 Concrete Sidewalks & Driveways. 50 cubic yards @ $60.00 per cubic yard.		(3,000.00)
Bid Item #18:	Aggregate Base Class 2. 180 cubic yards @ $17.00 per cubic yard.		(3,060.00)
Bid Item #19:	Class 3000 Concrete Base, 8-Inch Thick.		(13,150.00)
Bid Item #20:	Liquid Asphalt Curing Seal. 2 tons at $200.00 per ton.		(400.00)
Bid Item #21:	Asphalt Emulsion Paint Binder. 1 ton at $200.00 per ton.		(200.00)
Bid Item #22:	Aggregate for Type B Asphalt Concrete. 274 tons at $15.00 per ton.		(4,110.00)
Bid Item #23:	Paving Asphalt for Type B Asphalt Concrete. 20 tons at $15.00 per ton.		(300.00)
Bid Item #24:	Bar Reinforced Steel. 645,000 pounds at $0.13 per pound		(83,850.00)
	Subtotal	$	(108,970.00)

The following additional pay items are added to the contract:

Pay Item #92:	Revised traffic maintenance and control. Lump Sum Addition of One Hundred Fifty Thousand Dollars and No Cents.	$	150,000.00
Pay Item #93:	West end traverse tunnel bulkhead 1S0032 interface. Lump Sum Addition of Five Thousand Dollars and No Cents.		5,000.00
Pay Item #94:	Revised MUNI track facilities temporary. Lump Sum Addition of One Million Twenty-Nine Thousand Eight Hundred Twenty-Five Dollars and No Cents.		1,029,825.00

CONTRACT CHANGE

CONTRACT NO. 1S0031 CONTRACT TITLE: Subway Structures
CONTRACT CHANGE NO. 6 Van Ness Station to Duboce Portal
S.F. Outer Market Street Line

TO: Fruin-Colnon Corporation
and Dravo Corporation

Pay Item #95:	Supporting and maintaining PT&T telephone facilities. Lump Sum Addition of Twenty-Three Thousand Dollars and No Cents	$ 23,000.00
Pay Item #96:	Supporting and maintaining underground facilities. Lump Sum Addition of Fifty-Five Thousand Dollars and No Cents.	55,000.00
Pay Item #97:	MUNI power facilities, temporary work. Lump Sum Addition of Ninety-Five Thousand Dollars and No Cents.	95,000.00
Pay Item #98:	MUNI trackwork support steel. Lump Sum Addition of One Hundred Ten Thousand Seven Hundred Sixty-Three Dollars and No Cents.	110,763.00
Pay Item #99:	Revised cut-and-cover excavation. 128,200 cubic yards at $19.00 per cubic yard. Additional Cost — Two Million Four Hundred Thirty-Five Thousand Eight Hundred Dollars and No Cents.	2,435,800.00
Pay Item #100:	Revised cut-and-cover backfill. 38,000 cubic yards at $5.80 per cubic yard. Additional Cost — Two Hundred Twenty Thousand Four Hundred Dollars and No Cents	220,400.00
Pay Item #101:	Grouting abandoned sewers over tunnel. Lump Sum Addition of Five Thousand Dollars and No Cents.	5,000.00
Pay Item #102:	Free duct banks at manhole face. 3 ducts at $300.00 per duct. Additonal cost — Nine Hundred Dollars and No Cents.	900.00
Pay Item #103:	Class 4000 concrete cut-and-cover subway structure. 33,337 cubic yards at $52.00 per cubic yard. Additional Cost — One Million Seven Hundred Thirty-Three Thousand Five Hundred Twenty-Four Dollars and No Cents.	1,733,524.00

It is agreed that the Contractor will be reimbursed for the satisfactory completion of the following items of work on the basis of the stipulated fixed quantities:

CONTRACT CHANGE

CONTRACT NO. 1S0031 CONTRACT TITLE: Subway Structures
Van Ness Station to Duboce Portal
S. F. Outer Market Street Line

CONTRACT CHANGE NO. 6

TO: Fruin-Colnon Corporation
and Dravo Corporation

Pay Item #104:	Revised street decking installation and removal. 1,000 square yards at $80.00 per square yard (fixed quantity). Additional Cost — Eighty Thousand Dollars and No Cents.	$ 80,000.00
Pay Item #105:	Tunnel Excavation. 7,989 cubic yards at $67.00 per cubic yard (fixed quantity). Additional Cost — Five Hundred Thirty-Five Thousand Two Hundred Sixty-Three Dollars and No Cents.	535,263.00
Pay Item #106:	Furnishing and installing tunnel support steel. 335,540 pounds at $0.45 per pound (fixed quantity). Additional Cost — One Hundred Fifty Thousand Nine Hundred Ninety-Three Dollars and No Cents.	150,993.00
Pay Item #107:	Furnishing and installing tunnel lagging, blocking, foot blocks and collar braces. 62,800 FBM at $0.60 per FBM (fixed quantity). Additonal Cost — Thirty-Seven Thousand Six Hundred Eighty Dollars and No Cents.	37,680.00
Pay Item #108:	Furnish and apply pneumatically placed gunite or concrete. 235 sacks at $30.00 per sack (fixed quantity). Additional Cost — Seven Thousand Fifty Dollars and No Cents.	7,050.00
Pay Item #109:	Furnish and install No. 11 reinforcing steel bar spiling. 340 linear feet at $5.00 per linear foot (fixed quantity). Additional Cost — One Thousand Seven Hundred Dollars and No Cents.	1,700.00
Pay Item #110:	Furnishing, installing and grouting 1-inch diameter rock bolts. 200 linear feet at $15.00 per foot (fixed quantity). Additional Cost — Three Thousand Dollars and No Cents.	3,000.00

CONTRACT CHANGE

CONTRACT NO. 1S0031 CONTRACT TITLE: Subway Structures
CONTRACT CHANGE NO. 6 Van Ness Station to Duboce Portal
S. F. Outer Market Street Line

TO: Fruin-Colnon Corporation
and Dravo Corporation

Pay Item #111:	Furnishing and placing tunnel backfill grout. 2,100 sacks at $5.00 per sack (fixed quantity). Additioral Cost — Ten Thousand Five Hundred Dollars and No Cents.	$ 10,500.00
Pay Item #112:	Furnishing and placing concrete tunnel lining. 2,351 cubic yards at $80.00 per cubic yard (fixed quantity). Additional Cost — One Hundred Eighty-Eight Thousand Eighty Dollars and No Cents.	188,080.00
Pay Item #113:	Furnishing and installing tunnel reinforcing steel. 222,195 pounds at $0.17 per pound (fixed quantity). Additional Cost — Thirty Seven Thousand Seven Hundred Seventy-Three Dollars and No Cents.	37,773.00

Total Agreed Base — Cost Reduction	$196,083.00
Less Agreed Original Cost of Cross Passage	(25,000.00)
Agreed Total Base	$171,083.00

The following items of work resulting from this cost reduction proposal are added to the contract:

Pay Item #114:	Furnish and install pedestrian walkway and handrail. Estimated Cost — Twenty Thousand Dollars and No Cents.	$ 20,000.00
Pay Item #115:	Furnish and install four (4) tunnel seals. 4 seals at $5,300.00 per seal. Additional Cost — Twenty-One Thousand Two Hundred Dollars and No Cents.	21,200.00
Pay Item #116:	Provide additional engineering as required by designer. Lump Sum Addition of Thirteen Thousand Six Hundred Seventy-Seven Dollars and No Cents.	13,677.00

The following provisional items are added to the contract. Payment will be limited to quantity specified for each item.

CONTRACT CHANGE

CONTRACT NO. 1S0031
CONTRACT CHANGE NO. 6

CONTRACT TITLE: Subway Structures
Van Ness Station to Duboce Portal
S. F. Outer Market Street Line

TO: Fruin-Colnon Corporation
and Dravo Corporation

Pay Item #117:	Furnishing and installing additional tunnel lagging, blocking, foot blocks and collar braces over and above the first 62,800 FBM. 40,460 FBM at $0.55 per FBM. Additional Cost Not to Exceed Twenty-Two Thousand Two Hundred Fifty-Three Dollars and No Cents.	$22,253.00
Pay Item #118:	Furnishing and placing additional tunnel gunite over and above the first 235 sacks. 840 sacks at $16.00 per sack. Additional Cost Not to Exceed Thirteen Thousand Four Hundred Forty Dollars and No Cents.	13,440.00
Pay Item #119:	Furnishing and installing additional No. 11 reinforcing steel bar spiling over and above the first 340 linear feet. 1,360 linear feet at $4.15 per linear foot. Additional Cost Not to Exceed Five Thousand Six Hundred Forty-Four Dollars and No Cents.	5,644.00

It is agreed that the sum of One Hundred Seventy-One Thousand Eighty-Three Dollars and No Cents ($171,083.00) is a fixed base from which the total savings are to be shared evenly between the Contractor and the District. Total savings to be shared will be determined as follows:

Deduct payments made under the following pay items:

Pay Item #114 — Estimated	$20,000.00
Pay Item #115 —	$21,200.000
Pay Item #116 — Lump Sum	$13,677.00

Deduct payments made under Pay Items 117, 118 and 119 up to a maximum limit as follows:

Pay Item #117 —	$22,253.00	
Pay Item #118 —	$13,440.00	
Pay Item #119 —	$ 5,644.00	
Maximum Total		$41,337.00

Deduct Engineer's redesign charges resulting from this contract change:

Estimated $ 7,400.00

CONTRACT CHANGE

CONTRACT NO. 1S0031 CONTRACT TITLE: Subway Structures
CONTRACT CHANGE NO. 6 Van Ness Station to Duboce Portal
S. F. Outer Market Street Line

TO: Fruin-Colnon Corporation
and Dravo Corporation

Deduct the cost of any other necessary and authorized items of work resulting from this contract change which would not have been required by the original design. Cost of such work shall be established and agreed to by the Contractor and the Engineer.

The net resulting savings shall be shared equally by the District and the Contractor.

Pay Item #120: Agreed Total Base — One Hundred Seventy-One Thousand Eighty-Three Dollars and No Cents. $171,083.00

Less Amount Paid Under Pay Item #114	—	Estimated	(20,000.00
Less Amount Paid Under Pay Item #115	—		(21,200.00)
Less Amount Paid Under Pay Item #116	—	Lump Sum	(13,677.00)
Less Amount Paid Under Pay Item #117	—	Maximum	(22,253.00)
Less Amount Paid Under Pay Item #118	—	Maximum	(13,440.00)
Less Amount Paid Under Pay Item #119	—	Maximum	(5,644.00)
Estimated Total Engineer's Redesign Cost	—		

Estimated Minimum Savings to be Shared Equally $ 67,469.00

Contractor's Share of Value Engineering Proposal. Estimated Minimum of Thrity-Three Thousand Seven Hundred Thirty-Five Dollars and No Cents. $33,735.00

Appendix B

RAPID TRANSIT SYSTEM COMPUTATION PROGRAM

A digital computer program entitled TUNNEL was written for the purpose of calculating the costs for constructing the underground segments of rapid transit systems. This program was derived from a study of four generalized tunneling models: (1) cut-and-cover line, (2) cut-and-cover station, (3) compressed-air tunnels, and (4) free-air tunnels. A flow diagram of the program and a program listing and printout are shown in Figures B-1 and B-2.

The data deck consists of two parts: the program data, and the input data, as described in the model. The program data are an integral part of the model and are intended to remain constant. The input data specify the particular case(s) for which the calculations are to be performed. A list of all input variables and their corresponding designations in the model are found in Table B-1.

The program data, which comprise the front of the data deck, are arranged as listed in Table B-2. Sample formats and their corresponding format statements for all program data as well as input data are found in Figure B-3.

To run the program, the user is required to provide the following information:

(1) Number of cases to be run

(2) Type of case

IC 1 for cut-and-cover line
2 for cut-and-cover station
3 for compressed-air tunnel
4 for free-air tunnel

(3) Number of project work events

IP 7 for tunnel projects
8 for cut-and-cover projects

(4) The values of labor productivity and labor and material escalation factors

(5) Physical and institutional control values:

'1' low
'2 medium
'3' high

(6) Project measures

Length, plan area, excavation volume, and backfill volume for cut-and-cover projects

Length for tunnel projects

(7) Project work event titles for both types of projects, and relevant project measures and unit titles for cut-and cover projects.

These data are placed after the program data in the following order:

Card 1: Number of cases to be run

2: Case number and number of project work events (in that order)

3: Productivity, materials escalation factor, and labor escalation factor (in that order)

4: Twelve values for levels of α 1

5: Twelve values for levels of α 2

6: Twelve values for levels of α 3

7: Seven values for level of physical controls

8(a): If cut-and-cover project: length, plan area, excavation volume, and backfill volume (in that order)

8(b): If tunnel project: length of tunnel

9-15(16): Titles for project work events (eight cards for cut-and-cover project; seven cards for tunnel projects)

(17-24): Titles for relevant project measures and units if cut-and-cover projects (eight cards)

Cards 2 through 8 are repeated for the number of cases specified. Cards 9-15(24) need only be inserted after the first case of a run and after the data for a project which is different from that preceding it. The project work event titles and relevant project measure and unit titles must be supplied in the same sequence as listed in the model in order to correspond to the correct unit costs and total element costs when printed out. To avoid repetitive punching and reading in of titles, it is best to run all of one project and then change to the other, if desired.

A list of names used within the program is given in Table B-3 to aid in program revision should it be necessary.

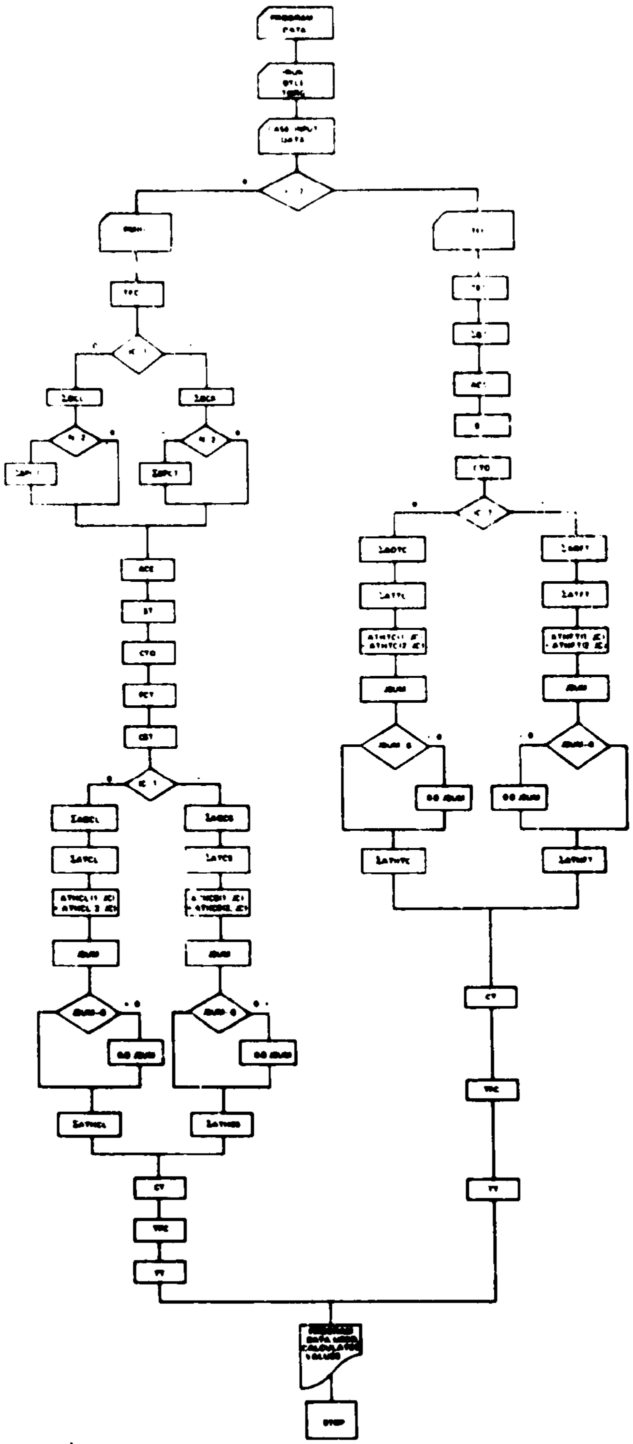


Figure B-1. Flow Diagram

```
      DOUBLE PRECISION MAE,RPM,ATLE,TORQUE
      DIMENSION LC(8,4),RCL(8,7,3),RCS(8,7,3),RT(7,7,3),GCL(3,3),GCS(3,3
     1),GT(3,3),AUCL(12,3),ATCL(12,3),ATMCL(12,3),AUCS(12,3),ATCS(12,3),
     2ATMCS(12,3),AUTC(12,3),ATTC(12,3),ATMTC(12,3),AOFT(12,3),ATFT(12,3
     3),ATMFT(12,3),FU(4),EL(4),EM(4),Z(4),DM(4),RP(8),TEC(8),RP(7),ACE(
     48),LE(8),MAE(8,8),RPM(8,4),ATLE(7,8),TORG(12,9),JU(12),JT(12),JTM(
     512),ATIME(4)
      READ(2,3) ((LC(I,J),I=1,8),J=1,2)
      READ(2,20)  ((LC(I,J),I=1,7),J=3,4)
      READ(2,19) (ATIME(I),I=1,4)
      DO 90 K=1,3
   90 READ(2,7) ((RCL(I,J,K),I=1,8),J=1,7)
      DO 91 K=1,3
   91 READ (2,7) ((RCS(I,J,K),I=1,8),J=1,7)
      DO 92 K=1,3
   92 READ (2,8) ((RT(I,J,K),I=1,7),J=1,7)
      READ(2, 5)  ((GCL(I,J),I=1,3),J=1,3)
      READ(2, 5) ((GCS(I,J),I=1,3),J=1,3)
      READ(2,5) (GT(3,J),J=1,3)
      READ(2,6)((AUCL(I,J),I=1,12),J=1,3)
      READ(2,12)  ((ATCL(I,J),I=1,12),J=1,3)
      READ(2,12)((ATMCL(I,J),I=1,12),J=1,3)
      READ (2,6 )  ((AUCS(I,J),I=1,12),J=1,3)
      READ(2,12)  ((ATCS(I,J),I=1,12),J=1,3)
      READ(2,12) ((ATMCS(I,J),I=1,12),J=1,3)
      READ (2,6 ) ((AUTC(I,J),I=1,12),J=1,3)
      READ (2,12) ((ATTC(I,J),I=1,12),J=1,3)
      READ (2,12) ((ATMTC(I,J),I=1,12),J=1,3)
      READ (2, 6) ((AOFT(I,J),I=1,12),J=1,3)
      READ (2,12) ((ATFT(I,J),I=1,12),J=1,3)
      READ (2,12)((ATMFT(I,J),I=1,12),J=1,3)
      DO 93 I=1,4
   93 READ (2,9) EU(I),EL(I),EM(I),Z(I),DM(I)
      IPL=0
      READ (2,1) INUM
      DO 400 JW=1,INUM
      IF(IPL-1) 105,105,106
  105 READ (2,17)  ((ATLE(I,J),J=1,7),I=1,7)
      READ(2,18) ((TORG(I,J),J=1,9),I=1,12)
  106 WRITE(5,11)
      READ (2,2) TC,TP
      READ (2,5) P,FM,FL
      READ (2,13) (JU(I),I=1,12)
      READ (2,13) (JT(I),I=1,12)
      READ (2,13) (JTM(I),I=1,12)
      READ (2,21) (RP(I),I=1,7)
      SAUM=0.0
      SATM=0.0
       SATMM=0.0
       SUPMM=0.0
      JSUM=0
      STM=0.0
      SPCTM=0.0
      I[illegible]
  1[illegible] READ(2,4) (RPM(I),I=1,4)
```

Figure B-2. Program Listing and Printout

```
          TEC(1)=UC(1,IC)*PM(1)
          TEC(2)=UC(2,IC)*PM(2)
          TEC(3)=UC(3,IC)*PM(1)
          TEC(4)=UC(4,IC)*PM(3)
          TEC(5)=UC(5,IC)*PM(4)
          TEC(6)=UC(6,IC)*(PM(3)-PM(4))
          TEC(7)=UC(7,IC)*PM(1)
          TEC(8)=UC(8,IC)*(PM(3)-PM(4))
          DO 102 I=1,8
          IF(IC-1) 117,117,118
      117 DO 103 J=1,7
          K=KP(J)
      103 SUMA=SUMA+BCL(I,J,K)
          GO TO 115
      118 DO 116 J=1,7
          K=KP(J)
      116 SUMB=SUMB+BCS(I,J,K)
      115 IF (I-3) 133,133,134
      133 N=KP(I)
          IF (IC-1) 119,119,105
      119 ACE(I)=TEC(I)*(1.+SUMA)*(1.+GCL(I,N))
          IF(N-2) 210,211,210
      210 SPCT=SPCT+(TEC(I)*(1.+BCL(I,I,N))*(GCL(1,N)))
      211 GO TO 172
      105 ACE(I)=TEC(I)*(1.+SUMB)*(1.+GCS(I,N))
          IF (N-2) 212,213,212
      212 SPCT=SPCT+(TEC(I)*(1.+BCS(I,I,N))*(GCS(1,N)))
      213 GO TO 172
      134 ACE(I)=TEC(I)*(1.+SUMB)
      172 SUMB=0.0
      102 CONTINUE
          DO 104 I=1,8
      104 ST=ST+ACE(I)
          CTO=ST*(1.+UM(IC))
          PCT=(SPCT/CTO)*0.5*TIME(IC)
          CST=CTO+(PCT*Z(IC))
          DO 250 I=1,6
      250 JSUM=JSUM+JU(I)
          IF(IC-1) 137,137,138
      137 DO 105 I=1,12
          JA=JO(I)
          IF(JSUM-6) 251,252,252
      252 IF(I-6) 253,253,251
      253 IF(I-2) 251,251,254
      254 SAO=SAO+(0.8*AGCL(I,JA))
          GO TO 255
      251 SAO=SAO+AUCL(I,JA)
      255 JM=JT(I)
          SAT=SAT+ATCL(I,JM)
          TC=JTM(I)
      105 SATM=SATM+ATMCL(I,JC)
          GO TO 139
      138 DO 130 I=1,12
          JA=JO(I)
          IF(JSUM-6) 201,202,202
      202 IF(I-6) 203,203,201
```

Figure B-2 (Cont'd). Program Listing and Printout

```
 203 IF(I-2) 201,201,204
 204 SAO=SAO+(0.80*ADCS(I,JA))
     GO TO 205
 201 SAO=SAO+ADCS(I,JA)
 205 JB=JT(I)
     SAT=SAT+ATCS(I,JB)
     JC=JTM(I)
 136 SATM=SATM+ATMCS(I,JC)
 139 SATM=SATM-(EL+((1./PP)-1.))
     CT=CST+(1.+SATM)-SAT+SAO+Z(IC)
     TPC=CT+((EL(IC)+FL)+(EM(IC)+FM)+EU(IC))
     TT=TIME(IC)+PCT+SAO
     GO TO 186
 181 READ(2,10)TM
     TEC(1)=UC(1,IC)
     TEC(2)=UC(2,IC)
     DO 187 I=3,7
 187 TEC(I)=UC(I,IC)+TM
     DO 112 I=1,7
     DO 109 J=1,7
     K=KP(J)
 109 SUMB=SUMB+BT(I,J,K)
     IF (I-3) 110,111,110
 111 N=KP(3)
     ACE(3)=TEC(3)*(1.+SUMB)*(1.+GT(3,N))
     GO TO 192
 110 ACE(I)=TEC(I)*(1.+SUMB)
 192 SUMB=0.0
 112 CONTINUE
     DO 113 I=1,7
 113 ST=ST+ACE(I)
     CTO=ST+(1.+CM(IC))
     DO 276 I=3,6
 276 JSUM=JSUM+JO(I)
     IF (IC-3) 132,132,135
 132 DO 150 I=1,12
     JA=JP(I)
     IF(JSUM-6) 271,272,272
 272 IF(I-6) 273,273,271
 273 IF(I-2) 271,271,274
 274 SAO=SAO+(0.80*AOTC(I,JA))
     GO TO 275
 271 SAO=SAO+AOTC(I,JA)
 275 JB=JT(I)
     SAT=SAT+ATTC(I,JB)
     JC=JTM(I)
 150 SATM=SATM+ATMTC(I,JC)
     GO TO 159
 135 DO 114 I=1,12
     JA=JP(I)
     IF(JSUM-6) 281,282,282
 282 IF(I-6) 283,283,281
 283 IF(I-2) 281,281,284
 284 SAO=SAO+(0.80*AOFT(I,JA))
     GO TO 285
 281 SAO=SAO+AOFT(I,JA)
```

Figure B-2 (Cont'd). Program Listing and Printout

```
  205 JM=JT(I)
      SAT=SAT+ATFT(I,JM)
      JC=JTM(I)
  114 SATM=SATM+ATMFT(I,JC)
  159 SATM=SATM*(EL*((1./P)-1.))
      CT=CTL*(1.+SATM)+SAT+SAJ+Z(IC)
      TPC=CT*((EL(IC)*FL)+(EM(IC)*FM)+EO(IC))
      TT=TIME(IC)+SAC
  116 IF(IC-2) 125,126,128
  125 WRITE (5,52)
      GO TO 122
  126 WRITE (5,79)
      GO TO 122
  128 IF(IC-3) 120,120,127
  127 WRITE (5,78)
      GO TO 122
  120 WRITE (5,51)
  122 IF (IPE-IP) 123,124,123
  123 READ (2,14) ((PAE(I,J),J=1,6),I=1,IP)
       IF(IP-7) 158,124,158
  158 READ (2,15) ((HPM(I,J),J=1,4),CE(I),I=1,8)
  124 WRITE (5,53)
      IF (IP-7) 150,161,160
  160 PM(8)=PM(3)-PM(4)
      PM(7)=PM(1)
      PM(6)=PM(3)-PM(4)
      PM(5)=PM(4)
      PM(4)=PM(3)
      PM(3)=PM(1)
      WRITE (5,54) ((PAE(I,J),J=1,6),(HPM(I,J),J=1,4),PM(I),CE(I),UC(I,I
     1C),CF(I),TEC(I),I=1,8)
      WRITE (5,57)
      WRITE (5,58)
      IF (IC-1) 140,140,141
  140 DO 129 J=1,7
      K=KP(J)
  129 WRITE (5,66)  (BTLF(J,JB),JB=1,7),(BCL(I,J,K),I=1,8),K
      WRITE (5,77)
      DO 142 I=1,3
      K=KP(I)
  142 WRITE (5,75)  (PAE(I,J),J=1,6),GCL(I,K),K
      WRITE (5,76) SP(IC)
      WRITE (5,62)
      WRITE (5,63) ((PAE(I,J),J=1,6),ACE(I),I=1,8)
      WRITE(5,83) CST
      WRITE (5,11)
      WRITE (5,54)
      DO 103 I=1,12
      JA=JA(I)
      JM=JT(I)
      JC=JTM(I)
  103 WRITE(5,65) (TCHG(I,J),J=1,9),ACL(I,JA),JA,ATCL(I,JM),JM,ATMCL(I,
     1JC),JC
      GO TO 162
  141 DO 143 J=1,7
      K=KP(J)
```

Figure B-2 (Cont'd). Program Listing and Printout

```
143 WRITE (5,60)  (WTLE(J,JB),JB=1,7),(WCS(I,J,K),I=1,8),K
    WRITE (5,77)
    DO 144 I=1,3
    N=KP(I)
144 WRITE(5,75)  (PRE(I,J),J=1,6),GCS(I,N),N
    WRITE (5,76) UM(IC)
    WRITE (5,62)
    WRITE (5,63) ((PRE(I,J),J=1,6),ACE(I),I=1,8)
    WRITE(5,M0) CST
    WRITE (5,11)
    WRITE (5,64)
    DO 181 I=1,12
    JA=JO(I)
    JB=JT(I)
    JC=JTH(I)
181 WRITE(5,65) (TCHG(I,J),J=1,9),AUCS(I,JA),JA,ATCS(I,JB),JB,ATHCS(I,
   1JC),JC
    GO TO 102
101 WRITE (5,55) ((PRE(I,J),J=1,6),TFC(I),I=1,2)
    WRITE(5,56) ((PRE(I,J),J=1,6),TM,UC(I,IC),TEC(I),I=3,7)
    WRITE (5,57)
    WRITE (5,59)
    DO 147 J=1,7
    K=KP(J)
147 WRITE (5,61)  (WTLE(J,JB),JB=1,7),(WT(I,J,K),I=1,7),K
    N=KP(3)
    WRITE (5,77)
    WRITE (5,75)  (PRE(3,J),J=1,6),WT(3,N),N
    WRITE (5,76) UM(IC)
    WRITE (5,62)
    WRITE (5,63) ((PRE(I,J),J=1,6),ACE(I),I=1,7)
    WRITE (5,58) CTU
    WRITE (5,11)
    WRITE (5,64)
    IF (IC-3) 145,145,146
145 DO 182 I=1,12
    JA=JO(I)
    JB=JT(I)
    JC=JTH(I)
182 WRITE(5,65) (TCHG(I,J),J=1,9),AUTC(I,JA),JA,ATTC(I,JB),JB,ATHTC(I,
   1JC),JC
    GO TO 102
146 DO 183 I=1,12
    JA=JO(I)
    JB=JT(I)
    JC=JTH(I)
183 WRITE(5,65) (TCHG(I,J),J=1,9),AUFT(I,JA),JA,ATFT(I,JB),JB,ATHFT(I,
   1JC),JC
102 WRITE (5,66) P
    WRITE (5,67) EL(IC)
    WRITE (5,68) Z(IC)
    WRITE (5,69) CT
    WRITE (5,70) FL
    WRITE (5,71) PM
    WRITE (5,72) EM(IC)
    WRITE (5,73) EP(IC)
```

Figure B-2 (Cont'd). Program Listing and Printout

```
      WRITE (5,74) TPC
      WRITE(5,61) TI
      IPL=IP
  400 CONTINUE
    1 FORMAT (I5)
    2 FORMAT (2I5)
    3 FORMAT(8F8.2)
    4 FORMAT(4F10.0)
    5 FORMAT (3F10.3)
    6 FORMAT(12F5.2)
    7 FORMAT (8F5.2)
    8 FORMAT(7F5.2)
    9 FORMAT(3F10.4,F10.0,F10.4)
   10 FORMAT(5F5.2,7F7.0)
   11 FORMAT(1H1)
   12 FORMAT (12F5.4)
   13 FORMAT (12I2)
   14 FORMAT (6A5)
   15 FORMAT (5A5)
   16 FORMAT(F14.0)
   17 FORMAT (7A5)
   18 FORMAT (9A5)
   19 FORMAT(4F5.0)
   20 FORMAT (2F10.2,5F8.2)
   21 FORMAT (7I2)
   50 FORMAT(//,2X,'TOTAL ADJUSTED EVENT COSTS',16X,F13.2,10X,'(INCLUDES
     1 MISCELLANEOUS FRACTIONS)')
   51 FORMAT(49X,'COMPRESSED AIR TUNNEL'//)
   52 FORMAT(50X,'CUT AND COVER LINE'//)
   53 FORMAT(2X,'PROJECT WORK EVENT',17X,'RELEVANT PROJECT MEASURE',10X,
     1'UNIT COST',8X,'TOTAL EVENT COST'//)
   54 FORMAT(2X,6A5,5X,4A5,F8.0,2X,A5,5X,F8.2,'/',A5,F10.2)
   55 FORMAT(2X,6A5,5X,'LUMP SUM',40X,F10.2)
   56 FORMAT(2X,6A5,5X,'LENGTH OF TUNNEL',F10.0,2X,'FT',10X,F8.2,'/FT',0
     1X,F16.2)
   57 FORMAT(//,42X,'PROJECT WORK EVENT NUMBER'//)
   58 FORMAT(45X,'1.',7X,'2.',7X,'3.',7X,'4.',7X,'5.',7X,'6.',7X,'7.',7X
     1,'8.',6X,'9'/)
   59 FORMAT(47X,'1.',8X,'2.',8X,'3.',8X,'4.',8X,'5.',8X,'6.',8X,'7.',8X
     1,8X,'9'//)
   60 FORMAT(2X,7A5,7X,6(F5.3,4X),I1)
   61 FORMAT(2X,7A5,8X,7(F5.3,5X),I1)
   62 FORMAT(///,2X,'EVENT',35X,'ADJUSTED EVENT COST'//)
   63 FORMAT(2X,6A5,10X,F13.2)
   64 FORMAT(//,2X,'INSTITUTIONAL CONTROLS',23X,'NO. DELAY',5X,'J',10X,'
     1LUMP SUM',5X,'J',8X,'FRACTION TOTAL COST',5X,'J'//)
   65 FORMAT(2X,9A5,3X,F4.2,7X,I1,10X,F8.0,5X,I1,14X,F6.4,12X,I1)
   66 FORMAT(//2X,'LABOR PRODUCTIVITY',10X,F4.2//)
   67 FORMAT(2X,'FRACTION OF TOTAL COST ATTRIBUTED TO LABOR',10X,F4.2//)
   68 FORMAT(2X,'OVERHEAD COST PER MONTH',16X,F8.0//)
   69 FORMAT(2X,'TOTAL COST(EXCLUDING ESCALATION)',8X,F16.2//)
   70 FORMAT(2X,'LABOR ESCALATION FACTOR',10X,F4.1//)
   71 FORMAT(2X,'MATERIALS ESCALATION FACTOR',10X,F4.1//)
   72 FORMAT (2X,'FRACTIONAL COST ATTRIBUTED TO MATERIALS',10X,F4.2//)
   73 FORMAT(2X,'FRACTIONAL COST ATTRIBUTED TO OVERHEAD',10X,F4.2//)
   74 FORMAT(2X,'TOTAL PROJECT COST',F10.2)
```

Figure B-2 (Cont'd). Program Listing and Printout

```
      75 FORMAT(2X,9A5,8X,F14.3,13X,I1)
      76 FORMAT(//,2X,'MISCELLANEOUS FRACTIONS',10X,F6.3//)
      77 FORMAT(//,2X,'PROJECT WORK EVENT',20X,'GAMMA VALUE',10X,'N'//)
      78 FORMAT (52X,'FREE AIR TUNNEL'//)
      79 FORMAT (40X,'CUT AND COVER STATION'//)
      80 FORMAT(//,2X,'TOTAL ADJUSTED EVENT COSTS',10X,F13.2,10X,'(INCLUDES
        1 MISCELLANEOUS FRACTIONS AND ADJUSTMENT FOR DELAY)')
      81 FORMAT(//,2X,'TOTAL TIME',5X,F10.1,5X,'MONTHS')
         CALL EXIT
         END

$LOC

     ROUTINES CALLED:
     EXIT

     OPTIONS =/ON,/OP:3,/GU

     BLOCK        LENGTH
     MAIN.    8387    (040606)*

     **COMPILER ----- CORE**
        PHASE         USED  FREE
     DECLARATIVES  01103  40437
     EXECUTABLES   01543  39537
     ASSEMBLY      03131  11549
```

Figure B-2 (Cont'd). Program Listing and Printout

SYMBOL	FORMAT	NO. OF CARDS	CARD COLUMNS 1–80
UC(I,J) for J = 1, 2	6F8.2	2	[illegible]
UC(I,J) for J = 3, 4	2F10.2, 6F8.2	2	[illegible]
STIME(I)	4F5.0	1	[illegible]
BCL(I,J,K), BCS(I,J,K)	8F5.2	42	[illegible]
BT(I,J,K)	7F5.2	21	[illegible]
GCL(I,J), GCS(I,J), GT(3,J)	3F10.3	7	[illegible]
AOCL, AOCS, AOTC, AOFT	12F5.2	12	[illegible]
ATCL, ATCS, ATTC, ATFT	5F5.0, 7F7.0	12	[illegible]
ATHCL, ATHCS, ATHTC, ATHFT	12F6.4	12	[illegible]
EO, EL, EM, Z, DM	3F10.3, F10.0, F10.3	4	[illegible]
IRUN	I5	1	[illegible]
BTL(I,J)	7A5	7	[illegible]
TORG(I,J)	9A5	12	[illegible]
IC, IP	2I5	*	[illegible]
P, FM, FL	3F10.3	*	[illegible]
JD, JT, JTH	12I2	*	[illegible]
KP	7I2	*	[illegible]
PR(I) for Cut and Cover Project	4F10.0	*	[illegible]
TM for Tunnel Project	F10.0	*	[illegible]
PWE(I,J)	6A5	*	[illegible]
RPM(I,J), CE(I)	4A5,A5	*	[illegible]

*Depends on number of cases run

Notes: n n Represent Numbers
a a Represent Letters
All I Formats Are Right Justified
All F Formats Justified by Decimal Placement

Figure B-3. Input Data Format

TABLE B-1: LIST OF INPUT VARIABLE NAMES

Variable Name	Model Name	Comments
UC(I,J)	unit cost functions	J=case number (1-4) I=number of project work events
BTIME (I)	base time	I=case number (1-4)
BCL(I,J,K)	β_{ijk}-cut-and-cover-line	I=project work event J=1-7 K=1-3
BCS(I,J,K)	β_{ijk}-cut-and-cover station	
BT(I,J,K)	β_{ijk}-tunnel	
GCL(I,J)	γ_{in} cut-and-cover line	I=1-3 N=1-3
GCS(I,J)	γ_{in}-cut-and-cover station	
GT(3,J)	γ_{3n}-tunnel	N=1-3
AOCL(I,J)	$\alpha 1$ cut-and-cover line	I=1-12 J=1-3
ATCL(I,J)	$\alpha 2$ cut-and-cover line	
ATHCL(I,J)	$\alpha 3$ cut-and-cover line	
AOCS(I,J)	$\alpha 1$ cut-and-cover station	
ATCS(I,J)	$\alpha 2$ cut-and-cover station	
ATHCS	$\alpha 3$ cut-and-cover station	
AOTC(I,J)	$\alpha 1$ compressed air tunnel	
ATTC(I,J)	$\alpha 2$ compressed air tunnel	
ATHTC(I,J)	$\alpha 3$ compressed air tunnel	
AOFT(I,J)	$\alpha 1$ free air tunnel	
ATFT(I,J)	$\alpha 2$ free air tunnel	
ATHFT(I,J)	$\alpha 3$ free air tunnel	
EO(I)	ϵ_o	I=case number (1-4)
EL(I)	ϵ_ℓ	

TABLE B-1 (Continued)

Variable Name	Model Name	Comments
EM(I)	ε_m	I=case number (1-4)
Z(I)	z	
DM(I)	δ_M	
IRUN	number of cases to be run	
TORG(I,J)	titles for institutional controls	I=1-12 J=1-7
BTLE(I,J)	physical control titles	I=1-7
IC	case number	1-cut-and-cover line 2-cut-and-cover station 3-compressed air tunnel 4-free air tunnel
IP	number of project work events	7-tunnel 8-cut-and-cover
P	labor productivity	
FM	materials escalation factor	
FL	labor escalation factor	
JO(I)	level of institutional control for α1	I=1-12
JT(I)	level of institutional control for α2	I=1-12
JTH(I)	level of institutional control for α3	I=1-12
KP(I)	level of physical control	I=1-7

TABLE B-1 (Continued)

Variable Name	Model Name	Comments
PM(I)	project measures for cut-and-cover projects	I=1: length 2: plan area 3: volume excavated 4: backfill volume
TM	length of tunnel for tunnel projects	
		J=1-4
PWE(I,J)	project work event titles	J=1-6 I=1-7(8)
RPM(I,J)	relevant project measure titles for cut-and-cover projects	I=1-8 J=1-4
CE(I)	titles for units of measure for cut-and-cover projects	I=1-8

TABLE B-2 ARRANGEMENT OF PROGRAM DATA

Card No.		Description	Comment
1		unit costs for cut-and-cover line	8 values in order listed*
2		unit costs for cut-and-cover station	
3		unit costs for compressed air tunnel	7 values in order listed
4		unit costs for free air tunnel	
5		base times for all projects	order: cut-and-cover line, station; compressed and free air tunnels
6-12	for cut-and-cover line	$\beta ij1$ (low)	8 values (corresponding to project work events as listed) per card; 7 cards, each representing a physical control in order listed
13-19		$\beta ij2$ (med.)	
20-26		$\beta ij3$ (high)	
27-33	for cut-and-cover station	$\beta ij1$ (low)	Same arrangement as β values for cut-and-cover line
33-39		$\beta ij2$ (med.)	
40-46		$\beta ij3$ (high)	
47-53	for tunnel projects	$\beta ij1$ (low)	7 values (corresponding to project work events as listed) per card; 7 cards each representing a physical control in order listed
54-60		$\beta ij2$ (med.)	
61-67		$\beta ij3$ (high)	

Card No.		Description	Comment
68		γ_{11} (low)	3 values for project work events 1-3 (see list)
69	for cut-and-cover line	γ_{12} (med.)	
70		γ_{13} (high)	
71		γ_{11} (low)	3 values for project work events 1-3 (see list)
72	for cut-and-cover station	γ_{12} (med.)	
73		γ_{13} (high)	
74		γ_{3n} for tunnel projects	"low", "med.", and "high" value for "Underpinning" on tunnel projects
75		$\gamma 1_{11}$ (low)	12 values per card for institutional controls in order listed
76		$\gamma 1_{12}$ (med.)	
77		$\gamma 1_{13}$ (high)	
78	for cut-and-cover line	$\gamma 2_{11}$ (low)	
79		$\gamma 2_{12}$ (med.)	
80		$\gamma 2_{13}$ (high)	
81		$\gamma 3_{11}$ (low)	
82		$\gamma 3_{12}$ (med.)	
83		$\gamma 3_{13}$ (high)	

Card No.		Description		Comment
84		γ^1_{11}	(low)	
85		γ^1_{12}	(med.)	
86		γ^1_{13}	(high)	
87		γ^2_{11}	(low)	
88		γ^2_{12}	(med.)	
89	for cut-and-cover station	γ^2_{13}	(high)	12 values per card for institutional controls in order listed
90		γ^3_{11}	(low)	
91		γ^3_{12}	(med.)	
92		γ^3_{13}	(high)	
93		γ^1_{11}	(low)	
94		γ^1_{12}	(med.)	
95		γ^1_{13}	(high)	
96		γ^2_{11}	(low)	
97	for compressed air tunnel	γ^2_{12}	(med.)	12 values per card for institutional controls in in order listed
98		γ^2_{13}	(high)	
99		γ^3_{11}	(low)	
100		γ^3_{12}	(med.)	
101		γ^3_{13}	(high)	

Card No.		Description	Comments
102		γ^1_{11}	
103		γ^1_{12}	
104		γ^1_{13}	
105	for free air tunnel	γ^2_{11}	12 values per card for institutional controls in order listed
106		γ^2_{12}	
107		γ^2_{13}	
108		γ^3_{11}	
109		γ^3_{12}	
110		γ^3_{13}	
111		ε_o, ε_e, ε_m, s, δ_M	for cut-and-cover line
112			for cut-and-cover station
113			for compressed air tunnel
114			for free air tunnel

*For list of project work elements, and physical and institutional controls, see sample print outs following program listing in Figure B-2.

Table B-2

PROGRAM DATA – COMPRESSED AIR TUNNEL

COMPRESSED AIR TUNNEL

PROJECT WORK EVENT	RELEVANT PROJECT MEASURE		UNIT COST	TOTAL EVENT COST
1. MOBILIZATION	LUMP SUM			[illegible]
2. SHAFT CONSTRUCTION	LUMP SUM			[illegible]
3. UNDERPINNING	LENGTH OF TUNNEL	3000. FT	70.00/FT	[illegible]
4. LINER, GROUT AND CAULK	LENGTH OF TUNNEL	3000. FT	1650.00/FT	[illegible]
5. EXCAVATION	LENGTH OF TUNNEL	3000. FT	[illegible]/FT	[illegible]
6. MUCK DISPOSAL	LENGTH OF TUNNEL	3000. FT	30.00/FT	[illegible]
7. CONCRETE AND CLEANUP	LENGTH OF TUNNEL	3000. FT	170.00/FT	[illegible]

PROJECT WORK EVENT NUMBER

	1.	2.	3.	4.	5.	6.	7.
UTILITY COMPLEXITY	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
TRAFFIC CONDITIONS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
EXISTING STRUCTURES	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
GROUND CONDITIONS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
ARCHITECTURAL REQUIREMENTS	[illegible]	0.210	0.210	[illegible]	[illegible]	[illegible]	[illegible]
WEATHER	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
FILL DEMAND	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

PROJECT WORK EVENT	GAMMA VALUE	
3. UNDERPINNING	-1.000	1

MISCELLANEOUS FRACTIONS [illegible]

EVENT	ADJUSTED EVENT COST
1. MOBILIZATION	[illegible]
2. SHAFT CONSTRUCTION	[illegible]
3. UNDERPINNING	0.00
4. LINER, GROUT AND CAULK	[illegible]
5. EXCAVATION	[illegible]
6. MUCK DISPOSAL	[illegible]
7. CONCRETE AND CLEANUP	[illegible]
TOTAL ADJUSTED EVENT COSTS	[illegible] (INCLUDES MISCELLANEOUS FRACTIONS)

Table B-2 (Cont'd)

PROGRAM DATA – COMPRESSED AIR TUNNEL

INSTITUTIONAL CONTROLS	MO. DELAY	J	LUMP SUM	J	FRACTION TOTAL COST	J
OPTIMAL PROJECT SCHEDULE	1.00	2	0.	2	0.0040	2
SYSTEM WIDE LABOR AGREEMENT	1.00	2	0.	2	0.0000	2
OWNER ACQUIRED WORK AREA	1.00	2	0.	2	0.0000	2
OWNER ACQUIRED RIGHT-OF-WAY	1.00	2	0.	2	0.0000	2
OWNER ACQUIRED ENTRY PERMIT	0.50	2	0.	2	0.0000	2
OWNER ACQUIRED BUILDING PERMIT	0.50	2	3520.	2	0.0000	2
OWNER SUPPLIED MATERIALS	1.00	2	0.	2	0.0261	2
OWNER PURCHASED INSURANCE	[illegible]	2	0.	2	0.0233	2
OWNER ENFORCED ENVIRONMENTAL REQUIREMENTS	[illegible]	2	130000.	2	0.0000	2
ADVANCE PAYMENT	0.01	2	20000.	2	0.0000	2
EFFICIENT CASH FLOW	0.00	2	0.	2	0.0025	2
SAFETY	[illegible]	2	-50000.	2	0.0100	2

LABOR PRODUCTIVITY 1.00

FRACTION OF TOTAL COST ATTRIBUTED TO LABOR 0.43

OVERHEAD COST PER MONTH [illegible]

TOTAL COST(EXCLUDING ESCALATION) 17241622.00

LABOR ESCALATION FACTOR 1.0

MATERIALS ESCALATION FACTOR 1.0

FRACTIONAL COST ATTRIBUTED TO MATERIALS 0.57

FRACTIONAL COST ATTRIBUTED TO OVERHEAD 0.00

TOTAL PROJECT COST [illegible]

TOTAL TIME [illegible] MONTHS

Table B-2 (Cont'd)

PROGRAM DATA – CUT-AND-COVER STATION

CUT AND COVER STATION

PROJECT WORK EVENT	RELEVANT PROJECT MEASURE			UNIT COST	TOTAL EVENT COST
1. UTILITIES	LENGTH OF PROJECT	830.	FT	1493.00/FT	1251134.26
2. DECK AND TRAFFIC CNTRL	PLAN AREA	9522.	SQ YD	73.20/SQ YD	695400.00
3. UNDERPINNING	LENGTH OF PROJECT	830.	FT	478.00/FT	4?0504.20
4. EXCAVATION	VOLUME EXCAVATED	113218.	CU YD	22.51/CU YD	2548537.25
5. BACKFILL	VOLUME BACKFILLED	23704.	CU YD	8.12/CU YD	192470.48
6. CONCRETE	NET VOLUME	80514.	CU YD	90.40/CU YD	5317131.50
7. RESTORATION	LENGTH OF PROJECT	830.	FT	190.00/FT	158040.00
8. MUCK DISPOSAL	NET VOLUME	80514.	CU YD	1.90/CU YD	175447.44

PROJECT WORK EVENT NUMBER

	1.	2.	3.	4.	5.	6	7.	8.	*
UTILITY COMPLEXITY	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
TRAFFIC CONDITIONS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1
EXISTING STRUCTURES	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1
GROUND CONDITIONS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1
ARCHITECTURAL REQUIREMENTS	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1
WEATHER	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1
FILL DEMAND	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1

PROJECT WORK EVENT	GAMMA VALUE	*
1. UTILITIES	-0.500	1
2. DECK AND TRAFFIC CNTRL	-0.500	1
3. UNDERPINNING	-0.500	1

MISCELLANEOUS FRACTIONS [illegible]

EVENT	ADJUSTED EVENT COST
1. UTILITIES	896355.75
2. DECK AND TRAFFIC CNTRL	672815.82
3. UNDERPINNING	220310.00
4. EXCAVATION	3313400.52
5. BACKFILL	216423.19
6. CONCRETE	5317131.50
7. RESTORATION	158092.36
8. MUCK DISPOSAL	175447.44
TOTAL ADJUSTED EVENT COSTS	1?908?07.82

(INCLUDES MISCELLANEOUS FRACTIONS AND ADJUSTMENT FOR DELAY)

Table B-2 (Cont'd)

PROGRAM DATA – CUT-AND-COVER STATION

INSTITUTIONAL CONTROLS	MO. DELAY	J	LUMP SUM	J	FRACTION TOTAL COST	J
OPTIMAL PROJECT SCHEDULE	1.00	2	0.	2	0.0300	2
SYSTEM WIDE LABOR AGREEMENT	1.00	2	0.	2	0.0000	2
OWNER ACQUIRED WORK AREA	1.00	2	0.	2	0.0000	2
OWNER ACQUIRED RIGHT-OF-WAY	1.00	2	0.	2	0.0000	2
OWNER ACQUIRED PRIVATE PERMITS	0.50	2	0.	2	0.0000	2
OWNER ACQUIRED BUILDING PERMIT	0.50	2	3500.	2	0.0000	2
OWNER SUPPLIED MATERIALS	0.00	2	0.	2	0.0000	2
OWNER PURCHASED INSURANCE	0.00	2	0.	2	0.0126	2
OWNER ENFORCED ENVIRONMENTAL REQUIREMENTS	0.00	2	0.	2	0.0033	2
ADVANCE PAYMENT	0.00	2	30000.	2	0.0000	2
EFFICIENT CASH FLOW	0.00	2	0.	2	-0.0025	2
SAFETY	0.00	2	-02000.	2	0.0100	2

LABOR PRODUCTIVITY 1.0

FRACTION OF TOTAL COST ATTRIBUTED TO LABOR 0.33

OVERHEAD COST PER MONTH [illegible]

TOTAL COST(EXCLUDING ESCALATION) 11508876.00

LABOR ESCALATION FACTOR 1.0

MATERIALS ESCALATION FACTOR 1.0

FRACTIONAL COST ATTRIBUTED TO MATERIALS 0.67

FRACTIONAL COST ATTRIBUTED TO OVERHEAD 0.00

TOTAL PROJECT COST [illegible]

TOTAL TIME [illegible] MONTHS

TABLE B-3: LIST OF PROGRAM NAMES

Name	Representation
TEC(I)	total event costs
SUMB	$\sum_{j=1}^{7} \beta_{ijk}$
SPCT	$\sum_{i=1}^{3}$ TEC (I) $(1 + \beta_{ijk})$ $(\gamma_{i,k})$
ACE(I)	adjusted event costs
ST	$\sum_{I=1}^{IP}$ ACE(I)
CTO	C_{TO}
PCT	$(SPCT/C_{TO})$ (0.5) (B_T)
CST	C_{TO} + (PCT) (z)
JSUM	$\sum_{i=3}^{6} \alpha 1$
SAO	$\alpha 1T$
SAT	$\alpha 2T$
SATH	$\alpha 3T$
CT	C_{T1}
TPC	C_T
TT	B_T + PCT + $\alpha 1T$ (for cut-and-cover projects)
	$B_T + \alpha 1T$ (for tunnel projects)

Appendix C

ACCIDENT REPORT SUMMARY AND REPORT FORMS

Frequency rate = Number of lost time injuries per million manhours
Severity rate = Number of days lost per million manhours
(C) = Job completed

Page 1 of 4

PHASE I

WASHINGTON METROPOLITAN AREA TRANSIT AUTHORITY
ACCIDENT EXPERIENCE SUMMARY

Prepared by Metro Insurance Administrators

CONSTRUCTION CONTRACTS

Contract No	Reporting Organizations	Manhours Worked This Month	Manhours Worked To Date	Lost Time Injuries This Month	Lost Time Injuries To Date	Days Lost This Month	Days Lost To Date	Frequency Rate To Date	Severity Rate To Date	[illegible] To Date	[illegible] Cost This Month	[illegible]
1A0011	Peter Kiewit Sons' Co.	56,212	1,682,624	3	28	56	431	16.6	256.1	33,425	0	A-1
1A0021	Amer. Structures & MEMCO	29,911	975,186	1	46	2	220	47.2	225.9	500	0	A-2
1A0031	Intercounty Associates	36,487	742,928	3	24	110	7109	32.3	9568.9	0	0	A-3
1A0043	S. A. Healy Co.	430	639,351	0	12	0	205	18.7	320.6	3,300	0	A-4a
1A0044	Granite Construction	32,568	396,680	0	5	0	62	12.6	156.0	0	0	A-4c
1B0011	Ball-Shea-Norair	27,899	1,881,224	0	51	440	2984	27.1	1586.2	110,000	0	B-1
1B0021	Norair Engineering	37,235	650,004	0	36	0	607	53.5	932.5	41,200	0	B-2
1B0031	Norair Engineering	3,342	16,448	0	2	0	26	60.7	1580.7	400	400	B-3a
1B0032	PC2-Morgentine	16,604	271,530	1	21	21	360	77.3	1325.8	[illegible],008	0	B-3b
1B0033	Norair Engineering	9,497	68,092	0	5	0	*57	73.4	837.1	1,390	0	B-3c
1B004a	Square/LaFera	***1000	8,107	0	1	12	12	123.3	1480.2	0	0	B-4a
1B004b	Granite Construction	6,805	128,919	0	6	*17	171	46.5	1326.4	0	0	B-4b
1B0051	Metro Track Constr.	12,458	311,639	0	12	0	329	38.5	1055.7	0	0	B-5b
1B0061	Allied Contractors	2,298	46,026	0	0	0	0	0	0	[illegible]	0	B-6
124202	Geo. Hyman Constr. Co.	8,922	240,948	0	2	0	49	8.3	203.0	[illegible],100	0	WMATA Shops
124201	Jonn Corp.	2,868	35,204	0	0	0	0	0	0	0	0	WTC Shops

* Includes all subcontractors accident experience

Signature

Month - Year
February 1973

Frequency Rate = Number of lost time injuries per million manhours
Severity Rate = Number of days lost per million manhours
(C) = Job Completed

Page 2 of 4

WASHINGTON METROPOLITAN AREA TRANSIT AUTHORITY
ACCIDENT EXPERIENCE SUMMARY

Prepared by Metro Insurance Administrators

CONSTRUCTION CONTRACTS

TOTALS TO DATE

CONTRACT NO.	Reporting Organizations	Manhours Worked This Month	Manhours Worked To Date	Lost Time Injuries This Month	Lost Time Injuries To Date	Days Lost This Month	Days Lost To Date	Frequency Rate To Date	Severity Rate To Date	Estimated Damage Cost To Date	Estimated Damage Cost This Month	Section Number
327022	Empire Soils	1760	31,149	0	1	0	13	32.1	417.3	0	0	Test Boring
327022	Soils Consultants	656	13,242	0	0	0	0	0	0	0	0	"
327022	Warren George, Inc.	80	2,708		0	0	0	0	0	0	0	"
327022	Schnabel Foundation	0	794	0	0	0	0	0	0	0	0	"
327022	American Dewatering	0	1,878	0	0	0	0	0	0	0	0	"
327022	Foundation Test Service	0	2,546	0	0	0	0	0	0	0	0	"
327022	Raymond Conc. Pile Co.	598	750	0	0	0	0	0	0	0	0	"
327022	Sprague & Henwood	0	8,110	0	0	0	0	0	0	0	0	"
327022	Moretrench American	0	136	0	0	0	0	0	0	0	0	"
327022	Giles Drilling Corp.	0	1,668	0	0	0	0	0	0	0	0	"
327022	Maryland Fdn. Testing	0	2,138	0	0	0	0	0	0	0	0	"
327022	Spencer, White & Prentis	0	136	0	0	0	0	0	0	0	0	"
	Completed Contracts		89,054									
	*Carry-over days **Adjusted for over-charge in Jan. 73 ***Estimated Manhours for February											
	Total Project Experience Previous Month		7,973,209		251		12,168	31.4	1564.9	$199,983		
	This Mo	277,030		8		258		28.8	931.3		$ 400	
	TOTAL PROJECT EXPERIENCE		8,250,239		259		12,426	31.1	1506.1	200,383		

Signature E. E. Hayes

Month - Year
February 1973

Frequency rate = Number of lost time injuries per million manhours
Severity rate = Number of days lost per million manhours
(C) = Job completed

WASHINGTON METROPOLITAN AREA TRANSIT AUTHORITY
ACCIDENT EXPERIENCE SUMMARY

Prepared by Fetro Insurance Administrators

Contract No	Reporting Organizations	CONSTRUCTION CONTRACTS: Manhours Worked This Month	Manhours Worked To Date	Lost Time Injuries This Month	Lost Time Injuries To Date	Days Lost This Month	Days Lost To Date	TOTALS TO DATE: Frequency Rate To Date	Severity Rate To Date	Estimated Damage Cost To Date	Estimated Damage Cost This Month	Section Number
1C0011	Early-Massman	17,070	77,731	2	2	14	14	25.7	180.1	$1750	$1250	C-1
1C0021	Morrison-Knudsen	37,529	488,795	0	7	0	75	14.3	153.4	[illegible]	857	C-2
1C0031	Massman-Kiewit-Early	30,495	388,924	0	4	0	81	10.2	208.2	[illegible]	0	C-3
1C0041	Shea-S&M-Ball	27,227	368,176	3	14	66	213	38.0	578.5	[illegible]	0	C-4
1C0051	Shea-Ball	36,274	405,812	5	18	62	624	44.3	1537.6	0	0	C-5
1C0062	Norair Engineering	13,995	105,061	0	2	0	3	19.9	28.5	[illegible]	0	C-6b
1C0071	Square/LaFera	18,320	102,416	0	7	0	74	68.3	722.5	[illegible]	500	C-7
1C0081	Peter Kiewit Sons' Co.	8,937	22,8111	0	0	0	0	0	0	0	0	C-8a
1D0011	P&Z/Shea	8,766	25,099	1	2	20	23	79.7	916.4	[illegible]	0	D-1
1D0021	Swindell/Dressler/Jackson	32,548	106,043	1	4	5	30	37.7	282.9	0	0	D-2
1D0031	Slattery Associates	36,848	124,275	2	6	52	60	48.3	482.8	0	0	D-3
1D0041	S&M/Traylor	11,894	30,82	0	0	0	0	0	0	[illegible]	0	D-4a
1D0042	Merg/Steers/Arundel	19,103	68,791	1	1	1	1	14.5	14.5	800	1300	D-4b
1D0043	Healy/Kruse	None	None									D-4c
1D0061	Healy/Kruse	30,643	65,957	0	0	0	0	0	0	30	0	D-6
1D0071	Norair Engineering	4,621	4,621									D-7

Includes all subcontractors accident experience

Signature

Month - Year: February 1973

Frequency rate = Number of lost time injuries per million manhours
Severity rate = Number of days lost per million manhours
(C) = Job Completed

WASHINGTON METROPOLITAN AREA TRANSIT AUTHORITY   Prepared by Metro Insurance Administrators

ACCIDENT EXPERIENCE SUMMARY

CONSTRUCTION CONTRACTS

Contract No.	Reporting Organizations	Manhours Worked This Month	Manhours Worked To Date	Lost Time Injuries This Month	Lost Time Injuries To Date	Days Lost This Month	Days Lost To Date	Frequency Rate To Date (Totals to Date)	Severity Rate To Date	Estimated Damage Cost To Date	Estimated Damage Cost This Month	Section Number
1F0012	Bravo Corp.	None	None									F-1b
124101	Geo. Hyman Constr. Co.	24,308	266,532	1	11	1	305	41.27 ✓	1144	37,085	50	CCCB
124081	Petro Track Constr.	0	2,772	0	0	0	0	0	0	0	0	TW-1
124209	Mead Constr. Co.	3,055	7,333	0	0	0	0	0	0	0	0	D-5d 2
124206	Gen. Railway Signal Co.	2,398	8,676	0	0	0	0	0	0	0	0	B-5c3
180062	Corson & Gruman	7,596	19,055	0	1	0	1	52.4	52.4	[illegible]	0	B-6b
183011	Geo. Hyman Constr. Co.	878	878	0	0	0	0	0	0	0	0	FB-1
122011	Gen. Railway Signal Co.	1,430	3,319	1	1	1	1	301.3	301.3	0	0	ATC
	Completed Contracts		25,252									
	Total Project Experience Previous Month		2,358,131		63		1187	.6.7	503.3	$49,098		
	This Month	373,935		17		222		45.4	593.6		$3497	
	TOTAL PROJECT EXPERIENCE		2,732,066		80		1409	29.2	515.7	$52,595		

Signature [signature]

Month - Year: February 1973

WASHINGTON METROPOLITAN AREA TRANSIT AUTHORITY
REPORT OF ACCIDENT OR DAMAGE TO EQUIPMENT OR PROPERTY

DATE OF REPORT ____________

CONTRACTOR ____________ CONTRACT NO. ____________

SUB CONTRACTOR ____________ SECTION DESIGNER ____________

REPORT NO. ____________

LOCATION OF ACCIDENT ____________

EQUIPMENT INVOLVED (DESC. & SERIAL NOS.)(OWNER) ____________

DAMAGE RESULTING FROM ACCIDENT ____________

WERE THERE PERSONAL INJURIES YES ☐ NO ☐ IF "YES" PREPARE FORM C-24

ESTIMATED VALUE OF DAMAGES $____________

WITNESSES TO ACCIDENT ____________

WAS (WERE) STATEMENT (S) OBTAINED FROM WITNESS (ES) YES ☐ NO ☐

ARE STATEMENTS ATTACHED YES ☐ NO ☐

REMARKS ____________

TIME OF ACCIDENT ________ AM ________ PM DATE ____________

WEATHER CONDITIONS ____________ TEMP ________ °F

ROADWAY OR SURFACE ________ WET ☐ DRY ☐ ICY ☐ * OTHER ☐

* IF "OTHER" EXPLAIN ____________

IF MORE SPACE IS REQUIRED, USE a separate SHEET FOR ADDITIONAL INFORMATION AND SKETCHES

1. white - Bechtel Safety
2. yellow - R.E.
3. pink - Contractor

SIGNED ____________

TITLE ____________

FORM NO. C - 23

WASHINGTON METROPOLITAN AREA TRANSIT AUTHORITY

SUPERVISORS REPORT OF ACCIDENT

1. Contract Number	2. Date of accident - Time - AM or PM
3. Project Section	4. Location of accident
5. Reporting organization	6. Contractor or Subcontractor involved
7. Injury ☐ Lost time ☐ Critical ☐ Fatal	8. Damage* ☐ Fire ☐ Property ☐ Equipment
9. Injured person and address	10. Occupation of injured ☐ Male ☐ Female Age Employer Address
11. Nature of injury	12. Date stopped work / 13. Date returned
14. First aid by	15. Ambulance
16. Hospital	17. Attending Physician
18. Witnesses or persons responding, including addresses	
19. Fire Department	20. Police Department
21. Equipment and/or materials involved	
22. Primary cause of accident	
23. Secondary cause	
24. Contributing factors	
25. Supervisor's corrective action	Supervisor's signature
26. Project Supt.'s corrective action	Project Supt.'s signature
27. Date this report	*Attach a list of damaged property and/or equipment excluding motor vehicles. Indicate owner's names and addresses.

FORM NO. C-24

28. WMATA Safety regulations involved Part__________ Chapter ________ Par.________

29. Photographs attached

30. Sketch showing location of nearby structures, materials, equipment, etc., with approximate scale of distances.

31. Narrative description of events previous, during and immediately after the accident.

32. If injury was sustained by visitor to job site, were visitor's pass requirements complied with (Sec. 10. Management Manual)? Yes No

WASHINGTON METROPOLITAN AREA TRANSIT AUTHORITY
REPORT OF PERSONAL INJURY

CONTRACTOR Shea-S&M-Ball
SUB CONTRACTOR [illegible]

DATE OF REPORT 22 July 1971
CONT. NO. [illegible]
SECTION DESIGNER [illegible]

REPORT NO. 1

NAME OF INJURED [illegible]
SEX M [X] F [ ]
ADDRESS 635 N. [illegible] Ave., Baltimore, Md. 21205
AGE 26
MARRIED X
SINGLE
NO. DEPENDANTS 3
AGES 26, 9, 4
OCCUPATION Laborer

LOCATION WHERE INJURY OCCURRED Rock Creek Bridge

TIME OF INJURY ______ AM 5:30 PM
ACCIDENT DATE 14 July 1971
WEATHER clear
TEMP. 90 °F

TYPE OF INJURY Strained back.

HOW SUSTAINED Jumped off of truck backwards to get away from moving beam.

WAS INJURED PERSON TAKEN TO DOCTOR [ ] No HOSPITAL [ ] OTHER [✓] No

* IF OTHER EXPLAIN HERE

NAME & ADDRESS OF DOCTOR Dr. Silverstein, 412 East Madison Street, Baltimore, Maryland

NAME & ADDRESS OF HOSPITAL Union Memorial Hospital
33rd and Calvert Street
Baltimore, Maryland

WILL LOSE TIME ______ YES [X] NO [ ]
EST. LOST TIME 3 wks. [illegible]

WAS SAFETY RULE ALLEGEDLY VIOLATED YES [X] NO [ ]

IF YES WHAT RULE ALLEGEDLY VIOLATED Standard procedure is you don't pick up any

ACTION TAKEN TO PREVENT REPETITION any long [illegible] from a truck without [illegible] off of truck first. Was told never to jump fro[m] [illegible]

WITNESSES TO ACCIDENT
J. P. Olivera
5119 Greenwich Avenue
Baltimore, Md. 21229

WAS STATEMENT TAKEN FROM INJURED YES [X] NO [ ]
WAS STATEMENT(S) TAKEN FROM WITNESS(ES) YES [ ] NO [X]

NOTE: USE BACK OF THIS SHEET FOR ADDITIONAL EXPLANATION OR SKETCHES.

REMARKS I was not notified until 16 July 1971. This man came to work on Friday 16 July, worked 11 hours and said he would be back to work Saturday 17 July. Did not report for work on 17 July or 19 July Came to our office to fill out accident report on 19 July.

[illegible]

[illegible] NO. [illegible] [illegible] Johnson

WASHINGTON METROPOLITAN AREA TRANSIT AUTHORITY

SUPERVISORS REPORT OF ACCIDENT

1. Contract Number
[illegible]

2. Date of accident - Time - AM or PM
14 July 1971 - 5:30 p.m.

3. Project Section
C4

4. Location of accident
Rock Creek Park

5. Reporting organization
Shea S&M Ball

6. Contractor or Subcontractor involved
P&Z-MERGENTIME AJV

7. Injury
☒ Lost time ☐ Critical ☐ Fatal

8. Damage*
☐ Fire ☐ Property ☐ Equipment

9. Injured person and address
Michael Davidson
638 N. Belnord Avenue
Baltimore, Maryland 21205

10. Occupation of injured
Laborer

☒ Male ☐ Female

Age 36

Employer P&Z-Mergentime AJV

Address 10 E St., N.E., Wash.,D.C. 20002

11. Nature of injury
Said he hurt his back.

12. Date stopped work
16 July 1971

13. Date returned
--

14. First aid by
no

15. Ambulance
no

16. Hospital Union Memorial
33rd & Calvert St.
Baltimore, Maryland

17. Attending Physician Dr. Silverstein
412 E. Madison St., Baltimore, Md.

18. Witnesses or persons responding, including addresses
J. P. Olivera Phone: 728-1129
3119 Greenwich Avenue
Baltimore, Maryland 21229

19. Fire Department
no

20. Police Department
no

21. Equipment and/or materials involved
Semi truck.

22. Primary cause of accident
Jumped from truck rather than climbing down.

23. Secondary cause

24. Contributing factors
Picking I beam from truck while still standing on truck.

25. Supervisor's corrective action

Supervisor's signature
[illegible]

26. Project Supt.'s corrective action

Project Supt.'s signature

27. Date this report
[illegible]

*Attach a list of damaged property and/or equipment excluding

FORM NO. C-2-

29. WMATA Safety regulations involved Part__________ Chapter ________ Par.________

30. Photographs attached

Sketch showing location of nearby structures, materials, equipment, etc., with approximate scale dimensions.

31. Narrative description of events previous, during and immediately after the accident.

I, Al Johnson, was not notified of the accident until 16 July 1971. This man reported for work on the 16th, worked 11 hours and said he felt good and that he would be in on Saturday 17 July. He has not reported for work as yet.

THE USE OF THIS FORM IS REQUIRED UNDER THE PROVISIONS OF THE WORKMEN'S COMPENSATION ACT.

COMMONWEALTH OF VIRGINIA
DEPARTMENT OF WORKMEN'S COMPENSATION
INDUSTRIAL COMMISSION OF VIRGINIA
RICHMOND

C5 LT

Case of ______
File No. ______

EMPLOYER'S FIRST REPORT OF ACCIDENT

(Every question must be answered)

Employer

1. Name of Employer Shea-Ball
2. Office address: No. and St. 1750 Lynn St. City or Town Arlington State Virginia
3. Insured by: Name of Company Argonaut
4. Give nature of business (or article manufactured) Construction

Time and Place

5. (a) Location of plant or place where accident occurred Arlington (City or County)
Department Underground State if employer's premises Yes
(b) If injured in a mine, did accident occur on surface, underground, shaft, drift or mill Underground
6. (a) Date of Injury Aug 21 1972 Day of week Mon Hour of day ______ A. M. ______ P. M.
(b) Was injured paid in full for day he was injured? Yes
7. Date incapacity began 8/22/72 19 ___ A. M. 7:00 P. M.
8. Was injured paid in full for day incapacity began? No
9. When did you or foreman first know of accident? Aug 21, 1972
10. Name of foreman Wayne Eldrige

Injured Person

11. Name of Injured BYRD, FIELDING (First Name) (Middle Initial) (Last Name) 229-48-6594
12. Address: No. and St. Loretta City or Town ______ State Virgin
13. Check (✓) Married X Single ___ Widowed ___ Widower ___ Divorced ___; Male X Female ___; White ___ Colored ___
14. Nationality United States Citizen Speak English Yes
15. Age 30 Did you have on file employment certificate or permit? Yes
16. (a) Occupation when injured Laborer (b) Was this his or her regular occupation? Yes
(If not state in what department or branch of work regularly employed)
17. (a) How long employed by you? ______ (b) Piece or time worker time (c) Wages per hour $ 5.77
18. (a) No. hours worked per day 8 (b) Wages per day $ 46.16
(c) No. days worked per week 5 (d) Average weekly earnings $ 230.00
(e) If board, lodging, fuel or other advantages were furnished in addition to wages, give estimated value per day, week or month N/A

Cause of Injury

19. Machine, tool or thing causing injury N/A 20. Kind of power, (hand, foot, electrical, steam, etc.) ______ 21. Part of machine on which accident occurred N/A
22. (a) Was safety appliance or regulation provided? Yes (b) Was it in use at time? Yes
23. Was accident caused by injured's failure to use or observe safety appliance or regulation? No
24. Describe fully how accident occurred, and state what employee was doing when injured. While lifting heavy objects in shaft employee strained lower back.
25. Name and address of witness Wayne Eldrige

Nature of Injury

26. Nature and location of injury (describe fully exact location of amputation or fractures, right or left) Strain of lower back
27. Probable length of disability ______ 28. Has injured returned to work? Yes
If so, date and hour 8/23/72 7:00 AM At what wage $ Same
29. At what occupation? Same
30. (a) Name and address of physician P.A. [illegible]
(b) Name and address of hospital ______

Fatal

31. Has injured died? No If so, give date of death ______

Date of this report 8/25/72 Firm name Shea Ball
Form No. [illegible] Signed by [signature] Official Title Safety Superintendent

C-11

A Copy shall be mailed to the Department of Labor and Industry, 301 W. Preston St., Baltimore, Md. 21201

Complete and send immediately to --

WORKMEN'S COMPENSATION COMMISSION

108 E. LEXINGTON STREET, BALTIMORE, MD. 21202

STANDARD FORM FOR EMPLOYER'S FIRST REPORT OF INJURY OR OCCUPATIONAL DISEASE

DO NOT WRITE IN THIS SPACE

WCC CLAIM #

DOCTOR'S REPORT Yes [ ] No [ ]

SOUNDEX #

EVERY QUESTION MUST BE ANSWERED AND FORM SIGNED

PLEASE PRINT OR TYPE

1 EMPLOYER – Name – (Give name under which concern does business)

2 Mail Address – (No. and Street) (City or Town) (State) (Zip) Phone

3 Nature of Business – (Manufacturing shoes, retailing men's clothes, trucking, etc.) | 3a. Insured By – (Name of company)

4 TIME AND PLACE – Location of plant or place where accident or disease occurred | Department – State if employer's premises – Yes [ ] No [ ]

5 Date of injury 19 Day of week Hour of day A.M. [ ] P.M. [ ] | 6. Was injured paid for one half or more for day of injury? Yes [ ] No [ ]

7 Date disability began 19 A.M. [ ] P.M. [ ] | When did you or foreman first know of injury? | Name of foreman

8 INJURED PERSON – Name of injured – (First – Middle – Last Name) | Social Security No.

9 Address – (No. and Street) (City or Town) (State) (Zip)

10. Check ( ) Married [ ] Single [ ] Widowed [ ] Divorced [ ] Male [ ] Female [ ] | 11. Nationality | Speak English Yes [ ] No [ ]

12. Age | Did you have on file employment certificate or permit? Yes [ ] No [ ] | (a) Occupation when injured

13. Was this his or her regular occupation? Yes [ ] No [ ] (If not, state in what department or branch of work regularly employed)

14. How long employed by you? | (a) Pieceworker [ ] Timeworker [ ] | 15. No. of hours worked per day per week | No. of days worked per week

16. Wages: $ per hour, or $ per day, or $ per week. | (If paid on other than a time basis, such as piece work or Commission – Average weekly earnings $

17. If board, lodging, tips, fuel or other advantages were furnished in addition to wages, give estimated value per day, week or month

18. CAUSE AND NATURE OF INJURY OR OCCUPATIONAL DISEASE | 19. Probable length of disability

20. Machine, tool or thing causing injury | 21. Kind of power (hand, foot, electrical, steam, etc.)

22. Part of machine on which accident occurred | 23. (a) Was safety appliance or regulation provided (b) Was it in use at time

24. Was accident caused by injured's failure to use or observe safety appliance or regulation

25. Has injured returned to work? Yes [ ] No [ ] If so, date and hour | a. At what wage $ | b. At what occupation?

26. Name and address of physician

27. Name and address of hospital

28. FATAL CASES – Has injured died [ ] Yes [ ] No | If yes give date of death

Date of this report | Firm Name

Signed by | (Official Title)

SF1-Rev. 6/65

NATIONAL SAFETY CORPORATION

MONTHLY ACCIDENT SUMMARY

DO NOT WRITE IN THIS SPACE

PERIOD OF SUMMARY

FROM February 26, 1968 TO April 1, 1968

CONTRACTOR	CONTRACT
Morrison-Knudsen & Associates	1S0022

FEATURE	AVERAGE NO. OF MEN	TOTAL MAN HOURS	TOTAL ACCIDENTS	LOST TIME ACCIDENTS	DAYS LOST	TOTAL DOCTOR CASES	FREQUENCY RATE	SEVERITY RATE
PREVIOUS REPORTS		360,738	346	17	219	192		
PRIME CONTRACTOR	287	53,859	69	8	200	34	148.53	3,713
SUB CONTRACTORS								
Beylik Drill	7	580						
Pitcher Drill	3	136						
MONTHLY TOTALS	297	54,575	69	8	200	34	146.58	3,664
DATE CUM. FROM:		415,313	415	25	419	226	60.19	1,008

SUMMARY

DESCRIPTION	FOR PAST MONTH		FOR THE JOB TO DATE		REMARKS
	NO. OF ACCIDENTS	DAYS LOST	NO. OF ACCIDENTS	DAYS LOST	
TYPE OF ACCIDENT					
FALLING - FROM ELEVATIONS	1	9	10	20	
FALLING - ON LEVEL	5		16	1	
OBJECTS FALLING	6	9	35	62	
HANDLING MATERIAL	11	75	73	172	
STEPPING ON OBJECT			7		
STRIKING AGAINST OBJECTS	3		26	8	
EXPLOSIVES					
ELECTRICITY			4		
HAND TOOLS	12		32		
MACHINERY	5	92	16	102	
VEHICLES					
FLYING PARTICLES	6		61		
DUST FUMES OR GASES					
ALLERGY	13	5	53	38	
WELDING OR BURNING	2		21		
POISON IVY					
MISCELLANEOUS	5	10	52	10	
Decompression Illness			9		
NATURE OF INJURY					
HAND INJURIES	14	80	104	166	
EYE INJURIES	20		87		
FOOT - PUNCTURES			5		
FOOT - BRUISES OR CRUSHES	4	84	18	140	
BACK INJURIES	2		16	29	
HERNIA					
OTHER SPRAINS OR STRAINS	2	9	11	10	
FRACTURES - OTHER THAN HAND AND FOOT	2	22	6	33	
BURNS			27	5	
INFECTIONS			4		
HEAD INJURIES	1		6		
MISCELLANEOUS BRUISES AND LACERATIONS	3		29	2	
CONTUSIONS	3		18	1	
MISCELLANEOUS	18	5	75	33	
FATALITIES					
Decompression Illness			9		
CRAFT					
LABORERS	4	5	33	11	
CARPENTERS			1		
IRONWORKERS			4		
TRUCK DRIVERS	1		1		
CEMENT WORKERS			6		
OPERATING ENGINEERS	6		56		
PAINTERS					
ELECTRICIANS	2	5	15	16	
PIPEFITTERS					
PILE DRIVERS			5	57	
FIELD SUPERVISORY	5	17	41	27	
ENGINEERING	4		13		
OFFICE					
Miners	47	173	240	308	

OF CALIFORNIA
785 MARKET STREET
SAN FRANCISCO, CALIFORNIA

INDEMNITY		
MEDICAL		
ALLOCATED		
TOTAL		
CATASTROPHE	OCC. DIS	
EXTENT	SUBRO.	
BY:	TERRITORY	

EMPLOYER'S REPORT OF INDUSTRIAL INJURY

STATE OF CALIFORNIA - DEPARTMENT OF INDUSTRIAL RELATIONS
DIVISION OF LABOR STATISTICS AND RESEARCH

... must be answered fully to avoid further correspondence. FAILURE TO FILE IS A MISDEMEANOR SUBJECT TO MAXIMUM FINE OF $100. (Sections 6413, 6413).
... injury to an employee must be reported within five days after the injury. If the injury results in death, a report must be made by telephone or telegraph ... to the Division of Labor Statistics and Research, San Francisco, not later than 24 hours after death.

POLICY NUMBER

DO NOT WRITE IN THIS COLUMN: Case No., Employer No., Industry, Age, Sex and Marital Status, Weekly Wage, County, Accident Date, Occupation, Accident Type, Agency, Agency Part, Mech. Defect, Unsafe Act, Personal Defect, Nature of Injury, Location, Extent of Injury, Insurance Carrier, Report Rec'd, ... Day

EMPLOYER

1. Name (Give name under which business is done) Parsons Brinckerhoff - Tudor - Bechtel
2. Office Address (No. and Street) 814 Mission St. (City or Town) S.F.
3. Nature of business (Manufacturing shoes, retailing men's clothes, trucking for hire, etc.) Consulting Engineers

INJURED EMPLOYEE

4. Name BAIKSTON, Donald Social Security No. ...
5. Address (No. and Street) ... Fields, Dr. (City or Town) Oakland
6. Age 22 7. Sex: Check (V) Male X Female ____ 8. Check (V) Married X Single ____
9. Number of hours worked per day 8 ; per week 40 Number of days worked per week 5
10. Wages $____ per hour, or $____ per day, or $____ per week (If earnings of irregular rate, such as piece work or on commission basis, enter actual average weekly earnings for convenient period not to exceed one year.)
11. If board, lodging, or other advantages furnished in addition to wages, give estimated value $____ or $____ per week

ACCIDENT

12. Place of accident (No. and Street) 23rd & Mission (City or Town) S.F. (County) S.F.
13. On employer's premises (Yes or No) No 14. Department ____
15. Date of accident Jan. 1969 16. Hour of day 4:30 A.M. (P.M.) 17. Did injury result in disability beyond day of accident? (Yes or No) No 18. If yes, give date last worked ____ 19. Was injured paid in full for this day? (Yes or No) Yes 20. If injured in a mine, check (V) accident location: Surface ____ Mill ____ Underground X ...

CAUSE OF ACCIDENT

21. Occupation (job title) Inspector 22. How long employed by you at this occupation? Check (V) Less than 6 months ____ ; 6 months to 2 years X ; over 2 years ____ 23. What was employee doing when accident occurred? (Describe briefly such as: loading truck, operating drill press, shoveling dirt, walking down stairs, etc.) Checking a torque on a bolt.
24. How did the accident happen? (Describe fully, stating whether the injured person fell, was struck, etc.; give all factors contributing to accident. Use other side of report for additional space.)
Checking a torque on a bolt and the wrench slipped and my right hand hit another bolt with the back of my hand. Pain has been progressing so much, decided to have it examined.
25. What machine, tool, substance, or object was most closely connected with the accident? (Name the specific machine, tool, appliance, gas, liquid, etc., involved) Torque wrench
26. If mechanical apparatus or vehicle, what part of it? (State if gears, pulley, motor, etc.) ____
27. Were mechanical guards or other safeguards provided? (Yes or No) ____ 28. Was injured using them? (Yes or No) ____
29. What do you recommend for preventing this type of accident? (State the specific preventive measure that can be taken by employer and employee. Do not say, "By being more careful." Specify what should or should not be done.)

NATURE OF INJURY AND PART OF BODY AFFECTED

30. (Describe in detail the nature of the injury and the part of the body affected. For example: amputation of right index finger at second joint, fracture of ribs, lead poisoning, dermatitis of left hand, etc.)
Right hand and wrist, fracture of proximal base of 2nd metacarpal.
31. Name and address of physician Jerry H. Jescula, M.D. (referred him to Dr. ...)
32. Name and address of hospital 56 Julian Ave., Transit Compressed Air Med. Center
33. Has employee returned to work? (Yes or No) Yes 34. If yes, give date same 35. At what wage? $ same per ...
36. Did injury result in death? (Yes or No) No 37. If yes, give date ____
38. In case of death, give name and address of nearest relative ____
39. Is injured (a) Employed by Sub-Contractor No (b) An officer, partner or relative (by blood or marriage) of the Employer: No
Give details ____
40. Was injury caused by anyone else? NO Name ____
Address ____
41. On reverse side list names and addresses of witnesses.
42. Date Employer was notified of injury June 17, 1969 43. When will injured return to work? Same day
Signed by [signature] Official position ... Date ...
(Employer or authorized representative)

Filing of this report is not an admission of liability. ... No report of injury required to be filed by an employer or insurer by this chapter shall be admissible as evidence in any adversary proceeding before the Industrial Accident Commission ... Code Section 6412.

ADV 17 (HO) - 11-65

SEND REPORT IMMEDIATELY AFTER INJURY
DO NOT WAIT FOR DOCTOR'S REPORT

MAIL THIS COPY TO: C-15 NATIONAL SURETY CORPORATION ...
... MARKET STREET

TRANSIT COMPRESSED AIR MEDICAL CENTER
56 JULIAN AVENUE · SAN FRANCISCO, CALIFORNIA

NOTICE TO EMPLOYER
FIRST REPORT OF INJURY

178
REGISTER NO.

Employer: 86TB

Name of Injured: Bexleton, Donald Age: 32 Sex: M.

Home Address: Elgin field Dr Oakland Phone: [redacted] WD

Badge No.: ____ Craft: Inspector S.S. No.: [redacted]

Foreman: Pete Lord Was He Notified of This Injury: yes

By Whom: self

Date of Accident: @ Jan 1969 The Time: @ 4:30A

The Place in Relation To The Project: 23rd & Mission Sts 1R00 ft

Time Employee Started His Shift: 2A-8A

Employee's Statement of Cause of Injury: Checking a torque one bolt and the wrench slipped and my rt hand hit another bolt & the back of my hand. Pain has been progressing so much decided to have it [illegible]

Describe Nature of Injuries, and Body Parts Affected: Examined. Stated that he has had some pain since time of accident and that pain in [illegible] progressively worse [illegible]

What Care Was Given To The Injured: [illegible]

Referred 2 to Dr. [illegible] 6/18/69 M.R.

THE FIRST TREATMENT

A. First Aid: [illegible]
By Whom: [illegible] Hour and Date: 6-16-69

B. Medical Treatment: [illegible]
By Whom: [illegible] Hour and Date: 1130

Is Further Treatment Needed: [illegible] Back To Work: [illegible]

Home Hospital Other: [illegible]

Estimated Disability, if any: [illegible]

[illegible] USE ONLY

Occupation (Job Title): [illegible]

Wages: ____ Per Hour ____

Name and Address of Physician: ____

Badge No.: ____ Code: ____

Report Sent to Insurance Co.: ____ Date ____

Coded By ____

C-16

OF C[illegible]ORNIA
73[illegible] MARKET STREET
SAN FRANC[illegible]O, CALIFORNIA

INDEM.	
MEDICAL	
ALLOCATED	
TOTAL	
CATASTROPHE	O.C. PIS
EXTENT	SUBRO.
BY:	TERRITORY

EMPLOYER'S REPORT OF INDUSTRIAL INJURY

STATE OF CALIFORNIA - DEPARTMENT OF INDUSTRIAL RELATIONS
DIVISION OF LABOR STATISTICS AND RESEARCH

[illegible] must be answered fully to avoid further correspondence. FAILURE TO FILE IS A MISDEMEANOR SUBJECT TO MAXIMUM FINE OF $[illegible]. ([illegible] 6413) Every work injury to an employee must be reported within five days after the injury. If the injury results in death, a report must be made by telephone or telegraph [illegible] the Division of Labor Statistics and Research, San Francisco, not later than 24 hours after death.

POLICY NUMBER

DO NOT [illegible] IN THIS COLUMN

THE EMPLOYER

1. Name (Give name under which concern does business) Parsons Brinckerhoff-Tudor-Bechtel
2. Office Address (No. and Street) [illegible] Mission St. (City or Town) S.F.
3. Nature of business (Manufacturing shoes, retailing men's clothes, trucking for hire, etc.) Engineering Consultants

INJURED EMPLOYEE

4. Name GILBERT, James H. Social Security No. [redacted]
5. Address (No. and Street) [illegible] (City or Town) Pittsburg, Calif.
6. Age 49 7. Sex: Check (V) Male X Female 8. Check (V) Married Single
9. Number of hours worked per day 8 ; per week 40 Number of days worked per week 5
10. Wages: $ per hour, or $ per day, or $ per week. (If earnings at irregular rate, such as piece work or on commission basis, enter actual average weekly earnings for convenient period not to exceed one year.)
11. If board, lodging, or other advantages furnished in addition to wages, give estimated value $ or $ per week

ACCIDENT

12. Place of accident (No. and Street) 24th & Mission (City or Town) S.F. (County) S.F.
13. On employer's premises (Yes or No) No 14. Department
15. Date of accident 2-17-69 16. Hour of day 12 Midnight 17. Did injury result in disability beyond day of accident? (Yes or No) No 18. If yes, give date last worked 19. Was injured paid in full for this day? (Yes or No) Yes 20. If injured in a mine, check (V) accident location: Surface Mill Underground X Shaft

CAUSE OF ACCIDENT

21. Occupation (job title) Inspector field 22. How long employed by you at this occupation? Check (V) Less than 6 months ; 6 months to 2 years X; over 2 years 23. What was employee doing when accident occurred? (Describe briefly such as: loading truck, operating drill press, shoveling dirt, walking down stairs, etc.) Walking on boards above railroad ties.
24. How did the accident happen? (Describe fully, stating whether the injured person fell, was struck, etc.; give all factors contributing to accident. Use other side of report for additional space.) "I stepped on a board and my left leg and the board gave way. I then caught my left leg between two railroad ties (about a one foot drop)
25. What machine, tool, substance, or object was most closely connected with the accident? (Name the specific machine, tool, appliance, gas, liquid, etc., involved) Boards
26. If mechanical apparatus or vehicle, what part of it? (State if gears, pulley, motor, etc.)
27. Were mechanical guards or other safeguards provided? (Yes or No) 28. Was injured using them? (Yes or No)
29. What do you recommend for preventing this type of accident? (State the specific preventive measures that can be taken by employer and workers. Be specific. [illegible])

NATURE OF INJURY AND PART OF BODY AFFECTED

30. (Describe in detail the nature of the injury and the part of the body affected. For example: amputation of right index finger at second joint, fracture of ribs, lead poisoning, dermatitis of left hand, etc.) [illegible]algia, undetermined etiology
31. Name and address of physician James Lee, M.D.
32. Name and address of hospital [illegible] Med. Center, [illegible]
33. Has employee returned to work? (Yes or No) Yes 34. If yes, give date [illegible] 35. At what wage? $ per
36. Did injury result in death? (Yes or No) NO 37. If yes, give date
38. In case of death, give name and address of nearest relative
39. Is injured—a) Employed by Sub-Contractor? NO b) An officer, partner or relative (by blood or marriage) of the Employer? NO Give details
40. Was injury caused by anyone else? NO How Name Address
41. On reverse side list names and addresses of witnesses.
42. Date Employer was notified of injury 2-18-69 43. When will injured return to work? 2-1[illegible]-69
Signed by [signature] (Employer or authorized representative) Official position [illegible] Date 3-3-69

Filing of this report is not an admission of liability. "[illegible] report required to be filed by an employer or an insurer by this chapter shall be admissible as evidence in any adversary [illegible] Industrial Accident Commission." Labor Code, Section 6413.

[illegible] (REV) - [illegible]

MAIL THIS COPY TO: [illegible] CORPORATION OF CALIFORNIA
7[illegible] MARKET STREET
[illegible]

C-17

Case No.
Employer No.
Industry
Age
Sex and Marital Status
Weekly Wage
County
Accident Date
Occupation
Accident Type
Agency
Agency Part
Mech. Defect
Unsafe Act
Personal Defect
Nature of Injury
Location
Extent of Injury
Insurance Carrier
Report Log
Coded By

SEND REPORT IMMEDIATELY AFTER INJURY — DO NOT WAIT FOR DOCTOR'S REPORT

TRANSIT COMPRESSED AIR MEDICAL CENTER
56 JULIAN AVENUE · SAN FRANCISCO, CALIFORNIA

NOTICE TO EMPLOYER
FIRST REPORT OF INJURY

256
REGISTER NO.

MKK-IM0031

Employer: P.B.T.B

Name of Injured: Gilbert, James H Age: 49 Sex: ♂

Home Address: Bailey Road, Pittsburg, CA. Phone: [illegible] S M W D

Badge No.: ______ Craft: Field Inspector S.S. No.: [illegible]

Foreman: Peter Toal Was He Notified of This Injury: No

By Whom: Self.

Date of Accident: 17 Feb 69 (Approx) Time: Grave yard Shift p 2400

The Place in Relation To The Project: M-R Tunnel 24th + Mission St.

Time Employee Started His Shift: p 2400 17 Feb 69 Approx

Employee's Statement of Cause of Injury: "I SKp ped on a board c my (L) leg and the board gave way. I then caught my (L) leg between two railroad ties (About a onefoot drop)

Describe Nature of Injuries, and Body Parts Affected: [illegible] of ... cramps in both lat. thighs, not present on awakening, but progressive thru the day. x 2 wk duration.

What Care Was Given To The Injured

A. First Aid: Imp: myalgia, undetermined etiol.

By Whom: [illegible signature] Hour and Date: 26 Feb. 69 6:15 P

THE FIRST TREATMENT

B. Medical Treatment: ______

By Whom: ______ Hour and Date: ______

Is Further Treatment Needed: ______ Back To Work: ______

Home Hospital Other: ______

Estimated Disability, if any: ______

OFFICE USE ONLY

Occupation (Job Title) ______

Wages: ______ Per Hour

Name and Address of Physician: ______

Foreman's Report ______

Report Lag ______

Lost Time ______

Coded By ______

Badge No.: ______ Code: ______

Report Sent to Insurance Co.: ______ Date ______

C-18

NATIONAL SURETY CORPORATION OF CALIFORNIA

DOCTOR'S FIRST REPORT OF WORK INJURY

CLAIM No. ....

CLAIM DEPARTMENT

Immediately after first examination mail one copy directly to the Division of Labor Statistics and Research, P. O. Box 965, San Francisco 94103. Failure to file a report with the Division is a misdemeanor. (Labor Code, Sections 6407-6413.) Answer all questions fully.

Do not write in this space

1. EMPLOYER PARSONS BRINCKERHOFF TUDOR BECHTEL Policy No.
2. Address (No., St. & City) 603 So. Van Ness Avenue, San Francisco, Calif.
3. Business (Manufacturing shoes, building construction, retailing men's clothes, etc.)

4. EMPLOYEE (First name, middle initial, last name) GILBERT, James H. Social Sec. No. [redacted]
5. Address (No., St. & City) [redacted] Pittsburg, Calif. Tel. No. [redacted]
6. Occupation Field Inspector Age 49 Sex M Wt. Ht.
7. Date injured @ 2-17-69 Hour P.M. Date last worked 2-26-69
8. Injured at (No., St. & City) 24th & Mission Sts. MR Tunnel County San Francisco
9. Date of your first examination 2-26-69 Hour 6:15 P.M. Who engaged your services? Employee
10. Name other doctors who treated employee for this injury None

11. ACCIDENT OR EXPOSURE: Did employee notify employer of this injury? NO Employee's statement of cause of injury or illness:

"I stepped on a board with my Left leg and the board gave way. I then caught my L leg between two railroad ties (about a one foot drop.)."

12. NATURE AND EXTENT OF INJURY OR DISEASE (Include all objective findings, subjective complaints, and diagnoses. If occupational disease state date of onset, occupational history, and exposures.)

Myalgia, undetermined etiology.

13. X-rays: By whom taken? (State if none) None
Findings:

14. Treatment: Examination.

15. Kind of care (Office, home, or hospital) Office If hospitalized, date Estimated stay
Name and address of hospital
16. Further treatment (Estimated frequency and duration) None
17. Estimated period of disability for: Regular work return to work Modified work
18. Describe any permanent disability or disfigurement expected (State if none)
None anticipated.
19. If death ensued, give date
20. REMARKS (Note any pre-existing injuries or diseases, need for special examination or laboratory tests, other pertinent information.)

Name James [illegible] M.D. (Type or Print) Degree M.D. [PERSONAL SIGNATURE OF DOCTOR] [signature]

Date of report 2-27-69 Address (No., St. & City) 56 Julian Ave., San Francisco, Cal. Tel. No. 621-5472

Use reverse side if more space required

C-19

NATIONAL SURETY CORPORATION
OF CALIFORNIA

DOCTOR'S FIRST REPORT
OF WORK INJURY

CLAIM No ....

CLAIM DEPARTMENT

Immediately after first examination mail one copy **directly** to the Division of Labor Statistics and Research, P. O. Box ..., San Francisco 94103. ... (Labor Code Sections 6407-6413.) Answer all questions fully.

1. EMPLOYER PARSONS BRINCKERHOFF TUDOR BECHTEL Policy No
2. Address (No., St. & City) 663 So. Van Ness Avenue, San Francisco, California
3. Business (Manufacturing shoes, building construction, retailing, etc.)
4. EMPLOYEE (First name, middle initial, last name) BANKSTON, Donald Social Sec. No. [redacted]
5. Address (No. St. & City) [redacted] Fields Dr., Oakland, California Tel No. [redacted]
6. Occupation Inspector Age 32 Sex M Wt. Ht.
7. Date injured Approx. Jan. 1969 Hour @4:30A.M Date last worked returned to work
8. Injured at (No. St. & City) 23rd and Mission Streets 1M0011-0 County San Francisco
9. Date of your first examination 6-16-69 Hour 10:30A.M Who engaged your services? Employer
10. Name other doctors who treated employee for this injury None

11. ACCIDENT OR EXPOSURE: Did employee notify employer of this injury? YES Employee's statement of cause of injury or illness:
"Checking a torque on a bolt and the wrench slipped and my right hand hit another bolt with the back of my hand. Pain has been progressing so much, decided to have it examined."

12. NATURE AND EXTENT OF INJURY OR DISEASE (Include all objective findings, subjective complaints, and diagnoses. If occupational disease state date of onset, occupational history, and exposures.)

States that he has had some pain since time of accident and that pain has become progressively worse with some loss of gripping power. Has tender area at proximal end of 2nd. metacarpal, some weakness of right grip.

13. X-rays: By whom taken? (State if none) Transit Compressed Air Medical Center
Findings: Right hand and wrist, 8 views: reveals small, apparently old, chip fracture of proximal base of 2nd. metacarpal, right hand.

14. Treatment: Examination and referred to Marvin L. Gordon, M.D.

15. Kind of case (Office, home, or hospital) Office If hospitalized, date Estimated stay
Name and address of hospital
16. Further treatment (Estimated frequency and duration) See report of Dr. Marvin L. Gordon
17. Estimated period of disability for: Regular work " " Modified work
18. Describe any permanent disability or disfigurement expected (State if none) See report of Dr. Gordon
19. If death ensued, give date
20. REMARKS (Note any pre-existing injuries or diseases, need for special examination or laboratory tests, other pertinent information.)

Name Jerry H. Jessules, M.D. Degree M.D. (Type or Print) PERSONAL SIGNATURE OF DOCTOR [signature]
Date of report 6-16-69 Address (No. St. & City) 56 Julian Ave., San Francisco, Calif. Tel. ...

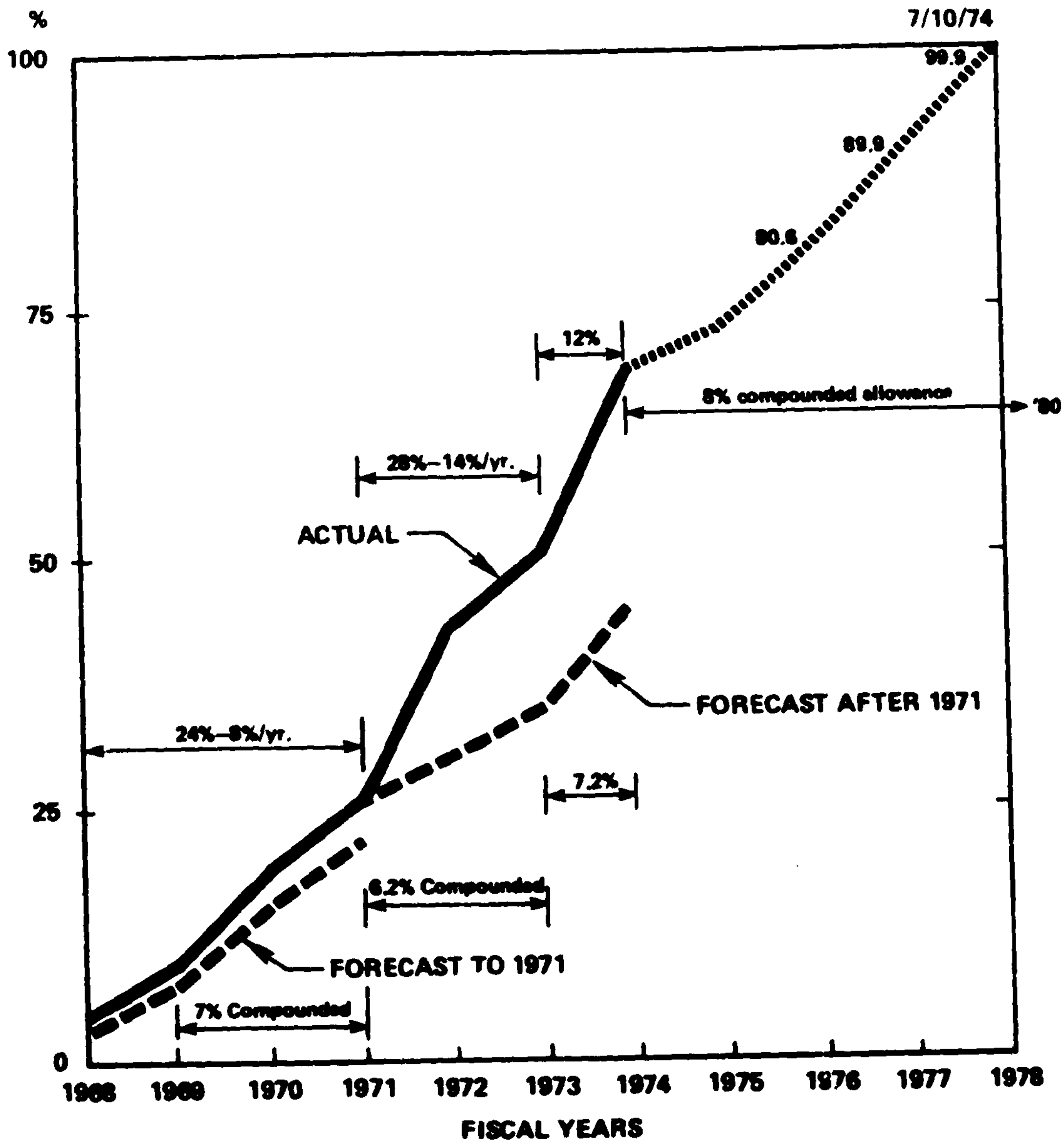
Use reverse side if more space required

C-20

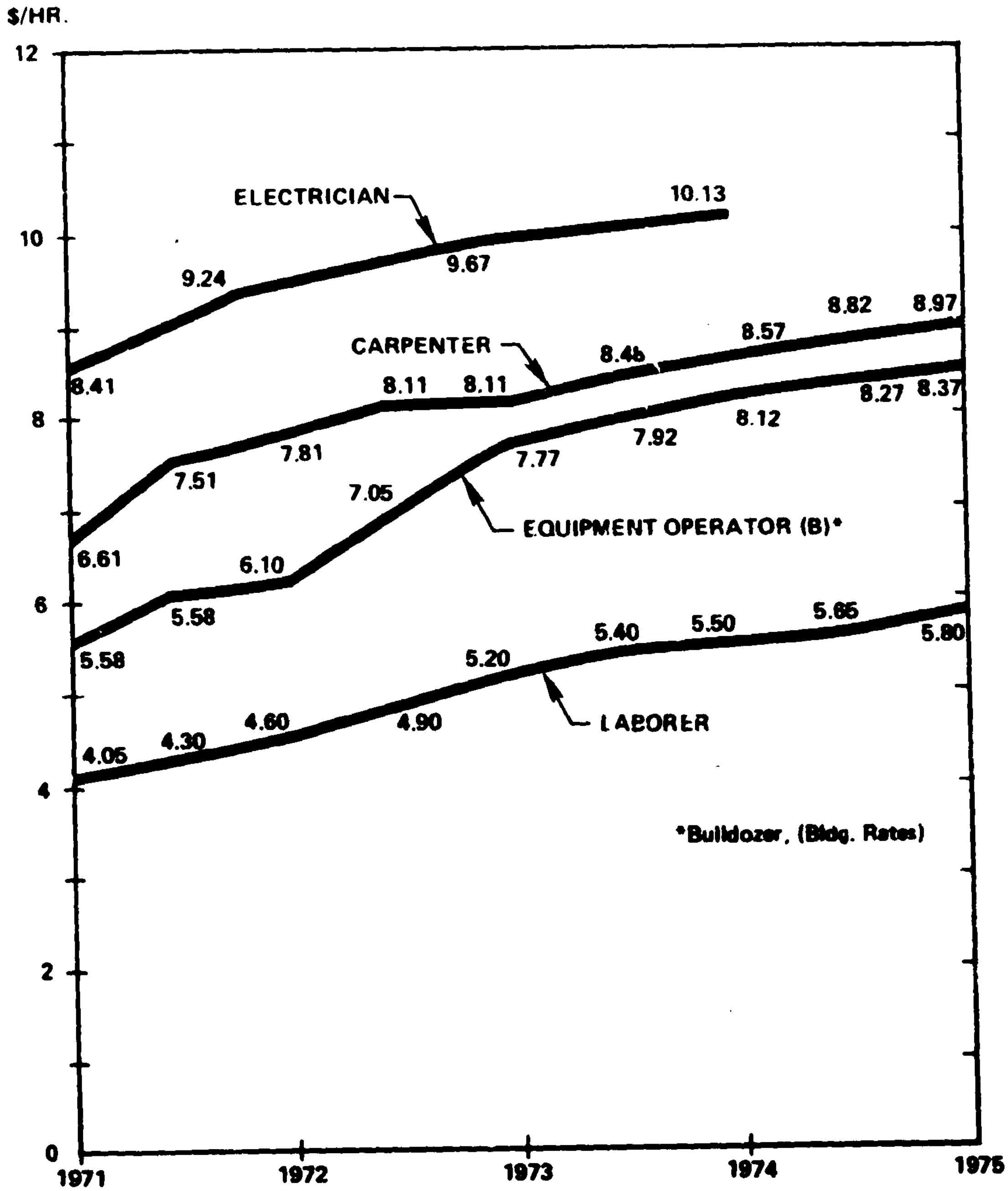
Appendix D

ESTIMATED ESCALATION VALUES

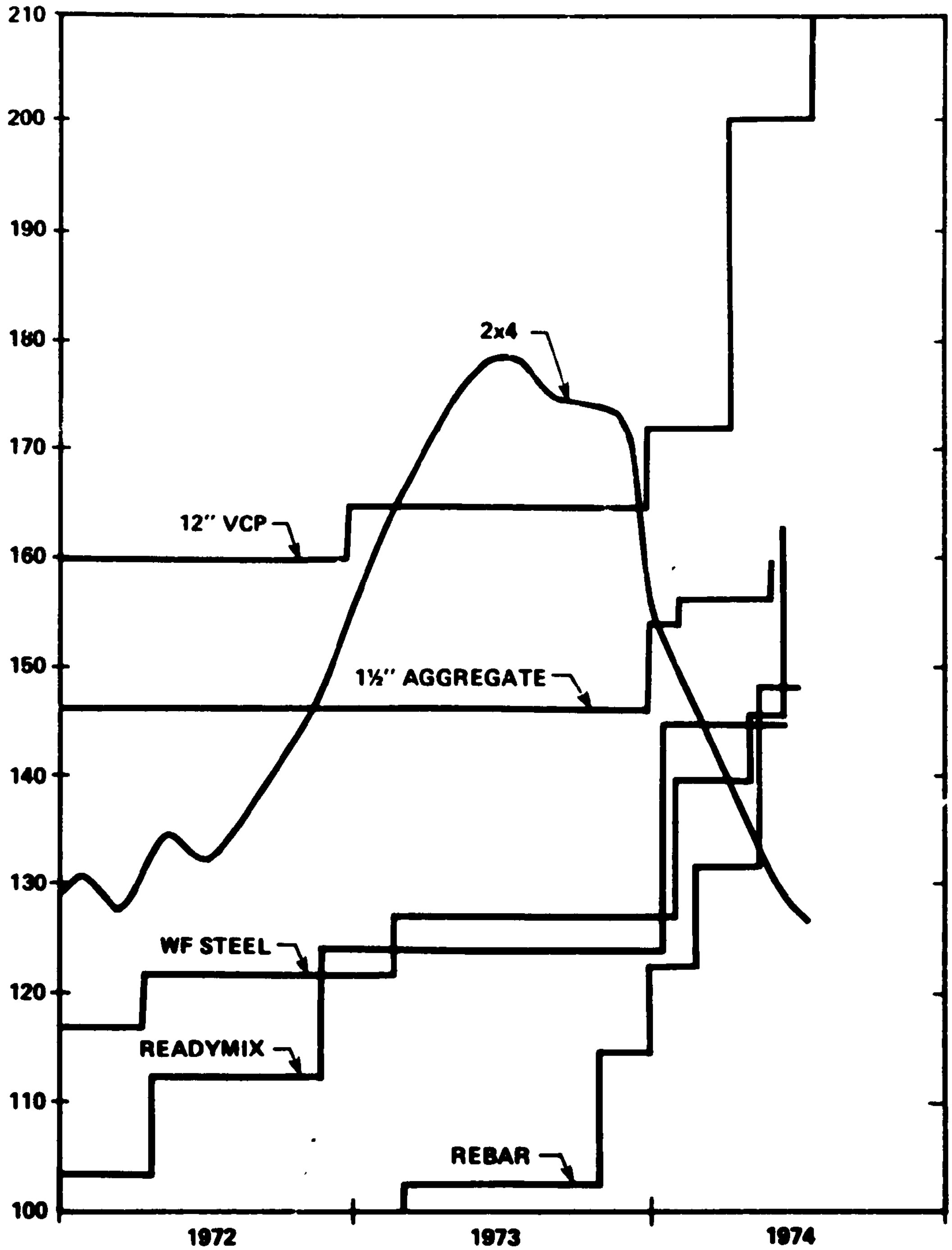
INFLATION COST
SOUTHEAST USA
CONSTRUCTION



SOUTHEAST USA
WAGE RATES
INCLUDING FRINGES



SOUTHEAST USA
MATERIAL PRICES



CONSTRUCTION MATERIAL & EQUIPMENT

LEAD TIME

Item	Lead Time (wks)*
Structural Steel	26
Steel Reinforcing	5–12
Masonry (Brick)	6–12
Cement	2–6
Wood Pile (treated)	13–28
Steel Pipe (galv.)	20
Steel Pipe (black)	12
Plumbing Fixtures	12–14
Chillers	16
Air Handlers	10–12
Primary Switchgear	40
Secondary Switchgear	26–40
Transformer (liquid)	48–72
Wire-HV (5-15KV)	18
Conduit	2–3

*as of July, 1974

Appendix E

ENGLISH BENTONITE SHIELD

Newly proved Bentonite shield – takes tunnels into new ground, cuts costs by a third

Engineers from as far afield as Canada, America and the Metro systems of Europe have this week been looking for the first time at a British development which will undoubtedly take soft ground tunnelling into a new era.

They have been watching the newly-developed bentonite shield in action the first in the world to work effectively in a full range of granular material. In such conditions as the water-bearing gravel of the short proving-run being driven in south London, the machine is showing that it can cut the cost of rival tunnelling methods by as much as a third.

Britain has long held a high reputation for its soft ground tunnelling expertise and the bentonite shield development brings together three groups who are as experienced as any – the London Transport Executive, consulting engineers Mott, Hay and Anderson, and the Edmund Nuttall/R. L. Priestley contractor/manufacturer combination.

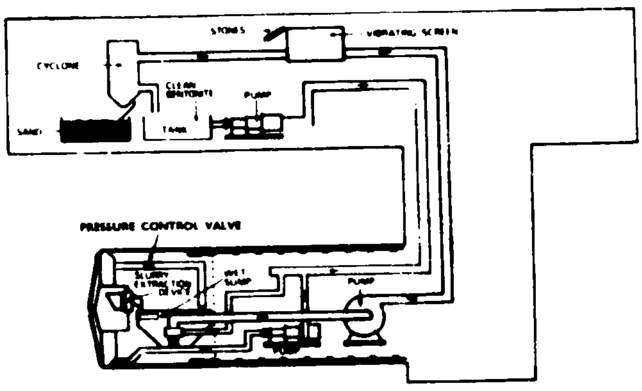
Two years ago the bentonite shield was just a piece of paper – a patent held by MHA partner John Bartlett. But the London Transport Executive, with the projected Fleet Line of the underground tube system due to push south of the river, knew that such extensions would need radically different methods of construction from those possible in north London's clay.

The bentonite shield uses the principles of a full-face rotary digger but excavates in a sealed chamber of bentonite slurry. The bentonite circuit runs to the surface and the constantly circulating slurry serves both to consolidate the face, keeping out water, and at the same time to remove spoil from the chamber.

The LTE obtained funds from the National Research Development Corporation – the government agency which promotes bright industrial ideas – for the major portion of the shield development costs, currently estimated at around £350,000.

At the end of 1970, tender invitations went out to four contractors, asking for the modification of one of the two types of machine which had worked on the Victoria Line – the KM drum digger and the McAlpine centre shaft machine. But in the intervening period Nuttall

New Civil Engineer, 21 September 1972



Bentonite circuit. The slurry/spoil mix discharges at atmospheric pressure into a sump just behind the shield and is then pumped to the surface where it is cleaned and recirculated

and its manufacturing subsidiary R. L. Priestley had produced their own mole – a machine which established a fine reputation for reliability and performance, particularly in making record advances in the clay of the 20 km Ely/Ouse water tunnels.

So it was not surprising that Priestley managing director Roy Burgess was keen to adapt the machine he knew best – 'I wanted it to be the bentonite part that was experimental, not the basic machine,' he says.

Nuttall was awarded the contract in January last year. First 40 weeks of the contract period were set aside for design and manufacture of the shield, to be followed by the crucial test – a proving run which called for the driving of a 180 m length of 4.1 m diameter running tunnel just north of New Cross station. This could be incorporated in the main Fleet Line scheduled to come later.

The Nuttall team, under director Alastair Biggart, has now driven the critical first 35 m of the proving run and is confident that with most of the major teething troubles ironed out the remainder of the drive will be far easier.

Some impressive statistics are coming out of the trial. On the basis of progress so far, LTE chief civil engineer Mr H. G. Follenfant estimates that the new method can cut £750,000 per mile off the £2½ million per mile which typical running tunnel would cost if driven in compressed air.

Alastair Biggart is confident that it will ultimately be possible to advance this type of tunnel by more than six rings per shift – less than two hours to excavate, build and grout a 900 m ring. Rates of three rings per shift have already been achieved with resident engineer Keith Larkin and agent Richard Lewis at the face – willing workers but hardly experienced miners.

The tunnel is being driven in water bearing gravel containing cobbles up to 250 mm across, grading to fine sand. It has 8 m of cover above the crown and the water table hovers around tunnel level.

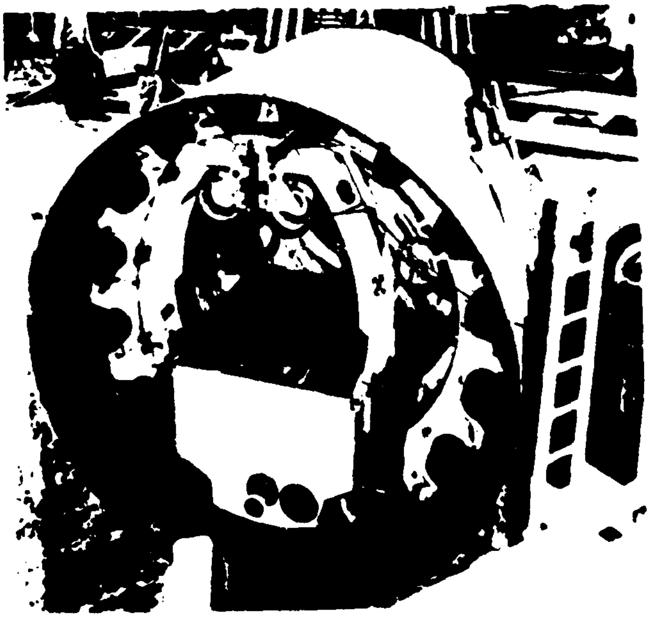
The bentonite slurry – about a 5 per cent mix – is maintained under pressure in the shield chamber and permeates the face ahead of the digger.

Measurements indicate that the slurry is penetrating about 900 mm into the face, sealing it against incoming water and consolidating what could otherwise fall as a heap of loose gravel.

Capacity of the whole bentonite circuit is just under 10,000 gallons and so far this has disappeared into the ground at a rate of around 800 gallons per ring advance. This consumption should drop when a more regular rate of advance is achieved.

In designing the equipment four main

15



Sump tank, rams and erector arms can be seen in this rear view of the shield

factors had to be considered maintaining pressure in the digging chamber while at the same time removing excavated material, minimising slurry seepage along the outside of the shield and into the tunnel behind, building lining while holding the machine in position against the face, and ensuring accurate steering.

Of these problems it was the first which proved most difficult. Spoil discharges to atmosphere into a wet sump immediately behind the sealing bulkhead of the shield. This is done so that the really large cobbles over 100 mm in size can be sifted out while the remaining material is pumped to the surface for separation by vibrating screen (for particles over 10 mm) and four cyclones.

But the arrangement means that some method of fine control of digging chamber pressure has to be provided. This is done by a pressure valve on an outlet which bypasses the main spoil/slurry extraction device, so compensating for momentary variations in chamber pressure caused by the Ligger outlet. Indications are that fluctuations in pressure can be kept within 15 kN per sq m (2 psi) of the value desired. In full operation about 700 gallons of slurry is circulated through the chamber each minute

Two methods of extracting spoil from the chamber have been tried. The first was a helical wheel which 'screwed' the material out at a fast and continuous rate but which suffered in the extremely abrasive material it was handling. It lasted for only a few rings before its seals failed.

This was replaced by what is in effect a hydraulically operated 'airlock' which has two sliding plates which operate alternately to allow spoil to enter and leave the lock. Improvements on both the helical and sliding plate devices are being investigated.

Leakage of slurry behind the shield is prevented by a length of thick bentonite grout injected through ports around the skin of the shield, forming a barrier between two circumferential nylon brush seals. This has not been totally successful and a more sophisticated mechanical seal is being designed.

Maintaining position of the shield while building a ring is achieved by retracting some of the rams, assembling part of the new ring, transferring the thrust, and completing the ring.

Accurate tunnel steering proved to be a matter of handling technique rather than any new design feature.

Roy Burgess must be happy that he decided to work on the machine he knows. Nuttall site engineer Alan Finch puts downtime caused by failures of the actual digger at zero, although he admits to not a few dousings in bentonite.

Engineers working on the experiment have not had much time so far to consider how far the results can be extrapolated. The equipment here provides for working pressure at the face up to 200 kN per sq m (30 psig) although normal pressure used has been only half this. It is generally felt that there are no significant obstacles to substantially higher pressures.

The machine has already shown that it can cope with some fairly formidable non-cohesive ground. It is also expected that it will be able to handle silts, although it is not possible to predict how it would handle proportions of clay.

The remaining 140 m of proving run should be completed early next year. Some engineers associated with the project hope that the run can be extended to perhaps a kilometre. That should prove without doubt that the British bentonite shield – a package estimated by NRDC to cost about £130,000 – is indeed ready for full scale commercial adoption.

ADRIAN COTTRILL

John Bartlett holds Mott, Hay and Anderson's patent on the bentonite tunnelling method, taken out in March 1965. He is a partner and director of the firm, which he joined in 1957. Here he assesses the potential for the consulting engineer of the machine which has evolved from his original idea

Water bearing sands and gravels have long been regarded as the tunneller's nightmare, especially when it has been important to prevent settlement of over-lying property. Tunnelling through such strata has been avoided whenever possible but when essential, it has required such techniques as compressed air, clay pocketing, chemical injection and freezing, all of them slow, expensive, labour intensive and sometimes of uncertain efficacy.

Cost of the new bentonite shield method and speed of construction will naturally vary in differing circumstances but even the prototype is now regularly advancing at a cutting rate of over half a metre per hour and it is gratifying to agree with the contractor that cost of construction in these difficult conditions is being very substantially reduced.

One of the most encouraging results of the experimental drive at New Cross is that there has been no perceptible settlement of the ground above and around the tunnel, despite most careful monitoring, and at no time during the drive has there been any loss of ground or apparent risk of loss of support at the face. It will, therefore, be suitable for driving tunnels through non-cohesive ground, close to the surface if desirable, underneath roads and buildings.

When the first underground railways were built in London over a century ago, the cut-and-cover methods used caused considerable disruption. For later development of the system, at the turn of the century, the obvious solution was to drive London's tubes down into the underlying blue clay. But the ideal place for an underground railway is just sufficiently below surface level to avoid services in the streets and noise in buildings, but at the same time avoiding expensive and time consuming escalators.

Many cities have faced the same dilemma without having London clay and much of the construction has been by cut-and-cover methods. These continue to cause disruption despite the development of ingenious methods of street decking and such devices as the construction of walls by slurry trench methods.

It was an inspection of the Milan method of wall construction using bentonite, together with some knowledge of the use of drilling muds in oil drilling which led to the idea of developing a mechanical tunnelling machine which used a thixotropic slurry kept at a suitable pressure not only to support the face but also to carry back the spoil from the face.

In various cities the bentonite shield method opens up the prospect of new rapid transit lines close to the surface using cut-and-cover construction at the stations, where disturbance is in any case inevitable, and driving the running tunnels with the shield. It should also have a useful application for large sewer and water tunnels and just as the walls of slurry trenches have proved to be well supported by the slurry down to depths well exceeding 30 m so it should be possible to apply the system to large diameter tunnels for roads.

Use of a liquid to support the face means that its pressure increases with depth exactly to match the increase of ground water pressure. This is infinitely preferable to compressed air where the invidious choice is between excessive pressure at the crown of the tunnel or insufficient pressure to hold back water and spoil at the invert.

An incidental advantage of the method has proved to be the provision of a perfectly watertight tunnel. The bentonite, permeating the ground around the tunnel as the machine advances, is giving a perfect seal and it may well be possible to eliminate caulking.

The method has limitations. Like all shielded machines it drives a single tunnel of fixed diameter and leaves the construction of openings and enlargements to be tackled subsequently.

How will it perform in varying ground conditions and in mixed faces? It can be converted into a fairly efficient orthodox digger shield with spoil disposal by conveyor. It has demonstrated its ability to deal with particles from silt up to 250 mm stones. Previous experience indicates that it would cut slowly but successfully through hard unreinforced concrete.

Its success in mixed faces will depend upon the technology of the various possible slurries. Thus in a gravel/chalk face, the chemical action of the chalk must not be allowed to destroy the thixotropic property of the slurry. In a sand/clay face the ability to remove the clay from the slurry will depend upon the nature of the clay. Much work remains to be done in such fields but the signs are very encouraging.

Appendix F

REPORT OF INVENTIONS

A diligent review of the work performed under this contract has revealed no new innovation, discovery, improvement or invention.