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-AND-COVER TUNNELING

Vol. 2. Cost Analyses and Systems Evaluation

DEPARTMENT OF TRANSPORTATION ★ UNITED STATES OF AMERICA ★

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Final Report

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Washington, D. C. 20590

FOREWORD

This report, Volume 2, Cost Analysis and Systems Evaluation, summarizes the constraints, the assumptions, and the results of a very ambitious study -- to develop a method for evaluating alternate construction schemes for cut-and-cover tunneling in urban areas. A method was developed and is directly applicable to highway and transit tunnels and subway stations, at various depths, and for five geologic conditions that typify most of the major metropolitan areas in the United States. The entire final report includes four volumes and an Executive Summary. The titles are given in the Abstract on the next page.

Volume 1 of the report was completed in 1976 and single copies were distributed to headquarters and field offices of the Federal Highway Administration and to State highway agencies. Volumes 2 and 3 and the Executive Summary are being given the same distribution. The Supplemental Volume, which contains the extensive cost data used in this study, is not being distributed. All volumes are available to the public at the National Technical Information Service.

Charles F. Scheffey
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Director, Office of Research
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NOTICE

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16. Abstract

This volume summarizes the findings of the entire study. It presents a method for comparing the costs of alternate construction schemes for cut-and-cover tunneling in urban areas. It considers both the cost of construction and the cost of urban disruption, enabling the planner to choose that construction most effective for his particular requirement.

The overall report "Cut-and-Cover Tunneling" includes additional volumes as follows:

Volume 1, Construction Methods, Design, and Activity Variations (FHWA-RD-76-28)

Volume 3, Summary Cost Analyses (FHWA-RD-76-30)

Supplemental Volume, Construction Cost Data, Four Basic Estimates (FHWA-RD-76-139)

Executive Summary (FHWA-RD-79-61)

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PREFACE

In June 1974, the U.S. Department of Transportation authorized Jacobs Associates to investigate different construction methods and associated costs relating to cut-and-cover tunneling operations for highway and transit structures. The objective of this effort was to determine the most cost-effective solution for a variety of situations. A report covering the first phase of the study entitled, "Cut-and-Cover Tunneling Volume 1: Construction Methods, Design and Activity Variations" has been published as Report No. FHWA-RD-76-28 (NTIS No. PB-257014).

Prior to completion of the second phase, the scope of work was expanded to include a greater variety of site and construction conditions. Findings and results of both the initial and expanded studies are presented in this final report. It pertains primarily to the cost of cut-and-cover construction plus general evaluations of the cost of environmental disruptions caused by the construction.

Although this volume is essentially complete in itself, the reader may wish to review Volume 1 for detailed information concerning work operations and activities, design guidelines, construction methods and costing procedures used in completing the study. For convenience, key figures, tables and design information from Volume 1 have been included in this volume.

The design of temporary and permanent structures was performed under the direction of J.L. Wilton, by P.B. Lawrence. Special computer control techniques needed to produce multiple estimates were developed by N.A. Tracy. Transcription of the report was by A.L. Russell.

General information and cost data relating to control of groundwater were provided by Ground/Water Technology Inc. (Moretrench American Corporation). The Bay Area Rapid Transit District provided information relating to various safety aspects of cut-and-cover construction. The help and cooperation offered by these and other organizations who contributed to the study effort is fully appreciated.

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INTRODUCTION

The need for new and improved transportation facilities through urban areas has been increasing rapidly. Of the different construction options available, cut-and-cover tunneling will probably continue to be a principal method of building these facilities. In some instances, it may be the only feasible alternative.

This report is intended to help the planner, designer and constructor select the most efficient cut-and-cover tunneling technique for his particular situation. This is accomplished by use of a series of multiple estimates, which provides a base of cost data by which the planner can evaluate his current project.

Five combinations of soil and groundwater conditions typical of most U.S. cities are considered. The study analyzes three methods of ground support: soldier piles and lagging, cast-in-place concrete walls and precast concrete panels; each used in conjunction with either internal or tieback bracing.

Cut-and-cover constructions are evaluated with respect to three transportation structures: a four-lane highway, a rapid transit station and a rapid transit line section. Each situation is analyzed on the basis of depth and different ground and site conditions typical of urban areas within major cities of the United States. Comparative evaluations are also made for cut-and-cover, inverted (under-the-roof), combination systems and several variations of cast-in-slurry concrete wall methods of construction.

Volume 1, Report No. FHWA-RD-76-28, provides a general review of cut-and-cover tunneling and describes different ground support methods and procedures currently used for transit construction. It evaluates requirements with respect to two urban sites and defines eleven major construction activities common to most cut-and-cover projects. Alternate methods of performing these activities are analyzed and their compatibility with different construction methods discussed.

Indirect and overhead requirements are treated separately as four additional activities. Volume 1 also contains design guidelines and other information and data used in evaluating the overall cut-and-cover tunnel design-construct process.

Volume 2 expands the design and other criteria given in Volume 1 to include three additional urban sites. Ground wall support and bracing systems are designed for 108 situations. Structural requirements and work and material quantities for major activities are given for 176 situations.

Volume 2 develops and compares construction costs for different types of cut-and-cover tunneling performed within urban areas. Total project costs are prepared in a manner similar to that used by general contractors in competitive bidding. They include all operations and activities necessary to complete the civil work requirements for each transit structure. Components of labor, equipment and materials are identified and a method provided by which costs can be updated to reflect different economic conditions of future projects.

The common data and systematic approach used provide a more versatile tool for preliminary planning estimates than using unit costs gathered from projects covering a variety of local site and construction conditions. The estimates were prepared using a common location, common year of construction, common physical site conditions (buildings, utilities, etc.), common design criteria, and a common rate library of labor, equipment and material prices. Costing of work items is uniform for all estimates. Overhead, administrative, and general costs are developed separately (but similarly) for each estimate, eliminating unbalanced bid prices. Examples are given in Sections 4 and 6 to show how cost data provided for 176 situations can be used by the reader to approximate the cost of jobs differing from the study conditions and requirements. Not only location and physical differences, but also local institutional restraints can be adjusted to suit the planner's situation.

The report discusses the cost of environmental disruptions; a serious disadvantage of cut-and-cover construction. These costs are based on a developed rationale which quantifies various disruptive elements in terms of dollars. The rationale treats those elements of disruption not normally allowed for or included in initial bid price of the project.

The most effective construction for a particular situation is determined by comparing the costs of construction and disruption for feasible alternatives. Examples are given to illustrate how this comparison is made when considering both cut-and-cover and inverted construction methods. The procedure enables the reader to identify the best technique for his specific site and structure requirements.

Volume 3, Report No. FHWA-RD-76-30, contains summary cost analyses of 15 cut-and-cover projects. These summaries give the unit costs of labor, equipment and material required to complete all operations and activities for a particular construction. Data from Volume 3 could be used by those wishing to develop a unit price cost estimate for a particular cut-and-cover tunneling situation.

The Supplemental Volume, Report No. FHWA-RD-76-139, provides all basic data for four study situations including quantities of work, production rates, labor crews, equipment, materials required, and costs. These basic data, particularly the cost estimates, were used for all the estimate situations considered in the study.

The English system of measure is used for all costing data and examples used to illustrate methods and procedures developed in the study. It was neither practical nor desirable to repeat the multiple estimates using S.I. units for all material quantities. S.I. equivalent values have been added to English unit dimensions in the text, and where practical, in the tables and figures of this volume. In other cases metric conversion factors are provided.

SECTION 1
CUT-AND-COVER TUNNELING, STUDY CRITERIA

1.1 GENERAL

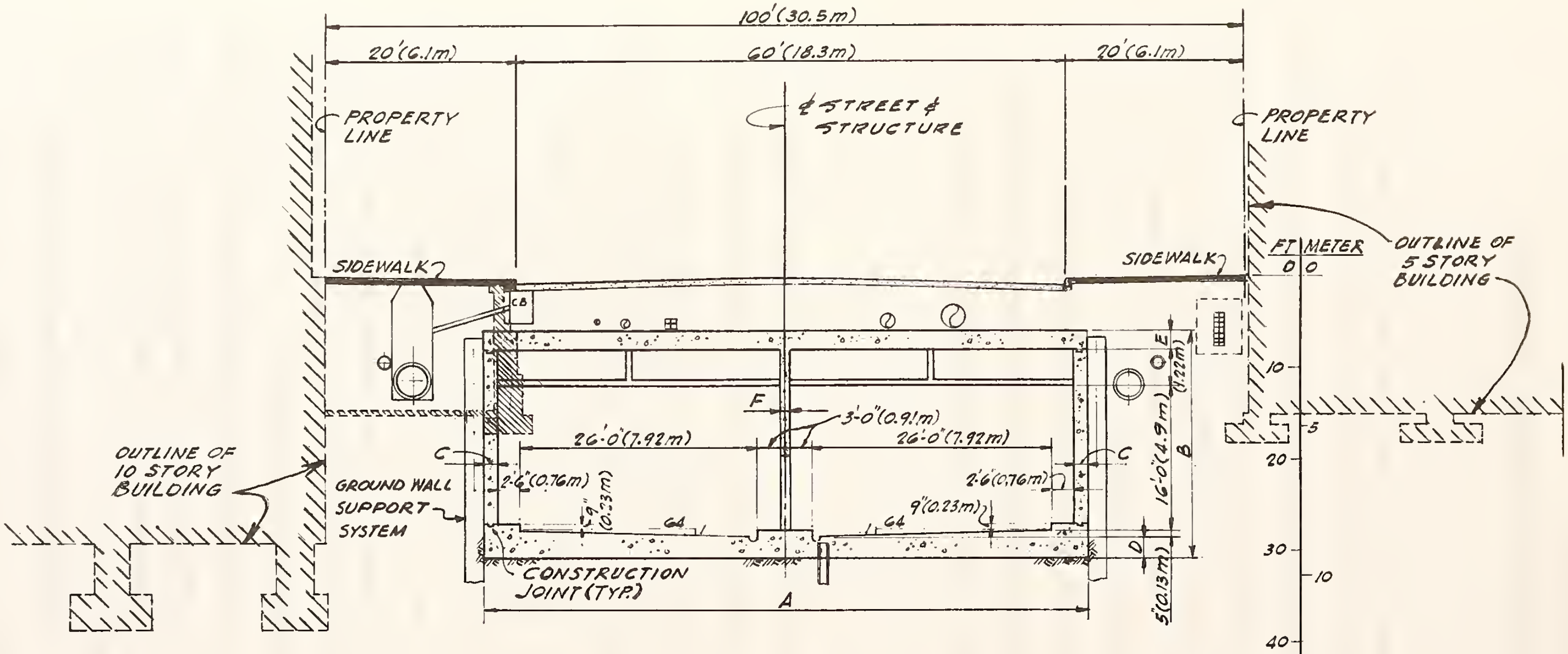
Basic fundamentals of cut-and-cover tunneling operations as well as general discussions pertaining to transit structures, urban sites, design guidelines and construction methods and activities are given in Volume 1. This section presents a brief summary review of information pertinent to the continuation of the study plus data relating to new site conditions which were added to the overall research effort. Due to the changed scope of work, there are minor differences between Volumes 1 and 2. They relate primarily to site and estimate code designations. Where such differences occur, Volume 2 supersedes Volume 1.

1.2 TRANSIT STRUCTURES

Three transit structures are considered: a four lane highway, a rapid transit station and a rapid transit line section. Since the study deals primarily with the determination and comparison of procedures and costs associated with different construction methods, only the structural shells (including embedded conduits, pipes, etc.) are considered. This is based on the assumption that architectural and mechanical-electrical requirements would be essentially the same for each type of structure regardless of construction method used and therefore would not affect comparative evaluations. Special sections such as end walls, transitions, vent shafts and entrances are treated separately.

The dimensions of walls and slabs of the structural shells are based on typical structure designs taking into account varying depths and soil types, surcharges and potential uplift forces due to groundwater conditions.

1.2.1 Highway Tunnel: The highway tunnel shown in Figure 1 consists of a reinforced concrete box structure with two traffic lanes on either side of a center wall. A divided



DIM.	LOW WATER TABLE						HIGH WATER TABLE					
	30' DEPTH		50' DEPTH		70' DEPTH		30' DEPTH		50' DEPTH		70' DEPTH	
	FT-IN	m	FT-IN	m	FT-IN	m	FT-IN	m	FT-IN	m	FT-IN	m
A	66-0	20.12	67-0	20.42	68-0	20.73	67-0	20.42	68-0	20.73	69-0	21.03
B	25-5	7.75	26-11	8.21	30-5	9.27	27-5	8.36	28-5	8.66	31-5	9.58
C	1-6	0.46	2-0	0.61	2-6	0.76	2-0	0.61	2-6	0.76	3-0	0.91
D	3-0	0.91	3-6	1.07	6-0	1.83	5-0	1.52	5-0	1.52	7-0	2.13
E	2-0	0.61	3-0	0.91	4-0	1.22	2-0	0.61	3-0	0.91	4-0	1.22
F	1-3	0.38	1-6	0.46	2-0	0.61	1-3	0.38	1-6	0.46	2-0	0.61

Figure 1. DETAILS OF FOUR-LANE HIGHWAY STRUCTURE

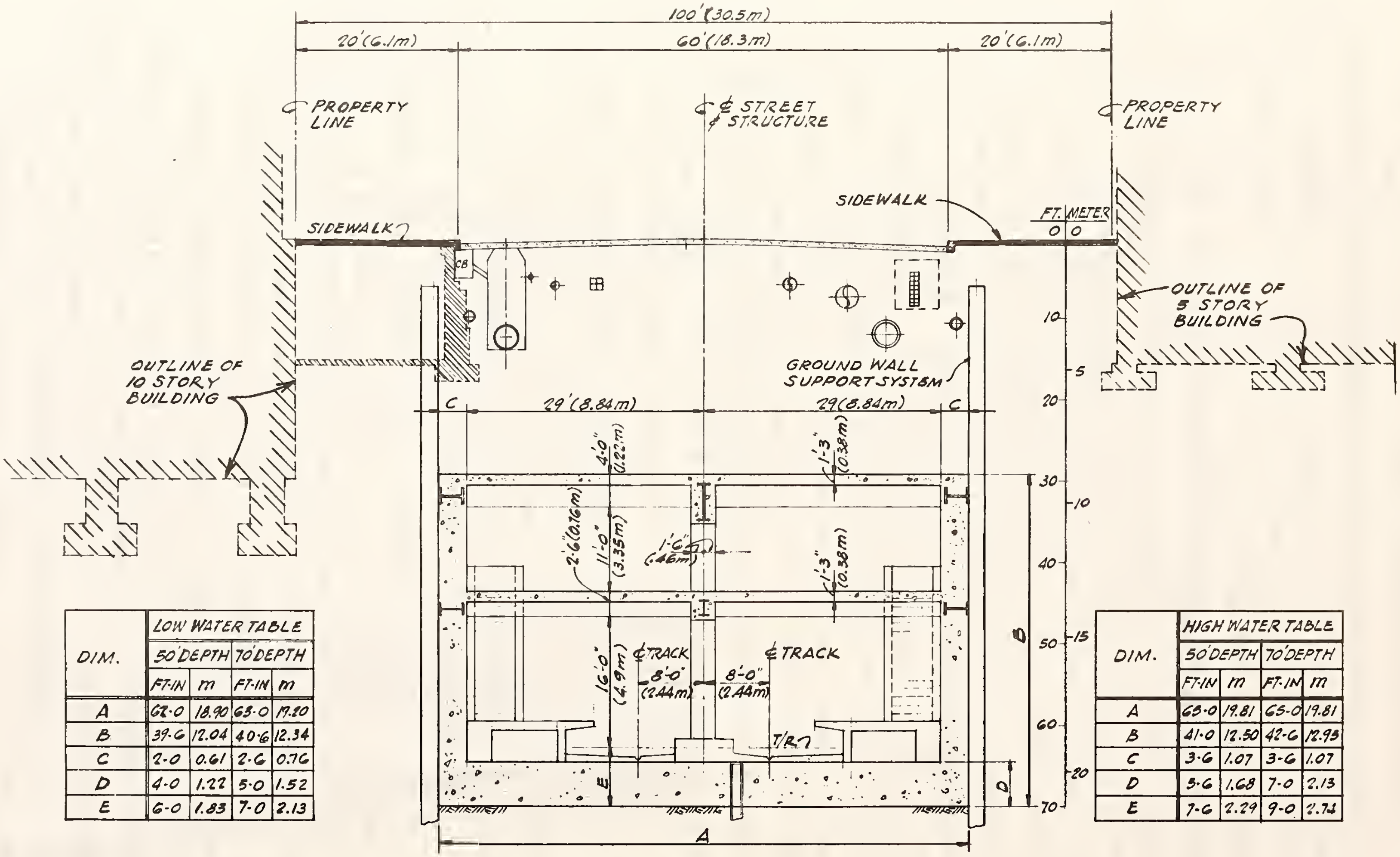
plenum chamber above the roadway is sufficiently large for forced air intake and exhaust as well as utility ducts and conduits. Lane widths and vertical clearances are consistent with current highway tunnel standards. For the purpose of this study, a 2,000 foot (610 m) length of tunnel is considered as a single construction contract.

1.2.2 Rapid Tranist Station: The cross section of a rapid transit station shown in Figure 2 is similar to several on the San Francisco Bay Area Rapid Transit (BART) system. It has reinforced concrete walls and composite structural steel and concrete slabs. The upper mezzanine level contains public areas for ticket booths, turnstiles and walkways as well as space for storage and mechanical-electrical equipment. The lower level contains trackway and platform loading areas.

The station is consistent with the line section shown in Figure 3, with tracks on either side of the center wall and platforms on the outside. If the line sections were driven tunnels, they would enter the station along the outside walls with a common loading platform area between. This would change the station configuration, but would not materially affect the overall evaluations made for the study. The station length of 700 feet (213 m) is about the same as used for both BART and Washington Metropolitan Area Transit Authority (WMATA).

1.2.3 Rapid Transit Line Section: The double track reinforced concrete box section shown in Figure 3 is typical of line sections used in most transit systems. The center wall contains frequent openings allowing track workers a place to stand while trains are passing and to facilitate air flow around high speed trains. For crossover sections, the center wall is eliminated and the roof slab thickened or reinforced with steel beams. The study considers a contract length of 2,000 feet (610m) which, with the 700-foot (213m) long stations, gives a reasonable spacing of stations of approximately one half mile (0.8km).

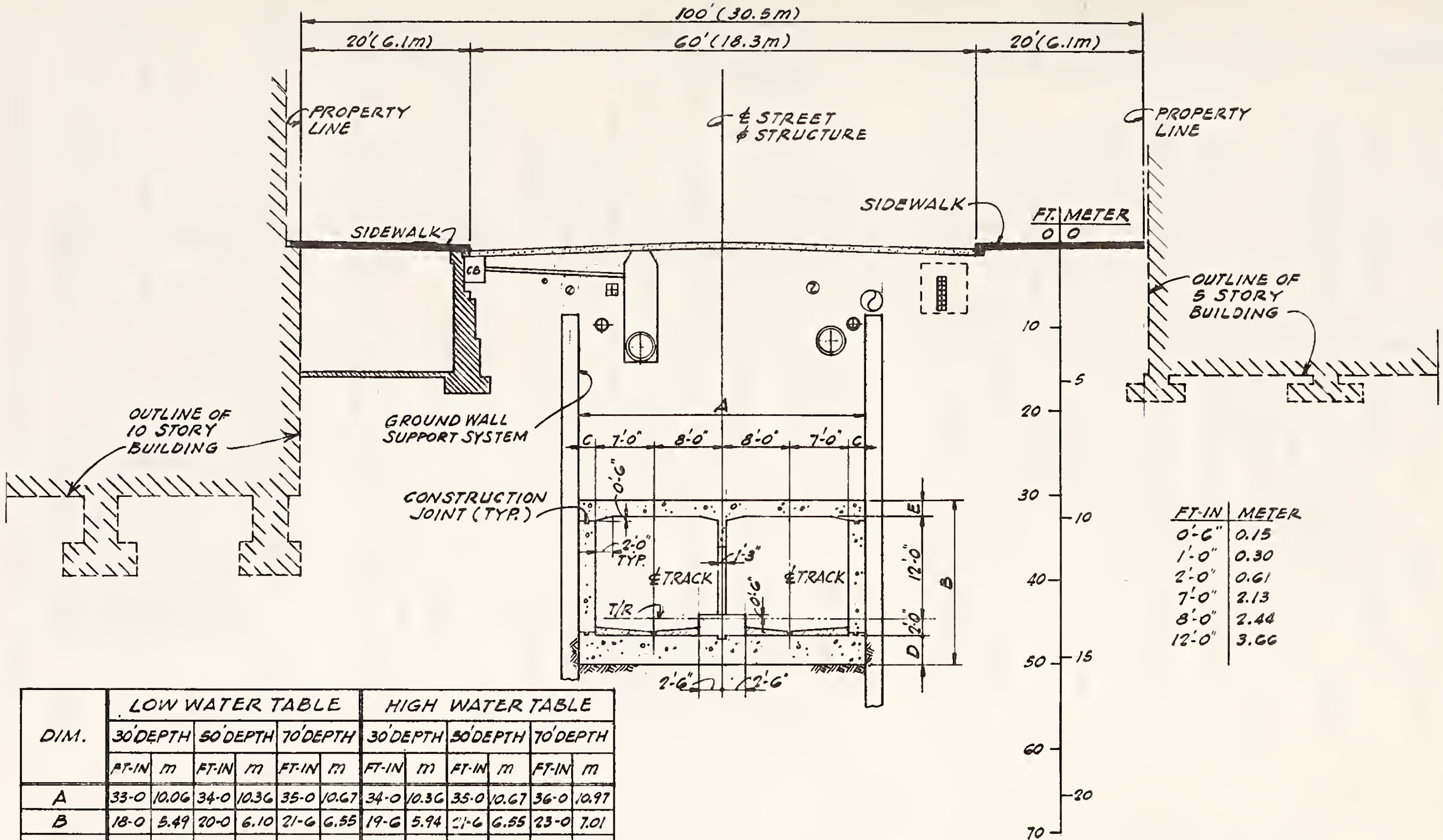
1.2.4 Depth of Structure: The cost of cut-and-cover construction is critically dependent on the depth of the structure below the ground surface. In most instances, an attempt is



DIM.	LOW WATER TABLE			
	50' DEPTH		70' DEPTH	
	FT-IN	m	FT-IN	m
A	62-0	18.90	63-0	19.20
B	39-6	12.04	40-6	12.34
C	2-0	0.61	2-6	0.76
D	4-0	1.22	5-0	1.52
E	6-0	1.83	7-0	2.13

DIM.	HIGH WATER TABLE			
	50' DEPTH		70' DEPTH	
	FT-IN	m	FT-IN	m
A	65-0	19.81	65-0	19.81
B	41-0	12.50	42-6	12.95
C	3-6	1.07	3-6	1.07
D	5-6	1.68	7-0	2.13
E	7-6	2.29	9-0	2.74

Figure 2. DETAILS OF RAPID TRANSIT STATION



DIM.	LOW WATER TABLE						HIGH WATER TABLE					
	30' DEPTH		50' DEPTH		70' DEPTH		30' DEPTH		50' DEPTH		70' DEPTH	
	FT-IN	m	FT-IN	m	FT-IN	m	FT-IN	m	FT-IN	m	FT-IN	m
A	33-0	10.06	34-0	10.36	35-0	10.67	34-0	10.36	35-0	10.67	36-0	10.97
B	18-0	5.49	20-0	6.10	21-6	6.55	19-6	5.94	21-6	6.55	23-0	7.01
C	1-6	0.46	2-0	0.61	2-6	0.76	2-0	0.61	2-6	0.76	3-0	0.91
D	2-6	0.76	3-6	1.07	4-6	1.37	3-0	0.91	4-0	1.22	5-0	1.52
E	1-6	0.46	2-6	0.76	3-0	0.91	2-6	0.76	3-6	1.07	4-0	1.22

FT.	METER
0	0
10	
	5
20	
30	
	10
40	
50	
	15
60	
	20
70	

FT-IN	METER
0'-6"	0.15
1'-0"	0.30
2'-0"	0.61
7'-0"	2.13
8'-0"	2.44
12'-0"	3.66

Figure 3. DETAILS OF TRANSIT LINE SECTION

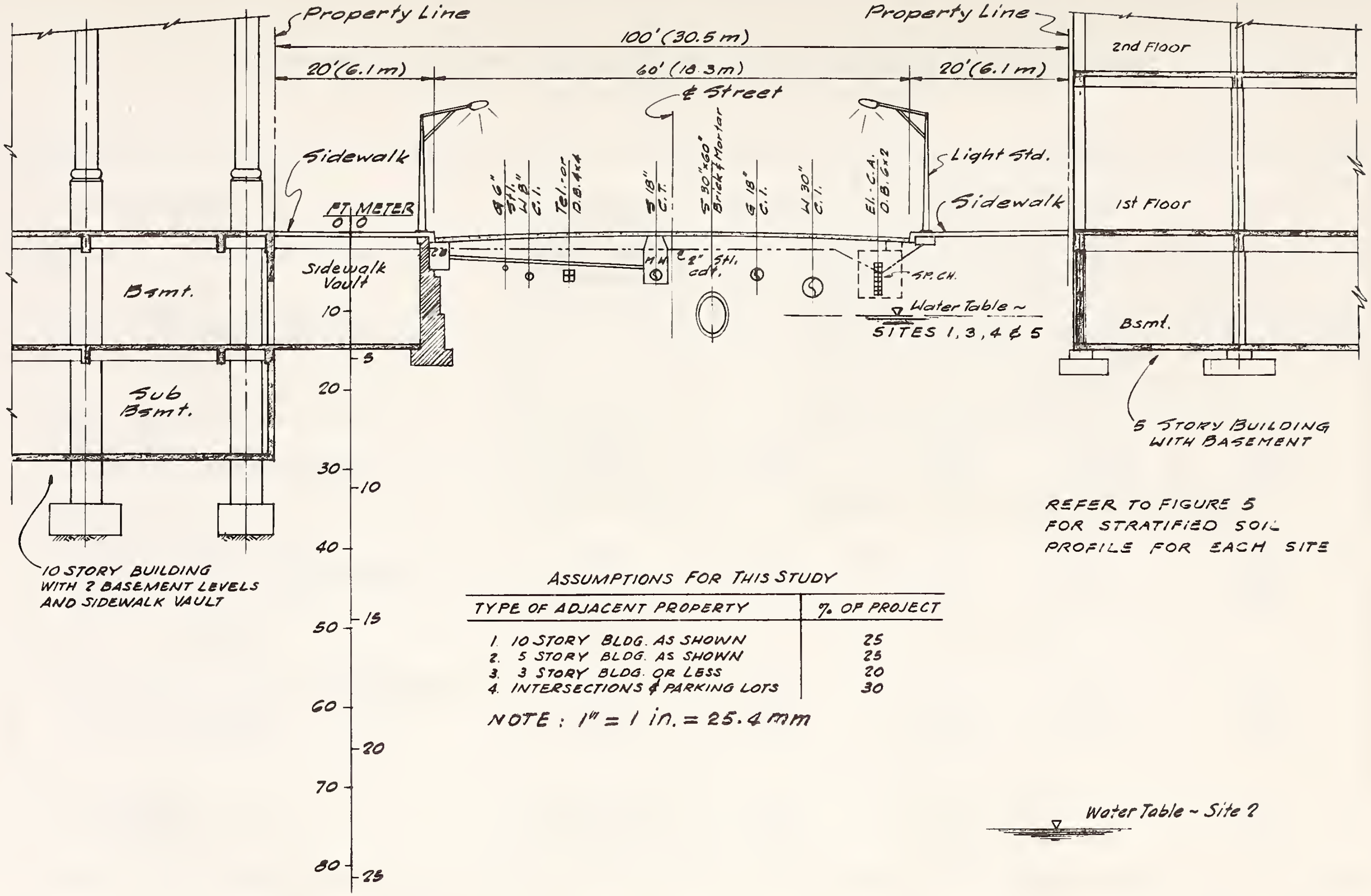
made to keep the work as shallow as possible. There are times, however, when the natural grade exceeds the allowable grade of road or track and the designer is forced to locate the structure deeper. The depth of existing utilities or other structures which can not be relocated can also affect the design depth. Problems (and cost) associated with access and ventilation are also greater for the deeper structures.

Three depths of excavation are considered: 30-foot (9.1 m), 50-foot (12.5 m) and 70-foot (21.3 m). Although the structures are shown at specific depths in Figures 1, 2, and 3, they are considered at the three depths for most study situations. Due to the 40-foot (12.2 m) height of the station structure, it is not evaluated for the 30-foot depth.

1.3 URBAN SITES

The physical configuration (buildings, utilities, etc.) assumed for the urban site is illustrated on Figure 4. All adjacent buildings are supported on spread footings. Many different configurations may be found at actual sites. The number and height of buildings or types of foundations and basements could vary significantly. Some sites may have considerably more utilities, others less. The effect on construction methods and cost due to differences between assumed and actual site configurations can be appraised as relative variations of requirements from those indicated for the assumed site. These variations are considered as related to applicable construction activities which are discussed later in the report.

1.3.1 Ground Conditions: Five different site conditions (soil types and ground water levels), representing most sites in major U.S. cities, have been specified for the study. Geological profiles of the sites are shown on Figure 5 and a general evaluation of different construction aspects is given on Table 1. Sites 1 and 2 were considered in Volume 1; sites 3, 4, and 5 were subsequently added. The sites are described on page 10.



ASSUMPTIONS FOR THIS STUDY

TYPE OF ADJACENT PROPERTY	% OF PROJECT
1. 10 STORY BLDG. AS SHOWN	25
2. 5 STORY BLDG. AS SHOWN	25
3. 3 STORY BLDG. OR LESS	20
4. INTERSECTIONS & PARKING LOTS	30

Figure 4. CROSS SECTION OF URBAN SITE (STUDY EXAMPLE)

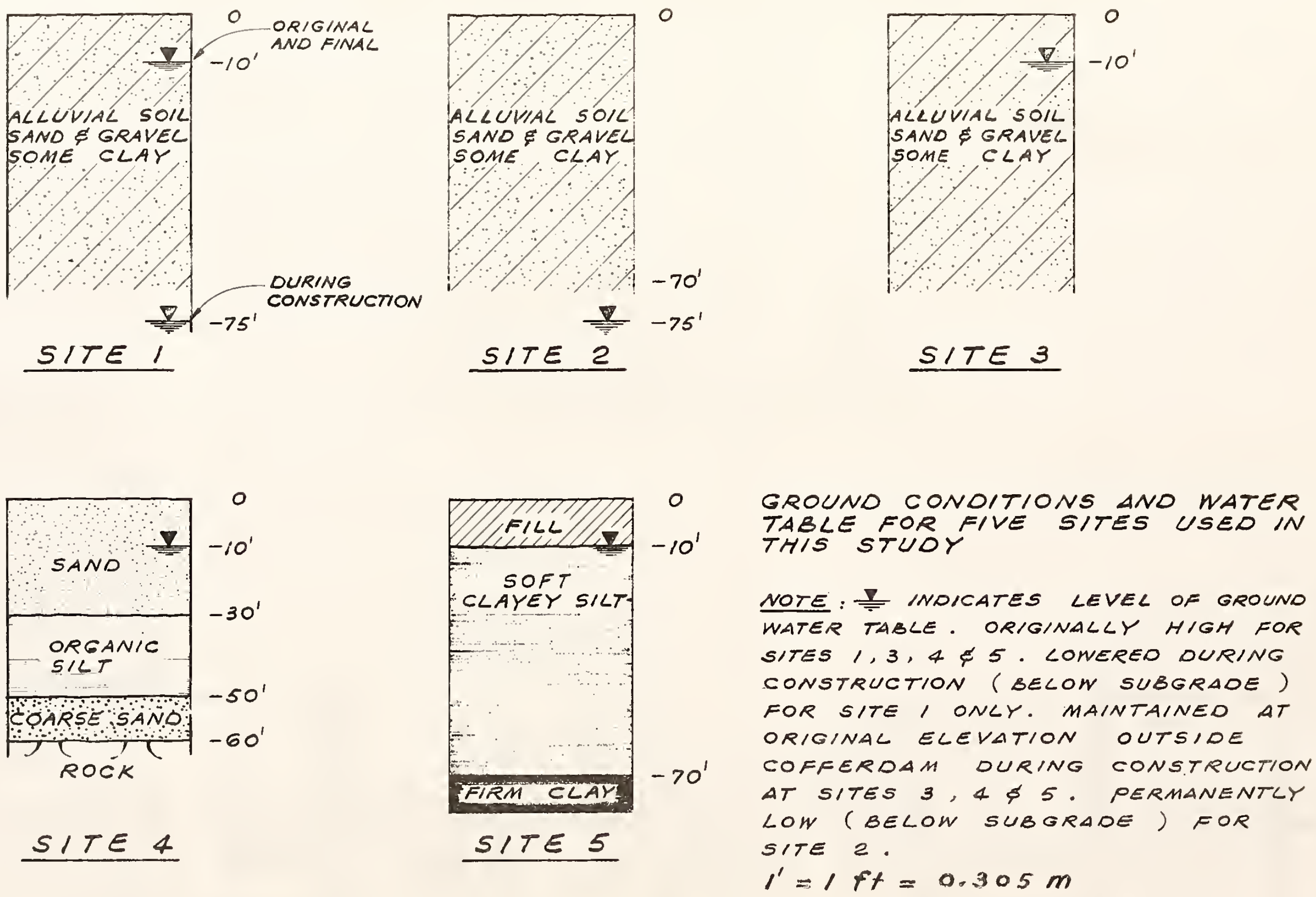


Figure 5. GEOLOGIC PROFILES - FIVE STUDY SITE CONDITIONS

Table 1. COMPATABILITY OF SITE CONDITIONS AND CONSTRUCTION METHODS

CRITERION	SITE 1	SITE 2	SITE 3	SITE 4	SITE 5
SOIL TYPE (for details: see Figure 5)	ALLUVIAL	ALLUVIAL	ALLUVIAL	SAND, SILT, & ROCK	SOFT CLAY STIFF CLAY
WATER TABLE:					
INITIAL	HIGH	LOW	HIGH	HIGH	HIGH
DURING CONSTRUCTION	LOW	LOW	HIGH	HIGH	HIGH
DEWATERING:					
PREDRAINAGE ONLY	YES	N.A.	NO	NO	NO
PREDRAINAGE W/RECHARGE	NO	N.A.	YES	NO	NO
TRENCH AND SUMP	NO	N.A.	NO	YES	YES
GROUND SUPPORT:					
SOLDIER PILES & LAGGING	YES	YES	NO	NO	NO
CAST-IN-SLURRY (SPTC)	YES	YES	YES	YES	YES
PRECAST PANELS	YES	YES	YES	YES	YES
BRACING:					
INTERNAL	YES	YES	YES	YES	YES
TIEBACKS	YES	YES	YES	YES*	NO

*Only if tieback anchorages in organic silt layer can be avoided.

Site 1: Water table high; soil is alluvial including sand, gravel and some clay. The water table can be lowered by dewatering without causing distress to adjacent buildings.

Site 2: Water table low; soil is similar to that of site 1.

Site 3: Water table high; soil is alluvial, similar to site 1. Unlike site 1, the water table outside the structure must be maintained as close to its original level as possible.

Site 4: Water table high; soil is interbedded sand and compressible organic silt over bed rock at 60 feet. Rock is considered to have surface fractures. Water table must be maintained high.

Site 5: Water table high; soil, except for surface fill, is soft clayey silt over firm clay at 70 feet (21.3m).

The soil types indicated for sites 1 and 3 are such that very little differential settlement of adjacent structures would occur if the sites were dewatered. There are instances, however, where area dewatering may not be permitted due to other considerations. This may be the case if foundations were supported on timber pilings which could deteriorate if not kept continuously wet or where hydrostatic heads must be maintained to prevent inflows through embankments or levies. Sites 4 and 5 contain compressible soils which can not be dewatered. The presence of rock at site 4 requires certain modifications of construction methods compared to the other sites.

1.4 CONSTRUCTION METHODS

As used herein, construction method refers to the type of ground wall support used for the open-cut excavation. Volume 1 describes eight different methods (including steel sheet piling, reinforced concrete placed in slurry, etc.) and gives a general evaluation of their applicability with respect to major construction activities. Of the various methods considered, three were chosen as being representative of current and future cut-and-cover construction in the United States. They are: 1) soldier piles and lagging, 2) cast-in-slurry concrete diaphragm walls and 3) precast concrete panel diaphragm walls. All three are considered for cut-and-cover construction and the diaphragm walls for inverted constructed. An indication of the adaptability of different construction methods with respect to the five site conditions is given on Table 1, page 9.

1.4.1 Soldier Piles and Lagging (SP&L) This is the most common method of ground support for cut-and-cover construction used today in the United States. Although there are several variations, it usually consists of vertical steel beams placed 6 feet to 10 feet (1.8 m to 3 m) apart with horizontal timber lagging bearing on the inside flanges. It is a relatively flexible ground support system, and, as it is not watertight, is not adaptable in areas where the groundwater level must be maintained. This ground support system is illustrated in Figure 6.

1.4.2 Cast-in-Slurry Concrete Diaphragm (SPTC): Two general variations of this type of ground support are currently used. One method, developed in Europe, consists of excavating full depth alternate slots about 20 feet long (6.1 m) using a bentonite slurry to support the sides. A reinforcing cage is placed in the slot which is then filled with tremie concrete. The process is repeated for in-between slots. The method developed in the United States and used in this study is the soldier pile and tremie concrete wall shown in Figure 7. Soldier piles placed from 6 to 10 feet (1.8m to 3m) apart provide the primary ground support as in the case of soldier piles and lagging. Tremie concrete is placed in a slurry filled slot between piles to transfer ground load to the piles. Under certain conditions, where pile spacing is more than 7 feet (2.1m), steel reinforcing is used in the concrete.

The surface of the tremie wall is subsequently covered with a 1-foot (0.3 m) thick finishing wall throughout the permanent structure (see Figure 7). This is primarily for aesthetic purposes and could be eliminated (thereby reducing

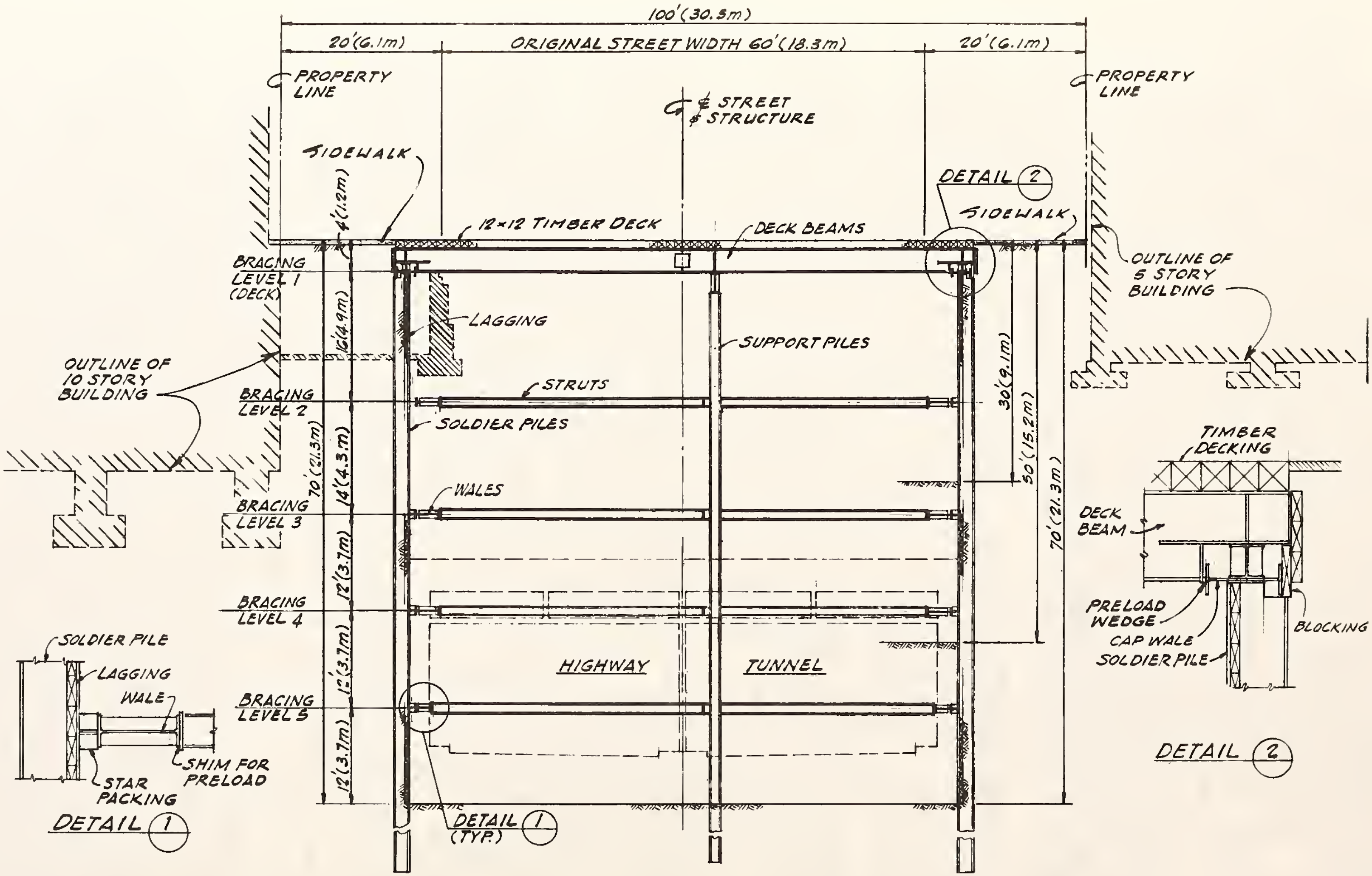


Figure 6. DETAILS OF GROUND SUPPORT - SOLDIER PILES AND LAGGING - INTERNAL BRACING

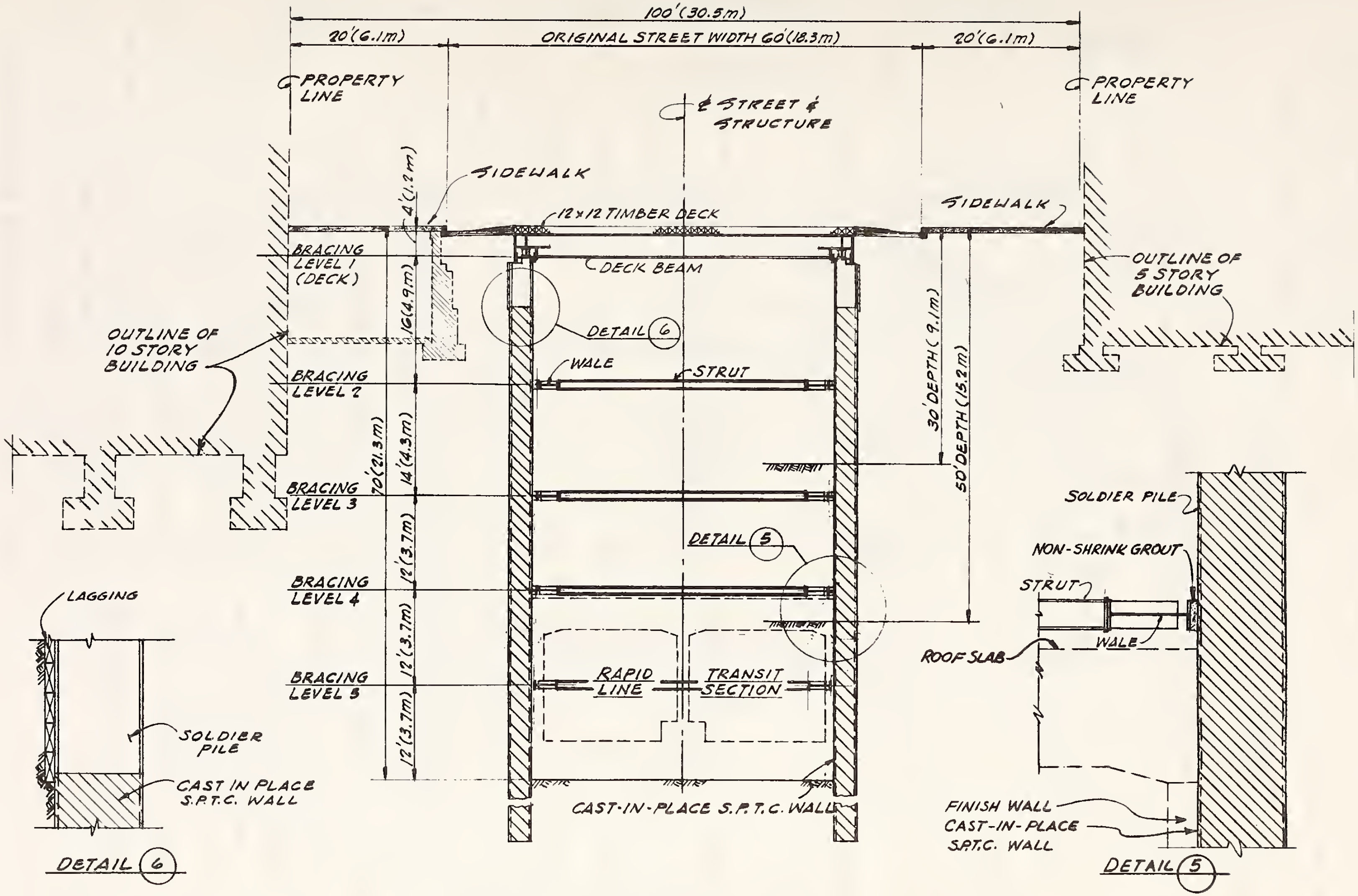


Figure 7. DETAILS OF GROUND SUPPORT - CAST-IN-PLACE CONCRETE WALLS (SPTC) - INTERNAL BRACING

overall costs) if architectural requirements permitted. This is especially pertinent with respect to the transit line and highway sections where appearances of side walls might be incidental to the overall use.

1.4.3 Precast Concrete Diaphragm (PCP): This type of ground support is a recent European development and has not yet been used in the United States. The method developed by Soletanche (Ref. 8) uses precast concrete panels placed in a cement grout filled slot. The grout hardens to provide firm support of the outside soil, minimizing ground movement. The grout is cleaned from the inside faces of the panels, which form the walls of the permanent structure. Various configurations of panels can be used. A study, specifically aimed at development of prefabricated structural panels for use in the United States is described in Ref. 43.* This type of ground support is shown in Figure 8.

1.4.4 Bracing of Ground Support Walls: Two methods are in general use; internal cross-bracing and tieback earth or rock anchors. Figures 6, 7 and 8 illustrate the use of internal bracing for three types of ground wall support. Figure 9 shows typical tieback anchor configurations for all three depths. Either bracing method can be used, provided other factors are favorable, for each of the ground support methods discussed above. Cross-bracing is more common in cut-and-cover tunnel construction even though tiebacks provide better access for excavation, structure construction and backfill. Tieback anchors should not be used in highly compressible soils.

1.4.5 Sites with Rock: Encountering rock above or near grade (site 4) requires that certain modifications of the construction methods be made. This pertains primarily to keying the support wall to the rock, providing adequate water cut-off and maintaining the integrity of the excavated rock surface below the support wall. If rock is encountered above the invert, the excavation could either be widened on either side to allow for a step-in at rock line or the soldier piles could be extended

*Note: References are listed on pages 287-290.

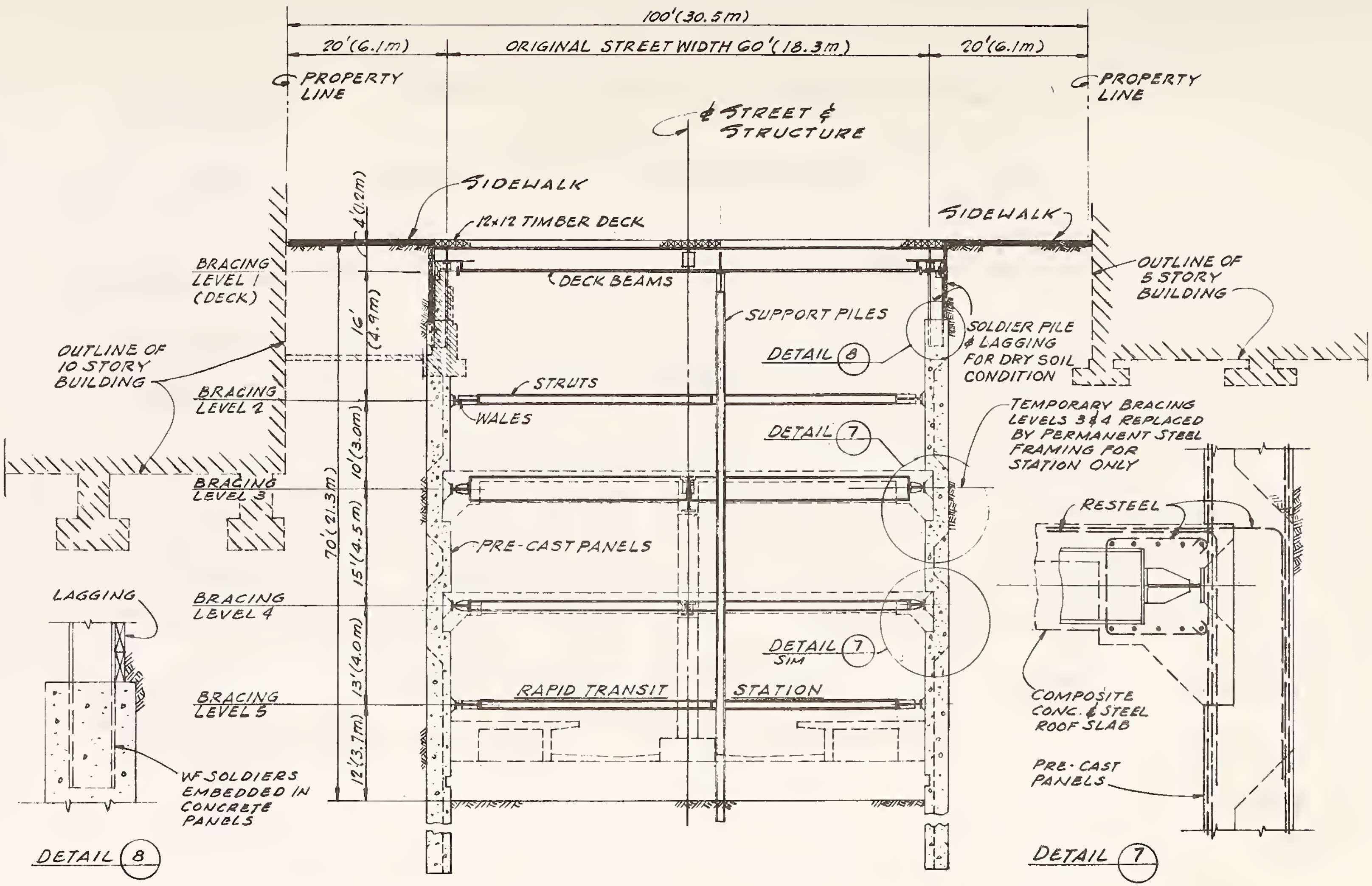
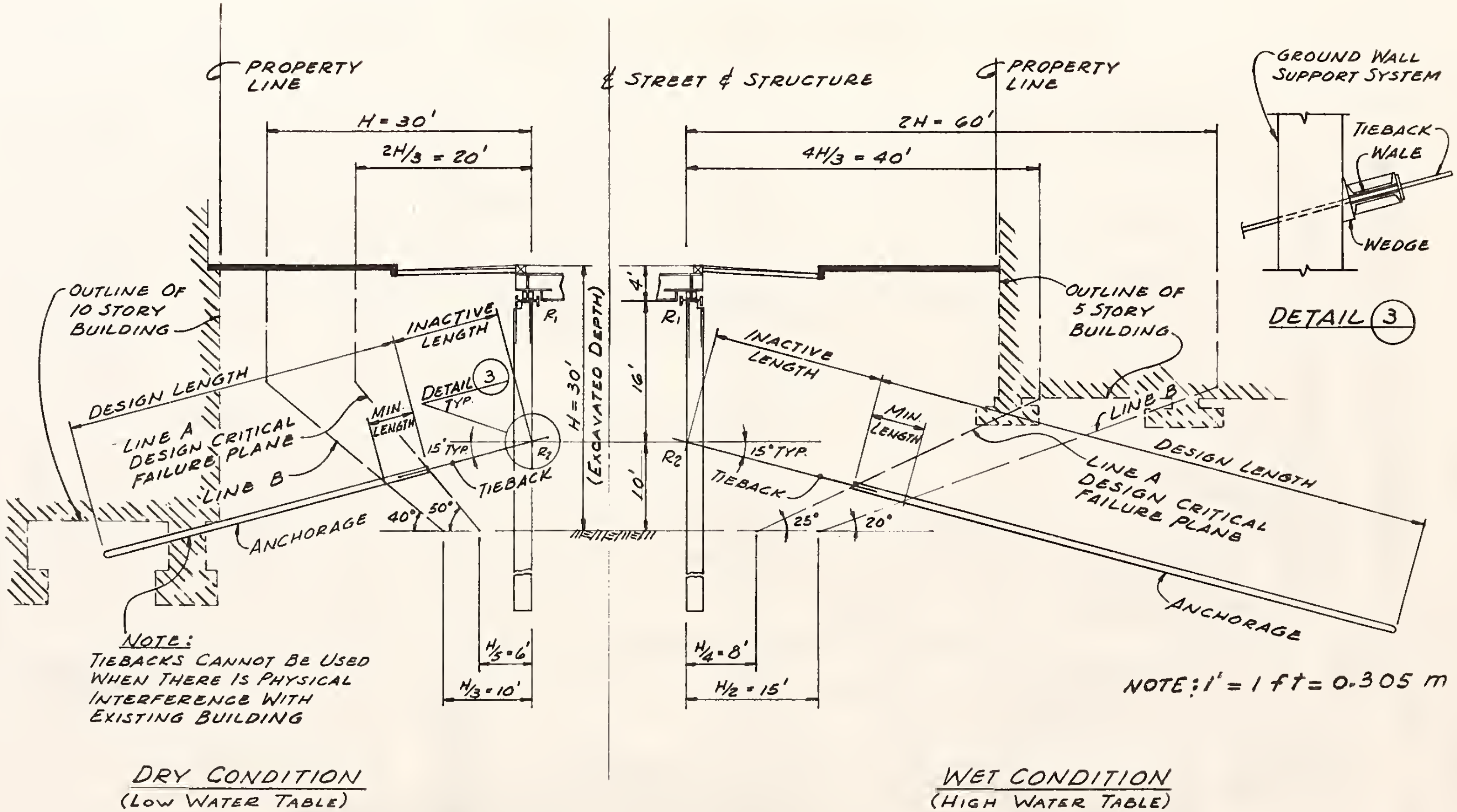
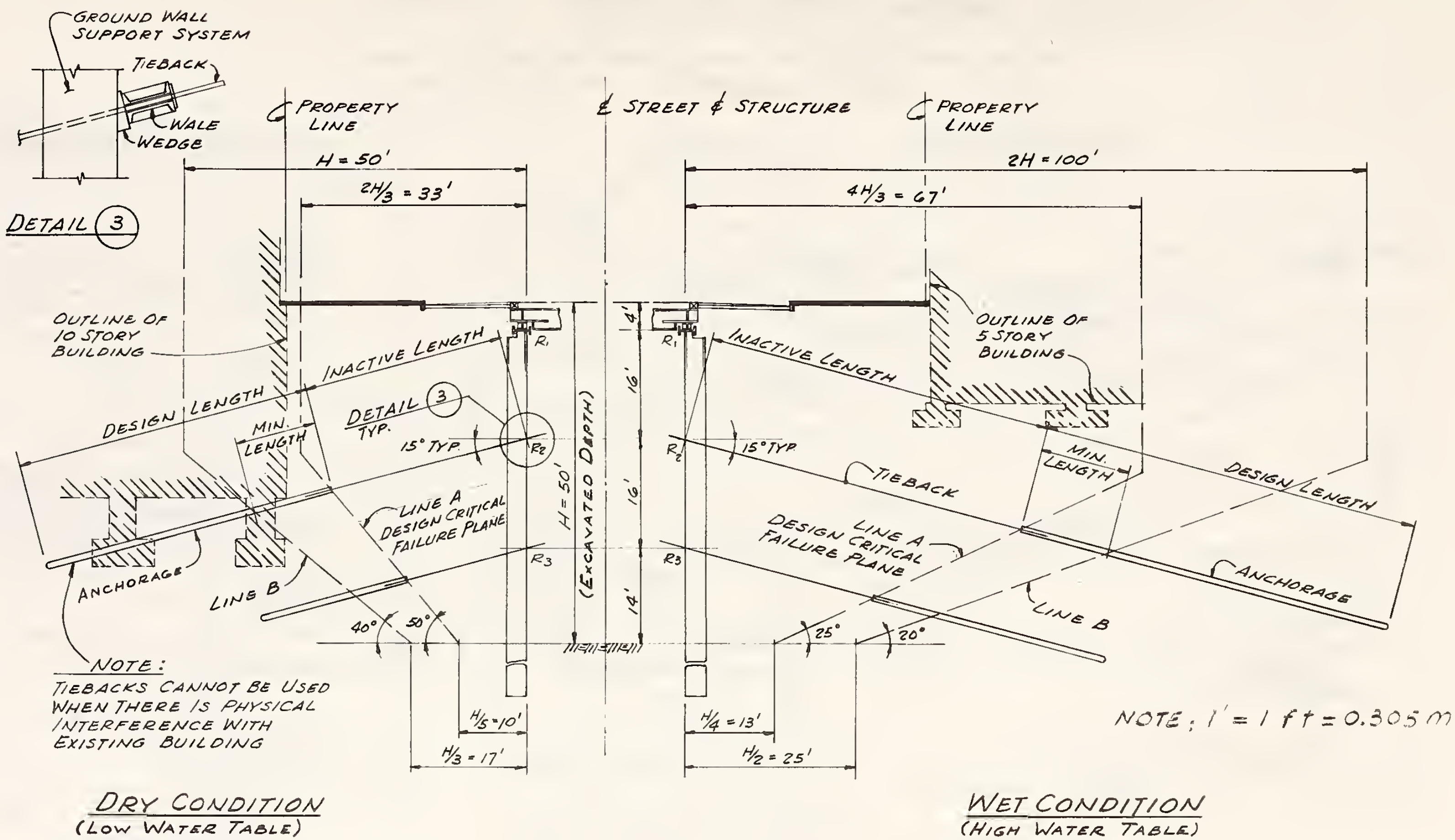


Figure 8. DETAILS OF GROUND SUPPORT - PRECAST PANELS - INTERNAL BRACING



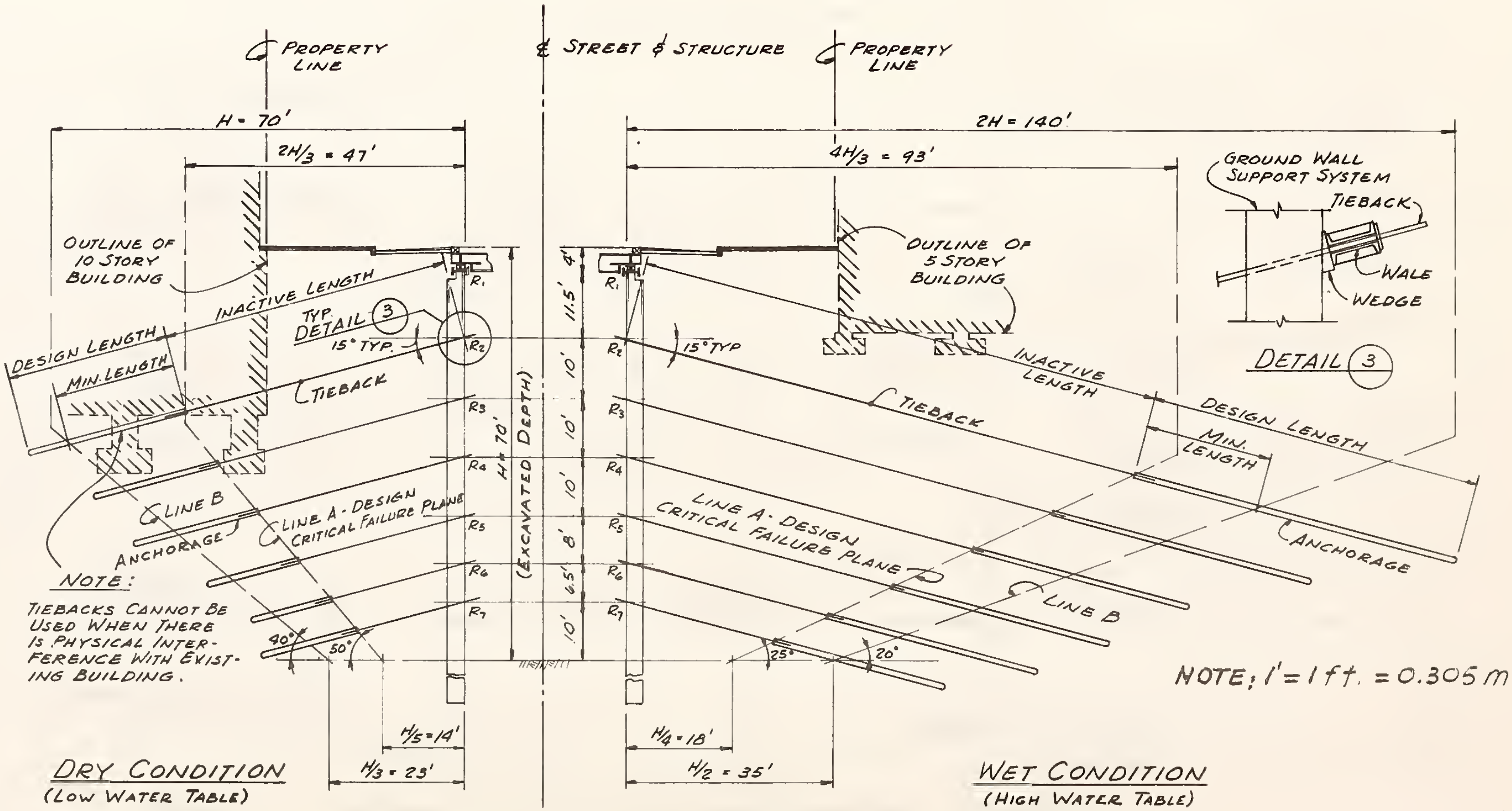
30 FT (9.1m) DEPTH-SITES 1, 2 & 3

Figure 9. DETAILS OF TIEBACK BRACING



50 FT. (15.2 m) DEPTH - SITES 1, 2 & 3

Figure 9. DETAILS OF TIEBACK BRACING (Continued)



70 FT. (21.3 m) DEPTH - SITES 1, 2 & 3

Figure 9. DETAILS OF TIEBACK BRACING (Continued)

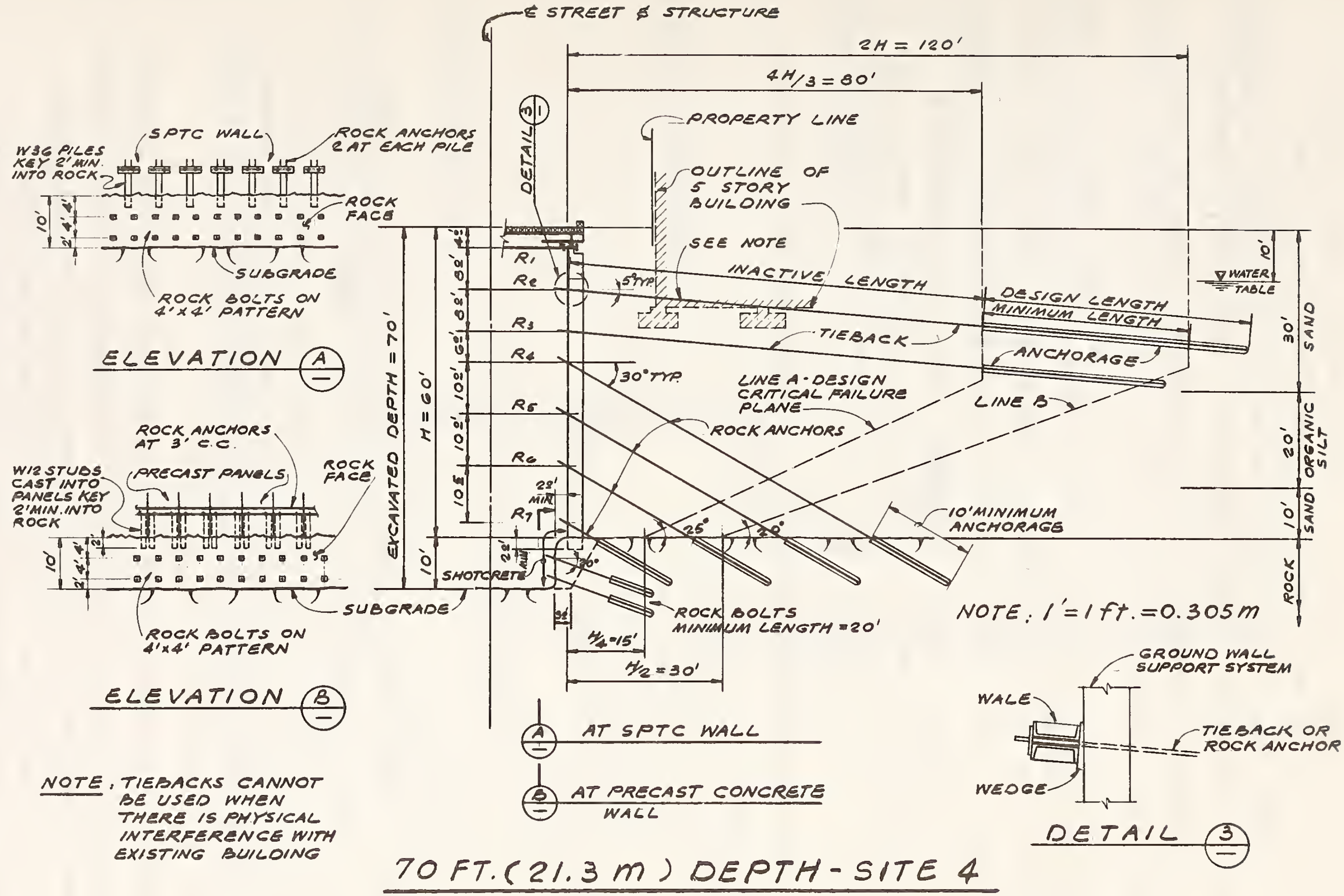


Figure 9. DETAILS OF TIEBACK BRACING (Continued)

below invert by rock drilling. In all cases, there will be added costs that do not occur at sites where rock is not present. These are in part compensated by eliminating the need for a deep cutoff wall. For purposes of this study, the construction procedure used at the earthrock interface of site 4 is illustrated on Figure 10.

1.5 CONSTRUCTION ACTIVITIES

Although no two cut-and-cover projects are the same, there are a number of basic construction activities, common to most, which can be used in comparing direct costs and evaluating variations due to different construction and site conditions. These direct cost activities are identified as follows:

A. Traffic Control
B. Maintenance, Replacement or Relocation of Utilities
C. Protection of Adjacent Structures
D. Groundwater Control
E. Installation of Decking
F. Installation of Ground Wall Support
G. Bracing of Ground Wall Support
H. Excavation
I. Construction of Permanent Structure
J. Backfill
K. Restoration

Each is comprised of a combination of several related sub-activities or work operations which in summation reflect the total effort required (type and quantity of work, etc.) to complete a particular structure. Some activities are determined by the chosen method of construction, others are dependent on contractual stipulations.

Volume 1 discusses these activities and provides general evaluations and tables showing their adaptability and requirements when considering different construction methods under varying site conditions. Figure 11 illustrates typical activities in the construction of a rapid transit station. These drawings are reproduced by permission of the Perini Corporation.

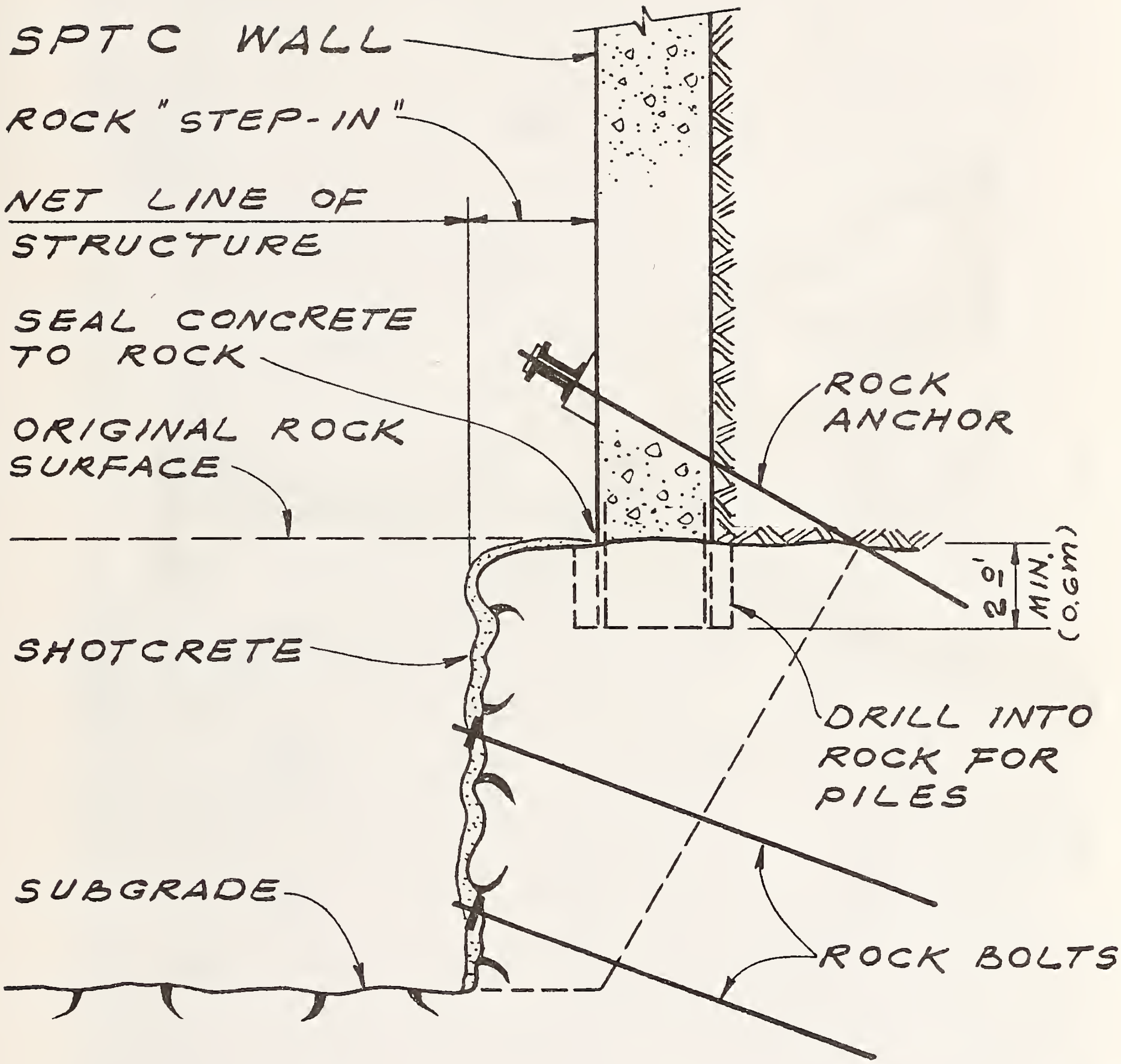
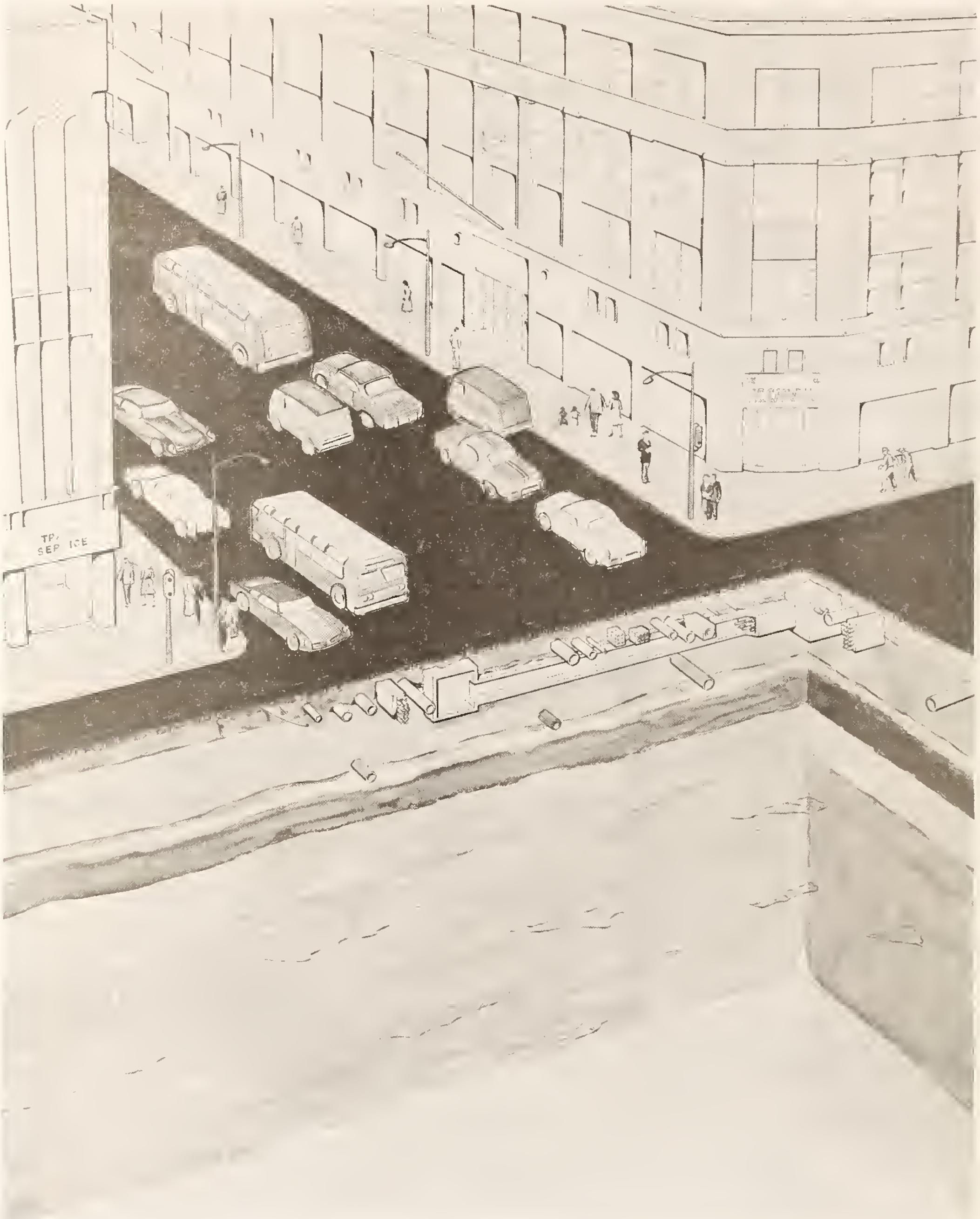


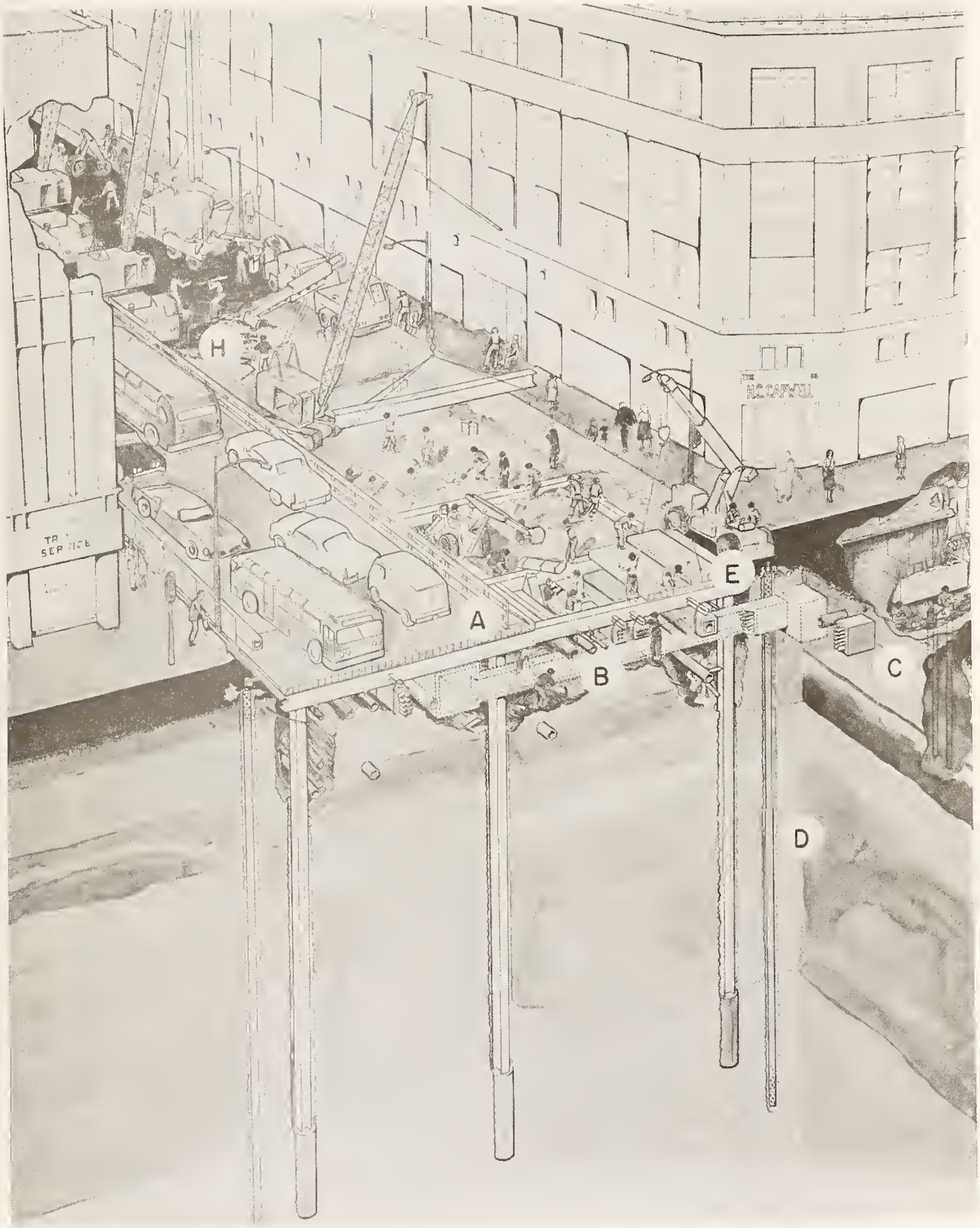
Figure 10. CONSTRUCTION PROCEDURES - SITES WITH ROCK



Worksite prior to start of project showing existing utilities below street surface

(Courtesy of The Perini Corporation)

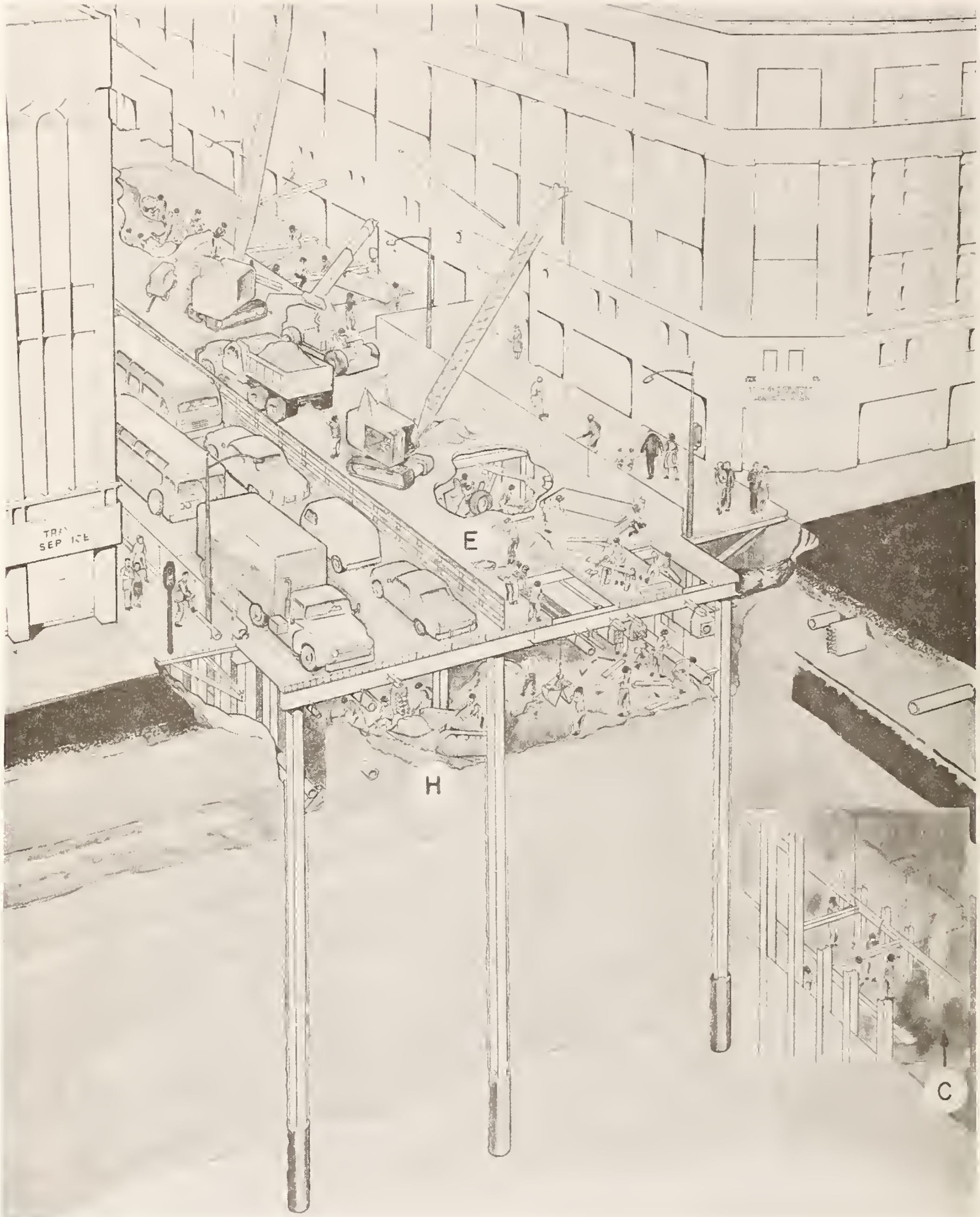
Figure 11 - TYPICAL CUT-AND-COVER CONSTRUCTION ACTIVITIES



Showing early activities of (A) traffic control, (B) utility maintenance, (C) underpinning (insert) (D) dewatering well casings, (E) decking installation, and (H) first pass of excavation.

(Courtesy of The Perini Corporation)

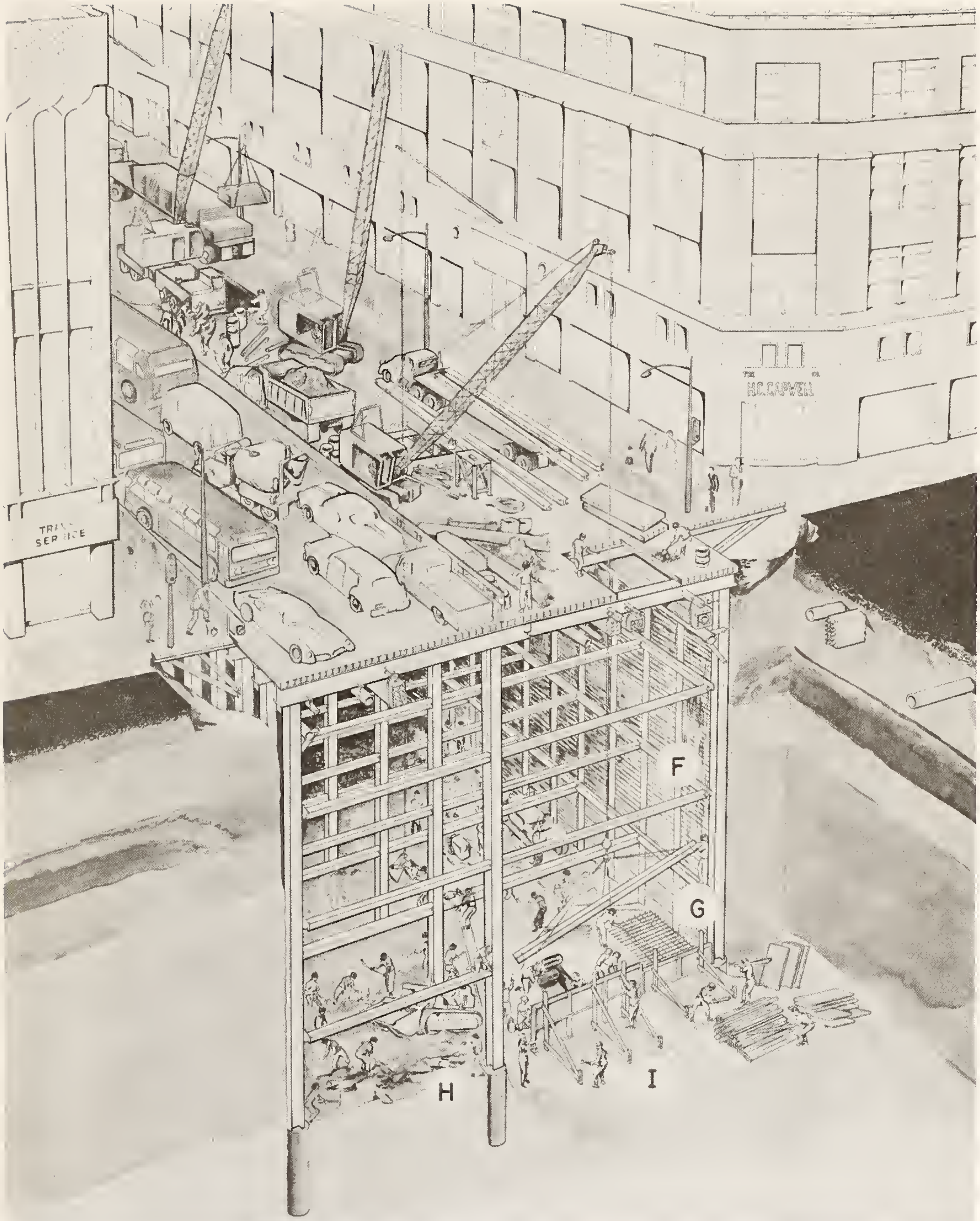
Figure 11 - TYPICAL CUT-AND-COVER CONSTRUCTION ACTIVITIES (Continued)



Showing (C) protection of adjacent structures (insert), (E) completion of decking installation, and (H) second pass of excavation.

(Courtesy of The Perini Corporation)

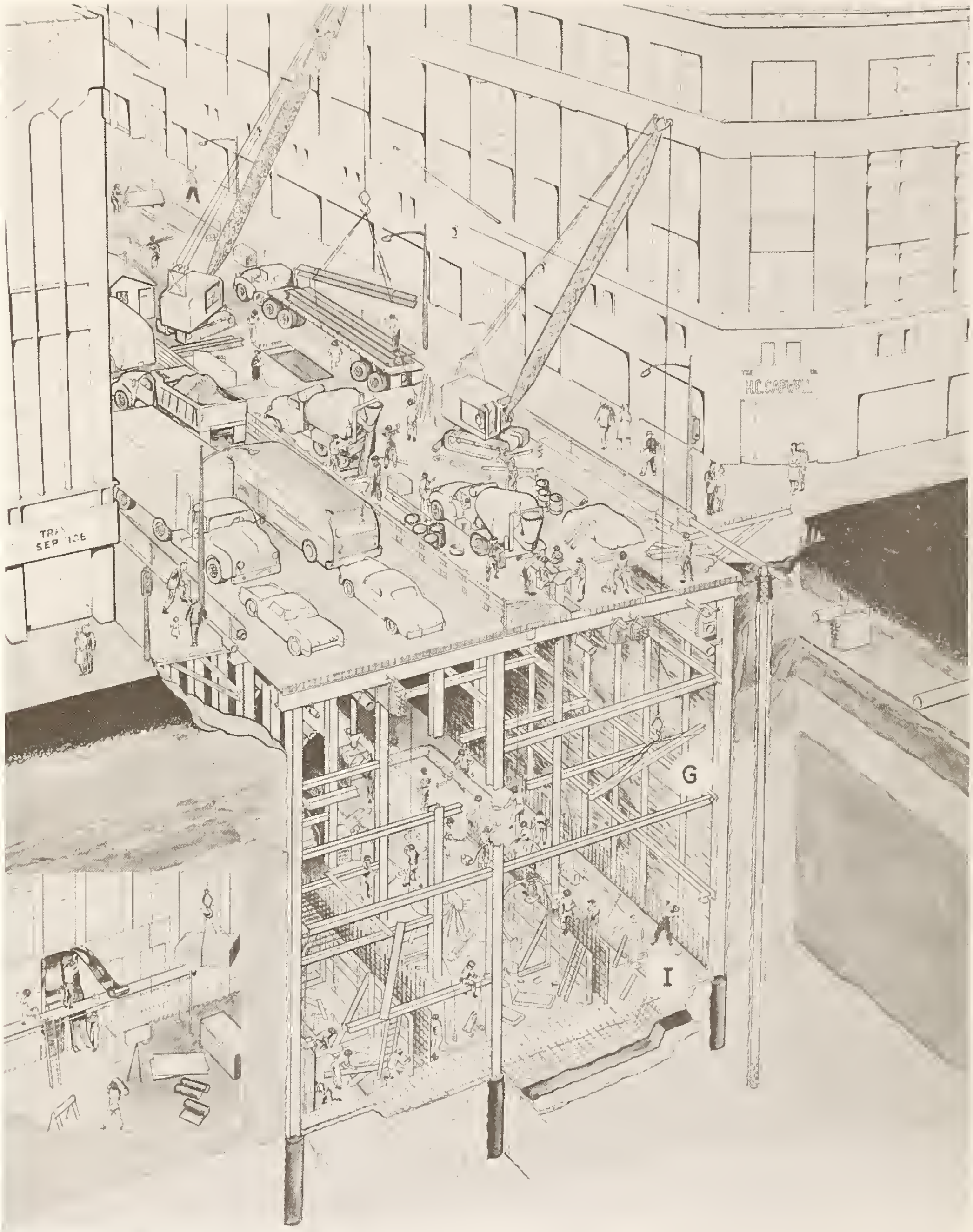
Figure 11 - TYPICAL CUT-AND-COVER CONSTRUCTION ACTIVITIES (Continued)



Showing (F) ground wall support, (G) bracing installation, (H) excavation, and (I) setting forms for base slab.

(Courtesy of The Perini Corporation)

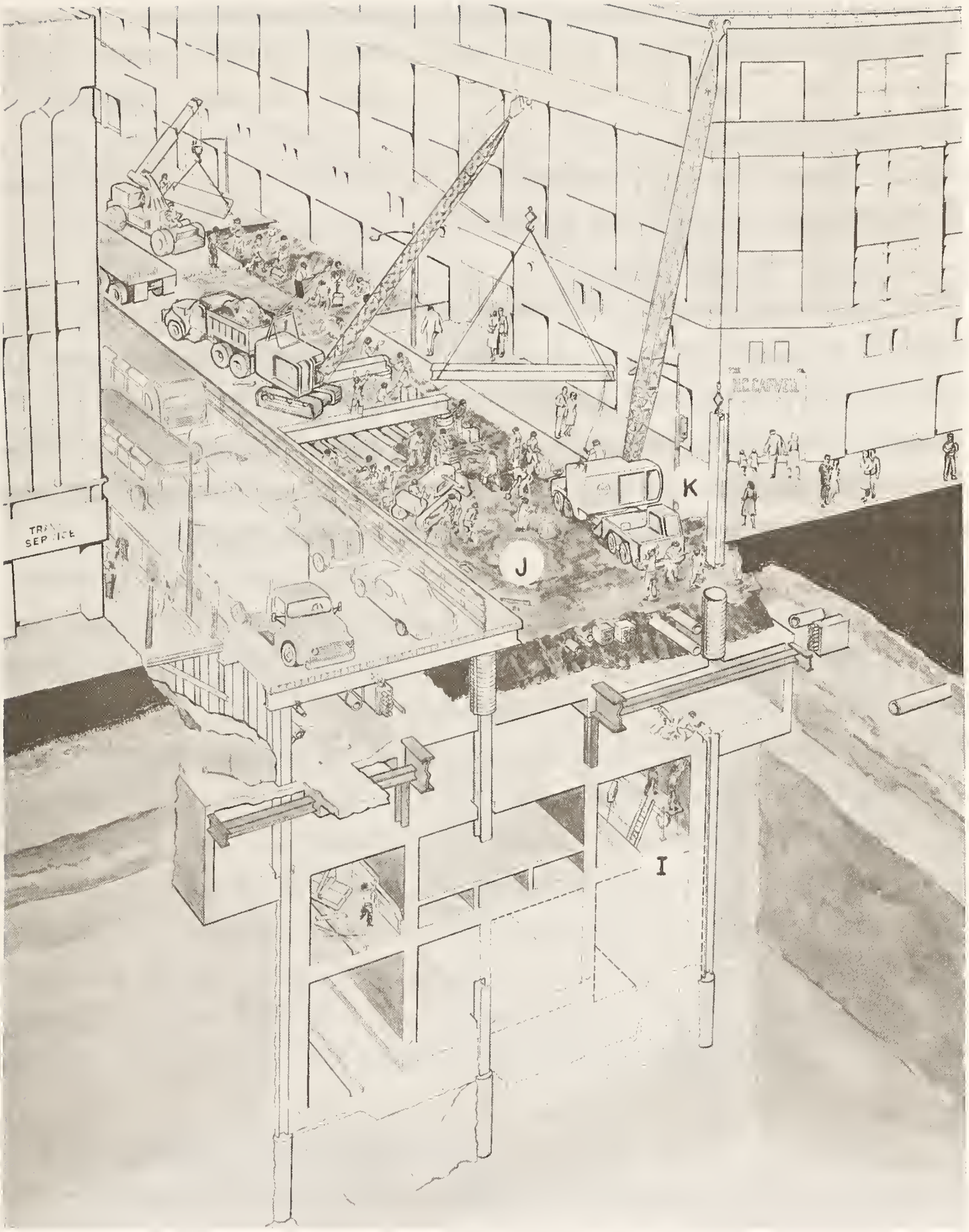
Figure 11 - TYPICAL CUT-AND-COVER CONSTRUCTION ACTIVITIES (Continued)



Showing (G) removal of bracing and (I) construction of the permanent structure. Insert shows installation of outer wall waterproofing.

(Courtesy of The Perini Corporation)

Figure 11 - TYPICAL CUT-AND-COVER CONSTRUCTION ACTIVITIES (Continued)



Showing (I) completion of permanent structure,
(J) backfill, removal of street decking, and
(K) surface restoration

(Courtesy of The Perini Corporation)

Figure 11 - TYPICAL CUT-AND-COVER CONSTRUCTION ACTIVITIES (Continued)

In addition to direct cost activities, it is also necessary to consider general and administrative expenses and plant costs. These include both fixed and time related items dependent on the type and duration of construction and are identified as follows:

N. Overhead - Fixed Costs

O. Overhead - Time Related Costs

P. Plant - Fixed Costs

Q. Plant - Time Related Costs

Project construction costs, as subsequently developed and discussed in this report, are defined in terms of these 15 activities. Contractor's mark-up is treated separately. The cost of disruption caused by each construction system can be calculated using a rationale suggested in Section 5.

SECTION 2
DESIGN GUIDELINES AND APPLICATIONS

2.1 GENERAL

Design requirements for cut-and-cover tunneling are considered as: 1) design of permanent structures - provided by the owner's engineer and, 2) design of temporary structures such as ground wall support and construction decking. The design of temporary structures is usually performed by the contractor on the basis of data and information provided by the owner. Other requirements, such as protection of adjacent buildings or maintaining groundwater levels, may or may not be specified depending on specific site and contract conditions.

The design of both permanent and temporary structures is dependent on the soil type and hydrological condition of the ground and the vertical and horizontal relationship between adjacent buildings and utilities with respect to the proposed construction. In most instances, these factors have a greater effect on the design of temporary structures than on the design of permanent structures. The site configuration used for all study situations is shown on Figure 4. Ground conditions assumed for the five study sites are shown on Figure 5.

A brief summary review of guidelines and criteria used in the analysis and design of cut-and-cover tunneling operations is given in the following paragraphs. A more detailed discussion is provided in Section 4 of Volume 1.

2.2 SOIL TYPES AND PROPERTIES

The design of cut-and cover structures varies significantly depending on the type of soil in which the structure is built. Since no two sites contain identical ground conditions, it is necessary to make separate designs for each situation. However, for study purposes, average or typical conditions can be considered which will provide adequate and cost effective designs for both permanent and temporary structures.

Even though most soils have some cohesive properties, it is common practice for a broad range of silty sands, clayey sands, sandy silts, sandy clays and even clayey silts to assume an "equivalent" non-cohesive soil for design purposes. The ordinary rules of soil mechanics for a non-cohesive soil (using an equivalent ϕ) are then applied to develop applicable lateral earth pressures for design of permanent, and to a greater extent temporary structures. This is the type of soil considered for sites 1, 2, and 3.

Cohesive soils including soft clays, clayey silts and firm clays exert lateral pressures which are dependent on the soil unit weight and the value of cohesion - 'c'. When dealing with soft clays or silts in excavation the problems of base stability and passive pressure becomes very critical. As these soils are very sensitive to disturbances, it is difficult to obtain accurate values of the soil cohesion in the undisturbed condition. These types of soil are found in site 5. Site 4 has both cohesive and non-cohesive soils as well as rock.

Physical properties of soils typified by the five study sites are shown on Table 2. These properties were used in the analyses and calculations of design requirements developed for the different cut-and-cover constructions considered in the study.

2.3 DEWATERING AND RECHARGING

It is likely that most transit structures will be built at sites with a relatively high water table level which affects both the design and construction of the structure. Several possibilities exist: 1) the area can be effectively dewatered without detrimental effects to adjacent areas or structures, 2) the water table must be maintained or 3) impervious nature of the soil is such that predrainage (dewatering) would be impractical.

In the first instance (site 1), dewatering during construction could be accomplished with deep wells, well point systems or other conventional methods. Recharging would not be

Table 2. SOIL PROPERTIES AND DEFINITIONS

SOIL PROPERTIES AND DEFINITIONS

SOIL PROPERTIES

SOIL TYPE	ϕ	c	γ	γ'
ALLUVIAL SOIL	33°	0	120 PCF	62 PCF
ORGANIC SILT	26°	0	125 PCF	65 PCF
SOFT CLAYEY SILT	0	500 PSF	112 PCF	50 PCF
FIRM CLAY	0	3000 PSF	122 PCF	60 PCF
EQUIVALENT SOIL AT SITE 4	29.7°	0	122 PCF	63 PCF

SYMBOLS USED IN THIS REPORT

SOIL MECHANICS:

- ϕ ANGLE OF INTERNAL FRICTION
- δ ANGLE OF WALL FRICTION
- C COHESION
- γ MOIST UNIT WEIGHT
- γ' SUBMERGED UNIT WEIGHT
- γ_w UNIT WEIGHT OF WATER
- K_a COEFFICIENT OF ACTIVE LATERAL EARTH PRESSURE
- K_o COEFFICIENT OF AT REST LATERAL EARTH PRESSURE
- K_p COEFFICIENT OF PASSIVE LATERAL EARTH PRESSURE

GENERAL ENGINEERING:

- A ADHESION (SKIN FRICTION)
- a DIST. BETWEEN GROUND WALL AND BLDG. FOUNDATION
- B WIDTH OF WALL.
- b WIDTH OF PILE.
- D PILE PENETRATION BELOW BOTTOM OF EXCAVATION
- D_a DEPTH FROM GROUND SURFACE TO MIDPOINT OF TIEBACK ANCHORAGE
- D_f DEPTH OF BUILDING FOUNDATION
- d DEPTH OF PILE.
- F.S. FACTOR OF SAFETY
- f FACTOR (DEPENDENT ON TIEBACK ANGLE AND F.S.)
- H DEPTH OF EXCAVATION
- H' WATER TABLE TO BOTTOM OF EXCAVATION.
- H_1 BUILDING FOUNDATION TO BOTTOM OF EXCAVATION
- K DIMENSIONLESS NUMBER.
- N PRESSURE INDEX.
- n NET BUILDING FOUNDATION LOAD.
- P_a ACTIVE PRESSURE (MOIST)
- P'_a ACTIVE PRESSURE (SUBMERGED)
- P_d MAGNITUDE OF ACTIVE LATERAL EARTH PRESSURE (MOIST)
- P'_d MAGNITUDE OF ACTIVE LATERAL EARTH PRESSURE (SUBMERGED)
- P_p PASSIVE PRESSURE (MOIST)
- P'_p PASSIVE PRESSURE (SUBMERGED)
- P_w WATER PRESSURE
- p_a ACTIVE PRESSURE GRADIENT (MOIST)
- p'_a ACTIVE PRESSURE GRADIENT (SUBMERGED)
- p_p PASSIVE PRESSURE GRADIENT (MOIST)
- p'_p PASSIVE PRESSURE GRADIENT (SUBMERGED)
- p_w WATER PRESSURE GRADIENT
- q EFFECTIVE SOIL PRESSURE AT DEPTH D_a
- q_f BUILDING FOUNDATION LOAD
- R RADIUS
- W MAGNITUDE OF BUILDING SURCHARGE LOAD.

SOIL MECHANICS AND GENERAL ENGINR. FORMULAE

COHESIONLESS SOILS:

$K_a = TAN^2(45 - \phi/2)$

$K_o = 1 - SIN\,\phi$ OR $\cong 0.5$

$K_p = TAN^2(45 + \phi/2)$ OR REFERENCE 16, Pg 462

FLEXIBLE WALLS, DEWATERED.

$K_d = 0.8 K_a \gamma H$

FLEXIBLE WALLS, NOT DEWATERED.

$P'_d = 0.8 K_a \gamma (H-H') + 0.8 K_a \gamma' H'$

$P_w = 63 H'$

SEMI-RIGID WALLS DEWATERED

$P_d = 0.4 (K_o + K_a) \gamma H$

SEMI-RIGID WALLS NOT DEWATERED

$P'_d = 0.4 (K_o + K_a) \gamma (H-H') + 0.4 (K_o + K_a) \gamma' H'$

$P_w = 63 H'$

ACTIVE & PASSIVE PRESSURE GRADIENTS

DEWATERED

$p_a = K_a \gamma$

$p_p = \dfrac{K_p \gamma}{F.S.}$

NOT DEWATERED

$p'_a = K_a \gamma'$

$p'_p = \dfrac{K_p \gamma'}{F.S.}$

COHESIVE SOILS:

SEMI-RIGID WALL, NOT DEWATERED

ABOVE SUBGRADE

$P'_d = [(H-H')\gamma + (H'\gamma')] - 4C$ OR

$0.4[(H-H')\gamma + (H'\gamma')]$ WHICHEVER IS GREATER

$P_w = 63 H'$

BELOW SUBGRADE

$P'_d = \gamma H - 4C$

ACTIVE AND PASSIVE PRESSURE GRADIENTS

ABOVE SUBGRADE

$P'_a = [(H-H')\gamma + (H'\gamma')] - 2C$

$P_w = 63 H'$

BELOW SUBGRADE

$P'_a = [(H-H')\gamma + (H'+D)\gamma'] - 2C$

$P_w = 63 H'$

$P_p = \dfrac{\gamma' D + 2C}{F.S.}$

BUILDING SURCHARGE:

$W = 0.4n\left(1 - \dfrac{a}{1.5H}\right)$ FOR $\dfrac{a}{H_1}$ FROM 0 TO 1.5

$W = 0$ FOR $\dfrac{a}{H_1} > 1.5$

VERTICAL BEARING CAPACITY:

SOLDIER PILES & LAGGING

BEARING CAPACITY $= K(b+d)D$

CONTINUOUS WALL

BEARING CAPACITY $= K(B+D)$

TIEBACK ANCHORS:

$A = \dfrac{Nq}{F.S.}$

WHERE $N = \dfrac{f(TAN\,\phi)}{K_a}$

$q = \gamma D_a$ OR $\gamma' D_a$

$f = .267$ FOR 15° ANGLE AND F.S. $= 2.0$

Note: 1 PSF = 1 lb./sq.ft. = 0.0479kPa, 1 PCF = 1 lb./cu.ft. = 16.02 kg/m^3

necessary. Any of the three ground wall support systems designed for dry soil conditions could be used, provided adequate safety precautions were taken against possible failure of the dewatering system. Design of the permanent structure would be based on high water table conditions.

Where the water table must be maintained, (site 3) impervious type ground support walls would be used. The excavation is physically isolated by establishing a water-tight "bath tub" in which the construction will occur. Pumping facilities would only be required to extract water from within the impervious shell. Open sumping and trenching may be possible at some depths, or the excavation could be effectively isolated by predraining the area of excavation and reintroducing the pumped water (recharging) to the soil mass beyond the support walls. Since recharging is much more difficult and less predictable than dewatering, great care must be taken to ensure that various components of the feedback loop operate as required. In either case, monitoring of the water table and dewatering system must be continuous and analyzed by experienced practitioners.

The design and effectiveness of a dewatering system relates to its ability to reduce the exit gradient (water flow-beneath the ground support wall) sufficiently to prevent piping or "boiling" of the soil within the excavation. In situations where fairly impermeable soils are found at reasonable depths below the excavation (which would probably be the case at most sites), the support walls could be extended into the impervious layer, thereby providing an effective cut-off seal.

If the pervious material is of great depth, the exit gradient can be reduced by increasing the depth of support wall embedment below the bottom of excavation. For all practical purposes, however, the exit gradient for assumed conditions at site 3 is not materially reduced beyond that achieved with an embedment depth of approximately 35 feet (10.7m). The distance between the bottom of the wall and top of an impervious layer as well as the width and depth of excavation affects the calculation of the exit gradient and consequently the design of the dewatering and ground wall support systems. For situations similar to site 3, it would be necessary to make a thorough geotechnical analysis of all factors: permeability, anisotropy, relative densities, stratigraphy, depth of excavation and cut-offs and location of the existing water table before determining the most effective dewatering method. It is likely that separate analyses would have to be made for each depth and type of structure considered. Open sumping and trenching (dewatering the soil within the support walls as the excavation proceeds) may be acceptable at shallower depths, but would probably not be permitted where the hydrostatic head exceeds 30 or 40 feet (9.1m or 12.2m) even though a lengthened flow path had been provided by embedment, theoretically sufficient to prevent piping. Considering a critical gradient for most granular soils of 1 and a safety factor of at least 2, the exit gradient must be less than 0.5.

Due to the organic silt layer at site 4, it would be necessary to recharge the overlying sand layer to prevent subsidence if the area was dewatered. However, due to the proximity of impervious materials (silt and rock), it is likely that effective seals at bottom of the diaphragm walls can be achieved so as to essentially eliminate the dewatering operation. Sumping and trenching and some interim pumping of the sand layers will be required as the excavation is lowered. Sealing a diaphragm wall to rock can be an expensive operation requiring special construction techniques and monitoring.

The soil profile at site 5 contains no permeable strata, hence predrainage and/or recharging would not be applicable.

The requirements for dewatering and subsequent design of temporary structures vary considerably with respect to site and construction conditions. In some instances, the need to reduce the exit gradient in soil below the excavation to prevent "piping" is more critical in determining cut-off depths than structural requirements for passive or bearing capacities of the ground support walls.

The above discussion is a general overview of dewatering analyses made for the study. Determinations of cut-off depths used for the design analyses are in general agreement with experimental results summarized in NAVFAC, DM-7 (Ref 18).

2.3.1 Special Dewatering Considerations at Site 3: For the special situation at site 3, an alluvial soil that should not be dewatered, the following assumptions are made:

1) The sand forming the aquifer has an equivalent isotropic permeability of about 200 cm x 10^{-4}/sec. However, since it is an alluvial deposit, anisotropic properties are assumed with horizontal permeability substantially greater than vertical permeability. This is typical of most alluvial soils.

2) The existing water table is 10 feet below the ground surface and the predrained water level within the diaphragm walls is maintained at least 3 feet below subgrade.

3) An impermeable layer is present at a depth of 100 feet below invert.

4) Although recharging is used to maintain the existing water table, it is assumed that reasonable variations in water level will be permitted.

Results of dewatering analysis for site 3 are shown on Table 3. The general schemes considered for the different sites are illustrated on Figure 12.

2.4 DESIGN OF PERMANENT STRUCTURES

Long term loadings assumed for the design of permanent structures are shown on Figure 13. In most cases the design is comparatively insensitive to changes in soil type for the following reasons:

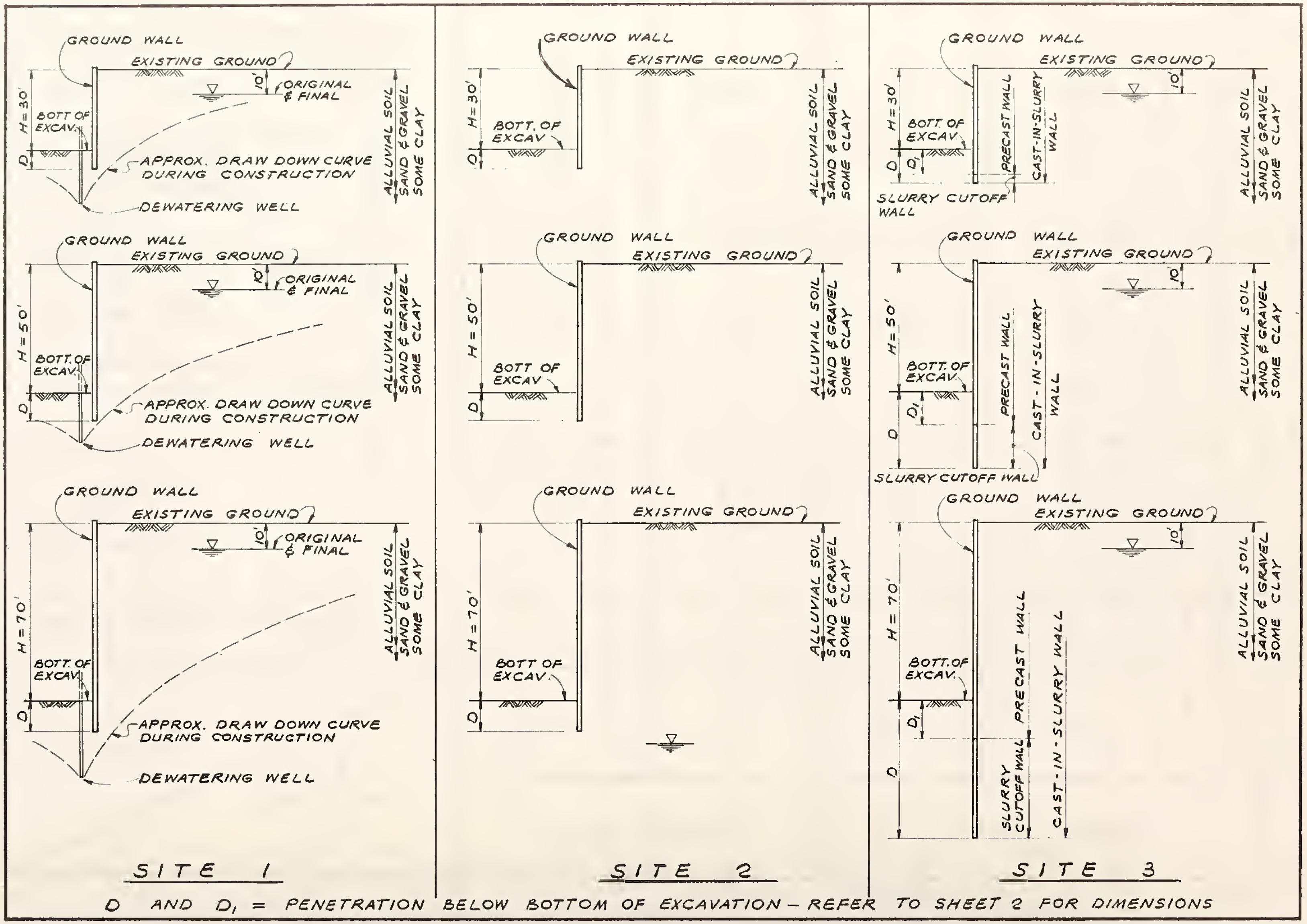
a) When the permanent water table is high (which is usually the case), a change in soil type or its competency will not result in a marked change in design vertical and lateral loads on the structure.

b) If the water table is low, the only variation in vertical loading would be possible differences of moisture content of backfill materials used.

Table 3. DEWATERING AND RECHARGE SYSTEMS AT SITE 3

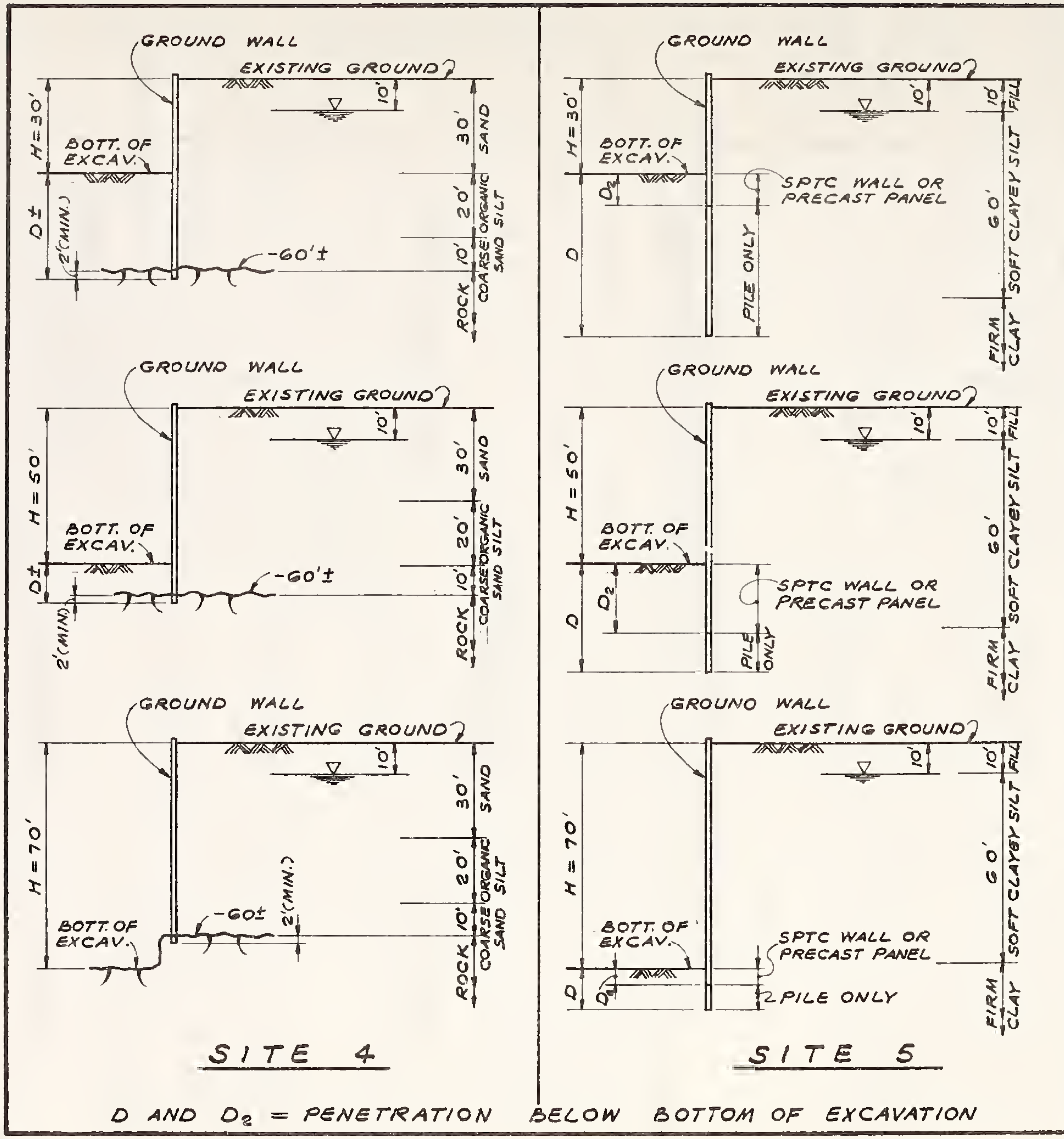
STRUCTURE / DESIGN ELEMENTS	700' STATION		2000' TUNNEL		
	50'	70'	30'	50'	70'
TOTAL DESIGN INFLOW Q (No cutoff or recharge)	1830 gpm	3375 gpm	1850 gpm	3635 gpm	5555 gpm
FLOW FACTORS:					
CUTOFF	90%	80%	100%	80%	70%
RECHARGE	120%	110%	125%	115%	105%
ADJUSTED FLOW - Q	1976 gpm	3287 gpm	2313 gpm	3344 gpm	4083 gpm
CUTOFF BELOW SUB GRADE (from NAVFAC)	17'	32'	10'	25'	40'
SCREEN LENGTH	20'	30'	20'	25'	35'
INDIVUAL WELL PUMP CAPACITY - Qw	180 gpm	270 gpm	180 gpm	225 gpm	315 gpm
NUMBER OF WELLS:					
THEORETICAL	11	13	13	15	13
ADJUSTED TO SITE	15	20	15	20	20
NUMBER OF RECHARGE WELLS	23	30	23	30	30
BOTTOM OF RECHARGE WELLS ABOVE TIP OF CUTOFF	15'	25'	5'	20'	30'

Note: 1' = 1 ft. = 0.305m, 1 gpm = 0.000063 m^3/s



Note: 1' = 1 ft. = 0.305m

Figure 12. SOIL AND GROUNDWATER CONDITIONS DURING CONSTRUCTION



SUPPORT CUTOFF (D)			4 LANE HIGHWAY TUNNEL RAPID TRANSIT STATION H=30'	H=50'	H=70'	DOUBLE BOX LINE STRUCTURE H=30'	H=50'	H=70'
INTERNAL BRACING ALTERNATE	SITE 1	SP&L	7'	11'	12'	7'	11'	12'
		SPTC	10'	10'	12'	10'	10'	12'
		PCP	10'	10'	12'	10'	10'	12'
	SITE 2	SP&L	7'	11'	12'	7'	11'	12'
		SPTC	10'	10'	12'	10'	10'	12'
		PCP	10'	10'	12'	10'	10'	12'
	SITE 3	SP&L	NA	NA	NA	NA	NA	NA
		SPTC	13'	30'	54'	15'	40'	66'
		PCP CONC (D_1)	10'	12'	15'	10'	12'	15'
		PCP SLURRY (D)	13'	30'	54'	15'	40'	66'
	SITE 4	SP&L	NA	NA	NA	NA	NA	NA
		SPTC	32'	12'	2'	32'	12'	2'
		PCP	32'	12'	2'	32'	12'	2'
	SITE 5	SP&L	NA	NA	NA	NA	NA	NA
		SPTC CONC. (D_2)	10'	22'	5'	10'	22'	5'
		SPTC PILE (D)	52'	34'	15'	52'	33'	16'
		PCP CONC (D_2)	10'	22'	5'	10'	22'	5'
		PCP PILE (D)	52'	34'	15'	51'	33'	16'
TIEBACK ALTERNATE	SITE 1	SP&L	10'	17'	27'	10'	17'	27'
		SPTC	10'	10'	12'	10'	10'	12'
		PCP	10'	10'	12'	10'	10'	12'
	SITE 2	SP&L	10'	17'	27'	10'	17'	27'
		SPTC	10'	10'	12'	10'	10'	12'
		PCP	10'	10'	12'	10'	10'	12'
	SITE 3	SP&L	NA	NA	NA	NA	NA	NA
		SPTC	13'	30'	54'	15'	40'	66'
		PCP CONC. (D_1)	10'	12'	16'	10'	12'	16'
		PCP SLURRY (D)	13'	30'	54'	15'	40'	66'
	SITE 4	SP&L	NA	NA	NA	NA	NA	NA
		SPTC	32'	12'	2'	32'	12'	2'
		PCP	32'	12'	2'	32'	12'	2'
	SITE 5	NOT APPROPRIATE AT SITE 5						

Note: 1' = 1 ft. = 0.305m

Figure 12. SOIL AND GROUNDWATER CONDITIONS DURING CONSTRUCTION (Continued)

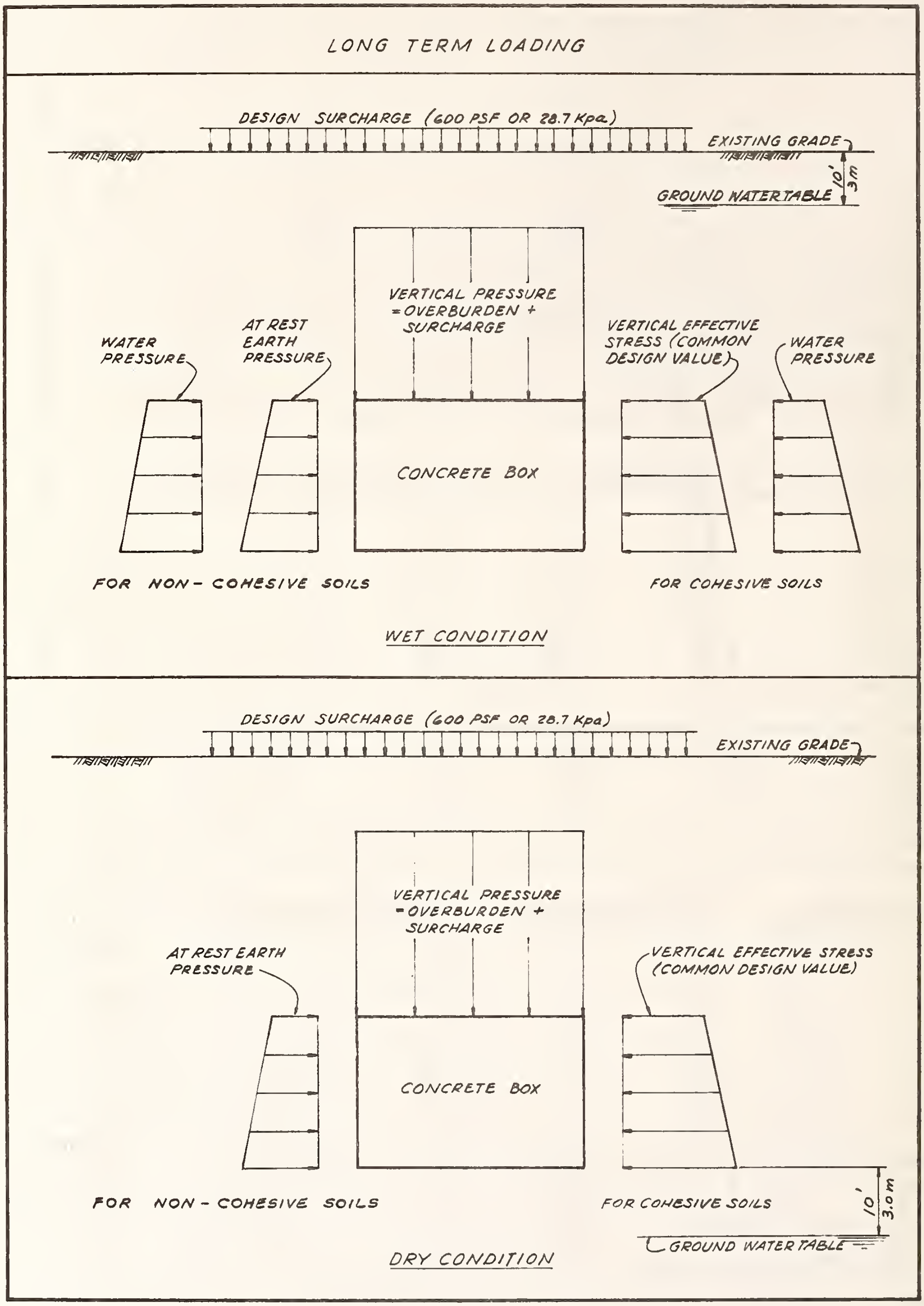


Figure 13. DESIGN LOADING LONG TERM

c) Lateral loads, exclusive of surcharge, will vary somewhat with changes in soil type. However, the actual effect of these variations on the design is usually less than other structural considerations such as a design for buoyancy.

Street and sidewalk live loads(surcharges) are considered at a common design value of 600 psf (28.7 kpa) for all sites.

Building surcharge loads do not impart significant additional lateral soil pressure to the walls of permanent structures unless the buildings in question are not underpinned, are relatively tall (heavy) and are unusually close to the plane of the cut-and-cover structure walls. Empirical formulae, such as shown on Figure 14 can be used for most types of building surcharge problems which would be encountered.

The basic design of permanent cut-and-cover structures shown on Figures 1, 2, and 3 conform generally to similar structures of recently completed transit systems. The designs were checked structurally for conformance with the study design criteria.

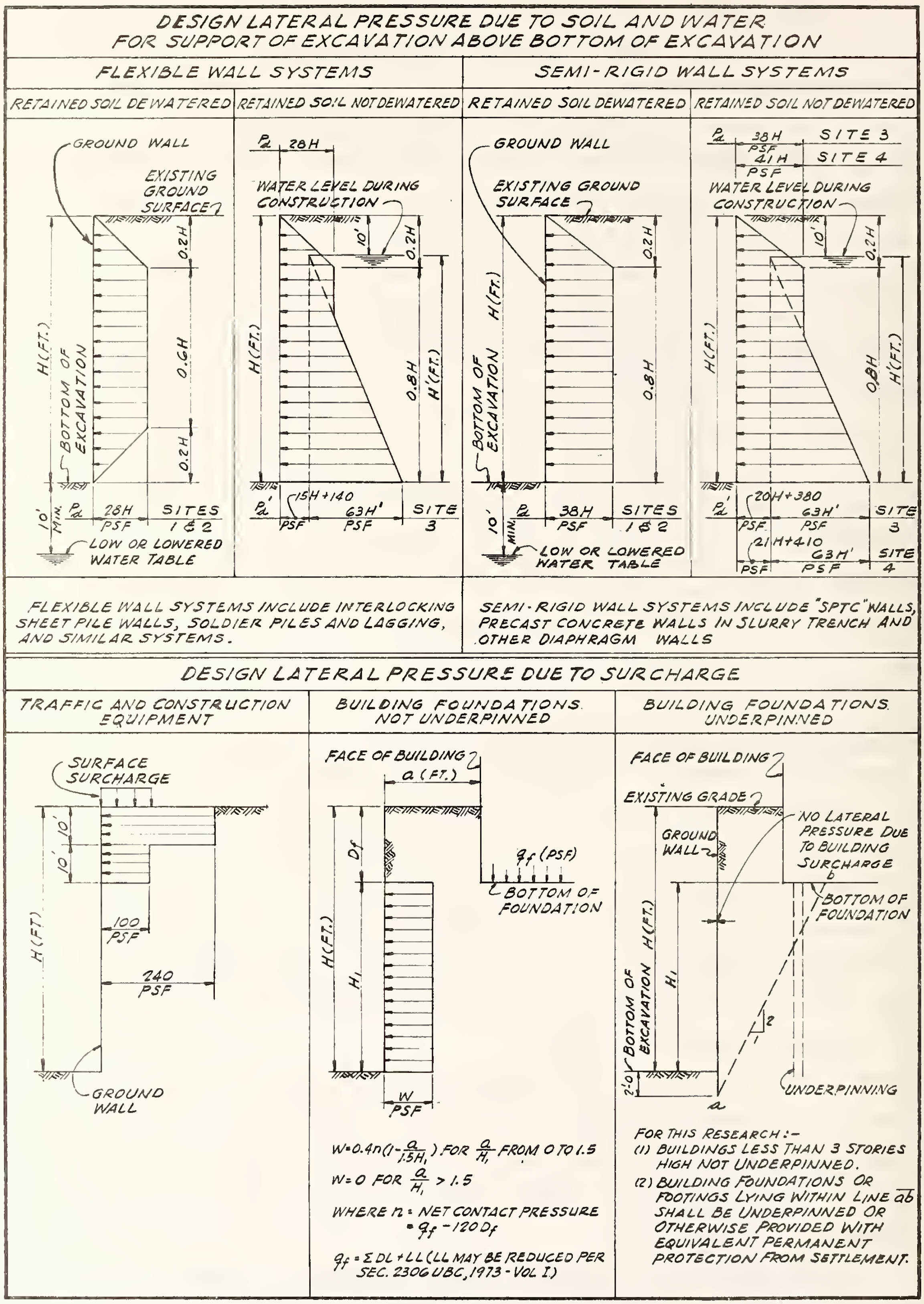
2.5 DESIGN OF TEMPORARY STRUCTURES

Although the design of temporary structures (ground support, decking, etc.) has been discussed rather extensively in various texts and manuals, there still remains differing opinions and practices in the engineering community regarding various theoretical and practical considerations involved. The design approach used herein is based on past experience of the study team and should provide adequate and effective designs for most cut-and-cover situations.

Summary criteria for the design and analysis of temporary structures are shown on Figure 14 in both English and metric (S.I.) systems. Design values and equations as discussed below refer to the English system. Applicable soil properties are given on Table 2, page 31.

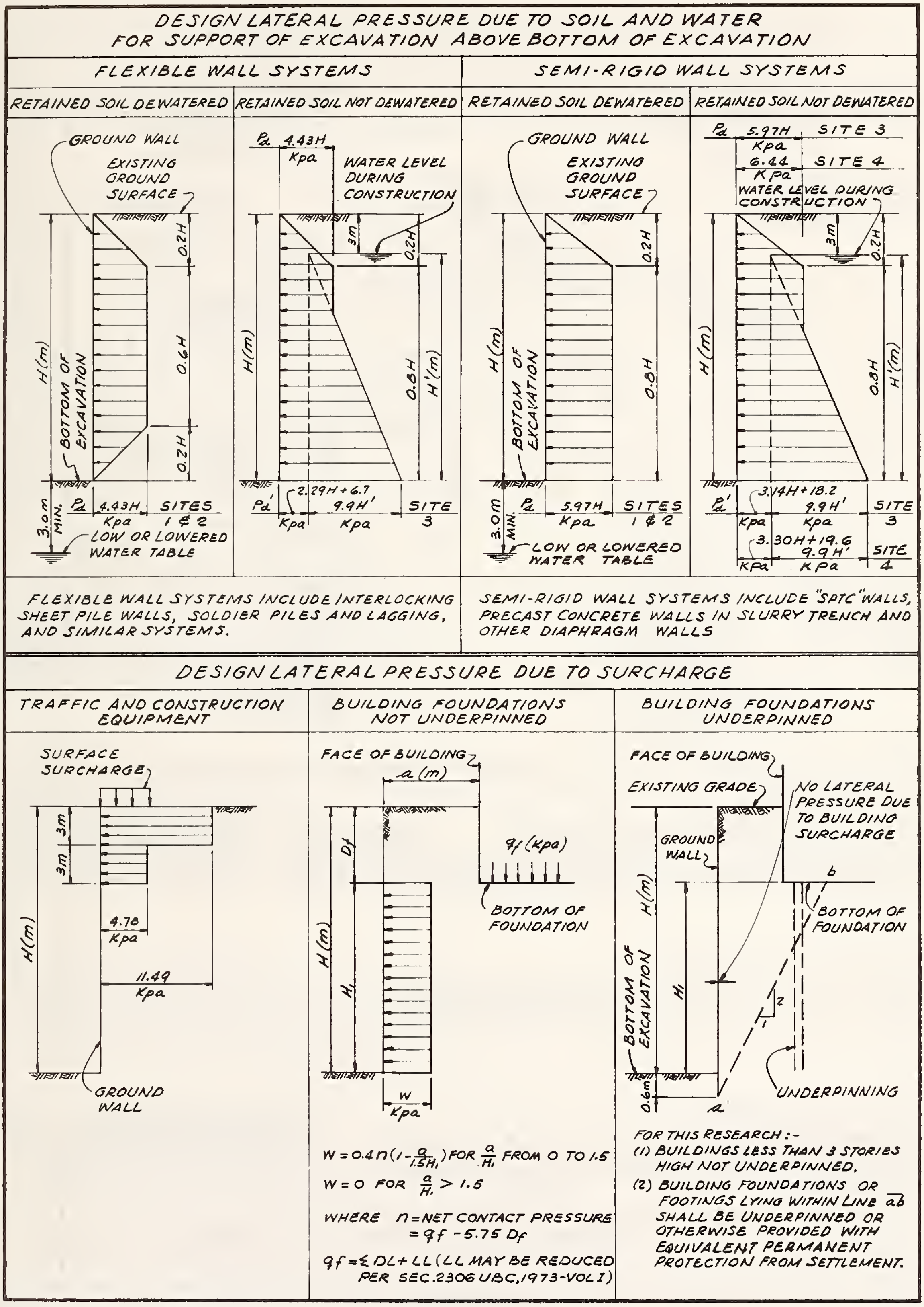
a) Design Lateral Pressure, Flexible Wall Systems, Retained Non-Cohesive Soil Dewatered (Figure 14-1)

This lateral pressure diagram is based on recommendations of Terzaghi and Peck (Ref 12) for non-cohesive soil. The



This sheet based on English units, equivalent S.I. units on next sheet

Figure 14. DESIGN LOADING DIAGRAMS



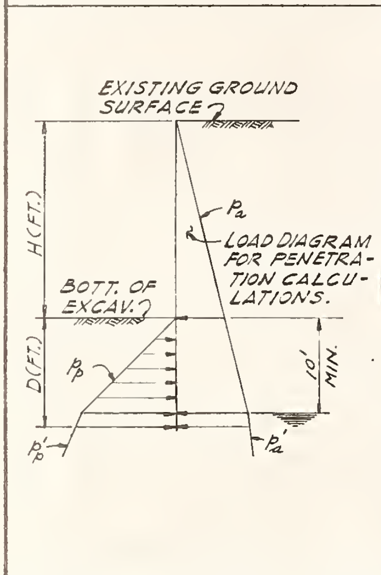
This sheet based on S.I. units; equivalent English units on previous page.

Figure 14. DESIGN LOADING DIAGRAMS (Continued)

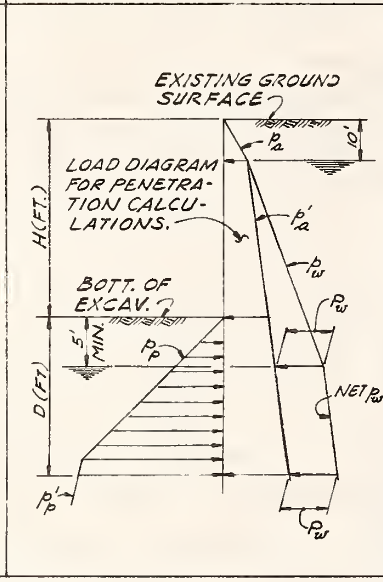
DESIGN PASSIVE RESISTANCE AND DESIGN VERTICAL BEARING CAPACITY OF SOIL BELOW BOTTOM OF EXCAVATION

DESIGN PASSIVE RESISTANCE

RETAINED SOIL DEWATERED

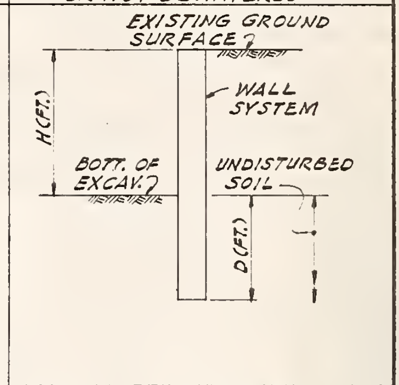


RETAINED SOIL NOT DEWATERED



DESIGN VERTICAL BEARING CAPACITY

RETAINED SOIL DEWATERED OR NOT DEWATERED



WALL SYSTEM	DESIGN VERTICAL SOIL SUPPORT		
	BEARING CAPACITY	UNITS	REMARKS
SOLDIER PILES AND LAGGING	K(b+d)D	KIPS PER PILE	d(FT.) b(FT)
CONTINUOUS CONC. WALL	K(B+D)	KIPS PER FT. OF WALL	B = AVG. WIDTH OF WALL

SITE 1,2 & 3

P_a = 35 PSF/FT P'_a = 18 PSF/FT P_p = 500 PSF/FT P'_p = 250 PSF/FT	SANDY SOIL MED. DENSE
P_w = 63 PSF/FT	

SITE 4

P_a = 40 PSF/FT. P'_a = 21 PSF/FT.	FINE SAND
P'_a = 25 PSF/FT. P_p = 520 PSF/FT. P'_p = 270 PSF/FT.	ORGANIC SILT
P'_a = 18 PSF/FT. P_p = 500 PSF/FT. P'_p = 250 PSF/FT.	COARSE SAND
P_w = 63 PSF/FT.	

D = PENETRATION BELOW BOTTOM OF EXCAVATION

NOTES:

1. IF SOLDIER PILE IS SET IN CONCRETE, SUBSTITUTE 3.14 R FOR (b+d). R = RADIUS OF CONCRETE ENCASEMENT.
2. K = H/25

SOIL PROPERTIES

SANDY SOIL-MEDIUM DENSE
- ϕ = 33° C = 0
- γ (MOIST) = 120 PCF
- γ' (SUBMERGED) = 62 PCF
- γ_w = 63 PCF.

FINE SAND
- ϕ = 30° C = 0
- γ (MOIST) = 120 PCF
- γ' (SUBMERGED) = 62 PCF

COARSE SAND
- ϕ = 33° C = 0
- γ (MOIST) = 120 PCF
- γ' (SUBMERGED) = 62 PCF

ORGANIC SILT
- ϕ = 26° C = 0
- γ (MOIST) = 125 PCF
- γ' (SUBMERGED) = 65 PCF

DECK STRUCTURE LOADS

LOADS FOR ROADWAY DECK STRUCTURES SHALL BE TAKEN FROM THE STANDARD SPECIFICATIONS FOR HIGHWAY BRIDGES, AMERICAN ASSOCIATION OF STATE HIGHWAY OFFICIALS, 1973.

BASIC UNIT STRESSES

1. STRUCTURAL STEEL SPECIFICATION FOR THE DESIGN, FABRICATION AND ERECTION OF STRUCTURAL STEEL FOR BUILDINGS, AMERICAN INSTITUTE OF STEEL CONSTRUCTION (AISC) 1970.
2. REINFORCED CONCRETE ~ BUILDING CODE REQUIREMENTS FOR REINFORCED CONCRETE (ACI 318-63) WORKING STRESS DESIGN.
3. TIMBER ~ UNIFORM BUILDING CODE, 1973 EDITION, VOL. I.

REFER TO SECTION 4.41(m) FOR ALLOWABLE STRESS INCREASES FOR TEMPORARY STRUCTURES

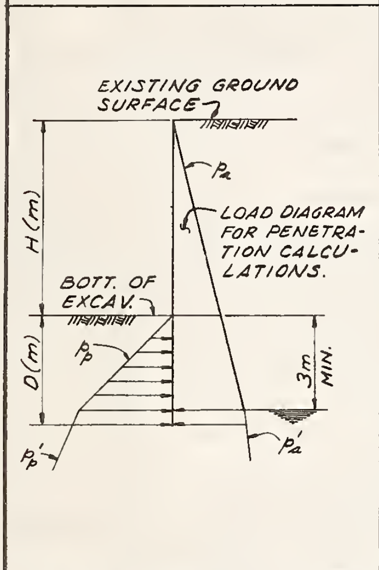
This sheet based on English units, equivalent S.I. units on next sheet.

Figure 14. DESIGN LOADING DIAGRAMS (Continued)

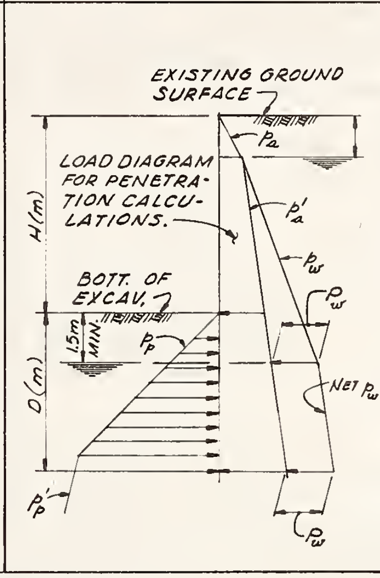
DESIGN PASSIVE RESISTANCE AND DESIGN VERTICAL BEARING CAPACITY OF SOIL BELOW BOTTOM OF EXCAVATION

DESIGN PASSIVE RESISTANCE

RETAINED SOIL DEWATERED

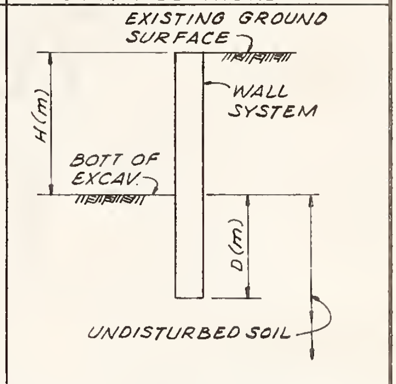


RETAINED SOIL NOT DEWATERED



DESIGN VERTICAL BEARING CAPACITY

RETAINED SOIL DEWATERED OR NOT DEWATERED



WALL SYSTEM	DESIGN VERTICAL SOIL SUPPORT		
	BEARING CAPACITY	UNITS	REMARKS
SOLDIER PILES AND LAGGING	K(b+d)D	KN PER PILE	d(m), b(m)
CONTINUOUS CONC. WALL	K(D+B)	KN PER m OF WALL	B = AVG WIDTH OF WALL

SITE 1, 2 & 3

P_a = 5.5 KPa/m
P'_a = 2.8 KPa/m
P_p = 78.6 KPa/m
P'_p = 39.3 KPa/m
P_w = 9.9 KPa/m
} SANDY SOIL MED. DENSE

SITE 4

P_a = 6.3 KPa/m
P'_a = 3.3 KPa/m
} FINE SAND

P'_a = 3.9 KPa/m
P_p = 81.7 KPa/m
P'_p = 42.4 KPa/m
} ORGANIC SILT

P'_a = 2.8 KPa/m
P_p = 78.6 KPa/m
P'_p = 39.3 KPa/m
} COARSE SAND

P_w = 9.9 KPa/m

D = PENETRATION BELOW BOTTOM OF EXCAVATION

NOTES:

1. IF SOLDIER PILE IS SET IN CONCRETE, SUBSTITUTE 3.14 R FOR (b+d)
   R = RADIUS OF CONCRETE ENCASEMENT
2. K = 6.3H

SOIL PROPERTIES

SANDY SOIL-MEDIUM DENSE
ϕ = 36.7 GRADS, C = 0
γ (MOIST) = 1.92 t/m³
γ' (SUBMERGED) = 1.00 t/m³
γ_w = 1.00 t/m³

FINE SAND
ϕ = 33.3 GRADS, C = 0
γ (MOIST) = 1.92 t/m³
γ' (SUBMERGED) = 1.00 t/m³

COARSE SAND
ϕ = 36.7 GRADS, C = 0
γ (MOIST) = 1.92 t/m³
γ' (SUBMERGED) = 1.00 t/m³

ORGANIC SILT
ϕ = 28.9 GRADS, C = 0
γ (MOIST) = 2.0 t/m³
γ' (SUBMERGED) = 1.04 t/m³

DECK STRUCTURE LOADS

LOADS FOR ROADWAY DECK STRUCTURES SHALL BE TAKEN FROM THE STANDARD SPECIFICATIONS FOR HIGHWAY BRIDGES, AMERICAN ASSOCIATION OF STATE HIGHWAY OFFICIALS, 1973.

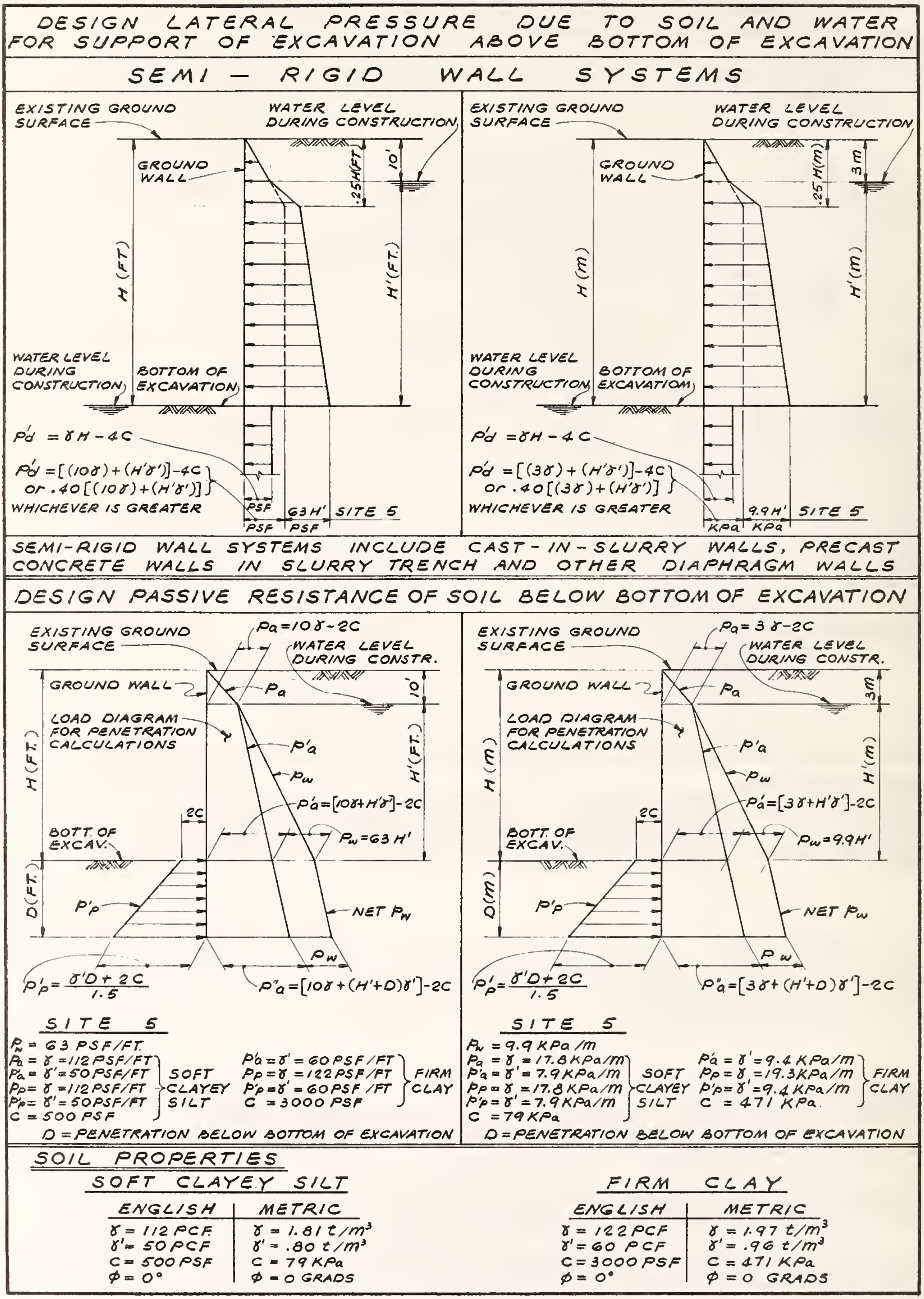
BASIC UNIT STRESSES

1. STRUCTURAL STEEL SPECIFICATION FOR THE DESIGN, FABRICATION AND ERECTION OF STRUCTURAL STEEL FOR BUILDINGS, AMERICAN INSTITUTE OF STEEL CONSTRUCTION (AISC) 1970.
2. REINFORCED CONCRETE - BUILDING CODE REQUIREMENTS FOR REINFORCED CONCRETE (ACI 318-63) WORKING STRESS DESIGN.
3. TIMBER - UNIFORM BUILDING CODE, 1973 EDITION, VOL. I.

} REFER TO SECTION 4.4.1(m) FOR ALLOWABLE STRESS INCREASES FOR TEMPORARY STRUCTURES

This sheet based on S.I. units, equivalent English units on previous sheet.

Figure 14. DESIGN LOADING DIAGRAMS (Continued)



This sheet based on both English units and equivalent S.I. units.

Figure 14. DESIGN LOADING DIAGRAMS (Continued)

magnitude of lateral pressure may be taken as Pd where:

$Pd = 0.8\ Ka \gamma H$

and where H is in feet.

b) Design Lateral Pressure, Flexible Wall Systems, Non-Cohesive Soil Not Dewatered (Figure 14-1)

Although this design condition is not common in cut-and-cover construction, it would, however, be applicable to a case in which sheet piles were used for the wall system and the water table could not be lowered. Values of Pd and P'd are also based on the recommendations of Terzaghi and Peck:

$Pd = 0.8\ Ka \gamma H$

$P'd = (0.8)\ Ka\ (10\gamma) + (0.8)\ (Ka)\ (H-10)\ (\gamma')$

$Pw = 63\ H'$

The relationship for P'd is applicable only to the specific case where the water table is 10 feet below grade.

c) Design Lateral Pressure, Semi-Rigid Wall System, Retained Non-Cohesive Soil Dewatered (Figure 14-1)

This type of wall system has only been used for about twenty years and appropriate design criteria is not included in standard texts.

The magnitude and shape of the lateral pressure diagram is a matter of engineering judgment for each specific case. For this study the following relationship is used:

$Pd = (0.4)\ (k_o + K_a)\ (\gamma)\ H$

d) Design Lateral Pressure, Semi-Rigid Wall Systems, Soil Not Dewatered (Figure 14-1)

Values of Pd and P'd are computed as follows:

$Pd = (0.4)(k_o + K_a)(\gamma)\ H$

$P'd = (0.4)(k_o+K_a)(10\gamma)+(0.4)(k_o+K_a)(H-10)(\gamma')$

$Pw = 63\ H'$

Again the value of P'd is applicable to a specific case with the water table 10 feet below grade.

e) Design Lateral Pressure, Semi-Rigid Wall Systems, Cohesive Soil Not Dewatered (Figure 14-5)

$P'd = \left[(H-H')\gamma + (H'\gamma')\right]\ -4C$, or

$P'd = 0.4\ \left[(H-H')\gamma + (H'\gamma')\right]$, whichever is greater

$Pw = 63\ H'$

f) <u>Design Lateral Pressure, Traffic and Construction Equipment Surcharge (Figure 14-1)</u>

The lateral pressure diagram for traffic and equipment surcharge is an approximation of the results which would be obtained by theory of elasticity for a 600 psf surcharge 12 feet wide (strip load) immediately behind the ground wall.

g) <u>Design Lateral Pressure Due to Surcharge, Building Foundations Not Underpinned (Figure 14-1)</u>

On cut-and-cover projects where the soil is reasonably competent, it is usual practice to develop empirical relationships for computations of lateral pressure due to building surcharge. The empirical equation on Figure 14-1 incorporates the following values:

q_f = Building foundation load, which is taken as the sum of all dead and live loads on the roof, floors and basement(s), using appropriate live load reduction. The load is considered as uniformly distributed over the building plan area and acting on the elevation of the building spread footing or mat foundation.

D_f = Depth of building foundation

n = Net building foundation load, which is equal to q_f minus the weight of soil replaced by the building. It is seen therefore that

$$n = q_f - \gamma D_f$$

W = 40% of n when the building line coincides with the ground wall system (a = o)

W = 0 if the horizontal distance between the building line and the ground wall equals 1.5 times the depth of the cut-and-cover structure invert below the building foundations (H_1 = 1.5a)

a = Minimum distance between ground wall and building foundation. Therefore,

$$W = 0.4n \left(1 - \frac{a}{1.5H_1}\right)$$

Although the equation is representative of current practice, care must be taken to recognize building surcharge conditions where empirical relationships are not applicable.

h) <u>Design Passive Resistance, Retained Soil Dewatered (Figure 14-3)</u>

The passive resistance diagram shown on Figure 14-3 is somewhat conservative, but is representative of criteria often used in cut-and-cover construction. Values of active and passive pressure gradients (p_a and p_p) are based on Rankine values:

$$p_a = Ka\gamma$$

$$p_p = \frac{Kp\gamma}{F.S.}$$

Where "F.S." - factor of safety is taken as 1.5.

For a driven soldier pile the passive resistance p_p may be considered as acting on a width three times the width of the soldier pile (efficiency factor = 3.0). For a soldier pile encased in concrete the passive resistance p_p may be considered as acting on a width 2.25 times the diameter of the concrete surrounding the piles (efficiency factor = 2.25).

i) <u>Design Passive Resistance, Retained Soil Not Dewatered (Figure 14-3)</u>

Values of pa, p'a, p_p and p'_p are shown on Figure 14-3 are Rankine values:

$$pa = Ka\gamma$$

$$p'a = Ka\gamma'$$

$$p_p = Kp\gamma$$

$$p'_p = \frac{Kp\gamma'}{F.S.}$$

Also: $pw = \gamma w$ = 63 psf/ft.

This diagram is applicable to semi-rigid diaphragm walls and to sheet pile walls. The depth of wall embedment below subgrade will, however, be controlled by the need to prevent or control piping in certain soil types.

j) <u>Design Vertical Bearing Capacity (Figure 14-3)</u>

Substantial vertical bearing capacity must be incorporated into the design of ground wall systems to account for the following types of vertical loads (as applicable).

Live and dead construction deck loads

Weight of ground wall

Weight of internal bracing

Vertical or downward component of tieback loads.

Usual practice in cut-and-cover construction is to develop empirical vertical bearing capacity formulae which will give reasonable results on the side of safety. The formulae suggested on Figure 14-3 are representative of this approach. In special cases of high concentrated vertical loads on a portion of the ground wall system this type of empirical formulae may yield unreasonable results and a more comprehensive design approach is warranted.

k) <u>Deck Structure Loads</u>

The minimum practical load criteria for construction decking is ordinarily considered to be AASHO HS-20-44 loading. Construction equipment (such as crawler cranes, truck cranes and modern transit mix trucks) often impart heavier loads. In these cases the deck structure should be designed for both AASHO HS-20-44 loading and applicable construction equipment loading. For this study, the following loadings are considered representative:

1. Any reasonable combination of three 11 ft. AASHTO HS-20-44 (MS-18) traffic lanes (public traffic) plus a working 50-ton crawler crane or truck crane (contractor's working area on deck) - or,
2. Four 11 ft. AASHTO HS-20-44 (MS-18) traffic lanes and two parking lanes (public traffic and/or equivalent contractor's work deck traffic).

1) Design Stresses for Temporary Structures

Design stresses for most components of cut-and-cover temporary structures are ordinarily taken at higher values than allowable design stresses for permanent structures. The following are representative of current practice:

1. Soldier Piles and Wales

   Design stress shall not exceed 120% of allowable stress.

2. Sheet Piles

   Bending stress F_b = 0.80 Fy where Fy = minimum yield stress.

3. Diaphragm Walls (SPTC and PCP Walls, etc.)

   Stresses shall not exceed 120% of allowable stresses (applies to temporary loads only).

4. Struts

   The slenderness ratio of struts shall not exceed 120 and the maximum axial stress to which the struts may be subjected shall not exceed 14,000 psi (96,500 kPa).

5. Timber Lagging

   Stresses shall not exceed 120% of allowable stresses.

6. Stress Bars or strands for Tiebacks

   Allowable tensile stress shall not exceed 0.60 f's, where f's is the minimum ultimate tensile strength (allow 0.80 f's for test load).

7. Deck Structure Framing Carrying Public Traffic

   Stresses shall be as specified in the latest edition of "Standard Specifications for Highway Bridges" as adopted by the American Association of State Highway and Transportation Officials (AASHTO - formerly AASHO).

8. Deck Structure Framing Carrying Constrtuction Loads Only

   Design stresses shall not exceed 100% of allowable stresses.

2.5.1 Design of Construction Decking: The loading criteria used for the design of decking should be representative for most urban areas. The concept of temporary support piles for deck beams near midspan for the highway tunnel and rapid transit station (Figures 6 and 8 on pages 12 and 15) is compatible with assumed traffic maintenance requirements. At many urban sites, however, it may be possible to divert traffic temporarily so that deck beams spanning the entire excavation can be used. The cost of construction decking ordinarily does not change markedly when this latter construction method is used; but the method does offer significant savings in excavation costs and in the cost of the construction of permanent structures.

2.5.2 Design of Ground Wall Support and Bracing: Developed criteria, load diagrams and guidelines presented here and in Section 4 of Volume 1 were used to design ground wall support systems for all cut-and-cover construction situations considered in the study. General arrangements of the systems are illustrated on Figures 5, 6, 7 and 8. Structural requirements are tabulated for each situation and presented as Tables 35 through 43 - Appendix A, page 213.

Material quantities and work requirements used in developing costs and subsequent comparisons of methods were developed from the given designs. Quantities for major items are listed as Tables 44 through 55 - Appendix B, page 223.

In all cases, the designs reflect both technical analysis and practical experience gained from the design of many "braced land cofferdams" completed by the study team on recent transit systems. Although the situations considered cover a broad spectrum of cut-and-cover variables it is likely that specific site conditions could require variations in design results. The general design criteria and formulae given in the tables allow for design with soil conditions not specifically covered in this study.

2.5.3 Design Guides and References: The following list of texts and/or design manuals are used extensively in the engineering community for the design of temporary structures associated with cut-and-cover construction. Each of these publications has been consulted in preparing the design criteria for this study. The reference numbers refer to complete bibliographic listings on page 287.

Terzaghi, 1943 (reference 11)
Terzaghi and Peck, 1948 (reference 12)
Terzaghi and Peck, 1967 (reference 13)
Teng, 1962 (reference 14)
Tschebotarioff, 1973 (reference 15)
Leonards, 1962 (reference 16)
Andersen, 1956 (reference 17)
NAVFAC, DM-7, 1971 (reference 18)
SMFD/ASCE, 1970 (reference 19)
Steel Sheet Piling Design Manual, 1974 (reference 20)
Prestressed Concrete Institute, 1974 (reference 21)
ASCE/SEONIC, 1970 (references 3, 4, 32, 33, 34, 38, 39)
AISC, 1973 (reference 22)
AASHO, 1973 (reference 23)
Uniform Building Code (reference 24)
Timber Construction Manual, 1966 (reference 25)

2.6 PERMANENT PROTECTION OF ADJACENT STRUCTURES

Ordinarily, the design of permanent and temporary cut-and-cover structures is not significantly affected by adjacent buildings. However, the total cost of a given project can be affected depending on the extent of underpinning or other protection required due to the construction.

General criteria used to determine the need for permanent protection of existing foundations is shown on Figure 14, page 40. It is assumed that buildings less than four stories in height will not require protection. The following table shows the permanent protection requirements for the various situations considered in the study.

Cut-and-Cover Structure		Permanent Protection 10 Story Building	Permanent Protection 5 Story Building
Figure 2			
Highway Tunnel	- 30 ft.* depth	No	No
Highway Tunnel	- 50 ft.* depth	No	Yes
Highway Tunnel	- 70 ft.* depth	Yes	Yes
Figure 3			
Double Box R.T.	- 30 ft.* depth	No	No
Double Box R.T.	- 50 ft.* depth	No	No
Double Box R.T.	- 70 ft.* depth	No	No
Figure 4			
Rapid Transit Station	- 50 ft.* depth	No	Yes
Rapid Transit Station	- 70 ft.* depth	Yes	Yes

Buildings 3 stories high or less: No permanent protection.
*30 ft. = 9.1m, 50 ft. = 15.2m, 70 ft. = 23.1m

Semi-rigid ground wall support systems - soldier pile and tremie concrete or precast concrete panels - are designed to offer permanent protection in lieu of underpinning, consequently the above tabulation applies only to soldier pile and lagging method of ground support. There are, however, certain lesser costs such as removing or support of sidewalk vaults or cornices, which would be applicable in all instances.

It is evident that the cost of permanent protection is dependent on the location, size and number of buildings affected by the construction. Figure 4, page 7, lists the assumptions made for this study. Building configurations at other sites would probably be different, therefore it will be necessary to make appropriate adjustments in cost of permanent protection as determined and explained later in the report. The use of a semi-rigid ground wall support system (usually more expensive than a flexible system) may be justified if it eliminates excessive amounts of underpinning or other permanent protection which otherwise might be required.

SECTION 3
CONSTRUCTION COST DATA

3.1 GENERAL

The term "construction cost data" is used to identify many types of costing information pertaining to construction work. It may refer to the number of work units completed by one man in an hour, or it may reflect the cost of completing a mile of tunnel when advancing at a given rate of progress. Although they include many different elements, cost data are usually considered with respect to specific projects on the basis of three categories of work: 1) direct costs - completing contractural work requirements, 2) indirect costs - general and administrative and plant and mobilization costs and 3) contractor's markup - contingencies and profit. Categories 1 and 2 represent the contractor's cost; the sum of the three, the bid price or total cost of construction normally considered by the owner agency.

Each category reflects the correlation and extension of various unit resource costs and quantities with respect to anticipated production or other requirements determined for the project. Starting with basic unit prices such as the cost of a man-hour of labor or a pound of steel, costs are calculated for all operations and then combined or grouped into work items to arrive at total direct cost - Category 1. Categories 2 and 3 relate to total project requirements. All costs are summarized as unit or lump sum bid prices extended against a bill of quantities established for the project. Section 5 of Volume 1 presents a discussion of different costing and bidding techniques normally followed in the United States.

The following paragraphs discuss various aspects of construction cost and provide basic data which can be used to determine the cost of cut-and-cover transit structures.

3.2 AVAILABLE COST DATA

Most available cost data consist of published bid prices submitted by contractors for a project or various types of cost records maintained by either the owner or contractor during the course of construction. The availability and reliability of these data for use in determining costs of future construction can be rated as shown below:

Type of Available Data	Availability	Reliability
Bid Prices	High	Low
Owner's Records	Moderate	Moderate
Contractor's Records	Low	High

As used above, reliability or lack of reliability refers primarily to the difficulty experienced by individuals not involved directly with initial preparation of the data to correlate costs with supposedly comparable work on the basis of resource or component variations. This is also discussed in Section 5 of Volume 1. However, available data can be used to provide fairly reasonable approximations of activity cost with respect to total cost of cut-and-cover construction. An example is given on Table 4 which shows the results of several analyses based on grouping and combining bid prices into eleven major activities such as excavation and utilities. The first analysis reflects twelve recent cut-and-cover projects in San Francisco and Washington investigated in this study; the second analysis refers to five projects as given in Reference 42, and the third is a general summary of costs taken from Reference 1. Although the percent of total cost shown for each activity is fairly consistent in the three analyses, it is unlikely that the same factors or cost data were used in all instances. Since the percentages represent "averages", they could be misleading for any specific project. In general, available cost data should not be used to determine costs of future work unless details of how those data were developed are known.

Table 4. RELATIVE COST OF ACTIVITIES IN CUT-AND-COVER CONSTRUCTION (% OF TOTAL BID PRICE)

	ACTIVITY	ANALYSIS #1	ANALYSIS #2	ANALYSIS #3	APPARENT AVERAGE
A	CONTROL TRAFFIC	1.5	2.0	1.0	1.5
B	UTILITIES	10.5	14.0	10.0	11.5
C	PROTECT ADJ STRUCTS	5.5	9.5	5.5	7.0
D	CONTROL GRD WATER	1.5	1.0	1.5	1.5
E	DECKING	4.0	5.0	7.5	5.5
F	GRD WALL SUPPORT				
G	BRACING	30.0	32.0	31.5	31.0
H	EXCAVATION				
I	PERM STRUCTURE	43.0	31.0	36.0	36.5
J	BACKFILL	2.5	2.5	5.0	3.5
K	RESTORATION	1.5	3.0	2.0	2.6

#1 Based on the costs of twelve recent projects studied by the writers
#2 Based on bid prices of five projects reported by Birkmyer (Ref. 42)
#3 Based on Sverdrup and Parcel summary (Ref. 1)

3.3 DEVELOPED COST DATA

Cost data can be developed for each construction situation in a manner normally used by general contractors in preparing a competitive bid. This entails a complete analysis of all work operations and requirements in terms of cost components and productivity needed to complete the work within the limitations of the contract. Since factors that affect cost; like quantities and types of work, site conditions and contractual stipulations are never the same for any two projects, it would be difficult to develop data applicable directly to all situations. Nevertheless, there are similarities and relationships in major activity requirements which if properly evaluated and correlated can be used to develop cost data typical of most cut-and-cover construction. These evaluations require a fundamental understanding of construction methods, procedures and production with respect to labor, equipment and material requirements which affect the direct and indirect costs. This basic understanding is acquired over a period of years and reflects the experience of the construction estimator used in developing costs for a project. Although techniques may differ, the following steps are normally used for the estimating process:

1. Ascertain project requirements. This entails studying the contract documents including design drawings, specifications, general conditions and other stipulations pertaining to the proposed work.
2. Investigate and evaluate site and other local conditions which would affect the work.
3. Make a quantity take-off of all segments of work; compare with given bill of quantities.
4. Establish basic price of labor, equipment and materials, consistent with the time and location of the project.
5. Determine method of construction and establish appropriate operations required to complete each item or segment of work. Most items will require several

operations; for instance, concrete work would normally include operations of: 1) prepare foundation, 2) build, set and strip forms, 3) place concrete, 4) cure and finish, etc. Identify specialty work to be completed by subcontractors.

6. Set up labor crews, equipment spreads and material requirements as needed to complete each operation.
7. Determine time to complete each operation on the basis of estimated production rates for respective labor crews and equipment spreads.
8. Establish cost of components (labor, equipment, materials and subcontracts) for each operation and item to obtain total direct cost of the work.
9. Prepare a construction schedule showing most effective sequence of work with respect to project requirements.
10. Determine indirect, general and plant expenses required but not included in direct costs.
11. Add contractor's profit, contingencies and escalation allowances appropriate for the work.

The above steps, which are illustrated in logic form on Figure 15, give a brief description of how cost data are usually developed for a specific job. Variations in quantities of work, methods of accomplishment and local and site conditions unique to a project are summarily considered. It is apparent that a considerable amount of study and detail is required for each situation. Often it is necessary to evaluate several alternatives before finalizing costs. The costs are summarized as bid prices reflecting the individual's appraisal of most effective manner for completing the work.

Cost data needed to evaluate and compare different cut-and-cover tunneling situations for this study are developed in general accordance with the above except that contractor's markup (Step 11) is considered separately. The general procedure is illustrated by developing four basic estimates which are discussed later in this section.

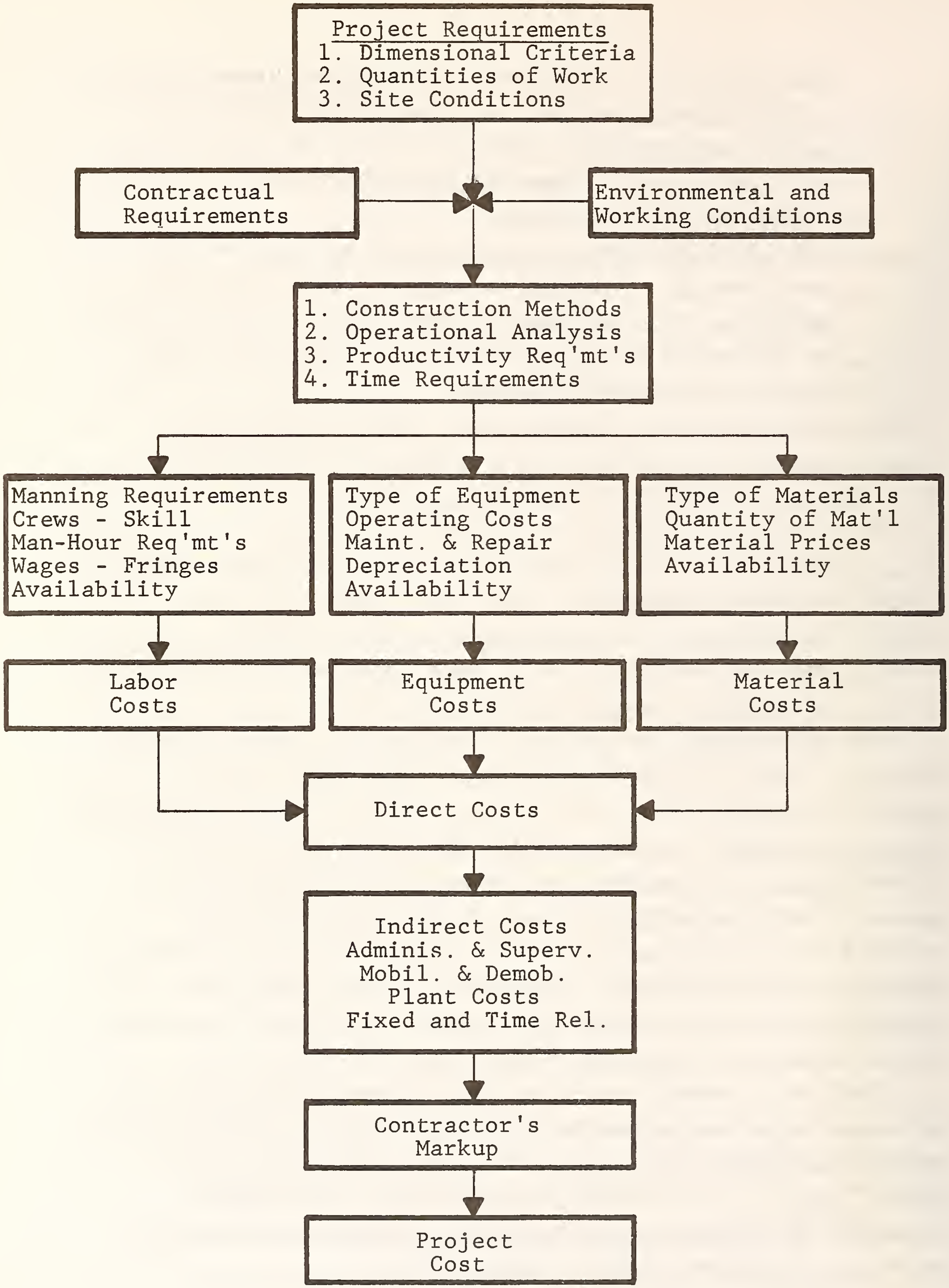


Figure 15. LOGIC FOR DEVELOPING COST DATA

3.3.1 Estimate Designations The open-trench cut-and-cover tunneling situations considered in this report reflect several variations of five major conditions affecting the construction:

1) Urban sites - Five each.
2) Transit structures - Three each.
3) Ground wall support - Three methods.
4) Depth of structure - 30, 50 and 70 feet (9.1m, 15.2m and 21.3m)
5) Bracing system - Two methods.

Details of the transit structures and urban sites are shown on Figures 1 through 5 and Table 1. Ground support and bracing details are illustrated on Figures 6 through 10. Design requirements and quantities of work are discussed in Section 2 and listed in Appendices A and B.

Different combinations of the above conditions give 270 possible construction situations. There are, however, certain combinations that would not be feasible from a construction standpoint. Soldier piles and lagging would not be used at a site with a high water table that could not be dewatered, and tiebacks are not practical in soft clays. In addition, the transit station can not be considered at the 30-foot (9.1m) depth. Eliminating these possibilities leaves 176 situations to be evaluated.

To identify each situation and corresponding cost estimate, a four character code is used which defines: 1) the particular site considered, 2) type of structure, 3) method of ground wall support and bracing and 4) depth of construction and high or low initial water table level.

The particular condition designated by each code character is listed on Table 5. The codes assigned to the 176 cost estimates are shown on Table 6. They identify the study conditions used to define each situation. These estimate codes, although similar, should not be confused with activity variation codes used in Volume 1 and discussed next.

Table 5. ESTIMATE CODE DESIGNATIONS

FIRST CHARACTER - Site Condition

- 1 - Site 1
- 2 - Site 2
- 3 - Site 3
- 4 - Site 4
- 5 - Site 5

SECOND CHARACTER - Type of Structure

- 1 - Four Lane Highway
- 2 - Rapid Transit Station
- 3 - Rapid Transit Line Section

THIRD CHARACTER - Ground Support & Bracing Method

- G - Soldier Piles & Lagging - Internal Bracing
- H - Soldier Piles & Lagging - Tieback Bracing
- J - SPTC Wall - Internal Bracing
- K - SPTC Wall - Tieback Bracing
- L - Precast Panel Wall - Internal Bracing
- M - Precast Panel Wall - Tieback Bracing

FOURTH CHARACTER - Depth of Excavation - Initial Water Table

- T - 30 ft (9.1m) Depth - High Water Table
- U - 30 ft (9.1m) Depth - Low Water Table
- V - 50 ft (15.2m) Depth - High Water Table
- W - 50 ft (15.2m) Depth - Low Water Table
- Y - 70 ft (21.3m) Depth - High Water Table
- Z - 70 ft (21.3m) Depth - Low Water Table

Table 6. ESTIMATE CODES - 176 STUDY SITUATIONS

DEPTH		30 FEET						50 FEET						70 FEET					
GROUND SUPPORT		SOLDIER PILES & LAGGING		CAST-IN SLURRY CONCRETE		PRECAST CONCRETE PANELS		SOLDIER PILES & LAGGING		CAST-IN SLURRY CONCRETE		PRECAST CONCRETE PANELS		SOLDIER PILES & LAGGING		CAST-IN SLURRY CONCRETE		PRECAST CONCRETE PANELS	
BRACING		INT.	T.B.	INT.	T.B.	INT.	T.B.	INT.	T.B.	INT.	T.B.	INT.	T.B.	INT.	T.B.	INT.	T.B.	INT.	T.B.
FOUR LANE HIGHWAY TUNNEL	SITE 1	1-1GT	1-1HT	1-1JT	1-1KT	1-1LT	1-1MT	1-1GV	1-1HV	1-1JV	1-1KV	1-1LV	1-1MV	1-1GY	1-1HY	1-1JY	1-1KY	1-1LY	1-1MY
	SITE 2	2-1GU	2-1HU	2-1JU	2-1KU	2-1LU	2-1MU	2-1GW	2-1HW	2-1JW	2-1KW	2-1LW	2-1MW	2-1GZ	2-1HZ	2-1JZ	2-1KZ	2-1LZ	2-1MZ
	SITE 3	-	-	3-1JT	3-1KT	3-1LT	3-1MT	-	-	3-1JV	3-1KV	3-1LV	3-1MV	-	-	3-1JY	3-1KY	3-1LY	3-1MY
	SITE 4	-	-	4-1JT	4-1KT	4-1LT	4-1MT	-	-	4-1JV	4-1KV	4-1LV	4-1MV	-	-	4-1JY	4-1KY	4-1LY	4-1MY
	SITE 5	-	-	5-1JT	-	5-1LT	-	-	-	5-1JV	-	5-1LV	-	-	-	5-1JY	-	5-1LY	-
RAPID TRANSIT STATION	SITE 1	-	-	-	-	-	-	1-2GV	1-2HV	1-2JV	1-2KV	1-2LV	1-2MV	1-2GY	1-2HY	1-2JY	1-2KY	1-2LY	1-2MY
	SITE 2	-	-	-	-	-	-	2-2GW	2-2HW	2-2JW	2-2KW	2-2LW	2-2MW	2-2GZ	2-2HZ	2-2JZ	2-2KZ	2-2LZ	2-2MZ
	SITE 3	-	-	-	-	-	-	-	-	3-2JV	3-2KV	3-2LV	3-2MV	-	-	3-2JY	3-2KY	3-2LY	3-2MY
	SITE 4	-	-	-	-	-	-	-	-	4-2JV	4-2KV	4-2LV	4-2MV	-	-	4-2JY	4-2KY	4-2LY	4-2MY
	SITE 5	-	-	-	-	-	-	-	-	5-2JV	-	5-2LV	-	-	-	5-2JY	-	5-2LY	-
RAPID TRANSIT LINE SECTION	SITE 1	1-3GT	1-3HT	1-3JT	1-3KT	1-3LT	1-3MT	1-3GV	1-3HV	1-3JV	1-3KV	1-3LV	1-3MV	1-3GY	1-3HY	1-3JY	1-3KY	1-3LY	1-3MY
	SITE 2	2-3GU	2-3HU	2-3JU	2-3KY	2-3LY	2-3MU	2-3GW	2-3HW	2-3JW	2-3KW	2-3LW	2-3MW	2-3GZ	2-3HZ	2-3JZ	2-3KZ	2-3LZ	2-3MZ
	SITE 3	-	-	3-3JT	3-3KT	3-3LT	3-3MT	-	-	3-3JV	3-3KV	3-3LV	3-3MV	-	-	3-3JY	3-3KY	3-3LY	3-3MY
	SITE 4	-	-	4-3JT	4-3KT	4-3LT	4-3MT	-	-	4-3JV	4-3KV	4-3LV	4-3MV	-	-	4-3JY	4-3KY	4-3LY	4-3MY
	SITE 5	-	-	5-3JT	-	5-3LT	-	-	-	5-3JV	-	5-3LV	-	-	-	5-3JY	-	5-3LY	-

Note: 1 ft. = 0.305m

3.3.2 Activity Designations: Each situation and cost estimate is evaluated with respect to fifteen activities described in Section 1. Activities A through K represent direct cost items; activities N, O, P and Q indirect and plant costs. As used here, the terms "activity" and "item" are interchangeable.

All activity requirements and major variations associated with each situation can be identified by a four character code similar to that used in the preceding paragraphs to identify different estimates. The first character shows the type of structure; the second, the activity letter (A, B, C etc.). The third and fourth characters are used to indicate site and construction conditions that have a major impact on the cost of the activity in the particular estimate situation being considered. The third character indicating the type of ground wall support and bracing and the fourth character the depth and soil condition. These code designations and conditions are listed on Table 7.

Although activity requirements vary for each different situation, there are certain conditions which have very little effect on the requirement and/or cost, with respect to the overall construction. For instance, the decking activity is dependent primarily on the type of structure and is essentially unaffected by the depth of excavation or soil type. Where a changed situation condition has no appreciable effect on the activity requirement, a zero is used in lieu of the code designation character. (See bottom Table 7.)

Each activity in turn is comprised of several individual work operations needed for completion. The number of operations, which are definable elements of work, could vary from 3 or 4 to 30 or 40. Operations are indicated and listed numerically in conjunction with applicable activity code.

The above discussion pertaining to estimate, activity and operation identification is given merely to acquaint the reader with the general coding format used in developing cost data and estimates and in preparing various summary tables given in the report. Subsequent reference to a particular cost estimate or

Table 7. ACTIVITY CODE DESIGNATIONS

FIRST CHARACTER - TYPE OF STRUCTURE

1. FOUR LANE HIGHWAY TUNNEL
2. RAPID TRANSIT STATION
3. TWIN BOX RAPID TRANSIT TUNNEL

SECOND CHARACTER - MAJOR ESTIMATE ACTIVITY

A. CONTROL TRAFFIC
B. UTILITY WORK
C. PROJECT ADJACENT STRUCTURES
D. CONTROL GROUND WATER
E. DECKING
F. GROUND WALL SUPPORT
G. BRACING
H. EXCAVATION
I. CONSTRUCT PERMANENT STRUCTURE
J. BACKFILL
K. RESTORATION

N. OVERHEAD (FIXED COSTS)
O. OVERHEAD (TIME RELATED COSTS)
P. PLANT (FIXED COSTS)
Q. PLANT (TIME RELATED COSTS)

THIRD CHARACTER - TYPE OF WALL AND/OR BRACING

A. SOLDIER PILE AND LAGGING WALL ONLY
B. S.P.T.C. WALL ONLY
C. PRECAST WALL ONLY

D. DIAPHRAGM WALL - IE, S.P.T.C. OR PRECAST WALL

E. INTERNAL BRACING ONLY
F. TIEBACK BRACING ONLY

G. SOLDIER PILE AND LAGGING WALL WITH INTERNAL BRACING
H. SOLDIER PILE AND LAGGING WALL WITH TIEBACK BRACING

J. S.P.T.C. WALL WITH INTERNAL BRACING
K. S.P.T.C. WALL WITH TIEBACK BRACING

L. PRECAST WALL WITH INTERNAL BRACING
M. PRECAST WALL WITH TIEBACK BRACING

FOURTH CHARACTER - DEPTH OF EXCAVATION AND/OR WET OR DRY SOIL CONDITION

N. 30 FT DEPTH ONLY
P. 50 FT DEPTH ONLY
Q. 70 FT DEPTH ONLY

R. WET CONDITION ONLY
S. DRY CONDITION ONLY

T. 30 FT DEPTH WITH HIGH WATER TABLE
U. 30 FT DEPTH WITH LOW WATER TABLE

V. 50 FT DEPTH WITH HIGH WATER TABLE
W. 50 FT DEPTH WITH LOW WATER TABLE

Y. 70 FT DEPTH WITH HIGH WATER TABLE
Z. 70 FT DEPTH WITH LOW WATER TABLE

NOTE: IN THE THIRD AND FOURTH CHARACTER WHERE NO VARIABLE CONDITION APPLIES A "0" (ZERO) WILL BE USED.

activity will be by code designations. By referring to Tables 5, 6 and 7, the reader should soon be able to correlate cost data and requirements with specific study conditions.

3.3.3 Basic Cost Estimates: For some situations the activities and operations would be similar in that they reflect the same general type of work. Requirements for excavating a cut-and-cover section using soldier piles and lagging for ground support would be practically the same as for cast-in-place diaphragm walls providing both methods use internal bracing and are suitably dewatered. Placing concrete for permanent structures usually entails the same general operations regardless of method of ground support used. However, there would be variations depending on quantities of work involved and effective production to be achieved. These variations are considered by: 1) varying the size and type of labor crews and equipment spreads, 2) varying material quantities or work requirements, 3) varying hourly production rates and 4) defining limits of operations in modular fashion so as to accommodate dimensional changes such as those caused by varying depths from 30 to 50 to 70 feet (9.1m to 15.2m to 21.3m). By using typical labor crews, equipment spreads and material requirements for all basic operations, it is possible to develop increments of cost data which can be combined, added or deleted to determine the cost of many cut-and-cover tunneling projects. To accomplish this and illustrate the procedure, detailed cost estimates were prepared for four situations that include most individual operations required for all possibilities. These basic estimates are:

1. Estimate 3-1KY -- Site 3, highway structure, 2,000 feet (610m) long, cast-in-place concrete wall (SPTC) with tieback bracing, 70-foot (21.3m) depth, wet soil.
2. Estimate 4-2JY -- Site 4, rapid transit station 700 (213m) feet long, cast-in-place concrete wall (SPTC) with internal bracing, 70-foot (21.3m) depth, wet soil.

3. Estimate 5-2 LY -- Site 5, rapid transit station, 700 (213m) feet long, precast concrete panels (PCP) with internal bracing, 70-foot (21.3m) depth, wet soil.
4. Estimate 1-3GY -- Site 1, rapid transit line section, 2,000 (610m) feet long, soldier piles and lagging (SP&L) with internal bracing, 70-foot (21.3m) depth, wet soil.

Since all four situations involve high groundwater tables (most likely condition in urban areas) additional analyses were made to determine variations in costs for sites with low water tables. This pertains primarily to control of groundwater - activity D - although the design of temporary support and permanent structure are also affected. Separate analyses were also made for variations in underpinning - activity C - and in handling utilities - activity B - as required by different widths and depths of structures.

Following the general steps outlined in paragraph 3.3, the estimates were prepared by using Jacobs Associates' estimating program and extended on an IBM 360 computer. The procedure includes the preparation of a rate deck listing all pertinent labor, equipment, material and subcontract price data. Labor is defined by trade, individual classification or crews and shows hourly cost of base wages, fringes and taxes. Hourly rates for equipment operation (fuel, lube, repair parts, power, depreciation and repair labor) were established for individual units and equipment groups or spreads. Unit cost of materials, (mbf of timber, tons of reinforcing steel, etc.) as well as subcontract prices for speciality items of work were established and included in the rate deck. Much of the subcontract data was provided by contractors performing similar work on current transit projects. The rate deck, which contains about 900 elements of cost, is applicable to a wide variety of cut-and-cover tunneling situations. It reflects mid 1974 labor wages, material prices and other costs in the Washington, D.C. area. Since the location and year of construction will be different for all future projects it will be necessary to make appropriate adjustments for variations in basic prices used in the rate deck. These adjustments are discussed in Section 6.

All information and data in the rate deck are coded for use by the computer. Table 8 shows the type of cost information provided.

Specific requirements: quantities of work, labor, equipment, material and rates of production were determined for each operation required to complete major activities for the basic estimates. To a large extent, these requirements reflect experience achieved in recent transit construction. This information was also coded and provided the input for the computer which extended all requirements against the cost data of the rate deck. The computer printouts show detailed cost information for all operations, activities and the job as a whole. They are too voluminous to include in this report so are presented for reference as a supplemental volume for those interested in that type of cost estimating detail. Summary cost analyses of all operations and activities for the four basic estimates are also included in Volume 3. Table 9 shows typical cost data for individual operations. It gives the requirement (description, quantity and production) and unit cost of each component as well as total unit direct cost. Table 10 is a summary of operation costs for a particular activity, the total of which is the direct cost of the activity. Table 11 shows partial summaries of different resource requirements (quantities and costs) included in the estimates. The analyses provided in Volume 3 have been condensed in Table 12 to show total activity component costs for the four basic estimates.

Costs reflecting different requirements (conditions not included in basic estimates) for activities B, C and D were determined in a similar manner. Component costs for activities B and C are shown on Table 13. Table 14 gives typical costs of activity D for various groundwater conditions and methods of ground support.

The detailed cost data given in Volume 3 and Tables 13 and 14 provide basic information needed to evaluate all cut-and-cover tunneling situations. The activity operations have been defined by increments of work to facilitate adjustments due to different situation requirements. For example, operations for activity H - Excavation - were developed for set increments of depth as detailed on Table 9 - Operation 5, Excavate 30 feet (9.1m) to 50 feet (15.2m). If the structure was considered at a 30-foot (9.1m) depth, operation 5 would be deleted from the cost analysis. Unit direct costs of operations and activities can be compared to show the effect of using different methods for the construction.

It is noted that costs do not include architectural finishing, trackage, roadbed or permanent mechanical-electrical installations except embedded conduits. Cost of these items would be essentially the same regardless of construction method used and consequently would not materially affect final comparisons. Also, the costs of appendages such as vent shafts or entrance ways are not included. They are considered separately in Section 4.6. In short, the basic estimates reflect total contractor's cost for constructing the structural shell of three types of transit structures. Activities A through K are considered as direct cost; N through Q as indirect and plant costs.

CONVERSION FACTORS

(for Tables 8 through 15)

1 IN = 1 in.	= 25.4mm	1 MBF	= 2.36 m^3
1 LF = 1 ft.	= 0.305m	1 LB	= 0.45 kg.
1 SF = 1 sq. ft.	= 0.093m^2	1 TON	= 907 kg.
1 SY = 1 sq. yd.	= 0.836m^2	1 BAG (94 lb)	= 42.6 kg
1 CY = 1 cu. yd.	= 0.765m^3	1 BAG (100 lb)	= 45.4 kg

Table 8. RATE DECK COST DATA

LABOR

		QTY	TOTAL	BASE	PRTAXES	INSUR	FRINGES
A	CARPENTERS,MWRT,PILEDR						
CARP	CARPENTER		10.97	8.50	.81	.85	.81
CARPF	CARPENTER FOREMAN		11.57	9.00	.86	.90	.81
CRPGF	CARPENTER GENERAL FORE		12.16	9.50	.90	.95	.81
PD	PILEDRIVER		11.16	8.66	.82	.87	.81
PDF	PILEDRIVER FOREMAN		11.76	9.16	.87	.92	.81
SAW	SAWMAN		10.97	8.50	.81	.85	.81
SUPCY	CASTING YARD SUPT.		12.16	9.50	.90	.95	.81
A	CEMENT MASONS						
CEM	CEMENT FINISHER		11.72	9.15	.87	.92	.78
CEMF	CEMENT FINISHER FOREMN		12.32	9.65	.92	.97	.78
A	ELECTRICIANS						
ELEC	ELECTRICIAN		12.47	9.35	.89	.94	1.29
ELECF	ELECTRICIAN FOREMAN		13.07	9.85	.94	.99	1.29
A	IRONWORKERS						
IWS	IRONWORKER STRUCTURAL		12.40	9.50	.90	.95	1.05
IWSF	IRONWORKER STR FOREMAN		13.00	10.00	.95	1.00	1.05
IWSGF	IRONWKER STR GEN FORE		13.30	10.25	.97	1.03	1.05

EQUIPMENT

		QTY	TOTAL	DEPREC	R/LABOR	DIESEL	GAS	LUBE	PARTS	TIRES	POWER
A	EXCAVATION EQUIPMENT										
CAT12	CAT 12G MOTOR GRADER		15.60	6.60	2.80	2.40		.40	3.00	.40	
CB10	CLAMSHELL BKT 1CY		1.35	.70	.28			.02	.35		
CB20	CLAMSHELL BKT 2CY		2.51	1.40	.47			.04	.60		
CB35	CLAMSHELL BKT 3 1/2 CY		4.33	2.00	.75			.08	1.50		
D6	D6C DOZER,140HP		17.06	6.90	5.59	2.12		.35	2.10		
D7	D7F DOZER,180HP		21.72	8.50	6.99	2.98		.50	2.75		
D8	D8H DOZER,270HP		30.05	12.30	9.32	4.08		.70	3.65		
G660	1/2CY GRADALL,G660		16.22	7.20	3.26	1.76		.50	3.30	.20	
HCB	HYDRAULIC SLOT CLAMBKT		6.07	5.00	.47			.10	.50		
HGROV	HAND GUIDE ROLLER VIBR		1.83	.50	.47		.33	.03	.50		
HHPV	HAND HELD PLATE VIBR		1.56	.30	.28		.44	.04	.50		
HHRC	HAND HELD RAMMER COMP		1.59	.35	.37		.33	.04	.50		
HORAM	3IN MTD PAVING BREAKER		3.88	1.50	.93			.20	1.25		
JD310	1/2CY BACKHOE-LOADER		6.35	2.00	1.40	.80		.15	1.85	.15	
JD350	44HP CRAWLER DOZER		3.76	1.50	.93	.68		.10	.55		

Table 8. RATE DECK COST DATA (continued)

JOB MATERIALS

			QTY	TOTAL	COST
ADMX	CONCRETE ADMIXTURES	CY		1.25	1.25
AGG	CONCRETE AGGRIGATE	CY		5.50	5.50
BENB	BENTONITE,BAGGED (100)	BAG		3.50	3.50
BENK	BENTONITE,BULK	TON		60.00	60.00
CEMBJ	CEMENT,BAGGED	BAG		2.65	2.65
CEMKJ	CEMENT,BULK	TON		32.50	32.50
CMP12	12IN CORR. METAL PIPE.	LF		6.00	6.00
CMP18	18IN CORR. METAL PIPE	LF		9.00	9.00
CONTJ	CONCRETE,TREMIE	CY		28.50	28.50
CON3J	CONCRETE,3000LB	CY		27.70	27.70
CON4J	CONCRETE,4000LB	CY		29.30	29.30
CON5J	CONCRETE,5000LB	CY		30.90	30.90
DECK	12 IN.TH.DECKING,FABR.	SY		35.00	35.00
GRT1J	GROUT,DELVP,10BAG MIX	CY		36.90	36.90
LAG3	LAGGING,TIMBER,3IN	MBF		220.00	220.00
LAG4	LAGGING,TIMBER,4IN	MBF		220.00	220.00
LUML	LUMBER,LAGGING 3&4IN	MBF		275.00	275.00
LUMU	LUMBER,USED-BLOCKING	MBF		150.00	150.00
LUM1	LUMBER,2X4,2X6,4X4	MBF		210.00	210.00
LUM2	LUMBER,6X6,8X8	MBF		295.00	295.00
LUM3	LUMBER,12X12	MBF		375.00	375.00
LUM4	LUMBER,12X12,C.L.LOTS	MBF		220.00	220.00
PLY1	PLYFORM,5/8IN	MSF		320.00	320.00
PLY2	PLYFORM,3/4IN	MSF		370.00	370.00
PLY3	PLYWOOD,STD,5/8IN	MSF		220.00	220.00
POLYF	POLYETHYLENE FLM 6 MIL	SY		.50	.50
QFLR	Q-STEEL DECKING	SF		1.50	1.50
REB1J	REINF STEEL,STD LENGTH	TON		320.00	320.00
REB2J	REINF STEEL CUT&BENT	TON		440.00	440.00
SAN1J	SAND FOR BACKFILL,ETC	CY		4.00	4.00
SAN2J	SAND FOR GROUT,MORTOR	CY		6.00	6.00
SAN3J	CONCRETE SAND	CY		5.00	5.00
SMHT	SEWER MANHOLES TEMP.	EA		360.00	360.00
SPP12	STEEL PIPE PILES-12IN	TON		350.00	350.00
STL1J	STRUCT STEEL MILL LOTS	TON		220.00	220.00
STL2J	STRUCT STEEL WHSE STK	TON		315.00	315.00
STL3J	FABR STEEL,LG.SECT.	TON		500.00	500.00
STL4J	FABR STEEL,LT.SECT.	TON		700.00	700.00
TBR	TIEBACK RODS	LF		1.58	1.58
THD	TIEBACK TENSION HEADS	EA		11.10	11.10
TIES1	FORM TIES-ONE SIDE	SF		.15	.15
TIES2	FORM TIES-TWO SIDES	SF		.10	.10
WIRE1	WIRE ROPE 5/8 IN.	LF		.50	.50

Table 8. RATE DECK COST DATA (continued)

PERMANENT MATERIALS

			QTY	TOTAL	COST
ADMXP	CONCRETE ADMIXTURES	CY		1.25	1.25
AGGP	CONCRETE AGGREGATE	CY		5.50	5.50
BASEP	BASE COURSE MATL	CY		6.00	6.00
BENP	BENTONITE PANELS (WP)	SF		.30	.30
CEMB	CEMENT, BAGGED	BAG		2.65	2.65
CEMKP	CEMENT, BULK	TON		32.50	32.50
CONTP	CONCRETE, TREMIE	CY		28.50	28.50
CON3P	CONCRETE, 3000LB	CY		27.70	27.70
CON4P	CONCRETE, 4000LB	CY		29.30	29.30
CON5P	CONCRETE, 5000LB	CY		30.90	30.90
GRT1P	GROUT DELVD. 10BAG MIX	CY		36.90	36.90
JOM	SIDEWALK JOINT MATL.	LF		.20	.20
MESH1	SHOTCRETE MESH	SF		.35	.35
REB1P	REINF STEEL, STD LENGTH	TON		320.00	320.00
REB2P	REINF STEEL, CUT&BENT	TON		420.00	420.00
SAN1P	SAND FOR BACKFILL, ETC	CY		4.00	4.00
SAN2P	SAND FOR GROUT, MORTAR	CY		6.00	6.00
SAN3P	CONCRETE SAND	CY		5.00	5.00
STLD	STEEL DECKING	SF		2.20	2.20
STL3P	FABR. STEEL, LG. SECT.	TON		500.00	500.00
STL5P	STRUCT STEEL, PERM, FABR	TON		700.00	700.00
SUBGP	SUBGRADE MATL	CY		5.00	5.00
TSC1	TRAFFIC SIG. CONTROLLER	EA		2000.00	2000.00

SUB-CONTRACT

			QTY	TOTAL	COST
BLC	BLDG. LATERAL CONNECT.	EA		500.00	500.00
CBI	CATCH BASINS	EA		950.00	950.00
CI30	30IN CI PIPE INSTALLED	LF		100.00	100.00
CND2	2IN ELECT. CONDUIT	LF		6.25	6.25
DIVE	DIVERT ELEC. 12WAY DUCT	LF		210.00	210.00
DIVG	DIVERT 6IN GAS INT.	LF		35.50	35.50
DIVL	DIVERT BLDG. LATERALS	EA		3000.00	3000.00
DIVS	DIVERT 18IN SEWER INT.	LF		87.35	87.35
DIVT	DIVERT 4X4 TEL. DCT. INT	LF		93.05	93.05
DIVW	DIVERT 8IN WATER INT.	LF		77.65	77.65
DI8	8IN DUCTILE IRON PIPE	LF		35.15	35.15
EMHC	ELECT. MANHOLE CONNECT.	EA		800.00	800.00

Table 9. COST DATA FOR OPERATIONS

TRANSIT STATION-PRECAST WALL-INTERNAL BRACING-SITE 5 — DOT 5-2LY

ITEM 2HEQ — EXCAVATION — 105300 CY

OPN 5 — EXCAVATE 30 TO 50 FT — 30100 CY — 43 DAY — 700 CY PER DAY

QTY			HRS / DAY	TOT HRS	RATE	TOTAL	UNIT COST	
1		LABORER FOREMAN	8	344	10.440	3591		
4		LABORER GENERAL	8	1376	9.670	13306		
2		AIR TOOL OPERATOR	8	688	9.840	6770		
1		COMPRESSOR OPERATOR	8	344	11.140	3832		
1		DOZER OPERATOR	8	344	11.110	3822		
3		FRONT END LOADER OPER	8	1032	11.360	11724		
2		CRANE OPERATOR	8	688	12.170	8373		
2		OILER	8	688	10.040	6908		
10		DUMP TR DRIVER	8	3440	8.040	27658		
		TOTAL DIRECT LABOR		8944		85984	2.857	
		AVERAGE PRODUCTIVITY		.297 MH/CY				
1		D7F DOZER,180HP	8	344	21.720	7472		
2		955 LOADER, 2CY	8	688	15.480	10650		
1		1/2CY BACKHOE-LOADER	8	344	6.350	2184		
1		600CFM PORT COMPRESSOR	8	344	8.980	3089		
2		65T TRUCK CRANE	8	688	35.980	24754		
2		CLAMSHELL BKT 3 1/2 CY	8	688	4.330	2979		
10		REAR DUMP,20CY.HIGHWAY	8	3440	15.780	54283		
		TOTAL EQUIPMENT				105411	3.502	
	LS	TOOLS, SUPPLIES				6019		.07 X LABOR TOTAL
30100	CY	DUMP COSTS-SILTS,CLAYS			1.500	45150		
		TOTAL JOB MATLS				51169	1.700	
		TOTAL OPERATION				242564	8.059	

Table 9. COST DATA FOR OPERATIONS (Continued)

TRANSIT STATION-PRECAST WALL-INTERNAL BRACING-SITE 5 — DOT 5-2LY

ITEM 2FCY — GROUND SUPPORT WALL — 11900 SY

OPN 2		PRECAST YARD		60 DA	60 DAY		1 DA	PER DAY
QTY			HRS / DAY	TOT HRS	RATE	TOTAL	UNIT COST	
1		CASTING YARD SUPT.	8	480	12.160	5837		
1		CARPENTER FOREMAN	8	480	11.570	5554		
2		CARPENTER	8	960	10.970	10531		
1		LABORER FOREMAN	8	480	10.440	5011		
4		LABORER CONCRETE	8	1920	9.670	18566		
1		RODMAN FOREMAN	8	480	12.560	6029		
1		RODMAN	8	480	11.910	5717		
2		CRANE OPERATOR	8	960	12.170	11683		
1		OILER	8	480	10.040	4819		
1		BATCH PLANT OPERATOR	8	480	11.850	5688		
1		FORK LIFT OPERATOR	8	480	11.360	5453		
1		FLATBED DRIVER	8	480	8.040	3859		
1		COMPRESSOR OPERATOR	8	480	11.140	5347		
1		MECHANIC	8	480	11.140	5347		
		TOTAL DIRECT LABOR		9120		99441	1657.350	
		AVERAGE PRODUCTIVITY		152	MH/DA			
1		600CFM PORT COMPRESSOR	8	480	8.980	4310		
1		FORK-LIFT	4	240	4.840	1162		
1		12T HYDRAULIC CRANE	4	240	16.560	3974		
1		65T TRUCK CRANE	4	240	35.980	8635		
1		MANITOWOC 3900-100T CR	4	240	41.200	9888		
1		TRACTOR-TRAILER	8	480	18.640	8947		
1		CONC BATCH PLANT OPER.	8	480	20	9600		QUOTE 8 DA
		TOTAL EQUIPMENT				46516	775.267	
	LS	TOOLS, SUPPLIES				6961		.07 X LABOR TOTAL
		TOTAL JOB MATLS				6961	116.017	
8042	CY	CONCRETE ADMIXTURES			1.250	10053		
5493	CY	CONCRETE AGGREGATE			5.500	30212		
3024	TON	CEMENT, BULK			32.500	98280		
1351	TON	REINF STEEL,CUT&BENT			420	567420		
4190	CY	CONCRETE SAND			5	20950		
302	TON	FABR.STEEL,LG.SECT.			500	151000		
527	TON	BOT. SOLD. PILE EXTEN.			255	134385		
		TOTAL PERM MATLS				1012300	16871.667	
480	HR	CASTING YARD WRITEOFF			50	24000		
3	MO	FORM RENTAL			7200	21600		
8042	CY	CASTING SUB. MARKUP			20	160840		
		TOTAL SUB-CONTRACT				206440	3440.667	
		TOTAL OPERATION				1371658	22860.967	

Table 10. SUMMARY COST DATA FOR ACTIVITIES

TRANSIT STATION-PRECAST WALL-INTERNAL BRACING-SITE 5 DOT 5-2LY

		TOTAL COST ANALYSIS			PROJECT SUMMARY				
		LABOR	EQPT	JOB MATL	PERM MATL	SUB-CONT	TOTAL	PCTOT	
2FCY 1	MOB.SLURRY PLT,EQUIP. 30 DA	17083 569.433	30490 1016.333	1196 39.867			48769 1625.633	.325	2FCY 1
2FCY 2	PRECAST YARD 60 DA	99441 1657.350	46516 775.267	6961 116.017	1012300 16871.667	206440 3440.667	1371658 22860.967	9.128	2FCY 2
2FCY 3	TRENCH @ WALL LOCATION 1400 LF	30927 22.091	4340 3.100	30615 21.868			65882 47.059	.438	2FCY 3
2FCY 4	EXCV SLOT FOR PANELS 17630 CY	107902 6.120	137821 7.817	7553 .428			253276 14.366	1.686	2FCY 4
2FCY 5	SET PRE-CAST PANELS 234 EA	75974 324.675	38601 164.962	22643 96.765			137218 586.402	.913	2FCY 5
2FCY 6	OPERATE SLURRY EQUIP. 166 DA	217327 1309.199	49083 295.681	171928 1035.711			438338 2640.590	2.917	2FCY 6
2FCY 7	DEMOBE.SLURRY EQUIP. 10 DA	9927 992.700	2816 281.600	695 69.500			13438 1343.800	.089	2FCY 7
2FCY 8	PLACE LAGGING 1ST.10FT 14000 SF	20219 1.444	1855 .133	10655 .761			32729 2.338	.218	2FCY 8
2FCY 9	CLN.PNL.& PATCH JT. 260 DA	102169 392.958	22921 88.158	16098 61.915			141188 543.031	.940	2FCY 9
2FCY 21	STATION END BULKHEADS 1011 SY	60660 60.000	30330 30.000	27499 27.200	99078 98.000	20220 20.000	237787 235.200	1.582	2FCY 21
2FCY ITEM	GROUND SUPPORT WALL 11900 SY	741629 62.322	364773 30.653	295843 24.861	1111378 93.393	226660 19.047	2740283 230.276	18.236	2FCY ITEM

Table 11. RESOURCE ANALYSES AND SUMMARIES

DOT 5-2LY

LABOR

		QTY	TOTAL	BASE	PRTAXES	INSUR	FRINGES
CARP	CARPENTER	20406.96	223864	173459	16530	17346	16530
CARPF	CARPENTER FOREMAN	2857.28	33059	25716	2457	2572	2314
PD	PILEDRIVER	5588.16	62364	48393	4582	4862	4526
PDF	PILEDRIVER FOREMAN	800	9408	7328	696	736	648
SAW	SAWMAN	864	9478	7344	700	734	700
SUPCY	CASTING YARD SUPT.	480	5837	4560	432	456	389
	CARPENTERS,MWRT,PILEDR		344010	266800	25397	26706	25107
CEM	CEMENT FINISHER	6264.48	73420	57320	5450	5763	4886
CEMF	CEMENT FINISHER FOREMN	1902.80	23442	18362	1751	1846	1484
	CEMENT MASONS		96862	75682	7201	7609	6370

EQUIPMENT

		QTY	TOTAL	DEPREC	R/LABOR	DIESEL	GAS	LUBE	PARTS	TIRES
CAT12	CAT 12G MOTOR GRADER	204.32	3187	1349	572	490		82	613	82
C835	CLAMSHELL BKT 3 1/2 CY	1208.64	5233	2417	906			97	1813	
D6	D6C DOZER,140HP	204	348C	1408	1140	432		71	428	
D7	D7F DOZER,180HP	508.32	11041	4321	3553	1515		254	1398	
HC8	HYDRAULIC SLOT CLAMBKT	1870.56	11354	9353	879			187	935	
HGROV	HAND GUIDE ROLLER VIBR	1161.36	2125	581	546		383	35	581	
HHPV	HAND HELD PLATE VIBR	3280.08	5117	984	918		1443	131	1640	
HORAM	3IN MTD PAVING BREAKER	87.52	340	131	81			18	109	
JD310	1/2CY BACKHOE-LOADER	3647.68	23163	7295	5107	2918		547	6748	547
JD500	1/2CY BACKHOE	175.04	992	333	212	133		26	289	
P890	90#8 PAVING BREAKER	175.04	165	35	33			9	88	
RD10H	REAR DUMP,10CY,HIGHWAY	5822.80	53279	9316	10830	9549		3203	14557	5823
RD20H	REAR DUMP,20CY,HIGHWAY	10992.96	173469	36277	30780	20667		8794	54965	21986
SHRT1	SHEEPSFOOT TOWED-SINGL	837.36	1516	586	469			84	377	
STR8	STATIC ROLLER-8TN	204.32	811	255	229	143		31	153	
920	920 WHEEL LOADER,1-1/2	551.84	5165	1987	1026	662		110	1380	
955	955 LOADER, 2CY	2027.84	31391	10849	8497	3731		811	7503	
	EXCAVATION EQUIPMENT		331828	87477	65778	40240	1826	14490	93577	28438

Table 11. RESOURCE ANALYSES AND SUMMARIES (continued)

DOT 5-2LY

JOB MATERIALS

			QTY	TOTAL	COST
BEN8	BENTONITE.BAGGED (100)	8AG	36120	126420	126420
CEMBJ	CEMENT.BAGGED	8AG	29740	78811	78811
CMP12	12IN CORR. METAL PIPE.	LF	1590	9540	9540
CMP18	18IN CORR. METAL PIPE	LF	1400	12600	12600
CON3J	CONCRETE.3000LB	CY	742.50	20567	20567
DECK	12 IN.TH.DECKING.FA8R.	SY	5289	185115	185115
LAG3	LAGGING.TIMBER.3IN	MBF	42	9240	9240
LUMU	LUMBER.USED-BLOCKING	MBF	30	4500	4500
LUM1	LUMBER.2X4.2X6.4X4	MBF	136.80	28728	28728
LUM2	LUMBER.6X6.8X8	M8F	6.50	1918	1918

PERMANENT MATERIALS

			QTY	TOTAL	COST
ADMXP	CONCRETE ADMIXTURES	CY	7254	9068	9068
AGGP	CONCRETE AGGREGATE	CY	4953	27242	27242
BASEP	BASE COURSE MATL	CY	625	3750	3750
CEM8	CEMENT.8AGGED	8AG	560	1484	1484
CEMKP	CEMENT. 8ULK	TON	2728	88660	88660
CON3P	CONCRETE.3000LB	CY	1000	27700	27700
CON4P	CONCRETE.4000LB	CY	20115	589370	589370
GRT1P	GROUT DELVD.108AG MIX	CY	525	19373	19373
JOM	SIDEWALK JOINT MATL.	LF	5200	1040	1040
REB2P	REINF STEEL.CUT&BENT	TON	2896	1216320	1216320
SAN1P	SAND FOR 8ACKFILL.ETC	CY	44100	176400	176400

SUB-CONTRACT

			QTY	TOTAL	COST
CBI	CATCH BASINS	EA	4	3800	3800
CI30	30IN CI PIPE INSTALLED	LF	700	70000	70000
CND2	2IN ELECT. CONDUIT	LF	760	4750	4750
DIVE	DIVERT ELEC.12WAY DUCT	LF	115	24150	24150
DIVG	DIVERT 6IN GAS INT.	LF	20	710	710
DIVL	DIVERT BLDG.LATERALS	EA	21	63000	63000
DIVS	DIVERT 18IN SEWER INT.	LF	160	13976	13976
DIVT	DIVERT 4X4 TEL.DCT.INT	LF	460	42803	42803
DIVW	DIVERT 8IN WATER INT.	LF	20	1553	1553
DI8	8IN DUCTILE IRON PIPE	LF	775	27241	27241

Table 12. SUMMARY OF ACTIVITY COSTS ($1,000) OF FOUR BASIC ESTIMATES

Estimate 3-1KY

ACTIVITY	LABOR	EQUIP.	JOB M&S	PERM MAT	SUB	TOTAL	% OF TOTAL
A CONTROL TRAFFIC (LS)	118	4	46	-	-	168	0.57
B UTILITY WORK (LS)	198	19	199	8	1,720	2,144	7.28
C PROT ADJ STRUCT (LS)	116	25	29	23	-	193	0.66
D CONTROL GRD WATER (LS)	-	-	-	-	1,091	1,091	3.70
E DECKING (16,222 SY)	793	251	1,870	-	-	2,914	9.89
F GRD WALL SUPPORT (31,111 SY)	1,132	681	2,672	-	-	4,485	15.22
G BRACING (456,000 LF)	1,758	773	1,835	-	-	4,366	14.82
H EXCAVATION (337,100 CY)	844	783	59	-	-	1,686	5.72
I CONST PERM STRUCT (64,900 CY)	2,277	166	408	4,044	483	7,378	25.04
J BACKFILL (183,000 CY)	352	69	25	751	-	1,197	4.06
K RESTORATION (13,350 SY)	186	27	18	100	42	373	1.27
N O H (FIXED COST) (LS)	67	30	231	-	-	328	1.12
O O H (TIME RELAT) (36 Mo)	2,102	118	527	-	-	2,747	9.32
P PLANT (FIXED COST) (LS)	82	25	80	-	19	206	0.70
Q PLANT (TIME RELAT) (36 Mo)	-	-	185	-	-	185	0.63
TOTAL	10,025	2,969	8,186	4,926	3,354	29,461	100.00

Table 12. SUMMARY OF ACTIVITY COSTS ($1,000) OF FOUR BASIC ESTIMATES (Continued)

Estimate 4-2JY

	ACTIVITY	LABOR	EQUIP	JOB M&S	PERM MAT	SUB	TOTAL	% OF TOTAL
A	CONTROL TRAFFIC (LS)	80	2	19	-	-	101	0.68
B	UTILITY WORK (LS)	65	6	67	2	549	689	4.68
C	PROT ADJ STRUCT (LS)	41	9	11	8	-	69	0.47
D	CONTROL GRD WATER (LS)	326	54	28	-	-	408	2.77
E	DECKING (5,911 SY)	301	110	678	-	-	1,089	7.40
F	GRD WALL SUPPORT (10,240 SY)	477	243	729	-	-	1,449	9.84
G	BRACING (1,823 Ton)	348	99	299	943	-	1,689	11.47
H	EXCAVATION (122,400 CY)	446	413	112	-	-	971	6.59
I	CONST PERM STRUCT (23,976 CY)	1,151	60	287	1,466	298	3,262	22.15
J	BACKFILL (47,600 CY)	160	18	11	190	-	379	2.58
K	RESTORATION (4,667 SY)	67	9	7	36	15	134	0.91
N	O H (FIXED COST) (LS)	101	46	220	-	-	367	2.49
O	O H (TIME RELAT) (41 Mo)	2,737	143	685	-	-	3,565	24.21
P	PLANT (FIXED COST) (LS)	120	29	117	-	24	290	1.97
Q	PLANT (TIME RELAT) (41 Mo)	-	15	249	-	-	264	1.79
TOTAL		6,418	1,256	3,521	2,645	886	14,726	100.00

Table 12. SUMMARY OF ACTIVITY COSTS ($1,000 OF FOUR BASIC ESTIMATES (Continued)

Estimate 5-2LY

	ACTIVITY	LABOR	EQUIP.	JOB M&S	PERM MAT	SUB	TOTAL	% OF TOTAL
A	CONTROL TRAFFIC (LS)	81	2	19	-	-	102	0.68
B	UTILITY WORK (LS)	65	6	67	2	549	689	4.59
C	PROT ADJ STRUCT (LS)	41	9	11	8	-	69	0.46
D	CONTROL GRD WATER (LS)	316	53	36	-	-	405	2.70
E	DECKING (5,289 SY)	258	84	619	-	-	961	6.40
F	GRD WALL SUPPORT (11,900 SY)	741	365	296	1,111	227	2,740	18.23
G	BRACING (2,100 Ton)	360	87	493	873	-	1,813	12.07
H	EXCAVATION (105,300 CY)	379	351	193	-	-	923	6.14
I	CONST PERM STRUCT (19,975 CY)	843	43	215	1,217	284	2,602	17.32
J	BACKFILL (40,600 CY)	136	16	10	162	-	324	2.15
K	RESTORATION (4,667 SY)	67	9	7	36	15	134	0.89
N	O H (FIXED COST) (LS)	101	46	224	-	-	371	2.47
O	O H (TIME RELAT) (39 Mo)	2,567	136	649	-	-	3,352	22.31
P	PLANT (FIXED COST) (LS)	120	29	117	-	24	290	1.93
Q	PLANT (TIME RELAT) (39 Mo)	-	14	236	-	-	250	1.66
TOTAL		6,075	1,251	3,193	3,410	1,098	15,027	100.00

Table 12. SUMMARY OF ACTIVITY COSTS ($1,000) OF FOUR BASIC ESTIMATES (Continued)

Estimate 1-3GY

	ACTIVITY	LABOR	EQUIP	JOB M&S	PERM MAT	SUB	TOTAL	% OF TOTAL
A	CONTROL TRAFFIC (LS)	88	3	31	-	-	122	0.78
B	UTILITY WORK (LS)	153	18	131	-	965	1,267	8.12
C	PROT ADJ STRUCT (LS)	22	7	7	-	-	36	0.23
D	CONTROL GRD WATER (LS)	-	-	-	-	973	973	6.24
E	DECKING (9,333 SY)	322	77	1,083	-	-	1,482	9.50
F	GRD WALL SUPPORT (31,111 SY)	646	190	801	-	-	1,637	10.49
G	BRACING (1,890 Ton)	361	105	970	-	-	1,436	9.20
H	EXCAVATION (186,700 CY)	533	506	37	-	-	1,076	6.89
I	CONST PERM STRUCT (35,040 CY)	1,181	67	173	2,140	302	3,863	24.75
J	BACKFILL (122,600 CY)	339	40	24	491	-	894	5.72
K	RESTORATION (13,350 SY)	23	6	2	23	42	96	0.61
N	O H (FIXED COST) (LS)	67	30	194	-	-	291	1.86
O	O H (TIME RELAT) (28 Mo)	1,583	90	415	-	-	2,088	13.38
P	PLANT (FIXED COST) (LS)	82	25	80	-	19	206	1.32
Q	PLANT (TIME RELAT) (28 Mo.)	-	6	136	-	-	142	0.91
TOTAL		5,400	1,169	4,084	2,654	2,301	15,608	100.00

Table 13. VARIATIONS IN COST FOR ACTIVITIES ($1,000)
B - UTILITIES
C - PROTECT ADJACENT STRUCTURES

CODE	LABOR	EQUIP	JOB M & S	PERM MATL	SUB	TOTAL
B. UTILITIES:						
1BAO	198	19	199	8	1,219	1,643
1BDO	198	19	199	8	1,720	2,144
2BAO	65	6	67	2	423	563
2BDO	65	6	67	2	549	689
3BAO	153	18	121	11	964	1,267
3BDO	153	18	121	11	1,465	1,768
C. PROTECT ADJACENT STRUCTURES:						
1CAN	116	25	29	23	-	193
1CAP	967	67	362	23	-	1,419
1CAQ	1,896	103	611	23	-	2,633
1CDO	116	25	29	23	-	193
2CAP	347	24	133	8	-	512
2CAQ	682	37	223	8	-	950
2CDO	41	9	11	8	-	69
3COO	21	7	8	-	-	36

Notes: These costs cover all variations of Activities B and C for all comparative estimates in this study. The Activity Code Designations (Table 7) indicate the conditions under which these sub-estimates are used.

Table 14. SAMPLES OF COSTS FOR CONTROL OF GROUNDWATER - ACTIVITY D

ESTIMATE	MAINT. AFTER FIRST 6 MOS.		SUB-CONTRACT COSTS				
			INSTALLATION & REMOVAL				
CODE	NO. MOS.	RATE	DEWATERING	RECHARGE	MAINT. FIRST 6 MOS.	MAINT. AFTER 6 MOS.	TOTAL COST
Site 1:							
1-1GT	6	25,762	260,634	-	149,641	154,572	564,847
1-1JT	6	25,762	260,634	-	149,641	154,572	564,847
1-1LT	5	25,762	260,634	-	149,641	128,810	539,085
1-1GV	8	29,662	454,658	-	172,250	237,296	864,204
1-1JV	8	29,662	454,658	-	172,250	237,296	864,204
1-1LV	7	29,662	454,658	-	172,250	207,634	834,542
1-1GY	10	31,851	566,708	-	183,684	318,510	1,068,902
1-1JY	10	31,851	566,708	-	183,684	318,510	1,068,902
1-1LY	9	31,851	566,708	-	183,684	286,659	1,037,051
Site 3:							
3-1JT	6	27,181	188,631	187,712	157,401	163,086	696,830
3-1LT	5	27,181	188,631	187,712	157,401	135,905	669,649
3-1JV	8	31,102	250,793	239,469	180,656	248,816	919,734
3-1LV	7	31,102	250,793	239,469	180,656	217,714	888,632
3-1JY	10	31,529	297,829	294,270	183,219	315,290	1,090,608
3-1LY	9	31,529	297,829	294,270	183,219	283,761	1,059,079

Note: Maintenance costs include one pump operator 24 hours per day, 7 days per week. This sheet has samples of Sites 1 & 3 with predrainage and recharging, as required.

Table 14. SAMPLES OF COSTS FOR CONTROL OF GROUNDWATER - ACTIVITY D (Continued)

ESTIMATE CODE	NO. OF MONTHS		COST OF TRENCHING	COST OF GRAVEL	SUMP INSTALLATION	COST OF PUMPING	TOTAL COST
	EXCAV.	PUMPING					
Site 4:							
4-1JT	6	14	75,900	-	10,500	174,300	260,700
4-1LT	6	13	75,900	-	10,500	161,850	248,250
4-1JV	8	16	101,200	15,000	10,500	199,200	325,900
4-1LV	8	15	101,200	15,000	10,500	186,750	313,450
4-1JY	10	18	126,500	15,000	10,500	224,100	376,100
4-1LY	10	17	126,500	15,000	10,500	211,650	363,650
Site 5:							
5-1JT	7	15	88,550	11,250	10,500	186,750	297,050
5-1LT	7	14	88,550	11,250	10,500	174,300	284,600
5-1JV	9	17	113,850	22,500	10,500	211,650	358,500
5-1LV	9	16	113,850	22,500	10,500	199,200	346,050
5-1JY	11	19	139,150	37,500	10,500	236,550	432,700
5-1LY	11	18	139,150	37,500	10,500	224,100	411,250

Note: Costs shown do not include added cost of excavation of wet soil. Those costs are included in Excavation (Item H) costs.
This sheet has samples of Sites 4 & 5 with trenching and sumping, as required.

3.4 RESOURCE REQUIREMENTS

Cost data developed for a project essentially summarizes by type and cost all resources needed to complete the project. The amount or quantity of these resources, which are classified as components of labor, equipment, and materials (subcontract costs broken into basic resources) can be used to determine potential variations in total costs when considering different project years and/or location. A construction method which requires a relatively high amount of labor as compared to another would be less competitive in a high labor wage area. Differences in material prices due to geographic locations would affect total project costs and possibly could affect the choice of construction method to be used.

Resource requirements for a project can be summarized as illustrated in Table 11. Typical resource quantities for several estimates considered in this study are given in Table 15. Since the same price data (rate deck) were used for all estimates, it is possible to show comparative percentages of total costs represented by each resource for the three methods of cut-and-cover tunneling. Although these percentages vary due to changes in depth, type of structure, etc., reasonable averages can be determined by considering a sufficient number of situations. Results of such an appraisal are shown below.

	Percent of Total Cost		
Resource	SP&L	SPTC	PCP
Labor	44%	40%	45%
Equipment	5%	6%	5%
Materials	51%	54%	50%

This relationship of resource requirements is considered with respect to variations in cost data discussed in Section 6.

3.5 CONSTRUCTION SCHEDULES

Project duration represents the effective sequencing of many elements of time which reflect in total the completion of

Table 15. TYPICAL RESOURCE REQUIREMENTS FOR CUT-AND-COVER OPERATIONS

ESTIMATE DESIGNATION CODE	RESOURCE						
	DIRECT LABOR (MH)	CONCRETE (CY)		STRUCTURAL STEEL (TONS)			
		GROUND SUPPORT	PERMANENT STRUCTURE	GROUND SUPPORT	BRACING	DECKING	PERMANENT STRUCTURE
2-1GZ	887,000	-	66,900	3,360	3,589	2,757	-
5-1JY	832,000	28,889	64,900	10,659	6,013	2,704	-
3-1KY (T)	810,000	40,889	64,900	5,558	1,448	2,704	-
1-1LY	787,000	18,136	62,000	-	4,080	2,663	-
2-2GZ	423,000	-	21,542	1,183	1,887	930	-
4-2JY	456,000	7,777	21,481	1,363	1,823	970	-
5-2LY	434,000	8,042	19,975	-	2,179	912	-
3-2MY (T)	420,000	7,254	19,975	-	537	912	1,245
1-3GY	437,000	-	35,040	2,100	1,890	1,428	-
1-3HY (T)	510,000	-	35,040	2,723	913	1,428	-
3-3JY	494,000	44,445	28,140	5,050	2,457	1,250	-
4-3LY	596,000	12,592	26,100	-	1,540	1,414	-

Direct labor manhours include general service crew and equipment repair labor.
(T) Tieback estimate

1 CY - 1 cu. yd. = $0.765 m^3$, 1 Ton = 907 kg.

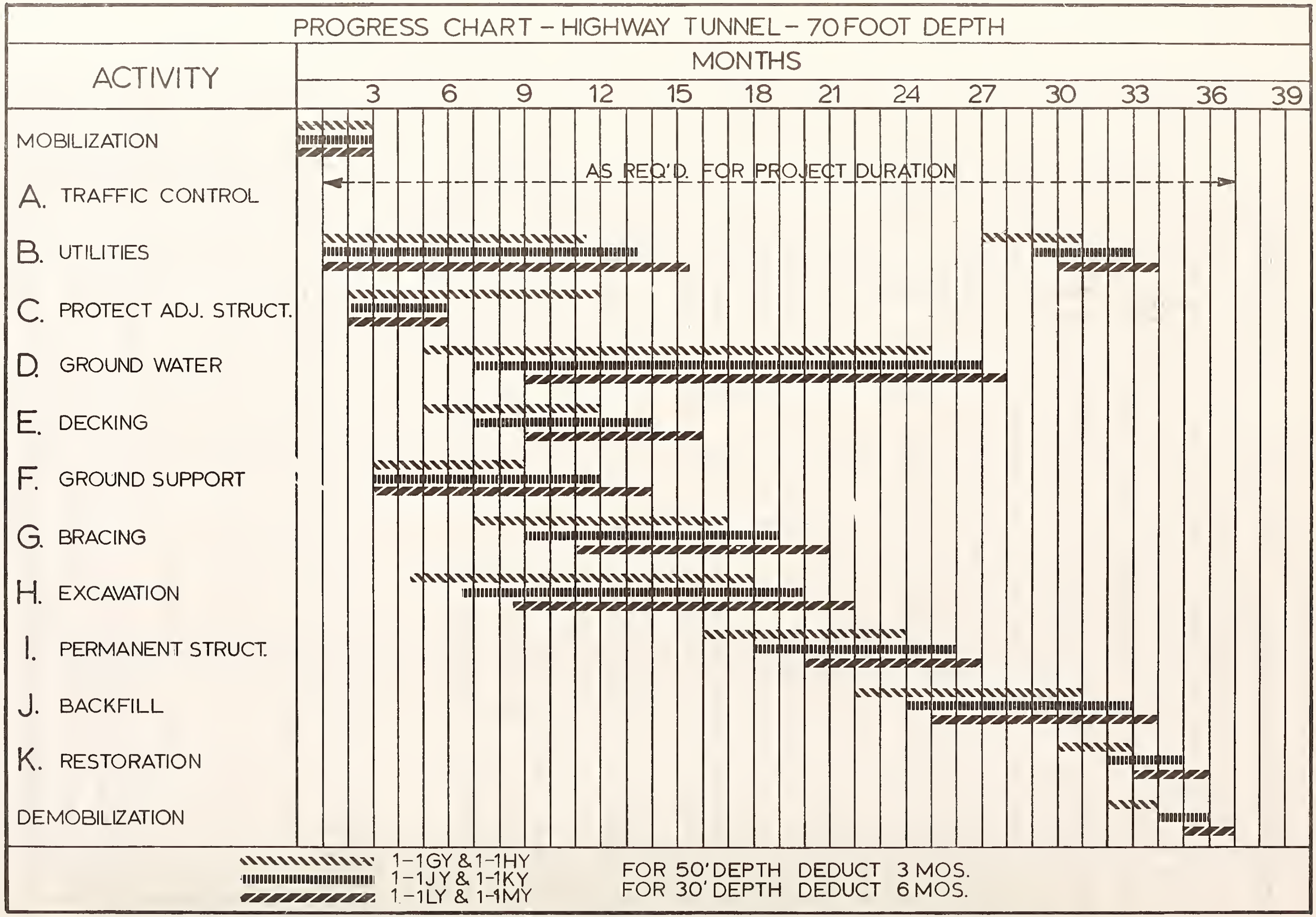
all required activities. As discussed in paragraph 5.5 of Volume 1 there are several methods by which this sequencing of operation time can be made. Analytical methods such as CPM are normally used on large projects but for purposes of this study the operation time requirements developed for the basic estimates are combined to arrive at total activity time and plotted in proper sequence on a time scale (bar graph) to show project duration. Figure 16 shows comparative schedules for constructing a four lane highway section at site 1. Schedules for a rapid transit station and line section at the same site are shown on Figures 17 and 18, respectively. All schedules are based on working five days per week. The number of shifts per day depends on the particular activity being performed but, in general, the schedules reflect one shift per day. The charting tapes used for activity durations indicate the method of construction being considered. The schedules are for structures built at a 70-foot (21.3m) depth. Reductions in total time due to construction at 30 and 50 foot (9.1 and 15.2m) depths are noted on the bottom of the schedules.

Total time in months was used to determine the time related requirements for indirect activities O and Q for the basic estimates. Durations of individual direct cost activities are used as a measure of disruption which is discussed in Section 5.

3.6 SUMMARY

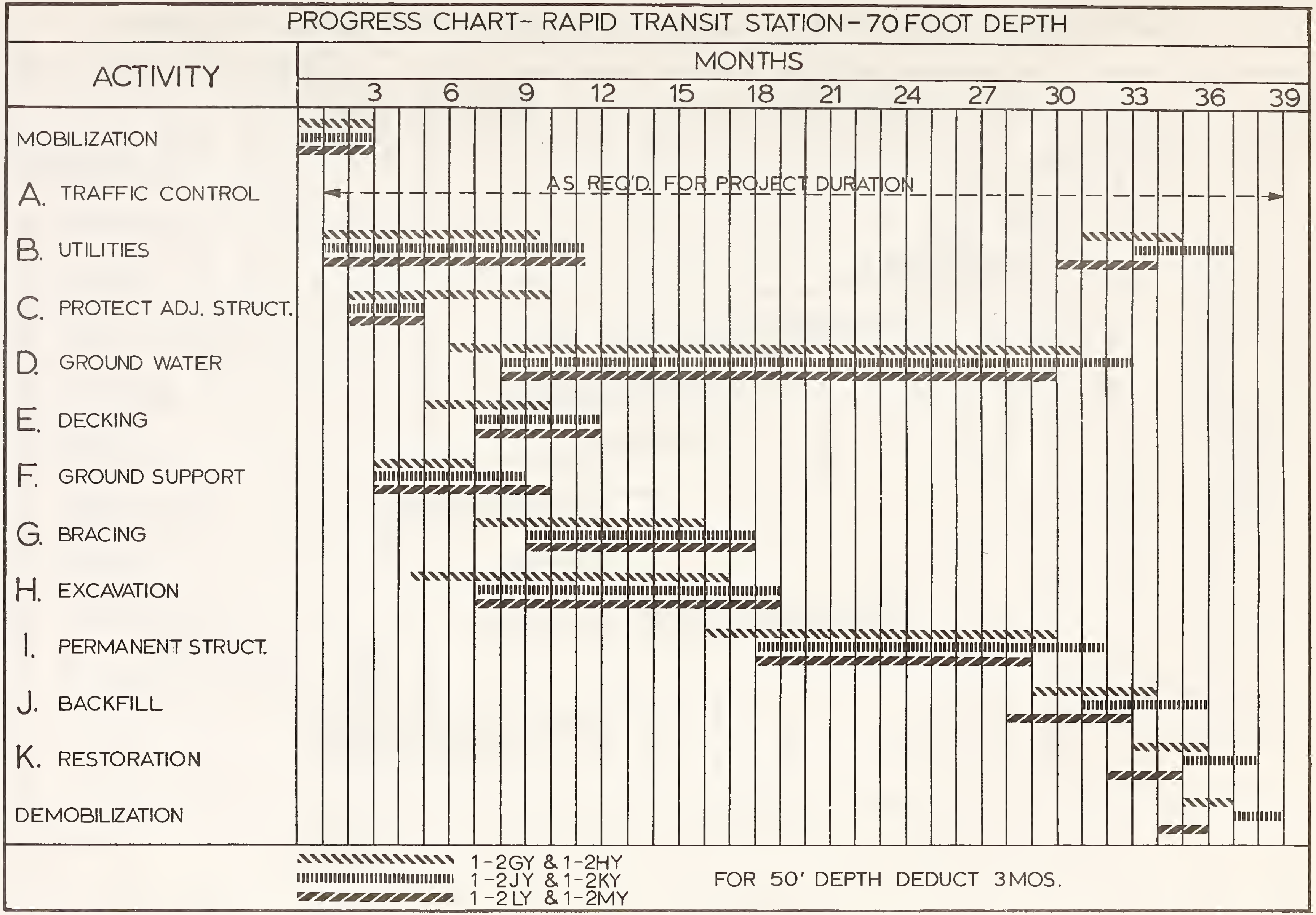
Construction cost data have been developed in general accordance with procedures used in making a competitive bid for a project. Costs are defined in terms of labor, equipment and material required to complete all operations and activities included in four basic estimates. Requirements are based on design guidelines given in Section 2 and determined quantities of work listed in Appendix B.

The cost data, basic estimates, general resource requirements and construction schedules developed in this section are used to determine costs for all situations considered in the study.



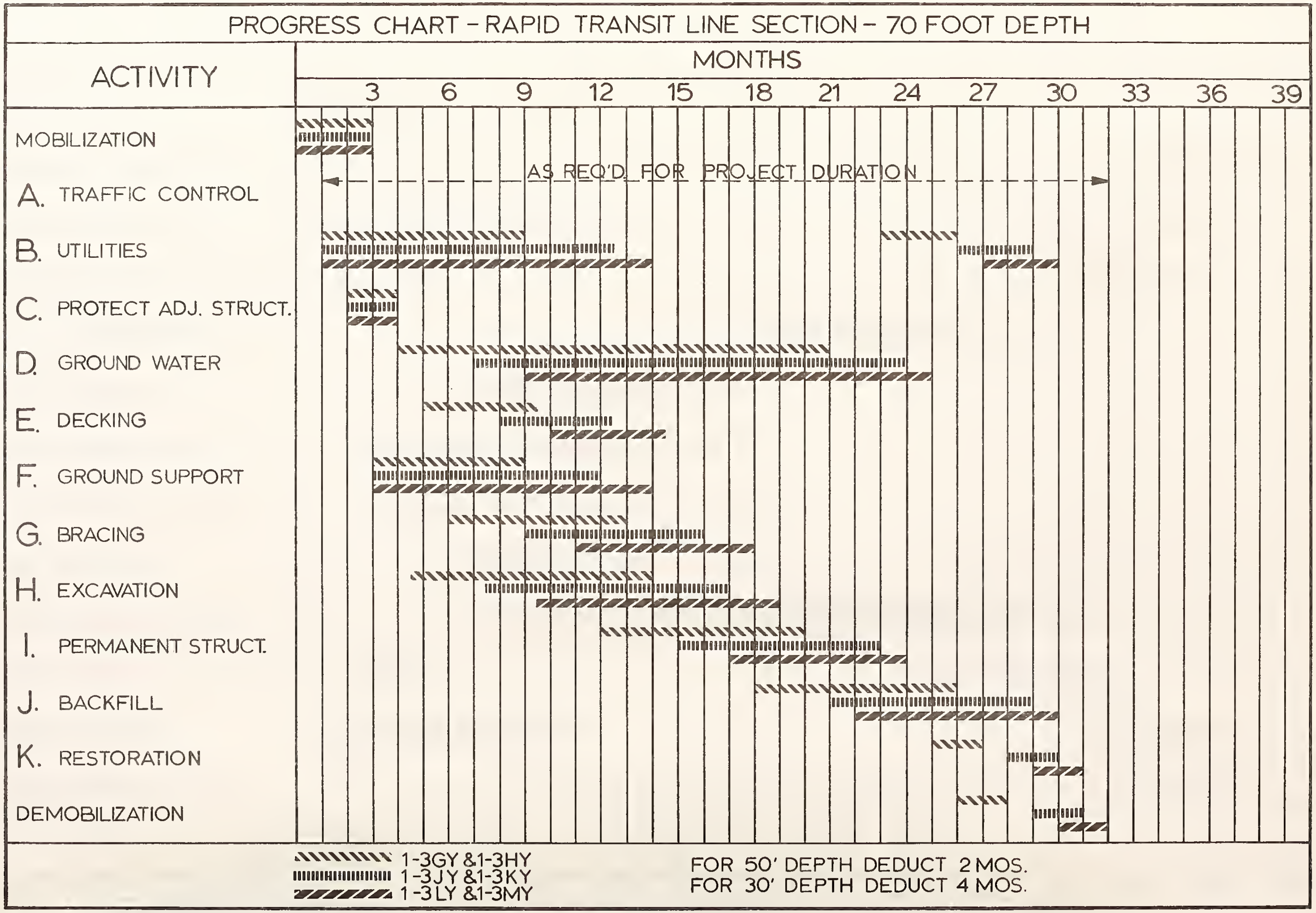
Note: 1' = 1 foot = 0.305m

Figure 16. CONSTRUCTION SCHEDULES - HIGHWAY TUNNEL - 70 FOOT DEPTH



Note: 1' = 1 foot = 0.305m

Figure 17. CONSTRUCTION SCHEDULES - TRANSIT STATION - 70 FOOT DEPTH



Note: 1' = 1 foot = 0.305m

Figure 18. CONSTRUCTION SCHEDULES - TRANSIT LINE SECTION - 70 FOOT DEPTH

SECTION 4

COST OF CUT-AND-COVER CONSTRUCTION

4.1 GENERAL

The preceding section describes how construction cost data are developed for typical cut-and-cover tunneling operations. Four basic estimates including work operations common to most situations were used to illustrate the overall costing procedure. Costs for both direct and indirect requirements (without contractor's markup) were summarized with respect to 15 major activities discussed in Section 1. Additional cost data pertaining to certain activity variations not included in the basic estimates are also given.

Several approaches were studied to see if common factors could be developed by which activity costs determined for the basic estimates could be adjusted to properly reflect cost of the other 172 study situations. It was found that no specific group of factors would be adequate. This is due primarily to the fact that variations in activity requirements are not consistent within groups or combinations of study conditions. Consequently, it was necessary to develop separate estimates for each situation in order to make comparative evaluations of cost.

As discussed in Section 3, making a detailed cost estimate is a rather complex and time consuming effort. It is possible, however, to develop reliable costs for different situations by a more expedient method of adjusting costs of a basic (or completed) estimate to reflect conditions of the new situation. It requires two determinations: 1) determining variations in quantities or requirements for comparable work operations and 2) determining unit or lump sum costs applicable to the required adjustment. The general procedure is adaptable to the use of computer or hand-extension methods.

This section of the report describes the overall procedure and provides an example of how a cost estimate is developed by manual calculations. The individual estimates are identified by code as shown on Table 6

4.2 MULTIPLE ESTIMATES

Variations in operation or activity requirements for different situations are discussed in Volume 1. For example, when considering a low water table site, the control of groundwater - activity D - would be eliminated. There would also be some changes in the permanent structure slabs and walls and in ground support due to reduced structural requirements. Raising the structure from a depth of 70 feet (21.3m) to 50 feet (15.2m) reduces the amount of excavation, the area of ground wall support, the amount of bracing etc. Other variations due to differences in weight of piles or bracing also occur. In all cases, variations can be defined essentially by determining the increase or decrease in quantities of work required for comparable operations of different situations.

Quantities of work required for major operations and activities were determined for each situation on the basis of structure and ground support details and design guidelines given in Sections 1 and 2. Determinations were also made for related quantities such as formwork which would affect the cost of construction. Quantities for major activities are tabulated in Appendix B, page 223. Different units of measure could be used. Ground support areas could be expressed as "square feet" or "square yard" or piling could be shown as "per each" or by "lineal feet". This would be a judgement factor and dependent on the applicability of the unit measurement for the particular adjustment to be made. The quantities given in Appendix B can also be used to approximate requirements for situations differing from the study criteria. If a construction was made at a 40-foot (12.2m) depth, the quantity of excavation would be the average of that shown for 30 and 50-foot (9.1m and 15.2m) depths for comparable situations.

Differences in activity or operation requirements were determined by comparing those of a new situation with those developed for a basic or completed estimate most nearly reflecting conditions of the new situation. Activity costs of the basic estimates were then adjusted to reflect quantity variations extended against unit or lump sum prices of the respective operations. Appropriate allowances were made for production, crew sizes and equipment and material requirements as applicable to the particular adjustment being considered. Adjustments can be an addition or deletion, or merely a revision of component cost.

The estimate format and rate deck described in Section 3 were developed so that estimate input could be readily changed in accordance with differences in operation and activity requirements such as discussed above. New input was prepared and computerized estimates made for situations 1-1LY, 1-3HY, 2-1GZ, 2-2GZ, 3-2MY, 3-3JY, 4-3LY and 5-1JY. Summary analyses of operations and activities for these estimates are included in Volume 3. Following the same procedure but using manual calculations, estimates were also made for situations 1-1MY, 2-1HZ, 2-2HZ, 3-3KY, 4-2KY and 4-3MY.

These estimates plus the four basic estimates provide cost data for 18 situations; six for each transit structure, all built at a 70-foot (21.3m) depth. Each estimate includes the most severe conditions within a group of similar situations and is used as a base in developing costs for other estimates. As an example, estimate 2-1GZ (site 2, highway structure, SP&L, internal bracing, 70-foot depth and dry soil condition) includes all operations and cost data required to determine estimates 2-1GW and 2-1GU which represent the same construction but at 50 and 30-foot (15.2m and 9.1m) depths. Estimates 1-1GY, 1-1GV and 1-1GT; essentially the same construction, but at a site with a high initial water table, can also be made by adjusting various operation and activity requirements.

This process of essentially "building" new estimates from a completed or base estimate was used to develop costs for the remaining study situations. Summaries of all cost estimates are included as Appendix C, page 245.

As previously noted, costs are related to time of construction. In preparing the individual estimates, evaluations were made of differences in operation and activity time requirements so as to determine total project duration for each situation. These durations (in months) are shown on Quantity Tables in Appendix B, page 223.

A detailed example of how a manual estimate was prepared is given in the following paragraphs.

4.3 DEVELOPING A COST ESTIMATE BY EXTRAPOLATION

The procedure is illustrated by considering variations necessary to adjust estimate 1-1LY (site 1, four lane highway structure, PCP with internal bracing, 70-foot (21.3m) depth and high water table) to determine the cost when completing the same construction at a 30-foot (9.1m) depth, estimate 1-1LT. These estimates contain examples of all needed adjustments which are considered in three categories: 1) the addition or elimination of entire work operations, 2) adjustments for quantities on the basis of unit prices developed in a base estimate and 3) adjustment to time-related items for changes in estimated project duration.

Calculations used in making the adjustments are shown on Table 16. The heading of the table describes the new situation (1-1LT) and indicates the difference in construction time of 6 months between 1-1LT and base estimate 1-1LY (see Appendix B). Activity costs for estimate 1-1LY are obtained from Appendix C and entered in the appropriate column of Table 16. Unit costs for individual operations are given in Volume 3 and could be listed for respective activities. To simplify extensions, totals and adjustments are rounded off to the nearest $1,000. As mentioned, the terms "item" and "activity" are synonymous.

4.3.1 Adjustment of Work Operations: When the 18 base estimates were prepared, the work operations were chosen to facilitate the adjustment procedures for other situations. As an example, item H - Excavation for 1-1LY contains seven operations as shown by the summary on page 97:

Table 16. EXAMPLE CALCULATIONS FOR ADJUSTMENTS OF ACTIVITY COSTS TO REFLECT VARYING SITE AND CONSTRUCTION CONDITIONS

ESTIMATE DESIGNATION 1-1LT STRUCTURE HIGHWAY TUNNEL TIME ADJ. -6 MOS.

SUPPORT PRECAST PANEL BRACING INTERNAL DEPTH 30' SITE NO. 1

WORK ITEM	COST BASE EST. (1-1LY)	ADJUSTMENTS: TYPE: OPN	ADJUSTMENTS: TYPE: U.P.	ADJUSTMENTS: TYPE: TIME	ADJUSTMENTS: DESCRIPTION	ADJUSTMENTS: EXTENSION	ADJUSTMENTS: AMOUNT	ADJUSTED COST (1-1LT)
A. TRAFFIC CONTROL	168,000			X	Flagmen	6MOX1650	10,000	158,000
B. UTILITIES	2,144,000				-	-	-	2,144,000
C. PROT ADJ STRUCTURES	193,000				Depth	-	-	193,000
D. GROUNDWATER	1,037,000				Depth	(SEE TABLE 14)	498,000	539,000
E. DECKING	2,894,000		T(M)		Holes	6720LFX8.70	58,000	
			M		Piles	245TX220-	54,000	
			M		Steel	41TX500-	21,000	
			M		Deck Mats	445SYX35-	16,000	
							149,000	2,745,000

Notes: All adjustments negative, except as noted. "Item" synonymous with "activity".

Unit prices designated: T, Total; T(M), Total, modified; L,E, Labor & Equipment only, M, Material only

1 LF = 1 ft. = 0.305m
1 T = 1 ton = 907 kg
1 SY = 1 sq. yd. = $0.836m^2$

Table 16. EXAMPLE CALCULATIONS FOR ADJUSTMENTS OF ACTIVITY COSTS TO REFLECT VARYING SITE AND CONSTRUCTION CONDITIONS (continued)

ESTIMATE DESIGNATION 1-1LT STRUCTURE HIGHWAY TUNNEL TIME ADJ. -6 MO.

SUPPORT PRECAST PANEL BRACING INTERNAL DEPTH 30' SITE NO. 1

WORK ITEM	COST BASE EST. (1-1LY)	ADJUSTMENTS TYPE OPN	U.P.	TIME	DESCRIPTION	EXTENSION	AMOUNT	ADJUSTED COST (1-1LT)
F. GROUND SUPPORT	5,181,000		L,E	X	Yard *1	125 DA X 3309	414,000	
			M		Conc. Matl. *2	13383 CY x 40	535,000	
			M		Conc. Reinf.	2436 T x 420	1,023,000	
			M		Top Sol Pile	234 T X 500	117,000	
			T(M)		Slot Excav	24592 CY X 12	295,000	
			T		Set Panels	334 EA X 586	196,000	
				X	Oper Plant	100 DA X 1700	170,000	
			M		Slurry Matl	11209 CY X 16.33	183,000	
				X	Clean Wall	100 DA X 500	50,000	
			T		End Blkd	—	—	
							2,983,000	2,198,000
G. BRACING	2,964,000	#3-13			Levels	3, 4, & 5	2,182,000	
			M		Steel	605 T X 500	303,000	
			T		Tiebacks	—	—	
			T		TB Wale Rem	—	—	
			T		End Blkd	—	—	
							2,485,000	479,000

Notes: *1 Includes yard & form rental

*2 Includes yard markup

1 T = 1 ton = 907 kg
1 CY = 1 cu. yd. = $0.765 m^3$

Table 16. EXAMPLE CALCULATIONS FOR ADJUSTMENTS OF ACTIVITY COSTS TO REFLECT VARYING SITE AND CONSTRUCTION CONDITIONS (continued)

ESTIMATE DESIGNATION 1-1LT STRUCTURE HIGHWAY TIME ADJ. -6 MO.

SUPPORT PRECAST PANELS BRACING INTERNAL DEPTH 30' SITE NO. 1

WORK ITEM	COST BASE EST. (1-1LY)	ADJUSTMENTS: TYPE: OPN	U.P.	TIME	DESCRIPTION	EXTENSION	AMOUNT	ADJUSTED COST (1-1LT)
H. EXCAVATION	1,882,000	#5.6			Depth	(70'→30')	981,000	
			T		Width	—	—	
							981,000	901,000
I. PERMANENT STRUCTURE	6,741,000		M		Concrete	20260CYX30$^{\underline{50}}$	618,000	
			T		Reinforcing	1519TX630	957,000	
					Rebracing	—	—	
			M		Perm Steel	—	—	
					Wall W.P.	—	—	
							1,575,000	5,166,000
J. BACKFILL	1,328,000	#7.3			Depth	(38'-5)	1,047,000	
			T		Add'l Depth		169,000	
							1,216,000	112,000
K. RESTORATION	373,000				—	—	—	373,000
	24,905,000	SUB	TOTAL	-	DIRECT COSTS		9,897,000	15,008,000

Note: 1 T = 1 ton = 907 kg
1 CY = 1 cu. yd. = $0.765 m^3$

Table 16. EXAMPLE CALCULATIONS FOR ADJUSTMENTS OF ACTIVITY COSTS TO REFLECT VARYING SITE AND CONSTRUCTION CONDITIONS (continued)

ESTIMATE DESIGNATION 1-1LT STRUCTURE HIGHWAY TUNNEL TIME ADJ. -6 MO.

SUPPORT PRECAST PANELS BRACING INTERNAL DEPTH 30' SITE NO. 1

WORK ITEM	COST BASE EST. (1-1LY)	ADJUSTMENTS TYPE OPN	U.P.	TIME	DESCRIPTION	EXTENSION	AMOUNT	ADJUSTED COST (1-1LT)
N. OVERHEAD (FIXED)	323,000		T	X	Bond	12,000 X 5	60,000	263,000
O. OVERHEAD (TIME REL.)	2,828,000			X	Labor	6 MO X 33,800	203,000	
				X	Expenses	6 MO X 10,500	63,000	
				X	Serv Crew	6 MO X 34,900	209,000	
				X	Vehicles	6 MO X 1,000	6,000	
							481,000	2,347,000
P. PLANT (FIXED)	206,000				—	—	—	206,000
Q. PLANT (TIME REL.)	191,000			X	All	6 MO X 5,150	31,000	160,000
	3,548,000	SUB TOTAL - INDIRECT COSTS					572,000	2,976,000
	28,453,000	TOTAL COST					10,469,000	17,984,000
	4,268,000	15% MARKUP						2,698,000
	32,721,000	BID PRICE						20,682,000

1HEQ	1	BREAK PAVEMENT & HAUL 14,000 SY	$ 48,852 3.489/SY
1HEQ	2	EXCAVATE FIRST 5 FT 23,300 CY	195,219 8.382/CY
1HEQ	3	EXCAVATE 5 TO 22 FT 79,300 CY	367,470 4.634/CY
1HEQ	4	EXCAVATE 22 TO 30 FT 37,300 CY	197,143 5.285/CY
1HEQ	5	EXCAVATE 30 TO 50 FT 93,300 CY	464,742 4.981/CY
1HEQ	6	EXCAVATE 50 TO 70 FT 93,300 CY	516,398 5.535/CY
1HEQ	7	FINE GRADE INVERT 14,000 SY	91,999 6.571/SY
1HEQ	ITEM	EXCAVATION 326,500 CY	1,881,895 5.764/CY

Note: 1 FT = 0.305m, 1 SY = 0.837 m^2, 1 CY = 0.765 m^3

To adjust this work item to a comparable estimate at 50-foot depth (1-1LV), it is only necessary to deduct the cost of operation 6. At a 30-foot (9.1m) depth (1-1LT), the cost of operations 5 and 6 are deducted as shown on the third sheet of Table 16. Deleting these operations gives a total direct cost for the excavation item of 1-1LT of $900,755. The total quantity of excavation is 139,900 CY giving an item unit cost of $6.44/CY. A common but less accurate adjustment can be made by deducting the total quantity of excavation represented by operations 5 and 6 (186,600 CY) at the original weighted average unit item cost of $5.76/CY, leaving a total for the item of $806,333. In this latter instance, the adjustment does not properly reflect the actual cost of operation 1 (breaking pavement), the high cost of operation 2 (excavating around utilities), and 7 (fine grade invert), which are all required regardless of depth of excavation. Wherever possible, operation type adjustments should be used in preference to deleting quantities extended against the item unit cost.

Operation adjustments are also used for item G - Bracing and item J - Backfill. However, in both of these items, additional adjustments in operation unit prices are necessary due to different requirements at shallower depths which require not only fewer levels of bracing (a reduction in operations) but also lighter weight bracing members due to reduced ground loads.

4.3.2 Adjustments by Unit Prices: After operation adjustments are made, most of the remaining adjustments of direct cost items consist of multiplying the difference in quantities between the base and new estimate by a unit price developed in the base estimate. The unit price adjustment can take several forms depending on the particular operation involved and the judgment of the estimator. These include: 1) total unit cost of all contributing resources (labor, equipment and material), 2) a modified unit cost, 3) labor and equipment unit cost only, and 4) material unit cost only.

Where the adjustment occurs in one operation, the unit price developed for that operation should be used as being most accurate; where multiple operations are involved, a weighted average unit price should be used. Where adjustments are relatively minor, rounded unit prices will suffice.

Total unit prices are used for modifying operations where the cost is proportional to the resource effort involved, such as providing and placing reinforcing steel or excavating at a particular level. If, for instance, a structure was several feet wider than the one in the base estimate, the additional excavation would require the same amount of effort per cubic yard to remove and haul, at a given depth, as the original base estimate excavation.

An example of a modified total unit cost is shown in item E, Decking, of Table 16. The adjustment described as "holes" applies to operation 2, Drilling Holes, and operation 5, Backfilling Holes. While the same number of holes is required for the 30-foot (9.1m) depth as the 70-foot (21.3m) depth, the total length drilled is far less. There are costs associated with moving and setting up the drill at each location regardless of the depth drilled. To reflect these costs, an hour of drill crew time per hole was allowed, reducing the unit price used for the adjustment by about 10 percent. For this particular adjustment, a unit measure of "lineal feet of hole" was used instead of the "per each" unit given in the cost summaries. While this modification is not too significant in this example, it is more pertinent in the SP&L and SPTC estimates, where up to 50,000 feet (15,240m) of hole drilling is required for the ground support items.

Under item F, Ground Support, the changes required to properly modify the operation of Casting Precast Panels is too complex to adjust with one unit price. The first four adjustments for this item show changes required for the casting operation. The labor and equipment costs are proportional to time of utilization, and have been converted to a daily rate for adjustment, based on the number of days needed to cast the particular number and size of panels required. The materials have been separated into three categories as the reinforcing and top soldier piles are not proportional to the volume of concrete. Most other operations are simpler and a single unit price change is sufficient. In this case, the variation in this one operation amounts to about $2,400,000, justifying the additional detailed breakdown.

Material unit price adjustments, without corresponding labor and equipment changes, are warranted under conditions where a reduction in quantity is not accompanied by a reduction in time required to perform an operation. Reducing the weight, but not the number of pieces of bracing does not materially reduce the work for the crew which must perform the same amount of work but with lighter members. In the same sense, reducing the thickness of a concrete wall of the permanent structure because of shallower depth does not reduce the forming, stripping, cleanup or finishing required. While the pour time may be reduced, the work crew will usually be paid for the same number of hours regardless of a minor reduction in actual pour time. In these and similar cases, adjustments are based on material unit prices only. The reinforcing steel placed in these walls is adjusted by the full unit price indicated.

4.3.3 Time-Related Adjustments: Time-related adjustments can be seen in items O and Q (page 4 of Table 16). These adjustments are straightforward. The average cost per month for overhead labor (item O) is reduced by the difference in number of months of project duration of the two estimates. Since the two projects considered are essentially similar in scope, if not in time of construction, the same number of overhead personnel would be required for each. If the scope of work were to change, other adjustments might have to be made in these items. While the estimates were prepared to keep costs of work items separate for easy identification and comparison, it is possible for simplifying adjustments, to combine all time-related costs into one monthly adjustment rate.

4.3.4 Other Adjustments: An adjustment not mentioned previously is the lump sum adjustment shown for item D, Control of Groundwater. This is a complex adjustment when varying structure depth involving drilling, installation, pump sizes, operating costs and maintenance costs, as well as time-oriented costs due to reduced construction period. These variables have been estimated separately for all study situations by Ground/Water Technology Inc., acting as a consultant. A summary of estimate variations for this item is given in Table 14, which was used to make the adjustment shown in the example.

Several items such as utilities were not changed. The work involved in relocating and maintaining utilities is not dependent on how deep the structure will go or whether groundwater is present below the utilities. In extending a base estimate to a situation where utilities are different from those assumed, suitable operation adjustments would be required. Typical utility types and sizes were used in the basic estimates (Volume 4) to facilitate such adjustments. Differences due to underpinning requirements - protection of adjacent structures - can also be evaluated by considering various combinations of operations used for this item in the basic estimates.

After direct and indirect costs are computed for the new situations, an allowance of 15% is added for contractor's markup. This is discussed in paragraph 4.4.

Since site, structure and support conditions for base estimate 1-1LY are similar to those of 1-1LT, except for depth 70 feet (21.3m) vs 30 feet (9.1m), all adjustments used in the example were reductions in costs determined for the base estimate. This need not be a factor in extending estimates to a new situation as adjustments can be either additions or reductions.

Determining costs for alternate locations, depths, etc. may require several calculations using an appropriate data base to assure reasonable and comparable results. The estimates made for this study are well suited for this purpose, as they cover a wide variety of conditions and are based on common design and construction cost data. In evaluating a new situation, it is possible to use one or more estimates similar to the situation being considered and vary by unit prices, interpolation or extrapolation, those items which show significant cost changes under different conditions. Appropriate lump sum adjustments can be made to cover a number of minor variations. Thus, comparative estimates for alternate sites can be readily produced in the pre-design stage by using one or more of the developed base estimates.

4.3.5 Conditions Applicable to Use of Method: The type of situations which can be evaluated by this procedure include:

1. Structures of different width, length, depth or cross section.
2. Different types, sizes or number of utilities. This would also include situations such as park areas or other off street areas having no utilities.
3. Adjacent strucutures with different underpinning or support requirements.

4. Different soil conditions requiring modified dewatering or excavation techniques.
5. Areas such as parks or side streets where decking and traffic control requirements are less stringent.
6. To a certain extent, the method could be used to evaluate situations using different ground support systems such as described in Volume 1. In this case, however, it would be necessary to make a new estimate for activity F. Other activities could be adjusted as discussed.

In some instances, it may be adequate to make only general evaluations of total costs rather than using item by item adjustments shown in the example. This might be the case where it was desired to approximate the cost of 1,000 feet (305m) of line section instead of the 2,000-foot (610m) length considered in the study. Assuming conditions were essentially the same except for length, it would be reasonable to assume that the total direct cost would vary in proportion to project length; fixed costs of overhead would be the same and time related costs would vary with respect to project duration. Table 17 shows how three developed estimates might be adjusted for different project lengths. It can be seen that in this particular case, percentage variation in cost from the base estimates due to changes in length of structure are approximately the same for all three methods of construction.

The greater the difference in conditions from those of the developed estimates, the more difficult and exacting will the necessary adjustments become. Although reliability of results will decrease with complexity of adjustments, this method will provide greater accuracy than trying to estimate the cost of future work by using available unit bid prices submitted for other projects and which in all probability were developed from different cost data.

In preparing a new estimate, the types of adjustments described in the example should be made first and then general adjustments due to changes in length, etc. Adjustments due to

Table 17. EFFECT OF PROJECT LENGTH ON CONSTRUCTION COST ($1,000)

RAPID TRANSIT TUNNEL - INTERNAL BRACING 50' DEEP SITE 1				
DESCRIPTION	LENGTH OF TUNNEL			
	1000 LF	2000 LF	3000 LF	4000 LF
SOLDIER PILES & LAGG.:		(1-3GV)		
DURATION (MOS.)	22	26	30	33
DIRECT COST	5,309	10,618	15,927	21,236
IND. - FIXED	483	483	483	483
IND. - TIME REL.	1,743	2,060	2,377	2,615
TOTAL COST	7,535	13,161	18,787	24,334
COST/LF	7.54	6.58	6.26	6.08
% OF 2000' BASE	114.5%	100.0%	95.2%	92.4%
CAST-IN-SLURRY:		(1-3JV)		
DURATION (MOS.)	26	29	33	36
DIRECT COST	5,900	11,800	17,700	23,600
IND. - FIXED	483	483	483	483
IND. - TIME REL.	2,078	2,318	2,638	2,878
TOTAL COST	8,461	14,601	20,821	26,961
COST/LF	8.46	7.30	6.94	6.74
% OF 2000' BASE	115.9%	100.0%	95.1%	92.3%
PRECAST PANELS:		(1-3LV)		
DURATION (MOS.)	26	30	34	37
DIRECT COST	5,997	11,994	17,991	23,988
IND. - FIXED	498	498	498	498
IND. - TIME REL.	2,095	2,417	2,739	2,981
TOTAL COST	8,590	14,909	21,228	27,467
COST/LF	8.59	7.45	7.08	6.87
% of 2000' BASE	115.2%	100.0%	94.9%	92.1%

Note: 1 LF = 1 ft. = 0.305m

different years of construction or locations would then be made in accordance with procedure discussed in Section 6.

This method should not be applied to construction outside the United States without a thorough investigation of labor productivity and wages, equipment utilization and material prices for the country involved. Differences in these components in all phases of construction could materially affect determined requirements and costs. Construction procedures, legal and safety regulations and contractual stipulations could also affect results. In most cases of overseas construction, producing a new estimate would probably be simpler and more accurate than adjusting all of the details in an estimate based on U.S. practices and costs.

4.4 BID PRICES

In final evaluations of cut-and-cover construction, it is usual to compare the bid price of the work. This price, which includes costs as determined for the study estimates plus an allowance for contractor's mark-up, is normally expressed as unit or lump sum prices extended against a bill of quantities. For this purpose, the bill of quantities for any situation is taken as the eleven direct cost activities (activities A through K) treated as lump sum items. Bid prices would be the activity direct cost plus a proportionate allowance to reflect indirect costs and markup. Using a uniform markup of 15 percent, (15% of direct plus indirect costs) bid prices for the four basic estimates (Section 3) would be as shown on Table 18. An example of how bid prices are determined can be seen by considering estimate 1-3GY (see Table 44-11). Total direct cost (activities A through K) is $12,881,000; total indirect cost (activities N, O, P and Q) is $2,727,000. Adding 15% to the sum gives a total bid price of $17,949,000. This bid price is 1.393 times the direct cost. Multiplying cost of activities A through K by 1.393 gives their respective bid prices.

Comparing direct cost of activities A-K (Table 12) with bid prices shows a difference of from 30 to 59 percent. These

Table 18. ACTIVITY BID PRICES - BASIC ESTIMATES

	ACTIVITY	ESTIMATE			
		4-2JY TRANSIT STATION SPTC INT. BRACING	3-1KY HIGHWAY TUNNEL SPTC TIEBACKS	5-2LY TRANSIT STATION PRECAST PANELS INT. BRACING	1-3GY TRANSIT TUNNEL SOLDIER PILES INT. BRACING
A	TRAFFIC CONTROL	167,000	219,000	164,000	170,000
B	UTILITY WORK	1,139,000	2,794,000	1,106,000	1,766,000
C	PROTECT ADJ STRUCT	114,000	252,000	111,000	50,000
D	GROUNDWATER CONTROL	675,000	1,422,000	650,000	1,356,000
E	DECKING	1,801,000	3,798,000	1,544,000	2,065,000
F	GROUND WALL SUPPORT	2,397,000	5,846,000	4,401,000	2,281,000
G	BRACING	2,793,000	5,690,000	2,911,000	1,999,000
H	EXCAVATION	1,604,000	2,197,000	1,482,000	1,499,000
I	CONST PERM STRUCT	5,395,000	9,616,000	4,177,000	5,383,000
J	BACKFILL	628,000	1,560,000	520,000	1,246,000
K	RESTORATION	222,000	486,000	215,000	134,000
	TOTAL BID PRICE	16,935,000	33,880,000	17,281,000	17,949,000

percentages reflect the relationship between the direct cost of performing the work and corresponding indirect and markup costs for the respective construction. They vary for each situation and could range upwards of 70 percent. If indirect and markup costs are prorated or "spread" uniformly in proportion to the direct cost of each activity (as done above) the resulting bid price is referred to as "balanced"; if not, the bid would be "unbalanced". In all cases, the total obtained by extending the bill of quantities against bid prices would equal the sum of direct cost plus indirects and markup.

Total bid prices determined for the 176 construction situations are given in Table 19. Activity bid prices for all estimates can be determined as discussed above in conjunction with summaries given in Appendix C. Unit bid prices are obtained by dividing activity bid price by respective quantity of work. Table 20 shows typical unit bid prices for several methods and depths of construction. Subsequent reference to construction cost implies a bid price as discussed above.

4.5 COMPARISON OF COST ESTIMATES

The format used for Table 19 is designed for ease of comparison of total project costs for different construction methods under varying site and depth conditions for each of the three structures. Forty different situations are considered (three structures each at two or three depths for five sites). The costs of two to six alternate construction methods are shown, depending on applicability to site conditions, for each of these situations.

A discussion of trends indicated by this table is in order. A simple listing of the number of situations where each respective method is most cost effective could be misleading as not all situations are equal. Structures will be located at shallow depths where possible, some site conditions are more common than others, and some methods are not applicable to all situations. Some general trends can be noted and then results at each site will be discussed.

Table 19. BID PRICES ($MILLION) - 176 STUDY SITUATIONS

DEPTH		30 FEET						50 FEET						70 FEET					
GROUND SUPPORT		SOLDIER PILES & LAGGING		CAST-IN SLURRY CONCRETE		PRECAST CONCRETE PANELS		SOLDIER PILES & LAGGING		CAST-IN SLURRY CONCRETE		PRECAST CONCRETE PANELS		SOLDIER PILES & LAGGING		CAST-IN SLURRY CONCRETE		PRECAST CONCRETE PANELS	
BRACING		INT.	T.B.	INT.	T.B.	INT.	T.B.	INT.	T.B.	INT.	T.B.	INT.	T.B.	INT.	T.B.	INT.	T.B.	INT.	T.B.
FOUR LANE HIGHWAY TUNNEL	SITE 1	19.21	18.94	20.60	20.48	20.68	20.56	24.91	24.83	25.20	24.93	25.58	25.36	32.09	32.21	31.68	31.45	32.72	32.85
	SITE 2	17.54	17.28	19.23	19.10	19.33	19.21	22.96	22.88	23.56	23.29	23.97	23.75	30.09	30.22	30.02	29.79	31.09	31.23
	SITE 3	-	-	20.78	20.88	20.99	21.10	-	-	25.95	26.37	26.37	26.76	-	-	33.58	33.88	34.17	35.19
	SITE 4	-	-	21.19	22.02	21.58	22.45	-	-	25.97	27.87	26.59	28.53	-	-	32.10	34.61	33.84	36.22
	SITE 5	-	-	24.09	-	25.38	-	-	-	30.28	-	30.76	-	-	-	35.20	-	35.82	-
RAPID TRANSIT STATION	SITE 1							14.37	14.61	14.37	14.50	13.80	13.94	17.00	17.33	16.84	17.27	16.67	17.18
	SITE 2			TOO SHALLOW				12.81	13.05	13.17	13.30	12.70	12.84	15.20	15.53	15.31	15.74	15.14	15.75
	SITE 3			FOR STATION				-	-	14.57	14.97	14.07	14.45	-	-	17.38	18.06	16.97	17.90
	SITE 4							-	-	14.33	15.32	13.90	14.89	-	-	16.94	18.11	16.86	18.14
	SITE 5							-	-	15.48	-	15.09	-	-	-	17.53	-	17.28	-
RAPID TRANSIT LINE SECTION	SITE 1	12.25	12.31	13.78	13.87	13.73	13.84	15.14	15.77	16.79	17.40	17.15	17.79	17.95	19.50	20.11	22.10	21.05	23.03
	SITE 2	11.09	11.15	12.83	12.93	12.81	12.93	13.65	14.28	15.53	16.15	15.92	16.57	16.24	17.79	18.66	20.65	19.63	21.61
	SITE 3	-	-	13.94	14.26	13.99	14.33	-	-	17.76	19.13	17.98	19.28	-	-	21.63	24.78	22.14	24.97
	SITE 4	-	-	14.20	15.11	14.43	15.38	-	-	17.24	20.32	17.82	21.10	-	-	21.26	24.35	23.06	26.41
	SITE 5	-	-	16.68	-	17.82	-	-	-	20.58	-	21.33	-	-	-	23.16	-	23.48	-

Situations where construction method is not considered applicable for this study are shown thus (-).

Table 20. TYPICAL UNIT BID PRICES ($) FOR DIFFERENT METHODS AND DEPTH OF CONSTRUCTION - SITE 1

INTERNAL BRACING - HIGH GROUNDWATER									
WORK ACTIVITY & STRUCTURE	SOLD PILES & LAGGING			CAST-IN-PLACE (SPTC)			PRECAST CONC PANELS		
	DEPTH			DEPTH			DEPTH		
	30'	50'	70'	30'	50'	70'	30'	50'	70'
DECKING (SY)									
1. Highway Tunnel	237	233	230	241	237	236	247	241	241
2. Transit Station	-	290	286	-	300	295	-	294	288
3. Line Section	240	229	221	242	217	212	239	223	217
GROUND SUPPORT (SY)									
1. Highway Tunnel	87	83	80	186	160	162	227	205	219
2. Transit Station	-	102	98	-	232	226	-	293	302
3. Line Section	94	88	73	193	168	152	226	208	205
BRACING (TON)									
1. Highway Tunnel	1,195	1,043	914	1,307	1,062	958	1,260	1,047	954
2. Transit Station*	-	1,539	1,364	-	1,566	1,384	-	1,540	1,353
3. Line Section	1,288	1,125	1,058	1,427	1,119	1,064	1,327	1,110	1,067
EXCAVATION (CY)									
1. Highway Tunnel	8.86	7.81	7.51	8.82	7.87	7.58	8.88	7.89	7.57
2. Transit Station	-	9.71	9.19	-	9.93	9.40	-	9.81	9.23
3. Line Section	9.57	8.33	8.04	9.49	8.34	8.00	9.61	8.38	7.99
PERM STRUCTURE (CY)**									
1. Highway Tunnel	165	153	137	168	159	143	171	160	143
2. Transit Station	-	221	204	-	250	228	-	227	207
3. Line Section	187	166	154	199	177	165	205	179	165

*Includes permanent steel

**Includes all permanent structure costs

1' = 1 ft. = 0.305m

1 SY = 1 sq. yd. = $0.836 m^2$

1 Ton = 907 kg

1 CY = 1 cu. yd. = $0.765 m^3$

One of the most obvious conclusions is that cost increases rapidly with depth of structure regardless of which site, method or structure we are discussing. Cost increases of 50% to 70% are noted from 30 ft. (9.1m) to 70 ft. (21.3m) depths. Although a planner may not have an option in determining depth of structure, it can be important when estimating trade-off costs of alternate alignments.

Another general observation is that internal bracing is generally more cost effective than tiebacks for cut-and-cover tunnels. Although tiebacks are competitive in some cases; and in a few, less expensive than internal bracing, the following discussion relates primarily to internal bracing estimates with special comments on tiebacks as appropriate. Future changes in material prices, or improvement of installation techniques could alter this situation. Therefore, it is necessary to note the trends indicating where such improvements would prove most effective.

4.5.1 - Site 1 Estimates: The ground conditions at site 1 are considered representative of the majority of sites for urban transportation tunnels in the United States. Consequently the evaluations made in comparing construction methods at this site will be used as a yardstick to compare results at other sites. All six combinations of ground support and bracing are compatible to the eight structure and depth situations at this site.

While soldier piles and lagging (SP&L) is most cost effective at the 30 ft. (9.1m) and 50 ft. (15.2m) depths of the highway tunnel the SPTC wall is lowest at the 70 ft. (21.3m) depth. For the station, the precast panel wall (PCP) has the lowest total cost for both the 50 ft. (15.2m) and 70 ft. (21.3m) depth with the SPTC wall a close second. This is due to a larger proportion of diaphragm walls being utilized as permanent structural walls at the two level station. For the rapid transit tunnel the cost of the SP&L wall is well below that of the two diaphragm walls at all depths.

It is of interest to note the difference in efficiencies between the highway tunnel and rapid transit tunnel. For the transit tunnel the difference in cost between SP&L and SPTC estimates increase progressively from 30 ft (9.1m) to 50 ft (15.2m) to 70 ft (21.3m). For the highway tunnel, the difference decreases from 30 ft. (9.1m) to 50 ft. (15.2m), and at 70 ft. (21.3m) the SPTC wall is less expensive. A review of activity cost summaries in Appendix C shows this change is due to increased cost of item C (adjacent structure protection-underpinning) for deeper sections of the highway tunnel. The transit tunnel is narrow compared to street width and does not require underpinning of adjacent structures. This shows quite clearly that where underpinning costs are high, they could offset the apparent economy of SP&L wall construction. This factor affects the economies of both wide structures, the highway tunnel and station.

The width of structure also affects the economy of internal and tieback bracing. The two bracing systems are roughly the same for each type of wall system at all three depths of the wide highway tunnel. At the narrow transit tunnel they are competitive only at 30 ft. (9.1m), with tieback bracing increasingly more expensive at 50 ft. (15.2m) and 70 ft. (21.3m). A review of activity G costs for the stations in Appendix C indicate lower costs of tieback bracing compared to internal bracing. This is due to the fact that the permanent steel of the roof and mezzanine slabs double as temporary steel for the internal bracing methods and are included in item F. In the tieback estimates, the permanent steel is installed with the structure and is included in item I. The apparent low cost of bracing in this case is offset by a higher cost of permanent structure.

4.5.2 Site 2 Estimates: This site has the same alluvial soil as site 1; the only difference being that site 2 has a permanently low water table (below invert). This means that the permanent structure is designed for lighter loads, (not having a water surcharge) and of course, the site does not require dewatering. Estimates at site 2 are consistently lower than comparable estimates at site 1 with differences varying between 6% and 12% of total cost. With comparable estimates at both extremes of high and low water tables it would not be difficult to interpolate costs for a situation partway between these two. It can be observed that all trends and economies discussed for site 1 also are applicable at site 2.

4.5.3 Site 3 Estimates: The soil at this site is similar to sites 1 and 2, with a high water table as at site 1. Unlike site 1, however, the water table cannot be lowered. These estimates include dewatering within the diaphragm walls with a recharge system maintaining the high water table outside. For sites where these conditions exist, each must be assessed individually as to its capability of being successfully recharged. Soldier pile and lagging construction is precluded by these conditions because this type of wall is not watertight.

The SPTC and PCP estimates prepared for site 3 vary from 1% to 12% higher than the comparable estimates at site 1 where the water table can be lowered. In general, differences are less at the shallow depths and increase with depth. Variations in three major work activities contribute to these increased costs. Dewatering and recharge costs are slightly higher than site 1, but the main difference is in the cost of ground support walls and bracing. Due to the high water table during construction, the walls and bracing must be heavier to support the added head of water, and the cutoff walls are lengthened to prevent boiling of the invert.

Tiebacks are longer and more difficult to install in wet soil, adding to the cost of these estimates. It can be seen on Table 19 that tieback/internal bracing cost ratio is higher at site 3 than at site 1, and that the differences increase with depth due to the greater number of ties required. In general, tiebacks are less competitive at site 3 than site 1. Otherwise the same general trends of economies and efficiencies noted for site 1 are present for site 3. The SPTC walls are most cost effective for the highway tunnel and transit tunnel for all depths, and the precast panel wall less expensive for the station at both depths. As at site 1 the economy of the panels are more effective on the two-level station than the single-level tunnels.

4.5.4 - <u>Site 4 Estimates</u>: Unlike sites 1, 2 and 3, site 4 does not have uniform soil conditions at all depths. Sand exists from ground level to 30 ft. (9.1m) and from 50 ft. (15.2m) to 60 ft. (18.3m). There is a silt layer from 30 ft. (9.1m) to 50 ft. (15.2m) and rock below 60 ft. (18.3m). As in the case of site 3, the water table is high and cannot be lowered, so that soldier pile and lagging estimates have not been considered. While these conditions are less common than site 1 conditions, they have been encountered in some recent sections of transit construction in Washington and Baltimore. Their effects on construction costs are not the same for all depths or structures. Costs generally run higher than at site 1, with internal bracing estimates being up to 10% higher and tieback bracing estimates 8% to 19% higher.

For the 30 ft. (9.1m) and 50 ft. (15.2m) depths the cost differences between site 4 and site 1 estimates are found in the cost of groundwater control, ground support system and excavation. Because of the silt layer it is impractical to recharge the groundwater. Control of groundwater is achieved by trenching and sumping which interferes with, and reduces excavation progress, and increases its cost. The silt layer does not afford the passive resistance of the alluvial soil of site 1 which increases the depth of the cutoff walls required.

At the 70 ft. (21.3m) depth where bedrock is encountered, there are other changes which affect costs. Some of these changes balance each other and so are not immediately apparent. The diaphragm walls must be structurally keyed into rock and properly sealed. The remaining rock to invert must be removed by drilling and blasting. In addition, the walls must be moved out to allow a reasonable "step" in the rock before excavating down. This increases the cost of earth excavation and backfill with minor increases in decking width and strut length. On the other hand, since the ground wall is keyed into rock at 60 ft. (18.3m) it eliminates the need for a deep cutoff below the invert as at site 3. This saving is higher for SPTC walls than for PCP walls as the SPTC cutoff contains more concrete and steel, while most of the cutoff of PCP walls are hardened cement slurry mix. The additional costs and savings result in the internal bracing estimate costs to be roughly on a par with comparable site 3 estimates at 70 ft. (21.3m) despite the problems with silt and rock.

In the case of tieback estimates, however, the savings do not offset the higher cost of tieback installation. Tiebacks cannot be successfully anchored in the compressible silt layer. Anchors above it can be installed on comparatively flat angles. In the silt layer itself, the ties must be angled down and lengthened to develop anchorage in the sand or rock layers below. This increases the cost of the tieback estimates in general, particularly at the 50 ft. (15.2m) and 70 ft. (21.3m) depths. Actually the tieback estimates are not competitive with internal bracing at any situation at site 4, and short of a dramatic breakthrough of installation costs need not be considered under these conditions. As in the case of site 3, SPTC wall estimates are most economical for the highway and transit tunnels while the PCP wall estimates are less expensive for the stations.

4.5.5 - Site 5 Estimates - Site 5 consists of soft clay below fill to a depth of 70 ft. (21.3m) where it is underlain by stiff clay. It has a high water table which cannot be lowered. The soft compressible clay not only precludes predrainage but also all use of tiebacks. Due to the need to maintain the high water table, SP&L wall support estimates are not used, reducing the possible support variations to two, SPTC or PCP with internal bracing. The major effect on costs is the presence of soft clay. It is difficult to drain and expensive to excavate. As in the case of the silt layer at site 4, the soft clay is not capable of developing sufficient passive resistance for the support wall. The diaphragm wall must be extended to penetrate the stiff clay layer for all depths of structure. This also increases the load carried resulting in heavier walls and bracing than other sites.

These factors result in higher costs at site 5 than any other sites for comparable internal bracing estimates. Cost increases over site 1 estimates vary from 4% to 30% with the respective increases of SPTC wall and PCP wall estimates about the same. Due mainly to the extra long cutoff walls at the shallow sections, the largest percentage increases are at 30 ft. (9.1m) and decrease at 70 ft. (21.3m). This is opposite to some of the cost trends noted at other sites.

With respect to cost comparisons on the basis of ground support, the same trends noted for sites 3 and 4 apply. The SPTC wall estimates are most economical for the highway and transit tunnels while the PCP wall estimates are less expensive for the station.

4.6 COST OF APPENDAGE STRUCTURES

As previously mentioned, the cost estimates apply only to the structural shells of the three transit structures. In all likelihood, however, there will be appendage structures such as vent shafts and entrances associated with each situation. In order to appraise the overall cost of a project, estimates were made for several structures that may be included in a contract package. Table 21 lists estimated bid prices of these ancillary structures based on method and depth of construction.

When evaluating different projects, costs of included appendages could be added to the bid prices given on Table 19. For instance, a transit station constructed by precast panel method at a 70-foot (21.3m) depth may require two entrances (2 x $355,000), one vent shaft ($495,000) and one emergency exit ($320,000). The structure bid price would be increased by approximately $1,525,000 to allow for this additional construction.

Although entrances and shafts would be specified in final design, there may be instances; such as at a high water table

Table 21. ESTIMATED BID PRICES ($) FOR TYPICAL APPENDAGE STRUCTURES AND END BULKHEADS

STRUCTURE	TUNNEL DEPTH	STRUCTURE BUILT WITHIN OUTER EXCAV LIMITS OF TUNNEL	STRUCTURE BUILT OUTSIDE GENERAL EXCAVATION		
			SOLDIER PILES & LAGGING	CAST-IN-PLACE (SPTC)	PRECAST CONC PANELS
STATION ENTRANCE	50	N.A.	180,000	185,000	175,000
	70		335,000	385,000	355,000
EMERGENCY EXIT	30	40,000	90,000	100,000	95,000
	50	85,000	185,000	215,000	195,000
	70	115,000	295,000	350,000	320,000
VENT SHAFT	30	60,000	145,000	155,000	150,000
	50	130,000	285,000	340,000	295,000
	70	180,000	455,000	545,000	495,000
END BULKHEADS:					
HIGHWAY TUNNEL	30		45,000	65,000	70,000
	50	N.A.	105,000	160,000	165,000
	70		215,000	340,000	335,000
RAPID TR. TUNNEL	30		20,000	30,000	30,000
	50	N.A.	40,000	65,000	65,000
	70		70,000	110,000	105,000

NOTES: Station entrance excavation to mezzanine level only, other structures excavated to base slab.
Cost of mechanical equipment not included.
End bulkheads may or may not be required depending on contract packages.

1 ft. = 0.305m

site that could not be dewatered, where the need for adequate end bulkheads may be left to the discretion of the contractor. In this case, and depending on sequencing and interface requirements of contiguous contracts, it may be necessary to include the cost of end bulkheads in applicable construction estimates. They have not been included in total bid prices or other summaries for the highway and rapid transit tunnels, but could be added as shown on Table 21. The station estimates include the cost of end bulkheads.

4.7 NEW TECHNOLOGIES

History has shown that new technological developments, resource considerations and various environmental aspects have affected construction work in many different ways. Some, such as the tunnel boring machine have enabled the industry to offset, to a certain degree, the inflationary increases in costs experienced in recent years. Others have contributed significantly to increased costs.

How new techniques would affect future construction is hard to predict. Although each would have a different effect on various situations, a general evaluation could be made by considering the relative mix of cost components as given on page 100 By adjusting each component percentage-wise in accordance with best appraisal of potential effect of new technologies, it would be possible to make an approximation of total cost variation. Assuming a new technology would save 15% of the labor while adding 25% to the equipment cost required for a precast panel job, the estimated bid price would be about 95% of that listed for the particular situation on Table 19, or a net saving of 5%. $\left[1.00 - (0.45 \times 0.15) + (0.05 \times 0.25)\right] = 5\%$.

4.8 SUMMARY

This section illustrates how construction costs can be determined for many cut-and-cover tunneling situations. Due to the many variables involved, there is no quick and easy solution. Each situation must be evaluated separately. Estimate adjustments require a general knowledge of how cost data is developed and how it is affected by varying work requirements.

Cost data provided in Appendix C and Volume 3 enable the planner to compare 176 situations. Significant differences in activity costs due to methods of construction can be identified. The bar graph of Figure 19 provides a visual comparison when considering different methods for a transit line section. It can be seen that some of the activities show greater changes than reflected in differences of total project costs and in some cases offset each other. Figure 20 shows a comparison of total costs with respect to bracing methods and width and depth of structure. Other graphs or charts could be prepared for specific planning or study purposes.

By following the examples and using the various tables, a planner should soon be able to make reliable estimates for new situations.

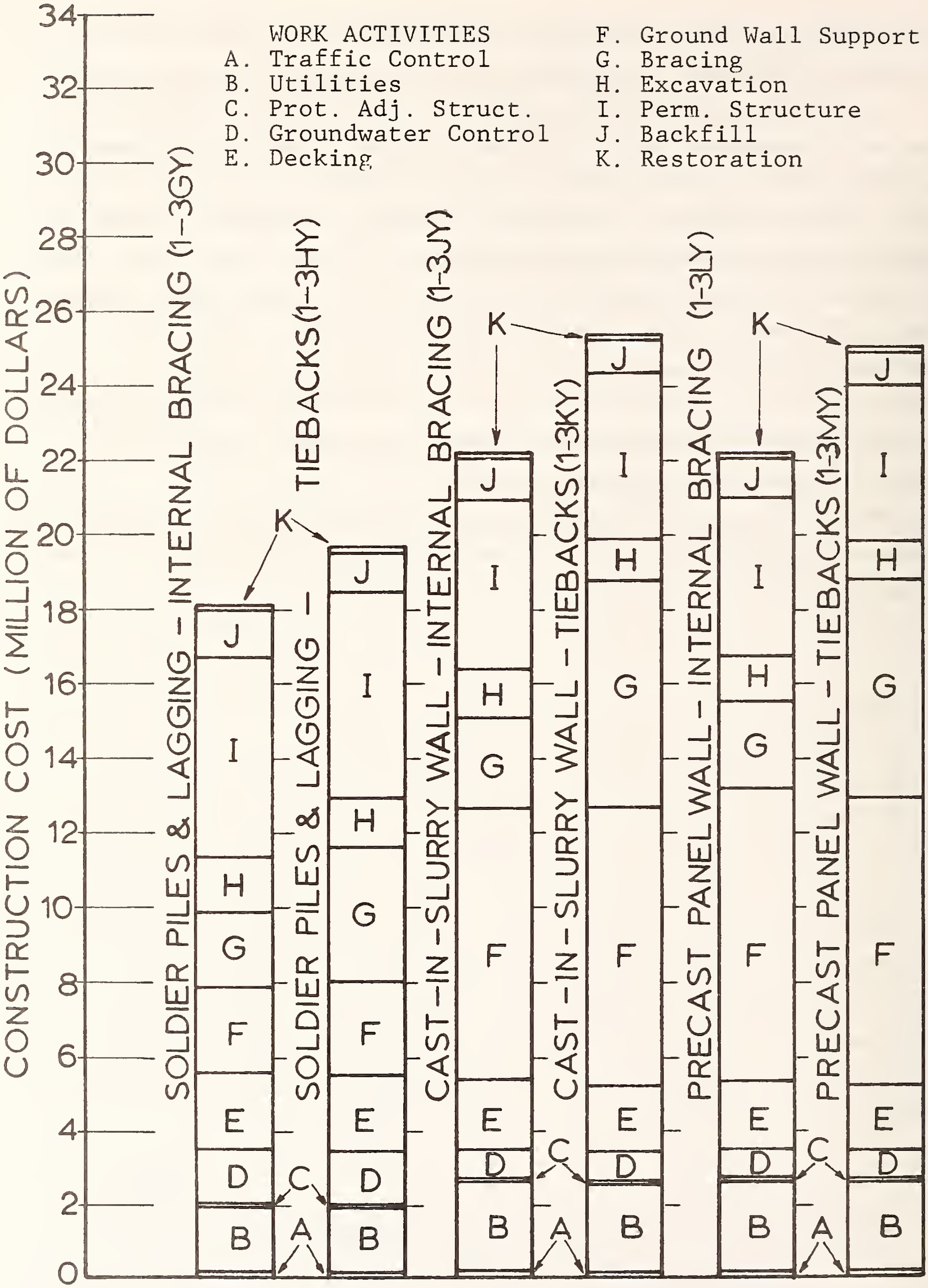


Figure 19. RAPID TRANSIT LINE SECTION
70' DEPTH – HIGH GROUNDWATER

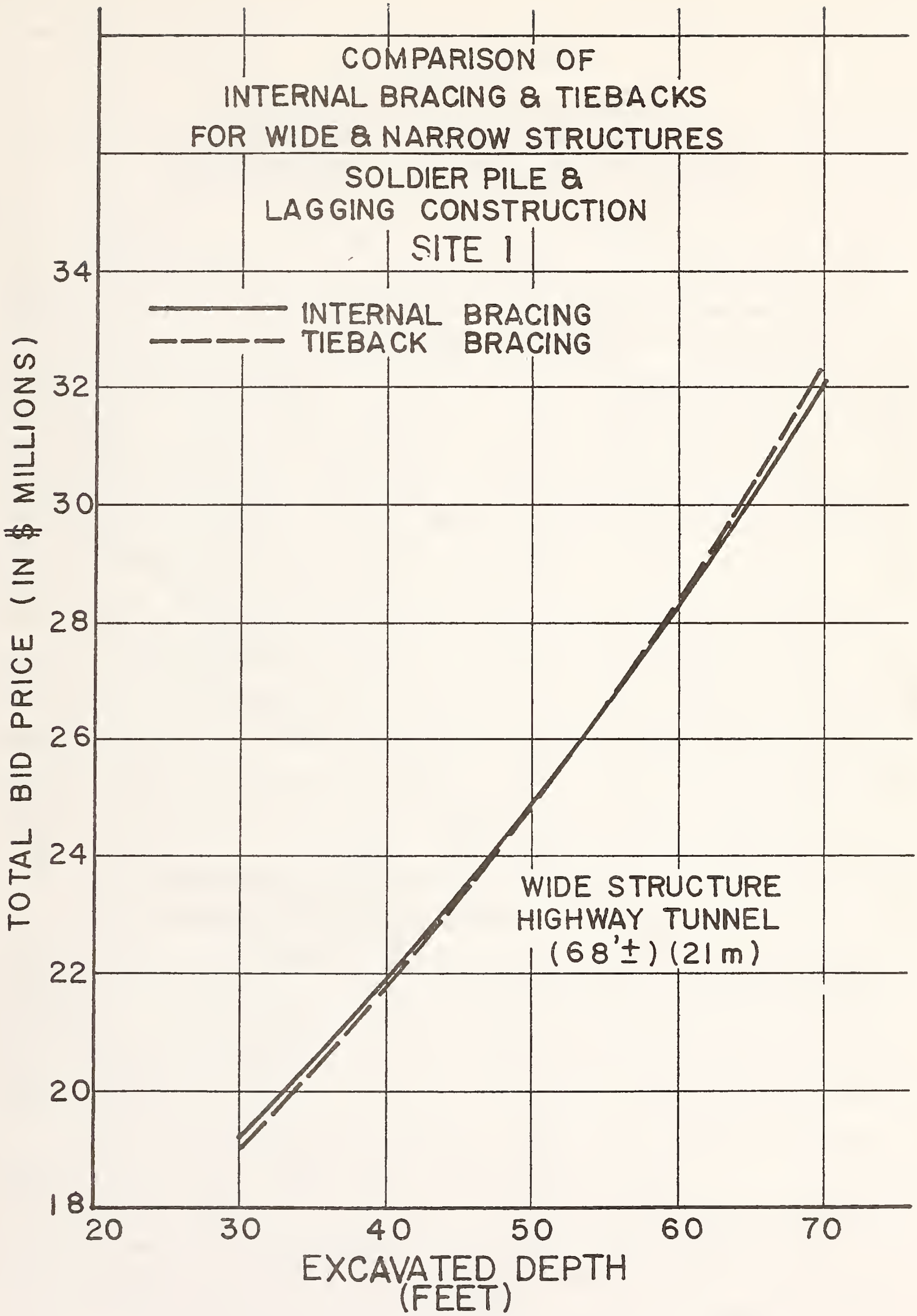


Figure 20. COMPARISON OF BRACING METHODS

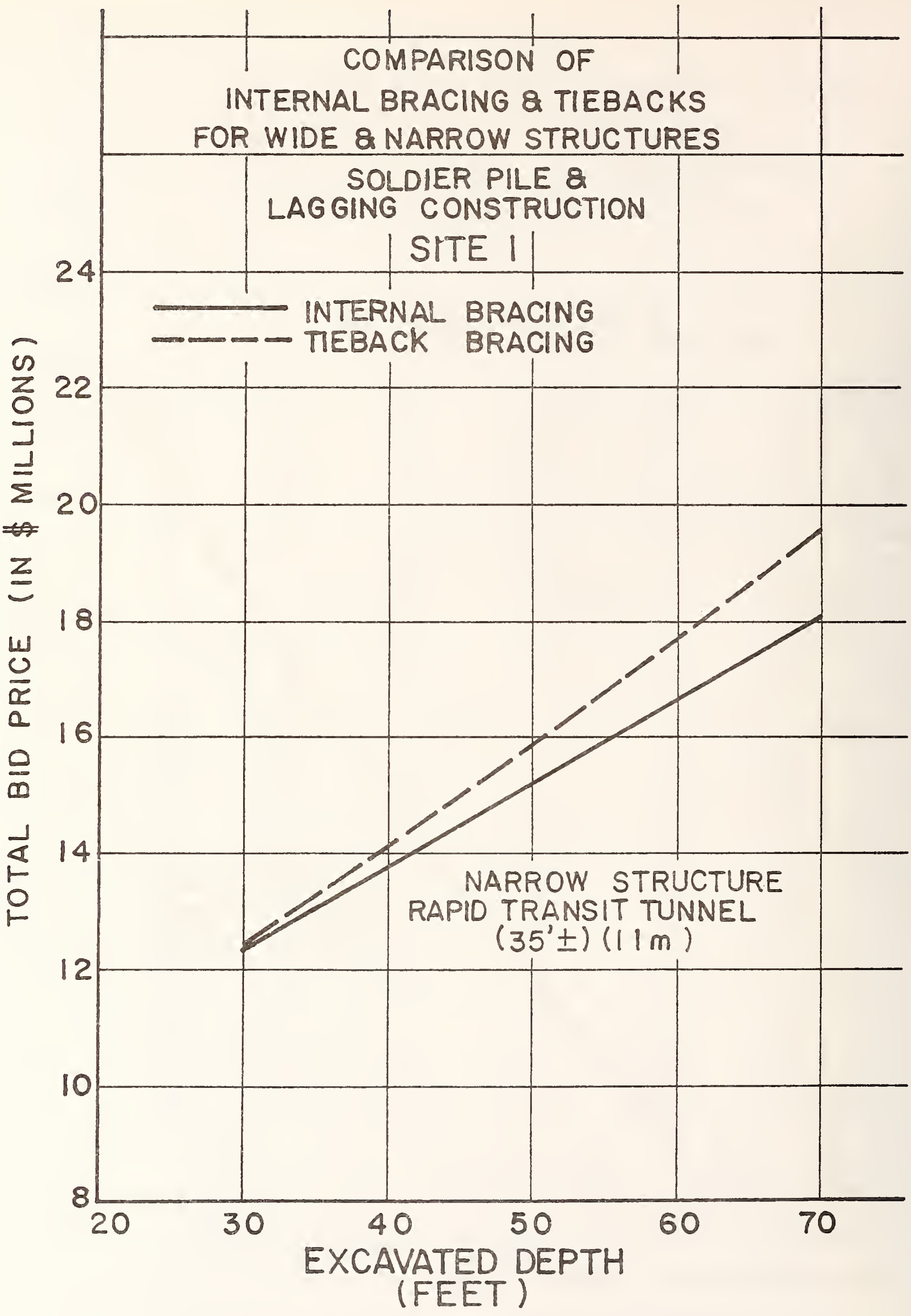


Figure 20. COMPARISON OF BRACING METHODS (Continued)

SECTION 5
RATIONALE FOR QUANTIFYING ENVIRONMENTAL DISTURBANCE AND DISRUPTION

5.1 GENERAL

Quantification of disruption to the socio-economic environment poses a complicated problem in the overall evaluation of cut-and-cover construction in urban areas. Most studies dealing with the impact of transportation schemes relate primarily to "long term" effects of the completed system rather than the relatively "short term" impacts experienced during the actual construction. Some short term disturbances can be generalized in a more or less quantitative manner, others can only be considered in a qualitative sense reflecting the opinions of those making the analysis.

Certain impacts change with time. For instance, an initial disturbance of having to walk two additional blocks to the office may likely be accepted as a normal condition within a short period of time. Conversely, temporary patronage of a nearby competitive retail store may soon result in a permanent loss of trade for a construction-affected store. Quantifying verbal complaints or aesthetic displeasures is impossible.

Many of the disruptive influences are more dependent on the physical dimensions of the work than on the method of construction being used. Regardless of method, the disruption caused by constructing a narrow transit line section in the middle of a wide street would be small compared to that caused by a highway or station section built within the confines of a narrow street.

In all instances the adverse impacts are relative to the sensitivity of the urban site and adjacent area.

A requirement of the study is to develop a rationale for quantifying in dollars the environmental disturbances and disruptions caused by three methods of cut-and-cover construction. These disruptions, which include different physical, social and economic elements, are considered with respect to three measurable criteria: 1) Business, 2) Social, and 3) Safety. Although interrelated, each is treated separately and then combined in final quantification. In essence, the adverse effects of construction on local businesses are considered as negative impacts. That is, the quantification is measured as the potential loss of revenue. In an opposite sense, social disruptions are measured as the additional time and effort (equated to dollars) required to perform normal daily routines. The safety criterion is related to types and total cost of construction.

A dollar amount is established which reflects a preconstruction value against which each criterion is measured or evaluated. These amounts; referred to as "value bases," are dependent on the characteristics of the site and on project requirements.

Possibilities, such as agency purchase and subsequent sale of adjoining property or other redevelopment schemes which tend to mitigate disruptive impacts are not considered, nor is allowance made for long-term effects which are assumed to be comparable in all instances. The initial planning and design of a project normally includes the investigation and specification of certain traffic patterns, utility relocations, etc. which must be adhered to during construction. Although these requirements can be attributed to disruptive aspects of cut-and-cover operations, additional cost involved is assumed to be reflected in project bid prices and therefore not included in this rationale. No distinction is made as to whether the cost of disruption is to be borne by the contracting agency, contractor, private enterprises or the general public.

The following paragraphs outline the proposed rationale. The intent is to develop a methodology by which reasonable assessments in terms of dollars can be made. The assessments should be considered primarily as a means by which relative comparisons of impacts can be made for different situations and construction methods. They deal with disturbances experienced within the immediate construction area and do not relate to compromising off-site impacts which may occur.

5.2 VALUE BASES

To quantify any set of conditions in dollars, it is necessary to have a common monetary or value base by which the relative effects of considered factors can be measured. Since each quantification criterion (Business, Social and Safety) is affected by and reflects different conditions, it is necessary to establish a value base for each. All are dependent on the existing socio-economic and physical conditions peculiar to the site and project being studied. Even when considering the same disruptions, the dollar impact or cost would be considerably different within a highly developed business district than in a residential area.

As used herein, a value base is a predetermined dollar amount used as a datum against which the effects of construction disturbances are measured. In some instances, it may be possible to establish a reliable base, in others it will be necessary to use "best judgment" based on available information. The following paragraphs describe how dollar amounts are determined for each of the value bases.

5.2.1 Business: This criterion deals with the potential financial loss incurred by businesses immediately adjacent to the construction (street frontage). Consequently, the value base must reflect a dollar amount representing the volume of sales, service, etc. that would be affected by cut-and-cover operations. It is determined by considering the total annual volume for the year just prior to start of construction. Although each site would present different factors, conditions and mix of commercial enterprises, it is assumed that the following tabulation is indicative of a typical business-commercial section affected by the construction of a 2,000-foot (610m) long highway structure.

Type of Business	% of Total Establishments	Estimated Annual Volume	% of Annual Volume
Retail and Services	70	$40,000,000	83
Offices, etc.	25	6,000,000	13
Entertainment	5	2,000,000	4

Similar tabulations showing average or approximate annual dollar volumes for specific urban sites could be prepared by using information from local Chambers of Commerce or other agencies. If factual data were not available, it would be necessary to make general assumptions of the prevailing business activity.

In quantifying the potential impact, it is also necessary to make some evaluation of the financial stability or status of affected businesses. It would not be reasonable to include in the cost of disruption the dollar amounts representing businesses which may be on the verge of bankruptcy; contemplating a move to a new location, or making other changes which would occur regardless whether the construction was undertaken or not. Some of the factors to consider are:

1. Are the existing businesses thriving or just breaking even?
2. Are there comparable retail and service facilities located within the general area or at a nearby shopping complex? The auto-oriented shopper would probably consider an additional few miles of driving as incidental compared to a few minutes of inconvenience due to construction.
3. Are the services unique and not easily duplicated?
4. Are the businesses daytime oriented, or do they depend primarily on nighttime patronage when construction activities are generally minimized?

These and other conditions, which should be investigated for each area, can be summarized as a "stability factor." For purposes of this analysis it is suggested that factors ranging from 0.5 to 0.9 be used. A factor of 0.5 representing a business situation which is very marginable, i.e. might possibly close or move regardless of the construction. A factor of 0.9 reflecting a stable business in which loss of revenue could be attributed to the construction. Stability factors would be determined for the respective types of businesses involved. Multiplying the estimated annual volume by the assigned stability factor gives the dollar amount (value base) by which the disruptions of cut-and-cover construction are measured. For example, assuming a business situation with a mix and dollar volume as shown on the preceding page and stability factors of 0.5 for retail and services, and 0.90 for both offices and entertainment the determined value base would be $27,200,000.

In some instances there could be positive aspects which might affect the value base. The potential loss of business by a retail clothing store may be offset by an equal volume of business generated by a short-order diner established primarily to serve construction workers. Revenues lost by construction-affected stores may be reflected as increased sales for comparable stores within the general area. Although these and other posssibilities should probably be considered, it is likely that any attempt to do so would be so involved, and of such a random nature as to contribute little to the quantification process.

5.2.2 Social: This criterion includes many intangible elements attributable to cut-and-cover construction such as noise and air pollution, aesthetics and inconvenience to pedestrians and traffic. Some can be summarily quantified as contributing to adverse economic impacts as discussed in paragraph 5.2.1. Others would be practically impossible to quantify in terms of dollars.

Some of the disturbances are being controlled or eliminated through efforts of agencies like OSHA or EPA. Noise can be reduced by use of mufflers or other sound dampening procedures which could increase initial cost of some construction equipment by about 10 percent. Sweeping and washing of streets or wetting of dust contributing materials help in reducing air pollution. Covered and decorative walkways will be provided for pedestrians. Although there may be variations in associated costs depending on method of construction, it is doubtful that differential dollar values could be assigned. A method using slurry would require an increased effort for cleaning streets, while noise control would be more critical when driving soldier piles. Since it is likely that contract documents will contain regulatory provisions covering most of these disruptive elements, it is assumed that costs to comply will be included in initial bid prices and therefore not considered in this value base. Costs would be essentially the same for all three methods of construction.

A disturbance which can be quantified is the inconvenience to pedestrian and vehicular traffic caused by the construction. The magnitude of this disturbance is dependent on volume of traffic through the construction site and the convenience afforded by alternate routes or bypasses. Vehicular traffic can be defined as commercial (delivery trucks, etc.) and non-commercial (private cars, transit, etc.).

There are many physiological and philosophical methods of evaluating public inconvenience but for purposes of this rationale the following is used:

The inconvenience caused pedestrians and vehicles by construction activities is measured as additional increments of time (quantified in dollars) required to accomplish normal daily routines. Therefore, the value base needed to appraise the social criterion must reflect an equivalent dollar amount of pre-construction daily routines. It is determined by considering: 1) the approximate number of pedestrian and vehicle trips per day, 2) time required for each trip and 3) an evaluation of the dollar equivalent of time expended.

Number of trips per day within or through the site can be determined from traffic surveys taken prior to construction and could be identified as follows:

	Low Density Trips/day	Med. Density Trips/day	High Density Trips/day
Pedestrian	300 - 700	700 - 1,500	1,500 - 2,500
Commercial Vehicles	30 - 50	50 - 80	80 - 120
Non-Commercial Vehicles	200 - 600	600 - 1,200	1,200 - 2,000

An approximation of time required for each trip; which can also be assessed from pre-construction activities, may be as shown below:

Pedestrian	8 minutes
Commercial Vehicles	20 minutes
Non Commercial Vehicles	3 minutes

The value of time is arbitrarily taken as:

Pedestrian	\$ 8.00 per hour
Commercial Vehicles	\$30.00 per hour
Non Commercial Vehicles	\$15.00 per hour

Assuming 250 days per year, the social value base for a median density situation would range from \$425,000 to \$825,000.

5.2.3 Safety: An important aspect of any cut-and-cover construction is safety. This applies not only to the work itself, but also the general public and adjoining buildings and facilities. Although every effort is made to assure a safe job, actual experience is usually somewhat less than perfect. Each construction and urban site present different factors and conditions which would affect this criterion.

Many of the major elements involved such as ground or surface water control, underpinning, protection of adjacent buildings and ground stability are specified in the documents and associated costs allowed for in total bid prices.

There are, however, other costs not normally included in initial evaluations. They pertain to such items as bodily injury and property damage claims resulting from the construction. Although these claims are generally handled through various insurances, they represent additional cost of the work. Since they usually relate to the total dollar amount of the contract, the value base for the safety criterion is taken as the bid price of the construction.

5.2.4 Summary: The three value bases provide datums by which the disturbances and disruptions of cut-and-cover construction not normally allowed for in initial bid prices can be quantified. Each base is affected by different aspects of the construction. In most cases, the adverse impacts are due more to cut-and-cover operations per se than to a particular method of construction. Also, physical features and configurations of the urban site can have a greater affect on the cost of disruption than the method of construction used.

The business and social value bases will be adjusted by means of weighted factors reflecting the relative impacts of various construction activities. The dollar difference between the original and factored bases is taken as the quantified cost of disruption. It is apparent that this method is dependent on initial appraisal of the value bases. The dollar amounts in the examples are used merely to illustrate the rationale and may or may not be typical of any particular site.

The value base (bid price) considered for the safety criterion is already used as a general measure for evaluating safety aspects of construction. For purposes of this rationale, it is factored by means of percentages determined from historical records pertaining to safety experience of various cut-and-cover projects.

Although the value bases are defined for cut-and-cover operations, it is likely that the same or similar bases could be used in evaluating the impact of underground or other surface construction. By developing and using comparable value bases, relative cost of disruptions could be determined for different modes of construction.

The discussion of business and social bases relates to a commercial area. In areas of high rise apartments or single family residences, the determination of dollar amounts for businesses and pedestrian and vehicle trips would be based on actual conditions of the site. The business value base for apartments could be considered as the total annual rent payments of the affected buildings. Due to the temporary nature of construction, the stability factor would probably be considered as 0.8 or 0.9. These and similar evaluations would be made for each construction situation.

5.3 WEIGHTING FACTORS - BUSINESS AND SOCIAL

Factors affecting the business and social value bases are considered with respect to: 1) time and 2) the physical dimensions of the construction and site.

Time-related disruptions vary in both duration and magnitude. The general nuisance of any construction work over an extended period of time has a definite impact on the environment. The magnitude of this impact is dependent on the physical dimensions or characteristics of the site and the type of construction activity being performed.

Physical dimensions defining the length, width and depth of construction are essentially set by contract documents. Although these dimensions may vary slightly depending on method of construction, the magnitude of disruption is dependent primarily on the overall relationship between the size of the structure and available street area within which the construction is made. A method requiring an additional 5 feet (1.5m) of excavation width to accommodate the ground support system as compared to another, (soldier pile and lagging vs. precast diaphragms) would cause little difference in total disruption if the street was wide. On the other hand, if the street was narrow, this additional 5-foot (1.5m) width could preclude the use of one lane of traffic which would have a significant effect on disruption.

Although there are many possibilities which might be considered, for purposes of this rationale the business and social value bases are factored as discussed in the following paragraphs.

5.3.1 Time-Related - Duration: This element of disruption relates to total time required to complete the construction regardless of method being used or structure being built. Its exact effect on business and social value bases is hard to specify except in a general sense that business activity would decline over an extended period of time and that inconvenience to pedestrian and vehicular traffic would continue in proportion to time.

Some businesses may close after a few months of disruption; some may move to a new location while others may continue "business-as-usual." Variations in total volume of business during the construction might possibly be obtained from the Internal Revenue Service, Merchant Associations or similar agencies. However, even if available, it would be necessary to make determinations as to whether or not the changes were due primarily to construction activities or to other economic conditions. This relates to the stability factor previously mentioned.

Various mathematical calculations can be made to determine the additional time required to complete "pre-construction routines" during the course of construction. Assuming the same number of vehicle and pedestrian trips would be made; either through or around the construction, the quantification of disruption for the social base would be proportional to the percentage increase in time for trip and the duration of disruption in terms of years.

In line with the above, suggested weighting factors assigned to this element of disruption are given below:

Adjustment Factors for Duration

Value	Duration of Construction				
Base	24 mo.	28 mo.	32 mo.	36 mo.	40 mo.
Business	0.89	0.88	0.87	0.85	0.84
Social	1.50	1.65	1.80	1.95	2.10

These factors are based on preliminary evaluations of potential loss of business over an extended period of time and the continued disruption of pedestrian and vehicle traffic during construction. They are applicable to all three methods of construction. Factors for other duration times would be extrapolated from the given values.

Another aspect of duration is its relation to the calendar year. A construction requiring 28 months to complete could disrupt two or three Christmas seasons depending on month of start. Although the same duration is considered, the potential impact would be greater if three seasons were involved. This condition should be considered in the initial planning phase.

5.3.2 Time-Related - Magnitude: This factor relates to the magnitude of disruption and corresponding completion time of each of the eleven major construction activities (see Section 1). An activity that causes severe surface disruption, such as decking, contributes more to the total disruption than say groundwater control. Also, the effect of each activity on total disruption varies with depth. The disruption caused by the decking activity for a highway structure would be essentially the same in all cases but would represent a greater percent of total job disruption at the shallower depths. To show this relationship between activity disruption and times, with respect to type of structure and method of construction, an evaluation matrix was prepared for nine situations at a 70-foot (21.3m) depth. See Table 22.

The 'weighting factors' listed on Table 22 show the relative disruption caused by each activity with respect to total disruption based on a scale of 100. Values assigned represent "best judgment" when considering the different combinations of transit structure and construction method. Time to complete an activity is determined from basic estimates and schedules presented in Section 3. The 'scoring factors' indicate the relationship of times to complete the same activity for a particular structure when using different construction methods. For example, when considering a highway structure, the time to complete activity C using the soldier pile and lagging method is two and a half times longer than

Table 22. MAGNITUDE OF DISRUPTION - EVALUATION MATRIX

HIGHWAY TUNNEL

ACTIVITY		SOLDIER PILES & LAGGING			CAST-IN-SLURRY (SPTC)			PRECAST CONCRETE PANELS		
		Weighting Factor	Scoring Factor	Weighted Score	Weighting Factor	Scoring Factor	Weighted Score	Weighting Factor	Scoring Factor	Weighted Score
A	TRAFFIC CONTROL	3	1.0	3.0	4	1.0	4.0	4	1.0	4.0
B	UTILITY WORK	15	1.0	15.0	17	1.0	17.0	16	1.0	16.0
C	PROTECT. ADJ. STRUCT.	8	2.5	20.0	2	1.0	2.0	2	1.0	2.0
D	GROUNDWATER CONTROL	3	1.1	3.3	1	1.1	1.1	1	1.0	1.0
E	DECKING	22	1.0	22.0	22	1.0	22.0	22	1.0	22.0
F	GROUND WALL SUPPORT	12	1.0	12.0	17	1.5	25.5	18	1.83	32.9
G	BRACING	2	1.0	2.0	2	1.0	2.0	2	1.0	2.0
H	EXCAVATION	12	1.0	12.0	12	1.0	12.0	12	1.0	12.0
I	CONST. PERM. STRUCT.	12	1.14	13.7	12	1.14	13.7	12	1.0	12.0
J	BACKFILL	6	1.0	6.0	6	1.0	6.0	6	1.0	6.0
K	RESTORATION	5	1.0	5.0	5	1.0	5.0	5	1.0	5.0
WEIGHTED SCORE				114.00			110.30			114.90
SOCIAL FACTOR				1.14			1.10			1.15
BUSINESS FACTOR				0.88			0.91			0.87

Table 22. MAGNITUDE OF DISRUPTION - EVALUATION MATRIX (continued)

RAPID TRANSIT STATION

	ACTIVITY	SOLDIER PILES & LAGGING			CAST-IN-SLURRY (SPTC)			PRECAST CONCRETE PANELS		
		Weighting Factor	Scoring Factor	Weighted Score	Weighting Factor	Scoring Factor	Weighted Score	Weighting Factor	Scoring Factor	Weighted Score
A	TRAFFIC CONTROL	3	1.0	3.0	4	1.0	4.0	4	1.0	4.0
B	UTILITY WORK	15	1.0	15.0	17	1.19	20.2	16	1.19	19.1
C	PROTECT. ADJ. STRUCT.	8	2.67	21.4	2	1.0	2.0	2	1.0	2.0
D	GROUNDWATER CONTROL	3	1.1	3.3	1	1.1	1.1	1	1.0	1.0
E	DECKING	22	1.0	22.0	22	1.0	22.0	22	1.0	22.0
F	GROUND WALL SUPPORT	12	1.0	12.0	17	1.5	25.5	18	1.75	31.5
G	BRACING	2	1.0	2.0	2	1.0	2.0	2	1.0	2.0
H	EXCAVATION	12	1.04	12.5	12	1.0	12.0	12	1.0	12.0
I	CONST. PERM. STRUCT.	12	1.27	15.2	12	1.27	15.2	12	1.0	12.0
J	BACKFILL	6	1.0	6.0	6	1.0	6.0	6	1.0	6.0
K	RESTORATION	5	1.0	5.0	5	1.0	5.0	5	1.0	5.0
WEIGHTED SCORE				117.40			115.00			116.60
SOCIAL FACTOR				1.17			1.15			1.16
BUSINESS FACTOR				0.85			0.87			0.86

Table 22. MAGNITUDE OF DISRUPTION - EVALUATION MATRIX (continued)

RAPID TRANSIT LINE SECTION

	ACTIVITY	SOLDIER PILES & LAGGING			CAST-IN-SLURRY (SPTC)			PRECAST CONCRETE PANELS		
		Weighting Factor	Scoring Factor	Weighted Score	Weighting Factor	Scoring Factor	Weighted Score	Weighting Factor	Scoring Factor	Weighted Score
A	TRAFFIC CONTROL	3	1.0	3.0	4	1.0	4.0	4	1.0	4.0
B	UTILITY WORK	15	1.0	15.0	17	1.3	22.4	16	1.54	24.6
C	PROTECT. ADJ. STRUCT.	8	1.0	8.0	2	1.0	2.0	2	1.0	2.0
D	GROUNDWATER CONTROL	3	1.0	3.0	1	1.0	1.0	1	1.0	1.0
E	DECKING	22	1.0	22.0	22	1.0	22.0	22	1.0	22.0
F	GROUND WALL SUPPORT	12	1.0	12.0	17	1.5	25.5	18	1.83	32.9
G	BRACING	2	1.0	2.0	2	1.0	2.0	2	1.0	2.0
H	EXCAVATION	12	1.0	12.0	12	1.0	12.0	12	1.0	12.0
I	CONST. PERM. STRUCT.	12	1.14	13.7	12	1.14	13.7	12	1.0	12.0
J	BACKFILL	6	1.0	6.0	6	1.0	6.0	6	1.0	6.0
K	RESTORATION	5	1.0	5.0	5	1.0	5.0	5	1.0	5.0
WEIGHTED SCORE				101.70			115.60			123.50
SOCIAL FACTOR				1.02			1.16			1.24
BUSINESS FACTOR				0.98			0.86			0.81

when using either of the other methods. The respective scoring factors would be 2.5, 1 and 1. The sum of weighted scores (product of weighting and scoring factors) gives a relative evaluation of the magnitude of disruption for each method of construction.

The average weighted scores for the three transit structures are 111.0 for SP&L; 113.6 for SPTC and 118.3 for PCP. Factors for adjusting both business and social value bases are established by referring these scores to total disruptive measure of 100. Since impact on business criterion reflects a decrease, a reciprocal is used. These adjustment factors are shown below.

Adjustment Factors for Magnitude - 70-Foot Depth

Value Base	SP&L	SPTC	PCP
Business	0.90	0.88	0.85
Social	1.11	1.14	1.18

When considering a specific structure, adjustment factors could be determined from the respective matrix instead of using the average as shown above.

5.3.3 Physical Dimensions: The magnitude of disruption depends to a large extent on the relationship between the physical dimensions of the construction and the width of the street within which the construction is made. It may be possible to make analytical analyses of this relationship but for purposes of this rationale the following is used:

Ratio of Street Width to Width of construction	Adjustment Factors for Dimensions
1:1	1.20
1.5:1	1.08
2:1	1.05

5.3.4 Combined Factors - Magnitude & Dimensions: Since "magnitude" is dependent on "dimensions", a combined weighting factor is used to show their effect on both business and social value bases. The magnitude adjustment factors for "business" are divided by the dimension factor. The magnitude factors for "social" are multiplied by the dimension factor. These combined factors, which indicate the magnitude of disruption caused by different construction methods at 70-foot (21.3m) depths in streets of varying widths, are shown below,

COMBINED WEIGHTING FACTORS - 70 FT (21.3m) DEPTH

Value Base	Method of Construction	Physical Dimension Ratio St. Width to Structure R = 1:1	R = 1.5:1	R = 2:1
Business	SP&L	0.75	0.83	0.86
	SPTC	0.73	0.81	0.84
	PCP	0.71	0.79	0.81
Social	SP&L	1.33	1.20	1.17
	SPTC	1.37	1.23	1.20
	PCP	1.42	1.27	1.24

Combined weighting factors for 50 and 30 foot (15.2m and 9.1m) depths (see following tabulations) were determined in the same general manner as discussed above by developing additional evaluation matrixes for the respective depths.

COMBINED WEIGHTING FACTORS - 50 FT (15.2m) DEPTH

Value Base	Method of Construction	Physical Dimension Ratio St. Width to Structure R = 1:1	R = 1.5:1	R = 2:1
Business	SP&L	0.79	0.86	0.90
	SPTC	0.77	0.84	0.88
	PCP	0.75	0.82	0.85
Social	SP&L	1.28	1.16	1.12
	SPTC	1.31	1.18	1.15
	PCP	1.36	1.22	1.19

COMBINED WEIGHTING FACTORS - 30 FT (9.1m) DEPTH

Value Base	Method of Construction	Physical Dimension Ratio St. Width to Structure R = 1:1	R = 1.5:1	R = 2:1
Business	SP&L	0.82	0.90	0.94
	SPTC	0.80	0.88	0.92
	PCP	0.78	0.86	0.89
Social	SP&L	1.23	1.11	1.08
	SPTC	1.26	1.13	1.11
	PCP	1.30	1.17	1.13

5.4 WEIGHTING FACTOR - SAFETY

The factors used in quantifying the safety value base are based on historical data relating third party claims or damages to the dollar amount of construction involved.

Records of 14 BART cut-and-cover projects totaling some $139,000,000 in cost show third party claims and losses amounting to about $2,400,000 or approximately 1.7 percent of the construction cost. Percentage amount of claims for 12 soldier pile and lagging projects varied from 0.3 percent to 3 percent with an overall average of 1.4 percent. Corresponding percentages for two SPTC projects were 1.0 percent and 4.5 percent with an average of 2.6 percent. No data pertaining to precast diaphragm wall methods were available.

Although the safety experience of any job depends on the individual contractor and the effectiveness of his safety program and method of operation, historical data considered for this study indicates that a reasonable quantification factor would be in the order of 2 percent for soldier pile and lagging method and 2½ percent for the other two methods. These percentages could be adjusted to reflect more detailed information as it becomes available. They could also vary significantly depending on trends of future court decisions with respect to awards for damages.

5.5 COST OF DISRUPTION AND DISTURBANCES

Costs of disruptions are quantified with respect to the three determined value bases - Business, Social and Safety. Each is affected differently by various weighting factors and job conditions. The impact on "business" is more dependent on the magnitude of disruption than on duration. Conversely, duration has a greater impact on "social" than does the magnitude. Data from historical records used to quantify "safety" reflect all factors and job conditions.

Considering the above and previous discussions, the cost of disruption with respect to the business and social value bases would be determined by use of the following equations:

$$C_B = B - \left[B \times (0.40d + 0.60m)\right] \qquad (1)$$

$$C_S = S \times \left[(0.70d + 0.30m) - 1\right] \qquad (2)$$

Where:

C_B = Cost of disruption - business

C_S = Cost of disruption - social

B = Business value base

S = Social value base

d = Adjustment factor for Duration (page 130)

m = Combined weighting factor for Magnitude (pages 136 and 137)

The factor "d" relates to actual project duration and does not vary with respect to other construction conditions. Factor "m" varies with depth, dimension ratios and method of construction; therefore different factors would be used for each situation. In both cases, factors must relate to the "value base" being considered. The decimals; 0.40, 0.60, etc., show the proportion of cost attributed to duration (d) or magnitude (m).

The cost of disruption associated with safety is taken as a percentage of total construction cost and is designated as C_{SA}. The sum of $C_B + C_S + C_{SA}$ equals the quantified cost of disruption. The general relation of factors and equations is shown on Figure 21. The factors for 'magnitude' (m) are those for a construction depth of 70 feet (21.3m).

Adjustment for Business Criterion

$$C_B = B - \left[B \times (0.40d + 0.60m)\right]$$

Business Value Base - 'B'

Duration 0.40

Total Construction Time				
24 Mo	28 Mo	32 Mo	36 Mo	40 Mo
0.89	0.88	0.87	0.85	0.84

Magnitude 0.60

Method of Construction	Ratio - Street W to Const		
	R = 1:1	R = 1.5:1	R = 2:1
Sold Pile & Lag	0.75	0.83	0.86
SPTC	0.73	0.81	0.84
Precast	0.71	0.79	0.81

Adjustment for Social Criterion

$$C_S = S \times \left[(0.70d + .30m) - 1\right]$$

Social Value Base - 'S'

Duration 0.70

Total Construction Time				
24 Mo	28 Mo	32 Mo	36 Mo	40 Mo
1.50	1.65	1.80	1.95	2.10

Magnitude 0.30

Method of Construction	Ratio - Street W to Const		
	R = 1:1	R = 1.5:1	R = 2:1
Sold Pile & Lag	1.33	1.20	1.17
SPTC	1.37	1.23	1.20
Precast	1.42	1.27	1.24

Adjustment for Safety Criterion (C_{SA})

Soldier Pile and Lagging = Construction Cost x 0.02
SPTC and Precast Panels = Construction Cost x 0.025

Cost of Disruption = $C_B + C_S + C_{SA}$

Figure 21. RATIONALE FOR QUANTIFYING COST OF DISRUPTION

If 30-foot or 50-foot (9.1m or 15.2m) depths were considered, applicable factors from pages 136 or 137 would be substituted in the tabulations and used to extend the equations. The following situation illustrates the rationale.

A highway tunnel structure is to be built at an urban site where the street width is one and one-half times the structure width. The depth of construction is 30 feet (9.1m). The business value base has been determined to be $27,200,000; the social value base, $825,000. The estimated cost and time required to complete the structure by three different methods of construction is shown as follows:

Method	Cost	Time
Soldier Pile and Lagging	$19,200,000	28 mo.
Cast-in-Place Concrete	$20,600,000	30 mo.
Precast Concrete	$20,700,000	31 mo.

The cost of disruption would be calculated as shown on Table 23. Summaries are given below:

Cost of Disruption ($1,000)

	Construction Method		
Criteria	Soldier Pile and Lagging	Pour in Place Concrete	Precast Concrete
Business	$2,938	$3,318	$3,672
Social	403	451	483
Safety	384	515	518
Total	$3,725	$4,284	$4,673

Based on conditions of the example and in accordance with the rationale proposed herein, the cost of disruption would be quantified as about $4,227,000 (average value). Soldier pile and lagging method would cause the least disruption. Disruption caused by using the cast-in-place or precast method would be 15 to 25 percent greater.

It is apparent that the major portion of cost (78% $\pm$) relates to business conditions assumed for the site. Using average calculations, the affected businesses would experience

Table 23. DETERMINATION OF COST OF DISRUPTION ($1,000)

EXAMPLE FOR RATIONALE

Soldier Pile and Lagging

$$C_B = 27{,}200 - [27{,}200\ (0.40 \times 0.88 + 0.60 \times 0.90)] = 2{,}938$$

$$C_S = 825 \times [(0.70 \times 1.65 + 0.30 \times 1.11) - 1] = 403$$

$$C_{SA} = 19{,}200 \times 0.02 = \underline{384}$$

$$3{,}725$$

SPTC

$$C_B = 27{,}200 - [27{,}200\ (0.40 \times 0.875 + 0.60 \times 0.88)] = 3{,}318$$

$$C_S = 825 \times [(0.70 \times 1.725 + 0.30 \times 1.13) - 1] = 451$$

$$C_{SA} = 20{,}600 \times 0.025 = \underline{515}$$

$$4{,}284$$

Precast Panels

$$C_B = 27{,}200 - [27{,}200\ (0.40 \times 0.873 + 0.60 \times 0.86)] = 3{,}672$$

$$C_S = 825 \times [(0.70 \times 1.763 + 0.30 \times 1.17) - 1] = 483$$

$$C_{SA} = 20{,}700 \times 0.025 = \underline{518}$$

$$4{,}673$$

a decline in sales (revenue) of about $110,000 per month during the 30 month construction period. Depending on type and size of individual enterprises, their prorated loss may or may not be critical to continued operation.

5.6 SUMMARY

Even though many qualitative aspects of disruption caused by cut-and-cover construction can be readily seen and described, any rationale used to quantify the disruption must at best, be considered only as a pragmatic approach to the problem. The magnitude and relative costs depend upon the particular situation and individuals making the analysis. To fully evaluate the cost of disruption for a specific project would require a study effort which would overlap the actual construction period by several years. Even then the results might not be directly applicable to any other situation.

The proposed rationale relates the cost of disruption to three value bases which to a large extent can be defined in the pre-construction period. For the example used, the affect of disruption on "business" - dollars - was most significant in overall evaluations. However, with the present concern in the United States for improving the environment, it may be that a greater emphasis should be placed on elements of social disruptions such as inconvience or noise or air pollution. It is also apparent that a seemingly minor loss of revenue experienced by a small business or enterprise might be critical to their continuance in business. These physiological aspects will have to be evaluated by different environmental disciplines.

Most disruptions are due more to inherent characteristics of cut-and-cover construction than to any particular method being used and are probably more sensitive to duration than magnitude. Although the various elements considered and the adjustment and weighting factors assigned reflect reasonable evaluations of cut-and-cover operations, considerably more study and factual data will be required before specific values can be developed. The proposed rationale presents a method by which different factors can be assimilated and evaluated so as to give a relative indication of the disruptive impacts involved.

As noted, certain elements of disruption have been excluded on the premise that existing environmental, safety and contractural regulations are such that additional cost of complying would be included in initial bid price of the work. As more regulations are imposed to reduce disruptive impacts, it is reasonable to assume that the cost of construction will increase accordingly. At some point in time it will be necessary to determine the "break-even" point between the cost of the "cure" and the cost of "disruption."

The urban site characteristics, which essentially establish and control the degree and cost of disruption, also materially affect the initial construction cost. A rapid transit station built at a congested downtown site would obviously cost more than one constructed in a vacant tract of land where construction activities would not be hindered by outside influences. The potential combined savings in both construction and disruption with respect to site selection should be considered in initial transit planning.

When considering open-trench construction the very purpose of a transportation system (providing maximum service to largest number of people) is in direct conflict with the existing environment. Facilities must be situated at high density locations which, in turn, are most sensitive to disruptive impacts of construction. Within the limitations of existing technology and as long as the need for mass transit exists, it must be accepted that construction disruption is an inherent characteristic of the transportation system. Fortunately, these disruptions are relatively short term compared to the overall benefit. Within options normally available, the planner can only hope to achieve that type of construction having the least impact on the environment. The rationale presented herein may help in that respect.

The rationale was developed for three open-trench construction methods. Section 8 of the report considers the use of inverted, or "under-the-roof" method of construction. The rationale used to quantify its disruptive impact is similar to the procedure discussed in this section.

SECTION 6
EFFECTIVE COST OF CONSTRUCTION

6.1 GENERAL

Determination of the most efficient construction for a particular cut-and-cover tunneling situation should consider both the cost of construction and cost of disruption associated with feasible alternatives.

Some possibilities may be eliminated by decisions relating to socio-economic or physical requirements of the overall transportation system. A predetermined location of a transit station at a site which can not be dewatered would eliminate the potential use of soldier-piles-and-lagging method of construction. Tieback bracing would not be used if adequate underground easements were not available. It is likely, however, that at least two different construction methods could be considered for each project.

This section of the report shows how the most cost-effective solution can be determined for specific site and design requirements. It considers the total construction rather than individual activities as previously discussed and evaluates each alternative with respect to three parameters.

A. Cost of Construction: To enable the planner to determine that method of construction which would afford least cost of completing a specific structure at a given site.

B. Updating Construction Costs: To enable the planner to make realistic adjustments of costs so as to accommodate variations in prices due to changes in time (year of construction) or location.

C. Cost of Disruption: To enable the planner to quantify in dollars the relative environmental impacts associated with different methods of construction.

The diagram of Figure 22 shows the general procedure of determining effective cost for cut-and-cover tunneling projects.

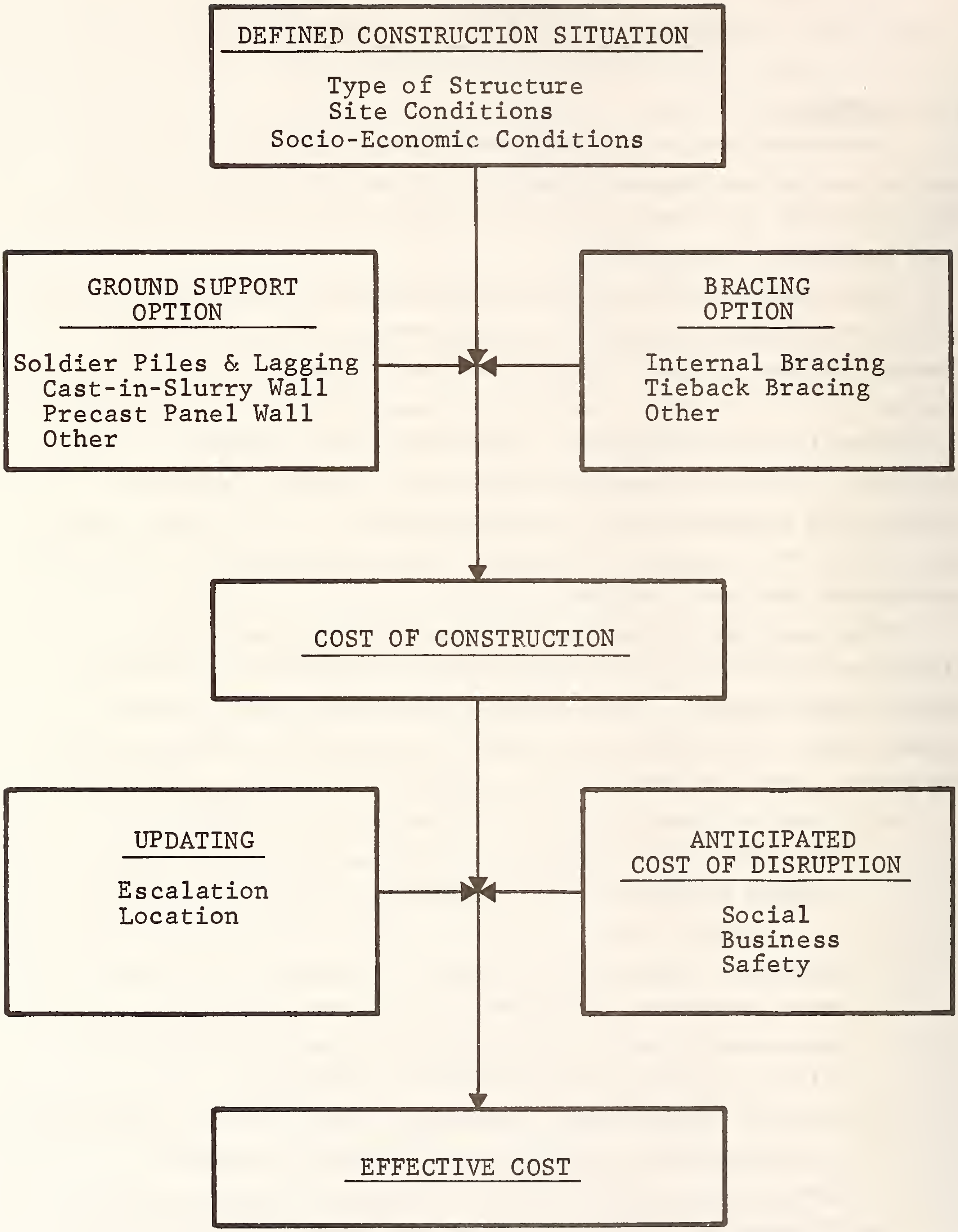


Figure 22. LOGIC DIAGRAM - EFFECTIVE COSTS

6.2 COST OF CONSTRUCTION

Construction cost data, based upon Washington, D.C. prices in 1974, have been used to develop estimated bid prices for 176 different cut-and-cover situations (see Table 19, page 107). An example is given to illustrate how cost estimates can be made for situations with conditions differing from those assumed for the study such as lengths of structures or urban site configurations.

Using the cost data, information, and general procedures given in this report, a planner can make reasonable estimates of cost (parameter A) for most cut-and-cover tunneling projects likely to be considered for future transit construction. Variations in cost due to known differences can be approximated by factoring given bid prices. Adjustments for length of structure can be made as shown in Table 17, page 103. Allowances can also be made for various appendage structures which may be required (Table 21, page 115).

All costs have been developed on the basis of mid 1974 prices applicable to the Washington, D.C. area. In comparing alternatives, it will be necessary to adjust or update costs with respect to prices applicable to the year of construction and location. This is done by factoring basic components of cost as discussed in the following paragraphs.

6.3 UPDATING CONTRUCTION COSTS

The total cost of construction (direct and indirect costs) can be considered with respect to three basic components as shown below:

Components of Cost

Labor	Equipment	Material
Direct	Depreciation	Fuel-Lube
Repair	Parts and tires	Job Materials
Indirect		Perm. Materials

Subcontract work is included with respective components. Contractor's markup is added as a percentage of the total cost.

Each component reflects the summation of many unit prices established for included resources. Table 24 shows typical prices used in the estimates. Since determination of component cost for all situations was based on the same cost data, any variation in prices would be reflected proportionately in all estimates.

Adjustments of cost due to changes in time or location - parameter B - are dependent on: 1) relative percent of total cost represented by each component and 2) variation in basic prices considered for each component.

The percentage of total project cost represented by each component can be determined from analyses of basic estimates as discussed in paragraph 3.4. Average percentages for the three methods of cut-and-cover construction are shown below:

	Percent of Total Cost		
Method of Construction	Labor L	Equipment E	Materials M
Soldier Piles & Lagging	44	5	51
SPTC	40	6	54
Precast Panels	45	5	50

These percentages will vary for each situation. For structures built at a 30-foot (9.1m) depth, the labor component will be a larger proportion of total costs than shown and the material component somewhat less. The opposite would be true when considering construction at a 70-foot (21.3m) depth. There would also be slight variations due to type of structure. The percent of labor for a transit station being higher than for either the highway or line structures. When using tiebacks, labor and equipment will increase with a corresponding decrease in material component. Although these variations might be in the order of plus or minus 3 percent, the given percentages are representative of cut-and-cover construction and can be used to update given costs to evaluate future work.

Table 24. TYPICAL PRICES ($) FOR BASIC COMPONENTS WASHINGTON, D.C. AREA, MID-1974

LABOR WAGES					
CLASSIFICATION	BASE	P.R. TAXES	INS	FRINGES	TOTAL
CARPENTER (FOREMAN)	9.00	0.86	0.90	0.81	11.57
IRON WORKER (STRUCTURAL)	9.50	0.90	0.95	1.05	12.40
LABORER (CONCRETE)	7.48	0.71	0.75	0.73	9.67
OPER. ENG. (CLASS 2)	9.67	0.92	0.97	0.12	11.68
TEAMSTER (FLATBED)	6.35	0.60	0.64	0.45	8.04

MATERIAL PRICES		
ITEM	UNIT	COST
CONCRETE (4000 psi)(27,600 kPa)	CY	29.30
RE STEEL - CUT & BENT	TON	420.00
STRUCTURAL STEEL - WALES & BRACING	TON	500.00
TIMBER - DECKING & LAGGING	MBF	240.00
FUEL - DIESEL	GAL	0.40

EQUIPMENT PURCHASES	
UNIT	F.O.B. COST
2 CY FRONT END LOADER	38,000
12 TON HYDRAULIC CRANE	44,000
10 CY DUMP TRUCK	34,000

Note: 1 CY = $0.765 m^3$, 1 Ton = 907 kg, 1 MBF = $2.36 m^3$, 1 GAL = 3.79 liters

The change in total project cost due to variations in component prices is determined by comparing prices used in the basic estimates (rate deck) with comparable prices pertaining to the new or planned construction situation. Although each component includes many individual items, reasonable evaluations can be made by considering the major items in each. For instance, the material component may include items of concrete, structural steel, wood forms, reinforcing steel, waterproofing material, gravel, form ties, small tools, fuel, etc. If the concrete and steel items represent 60 percent of the total component cost, adjustments could be made by considering only those two items.

By adjusting each component (expressed as percent of total cost) by factors showing differences in price data, it is possible to project costs given herein to some future time or place of construction. The procedure is illustrated by the following equation:

$$E_F = E_B \left[X \frac{L_2}{L_1} + Y \frac{E_2}{E_1} + Z \frac{M_2}{M_1} \right] \qquad (3)$$

Where:

E_F = Estimated cost of future work - year F

E_B = Construction cost as per this study - 1974

X, Y, & Z = Percentages (decimal, for labor, equipment and material components respectively)

L_1, E_1, M_1 = Basic price data (Table 24)

L_2, E_2, M_2 = Projected price data

Adjustments in component costs are determined as follows:

6.3.1 Labor: Basic hourly wages for various labor classifications are shown on Table 24. The actual number and mix of labor such as carpenters and operating engineers varies depending on method and depth of construction and type of structure. By using detailed resource analyses illustrated by Table 11, it is possible to establish typical composite crews for each method of construction. Using these crews and applicable hourly wages, the average hourly labor cost can be determined for each situation. This is shown by the upper part of Table 25. The average costs reflect L_1 values used in equation (3). A corresponding L_2 value would be obtained in the same manner except that hourly labor cost for the proposed construction would be substituted in the Basic Cost column. The ratio of $L_2 \div L_1$ being the labor component adjustment factor.

6.3.2 Equipment: Variation in basic cost for equipment is difficult to specify as it is unlikely that any two individuals would use the same evaluation procedure. One may consider all new equipment, another good used equipment. Costs or charges to a job would be made accordingly. Since this component; which essentially defines the capital investment in equipment, parts and tires, represents only a small percent of total cost, relative evaluations would be adequate. Consequently the following procedure is used.

Basic cost, or E_1 value, is the sum of F.O.B. prices ($1,000) paid for typical units of equipment used in cut-and-cover construction as shown at the bottom of Table 24. An E_2 value is obtained by substituting F.O.B. costs ($1,000) for the same units of equipment that would be applicable to the new construction. The same adjustment factor ($E_2 \div E_1$) is used to evaluate all three methods of construction.

6.3.3 Materials: The adjustment for materials is determined essentially the same as for labor. Using resource analyses, representative types and quantities of materials have been determined for each method of construction. Extending these quantities against basic material prices shown on Table 24, gives the basic material component M_1. This is illustrated on the lower portion of Table 25. M_2 values would be obtained by substituting material prices determined for the proposed construction and extending them against the indicated quantities.

6.3.4 Summary: By substituting appropriate values for the different factors in equation (3), page 150, it is possible to

Table 25. DETERMINATION OF AVERAGE COMPONENT COSTS ($) - LABOR AND MATERIALS

BASIC COST FOR LABOR COMPONENTS

CLASSIFICATION	BASIC COST PER M.H.	SOLD PILES & LAGGING		CAST-IN-SLURRY (SPTC)		PRECAST CONC PANELS	
		TYP CREW	COST	TYP CREW	COST	TYP CREW	COST
CARPENTER	11.57	1.2	13.88	1.1	12.73	1.3	15.04
IRON WORKER	12.40	1.1	13.64	1.1	13.64	1.2	14.88
LABORER	9.67	5.7	55.12	4.8	46.42	5.2	50.28
OPER. ENGR.	11.68	3.4	39.71	2.8	32.70	3.9	45.55
TEAMSTER	8.04	1.0	8.04	1.0	8.04	1.0	8.04
EQUIV. HOURS		12.4	130.39	10.8	113.53	12.6	133.79
AVG. HOURLY COST			10.52		10.51		10.62

BASIC COST FOR MATERIAL COMPONENTS

ITEM	UNIT	BASIC COST	SOLD PILES & LAGGING		CAST-IN-SLURRY (SPTC)		PRECAST CONC PANELS	
			QTY	COST	QTY	COST	QTY	COST
CONCRETE	CY	29.30	8.2	240	13.0	381	6.9	202
RE STEEL	TON	420.00	0.5	210	0.6	252	0.7	294
STRUCT STEEL	TON	500.00	1.0	500	1.2	600	1.0	500
TIMBER	MBF	240.00	0.6	144	0.4	96	0.2	48
FUEL	GAL	0.40	100.0	40	100.0	40	100.0	40
TOTAL				1134		1369		1084

Note: 1 CY = 0.765m^3, 1 Ton = 907 kg, 1 MBF = 2.36m^3, 1 GAL = 3.79 liters project given construction costs to some future date or place of construction. L_2, E_2 and M_2 values would have to be calculated for each situation. Costs relating to the three methods of cut-and-cover construction would be updated in accordance with the following equations:

SP&L

$$E_F = E_B \left[0.44 \frac{L_2}{10.52} + 0.05 \frac{E_2}{116} + 0.51 \frac{M_2}{1134} \right] \quad (4)$$

SPTC

$$E_F = E_B \left[0.40 \frac{L_2}{10.51} + 0.06 \frac{E_2}{116} + 0.54 \frac{M_2}{1369} \right] \quad (5)$$

PCP

$$E_F = E_B \left[0.45 \frac{L_2}{10.62} + 0.05 \frac{E_2}{116} + 0.50 \frac{M_2}{1084} \right] \quad (6)$$

If specific data required to determine L_2, E_2, and M_2 values are not available, it would be necessary to use "best judgment" values. This could be the case when existing labor agreements expire before the proposed start date. It can be seen by the above equations that the relation of projected costs for each method would remain essentially the same if all were adjusted to the same start date. This of course would change if new techniques were developed which materially altered the component percentages of any of the methods.

The above process could be approximated by using various indexes such as the U. S. Construction Cost Component Indexes shown on Table 26. In this instance, the individual component percentages would be factored by using the ratios of respective indexes (projected or actual) to obtain estimated cost of future work.

Adjustments to a future start date do not include potential escalation costs that may occur through period of actual construction, say, from 1980 to 1984. An approximation of those costs would be made by prorating total projected costs (1980) through the construction period in accordance with

Table 26. U.S. CONSTRUCTION COST COMPONENT INDEXES FOR YEARS 1960 TO 1974* (1967 = 100)

COST COMPONENT	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973	1974
MAJOR COST COMPONENTS:															
LABOR (COMPOSITE)	75.7	79.5	80.5	82.9	86.1	90.1	94.7	100.0	108.5	117.9	127.7	136.3	143.7	151.2	162.9
MATERIALS (COMPOSITE)	95.5	93.7	93.4	93.6	94.7	95.8	98.8	100.0	105.6	111.9	112.5	119.5	126.6	138.5	160.9
EQUIPMENT (COMPOSITE)	86.7	88.0	88.2	89.8	92.0	94.5	97.4	100.0	105.8	110.4	115.6	121.6	125.9	131.2	156.5
PRIMARY MATERIALS:															
CONCRETE	96.6	96.8	97.1	96.9	96.1	96.3	97.8	100.0	102.6	107.2	113.6	122.7	127.9	133.3	153.3
REINFORCING STEEL	107.3	104.8	99.7	90.3	91.5	99.7	100.8	100.0	99.3	100.3	109.2	117.1	114.7	124.1	201.5
STRUCTURAL STEEL	93.4	93.4	93.4	94.1	96.2	96.2	99.9	100.0	101.8	108.1	115.3	126.8	134.6	140.7	179.0
LUMBER	93.9	89.9	89.8	89.5	89.6	91.2	100.2	100.0	113.7	126.0	114.5	133.8	151.5	187.9	184.5

*Derived from cost indexes of U. S. Dept. of Commerce and U. S. Dept. of Labor, Bureau of Labor Statistics anticipated annual expenditures. These yearly costs would then be factored with respect to applicable indexes. The difference between the 1980 cost and the sum of factored yearly expenditures being the cost of escalation.

If new technologies or other conditions which would affect the construction were anticipated for future work, it would be necessary to make appropriate adjustments of component percentages shown on page 148. The new percentages would then be substituted in respective equations for purposes of updating costs.

6.4 UPDATING RATE DECK

The described procedure is a convenient method of updating total costs given in this report as would be needed in comparing future construction alternatives.

A more exacting procedure would be to change all prices contained in the initial rate deck to agree with those applicable to the actual year of construction. To show a relative comparison of results, cost data of the rate deck were updated to 1977 and computer estimates made for situations 1-3GY, 1-3JY and 1-3KY. Table 27 shows comparable activity and total costs for the years 1974 (basic estimates) and 1977 and the percentage variation of each.

Following the procedure discussed in paragraph 6.3 and using equations 4, 5 and 6, estimated 1977 costs for the three estimates showed increases of 21.9% for soldier piles and lagging (SP&L), 21.8% for cast-in-slurry (SPTC) and 20.6% for precast panels (PCP). These are in substantial agreement with results shown on Table 27.

It is noted that percentage increases for individual activities vary by as much as ± 7% from the total project increase. This, of course, is due to variations in actual mix of resources for the activities as compared to the overall averages used in the updating process.

Table 27. CONSTRUCTION COST ESCALATION ($1000) 1974 to 1977

RAPID TRANSIT LINE STRUCTURE

SITE 1 - 70 FT. (21.3m) DEPTH

GROUND SUPPORT		SOLD. PILES & LAGGING			CAST-IN-SLURRY (SPTC)			PRECAST CONC. PANELS		
EST. DESIGNATION		1-3GY			1-3JY			1-3LY		
YEAR		1974	1977	% Inc.	1974	1977	% Inc.	1974	1977	% Inc.
A	TRAFFIC CONTROL	122	157	28.7	122	157	28.7	122	157	28.7
B	UTILITY WORK	1,267	1,583	24.9	1,768	2,208	24.9	1,768	2,208	24.9
C	PROTECT ADJ.STRUCT.	36	47	30.6	36	47	30.6	36	47	30.6
D	GROUNDWATER CONTROL	973	1,217	25.1	973	1,217	25.1	941	1,177	25.1
E	DECKING	1,482	1,829	23.4	1,358	1,678	23.6	1,320	1,630	23.5
F	GROUND WALL SUPPORT	1,637	2,084	27.3	3,417	4,285	25.4	4,595	5,519	20.1
G	BRACING	1,435	1,748	21.8	1,634	1,991	21.8	1,572	1,916	21.9
H	EXCAVATION	1,076	1,407	30.8	957	1,251	30.7	897	1,172	30.7
I	CONST.PERM.STRUCT.	3,863	4,480	16.0	3,342	3,904	16.8	3,109	3,633	16.9
J	BACKFILL	894	1,114	24.6	795	990	24.5	744	928	24.7
K	RESTORATION	96	116	20.8	96	116	20.8	96	116	20.8
SUB TOTAL - DIRECT		12,881	15,782	22.5	14,498	17,844	23.1	15,200	18,503	21.7
N	OVERHEAD (FIXED)	291	360	23.7	294	365	24.1	312	385	23.4
O	OVERHEAD (TIME REL)	2,088	2,556	22.4	2,329	2,852	22.5	2,423	2,966	22.4
P	PLANT (FIXED)	206	253	22.8	206	253	22.8	206	253	22.8
Q	PLANT (TIME REL)	142	179	26.1	159	200	25.8	3,106	207	22.5
SUB TOTAL - INDIRECT		2,727	3,348	22.8	2,988	3,670	22.8	3,106	3,811	22.7
TOTAL COST		15,608	19,130	22.6	17,486	21,514	23.0	18,306	22,314	21.9
MARKUP		2,341	2,870		2,623	3,227		2,746	3,347	
BID PRICE		17,949	22,000	22.6	20,109	24,741	23.0	21,052	25,661	21.9

6.5 COST OF DISRUPTION

Parameter C relates to the cost of disruption. A rationale for quantifying this cost is presented in Section 5. It entails the establishment of several value bases - business, social and safety - which are then factored to reflect the impacts of construction. Any dollar amount assigned to this element of cost would depend primarily on pre-construction social-economic and physical characteristics of the urban site being investigated. Disruptions are due more to the cut-and-cover process itself than to any method of construction. In evaluating future work it might be desirable to update amounts of determined value bases to start of construction. However, this refinement is not considered in this study.

The cost of disruption with respect to business and social value bases requires an approximation of actual construction time for the situation being considered. Project duration in months shown on tables in Appendix B, page 223, can be used for this appraisal. Once the business and social value bases are established and construction costs and times determined, the cost of disruption can be calculated by following the procedure illustrated on Figure 21 and Table 23.

6.6 DETERMINATION OF EFFECTIVE COST

Initial planning of a transit system would probably include general evaluations of construction and disruption costs associated with different urban site locations so as to determine most feasible alignment. Table 19 and other information contained in this report can be used for this purpose.

Ideally, the system would be routed to take maximum advantage of construction economies afforded by shallow depths and ground conditions similar to site 2. Since this choice would be highly unlikely for the entire system, the planner must determine most effective cost for individual structures along the route.

The procedure is illustrated by considering two cut-and-cover situations. Pertinent data affecting the construction and which are definable in the pre-construction stage are shown as follows:

Construction Situation	Example 1	Example 2
Location	San Francisco	Washington, D.C.
Urban Site	Commercial	Commercial
Width of Street	120' (36.6m)	90' (27.4m)
Soil Condition	site 3	site 1
Business Value Base	$7,000,000	$15,000,000
Social Value Base	$ 400,000	$ 800,000
Off-Site Easements for tieback	None	None
Structure	Highway Tunnel	Transit Station
Depth (Grade)	30' (9.1m)	50' (15.2m)
Length	2,000' (610m)	700' (213m)
Width	67' (20.4m)	65' (19.8m)
Start of Construction	1978	1976

Two methods of construction could be used for example 1 and three for example 2. The estimated cost (mid-1974) for each method is obtained from Table 19, page 107, by identifying the conditions of the example with those of that table. Since no easements are available for tiebacks, internal bracing will be required in all cases. Time to complete each construction is taken from tables in Appendix B. These costs and times are shown as follows:

Construction Method	Cost of Construction '74		Time of Construction	
	Example 1	Example 2	Example 1	Example 2
SP&L	N.A.	$14,370,000	N.A.	34 Mo
SPTC	$20,780,000	14,370,000	30 Mo	36 Mo
PCP	20,990,000	13,800,000	31 Mo	33 Mo

To project costs to proposed start dates, it is necessary to determine the prevailing labor, material and equipment prices for the items listed on Table 24, page 149. Prices would be obtained from local unions, suppliers and equipment dealers. For purposes of this illustration it is assumed that the following hourly and unit prices have been obtained:

Item	Example 1 1978	Example 2 1976
Labor:		
Carpenter	$ 16.20	$ 13.90
Ironworker	17.50	14.90
Laborers	13.50	11.60
Operating Eng	16.40	14.00
Teamster	12.20	10.10
Materials:		
Conc.	$ 39.00	$ 33.70
Re. Steel	520.00	460.00
Struct. Steel	640.00	550.00
Timber	310.00	275.00
Fuel	0.52	0.45
Equipment		
F.E. Loader	$54,000	$46,000
Hydraulic Crane	60,000	54,000
Dump Truck	41,000	39,000

Using the above prices and procedure shown on Table 25 and discussed in paragraph 6.4, the following equations are developed which show adjustments necessary to update 1974 estimates to respective start dates.

SP&L

$$E_{78} = E_{74}\left[0.44\ \frac{14.81}{10.52} + 0.05\ \frac{155}{116} + 0.51\ \frac{1458}{1134}\right] \quad (7)$$

$$E_{76} = E_{74}\left[0.44\ \frac{12.65}{10.52} + 0.05\ \frac{139}{116} + 0.51\ \frac{1266}{1134}\right] \quad (8)$$

SPTC

$$E_{78} = E_{74}\left[0.40\ \frac{14.82}{10.51} + 0.06\ \frac{155}{116} + 0.54\ \frac{1763}{1369}\right] \quad (9)$$

$$E_{76} = E_{74}\left[0.40\ \frac{12.65}{10.51} + 0.06\ \frac{139}{116} + 0.54\ \frac{1529}{1369}\right] \quad (10)$$

PCP

$$E_{78} = E_{74}\left[0.45\ \frac{14.95}{10.62} + 0.05\ \frac{155}{116} + 0.50\ \frac{1387}{1084}\right] \quad (11)$$

$$E_{76} = E_{74}\left[0.45\ \frac{12.78}{10.62} + 0.05\ \frac{139}{116} + 0.50\ \frac{1205}{1084}\right] \quad (12)$$

Extending the equations provides an estimation of cost for each construction at anticipated start dates. These costs are shown below:

Construction Method	Cost of Construction Example 1-1978	Example 2-1976
Soldier Pile & Lag	N.A.	$16,640,000
SPTC	$27,845,000	16,626,000
Precast	28,148,000	15,967,000

The next step is to make an appraisal of the cost of disruption associated with each construction (see Section 5). The dollar amounts for business and social value bases are given for the examples. The projected cost of construction and project durations are shown above. The ratio of street width to structure width is approximately 2:1 for Example 1 and 1.5:1 for Example 2. Using appropriate factors and extending the equations of Section 5, the cost of disruption for Example 2 is determined as shown on Table 28. Similar calculations were made for Example 1. Totals are given as follows:

Construction Method	Cost of Disruption Example 1	Example 2
Soldier Pile & Lag	N.A.	$ 2,962,000
SPTC	$1,598,000	3,331,000
Precast	1,752,000	3,291,000

Adding the costs of construction and disruption shows that the SPTC method would be most effective for the San Francisco site (Example 1) and the precast panel method for the Washington, D.C. site (Example 2).

Table 28. DETERMINATION OF EFFECTIVE COST

COST OF DISRUPTION ($1,000) - EXAMPLE 2

Soldier Pile and Lagging

$$C_B = 15{,}000 - \left[15{,}000\ (0.40 \times 0.86 + 0.60 \times 0.86)\right] = 2{,}100$$

$$C_S = 800 \times \left[(0.70 \times 1.875 + 0.30 \times 1.16) - 1\right] = 529$$

$$C_{SA} = 16{,}640 \times 0.02 = \underline{333}$$

$$2{,}962$$

SPTC

$$C_B = 15{,}000 - \left[15{,}000\ (0.40 \times 0.85 + 0.60 \times 0.84)\right] = 2{,}340$$

$$C_S = 800 \times \left[(0.70 \times 1.95 + 0.30 \times 1.18) - 1\right] = 575$$

$$C_{SA} = 16{,}626 \times 0.025 = \underline{416}$$

$$3{,}331$$

Precast Panels

$$C_B = 15{,}000 - \left[15{,}000\ (0.40 \times 0.875 + 0.60 \times 0.82)\right] = 2{,}370$$

$$C_S = 800 \times \left[(0.70 \times 1.837 + 0.30 \times 1.22) - 1\right] = 522$$

$$C_{SA} = 15{,}967 \times 0.025 = \underline{399}$$

$$3{,}291$$

6.7 Summary

In appraising the effective cost (1974 cost plus updating plus disruption) of future cut-and-cover construction, it will be necessary to evaluate each situation independently. In most cases, the relation of determined effective costs will be approximately the same as indicated by the 1974 estimates. Although the largest variation would be in the evaluation of the cost of disruption, updating costs to a future start date could alter results.

The 1974 estimated costs should be adjusted for possible variations in site and construction conditions and allowances made for appendage structures that may be required. A check-list of all adjustments required for producing an estimate of effective cost of a proposed project based on the results of this study is given in the conclusions and recommendations section in paragraph 10.2.7, page 210.

SECTION 7
INVERTED CONSTRUCTION METHODS

7.1 GENERAL

To this point the report has dealt with cut-and-cover construction methods that are more or less standard for transportation tunnels within the United States. Although precast panels have not previously been used for ground support, they would not pose a radical departure from accepted methods, techniques and equipment usage. Cast-in-slurry concrete walls, and the casting and handling of precast panels are techniques practiced by U.S. contractors, though neither is as common here as in Europe.

There is a constantly growing awareness and concern of the surface disruption caused by cut-and-cover construction. Recent experiences of BART in San Francisco and WMATA in Washington, have tended to emphasize the problem. While the needs and benefits of such systems are generally acknowledged, the impact on local business and residents during the normal two to four year construction period for individual project segments is of great concern to all.

One solution is to construct as much of the system as possible by tunneling. On Market Street in San Francisco, and in downtown Washington, most line sections were shield driven tunnels while the stations were constructed by cut-and-cover techniques. Tunneling is often more expensive than cut-and-cover, especially when tunnels are shallow, or when soil and groundwater conditions require the use of compressed air. Large spans are difficult and expensive to support in tunnels unless they are in competent rock. Tunneling, on the other hand, has potentially the least disruptive effect on surface environment.

A new approach to cut-and-cover tunneling has been used successfully in Europe and Canada, based on a significant change in construction procedures and operation sequences. Known as "inverted" or "under-the-roof" construction, its main advantage is minimizing surface disruption.

7.2 ADVANTAGES AND LIMITATIONS OF INVERTED CONSTRUCTION

Figure 23 shows the general construction sequence for inverted construction. The ground support walls are placed first. These walls must carry the permanent street deck (roof slab) and all live and dead loads plus horizontal ground loads, which virtually eliminates the possibility of using soldier piles unless they can be driven to sound rock. Concrete diaphragm walls, either cast-in-slurry or precast, are indicated. If the structure is wide, a center wall may also be required. The street is excavated to a depth sufficient to place the permanent roof slab. This can be reinforced concrete cast-in-place or continuous precast slabs. While cast-in-place concrete is cheaper, the additional time to form, place rebar, pour and cure for two to four weeks reduces the advantages of minimizing disruption. Precast roof slabs can be placed concurrent with excavation and are capable of supporting street loads on the same day. The street is then restored and excavation proceeds below the roof, with access provided by side ramps or shafts. Upon completion of excavation, the base slab is placed and the walls and other inside work completed.

Several factors limit the applicability of this method. For economy, the structure should be close to the surface and the permanent roof slab should coincide with the street grade. If the roof slab is several feet below the street level it is necessary to excavate deeper, place the roof slab and then place backfill before restoring the street. This additional step delays restoration and increases the load on the roof and subsequently the diaphragm walls. Without a base slab, there is a limit to the depth of backfill the walls can carry to the soil beneath them. A possible alternative is to keep the street slab close to the surface leaving a void between it and the roof of the structure.

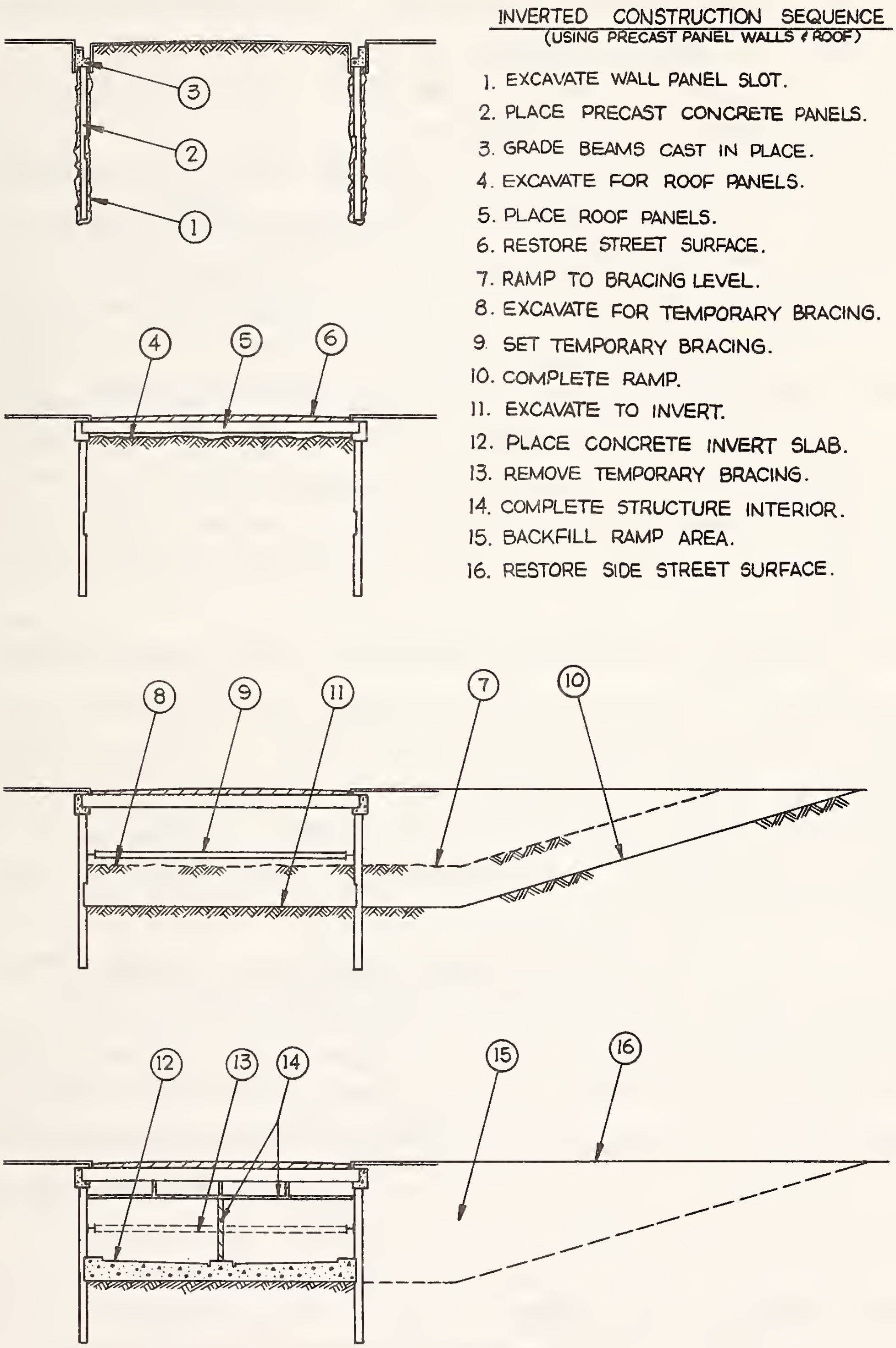


Figure 23. INVERTED CONSTRUCTION SEQUENCE

Excavating and concreting below a restored street with only side ramps or shafts for access limits construction procedures and increases direct costs for those work operations involved. The type and size of equipment that can be used is also limited. If a center wall is required the difficulties of excavation and access are increased.

Probably the most difficult problem in using this method of construction in an urban area is the relocation and maintenance of utilities. It is apparent that if the roof of structure also forms the permanent street surface all existing utilities must be removed. If the roof is below the utilities, precast beams spanning from wall to wall cannot be placed until the utilities are removed. Support and maintenance of utilities while excavating, placing concrete and backfilling, not only increases surface disruption exposure time but presents difficult construction problems if the utilities are large, or old and brittle.

If the structure is narrow compared to the street width, it may be possible to relocate all utilities to the sides. However, the disruption that this would create offsets the one being eliminated, as all utilities must be moved and in service before excavation and removal of old services can begin. In the case of large main utilities passing through the area, it may be possible to relocate them to a parallel street prior to construction. Any city that considers building cut-and-cover transportation tunnels should plan and build future utility mains in streets or right-of-ways other than those streets that might be used for the tunnels. In any event, smaller local utility lines of all types will be needed to provide continuous service to buildings on both sides of the street during and after the construction period.

7.3 UTILITY TUNNELS - UTILIDORS

One way to provide for these services and still keep surface disruption to a minimum is to drive small utility tunnels, or "utilidors" on both sides of the street, outside the structure. These tunnels would have to be excavated, lined and have new utilities placed in them before the old lines could be abandoned to start open-cut work.

While utility tunnels have been constructed in other countries, there has been little use of them in the United States. This could be due to the general reluctance of private and public utility owners to share cost and maintenance of such structures. The tunnels should be placed near the surface to facilitate connection to existing and future buildings. Although these tunnels could probably be constructed for less money by cut-and-cover methods, such a procedure would defeat the main purpose of reducing surface disruption. To reduce tunnel size and cost, only local utilities should be placed in the tunnels with large mains relocated to parallel streets. Tunnels would be required on both sides of the street to avoid cross laterals passing through the structure. This can become a major problem at intersections where normally many utilities cross. Water and electric lines can be connected to longitudinal lines with cross ties at the ends of the structure. If the structure is long, sleeves for small cross utilities can be provided in the roof of the structure. Where large utilities are involved, it would be necessary to drive a cross tunnel below the bottom of the structure from shafts in side streets.

7.4 EXAMPLES OF INVERTED CONSTRUCTION

Inverted construction has been used in Europe for both highway tunnels and rapid transit line sections as described by D'Appolonina, et al, (Reference 8). In the cases described, cast-in-place roof slabs were supported on precast concrete panel walls.

In Edmonton, Alberta, Canada, the Jasper Avenue Station, part of a light rail transit system below the busiest street in downtown Edmonton, is being built by the inverted construction method. It is a two level structure, similar to the study station, with a mezzanine level above and two tracks and station platform below. Reinforced, cast-in-place concrete tangent piles form the structural diaphragm walls. Precast, prestressed beams, four foot wide (1.2m) and sixty-six feet (20.1m) long form the roof of the structure and street support.

A low permanent water table and hard glacial till with a long stand-up time make the tangent pile wall economically competitive. The 42" (1.07m) diameter holes were drilled and concreted in leap-frog sequence, allowing several days cure before drilling the intermediate pile holes. Four of every five piles support the mezzanine level while the fifth extends down to bedrock and is belled to enlarge the bearing area. The fifth pile supports the longitudinal grade beams that carry the precast roof and permanent street. An 18" (0.46m) thick track slab was placed on grade. The use of this relatively thin slab was possible because of the absence of groundwater uplift.

The excavation and placing of the roof was done in the summer of 1975 causing only four months of disruption while traffic was diverted to other streets. All utilities except gas had been placed in two 8-foot (2.4m) diameter hand mined tunnels located below the sidewalks prior to station construction. Excavation below the roof was carried on through the long severe Canadian winter using a ramp from a side street. Dump trucks drove down the ramp and were loaded by front-end loaders. The ramp was covered to protect the workers from the cold air which dropped to as low as -35° F (-37°C).

The success of this under-the-roof construction can be seen in Figure 24. The upper photograph was taken on Jasper Avenue immediately above the station while excavation was being carried on with no apparent effect on surface transportation, pedestrians or business. The casual visitor is unaware that construction work is being performed below unless he is told, or notices dump trucks emerging from the side street ramp. The lower photograph shows typical conjestion when using cut-and-cover methods.

Jasper Avenue,
Edmonton, Alberta
during station
excavation
Winter 1975

Market Street,
San Francisco
during station
excavation
Spring 1969

Figure 24. COMPARISON OF SURFACE DISRUPTION - INVERTED AND OPEN-TRENCH CONSTRUCTION

7.5 COMBINED CUT-AND-COVER AND INVERTED CONSTRUCTION

Although the inverted construction method is a departure from the normal procedures followed by U. S. contractors, a combination of cut-and-cover and inverted construction more consistent with current practice can be used to reduce surface disruption and overall construction time. With this method, the contractor follows normal procedures of handling utilities, installing ground support (preferably a diaphragm wall), placing temporary decking, bracing and excavating from the deck. Upon completion of excavation, he places the base slab and then the roof slab. He can then proceed with backfill and utility and pavement restoration simultaneous with completion of interior walls, slabs and finish work in the structure below.

The combined method is not as dramatic or complete as the inverted construction method in reducing surface disruption. At best, it can save only a few months over the traditional cut-and-cover sequence. Limiting access for completion of the structure increases some direct costs. All the disruption and expense of constructing and removing a temporary street deck is still present.

7.6. EXAMPLES OF COMBINATION CONSTRUCTION METHOD

The only example known to the study team of the use of the combination method in the United States is the Civic Center Station on Market Street in San Francisco, (Reference 7). The station shell was completed in 1971 and contains three levels, a mezzanine level, a track and platform level for Muni light rail trolleys, and a track and platform level for BART trains. The roof is about 10 feet (3.0m) below the surface and the excavated invert about 70 feet (23.1m) below the street. The ground support system consisted of 3-foot (0.9m) thick SPTC walls for the major portion of the station with 2-foot (0.6m) thick SPTC walls at the widened mezzanine level and station entrances.

The SPTC walls were designed to be incorporated as structural walls for the station with a 1-foot (0.3m) thick cast-in-place finish wall, where exposed to the public. The slabs are a composite steel and concrete construction similar to the study station. The permanent steel of roof and slab levels served as internal bracing during construction. They were supplemented by two levels of temporary bracing.

During the course of construction, it was decided to place the roof concrete prior to completing walls and slabs below. This measure was instituted to reduce the overall construction time. Since this procedure had not been anticipated prior to start of construction, it was necessary to redesign portions of the structure to permit pouring and loading the roof before completing the structure below. The problems of redesign were simplified because the SPTC wall could support the structural roof steel. With the base slab more than 50 feet (15.2m) below the roof, forms and platforms were hung from the roof steel, except at the side entrances where mezzanine slabs, already in place, supported scaffolding. The composite roof was supported on top of the SPTC wall with the soldier piles extending through the roof to support the temporary street deck. If a soldier pile and lagging ground support system had been used initially, the problem of redesign would have been extremely difficult, if not impossible.

7.7 STUDY SITUATIONS - INVERTED AND COMBINATION METHODS

The above paragraphs have discussed various aspects of inverted and combination methods of constructing facilities for mass transportation systems. Different cut-and-cover methods have been discussed in previous sections. To compare or evaluate the advantages and disadvantages of each, it is necessary to consider them for the same construction. Of the different situations studied, it was decided that the most applicable for either inverted, combination or cut-and-cover methods would be a highway tunnel section constructed at a 30-foot (9.1m) depth. Since the inverted method requires a diaphragm type wall, situation 1-1LT (site 1, highway structure, 30-foot (9.1m) depth, wet soil, internal bracing, precast panels) was chosen.

Assuming the same site configuration (utilities, etc.) as discussed in Section 1, a typical cross section of the highway tunnel using the inverted method of construction is shown on Figure 25. Utility tunnels for local service lines flank the structure under both sidewalk areas. It is not desirable to have either large water or gas mains in the tunnels. They are shown under the left side walk to avoid conflict with the access ramp area, but they could also be diverted to another street. The access ramps are constructed in side streets. They should not be more than 1,000 feet apart to avoid excessively long runs for the excavating equipment.

Though not shown in the cross section, following cost estimates consider 20-foot x 20-foot (6m x 6m) shafts constructed on either side of each intersection for driving utility tunnels, making connections to cross utilities, and housing utility chambers. The utilidors, shown in larger scale on Figure 26, are 10 feet (3.0m) in diameter, large enough for future inspection, maintenance and improvement of utilities. The gas line is shown encased in concrete with capped connections outside the tunnel for building services. It could also be in a separate trench, but for safety purposes should not be exposed in the tunnel with electrical services. With utility tunnels on either side of the street, some duplication of lines (such as two gas lines) is necessary to avoid service lines crossing through the highway tunnel. Others, such as multiple electric and telephone ducts can be divided between the two.

The roof of the highway tunnel is shown as precast, prestressed members spanning the full width between outer walls. The center dividing wall is placed later. This is to facilitate excavation and bracing under the roof, both of which would be greatly hampered by a center wall. Although the roof of precast sections is more expensive than a roof cast-in-place, the surface disruption exposure will be reduced as previously mentioned. In subsequent discussions, the situation using the inverted method is arbitrarily designated as estimate 1-4LT.

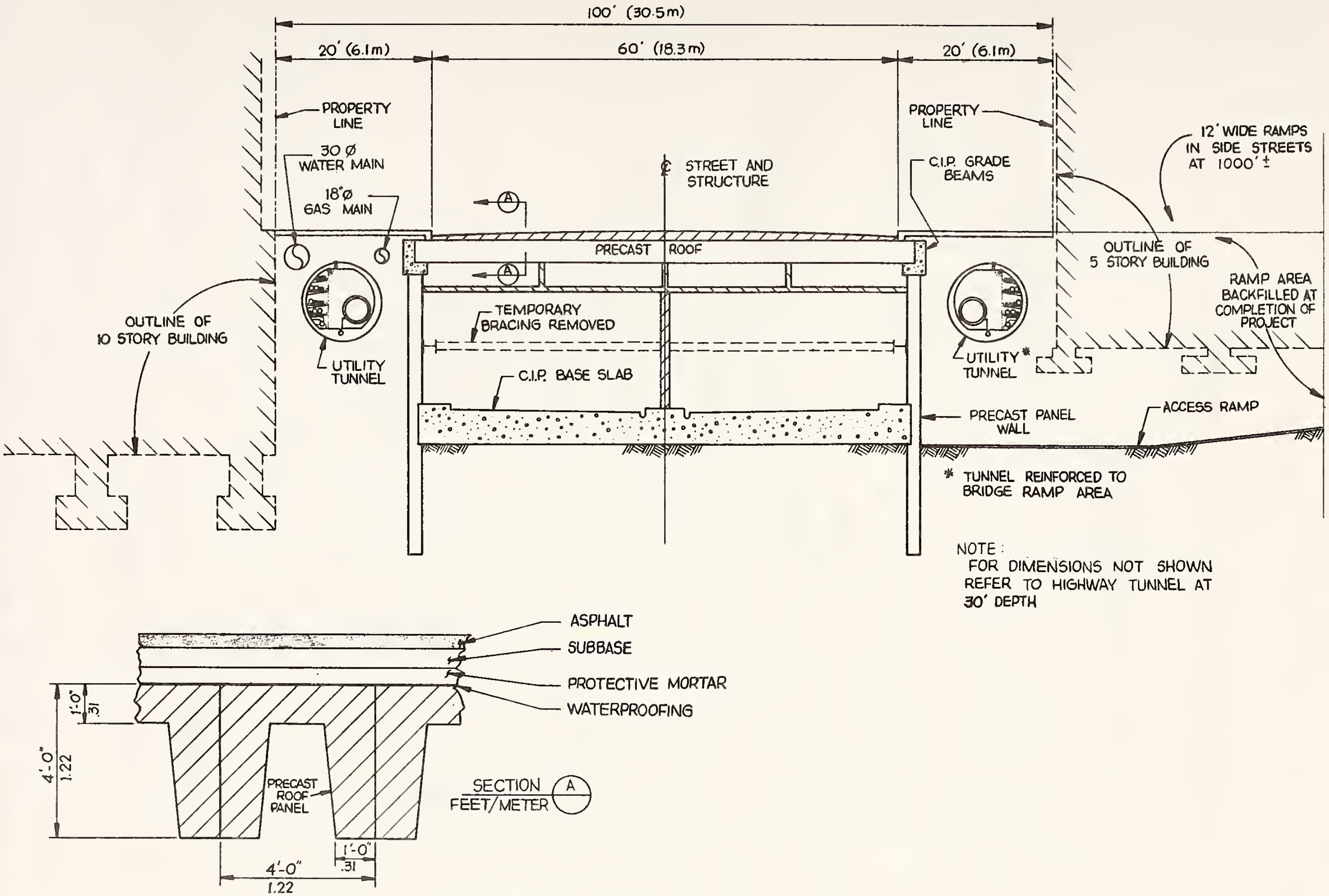


Figure 25. FOUR LANE HIGHWAY TUNNEL BY INVERTED CONSTRUCTION

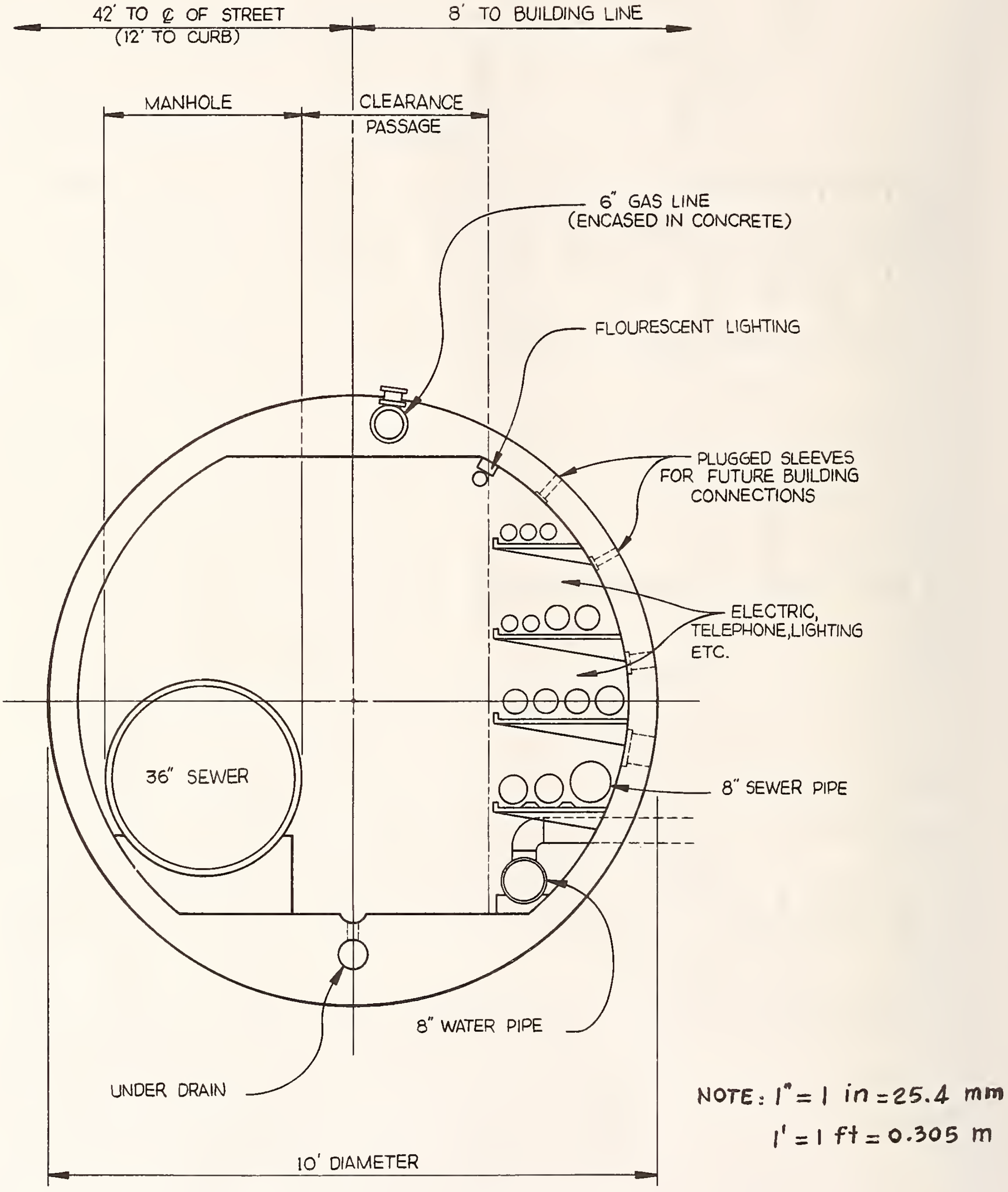


Figure 26. 10 FOOT (3.05m) DIAMETER UTILIDOR

The cross section of the combined construction method would be the same as the standard cut-and-cover construction shown on Figure 1, page 2. However, portions of the work sequence would be different. The estimate for the combined method is designated as 1-7LT.

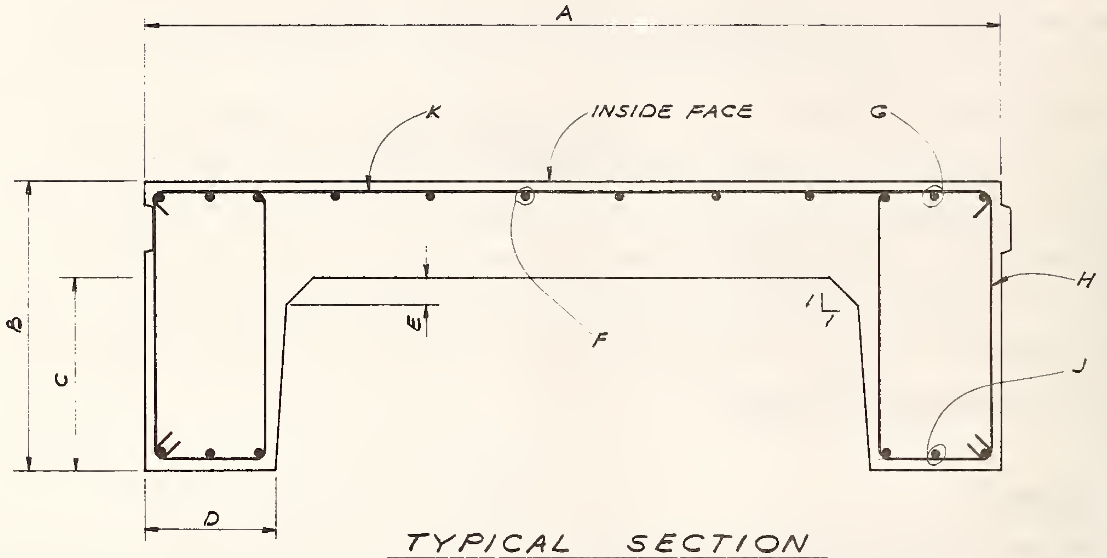
Various sections of precast diaphragm wall panels could be used for either the cut-and-cover, combination or inverted methods. Figure 27 shows typical panel section and design data applicable to the construction situations considered in this study. For the example comparison discussed in Section 8, the panel section for the highway tunnel, 30-foot (9.1m) depth and site 1 condition is used.

7.8 SUMMARY

Although recent successful projects in other countries can be cited as examples, the use of inverted or combination methods of constructing transportation structures within the United States has been very limited. Part of the problem may rest with the more or less accepted practice that the contractor should not be directed which method of construction he should use. This practice supposedly places all responsibility of construction on the contractor. For efficient use of inverted or combination construction, such decisions must be made in the pre-design stage, so the structure can be designed accordingly. Based on previous experience within the United States, it is apparent that if site conditions permit, most contractors would select the soldier pile and lagging, cut-and-cover method as generally being the least expensive construction.

Another part of the problem is that no dollar values have been placed on disruptions of adjacent urban areas caused by the construction. A suggested rationale for evaluating this factor is discussed in Section 5.

Initial construction cost using inverted construction methods would be greater than traditional methods in most urban areas. This is due primarily to the high cost of utility

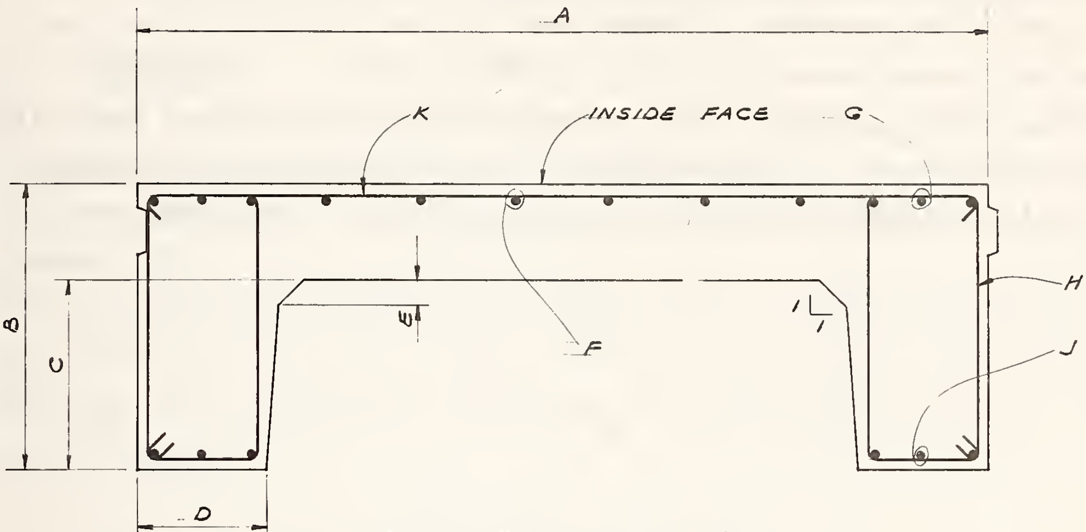


TYPICAL SECTION

GROUND SUPPORT AND BRACING SYSTEMS PRECAST CONCRETE WALL WITH INTERNAL BRACING OR TIEBACKS													
		SITES 1 & 2						SITE 3					
		HIGHWAY TUNNEL	HIGHWAY TUNNEL & RAPID TRANSIT STATION		RAPID TRANSIT LINE SECTION			HIGHWAY TUNNEL	HIGHWAY TUNNEL & RAPID TRANSIT STATION		RAPID TRANSIT LINE SECTION		
		H=30'	H=50'	H=70'	H=30'	H=50'	H=70'	H=30'	H=50'	H=70'	H=30'	H=50'	H=70'
A	FT.IN	12'-0"	9'-0"	6'-0"	12'-0"	9'-0"	6'-0"	12'-0"	9'-0"	6'-0"	12'-0"	9'-0"	6'-0"
	M	3.66	2.74	1.83	3.66	2.74	1.83	3.66	2.74	1.83	3.66	2.74	1.83
B	FT.IN	2'-0"	3'-0"	3'-0"	2'-0"	3'-0"	3'-0"	2'-0"	3'-0"	3'-0"	2'-0"	3'-0"	3'-0"
	M	.61	.91	.91	.61	.91	.91	.61	.91	.91	.61	.91	.91
C	FT.IN	1'-3"	2'-0"	2'-0"	1'-3"	2'-0"	2'-0"	1'-3"	2'-0"	2'-0"	1'-3"	2'-0"	2'-0"
	M	.38	.61	.61	.38	.61	.61	.38	.61	.61	.38	.61	.61
D	FT.IN	1' 0"	1'-0"	1'-0"	1'-0"	1'-0"	1'-0"	1'-4"	1'-4"	1'-4"	1'-4"	1'-4"	1'-4"
	M	.31	.31	.31	.31	.31	.31	.41	.41	.41	.41	.41	.41
E	FT.IN	0'-3"	0'-3"	0'-3"	0'-3"	0'-3"	0'-3"	0'-3"	0'-3"	0'-3"	0'-3"	0'-3"	0'-3"
	M	.08	.08	.08	.08	.08	.08	.08	.08	.08	.08	.08	.08
F		#4@12	#4@12	#4@12	#4@12	#4@12	#4@12	#4@12	#4@12	#4@12	#4@12	#4@12	#4@12
G		3 #14	3#14	4#14	3#14	3#14	3#10	4#14	3#18	3#18	4#14	3#18	3#14
H		#4@12	#4@12	#4@12	#4@12	#4@12	#4@12	#4@12	#4@12	#4@12	#4@12	#4@12	#4@12
J		3#14	3#14	4#14	3#14	3#14	5#11	4#14	3#18	3#18	4#14	3#18	1#11 2#18
K		#6@5	#6@6	#6@12	#6@5	#6@6	#6@12	#6@4	#6@5	#6@12	#6@4	#6@5	#6@12

Note: 1" = 1 in. = **25.4mm,** 1' = 1 ft. = 0.305m
Bar sizes: # = no. of 1/8" dia; i.e. #6 = 3/4" Dia. = 19.1mm

Figure 27. TYPICAL DESIGN OF PRECAST WALL PANELS



TYPICAL SECTION

		SITE 4						SITE 5					
		HIGHWAY TUNNEL	HIGHWAY TUNNEL AND RAPID TRANSIT STATION		RAPID TRANSIT LINE SECTION			HIGHWAY TUNNEL	HIGHWAY TUNNEL AND RAPID TRANSIT STATION		RAPID TRANSIT LINE SECTION		
		H=30	H=50	H=70	H=30	H=50	H=70	H=30	H=50	H=70	H=30	H=50	H=70
A	FT. IN	12'-0"	8'-0"	6'-0"	12'-0"	8'-0"	6'-0"	6'-0"	6'-0"	6'-0"	6'-0"	6'-0"	6'-0"
	M	3.66	2.44	1.83	3.66	2.44	1.83	1.83	1.83	1.83	1.83	1.83	1.83
B	FT. IN	2'-0"	3'-0"	3'-0"	2'-0"	3'-0"	3'-0"	4'-0"	4'-0"	4'-0"	4'-0"	4'-0"	4'-0"
	M	.61	.91	.91	.61	.91	.91	1.22	1.22	1.22	1.22	1.22	1.22
C	FT. IN	1'-3"	2'-0"	2'-0"	1'-3"	2'-0"	2'-0"	3'-0"	3'-0"	3'-0"	3'-0"	3'-0"	3'-0"
	M	.38	.61	.61	.38	.61	.61	.91	.91	.91	.91	.91	.91
D	FT. IN	1'-4"	1'-0"	1'-0"	1'-4	1'-0"	1'-0"	1'-4"	1'-4"	1'-4"	1'-4"	1'-4"	1'-4"
	M	.41	.31	.31	.41	.31	.31	.41	.41	.41	.41	.41	.41
E	FT. IN	0'-3"	0'-3"	0'-3"	0'-3"	0'-3"	0'-3"	0'-3"	0'-3"	0'-3"	0'-3"	0'-3"	0'-3"
	M	.08	.08	.08	.08	.08	.08	.08	.08	.08	.08	.08	.08
F		#4@12	#4@12	#4@12	#4@12	#4@12	#4@12	#4@12	#4@12	#4@12	#4@12	#4@12	#4@12
G		4#14	4#14	4#11	4#14	4#14	4#11	4#18	5#18	6#18	4#18	6#18	5#18
H		#4@12	#4@12	#4@12	#4@12	#4@12	#4@12	#4@12	#4@12	#4@12	#4@12	#4@12	#4@12
J		4#14	4#14	4#11	4#14	1#14 2#18	4#11	4#18	5#18	6#18	4#18	6#18	5#18
K		#6@4	#6@5	#6@12	#6@4	#6@5	#6@12	#5@12	#6@12	#5@6"	#5@12	#6@12	#5@6"

Table title: GROUND SUPPORT AND BRACING SYSTEMS — PRECAST CONCRETE WALL WITH INTERNAL BRACING OR TIEBACKS

Note: 1" = 1 in. = 25.4mm, 1' = 1 ft. = 0.305m
Bar Sizes: # = no. of 1/8" Dia; i.e. #6 = 3.4" Dia. = 19.1mm

Figure 27. TYPICAL DESIGN OF PRECAST WALL PANELS (Continued)

relocation which must be completed prior to start of the transit structure, and to a lesser extent, to the increased difficulty of working under-the-roof.

Section 8 presents a comparison of both construction and disruption costs associated with cut-and-cover, inverted (or under-the-roof) and combination construction methods. For this study, cut-and-cover construction is considered the "standard" or "regular" method to which the newer methods are compared.

SECTION 8

COMPARING EFFECTIVE COSTS

CUT-AND-COVER, INVERTED AND COMBINATION METHODS

8.1 GENERAL

The general procedure discussed in Section 6 is used to compare the effective cost of cut-and-cover, inverted and combination methods. The cut-and-cover situation chosen for the comparison is designated as 1-1LT (site 1, highway structure, PCP, internal bracing, and 30-foot (9.1m) depth). Designations of 1-4LT and 1-7LT are used for the inverted and combination methods of constructing the same structure under similar site conditions.

8.2 COST OF CONSTRUCTION AND SCHEDULES

Since operation requirements and sequencing of work for inverted and combination methods are different than cut-and-cover construction it was necessary to make new cost estimates for situations 1-4LT and 1-7LT. These computer estimates were prepared in the same manner as the base estimates discussed in Section 4 with new operations added as required. Although estimate 1-1LT had already been developed by hand extensions from base estimate 1-1LY, (paragraph 4.3, page 92), a new computer estimate was made to permit a more detailed comparison of construction methods. The three estimates are summarized in Table 29. Summary cost analyses of operations and activities are given in Volume 3. These costs, as for the other estimates, reflect mid-1974 prices in the Washington, D.C. area. Construction schedules showing activity and job durations are shown on Figure 28.

In the summary for 1-4LT, the direct cost ($3,407,000) of building the utility tunnels has been separated from utility installation, relocation and maintenance. Adding indirect and markup costs attributable to this item raises the cost of utility tunnels to over four million dollars. This is the main factor for the overall cost of inverted construction being some

Table 29. SUMMARY OF CONSTRUCTION COSTS - REGULAR, INVERTED AND COMBINATION METHODS ($)

FOUR LANE HIGHWAY TUNNEL

30' DEPTH - HIGH GROUNDWATER TABLE
PRECAST PANEL GROUND SUPPORT
WITH INTERNAL BRACING

	TYPE OF CONSTRUCTION	REGULAR	INVERTED	COMBINED
	ESTIMATE DESIGNATION	1-1LT	1-4LT	1-7LT
A	TRAFFIC CONTROL	158,000	126,000	153,000
B	UTILITY TUNNELS	-	3,407,000	-
	UTILITIES	2,144,000	1,989,000	2,144,000
C	PROTECT ADJ STRUCT	193,000	193,000	193,000
D	GROUNDWATER CONTROL	539,000	639,000	513,000
E	DECKING	2,745,000	-	2,745,000
F	GROUND WALL SUPPORT	2,198,000	2,105,000	2,198,000
G	BRACING	479,000	578,000	479,000
H	EXCAVATION	901,000	1,221,000	1,078,000
I	CONST PERM STRUCT	5,166,000	6,285,000	5,215,000
J	BACKFILL	112,000	54,000	134,000
K	RESTORATION	373,000	389,000	377,000
	SUB TOTAL - DIRECT	15,008,000	16,986,000	15,229,000
N	OVERHEAD (FIXED)	263,000	321,000	263,000
O	OVERHEAD (TIME REL)	2,347,000	2,738,000	2,098,000
P	PLANT (FIXED)	206,000	388,000	206,000
Q	PLANT (TIME REL)	160,000	296,000	143,000
	SUB TOTAL - INDIRECT	2,976,000	3,743,000	2,710,000
	TOTAL COST	17,984,000	20,729,000	17,939,000
	MARKUP	2,698,000	3,109,000	2,691,000
	BID PRICE	20,682,000	23,838,000	20,630,000
	PROJECT DURATION	31 MO	35 MO	28 MO

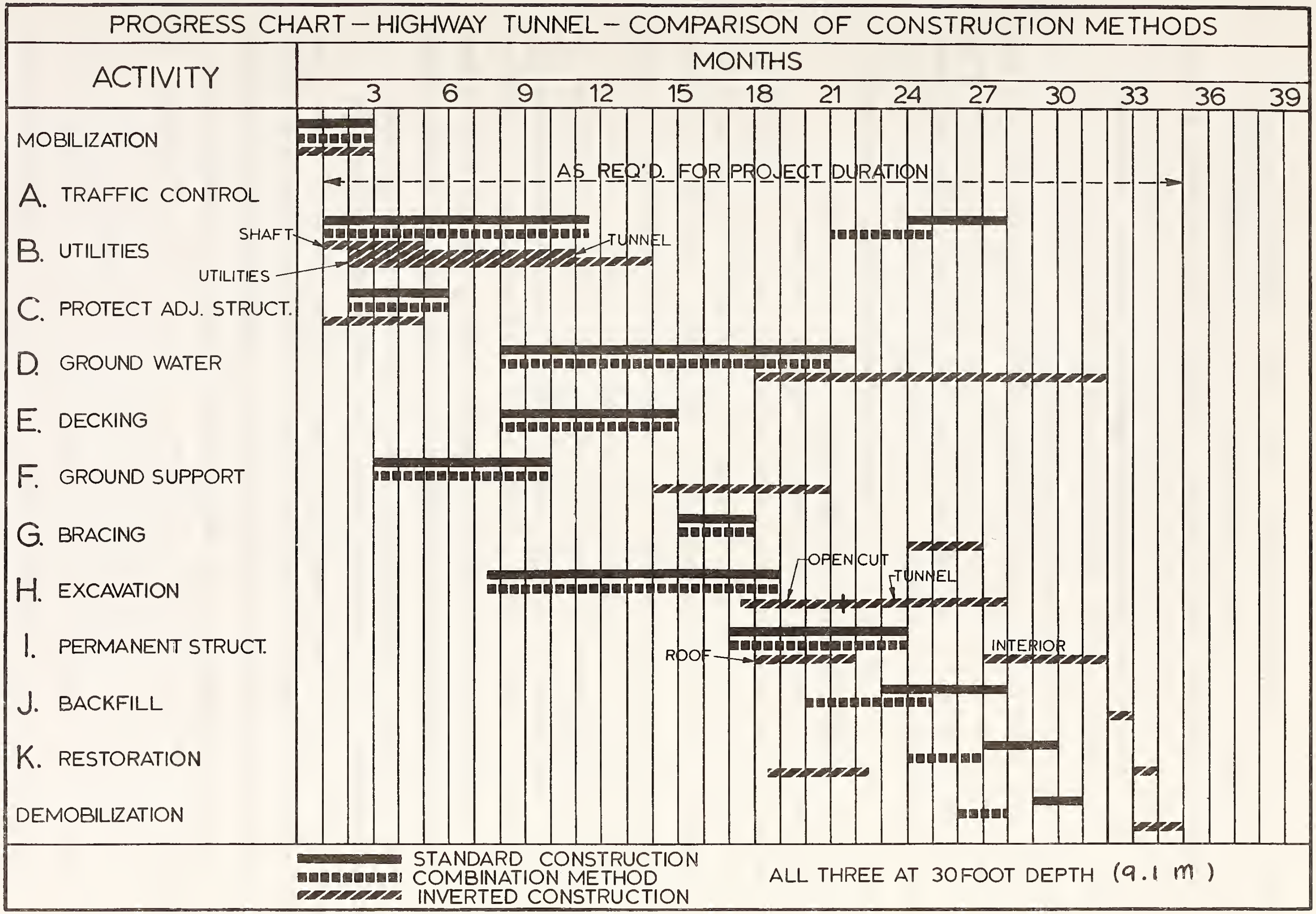


Figure 28. CONSTRUCTION SCHEDULES - REGULAR, INVERTED AND COMBINATION

three million dollars more than the other two methods. Other major differences include additional cost ($1,100,000) of permanent structure due to higher cost for the precast roof and difficulty of working with limited access. An increase in job duration adds to the time-related overhead costs. Although there is a saving of $2,745,000 for decking, this only partly compensates for the other higher costs.

The construction time of 35 months for 1-4LT can be seen on the schedule as resulting from not being able to start the main structure until utility work is complete. There might be some reduction in time by letting this work as a separate contract. However, this would result in duplicating certain fixed overhead costs negating some of the advantage, and possibly create a problem of interface coordination of the two contracts. While the total time for inverted construction is four months longer than cut-and-cover, the actual period of major surface disruption (excluding construction of shafts, utilidors, etc.) is only twelve months compared to about thirty months.

The costs of the combined construction method (1-7LT) are essentially the same as for cut-and-cover (1-1LT); Savings in indirect cost due to shorter construction period are offset by higher direct cost resulting from some work done under limited access conditions. Surface disruption time is reduced by three months due to simultaneous restoration and structure completion.

For purposes of comparing total effective costs of the three methods, it is assumed that the construction will be performed in San Francisco, starting in 1978. Value bases for "business" and "social" criteria used in determining cost of disruption are taken as $30,000,000 and $825,000 respectively. The width of street is one and one-half times the structure width.

8.3 UPDATING COSTS

To determine costs for future work, it is necessary to make adjustments which reflect the differences between cost data used for the base estimates and data applicable to the planned construction. Adjustments depend on the percent of total cost represented by components of labor, equipment and material and their respective variations from basic prices. The procedure is discussed in paragraph 6.4. Separate analyses were made to determine percentage of total cost represented by each component for the inverted and combination methods. Results are shown below. Those for the cut-and-cover PCP method 1-1LT are taken from page 83.

Method	Percent of Total Cost: Labor L	Equipment E	Materials M
Cut-and-Cover (1-1LT)	45	5	50
Inverted (1-4LT)	47	7	46
Combination (1-7LT)	44	5	51

Using resource analyses provided in the computer estimates, typical crew and material requirements were determined for 1-4LT and 1-7LT. These requirements were extended against basic prices to obtain average labor and material costs. Calculations were made in the same manner as discussed in paragraphs 6.4.1 and 6.4.3. Results are shown on Table 30. Crew and material quantities shown for the cut-and-cover method are taken from Table 25 - Precast Panels, page 152. Since that table was based on average requirements for several structures and depths, they do not reflect exactly the requirements for 1-1LT. However, the relative values ($L_2 \div L_1$ etc.) used to determine variations in component costs would be essentially the same. Also, slight variations between average component percentages and those determined for a specific situation would not materially affect the answers (see paragraph 6.3, page 147). The indicated average hourly wages and material prices represent L_1 and M_1 values used in equation (3). The equipment

Table 30. DETERMINATION OF AVERAGE LABOR AND MATERIAL COSTS ($)
INVERTED - COMBINATION AND OPEN-TRENCH CONSTRUCTION

BASIC COST FOR LABOR COMPONENTS

CLASSIFICATION	BASIC COST PER M.H.	INVERTED CONSTRUCTION		COMBINATION CONSTRUCTION		OPEN-TRENCH CONSTRUCTION	
		NO REQ'D	COST	NO REQ'D	COST	NO REQ'D	COST
CARPENTER	11.57	1.5	17.36	1.6	18.51	1.3	15.04
IRON WORKER	12.40	0.3	3.72	1.1	13.64	1.2	14.88
LABORER	9.67	4.6	44.48	7.3	70.59	5.2	50.28
OPER. ENGR.	11.68	3.7	43.22	3.3	38.54	3.9	45.55
TEAMSTER	8.04	1.0	8.04	1.0	8.04	1.0	8.04
EQUIV. HOURS & COST		11.1	116.82	14.3	149.32	12.6	133.79
AVG. HOURLY COST			10.52		10.44		10.62

BASIC COST FOR MATERIAL COMPONENTS

ITEM	UNIT	BASIC COST	INVERTED CONSTRUCTION		COMBINATION CONSTRUCTION		OPEN-TRENCH CONSTRUCTION	
			QTY	COST	QTY	COST	QTY	COST
CONCRETE	CY	29.30	7.3	214	11.8	345	6.9	202
RE STEEL	TON	420.00	0.7	294	0.9	378	0.7	294
STRUCT STEEL	TON	500.00	0.2	100	0.8	400	1.0	500
TIMBER	MBF	240.00	0.1	24	0.5	120	0.2	48
FUEL	GAL	0.40	100.0	40	100.0	40	100.0	40
TOTAL				672		1283		1084

Note: 1 CY = 0.765m, 1 Ton = 907 kg, 1 MBF = $2.36m^3$, 1 GAL. = 3.79 liters component adjustment factor - E_1 - is determined as discussed in paragraph 6.4.2. The same E_1 value is used for all three methods. Cost information needed to determine L_2, E_2, and M_2 values would be the same as given for Example 1, page 159 (San Francisco - 1978). Making necessary calculations and substituting appropriate factors in equation (3, page 150), the projected construction costs for the three methods would be determined by the following equations:

Cut-and-Cover

$$E_{78} = E_{74} \left[0.45 \frac{14.95}{10.62} + 0.05 \frac{155}{116} + 0.50 \frac{1387}{1084} \right] \quad (13)$$

Combination

$$E_{78} = E_{74} \left[0.44 \frac{14.69}{10.44} + 0.05 \frac{155}{116} + 0.51 \frac{1647}{1283} \right] \quad (14)$$

Inverted

$$E_{78} = E_{74} \left[0.47 \frac{14.82}{10.52} + 0.07 \frac{155}{116} + 0.46 \frac{860}{672} \right] \quad (15)$$

The 1978 cost for the cut-and-cover method is \$27,735,000; \$27,665,000 for the combination method and \$32,062,000 for the inverted method.

8.4 COST OF DISRUPTION

A rationale for quantifying the cost of disruption for various cut-and-cover methods is presented in Section 5. Since the relative disruptions (as compared to total disruption) caused by the eleven basic activities are different for the inverted and combination methods of construction, it was necessary to establish new weighting factors to quantify the business and social value bases. A matrix, similar to Table 22, page 132, was prepared showing relative magnitude of disruptions for the three methods all at a 30-foot (9.1m) depth. This matrix and determined adjustment factors are shown on Table 31. The indicated "scoring factors" are based on activity times shown for respective schedules on Figure 28, page 181.

Table 31. MAGNITUDE OF DISRUPTION - EVALUATION MATRIX CUT-AND-COVER, COMBINATION AND INVERTED METHODS

HIGHWAY TUNNEL*										
ACTIVITY		OPEN TRENCH CONSTRUCTION			COMBINATION CONSTRUCTION			INVERTED CONSTRUCTION		
		Weighting Factor	Scoring Factor	Weighted Score	Weighting Factor	Scoring Factor	Weighted Score	Weighting Factor	Scoring Factor	Weighted Score
A	TRAFFIC CONTROL	3	1.3	3.9	3	1.3	3.9	4	1.4	5.6
B	UTILITY WORK	20	0.7	14.0	18	0.7	12.6	25	0.8	20.0
C	PROTECT. ADJ. STRUCT.	2	1.3	2.6	2	1.3	2.6	2	1.3	2.6
D	GROUNDWATER CONTROL	1	1.0	1.0	1	0.9	0.9	2	1.0	2.0
E	DECKING	27	1.3	35.1	26	1.3	33.8	15	1.1	16.5
F	GROUND WALL SUPPORT	15	0.8	12.0	20	0.9	18.0	23	0.9	20.7
G	BRACING	2	0.4	0.8	2	0.4	0.8	2	0.3	0.6
H	EXCAVATION	8	1.2	9.6	8	1.1	8.8	12	0.8	9.6
I	CONST. PERM. STRUCT.	13	1.4	18.2	10	1.2	12.0	3	0.9	2.7
J	BACKFILL	2	0.6	1.2	3	0.7	2.1	2	0.8	1.6
K	RESTORATION	7	1.3	9.1	7	1.4	9.8	10	1.5	15.0
WEIGHTED SCORE				107.50			105.30			96.90
SOCIAL FACTOR				1.08			1.05			0.97
BUSINESS FACTOR				0.93			0.95			1.03

*Note: 30-foot depth - Precast walls - Internal Bracing - Wet Soil

Evaluations for combination and inverted methods should take into account disruptions along the construction street (same as for cut-and-cover methods) plus disruptions on cross streets or other areas used for access shafts or ramps. If those areas are normally conjested with traffic, movement of trucks and other equipment could cause significant disruptions. Weighting and scoring factors used on Table 31 for the combination and inverted methods take into account a general appraisal of what these conditions might be for a typical site and how they would affect total disruption. The decking activity for the inverted method reflects disruption during placement of precast roof panels.

With a street width to structure ratio of 1.5:1, the adjustment factor for dimensions is 1.08 (see page 135). Combined weighting factors used to adjust the business and social value bases, with respect to magnitude of disruption, are determined as discussed in paragraph 5.3.3, page 135, and are shown below:

COMBINED WEIGHTING FACTORS

MAGNITUDE & DIMENSIONS

Value Base	Construction Type	Ratio Street Width to Structure R = 1.5:1
Business	Cut-and-Cover	0.86
	Combination	0.88
	Inverted	0.95
Social	Cut-and-Cover	1.17
	Combination	1.13
	Inverted	1.05

Adjustment factors for duration were established for cut-and-cover techniques on the basis of total construction time regardless of method or type of construction. This generally applies also to the combination method wherein reduction of surface disruption is essentially reflected in reduced construction time. Consequently the durations to be considered in quantifying disruptions for the cut-and-cover and combination methods would be the respective construction times shown on Table 29; 31 months for the regular method and 28 months for the combination method.

There are certain portions of the overall construction period required for the inverted method in which disruptions would be considerably less than normally considered for cut-and-cover work. Approximately 12 months are required to build the utilidors. If they were constructed as tunnels; surface disruptions would be light. If built by open-trench methods, there would still be a fairly large, unobstructed portion of the street available for traffic. Completion of the transit structure (under-the-roof) after the street has been restored accounts for another 12 months of total construction time. Disruptions during this period should be minimal (see paragraph 7.4) except for possible interference on certain side streets or areas used for access ramps. Assuming disruptions caused by these two phases of the work to be about 1/3 of normal, the equivalent duration to be used for the inverted method would be 19 months (35 months - 2/3 of 24 months).

Adjustment factors for duration (see page 130) are determined with respect to times noted above. Cost of disruption associated with the safety criterion is taken as a percent of total cost.

Calculation of the cost of disruption for the three methods of construction is shown on Table 32. The effective costs are shown on page 191 and graphically on Figure 29.

Table 32. CUT-AND-COVER, COMBINATION AND INVERTED METHODS COST OF DISRUPTION ($1,000)

Cut-and-Cover

$$C_B = 30{,}000 - 30{,}000\,(0.40 \times 0.873 + 0.60 \times 0.86) = 4{,}050$$

$$C_S = 825 \times (0.70 \times 1.763 + 0.30 \times 1.17) - 1 = 483$$

$$C_{SA} = 27{,}735 \times 0.025 = \underline{693}$$

$$5{,}226$$

Combination

$$C_B = 30{,}000 - 30{,}000\,(0.40 \times 0.88 + 0.60 \times 0.88) = 3{,}600$$

$$C_S = 825 \times (0.70 \times 1.65 + 0.30 \times 1.13) - 1 = 408$$

$$C_{SA} = 27{,}665 \times 0.025 = \underline{692}$$

$$4{,}700$$

Inverted

$$C_B = 30{,}000 - 30{,}000\,(0.40 \times 0.915 + 0.60 \times 0.95) = 1{,}920$$

$$C_S = 825 \times (0.70 \times 1.313 + 0.30 \times 1.05) - 1 = 193$$

$$C_{SA} = 32{,}062 \times 0.025 = \underline{802}$$

$$2{,}915$$

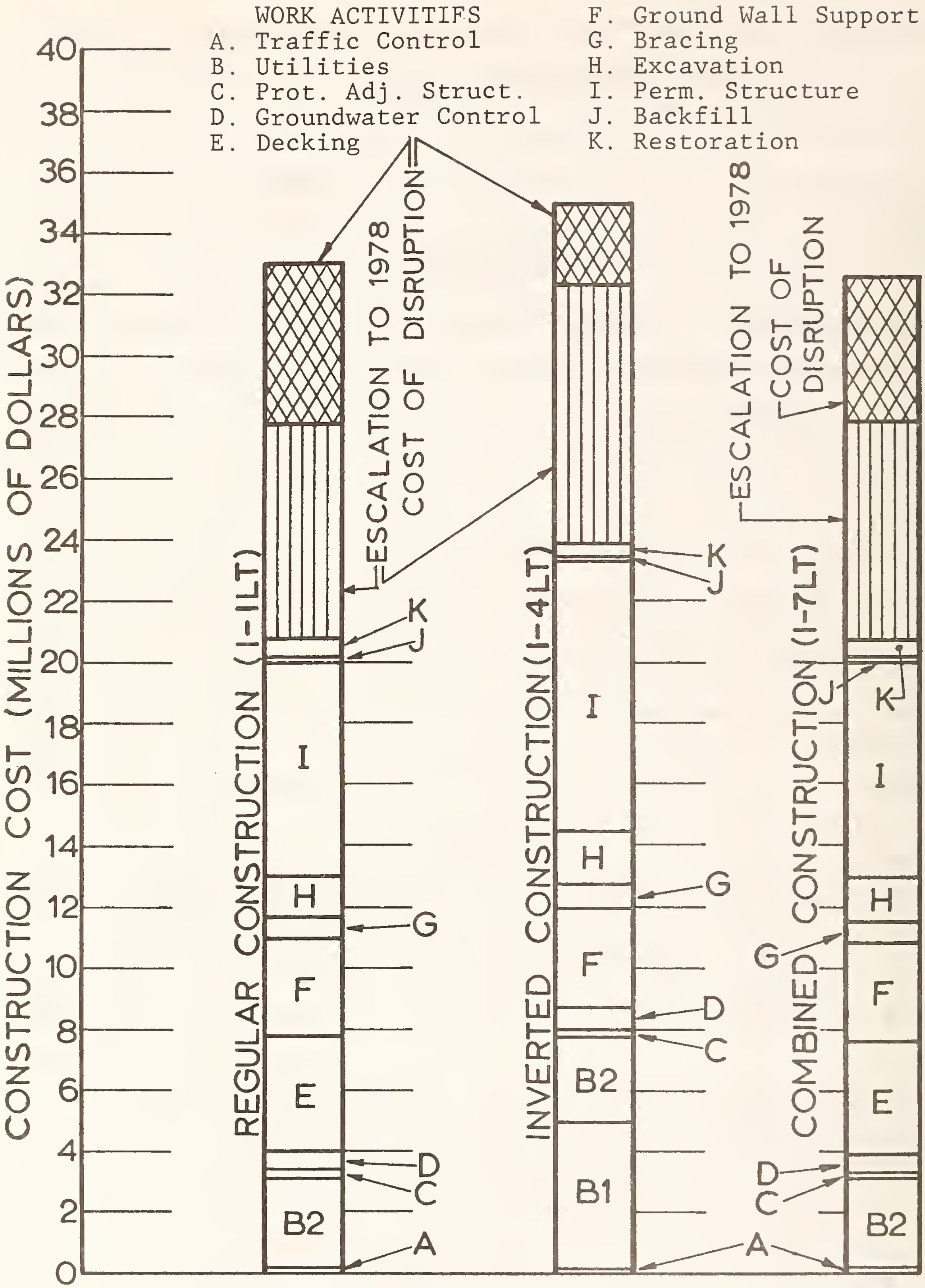


Figure 29. COSTS FOR REGULAR, INVERTED AND COMBINATION METHODS - HIGHWAY STRUCTURE

	Cut-and-Cover	Combination	Inverted
Estimated Cost 1974	$20,682,000	$20,630,000	$23,838,000
Estimated Cost 1978	27,735,000	27,665,000	32,062,000
Cost of Disruption	5,226,000	4,700,000	2,915,000
Effective Cost	$32,961,000	$32,365,000	$34,977,000

8.5 SUMMARY

Based on the example, the combination method offers the most effective solution. Although surface disruption (quantified in dollars) is considerably less when using the inverted method, its higher construction cost more than offsets this advantage.

Different site conditions could, of course, alter the results. For instance, if existing utilities were such that utilidors would not be required, the inverted method would offer the most cost effective construction. The same would be true if the business and social value bases had been higher. On the other hand, lower value bases would tend to show a greater advantage for the cut-and-cover and combination methods of construction.

The example also illustrates the type of problem facing the planner - that is, the "hard dollar" cost of construction must be evaluated with respect to a more-or-less intangible - the cost of disruption.

The decision that the combination or inverted method of construction would be preferable to standard cut-and-cover for a particular situation must be made during the planning phase and the project designed accordingly. This poses a problem in the normal procedure of contracting where the general method of construction is usually left to the discretion of the contractor. Leaving construction methods to the contractor assures that each contractor will base his competitive bid on methods that are most efficient and inexpensive for his organization to perform. This will usually result in minimum construction cost. However, other factors such as reduced disruption and impact on the community must be considered and these considerations may offset the apparent economy of low construction cost.

It is the aim of this section to appraise the planner of the trade-off values involved so that he is in a better position to make such a decision. Increased public involvement in the planning of transit systems; especially in areas affecting the environment, may or may not help in the solution. Decisions based primarily on emotions are sometimes hard to justify in terms of dollars.

SECTION 9

CAST-IN-SLURRY GROUND SUPPORT WALLS

9.1 GENERAL

Several methods of ground support are described in Volume 1 including three types of cast-in-slurry walls. Although these three support walls are similar in performance, there are differences in installation techniques, structural properties, and compatibility to bracing.

One method developed and used extensively in Europe consists of a series of cast-in-place reinforced concrete panels. The panels act as continuous vertical beams or slabs, spanning from bracing level to bracing level and transmitting soil and water loads to the bracing system, balanced by similar loads from the wall opposite.

Another system known as SPTC (soldier piles and tremie concrete) was developed by an American contractor. It has been used for transportation tunnels in the United States and experience records of its use were available to the study team. In this system, unreinforced concrete transmits the earth loads to closely spaced soldier piles similar to the behavior of soldier piles and lagging, except the concrete is watertight and rigid. The vertical soldier piles, in turn, transmit the load to the bracing system. The concrete and steel are not considered as a composite member. The SPTC wall was used for all study estimates involving a cast-in-slurry ground wall.

A third variation of slurry wall, which has also been used in the United States, is a combination of the two systems. The soldier piles are placed further apart than the SPTC wall with reinforced, cast-in-place concrete panels between. In this system the major reinforcing is horizontal acting as a simple span between soldier piles which, as in the case of the SPTC wall, transmit the ground loads to the bracing system.

All three methods provide a similar semi-rigid, relatively watertight wall that reduces the need for protection or underpinning of adjacent structures normally required by flexible wall systems. They also act as the permanent structural wall of the transportation tunnel or station. This section describes the advantages of each and compares construction costs.

9.2 REINFORCED, CAST-IN-PLACE PANELS

Typically, this type of wall is constructed by first excavating a shallow guide wall trench at the surface. Low concrete walls on either side of the trench act as guides for the slot excavating equipment and prevent the top of the earth from sloughing off. The shallow trench also aids in locating existing utilities.

The wall slot is excavated in panels about 20 feet (6.1m) long in a leapfrog pattern. The excavation is usally done by a special hydraulic grab bucket mounted on a vertical shaft from a crane. If the ground is hard or contains rock in the invert it may require the use of a drill mounted on a crane or a rail carriage straddling the slot. Occasional boulders may be broken by a "chisel," a heavy steel beam with hardened end edges. The slot is kept from caving by keeping it filled with a slurry mixutre of bentonite clay and water. The consistency of the mixture keeps most soil particles in suspension and coats the sides of the slot so it is relatively impervious. The excavation process constantly changes the volume of the slot and adds fresh soil to the mixture. To maintain the required specific gravity of the slurry, it is constantly recirculated to a surface plant where it is filtered, monitored and fresh materials added and returned to the slot.

Upon completion of panel excavation, a cage of reinforcing is assembled above the slot and lowered into position. Spacers, bearing plates, blockouts and keys may be wired to the reinforcing as required. The slot is then filled with tremie concrete with the concrete displacing the slurry, most of which is recovered for use in the next slot excavation.

Skipping one panel length, another panel is excavated and concreted in the same manner. When the alternate panels have acquired sufficient strength, the in-between panels are excavated and concreted. Various methods have been devised by contractors to improve the water tightness of the joints between panels including special end forms, keys and grout tubes. When exposed by structure excavation, the wall presents a relatively rough finish. Since the concrete is poured against the excavated slot, the concrete face will vary by several inches locally from a true plan and skewed bucket markes may result in abrupt differences. One disadvantage of a continuous rough concrete face is the placing and blocking of steel bracing. Bearing plates may be attached to the reinforcing cage for this purpose.

9.3 SPTC, CAST-IN-PLACE WALL

This type of wall has been used on several stations and sections of subway in San Francisco and Washington, D.C. Although guide walls are not necessary for excavating the wall slot, it is desireable to excavate a shallow trench along the wall to locate utilities. Soldier piles are usually placed on about 5 ft to 8 ft (1.5m to 2.4m) centers if the concrete is not reinforced. The thickness of the wall is equal to the section depth of the soldier piles.

In situations where soldier piles are 36" beams (0.91m) and are to be placed on 6 ft. (1.8m) centers; as in the case of highway structures at Site 1 for the 70-foot (23.1m) depths, it is usual to first drill auger holes at 12 ft. (3.7m) centers. These holes are filled with bentonite. When the hole has reached the required depth of embedment below the invert the soldier pile is lowered into it, splicing on sections; if required by the length, as it is lowered. Concrete is placed in the hole from the bottom to the level of the invert. Above the invert the hole is filled with sand or a very lean mix concrete.

A special bucket is used to excavate the wall slot between the soldier piles. These slots are also kept filled with bentonite slurry in the manner described for the reinforced panels. Each excavated slot is actually a double slot since the final wall will have piles on 6 ft (1.8m) centers. The bucket, attached to a vertical shaft mounted on a crane, is the same width as the soldier piles and when open fits between the flanges of the two piles. The piles thus act as guides for the bucket. The accuracy of wall alignement is determined by the placing of the soldier piles. When the slot excavation is complete, the inside of the flanges are given a final pass with special cleaning tools or brushes. This is very important as; except for occasional rock pockets in the concrete, leakage around the flanges is the most likely cause of problems with this type of wall.

After the slot is excavated and cleaned, a soldier pile is placed and fixed in the slot midway between the ends. Twin tremie pipes are installed in the double slot, and the concrete is placed, displacing the slurry. The level of concrete on both sides of the center pile is maintained at the same depth during the pour. The appearance of this wall; when exposed, is quite rough as in the case of the cast-in-place panels. Both require extraordinary methods of cleaning such as steam or water jet to remove the remaining slurry from the rough concrete. Due to the difficulty of controlling tremie concrete pours in deep slots under slurry, it is usual to find defects which require patching or repair work after structure excavation and cleaning off the slurry.

The placing of bracing is facilitated by the presence of soldier piles which permits steel to steel welding. For this reason, this type of wall is more consistent with American contractors' methods developed with soldier piles and lagging. The rough concrete wall, however, may project several inches beyond the pile requiring deep blocking in some areas.

9.4 COMBINATION, CAST-IN-SLURRY WALL

This type of wall has been used on several sections of subway in Washington, D.C. and New York City. The construction methods described for the reinforced panel and SPTC walls are also applicable to this type of wall. The soldier piles are heavier and placed further apart than in the case of the SPTC wall. Prepared cages of reinforcing steel placed in the slots enables the concrete to span between piles. Pile hole drilling, slot excavation and concreting are similar to those described. Reinforcing is lighter than in the case of the reinforced panel wall. Blocking and bracing are welded to the piles as with the SPTC wall. The same cleaning, patching and finishing methods are employed.

9.5 CONSTRUCTION COST COMPARISON

In comparing the cost of construcing the three types of cast-in-slurry support walls, estimate 1-3JY was used as the base. This estimate is for a rapid transit line section at 70-foot (23.1m) depth at Site 1. It has SPTC ground support walls and internal bracing. Soldier piles are W30 x 108 at 6 ft (1.83m) spacing. There are four levels of bracing below the deck level. Comparable estimates for the reinforced panels and combination walls were arbitrarily designated as 1-3JYA and 1-3JYB respectively. For purposes of comparison a modular panel length of 12 feet (3.66m), a double slot for SPTC wall and single slot for the other two, was adopted. While this is shorter than usual for a reinforced panel, the rate of excavation per cu. yd. is considered the same as for the other methods so the effect on overall cost is negligable.

A section through each wall, Figure 30, shows the soldier pile and reinforcing steel for each method. In designing these walls, American construction practices have been taken into consideration. The reinforced panel wall is heavier than it would likely be if used in Europe. European contractors have a tendency to conserve materials by making the wall lighter and using more levels of bracing. The bracing would also be lighter and probably knee braces and other fabrication aids would be used to conserve steel. The American contractor faced with considerably higher field labor and overhead costs uses heavier but fewer bracing members, keeping field fabrication to

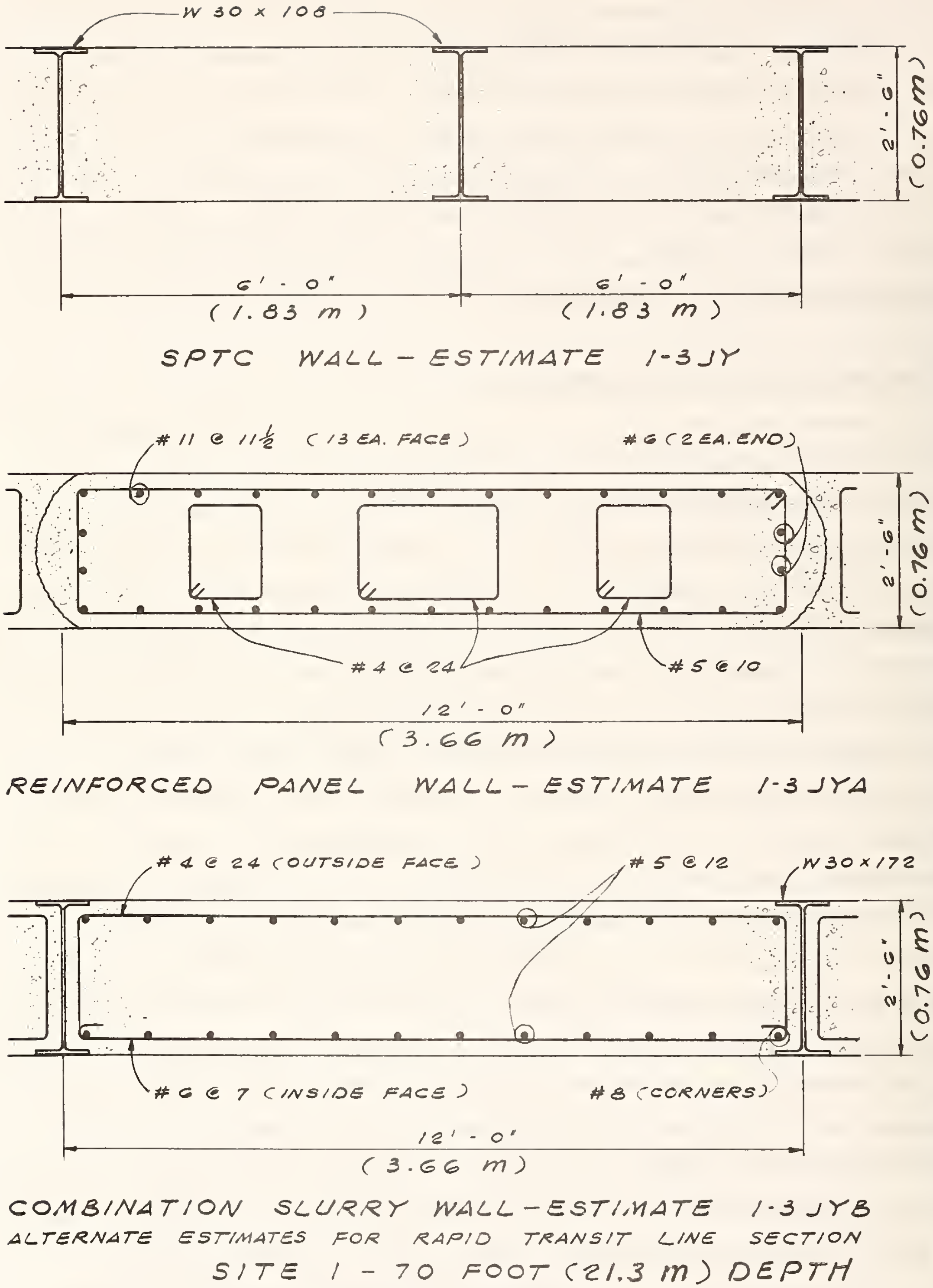


Figure 30. ALTERNATE CAST-IN-PLACE SLURRY WALLS

a minimum. This does not imply that one method is better than the other, but acknowledges a difference in economies that are reflected in construction practices. The three walls, therefore, are the same thickness. Piles and reinforcing steel have been designed for the same loads and spacing of bracing levels.

After running estimate 1-3JY (SPTC) by computer, the input was altered to produce 1-3JYA and 1-3JYB. The same 1974 rate deck of basic resource costs and typical labor crews was used for each. Rates of progress were similar to comparable operations in the other estimates produced for the study. For instance, the guide walls were taken from a precast panel estimate and the reinforcing fabrication crew from the permanent structure activity.

These estimates are summarized on Table 33. It shows the cost of the reinforced panel wall to be $850,000 higher than the SPTC wall and the combination method $420,000 higher. The major differences are in the cost of ground wall construction, with bracing and applicable indirect costs contributing minor amounts.

Since the cost of reinforcing steel which is a major cost factor for the reinforced panel method was unusually high in 1974 and slightly lower in 1977 (a negative trend compared to prices of other materials which increased by 20% to 30% in the same time) it was decided to rerun the estimates using an updated 1977 rate library. The results of these estimates and the percentage increase for each major work item are also shown on Table 33. The overall job costs for the SPTC project rose 23.0% while the reinforced panel rose 21.1% and the combination method 22.4%. The difference is more dramatic in the wall installation item F where the increase was 25.4%, 16.5% and 22.2% respectively. Total costs for 1977 show the reinforced panel project $630,000 higher than SPTC, and the combination method $390,000 higher.

These figures demonstrate quite clearly that ecomomies in construction costs are not static. The most economical system at this period may well change in five years. The example

Table 33. COMPARISON OF COSTS ($1000) OF SLURRY WALL CONSTRUCTION

RAPID TRANSIT LINE STRUCTURE

SITE 1 - 70 FT. (21.3m) DEPTH

	TYPE OF WALL	S.P.T.C.			REINF., C.I.P. PANELS			COMBINATION W/S.P.		
	ESTIMATE	1-3JY			1-3JYA			1-3JYB		
	ACTIVITY / YEAR	1974	1977	% Inc.	1974	1977	% Inc.	1974	1977	% Inc.
A	TRAFFIC CONTROL	122	157	28.7	122	157	28.7	122	157	28.7
B	UTILITY WORK	1,768	2,208	24.9	1,768	2,208	24.9	1,768	2,208	24.9
C	PROTECT ADJ.STRUCT.	36	47	30.6	36	47	30.6	36	47	30.6
D	GROUNDWATER CONTROL	973	1,217	25.1	973	1,217	25.1	973	1,217	25.1
E	DECKING	1,358	1,678	23.6	1,358	1,678	23.6	1,358	1,678	23.6
F	GROUND WALL SUPPORT	3,417	4,285	25.4	4,105	4,783	16.5	3,784	4,624	22.1
G	BRACING	1,634	1,991	21.8	1,676	2,044	22.0	1,634	1,991	21.8
H	EXCAVATION	957	1,251	30.7	957	1,251	30.7	957	1,251	30.7
I	CONST.PERM.STRUCT.	3,342	3,904	16.8	3,342	3,904	16.8	3,342	3,904	16.8
J	BACKFILL	795	990	24.5	795	990	24.5	795	990	24.5
K	RESTORATION	96	116	20.8	96	116	20.8	96	116	20.8
	SUB TOTAL - DIRECT	14,498	17,844	23.1	15,228	18,395	20.8	14,962	18,183	22.3
N	OVERHEAD (FIXED)	294	365	24.1	298	368	23.5	297	367	23.6
O	OVERHEAD (TIME REL)	2,329	2,852	22.5	2,329	2,852	22.5	2,329	2,852	22.5
P	PLANT (FIXED)	206	253	22.8	206	253	22.8	206	253	22.8
Q	PLANT (TIME REL)	159	200	25.8	159	200	25.8	159	200	25.8
	SUB TOTAL - INDIRECT	2,988	3,670	22.8	2,992	3,673	22.8	2,991	3,672	22.8
	TOTAL COST	17,486	21,514	23.0	18,220	22,068	21.1	17,856	21,855	22.4
	MARKUP	2,623	3,227	23.0	2,733	3,310	21.1	2,678	3,278	22.4
	BID PRICE	20,109	24,741	23.0	20,953	25,378	21.1	20,534	25,133	22.4

% Inc. = % Increase

illustrates the effect of only one major cost item out of step with others within a relatively short period of three years. Improvements in construction methods, design of new support systems, or development of new or composite materials could have similar effects. Results of this and similar type studies could be used to show trends of costs indicating areas where improvements could be most productive in reducing overall project costs.

9.6 REDUCING COSTS OF CAST-IN-SLURRY WALL PROJECTS

One method for reducing costs would be to eliminate where possible, the facia or finish wall in the permanent structure. There are three reasons for using a finish wall:

1) Aesthetics - The rough finish of the slurry wall is not uniform or pleasant to the eye; exposed steel surfaces will rust unless covered or treated.
2) Maintenance - A smooth concrete wall is easier to clean and less likely to spall.
3) Support - The finish wall may provide the main support for a slab above it, if there is difficulty in keying a load bearing slab into a cast-in-place slurry wall.

There may be occasions where these considerations are not important and it may be possible to eliminate the finish walls. This could occur in a highway or line section tunnel where the finish is less critical, or even in a station where a furred panel, or other type of architectural wall is contemplated. To determine the magnitude of savings due to elimination of the finish wall, details of the computer estimates with slurry walls were reviewed.

Several operations contribute to the added costs of providing a finish wall: forming, reinforcing, concreting and finishing. Each SPTC estimate includes 12-inch (0.31m) thick finish walls. Since these are not structural walls they are not affected by the depth of structure or site conditions so consequently cost the same in each estimate of a particular structure. The direct cost of the finish wall and resulting bid price savings rounded to the nearest $1000 due to eliminating these walls are:

Structure	Direct Cost	Bid Price Saving
Highway Tunnel	$269,000	$309,000
Rapid Transit Station		
Track Level	$245,000	$282,000
Mezzanine Level	182,000	209,000
Total	$427,000	$491,000
Rapid Transit Tunnel	$217,000	$250,000

In Section 4 of the report, the results for all study estimates are summarized and compared in Table 19, page 107. There are forty site and structure combinations where two to six applicable construction methods are compared on the basis of total cost. Of the forty situations, there are nine where one of the cast-in-slurry wall options (SPTC) would provide the lowest construction cost if the cost of the finish wall could be eliminated.

Eliminating the facia wall on the highway tunnel at site 1, 50-foot (15.2m) depth, makes the SPTC estimate cheaper than the soldier pile and lagging alternative which is shown as least expensive in Table 19. Elimination of the facia wall would not alter the comparative results of the highway tunnel for the other situations.

For eight of the ten site-depth situations shown for the rapid transit station, elimination of the facia wall would make the SPTC estimates less expensive than the precast panel wall estimates.

None of the construction economies would be altered by eliminating the facia walls for the rapid transit line section. In nine situations it is already least expensive and in the other six it is too much higher than the soldier piles and lagging method to become competitive by elimination of the finish walls.

SECTION 10
CONCLUSIONS & RECOMMENDATIONS

10.1 OBJECTIVE

The aim of the study was to develop data and procedures which can be used to evaluate and optimize the cut-and-cover tunnel design-construct process as it pertains to transportation structures in urban areas. This process requires a general understanding of the applicability and variatons in designs, construction methods and costs related to site and construction conditions. Optimization also requires that surface disruptions caused by cut-and-cover construction be considered.

The guidelines, cost data, equations, general procedures and examples given in the report can be used to determine the most efficient technique for a broad range of cut-and-cover situations.

10.2 CONCLUSIONS

Most conclusions derived from the study are based on systematic evaluations of 176 cut-and-cover constructions representing up to six alternatives for each of 40 transportation tunnel situations - three structures, five sites and three depths (transit station at only two depths) plus specific examples of inverted, combination and cast-in-slurry construction methods. Results presented in Table 19 (page 107), Appendix C, and other summaries show variations and trends in activity and total costs determined for the different conditions.

The estimate summaries in Appendix C, page 245, indicate that although there are general trends in total job costs, there is no general consistency in relative variations of activity costs with reference to either methods or depth and width of construction. Cost of some activities remain nearly constant for many situations while others vary considerably depending on site and construction conditions.

Because of the many variables involved, no construction method can be considered optimum for all situations of cut-and-cover tunneling. Each combination of site, structure and construction conditions must be evaluated individually to determine the most cost-effective solution. In some cases there will be only small differences in total costs between several construction alternatives. Any conclusions, therefore, must be qualified on the basis of each particular situation being investigated.

Some of the site and construction factors, and their effect on optimal costs of cut-and-cover construction are discussed briefly in the following paragraphs. Comments regarding combination and inverted methods and variations of the cast-in-slurry concrete diaphragm method are also included.

10.2.1 <u>Site Conditions</u>: The total cost of cut-and-cover tunneling is affected more by site conditions than the construction method being used. Of the five sites considered, conditions at site 2 are most favorable for cut-and-cover construction and provide least cost for all situations. With but one exception, costs are less at site 1 than at sites 3, 4, or 5. Construction at all 30-foot (9.1m) depths and about half of the 50-foot and 70-foot (15.2m and 21.3m) depths at site 3 is less expensive than at site 4. Construction at site 5 is from 3% to 24% more expensive than comparable work at site 4.

If alternate routes are available for a proposed transit system, initial planning should consider potential savings in construction costs due to maximum utilization of sites with most favorable conditions. Magnitude of savings can be assessed by using data provided on Table 19.

10.2.2 <u>Ground Wall Support and Bracing</u>: The ground wall support and bracing method (activities F and G) has the greatest potential variation in cost when considering different situations. It also affects the requirements and performance of other activities needed for completion.

The most cost effective construction method for the 40 transit situations are shown on Table 34. Where the soldier

Table 34. MOST COST EFFECTIVE CONSTRUCTION

FORTY STUDY SITUATIONS

CONSTRUCTION SITUATION	DEPTH		
	30'	50'	70'
HIGHWAY TUNNEL:			
SITE 1	SP&L/TB	SP&L/TB	SPTC/TB
SITE 2	SP&L/TB	SP&L/TB	SPTC/TB
SITE 3	SPTC/IB	SPTC/IB	SPTC/IB
SITE 4	SPTC/IB	SPTC/IB	SPTC/IB
SITE 5	SPTC/IB	SPTC/IB	SPTC/IB
RAPID TRANSIT STATION:			
SITE 1	-	PCP/IB	PCP/IB
SITE 2	-	PCP/IB	PCP/IB
SITE 3	-	PCP/IB	PCP/IB
SITE 4	-	PCP/IB	PCP/IB
SITE 5	-	PCP/IB	PCP/IB
RAPID TRANSIT TUNNEL:			
SITE 1	SP&L/IB	SP&L/IB	SP&L/IB
SITE 2	SP&L/IB	SP&L/IB	SP&L/IB
SITE 3	SPTC/IB	SPTC/IB	SPTC/IB
SITE 4	SPTC/IB	SPTC/IB	SPTC/IB
SITE 5	SPTC/IB	SPTC/IB	SPTC/IB

SP&L - Soldier Piles & Lagging
SPTC - Soldier Piles & Tremie Concrete
PCP - Precast Panels
1' = 1 ft. = 0.305m

TB - Tieback Bracing
IB - Internal Bracing

piles and lagging (SP&L) method was considered applicable as an alternative, it proved least expensive for 10 of 16 situations (63%). This is in general accordance with present industry practice, where the SP&L method is usually used (where feasible) if the option is left to the contractor. The SPTC method was most effective for 20 of 40 possibilities (50%) and the PCP method for 10 of 40 (25%).

In nearly all instances (34 out of 40) internal bracing affords lower costs than tieback bracing under comparable conditions. Exceptions are for wide structures where ground conditions are adaptable to tieback installations (non-compressible soils).

10.2.3 Width and Depth of Structure: A major factor in the choice of construction method (ground wall support system - activity F) is the need to provide protection or underpinning for adjacent structure foundations that fall within the zone of influence of the construction. This zone depends on the width and depth of the structure in relation to site configuration.

Increased costs of a semi-rigid wall system (SPTC or PCP) should be evaluated with reference to increased costs of underpinning (activity C) associated with use of a less expensive, flexible wall system - SP&L.

Figure 31 shows comparison of costs for flexible and semi-rigid wall systems related to depth and width of construction. Costs of flexible walls are affected by underpinning requirements established for the study at 50-foot (15.2m) and 70-foot (21.3m) depths. If underpinning requirements were greater than assumed, the semi-rigid systems would probably provide more cost-effective solutions for the wide deep structures than shown on Table 34.

Width also affects the competitive nature of bracing systems. Tiebacks are most effective in wide excavations; internal bracing for the narrower structures. The relatively high initial cost of tieback installations does not vary significantly with increase in width. Cost of internal bracing, however, increases substantially for the wider structures.

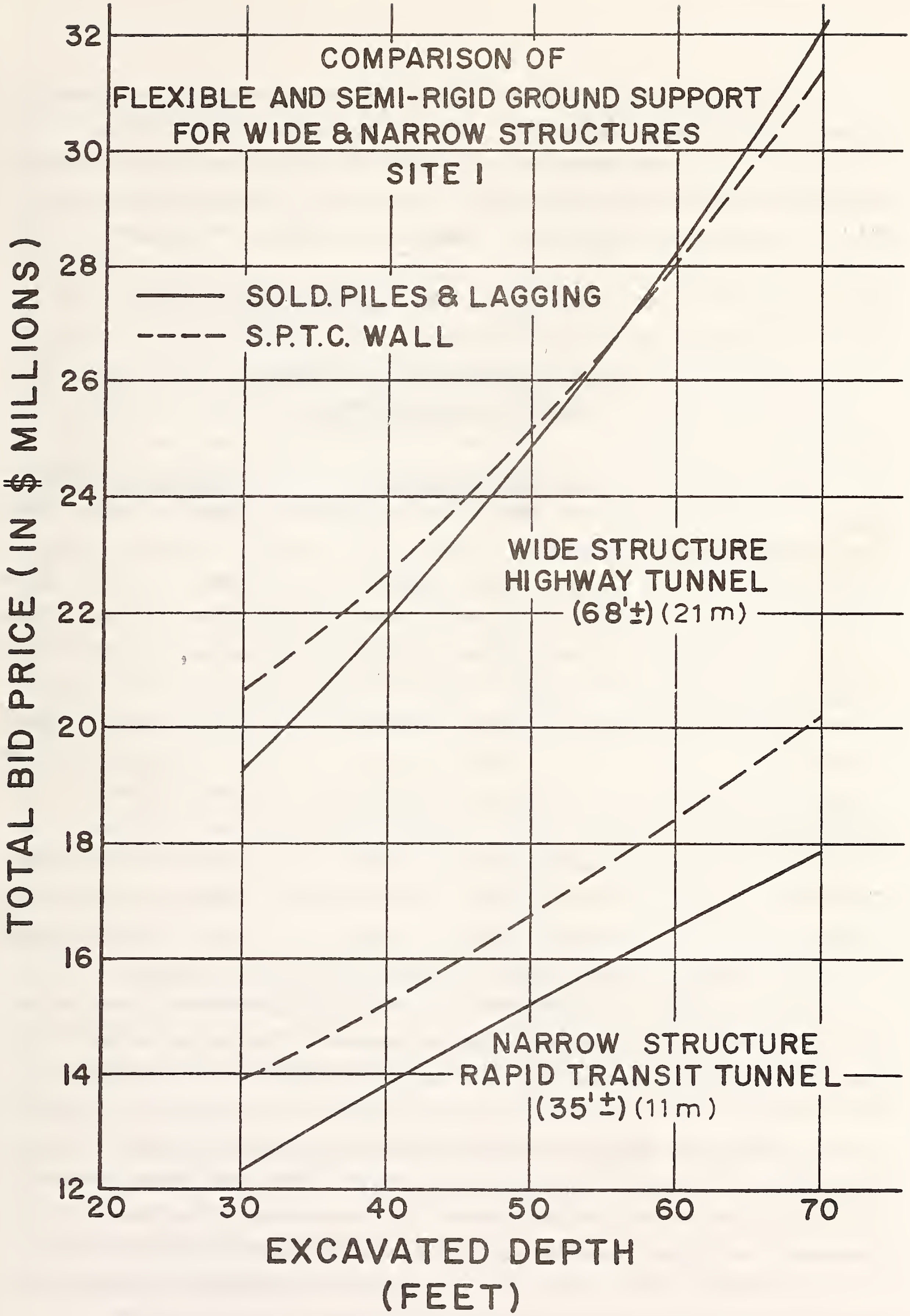


Figure 31. COMPARISON OF GROUND SUPPORT SYSTEMS

In most cases, there is nearly a straight line relation between total costs and depth of construction. Additional costs due to increased depth are generally greater (percentage wise) when using tieback bracing than with internal bracing. This is due to the increased length and number of anchors required as depth increases. Based on averages of all study situations, the following shows percentage increase in costs for the three construction depths.

PERCENTAGE INCREASE IN COST
DEPTH OF CONSTRUCTION

	Internal Bracing			Tie-back Bracing		
Depth	30'	50'	70'	30'	50'	70'
Highway Structure						
SP&L	100%	130%	170%	100%	131%	173%
SPTC	100%	124%	154%	100%	124%	158%
PCP	100%	124%	156%	100%	125%	162%
Station						
SP&L		100%	118%		100%	119%
SPTC		100%	117%		100%	119%
PCP		100%	119%		100%	123%
Line Section						
SP&L	100%	124%	153%	100%	128%	159%
SPTC	100%	123%	147%	100%	130%	164%
PCP	100%	124%	151%	100%	132%	170%

The above may be helpful in initial planning of route locations and could be used to approximate depths at which open-cut and underground tunneling techniques would be competitive.

10.2.4 Updating Costs: Transit planning usually requires the projection of costs to some future date. This is best accomplished by considering potential increases for individual resource components included in each method of construction (see paragraph 6.3). For all intents and purposes, however, the relationship of total costs determined for different methods will remain essentially the same if each is projected to the same date. This might not be true if new technologies were such as to alter relative mix of components for a particular method. In this case, adjustments should be made in the appropriate up-dating equation to determine differences in projected costs.

10.2.5 Cost of Disruption: The relatively intangible cost of disruption associated with cut-and-cover construction is becoming a critical factor to be considered in initial planning. The proposed rationale for quantifying disruption provides a means for at least relative evaluations. Based on the examples of cut-and-cover construction considered in the study, the surface disruption caused by using the soldier piles and lagging method is about 15% to 25% less than when using the SPTC and precast panel methods respectively. Disruption of the SPTC method is generally less than the precast panel method by about 6%. The most efficient construction with respect to disruption is the inverted method; where disruptions are 70% and 52% less than cut-and-cover and combination methods respectively.

Dollar amounts representing these relative percentages are dependent on various physical, social and economic elements associated with the particular site and construction. The rationale presents one means by which these elements can be evaluated.

10.2.6 Comparison of Different Cut-and-Cover Methods: The major cost advantage of inverted construction (elimination of decking activity - E) would, in most cases, be more than offset by additional or increased costs of handling utilities and completing excavation and permanent structure "under-the-roof". Surface disruptions caused by inverted construction are significantly less than for other methods. Under the right circumstances (minimal utility work and an urban site highly sensitive to disruption) the inverted method could be the most effective technique.

The combination method is competitive cost-wise with regular cut-and-cover construction and causes less surface disruption.

Of the three cast-in-slurry concrete diaphram wall alternatives, the soldier piles and tremie concrete (SPTC) method is most cost effective. Surface disruptions would be approximately the same for all three.

10.2.7 Producing New Cost Estimates: Using the results of this study to determine the effective cost of a future project, the following sequence is suggested as a guide and checklist for the planner:

1. Choose the most cost-effective estimate from Appendix C, page 245, whose physical characteristics: structure, soil, groundwater, depth, etc. most closely match those of the new project.

2. List major features of the new project that differ from those of the estimate from Appendix C that is to be used as a base estimate. Such features should include: a) length, depth and cross sectional area of structure, b) types and sizes of utilities, c) types of building requiring underpinning or other protection, d) areas where full decking would not be required and e) institutional restraints distinctive of the new project area that could affect the cost of traffic control, utilities, excavation, backfill or restoration.

3. Using the quantity tables in Appendix B, page 223, make adjustments to the base estimate activities and operations to product the new estimate (using prices of Washington, D.C. in 1974). This extrapolation procedure is described in paragraph 4.3, page 92, and illustrated in Table 16, page 93.

4. If the length of structure was not included in the adjustments in step 3, make this adjustment as described in paragraph 4.3.5, page 101, and illustrated in Table 17, page 103.

5. The cost estimates in Appendix C are for typical structure sections. Add in costs of appendage structures, bulkheads, etc. as required for the new structure. These costs

(using 1974 prices) are described in paragraph 4.6, page 114, and given in Table 21, page 115. This adjustment should be made after the length adjustment in step 4 as these costs are not proportional to the length of structure. They do include additional overhead and profit.

6. Adjust the estimate to the year and location of the project. This procedure is described in paragraph 6.3, page 147. It utilizes equation (3) on page 150 and an example of this calculation is given on page 153. An alternative method of making this adjustment is to use published cost indexes; however, care must be taken to insure that the index used is reasonable for the geographical area of the project.

7. If cost of disruption is to be considered, appropriate business and social bases and adjustment factors must be determined for the project location. These costs can then be calculated based on the suggested rationale described in paragraph 5.5, page 138, and using equations summarized in Figure 21, page 139. Use of these equations is illustrated in Table 23, page 141. Future research into the problems of quantifying construction disruption could conceivably modify or supersede this suggested method.

10.2.8 General Comments: The interdependency of all construction activities in cut-and-cover tunneling is such that no single activity, method or procedure can be considered optimal for all situations. The construction must be considered in total, taking into account the affect on activity cost and requirements due to variations in site and structure conditions.

All considerations have been based on United States construction practices which reflect most efficient use of labor, material and equipment under present economic conditions. A significant change in the relative cost of resources could alter the results presented herein.

10.3 RECOMMENDATIONS

The study has explored the efficiencies of methods and procedures involved in cut-and-cover tunneling and has indicated areas of related interest which might be considered for future investigations.

1. In some instances, a planner may be faced with the choice of using either open-cut or underground tunneling methods for a particular transit structure. At what depth, or under what conditions would costs of one or the other of these alternatives be most competitive? A study showing comparative evaluations of open-cut vs tunneling at selected sites would be helpful in this respect.

2. Surface disruptions caused by tunneling are obviously less than open-cut. Would this more-or-less intangible cost factor be sufficient to justify the use of the normally more expensive tunneling method? Some means should be provided by which this decision can be made; either by expanding the quantification rational proposed herein or in developing a new method.

3. Initial planning and design of a transit structure should consider different construction methods that could be used at the particular site. The design should be as compatible as possible with the most efficient method of construction. If internal bracing is indicated, will typical bracing levels interfer with construction of the permanent structure? Is maximum utilization of semi-rigid wall systems incorporated in the design?

Potential savings in these and other areas are sometimes offered by the contractor through value engineering procedures after the award. It is desirable, however, that the original bid documents be based on most optimal solution for both temporary and permanent construction. This report will help planners be more aware of possible savings through construction oriented design.

APPENDIX A
STRUCTURAL REQUIREMENTS FOR TEMPORARY STRUCTURES

The design of temporary structures - ground wall support system, bracing, and decking - is usually the responsibility of the contractor on the basis of criteria and data provided by the owner.

Design guidelines covering a wide range of site and construction conditions were developed and discussed in various sections of the report. Using this criteria, structural requirements for temporary structures were determined for 108 cut-and-cover tunneling support and bracing combinations. Results are presented as Tables 35 through 43 in this Appendix A. Tables 35 through 37 lists temporary support and decking requirements for sites 1 and 2 (loading conditions are the same for temporary support at these sites). Tables 38 through 43 list comparable requirements for sites 3, 4 and 5.

The size and spacing of structural members shown for different structures, depths and ground conditions were used to determine quantities of work for the 176 study cost estimates (see Appendix B). The tables can also be used to approximate temporary structure requirements for other cut-and-cover tunneling operations.

METRIC CONVERSION FACTORS
(for Tables 35 through 43)

1" = 1 in. = 25.4 mm
1' = 1 ft. = 0.305 m
1 lb. = 0.454 kg.
Steel shape sizes are given in standard English Units
i.e. W30 x 116 is a 30 in. (0.76m) deep beam, weighing
116 lbs./ft. (173 kg/m).

Table 35. GROUND SUPPORT AND BRACING SYSTEMS - SITES 1 & 2
SOLDIER PILES AND LAGGING

GROUND SUPPORT AND BRACING SYSTEMS
SOLDIER PILES AND LAGGING WITH INTERNAL BRACING OR TIEBACKS
SITES 1 & 2

			4 LANE HIGHWAY TUNNEL RAPID TRANSIT STATION (3)			DOUBLE BOX LINE STRUCTURE		
			H=30'	H=50'	H=70'	H=30'	H=50'	H=70'
GROUND SUPPORT SYSTEM		PILES	W24×84	W24×130 (5)	W24×160(V-50) (6)	W24×84	W24×130 (5)	W24×100 (8)
		PILE SPACING	8'-0"C.C.	8'-0"C.C.	8'-0"C.C.	8'-0"C.C.	8'-0"C.C.	8'-0"C.C.
		LAGGING D.F.	3×MATERIAL TO -20' ELEV., 4×MATERIAL -20' ELEV. TO SUBGRADE					
DECK FRAMING		DECK BEAMS (1)	W36×230	W36×230	W36×230	W36×230	W36×230	W36×230
		CAP BEAMS, INTERIOR	W30×116	W30×116	W30×116	—	—	—
		CAP BEAMS, EXTERIOR	W14×68	W14×68	W14×68	W14×119	W14×119	W14×119
		INTERIOR PILES (2)	HP14×73	HP14×73	HP14×73	—	—	—
		CAP WALES	W30×99	W30×99	W30×99	W30×99	W30×99	W30×99
		LATERAL BRACING	WT5×10.5 WT6×13.5	WT5×10.5 WT6×13.5	WT5×10.5 WT6×13.5	WT5×10.5 WT6×13.5	WT5×10.5 WT6×13.5	WT5×10.5 WT6×13.5
		DECKING D.F.	12×12	12×12	12×12	12×12	12×12	12×12
INTERNAL BRACING ALTERNATE	LEVEL NUMBER 2	WALES	W14×74	W30×116	W36×135	W16×88	W30×116	W33×130
		STRUTS (1)	HP14×73	W14×111	W14×142	HP14×73	W14×103	W14×111
	LEVEL NUMBER 3	WALES	—	W30×99	W36×160	—	W30×99	W30×108
		STRUTS (1)	—	W14×87	W14×150	—	W14×87	W14×111
	LEVEL NUMBER 4	WALES	—	—	W30×99	—	—	W30×116
		STRUTS (1)	—	—	W14×103	—	—	W14×111
	LEVEL NUMBER 5	WALES	—	—	W24×76	—	—	W24×76
		STRUTS (1)	—	—	W14×87	—	—	HP14×73
TIEBACK ALTERNATE	LEVEL NUMBER 2	WALES	][12×25	][18×58	][18×42.7	][12×25	][18×58	][18×42.7
		TIEBACKS (4)	1¼"φ 120/150 (7)	1¼"φ 155/190	1¼"φ 120/150	1¼"φ 120/150 (7)	1¼"φ 155/190	1¼"φ 120/150
	LEVEL NUMBER 3	WALES	—	][18×42.7	][18×42.7	—	][18×42.7	][18×42.7
		TIEBACKS (4)	—	1¼"φ 120/150	1¼"φ 120/150	—	1¼"φ 120/150	1¼"φ 120/150
	LEVEL NUMBER 4	WALES	—	—	][18×51.9	—	—	][18×51.9
		TIEBACKS (4)	—	—	1¼"φ 120/150	—	—	1¼"φ 120/150
	LEVEL NUMBER 5	WALES	—	—	][15×40	—	—	][15×40
		TIEBACKS (4)	—	—	1¼"φ 120/150	—	—	1¼"φ 120/150
	LEVEL NUMBER 6	WALES	—	—	][12×30	—	—	][12×30
		TIEBACKS (4)	—	—	1¼"φ 120/150 (7)	—	—	1¼"φ 120/150 (7)
PENETRATION BELOW SUBGRADE		INTERNAL BRACING ALTERNATE	7'	11'	12'	7'	11'	12'
		TIEBACK ALTERNATE	10'	17'	27'	10'	17'	27'

(1) DECK BEAMS AND STRUTS ARE AT 12'-0" C.C. SPACING AND IN SAME VERTICAL PLANE

(2) INTERIOR PILES ARE AT 12'-0" C.C. SPACING AND OFFSET 2'-0" FROM ℄ OF DECK BEAM

(3) RAPID TRANSIT STATION NOT CONSIDERED AT H=30' BECAUSE OF STRUCTURAL HEIGHT.

(4) ALL TIEBACKS ARE DYWIDAG OR EQUAL. 120/150 REFERS TO GRADE OF STEEL.

(5) USE W24×145 PILE FOR TIEBACK ALTERNATE.

(6) USE W24×110 (A-36) PILE FOR TIEBACK ALTERNATE — RAPID TRANSIT STATION.
USE W24×160 (A-36) PILE FOR TIEBACK ALTERNATE — HIGHWAY TUNNEL.

(7) TIEBACKS NOTED AT 8'-0" C.C., ALL OTHERS AT 4'-0" C.C..

(8) USE W24×110 (A-36) FOR TIEBACK ALTERNATE.

ALL STEEL MEMEBERS ARE ASTM A-36 UNLESS NOTED.

Table 36. GROUND SUPPORT AND BRACING SYSTEMS - SITES 1 & 2
S.P.T.C. WALL

GROUND SUPPORT AND BRACING SYSTEMS
S.P.T.C. WALL WITH INTERNAL BRACING OR TIEBACKS
SITES 1 & 2

			4 LANE HIGHWAY TUNNEL RAPID TRANSIT STATION ③			DOUBLE BOX LINE STRUCTURE		
			H = 30'	H = 50'	H = 70'	H = 30'	H = 50'	H = 70'
GROUND SUPPORT SYSTEM		PILES	W24×94	W30×124	W36×170 ⑤	W24×100	W30×124	W30×108 ⑤
		PILE SPACING	8'-0" C.C.	6'-0" C.C.	6'-0" C.C.	8'-0" C.C.	6'-0" C.C.	6'-0" C.C.
		LAGGING D.F.	3× MATERIAL TO -20' ELEV., 4× MATERIAL -20' ELEV. TO S.P.T.C. WALL					
DECK FRAMING		DECK BEAMS ①	W36×230	W36×230	W36×230	W36×230	W36×230	W36×230
		CAP BEAMS, INTERIOR	W30×116	W30×116	W30×116	—	—	—
		CAP BEAMS, EXTERIOR	W14×68	W14×68	W14×68	W14×119	W14×78	W14×78
		INTERIOR PILES ②	HP14×73	HP14×73	HP14×73	—	—	—
		CAP WALES	W30×99	W24×84	W24×84	W30×99	W24×76	W24×76
		LATERAL BRACING	WT5×10.5 WT6×13.5	WT5×10.5 WT6×13.5	WT5×10.5 WT6×13.5	WT5×10.5 WT6×13.5	WT5×10.5 WT6×13.5	WT5×10.5 WT6×13.5
		DECKING D.F.	12×12	12×12	12×12	12×12	12×12	12×12
INTERNAL BRACING ALTERNATE	LEVEL NUMBER 2	WALES	W21×62	W30×124	W36×135	W21×62	W30×124	W33×130
		STRUTS ⑦	HP14×73	W14×142	W14×167	HP14×73	W14×119	W14×142
	LEVEL NUMBER 3	WALES	—	W30×99	W36×150	—	W30×99	W30×116
		STRUTS ⑦	—	W14×103	W14×184	—	W14×87	W14×119
	LEVEL NUMBER 4	WALES	—	—	W30×99	—	—	W33×118
		STRUTS ⑦	—	—	W14×127	—	—	W14×127
	LEVEL NUMBER 5	WALES	—	—	W30×99	—	—	W30×108
		STRUTS ⑦	—	—	W14×127	—	—	W14×111
TIEBACK ALTERNATE	LEVEL NUMBER 2	WALES	][12×35	][18×51.9	][18×51.9	][12×35	][18×51.9	][18×51.9
		TIEBACKS ④	1¼"φ 155/190 ⑥	4-⅝"φ 205/230	1¼"φ 120/150	1¼"φ 155/190 ⑥	4-⅝"φ 205/230	1¼"φ 120/150
	LEVEL NUMBER 3	WALES	—	][15×50	][18×51.9	—	][15×50	][18×51.9
		TIEBACKS ④	—	1¼"φ 120/150	1¼"φ 120/150	—	1¼"φ 120/150	1¼"φ 120/150
	LEVEL NUMBER 4	WALES	—	—	II5 18×70	—	—	][18×51.9
		TIEBACKS ④	—	—	5-⅝"φ 205/230	—	—	1¼"φ 120/150
	LEVEL NUMBER 5	WALES	—	—	][18×51.9	—	—	II5 18×54.7
		TIEBACKS ④	—	—	1¼"φ 120/150	—	—	4-⅝"φ 205/230
	LEVEL NUMBER 6	WALES	—	—	][18×45.8	—	—	][18×45.8
		TIEBACKS ④	—	—	1¼"φ 120/150	—	—	1¼"φ 120/150
	LEVEL NUMBER 7	WALES	—	—	][13×31.8	—	—	][13×31.8
		TIEBACKS ④	—	—	1¼"φ 155/190 ⑦	—	—	1¼"φ 155/190 ⑦
PENETRATION BELOW SUBGRADE		INTERNAL BRACING ALTERNATE	10'	10'	12'	10'	10'	12'
		TIEBACK ALTERNATE	10'	10'	12'	10'	10'	12'

① DECK BEAMS AND STRUTS ARE AT 12'-0" C.C. SPACING AND IN SAME VERTICAL PLANE.

② INTERIOR PILES ARE AT 12'-0" C.C. SPACING AND OFFSET 2'-0" FROM ℄ OF DECK BEAM.

③ RAPID TRANSIT STATION NOT CONSIDERED AT H = 30' BECAUSE OF STRUCTURAL HEIGHT

④ ALL TIEBACKS ARE DYWIDAG OR EQUAL. 120/150 REFERS TO GRADE OF STEEL.

⑤ USE W36×135 PILE FOR TIEBACK ALTERNATE - RAPID TRANSIT STATION & LINE SECTION

⑥ TIEBACK AT 8'-0" C.C., ALL OTHERS AT 4'-0" C.C. UNLESS NOTED

⑦ TIEBACK AT 6'-0" C.C.

ALL STEEL MEMBERS ARE ASTM A-36 UNLESS NOTED

Table 37. GROUND SUPPORT AND BRACING SYSTEMS - SITES 1 & 2
PRECAST CONCRETE WALL

GROUND SUPPORT AND BRACING SYSTEMS
PRECAST CONCRETE WALL WITH INTERNAL BRACING OR TIEBACKS
SITES 1 & 2

			4 LANE HIGHWAY TUNNEL RAPID TRANSIT STATION ③			DOUBLE BOX LINE STRUCTURE		
			H=30'	H=50'	H=70'	H=30'	H=50'	H=70'
GROUND SUPPORT SYSTEM		PRECAST PANELS	24×144	36×108	36×72	24×144	36×108	36×72
		PILES (ABOVE)	W14×78	W24×100	W27×160	W18×96	W30×172	W24×120
		PILE SPACING	6'-0" C.C.	6'-0" C.C.	6'-0" C.C.	6'-0" C.C.	6'-0" C.C.	6'-0" C.C.
		LAGGING (D.F.)	3×MATERIAL TO -20 ELEV., 4×MATERIAL -20 ELEV. TO PRECAST WALL					
DECK FRAMING		DECK BEAMS	W36×230	W36×230	W36×230	W36×230	W36×230	W36×230
		CAP BEAMS, INTERIOR	W30×116	W30×116	W30×116	—	—	—
		CAP BEAMS, EXTERIOR	W14×68	W14×68	W14×68	W14×78	W14×78	W14×78
		INTERIOR PILES ②	HP14×73	HP14×73	HP14×73	—	—	—
		CAP WALES	W24×84	W24×84	W24×84	W24×76	W24×76	W24×76
		LATERAL BRACING	WT5×10.5 WT6×13.5	WT5×10.5 WT6×13.5	WT5×10.5 WT6×13.5	WT5×10.5 WT6×13.5	WT5×10.5 WT6×13.5	WT5×10.5 WT6×13.5
		DECKING (D.F.)	12×12	12×12	12×12	12×12	12×12	12×12
INTERNAL BRACING ALTERNATE	LEVEL NUMBER 2	WALES	W21×68	W30×124	W36×135	W21×68	W30×124	W33×130
		STRUTS ①	HP14×73	W14×142	W14×167	HP14×73	W14×119	W14×142
	LEVEL NUMBER 3	WALES	—	W30×99	W36×150	—	W30×99	W30×116
		STRUTS ①	—	W14×103	W14×184	—	W14×87	W14×119
	LEVEL NUMBER 4	WALES	—	—	W30×99		—	W33×118
		STRUTS ①	—	—	W14×127	—	—	W14×127
	LEVEL NUMBER 5	WALES	—	—	W30×99	—	—	W30×108
		STRUTS ①	—	—	W14×127	—	—	W14×111
TIEBACK ALTERNATE	LEVEL NUMBER 2	WALES	JC12×35	JC18×51.9	JC18×51.9	JC12×35	JC18×51.9	JC18×51.9
		TIEBACKS ④	1¼"φ 155/190	4-⅝"φ 205/230	1¼"φ 120/150	1¼"φ 155/190	4-⅝"φ 205/230	1¼"φ 120/150
	LEVEL NUMBER 3	WALES	—	JC15×50	JC18×51.9	—	JC15×50	JC18×51.9
		TIEBACKS ④	—	1¼"φ 120/150	1¼"φ 120/150	—	1¼"φ 120/150	1¼"φ 120/150
	LEVEL NUMBER 4	WALES	—	—	JC18×51.9	—	—	JC18×51.9
		TIEBACKS ④	—	—	1¼"φ 120/150	—	—	1¼"φ 120/150
	LEVEL NUMBER 5	WALES	—	—	JC18×51.9	—	—	JC18×51.9
		TIEBACKS ④	—	—	1¼"φ 120/150	—	—	1¼"φ 120/150
	LEVEL NUMBER 6	WALES	—	—	JC18×45.8	—	—	JC18×45.8
		TIEBACKS ④	—	—	1¼"φ 120/150	—	—	1¼"φ 120/150
	LEVEL NUMBER 7	WALES	—	—	JC18×58	—	—	JC18×58
		TIEBACKS ④	—	—	1¼"φ 155/190	—	—	1¼"φ 155/190
PENETRATION BELOW SUBGRADE		INTERNAL BRACING ALTERNATE	10'	10'	12'	10'	10'	12'
		TIEBACK	10'	10'	12'	10'	10'	12'

① DECK BEAMS AND STRUTS ARE AT 12'-0" C.C. SPACING AND IN SAME VERTICAL PLANE.

② INTERIOR PILES ARE AT 12'-0" C.C. SPACING AND OFFSET 2'-0" FROM ℄ OF DECK BEAM.

③ RAPID TRANSIT STATION NOT CONSIDERED AT H=30' BECAUSE OF STRUCTURAL HEIGHT.

④ ALL TIEBACKS ARE DYWIDAG OR EQUAL. 120/150 REFERS TO GRADE OF STEEL. TIEBACKS ARE AT 4'-0" C.C.

ALL STEEL MEMBERS ARE ASTM A-36 UNLESS NOTED

Table 38. GROUND SUPPORT AND BRACING SYSTEMS - SITE 3
S.P.T.C. WALL

GROUND SUPPORT AND BRACING SYSTEMS
S.P.T.C. WALL WITH INTERNAL BRACING OR TIEBACKS
SITE 3

			4 LANE HIGHWAY TUNNEL RAPID TRANSIT STATION ③			DOUBLE BOX LINE STRUCTURE		
			H=30	H=50'	H=70'	H=30'	H=50'	H=70'
GROUND SUPPORT SYSTEM		PILES	W24×100	W36×135 ⑤	W36×230 ⑥	W24×100	W36×135 ⑤	W36×135 ⑥
		PILE SPACING	8'-0"C.C.	6'-0"C.C.	6'-0"C.C.	8'-0"C.C.	6'-0"C.C.	6'-0"C.C.
		LAGGING (D.F.)	3× MATERIAL TO -20' ELEV.					
DECK FRAMING		DECK BEAMS ①	W36×230	W36×230	W36×230	W36×230	W36×230	W36×230
		CAP BEAMS, INTERIOR	W30×116	W30×116	W30×116	—	—	—
		CAP BEAMS, EXTERIOR	W14×68	W14×68	W14×68	W14×119	W14×78	W14×78
		INTERIOR PILES ②	HP14×73	HP14×73	HP14×73	—	—	—
		CAP WALES	W30×99	W24×84	W24×84	W30×99	W24×76	W24×76
		LATERAL BRACING	WT5×10.5 WT6×13.5	WT5×10.5 WT6×13.5	WT5×10.5 WT6×13.5	WT5×10.5 WT6×13.5	WT5×10.5 WT6×13.5	WT5×10.5 WT6×13.5
		DECKING (D.F.)	12×12	12×12	12×12	12×12	12×12	12×12
INTERNAL BRACING ALTERNATE	LEVEL NUMBER 2	WALES	W21×68	W33×130	W36×135	W21×68	W33×130	W33×130
		STRUTS ①	HP14×73	W14×142	W14×167	HP14×73	W14×127	W14×142
	LEVEL NUMBER 3	WALES	—	W30×116	W36×194	—	W30×116	W33×118
		STRUTS ①	—	W14×136	W14×228	—	W14×111	W14×127
	LEVEL NUMBER 4	WALES	—	—	W33×130	—	—	W36×160
		STRUTS ①	—	—	W14×158	—	—	W14×167
	LEVEL NUMBER 5	WALES	—	—	W36×150	—	—	W36×150
		STRUTS ①	—	—	W14×176	—	—	W14×150
TIEBACK ALTERNATE	LEVEL NUMBER 2	WALES	JC12×35	JC18×58	JC18×51.9	JC12×35	JC18×58	JC18×51.9
		TIEBACKS ④	1¼"φ 155/190 ⑦	4-⅝"φ 205/230	1¼"φ 120/150	1¼"φ 155/190 ⑦	4-⅝"φ 205/230	1¼"φ 120/150
	LEVEL NUMBER 3	WALES	—	JC18×45.8	JC18×51.9	—	JC18×45.8	JC18×51.9
		TIEBACKS ④	—	1¼"φ 155/190	1¼"φ 120/150	—	1¼"φ 155/190	1¼"φ 120/150
	LEVEL NUMBER 4	WALES	—	—	JC18×58	—	—	JC18×58
		TIEBACKS ④	—	—	1¼"φ 120/150	—	—	1¼"φ 120/150
	LEVEL NUMBER 5	WALES	—	—	II(S18×54.7)	—	—	II(S20×75)
		TIEBACKS ④	—	—	1¼"φ 155/190	—	—	6-⅝φ 205/230
	LEVEL NUMBER 6	WALES	—	—	II(S18×54.7)	—	—	II(S18×54.7)
		TIEBACKS ④	—	—	1¼"φ 155/190	—	—	1¼"φ 155/190
	LEVEL NUMBER 7	WALES	—	—	JC18×58	—	—	JC18×58
		TIEBACKS ④	—	—	1¼"φ 120/150	—	—	1¼"φ 120/150
PENETRATION BELOW SUBGRADE		INTERNAL BRACING ALTERNATE	10'	17'	32'	10'	24'	40'
		TIEBACK ALTERNATE	10'	17'	32'	10'	24'	40'

① DECK BEAM AND STRUTS ARE AT 12'-0"C.C. SPACING AND IN SAME VERTICAL PLANE.

② INTERIOR PILES ARE AT 12'-0"C.C. SPACING AND OFFSET 2'-0" FROM ℄ OF DECK BEAM.

③ RAPID TRANSIT STATION NOT CONSIDERED AT H=30' BECAUSE OF STRUCTURAL HEIGHT.

④ ALL TIEBACKS ARE DYWIDAGS OR EQUAL. 120/150 REFERS TO GRADE OF STEEL.

⑤ USE W36×150 PILE FOR TIEBACK ALTERNATE.

⑥ USE W36×160 PILE FOR TIEBACK ALTERNATE - RAPID TRANSIT STATION & LINE SECTION

⑦ TIEBACKS NOTED AT 8'-0"C.C., ALL OTHERS AT 4'-0" C.C.

ALL STEEL MEMBERS ARE ASTM A-36 UNLESS NOTED

Table 39. GROUND SUPPORT AND BRACING SYSTEMS - SITE 3
PRECAST CONCRETE WALL

GROUND SUPPORT AND BRACING SYSTEMS
PRECAST CONCRETE WALL WITH INTERNAL BRACING OR TIEBACKS
SITE 3

			4 LANE HIGHWAY TUNNEL RAPID TRANSIT STATION ③			DOUBLE BOX LINE STRUCTURE		
			H=30'	H=50	H=70'	H=30'	H=50'	H=70'
GROUND SUPPORT SYSTEM		PRECAST PANELS	24×144	36×108	36×72	24×144	36×108	36×72
		PILES (ABOVE)	W14×78	W24×100	W27×160	W18×96	W30×172	W24×120
		PILE SPACING	6'-0"C.C.	6'-0"C.C.	6'-0"C.C.	6'-0"C.C.	6'-0"C.C.	6'-0"C.C.
		LAGGING (D.F.)	3× MATERIAL TO -20' ELEV.,					
DECK FRAMING		DECK BEAMS	W36×230	W36×230	W36×230	W36×230	W36×230	W36×230
		CAP BEAMS, INTERIOR	W30×116	W30×116	W30×116	—	—	—
		CAP BEAMS, EXTERIOR	W14×68	W14×68	W14×68	W14×78	W14×78	W14×78
		INTERIOR PILES ②	HP14×73	HP14×73	HP14×73	—	—	—
		CAP WALES	W24×84	W24×84	W24×84	W24×76	W24×76	W24×76
		LATERAL BRACING	WT5×10.5 WT6×13.5	WT5×10.5 WT6×13.5	WT5×10.5 WT6×13.5	WT5×10.5 WT6×13.5	WT5×10.5 WT6×13.5	WT5×10.5 WT6×13.5
		DECKING (D.F.)	12×12	12×12	12×12	12×12	12×12	12×12
INTERNAL BRACING ALTERNATE	LEVEL NUMBER 2	WALES	W21×68	W33×130	W36×135	W21×68	W33×130	W21×68
		STRUTS ①	HP14×73	W14×142	W14×167	HP14×73	W14×127	W14×142
	LEVEL NUMBER 3	WALES	—	W30×116	W36×194	—	W30×116	W33×118
		STRUTS ①	—	W14×136	W14×228	—	W14×111	W14×127
	LEVEL NUMBER 4	WALES	—	—	W33×130	—	—	W36×160
		STRUTS ①	—	—	W14×158	—	—	W14×167
	LEVEL NUMBER 5	WALES	—	—	W36×150	—	—	W36×150
		STRUTS ①	—	—	W14×176	—	—	W14×150
TIEBACK ALTERNATE	LEVEL NUMBER 2	WALES	JC12×35	JC18×58	JC18×51.9	JC12×35	JC18×58	JC18×51.9
		TIEBACKS ④	1¼"φ 155/190	4-5/8"φ 205/230	1¼"φ 120/150	1¼"φ 155/190	4-5/8"φ 205/230	1¼"φ 120/150
	LEVEL NUMBER 3	WALES	—	JC18×45.8	JC18×51.9	—	JC18×45.8	JC18×51.9
		TIEBACKS ④	—	1¼"φ 155/190	1¼"φ 120/150	—	1¼"φ 155/190	1¼"φ 120/150
	LEVEL NUMBER 4	WALES	—	—	JC18×58	—	—	JC18×58
		TIEBACKS ④	—	—	1¼"φ 120/150	—	—	1¼"φ 120/150
	LEVEL NUMBER 5	WALES	—	—	II(S18×54.7)	—	—	II(S18×54.7)
		TIEBACKS ④	—	—	1¼"φ 155/190	—	—	1¼"φ 155/190
	LEVEL NUMBER 6	WALES	—	—	II(S18×54.7)	—	—	II(S18×54.7)
		TIEBACKS ④	—	—	1¼"φ 155/190	—	—	1¼"φ 150/190
	LEVEL NUMBER 7	WALES	—	—	JC18×58	—	—	JC18×58
		TIEBACKS ④	—	—	1¼"φ 120/150	—	—	1¼"φ 120/150
PENETRATION BELOW SUBGRADE ⑤		INTERNAL BRACING ALTERNATE	10'SCW 10'PCP	17'SCW 12'PCP	32'SCW 15'PCP	10'SCW 10'PCP	24'SCW 12'PCP	40'SCW 15'PCP
		TIEBACK ALTERNATE	10'SCW 10'PCP	17'SCW 12'PCP	32'SCW 16'PCP	10'SCW 10'PCP	24'SCW 12'PCP	40'SCW 16'PCP

① DECK BEAMS AND STRUTS ARE AT 12'-0"C.C. SPACING AND IN SAME VERTICAL PLANE.

② INTERIOR PILES ARE AT 12'-0"C.C. SPACING AND OFFSET 2'-0" FROM ℄ OF DECK BEAM

③ RAPID TRANSIT STATION NOT CONSIDERED AT H=30' BECAUSE OF STRUCTURAL HEIGHT.

④ ALL TIEBACKS ARE DYWIDAG OR EQUAL. 120/150 REFERS TO GRADE OF STEEL.
ALL TIEBACKS ARE 4'-0"C.C.

⑤ PENETRATIONS SHOWN FOR PRECAST PANELS (PCP) ARE THOSE REQUIRED FOR PASSIVE RESISTANCE. TO PREVENT PIPING, THE EXCAVATED SLOT IS EXTENDED BELOW TO THE SAME DEPTH AS REQUIRED FOR THE SPTC WALL. THIS SLURRY CUTOFF WALL (SCW) IS FILLED WITH A SLOW SETTING CEMENT SLURRY.
ALL STEEL MEMBERS ARE ASTM-A36 UNLESS NOTED.

Table 40. GROUND SUPPORT AND BRACING SYSTEMS - SITE 4
S.P.T.C. WALL

GROUND SUPPORT AND BRACING SYSTEMS
S.P.T.C. WALL WITH INTERNAL BRACING OR TIEBACKS
SITE No 4

			4 LANE HIGHWAY TUNNEL (7) RAPID TRANSIT STATION			DOUBLE BOX LINE STRUCTURE		
			H = 30'	H = 50'	H = 70'	H = 30'	H = 50'	H = 70'
GROUND SUPPORT SYSTEM		PILES	W 24x130	W 36x150	(1) W36x182	W 24x120	(1) W36x160	(1) W36x182
		PILE SPACING	8'-0" C.C.	6'-0" C.C.	6'-0" C.C.	8'-0" C.C	6'-0" C.C.	6'-0" C.C.
		LAGGING – D.F.	3 x MATERIAL TO -10' ELEV.					
DECK FRAMING		DECK BEAMS (3)	W36x230	W36x230	W36x230	W36x230	W36x230	W36x230
		CAP BEAMS, INTERIOR	W30x116	W30x116	W30x116	—	—	—
		CAP BEAMS, EXTERIOR	W14x68	W14x68	W14x68	W14x119	W14x78	W14x78
		INTERIOR PILES (4)	HP14x73	HP14x73	HP14x73	—	—	—
		CAP WALES	W30x99	W24x84	W24x84	W30x99	W24x76	W24x76
		LATERAL BRACING	WT5x10.5 WT6x13.5	WT5x10.5 WT6x13.5	WT5x10.5 WT6x13.5	WT5x10.5 WT6x13.5	WT5x10.5 WT6x13.5	WT5x10.5 WT6x13.5
		DECKING – D.F.	12x12	12x12	12x12	12x12	12x12	12x12
INTERNAL BRACING ALTERNATE	LEVEL NUMBER 2	WALES	W24x68	W33x130	W36x135	W24x76	W33x130	W33x118
		STRUTS (3)	HP14x73	W14x158	W14x158	HP14x73	W14x142	W14x136
	LEVEL NUMBER 3	WALES	—	W33x130	W36x135	—	W33x118	W36x135
		STRUTS (3)	—	W14x158	W14x176	—	W14x136	W14x167
	LEVEL NUMBER 4	WALES	—	—	][18x42.7	—	—	][18x42.7
		ROCK ANCHOR (5)	—	—	6-5/8"φ 205/230	—	—	6-5/8"φ 205/230
(2) TIEBACK ALTERNATE	LEVEL NUMBER 2	WALES	][15x33.9	][15x33.9	][15x33.9	][12x30.9	][12x30.9	][15x33.9
		TIEBACKS (6)	1"φ 120/150	1"φ 120/150	1"φ 120/150	1"φ 120/150	1"φ 120/150	1"φ 120/150
	LEVEL NUMBER 3	WALES	][15x33.9	][18x42.7	][15x33.9	][12x30.9	][12x30.9	][15x33.9
		TIEBACKS (6)	1"φ 120/150	1¼"φ 155/190	1"φ 120/150	1"φ 120/150	1"φ 120/150	1¼"φ 120/150
	LEVEL NUMBER 4	WALES	—	][15x33.9	][12x20.7	—	][12x30.9	][12x20.7
		ROCK ANCHOR (5)	—	1¼"φ 120/150 (5)	1"φ 120/150 (5)	—	1¼"φ 120/150 (5)	1"φ 120/150 (5)
	LEVEL NUMBER 5	WALES	—	][18x42.7	][12x30.9	—	][12x20.7	][12x25
		ROCK ANCHOR (5)	—	1¼"φ 120/150 (5)	1¼"φ 120/150 (5)	—	1¼"φ 120/150 (5)	1¼"φ 120/150 (5)
	LEVEL NUMBER 6	WALES	—	—	][15x33.9	—	][12x20.7	][15x33.9
		ROCK ANCHOR (5)	—	—	1¼"φ 155/190 (5)	—	1¼"φ 120/150 (5)	1¼"φ 155/190 (5)
	LEVEL NUMBER 7	WALES	—	—	][15x33.9	—	—	][15x33.9
		ROCK ANCHOR (5)	—	—	1¼"φ 155/190 (5)	—	—	1¼"φ 155/190 (5)
ROCK BOLTS		INTERNAL BRACING ALTERNATE	—	—	1"φ 120/150	—	—	1"φ 120/150
		TIEBACK ALTERNATE	—	—	1"φ 120/150	—	—	1"φ 120/150
PENETRATION BELOW SUBGRADE		INTERNAL BRACING ALTERNATE	KEY PILES 22' INTO ROCK	KEY PILES 22' INTO ROCK	KEY PILES 22' INTO ROCK	KEY PILES 22' INTO ROCK	KEY PILES 22' INTO ROCK	KEY PILES 22' INTO ROCK
		TIEBACK ALTERNATE	KEY PILES 22' INTO ROCK	KEY PILES 22' INTO ROCK	KEY PILES 22' INTO ROCK	KEY PILES 22' INTO ROCK	KEY PILES 22' INTO ROCK	KEY PILES 22' INTO ROCK

(1) USE W36x135 FOR TIEBACK ALTERNATE.
(2) ALL TIEBACKS ARE DYWIDAG OR EQUAL 120/150 REFERS TO GRADE OF STEEL.
(3) DECK BEAMS AND STRUTS ARE AT 12'-0" C.C. SPACING AND IN SAME VERTICAL PLANE.
(4) INTERIOR PILES ARE AT 12'-0" C.C. SPACING AND OFFSET 2'-0" FROM ℄ OF DECK BEAM.
(5) TWO ROCK ANCHORS AT EACH PILE.
(6) TIEBACKS AT 4'-0" C.C. UNLESS NOTED
(7) RAPID TRANSIT STATION NOT CONSIDERED AT H=30' BECAUSE OF STRUCTURAL HEIGHT.
ALL STEEL MEMBER ARE ASTM A-36 UNLESS NOTED.

Table 41. GROUND SUPPORT AND BRACING SYSTEMS - SITE 4
PRECAST CONCRETE WALL

GROUND SUPPORT AND BRACING SYSTEMS
PRECAST CONCRETE WALL WITH INTERNAL BRACING OR TIEBACKS
SITE No 4

			4 LANE HIGHWAY TUNNEL ③ RAPID TRANSIT STATION			DOUBLE BOX LINE STRUCTURE		
			H = 30'	H = 50'	H = 70'	H = 30'	H = 50'	H = 70'
GROUND SUPPORT SYSTEM		PRECAST PANELS	24 x 144	36 x 96	36 x 72	24 x 144	36 x 96	36 x 72
		PILES (ABOVE)	W18 x 64	W21 x 82	W24x100	W18x 64	W21x 82	W24x100
		PILE SPACING	6'-0"	4'-0"	6'-0"	6'-0"	4'-0"	6'-0"
		LAGGING - D.F	3 x MATERIAL TO -10' ELEV.					
DECK FRAMING		DECK BEAMS	W36x230	W36x230	W36x230	W36x230	W36x230	W36x230
		CAP BEAMS, INTERIOR	W30x116	W30x116	W30x116			
		CAP BEAMS, EXTERIOR	W14 x 68	W14 x 68	W14 x 68	W14x 78	W14 x 78	W14x 78
		INTERIOR PILES ②	HP14x 73	HP14 x 73	HP14x 73			
		CAP WALES	W24x 84	W24x 84	W24x 84	W24x 76	W 24x76	W24x 76
		LATERAL BRACING	WT5x10.5 WT6x13.5	WT5x10.5 WT6x13.5	WT5x10.5 WT6x13.5	WT5x10.5 WT6x13.5	WT5x10.5 WT6x13.5	WT5x10.5 WT6x13.5
		DECKING (D.F.)	12 x 12	12x12	12x12	12x12	12x12	12x12
INTERNAL BRACING ALTERNATE	LEVEL NUMBER 2	WALES	W 24x68	W33x130	W36x135	W24x76	W33x130	W33x118
		STRUTS ①	HP14x 73	W14x158	W14x158	HP14x73	W14x142	W14x136
	LEVEL NUMBER 3	WALES	—	W33x130	W36x135	—	W33x118	W36x135
		STRUTS ①	—	W14x158	W14x176	—	W14x136	W14x167
	LEVEL NUMBER 4	WALES	—	—	][18x42.7	—	—	][18x42.7
		ROCK ANCHOR ⑤	—	—	6-5/8"φ 205/230	—	—	6-5/8"φ 205/230
TIEBACK ALTERNATE	LEVEL NUMBER 2	WALES	][15x33.9	][15x33.9	][15x33.9	][12x30.9	][12x30.9	][15x33.9
		TIEBACKS ④	1"φ 120/150	1"φ 120/150	1"φ 120/150	1"φ 120/150	1"φ 120/150	1"φ 120/150
	LEVEL NUMBER 3	WALES	][15x33.9	][18x42.7	][15x33.9	][12x30.9	][12x30.9	][15x33.9
		TIEBACKS ④	1"φ 120/150	1¼"φ 155/190	1"φ 120/150	1"φ 120/150	1"φ 120/150	1¼"φ 120/150
	LEVEL NUMBER 4	WALES	—	][15x33.9	][12x20.7	—	][12x30.9	][12x20.7
		ROCK ANCHOR ⑤	—	1¼"φ 120/150	1"φ 120/150	—	1¼"φ 120/150	1"φ 120/150
	LEVEL NUMBER 5	WALES	—	][18x42.7	][12x30.9	—	][12x20.7	][12x25
		ROCK ANCHOR ⑤	—	1¼"φ 120/150	1¼"φ 120/150	—	1¼"φ 120/150	1¼"φ 120/150
	LEVEL NUMBER 6	WALES	—	—	][15x33.9	—	][12x20.7	][15x33.9
		ROCK ANCHOR ⑤	—	—	1¼"φ 155/190	—	1¼"φ 120/150	1¼"φ 155/190
	LEVEL NUMBER 7	WALES	—	—	][15x33.9	—	—	][15x33.9
		ROCK ANCHOR ⑤	—	—	1¼"φ 155/190	—	—	1¼"φ 155/190
ROCK BOLTS		INTERNAL BRACING ALTERNATE	—	—	1"φ 120/150	—	—	1"φ 120/150
		TIEBACK ALTERNATE	—	—	1"φ 120/150	—	—	1"φ 120/150
PENETRATION BELOW SUBGRADE		INTERNAL BRACING ALTERNATE	KEY PANELS INTO ROCK	KEY PANELS INTO ROCK	KEY PANELS INTO ROCK	KEY PANELS INTO ROCK	KEY PANELS INTO ROCK	KEY PANELS INTO ROCK
		TIEBACK ALTERNATE	KEY PANELS INTO ROCK	KEY PANELS INTO ROCK	KEY PANELS INTO ROCK	KEY PANELS INTO ROCK	KEY PANELS INTO ROCK	KEY PANELS INTO ROCK

① DECK BEAMS AND STRUTS ARE AT 12'-0" C.C. SPACING AND IN SAME VERTICAL PLANE.

② INTERIOR PILES ARE AT 12'-0" C.C. SPACING AND OFFSET 2'-0" FROM ℄ OF DECK BEAM.

③ RAPID TRANSIT STATION NOT CONSIDERED AT H = 30' BECAUSE OF STRUCTURAL HEIGHT.

④ ALL TIEBACKS ARE DYWIDAG OR EQUAL. 120/150 REFERS TO GRADE OF STEEL.
ALL TIEBACKS ARE 4'-0" C.C. SPACING.

⑤ ROCK ANCHORS AT 3'-0" C.C. SPACING.

ALL STEEL MEMBERS ARE ASTM A-36 UNLESS NOTED.

Table 42. GROUND SUPPORT AND BRACING SYSTEMS - SITE 5
S.P.T.C. WALL

GROUND SUPPORT AND BRACING SYSTEMS
S.P.T.C WALL WITH INTERNAL BRACING OR TIEBACKS
SITE No 5

			4 LANE HIGHWAY TUNNEL RAPID TRANSIT STATION			DOUBLE BOX LINE STRUCTURE		
			H = 30'	H = 50'	H = 70'	H = 30'	H = 50'	H = 70'
GROUND SUPPORT SYSTEM		PILES	W36x300 WITH ½"x15"x28' C PLs	W36x300 WITH 1"x15"x35' C PLs	W36x300 WITH 1½"x15"x38' C PLs	W36x300 WITH ½"x9"x24' C PLs	W36x300 WITH 1"x15"x30' C PLs	W36x300 WITH 1¼"x15"x30' C PLs
		PILE SPACING	6'-0"	6'-0"	6'-0"	6'-0"	6'-0"	6'-0"
		LAGGING - D.F.	3 x MATERIAL TO -10' ELEV.					
DECK FRAMING		DECK BEAMS	W36x245	W36x230	W36x230	W36x245	W36x230	W36x230
		CAP BEAMS, INTERIOR	W30x116	W30x116	W30x116	—	—	—
		CAP BEAMS, EXTERIOR	W14x68	W14x68	W14x68	W14x78	W14x78	W14x78
		INTERIOR PILES	HP14x73	HP14x73	HP14x73	—	—	—
		CAP WALES	W24x94	W24x84	W24x84	W24x94	W24x76	W24x76
		LATERAL BRACING	WT5x10.5 WT6x13.5	WT5x10.5 WT6x13.5	WT5x10.5 WT6x13.5	WT5x10.5 WT6x13.5	WT5x10.5 WT6x13.5	WT5x10.5 WT6x13.5
		DECKING - D.F.	12x12	12x12	12x12	12x12	12x12	12x12
INTERNAL BRACING ALTERNATE	LEVEL NUMBER 2	WALES	W36x135	W36x150	W36x160	W36x135	W36x135	W36x150
		STRUTS	W14x167	W14x202	W14x202	W14x150	W14x136	W14x176
	LEVEL NUMBER 3	WALES	—	W36x160	W36x194	—	W36x182	W36x182
		STRUTS	—	W14x246	W14x246	—	W14x219	W14x219
	LEVEL NUMBER 4	WALES	—	W36x150	W36x182	—	W36x182	W36x194
		STRUTS	—	W14x228	W14x246	—	W14x228	W14x264
	LEVEL NUMBER 5	WALES	—	—	W36x150	—	—	W36x170
		STRUTS	—	—	W14x193	—	—	W14x211
TIEBACK ALTERNATE			NOT APPROPRIATE AT SITE 5					
PENETRATION BELOW SUBGRADE		INTERNAL BRACING ALTERNATE	52'-PILE ONLY 10'-SPTC WALL	34'-PILE ONLY 22'-SPTC WALL	15'-PILE ONLY 5'-SPTC WALL	52'-PILE ONLY 10'-SPTC WALL	33'-PILE ONLY 22'-SPTC WALL	16'-PILE ONLY 5'-SPTC WALL

① DECK BEAMS AND STRUTS ARE AT 12'-0" C.C SPACING AND IN SAME VERTICAL PLANE.

② INTERIOR PILES ARE AT 12'-0" C.C. SPACING AND OFFSET 2'-0" FROM ℄ OF DECK BEAM.

③ RAPID TRANSIT STATION NOT CONSIDERED AT H=30' BECAUSE OF STRUCTURAL HEIGHT.

ALL STEEL MEMBER ARE ASTM A-36 UNLESS NOTED.

Table 43. GROUND SUPPORT AND BRACING SYSTEMS - SITE 5
PRECAST CONCRETE WALL

GROUND SUPPORT AND BRACING SYSTEMS
PRECAST CONCRETE WALL WITH INTERNAL BRACING OR TIEBACKS
SITE No 5

			4 LANE HIGHWAY TUNNEL RAPID TRANSIT STATION			DOUBLE BOX LINE STRUCTURE		
			H=30'	H=50'	H=70'	H=30'	H=50'	H=70'
GROUND SUPPORT SYSTEM		PRECAST PANELS	48x72	48x72	48x72	48x72	48x72	48x72
		PILES (ABOVE)	W24x130	W24x130	W24x130	W24x130	W24x130	W24x130
		PILE SPACING	6'-0"	6'-0"	6'-0"	6'-0"	6'-0"	6'-0"
		LAGGING – D.F.	3 X MATERIAL TO -10' ELEV.					
DECK FRAMING		DECK BEAMS	W36x245	W36x230	W36x230	W36x245	W36x230	W36x230
		CAP BEAMS, INTERIOR	W30x116	W30x116	W30x116	—	—	—
		CAP BEAMS, EXTERIOR	W14x68	W14x68	W14x68	W14x78	W14x78	W14x78
		INTERIOR PILES	HP14x73	HP14x73	HP14x73	—	—	—
		CAP WALES	W24x94	W24x84	W24x84	W24x94	W24x76	W24x76
		LATERAL BRACING	WT5x10.5 WT6x13.5	WT5x10.5 WT6x13.5	WT5x10.5 WT6x13.5	WT5x10.5 WT6x13.5	WT5x10.5 WT6x13.5	WT5x10.5 WT6x13.5
		DECKING – D.F.	12x12	12x12	12x12	12x12	12x12	12x12
INTERNAL BRACING ALTERNATE	LEVEL NUMBER 2	WALES	W36x135	W36x150	W36x160	W36x135	W36x135	W36x150
		STRUTS	W14x167	W14x202	W14x202	W14x150	W14x136	W14x176
	LEVEL NUMBER 3	WALES	—	W36x160	W36x194	—	W36x182	W36x182
		STRUTS	—	W14x246	W14x246	—	W14x219	W14x219
	LEVEL NUMBER 4	WALES	—	W36x150	W36x182	—	W36x182	W36x194
		STRUTS	—	W14x228	W14x246	—	W14x228	W14x264
	LEVEL NUMBER 5	WALES	—	—	W36x150	—	—	W36x170
		STRUTS	—	—	W14x193	—	—	W14x211
TIEBACK ALTERNATE			NOT APPROPRIATE AT SITE 5					
PENETRATION BELOW SUBGRADE		INTERNAL BRACING ALTERNATE	52'-PILE ONLY 10'-PRECAST PANEL	34'-PILE ONLY 22'-PRECAST PANEL	15'-PILE ONLY 5'-PRECAST PANEL	51'-PILE ONLY 10'-PRECAST PANEL	33'-PILE ONLY 22'-PRECAST PANEL	16'-PILE ONLY 5'-PRECAST PANEL
		PILES BELOW	W36x300 WITH ½"x15"C.PLS.	W36x300	W36x300	W36x300 WITH ½"x15"C.PLS	W36x300	W36x300

1. DECK BEAMS AND STRUTS ARE AT 12'-0" C.C. SPACING AND IN SAME VERTICAL PLANE.
2. INTERIOR PILES ARE AT 12'-0" C.C. SPACING AND OFFSET 2'-0" FROM ℄ OF DECK BEAM.
3. RAPID TRANSIT STATION NOT CONSIDERED AT H=30' BECAUSE OF STRUCTURAL HEIGHT.

ALL STEEL MEMBER ARE ASTM A-36 UNLESS NOTED.

APPENDIX B
QUANTITIES OF WORK
MAJOR CONSTRUCTION ACTIVITIES

Cost estimates prepared for this study are based on quantities and types of work determined for all operations and activities needed to complete each of the 176 study construction situations as well as additional special alternate situations, i.e. inverted construction. Quantities for major operations are listed in this Appendix B. Tables 44 through 47 show quantities for the soldier piles and lagging (SP&L) method of construction. Tables 48 through 51 and 52 through 55 give comparable quantities for the soldier piles and tremie concrete (SPTC) and the precast panel (PCP) methods respectively.

The codes (see Table 6, page 61) in the left hand columns identify quantities with respect to each cost estimate.

Quantities of work for situations with conditions differing from the study criteria can be approximated by extrapolation.

METRIC CONVERSION FACTORS
(for Tables 44 through 55)

1 LF = 1 ft. = 0.305 m
1 SF = 1 sq. ft. = 0.0929 m^2
1 SY = 1 sq. yd. = 0.836 m^2
1 CY = 1 cu. yd. = 0.765 m^3
1 TON = 907 kg

Table 44. MAJOR ESTIMATING QUANTITIES
SOLDIER PILE & LAGGING ESTIMATES
GROUND SUPPORT

ESTIMATE CODE	GROUND SUPPORT			
	NET AREA (SY)	PILE HOLES (LF)	PILES (TONS)	LAGGING (MBF)
HIGHWAY TUNNEL:				
1-1GT	13,333	18,500	819	400
1-1GV	22,222	30,500	2,048	720
1-1GY	31,111	41,000	3,360	1,040
1-1HT	13,333	20,000	882	400
1-1HV	22,222	33,500	2,501	720
1-1HY	31,111	48,500	3,960	1,040
2-1GU	13,333	18,500	819	400
2-1GW	22,222	30,500	2,048	720
2-1GZ	31,111	41,000	3,360	1,040
2-1HU	13,333	20,000	882	400
2-1HW	22,222	33,500	2,501	720
2-1HZ	31,111	48,500	3,960	1,040
RAPID TRANSIT STATION:				
1-2GV	8,500	10,736	721	252
1-2GY	11,900	14,432	1,183	364
1-2HV	8,500	11,792	880	252
1-2HY	11,900	17,072	871	364
2-2GW	8,500	10,736	721	252
2-2GZ	11,900	14,432	1,183	364
2-2HW	8,500	11,792	880	252
2-2HZ	11,900	17,072	871	364
RAPID TRANSIT TUNNEL:				
1-3GT	13,333	18,500	819	400
1-3GV	22,222	30,500	2,048	720
1-3GY	31,111	41,000	2,100	1,040
1-3HT	13,333	20,000	882	400
1-3HV	22,222	33,500	2,501	720
1-3HY	31,111	48,500	2,723	1,040
2-3GU	13,333	18,500	819	400
2-3GW	22,222	30,500	2,048	720
2-3GZ	31,111	41,000	2,100	1,040
2-3HU	13,333	20,000	882	400
2-3HW	22,222	33,500	2,501	720
2-3HZ	31,111	48,500	2,723	1,040

Table 45. MAJOR ESTIMATING QUANTITIES
SOLDIER PILE & LAGGING ESTIMATES
DECKING AND BRACING

ESTIMATE CODE	DECKING			BRACING	
	DECK AREA (SF)	PILES (TONS)	STEEL FRAME (TONS)	STEEL (TONS)	TIEBACKS (LF)
HIGHWAY TUNNEL:					
1-1GT	16,222	362	2,129	555	-
1-1GV	16,444	485	2,150	1,496	-
1-1GY	16,667	607	2,170	3,589	-
1-1HT	16,222	362	2,129	83	25,000
1-1HV	16,444	485	2,150	443	112,000
1-1HY	16,667	607	2,170	913	255,500
2-1GU	16,000	362	2,109	555	-
2-1GW	16,222	485	2,129	1,496	-
2-1GZ	16,444	607	2,150	3,589	-
2-1HU	16,000	362	2,109	83	25,000
2-1HW	16,222	485	2,129	443	112,000
2-1HZ	16,444	607	2,150	913	255,500
RAPID TRANSIT STATION:					
1-2GV	5,522	173	728	1,211	-
1-2GY	5,522	217	728	1,887	-
1-2HV	5,522	173	728	169	40,110
1-2HY	5,522	217	728	349	95,073
2-2GW	5,289	173	706	1,211	-
2-2GZ	5,367	217	713	1,887	-
2-2HW	5,367	173	706	169	40,110
2-2HZ	5,367	217	713	349	95,073
RAPID TRANSIT TUNNEL:					
1-3GT	8,889	-	1,387	359	-
1-3GV	9,111	-	1,408	892	-
1-3GY	9,333	-	1,428	1,890	-
1-3HT	8,889	-	1,387	83	22,500
1-3HV	9,111	-	1,408	443	105,000
1-3HY	9,333	-	1,428	913	247,500
2-3GU	8,667	-	1,367	359	-
2-3GW	8,889	-	1,387	892	-
2-3GZ	9,111	-	1,408	1,890	-
2-3HU	8,667	-	1,367	83	22,500
2-3HW	8,889	-	1,387	443	105,000
2-3HZ	9,111	-	1,408	913	247,500

Table 46. MAJOR ESTIMATING QUANTITIES
SOLDIER PILE & LAGGING ESTIMATES
STRUCTURE AND EARTHWORK

ESTIMATE CODE	PERMANENT STRUCTURE		EXCAV	BACKFILL	TIME
	CONCRETE (CY)	REINF STEEL (TONS)	GEN'L EXCAV (CY)	GEN'L BACKFILL (CY)	PROJECT DURATION (MOS)
HIGHWAY TUNNEL:					
1-1GT	48,760	3,534	148,900	9,900	28
1-1GV	56,200	4,091	251,800	105,800	31
1-1GY	74,300	5,447	357,800	194,200	34
1-1HT	48,760	3,534	148,900	9,900	28
1-1HV	56,200	4,091	251,800	105,800	31
1-1HY	74,300	5,447	357,800	194,200	34
2-1GU	36,880	2,646	148,900	19,800	28
2-1GW	46,580	3,372	251,800	105,800	31
2-1GZ	66,900	4,895	357,800	194,200	34
2-1HU	36,880	2,646	148,900	19,800	28
2-1HW	46,580	3,372	251,800	105,800	31
2-1HZ	66,900	4,895	357,800	194,200	34
RAPID TRANSIT STATION:					
1-2GV	24,569	1,748	84,200	13,500	34
1-2GY	27,096	1,938	117,900	45,500	37
1-2HV	24,569	1,748	84,200	13,500	34
1-2HY	27,096	1,938	117,900	45,500	37
2-2GW	18,892	1,325	84,200	13,500	34
2-2GZ	21,542	1,523	117,900	45,500	37
2-2HW	18,892	1,325	84,200	13,500	34
2-2HZ	21,542	1,523	117,900	45,500	37
RAPID TRANSIT TUNNEL:					
1-3GT	22,760	1,497	75,500	25,200	24
1-3GV	29,420	1,995	129,700	72,700	26
1-3GY	35,040	2,415	186,500	122,600	28
1-3HT	22,760	1,497	75,500	25,200	24
1-3HV	29,420	1,995	129,700	72,700	26
1-3HY	35,040	2,415	186,500	122,600	28
2-3GU	17,660	1,116	75,500	25,200	24
2-3GW	24,240	1,593	129,700	72,700	26
2-3GZ	29,420	1,995	186,500	122,600	28
2-3HU	17,660	1,116	75,500	25,200	24
2-3HW	24,240	1,593	129,700	72,700	26
2-3HZ	29,420	1,995	186,500	122,600	28

Table 47. MAJOR ESTIMATING QUANTITIES
SOLDIER PILE AND LAGGING ESTIMATES
INTERNAL BRACING DETAILS

ESTIMATE CODE	INTERNAL BRACING BY LEVELS *1				
	LEVEL 2 (TONS)	LEVEL 3 (TONS)	LEVEL 4 (TONS)	LEVEL 5 (TONS)	TOTAL (TONS)
HIGHWAY TUNNEL:					
1-1GT	555	-	-	-	555
1-1GV	831	665	-	-	1,496
1-1GY	1,051	1,142	764	632	3,589
2-1GU	555	-	-	-	555
2-1GW	831	665	-	-	1,496
2-1GZ	1,051	1,142	764	632	3,589
RAPID TRANSIT STATION:					*2, *3
1-2GV	525	336	225	-	1,211
1-2GY	351	819	336	400	1,887
2-2GW	525	336	225	-	1,211
2-2GZ	351	819	336	400	1,887
RAPID TRANSIT TUNNEL:					
1-3GT	359	-	-	-	359
1-3GV	483	409	-	-	892
1-3GY	539	500	514	337	1,890
2-3GU	359	-	-	-	359
2-3GW	483	409	-	-	892
2-3GZ	539	500	514	337	1,890

Notes:
*1. The decking (Item E) constitutes bracing level No. 1 for all estimates.
*2. Total steel bracing quantities of the station include an allowance for additional steel in the end bulkheads: 125 tons for 50' depth and 170 tons for 70' depths.
*3. The permanent steel framing of the station roof and mezzanine levels form: bracing levels 2 and 3 for the 50' depths, and bracing levels 3 and 4 for the 70' depths.

Table 48. MAJOR ESTIMATING QUANTITIES
CAST-IN-SLURRY (S.P.T.C.) WALL ESTIMATES
GROUND SUPPORT

ESTIMATE CODE	GROUND SUPPORT				
	NET AREA (SY)	PILE HOLES (LF)	PILES (TONS)	SLOT EXCAV (CY)	TREMIE CONCRETE (CY)
HIGHWAY TUNNEL:					
1-1JT	13,333	10,000	987	11,852	10,519
1-1JV	22,222	20,040	2,568	22,222	18,519
1-1JY	31,111	27,388	4,770	36,444	32,000
1-1KT	13,333	10,000	987	11,852	10,519
1-1KV	22,222	20,040	2,568	22,222	18,519
1-1KY	31,111	27,388	4,770	36,444	32,000
2-1JU	13,333	10,000	987	11,852	10,519
2-1JW	22,222	20,040	2,568	22,222	18,519
2-1JZ	31,111	27,388	4,770	36,444	32,000
2-1KU	13,333	10,000	987	11,852	10,519
2-1KW	22,222	20,040	2,568	22,222	18,519
2-1KZ	31,111	27,388	3,788	36,444	32,000
3-1JT	13,333	10,000	1,050	11,852	10,519
3-1JV	22,222	22,378	3,111	29,778	25,334
3-1JY	31,111	34,068	7,989	45,333	40,889
3-1KT	13,333	10,000	1,050	11,852	10,519
3-1KV	22,222	22,378	3,457	29,778	25,334
3-1KY	31,111	34,068	5,558	45,333	40,889
4-1JT	13,333	16,000	2,080	17,778	16,445
4-1JV	22,222	21,376	3,206	26,667	22,223
4-1JY	26,667	21,376	3,890	26,667	22,223
4-1KT	13,333	16,000	2,080	17,778	16,445
4-1KV	22,222	21,376	3,206	26,667	22,223
4-1KY	26,667	21,376	2,886	26,667	22,223
5-1JT	13,333	41,416	8,894	17,778	15,778
5-1JV	22,222	32,064	9,810	32,000	27,556
5-1JY	31,111	31,730	10,659	33,333	28,889
RAPID TRANSIT STATION (PART):					
1-2JV	8,500	7,020	899	7,778	6,481
1-2JY	11,900	9,594	1,671	12,756	11,200
1-2KV	8,500	7,020	899	7,778	6,481
1-2KY	11,900	9,594	1,327	12,756	11,200
2-2JW	8,500	7,020	899	7,778	6,481
2-2JZ	11,900	9,594	1,671	12,756	11,200
2-2KW	8,500	7,020	899	7,778	6,481
2-2KZ	11,900	9,594	1,327	12,756	11,200
3-2JV	8,500	7,839	1,090	10,422	8,866

Table 48. MAJOR ESTIMATING QUANTITIES
CAST-IN-SLURRY (S.P.T.C.) WALL ESTIMATES
GROUND SUPPORT (Continued)

ESTIMATE CODE	GROUND SUPPORT				
	NET AREA (SY)	PILE HOLES (LF)	PILES (TONS)	SLOT EXCAV (CY)	TREMIE CONCRETE (CY)
RAPID TRANSIT STATION (CONT'D):					
3-2JY	11,900	11,934	2,799	15,867	14,311
3-2KV	8,500	7,839	1,211	10,422	8,866
3-2KY	11,900	11,934	1,947	15,867	14,311
4-2JV	7,778	7,488	1,123	9,333	7,777
4-2JY	9,333	7,488	1,363	9,333	7,777
4-2KV	7,778	7,488	1,123	9,333	7,777
4-2KY	9,333	7,488	1,011	9,333	7,777
5-2JV	7,778	11,232	3,436	11,200	9,644
5-2JY	10,889	11,115	3,733	11,667	10,111
RAPID TRANSIT TUNNEL:					
1-3JT	13,333	10,000	1,050	11,852	8,889
1-3JV	22,222	20,040	2,568	22,222	18,519
1-3JY	31,111	27,388	3,030	36,444	32,000
1-3KT	13,333	10,000	1,050	11,852	8,889
1-3KV	22,222	20,040	2,568	22,222	18,519
1-3KY	31,111	27,388	3,788	36,444	32,000
2-3JU	13,333	10,000	1,050	11,852	8,889
2-3JW	22,222	20,040	2,568	22,222	18,519
2-3JZ	31,111	27,388	3,030	36,444	32,000
2-3KU	13,333	10,000	1,050	11,852	8,889
2-3KW	22,222	20,040	2,568	22,222	18,519
2-3KZ	31,111	27,388	3,788	36,444	32,000
3-3JT	13,333	10,000	1,050	11,852	8,889
3-3JV	22,222	24,716	3,427	32,889	28,445
3-3JY	31,111	36,740	5,050	48,889	44,445
3-3KT	13,333	10,000	1,050	11,852	8,889
3-3KV	22,222	24,716	3,808	32,889	28,445
3-3KY	31,111	36,740	5,985	48,889	44,445
4-3JT	13,333	16,000	1,920	17,778	14,815
4-3JV	22,222	21,376	3,420	26,667	22,223
4-3JY	26,667	21,376	3,890	26,667	22,223
4-3KT	13,333	16,000	1,920	17,778	14,815
4-3KV	22,222	21,376	2,886	26,667	22,223
4-3KY	26,667	21,376	2,886	26,667	22,223
5-3JT	13,333	40,748	8,562	17,778	13,334
5-3JV	22,222	31,396	9,539	32,000	27,556
5-3JY	31,111	32,398	10,096	33,333	28,889

Table 49. MAJOR ESTIMATING QUANTITIES
CAST-IN-SLURRY (S.P.T.C.) WALL ESTIMATES
DECKING AND BRACING

ESTIMATE CODE	DECKING			BRACING	
	DECK AREA (SY)	PILES (TONS)	STEEL FRAME (TONS)	STEEL (TONS)	TIEBACKS (LF)
HIGHWAY TUNNEL:					
1-1JT	15,778	362	2,088	514	-
1-1JV	16,222	485	2,097	1,750	-
1-1JY	16,222	607	2,097	4,187	-
1-1KT	15,778	362	2,088	116	26,000
1-1KV	16,222	485	2,097	448	117,000
1-1KY	16,222	607	2,097	1,231	337,384
2-1JU	15,778	362	2,088	514	-
2-1JW	16,222	485	2,097	1,750	-
2-1JZ	16,222	607	2,097	4,187	-
2-1KU	15,778	362	2,088	116	26,000
2-1KW	16,222	485	2,097	448	117,000
2-1KZ	16,222	607	2,097	1,231	337,384
3-1JT	15,778	362	2,088	525	-
3-1JV	16,222	485	2,097	1,972	-
3-1JY	16,222	607	2,097	5,033	-
3-1KT	15,778	362	2,088	116	47,500
3-1KV	16,222	485	2,097	457	197,000
3-1KY	16,222	607	2,097	1,448	456,000
4-1JT	15,778	362	2,088	518	-
4-1JV	16,222	485	2,097	2,200	-
4-1JY	18,000	607	2,261	2,650	-
4-1KT	15,778	362	2,088	298	125,000
4-1KV	16,222	485	2,097	562	413,000
4-1KY	18,000	607	2,261	650	547,920
5-1JT	15,778	362	2,088	1,143	-
5-1JV	16,222	485	2,097	4,459	-
5-1JY	16,222	607	2,097	6,013	-
RAPID TRANSIT STATION (PART):					
1-2JV	5,289	173	695	1,231	-
1-2JY	5,289	217	695	1,991	-
1-2KV	5,289	173	695	181	44,694
1-2KY	5,289	217	695	470	122,418
2-2JW	5,289	173	695	1,231	-
2-2JZ	5,289	217	695	1,991	-
2-2KW	5,289	173	695	181	44,694
2-2KZ	5,289	217	695	470	122,418
3-2JV	5,289	173	695	1,299	-

Table 49. MAJOR ESTIMATING QUANTITIES
CAST-IN-SLURRY (S.P.T.C.) WALL ESTIMATES
DECKING AND BRACING (Continued)

ESTIMATE CODE	DECKING			BRACING	
	DECK AREA (SY)	PILES (TONS)	STEEL FRAME (TONS)	STEEL (TONS)	TIEBACKS (LF)
RAPID TRANSIT STATION (CONT'D):					
3-2JY	5,289	217	695	2,100	-
3-2KV	5,289	173	695	174	75,254
3-2KY	5,289	217	695	586	174,192
4-2JV	5,289	173	695	1,346	-
4-2JY	5,911	217	753	1,823	-
4-2KV	5,289	173	695	197	144,600
4-2KY	5,911	217	753	227	191,860
5-2JV	5,289	173	695	1,473	-
5-2JY	5,289	217	695	2,203	-
RAPID TRANSIT TUNNEL:					
1-3JT	8,444	-	1,346	299	-
1-3JV	8,889	-	1,250	935	-
1-3JY	8,889	-	1,250	2,131	-
1-3KT	8,444	-	1,346	116	26,000
1-3KV	8,889	-	1,250	448	117,000
1-3KY	8,889	-	1,250	1,243	326,384
2-3JU	8,444	-	1,346	299	-
2-3JW	8,889	-	1,250	935	-
2-3JZ	8,889	-	1,250	2,131	-
2-3KU	8,444	-	1,346	116	26,000
2-3KW	8,889	-	1,250	448	117,000
2-3KZ	8,889	-	1,250	1,243	326,384
3-3JT	8,444	-	1,346	310	-
3-3JV	8,889	-	1,250	1,058	-
3-3JY	8,889	-	1,250	2,457	-
3-3KT	8,444	-	1,346	116	47,500
3-3KV	8,889	-	1,250	457	197,000
3-3KY	8,889	-	1,250	1,537	484,000
4-3JT	8,444	-	1,346	318	-
4-3JV	8,889	-	1,250	1,156	-
4-3JY	10,667	-	1,414	1,540	-
4-3KT	8,444	-	1,346	272	113,000
4-3KV	8,889	-	1,250	485	461,150
4-3KY	10,667	-	1,414	632	543,900
5-3JT	8,444	-	1,346	613	-
5-3JV	8,889	-	1,250	2,331	-
5-3JY	8,889	-	1,250	3,383	-

Table 50. MAJOR ESTIMATING QUANTITIES
CAST-IN-SLURRY (S.P.T.C.) WALL ESTIMATES
STRUCTURE AND EARTHWORK

ESTIMATE CODE	PERMANENT STRUCT		EXCAV	BACKFILL	TIME
	CONCRETE (CY)	REINF STEEL (TONS)	GEN'L EXCAV (CY)	GEN'L BACKFILL (CY)	PROJECT DURATION (MOS)
HIGHWAY TUNNEL:					
1-1JT	44,640	3,230	144,500	9,600	30
1-1JV	49,800	3,617	240,800	101,100	33
1-1JY	64,900	4,749	337,100	183,000	36
1-1KT	44,640	3,230	144,500	9,600	30
1-1KV	49,800	3,617	240,800	101,100	33
1-1KY	64,900	4,749	337,100	183,000	36
2-1JU	34,980	2,505	144,500	19,200	30
2-1JW	42,580	3,075	240,800	101,100	33
2-1JZ	60,120	4,391	337,100	183,000	36
2-1KU	34,980	2,505	144,500	19,200	30
2-1KW	42,580	3,075	240,800	101,100	33
2-1KZ	60,120	4,391	337,100	183,000	36
3-1JT	44,640	3,230	144,500	9,600	30
3-1JV	49,800	3,617	240,800	101,100	34
3-1JY	64,900	4,749	337,100	183,000	37
3-1KT	44,640	3,230	144,500	9,600	30
3-1KV	49,800	3,617	240,800	101,100	34
3-1KY	64,900	4,749	337,100	183,000	37
4-1JT	44,640	3,230	144,500	9,600	30
4-1JV	49,800	3,617	240,800	101,100	34
4-1JY	72,020	5,276	375,500	205,400	38
4-1KT	44,640	3,230	144,500	9,600	30
4-1KV	49,800	3,617	240,800	101,100	34
4-1KY	72,020	5,276	375,500	205,400	38
5-1JT	44,640	3,230	144,500	9,600	31
5-1JV	49,800	3,617	240,800	101,100	35
5-1JY	64,900	4,749	337,100	183,000	39
RAPID TRANSIT STATION (PART):					
1-2JV	19,146	1,345	77,700	12,500	36
1-2JY	21,481	1,520	108,800	42,000	39
1-2KV	19,146	1,345	77,700	12,500	36
1-2KY	21,481	1,520	108,800	42,000	39
2-2JW	16,815	1,170	77,700	12,500	36
2-2JZ	18,368	1,287	108,800	42,000	39
2-2KW	16,815	1,170	77,700	12,500	36
2-2KZ	18,368	1,287	108,800	42,000	39
3-2JV	19,146	1,345	77,700	12,500	37

Table 50. MAJOR ESTIMATING QUANTITIES
CAST-IN-SLURRY (S.P.T.C.) WALL ESTIMATES
STRUCTURE AND EARTHWORK (Continued)

ESTIMATE CODE	PERMANENT STRUCT		EXCAV	BACKFILL	TIME
	CONCRETE (CY)	REINF STEEL (TONS)	GEN'L EXCAV (CY)	GEN'L BACKFILL (CY)	PROJECT DURATION (MOS)
RAPID TRANSIT STATION (CONT'D):					
3-2JY	21,481	1,520	108,800	42,000	40
3-2KV	19,146	1,345	77,700	12,500	37
3-2KY	21,481	1,520	108,800	42,000	40
4-2JV	19,146	1,345	77,700	12,500	37
4-2JY	23,976	1,705	122,400	47,600	41
4-2KV	19,146	1,345	77,700	12,500	37
4-2KY	23,976	1,705	122,400	47,600	41
5-2JV	19,146	1,345	77,700	12,500	38
5-2JY	21,481	1,520	108,800	42,000	42
RAPID TRANSIT TUNNEL:					
1-3JT	19,860	1,283	71,200	23,700	27
1-3JV	24,580	1,637	118,600	66,400	29
1-3JY	28,140	1,904	166,000	109,000	31
1-3KT	19,860	1,283	71,200	23,700	27
1-3KV	24,580	1,637	118,600	66,400	29
1-3KY	28,140	1,904	166,000	109,000	31
2-3JU	16,280	1,014	71,200	23,700	27
2-3JW	20,980	1,367	118,600	66,400	29
2-3JZ	24,540	1,634	166,000	109,000	31
2-3KU	16,280	1,014	71,200	23,700	27
2-3KW	20,980	1,367	118,600	66,400	29
2-3KZ	24,540	1,634	166,000	109,000	31
3-3JT	19,860	1,283	71,200	23,700	27
3-3JV	24,580	1,637	118,600	66,400	30
3-3JY	28,140	1,904	166,000	109,000	32
3-3KT	19,860	1,283	71,200	23,700	27
3-3KV	24,580	1,637	118,600	66,400	30
3-3KY	28,140	1,904	166,000	109,000	32
4-3JT	19,860	1,283	71,200	23,700	27
4-3JV	24,580	1,637	118,600	66,400	30
4-3JY	35,260	2,430	204,500	136,300	33
4-3KT	19,860	1,283	71,200	23,700	27
4-3KV	24,580	1,637	118,600	66,400	30
4-3KY	35,260	2,430	204,500	136,300	33
5-3JT	19,860	1,283	71,200	23,700	28
5-3JV	24,580	1,637	118,600	66,400	31
5-3JY	28,140	1,904	166,000	109,000	34

Table 51. MAJOR ESTIMATING QUANTITIES
CAST-IN-SLURRY (S.P.T.C.) WALL ESTIMATES
INTERNAL BRACING DETAILS

ESTIMATE CODE	INTERNAL BRACING BY LEVELS *1				
	LEVEL 2 (TONS)	LEVEL 3 (TONS)	LEVEL 4 (TONS)	LEVEL 5 (TONS)	TOTAL (TONS)
HIGHWAY TUNNEL:					
1-1JT	514	-	-	-	514
1-1JV	1,004	746	-	-	1,750
1-1JY	1,159	1,280	874	874	4,187
2-1JU	514	-	-	-	514
2-1JW	1,004	746	-	-	1,750
2-1JZ	1,159	1,280	874	874	4,187
3-1JT	525	-	-	-	525
3-1JV	1,016	956	-	-	1,972
3-1JY	1,144	1,581	1,087	1,221	5,033
4-1JT	518	-	-	-	518
4-1JV	1,100	1,100	-	-	2,200
4-1JY	1,209	1,316	-	125	2,650
5-1JT	1,143	-	-	-	1,143
5-1JV	1,357	1,608	1,494	-	4,459
5-1JY	1,377	1,675	1,651	1,310	6,013
RAPID TRANSIT STATION (PART):					*2, *3
1-2JV	525	336	245	-	1,231
1-2JY	380	819	336	286	1,991
2-2JW	525	336	245	-	1,231
2-2JZ	380	819	336	286	1,991
3-2JV	525	336	313	-	1,299

Notes: *1. The decking (Item E) constitutes bracing level No. 1 for all estimates.

*2. Total steel bracing quantities of the station include an allowance for additional steel in the end bulkheads: 125 tons for 50' depth and 170 tons for 70' depths.

*3. The permanent steel framing of the station roof and mezzanine levels form: bracing levels 2 and 3 for the 50' depths, and bracing levels 3 and 4 for the 70' depths.

Table 51. MAJOR ESTIMATING QUANTITIES
CAST-IN-SLURRY (S.P.T.C.) WALL ESTIMATES
INTERNAL BRACING DETAILS (Continued)

ESTIMATE CODE	INTERNAL BRACING BY LEVELS *1				
	LEVEL 2 (TONS)	LEVEL 3 (TONS)	LEVEL 4 (TONS)	LEVEL 5 (TONS)	TOTAL (TONS)
RAPID TRANSIT STATION (CONT'D):					*2, *3
3-2JY	375	819	336	400	2,100
4-2JV	525	336	360	-	1,346
4-2JY	398	889	362	44	1,823
5-2JV	525	336	487	-	1,473
5-2JY	450	819	336	428	2,203
RAPID TRANSIT TUNNEL:					
1-3JT	299	-	-	-	299
1-3JV	531	404	-	-	935
1-3JY	598	515	538	480	2,131
2-3JU	299	-	-	-	299
2-3JW	531	404	-	-	935
2-3JZ	598	515	538	480	2,131
3-3JT	310	-	-	-	310
3-3JV	562	496	-	-	1,058
3-3JY	585	527	702	643	2,457
4-3JT	318	-	-	-	318
4-3JV	597	559	-	-	1,156
4-3JY	644	771	-	125	1,540
5-3JT	613	-	-	-	613
5-3JV	580	865	886	-	2,331
5-3JY	702	865	993	823	3,383

Notes: *1. The decking (Item E) constitutes bracing level No. 1 for all estimates.

*2. Total steel bracing quantities of the station include an allowance for additional steel in the end bulkheads: 125 tons for 50' depth and 170 tons for 70' depths.

*3. The permanent steel framing of the station roof and mezzanine levels form: bracing levels 2 and 3 for the 50' depths, and bracing levels 3 and 4 for the 70' depths.

Table 52. MAJOR ESTIMATING QUANTITIES
PRECAST CONCRETE GROUND SUPPORT ESTIMATES
GROUND SUPPORT

ESTIMATE CODE	GROUND SUPPORT				
	NET AREA (SY)	SLOT EXCAV (CY)	PRECAST PANELS		
			NO./SIZE	VOLUME (CY)	REINF (TONS)
HIGHWAY TUNNEL:					
1-1LT	13,333	11,852	334/2x12	4,753	765
1-1LV	22,222	26,667	446/3x9	10,887	1,361
1-1LY	31,111	36,444	668/3x6	18,136	3,201
1-1MT	13,333	11,852	334/2x12	4,753	765
1-1MV	22,222	26,667	446/3x9	10,887	1,361
1-1MY	31,111	36,444	668/3x6	18,136	3,201
2-1LU	13,333	11,852	334/2x12	4,753	765
2-1LW	22,222	26,667	446/3x9	10,887	1,361
2-1LZ	31,111	36,444	668/3x6	18,136	3,201
2-1MU	13,333	11,852	334/2x12	4,753	765
2-1MW	22,222	26,667	446/3x9	10,887	1,361
2-1MZ	31,111	36,444	668/3x6	18,136	3,201
3-1LT	13,333	12,741	334/2x12	5,408	1,057
3-1LV	22,222	35,556	446/3x9	12,488	2,310
3-1LY	31,111	55,100	668/3x6	21,416	4,358
3-1MT	13,333	12,741	334/2x12	5,408	1,057
3-1MV	22,222	35,556	446/3x9	12,488	2,310
3-1MY	31,111	55,100	668/3x6	21,416	4,358
4-1LT	13,333	17,778	334/2x12	8,497	1,661
4-1LV	22,222	27,556	500/3x8	11,278	1,940
4-1LY	26,667	27,556	668/3x6	12,592	1,605
4-1MT	13,333	17,778	334/2x12	8,497	1,661
4-1MV	22,222	27,556	500/3x8	11,278	1,940
4-1MY	26,667	27,556	668/3x6	12,592	1,605
5-1LT	13,333	48,593	668/4x6	12,362	1,360
5-1LV	22,222	49,778	668/4x6	21,898	3,033
5-1LY	31,111	50,370	668/4x6	22,958	3,857
RAPID TRANSIT STATION (PART):					
1-2LV	8,500	9,333	156/3x9	3,808	476
1-2LY	11,900	12,756	234/3x6	6,352	1,121
1-2MV	8,500	9,333	156/3x9	3,808	476
1-2MY	11,900	12,756	234/3x6	6,352	1,121
2-2LW	8,500	9,333	156/3x9	3,808	476
2-2LZ	11,900	12,756	234/3x6	6,352	1,121
2-2MW	8,500	9,333	156/3x9	3,808	476
2-2MZ	11,900	12,756	234/3x6	6,352	1,121
3-2LV	8,500	12,444	156/3x9	4,452	824

Table 52. MAJOR ESTIMATING QUANTITIES
PRECAST CONCRETE GROUND SUPPORT ESTIMATES
GROUND SUPPORT (Continued)

ESTIMATE CODE	GROUND SUPPORT				
	NET AREA (SY)	SLOT EXCAV (CY)	PRECAST PANELS		
			NO./SIZE	VOLUME (CY)	REINF (TONS)
RAPID TRANSIT STATION (CONT'D):					
3-2LY	11,900	11,852	234/3x6	4,319	695
3-2MV	8,500	26,667	156/3x9	10,887	1,361
3-2MY	11,900	36,444	234/3x6	18,136	2,167
4-2LV	8,500	11,852	176/3x8	4,319	695
4-2LY	10,200	26,667	234/3x6	10,887	1,361
4-2MV	8,500	36,444	176/3x8	18,136	2,167
4-2MY	10,200	9,644	234/3x6	4,111	524
5-2LV	8,500	17,422	234/4x6	7,671	1,062
5-2LY	11,900	17,630	234/4x6	8,042	1,351
RAPID TRANSIT TUNNEL:					
1-3LT	13,333	13,333	334/2x12	4,636	906
1-3LV	22,222	40,000	446/3x9	12,448	2,310
1-3LY	31,111	60,444	668/3x6	21,416	3,052
1-3MT	13,333	13,333	334/2x12	4,636	906
1-3MV	22,222	40,000	446/3x9	12,488	2,310
1-3MY	31,111	60,444	668/3x6	21,416	3,052
2-3LU	13,333	11,852	334/2x12	4,319	695
2-3LW	22,222	26,667	446/3x9	10,887	1,361
2-3LZ	31,111	36,444	668/3x6	18,136	2,167
2-3MU	13,333	11,852	334/2x12	4,319	695
2-3MW	22,222	26,667	446/3x9	10,887	1,361
2-3MZ	31,111	36,444	668/3x6	18,136	2,167
3-3LT	13,333	13,333	334/2x12	4,636	906
3-3LV	22,222	40,000	446/3x9	12,448	2,310
3-3LY	31,111	60,444	668/3x6	21,416	3,052
3-3MT	13,333	13,333	334/2x12	4,636	906
3-3MV	22,222	40,000	446/3x9	12,488	2,310
3-3MY	31,111	60,444	668/3x6	21,416	3,052
4-3LT	13,333	17,778	334/2x12	7,725	1,510
4-3LV	22,222	27,556	500/3x8	11,278	2,148
4-3LY	26,667	27,556	668/3x6	12,592	1,605
4-3MT	13,333	17,778	334/2x12	7,725	1,510
4-3MV	22,222	27,556	500/3x8	11,278	2,148
4-3MY	26,667	27,556	668/3x6	12,592	1,605
5-3LT	13,333	48,000	668/4x6	10,596	1,166
5-3LV	22,222	49,185	668/4x6	21,898	3,602
5-3LY	31,111	50,963	668/4x6	22,958	3,272

Table 53. MAJOR ESTIMATING QUANTITIES
PRECAST CONCRETE GROUND SUPPORT ESTIMATES
DECKING AND BRACING

ESTIMATE CODE	DECKING			BRACING	
	DECK AREA (SY)	PILES (TONS)	STEEL FRAME (TONS)	STEEL (TONS)	TIEBACKS (LF)
HIGHWAY TUNNEL:					
1-1LT	15,333	362	2,015	524	-
1-1LV	15,778	485	2,036	1,707	-
1-1LY	15,778	607	2,056	4,080	-
1-1MT	15,333	362	2,015	116	26,000
1-1MV	15,778	485	2,036	448	117,000
1-1MY	15,778	607	2,056	1,369	333,000
2-1LU	15,333	362	2,015	524	-
2-1LW	15,778	485	2,036	1,707	-
2-1LZ	15,778	607	2,056	4,080	-
2-1MU	15,333	362	2,015	116	26,000
2-1MW	15,778	485	2,036	448	117,000
2-1MZ	15,778	607	2,056	1,369	333,000
3-1LT	15,333	362	2,015	524	-
3-1LV	15,778	485	2,036	1,922	-
3-1LY	15,778	607	2,056	4,905	-
3-1MT	15,333	362	2,015	116	47,500
3-1MV	15,778	485	2,036	457	197,000
3-1MY	15,778	607	2,056	1,448	456,000
4-1LT	15,333	362	2,015	505	-
4-1LV	15,778	485	2,036	2,144	-
4-1LY	18,000	607	2,261	2,650	-
4-1MT	15,333	362	2,015	298	125,000
4-1MV	15,778	485	2,036	562	413,000
4-1MY	18,000	607	2,261	650	547,920
5-1LT	15,333	362	2,015	1,114	-
5-1LV	15,778	485	2,036	4,338	-
5-1LY	15,778	607	2,056	5,854	-
RAPID TRANSIT STATION (PART):					
1-2LV	5,289	173	695	1,231	-
1-2LY	5,289	217	695	1,991	-
1-2MV	5,289	173	695	171	44,694
1-2MY	5,289	217	695	522	127,206
2-2LW	5,289	173	695	1,231	-
2-2LZ	5,289	217	695	1,991	-
2-2MW	5,289	173	695	171	44,694
2-2MZ	5,289	217	695	522	127,206
3-2LV	5,289	173	695	1,299	-

Table 53. MAJOR ESTIMATING QUANTITIES
PRECAST CONCRETE GROUND SUPPORT ESTIMATES
DECKING AND BRACING (Continued)

ESTIMATE CODE	DECKING			BRACING	
	DECK AREA (SY)	PILES (TONS)	STEEL FRAME (TONS)	STEEL (TONS)	TIEBACKS (LF)
RAPID TRANSIT STATION (CONT'D):					
3-2LY	5,289	217	695	2,100	-
3-2MV	5,289	173	695	174	75,254
3-2MY	5,289	217	695	586	174,192
4-2LV	5,289	173	695	1,337	-
4-2LY	5,911	217	753	1,823	-
4-2MV	5,289	173	695	197	144,600
4-2MY	5,911	217	753	227	191,860
5-2LV	5,289	173	695	1,451	-
5-2LY	5,289	217	695	2,179	-
RAPID TRANSIT TUNNEL:					
1-3LT	8,000	-	1,168	310	-
1-3LV	8,444	-	1,209	898	-
1-3LY	8,444	-	1,209	2,041	-
1-3MT	8,000	-	1,168	116	26,000
1-3MV	8,444	-	1,209	448	117,000
1-3MY	8,444	-	1,209	1,369	333,000
2-3LU	8,000	-	1,168	310	-
2-3LW	8,444	-	1,209	898	-
2-3LZ	8,444	-	1,209	2,041	-
2-3MU	8,000	-	1,168	116	26,000
2-3MW	8,444	-	1,209	448	117,000
2-3MZ	8,444	-	1,209	1,369	333,000
3-3LT	8,000	-	1,168	309	-
3-3LV	8,444	-	1,209	1,015	-
3-3LY	8,444	-	1,209	2,282	-
3-3MT	8,000	-	1,168	116	47,500
3-3MV	8,444	-	1,209	457	197,000
3-3MY	8,444	-	1,209	1,448	456,000
4-3LT	8,000	-	1,168	305	-
4-3LV	8,444	-	1,209	1,106	-
4-3LY	10,667	-	1,414	1,540	-
4-3MT	8,000	-	1,168	272	113,000
4-3MV	8,444	-	1,209	485	461,150
4-3MY	10,667	-	1,414	632	543,900
5-3LT	8,000	-	1,168	586	-
5-3LV	8,444	-	1,209	2,227	-
5-3LY	8,444	-	1,209	3,228	-

Table 54. MAJOR ESTIMATING QUANTITIES
PRECAST CONCRETE GROUND SUPPORT ESTIMATES
STRUCTURE AND EARTHWORK

ESTIMATE CODE	PERMANENT STRUCT		EXCAV	BACKFILL	TIME
	CONCRETE (CY)	REINF STEEL (TONS)	GEN'L EXCAV (CY)	GEN'L BACKFILL (CY)	PROJECT DURATION (MOS)
HIGHWAY TUNNEL:					
1-1LT	41,740	3,015	139,900	9,300	31
1-1LV	46,900	3,402	233,200	97,900	34
1-1LY	62,000	4,534	326,500	177,200	37
1-1MT	41,740	3,015	139,900	9,300	31
1-1MV	46,900	3,402	233,200	97,900	34
1-1MY	62,000	4,534	326,500	177,200	37
2-1LU	32,080	2,290	139,900	18,600	31
2-1LW	39,680	2,860	233,200	97,900	34
2-1LZ	57,220	4,176	326,500	177,200	37
2-1MU	32,080	2,290	139,900	18,600	31
2-1MW	39,680	2,860	233,200	97,900	34
2-1MZ	57,220	4,176	326,500	177,200	37
3-1LT	41,740	3,015	139,900	9,300	31
3-1LV	46,900	3,402	233,200	97,900	35
3-1LY	62,000	4,534	326,500	177,200	38
3-1MT	41,740	3,015	139,900	9,300	31
3-1MV	46,900	3,402	233,200	97,900	35
3-1MY	62,000	4,534	326,500	177,200	38
4-1LT	41,740	3,015	139,900	9,300	31
4-1LV	46,900	3,402	233,200	97,900	35
4-1LY	69,800	5,112	375,500	205,400	39
4-1MT	41,740	3,015	139,900	9,300	31
4-1MV	46,900	3,402	375,500	97,900	35
4-1MY	69,800	5,112	324,400	205,400	39
5-1LT	41,740	3,015	139,900	9,300	32
5-1LV	46,900	3,402	233,200	97,900	36
5-1LY	62,000	4,534	326,500	177,200	40
RAPID TRANSIT STATION (PART):					
1-2LV	17,640	1,233	75,200	12,000	33
1-2LY	19,975	1,408	105,300	40,600	36
1-2MV	17,640	1,233	75,200	12,000	33
1-2MY	19,975	1,408	105,300	40,600	36
2-2LW	15,309	1,058	75,200	12,000	33
2-2LZ	16,863	1,175	105,300	40,600	36
2-2MW	15,309	1,058	75,200	12,000	33
2-2MZ	16,863	1,175	105,300	40,600	36
3-2LV	17,640	1,233	75,200	12,000	34

Table 54. MAJOR ESTIMATING QUANTITIES
PRECAST CONCRETE GROUND SUPPORT ESTIMATES
STRUCTURE AND EARTHWORK (Continued)

ESTIMATE CODE	PERMANENT STRUCT		EXCAV	BACKFILL	TIME
	CONCRETE (CY)	REINF STEEL (TONS)	GEN'L EXCAV (CY)	GEN'L BACKFILL (CY)	PROJECT DURATION (MOS)
RAPID TRANSIT STATION (CONT'D):					
3-2LY	19,975	1,408	105,300	40,600	37
3-2MV	17,640	1,233	75,200	12,000	34
3-2MY	19,975	1,408	105,300	40,600	37
4-2LV	17,640	1,233	75,200	12,000	34
4-2LY	22,789	1,617	122,400	47,600	38
4-2MV	17,640	1,233	75,200	12,000	34
4-2MY	22,789	1,617	122,400	47,600	38
5-2LV	17,640	1,233	75,200	12,000	35
5-2LY	19,975	1,408	105,300	40,600	39
RAPID TRANSIT TUNNEL:					
1-3LT	17,820	1,133	66,700	22,200	28
1-3LV	22,540	1,487	111,100	62,100	30
1-3LY	26,100	1,754	155,500	102,100	32
1-3MT	17,820	1,133	66,700	22,200	28
1-3MV	22,540	1,487	111,100	62,100	30
1-3MY	26,100	1,754	155,500	102,100	32
2-3LU	14,240	864	66,700	22,200	28
2-3LW	18,940	1,217	111,100	62,100	30
2-3LZ	22,500	1,484	155,500	102,100	32
2-3MU	14,240	864	66,700	22,200	28
2-3MW	18,940	1,217	111,100	62,100	30
2-3MZ	22,500	1,484	155,500	102,100	32
3-3LT	17,820	1,133	66,700	22,200	28
3-3LV	22,540	1,487	111,100	62,100	31
3-3LY	26,100	1,754	155,500	102,100	33
3-3MT	17,820	1,133	66,700	22,200	28
3-3MV	22,540	1,487	111,100	62,100	31
3-3MY	26,100	1,754	155,500	102,100	33
4-3LT	17,820	1,133	66,700	22,200	28
4-3LV	22,540	1,487	111,100	62,100	31
4-3LY	34,340	2,364	204,500	136,300	34
4-3MT	17,820	1,133	66,700	22,200	28
4-3MV	22,540	1,487	111,100	62,100	31
4-3MY	34,340	2,364	204,500	136,300	34
5-3LT	17,820	1,133	66,700	22,200	29
5-3LV	22,540	1,487	111,100	62,100	32
5-3LY	26,100	1,754	155,500	102,100	35

Table 55. MAJOR ESTIMATING QUANTITIES
PRECAST CONCRETE GROUND ESTIMATES
INTERNAL BRACING DETAILS

ESTIMATE CODE	INTERNAL BRACING BY LEVELS *1				
	LEVEL 2 (TONS)	LEVEL 3 (TONS)	LEVEL 4 (TONS)	LEVEL 5 (TONS)	TOTAL (TONS)
HIGHWAY TUNNEL:					
1-1LT	524	-	-	-	524
1-1LV	979	728	-	-	1,707
1-1LY	1,129	1,247	852	852	4,080
2-1LU	524	-	-	-	524
2-1LW	979	728	-	-	1,707
2-1LZ	1,129	1,247	852	852	4,080
3-1LT	524	-	-	-	524
3-1LV	990	932	-	-	1,922
3-1LY	1,115	1,541	1,059	1,190	4,905
4-1LT	505	-	-	-	505
4-1LV	1,072	1,072	-	-	2,144
4-1LY	1,209	1,316	125	-	2,650
5-1LT	1,114	-	-	-	1,114
5-1LV	1,321	1,564	1,453	-	4,338
5-1LY	1,341	1,631	1,607	1,275	5,854
RAPID TRANSIT STATION (PART):					*2, *3
1-2LV	525	336	245	-	1,231
1-2LY	380	819	336	286	1,991
2-2LW	525	336	245	-	1,231
2-2LZ	380	819	336	286	1,991
3-2LV	525	336	313	-	1,299

Notes: *1. The decking (Item E) constitutes bracing level No. 1 for all estimates.

*2. Total steel bracing quantities of the station include an allowance for additional steel in the end bulkheads: 125 tons for 50' depth and 170 tons for 70' depths.

*3. The permanent steel framing of the station roof and mezzanine levels form: bracing levels 2 and 3 for the 50' depths, and bracing levels 3 and 4 for the 70' depths.

Table 55. MAJOR ESTIMATING QUANTITIES
PRECAST CONCRETE GROUND SUPPORT ESTIMATES
INTERNAL BRACING DETAILS (Continued)

ESTIMATE CODE	INTERNAL BRACING BY LEVELS *1				
	LEVEL 2 (TONS)	LEVEL 3 (TONS)	LEVEL 4 (TONS)	LEVEL 5 (TONS)	TOTAL (TONS)
RAPID TRANSIT STATION (CONT'D):					*2, *3
3-2LY	375	819	336	440	2,100
4-2LV	525	336	351	-	1,337
4-2LY	398	889	362	44	1,823
5-2LV	525	336	473	-	1,459
5-2LY	438	819	336	416	2,179
RAPID TRANSIT TUNNEL:					
1-3LT	310	-	-	-	310
1-3LV	509	389	-	-	898
1-3LY	572	494	515	460	2,041
2-3LU	310	-	-	-	310
2-3LW	509	389	-	-	898
2-3LZ	572	494	515	460	2,041
3-3LT	309	-	-	-	309
3-3LV	539	476	-	-	1,015
3-3LY	450	515	687	630	2,282
4-3LT	305	-	-	-	305
4-3LV	571	535	-	-	1,106
4-3LY	644	771	-	125	1,540
1-3LT	586	-	-	-	586
1-3LV	556	826	845	-	2,227
1-3LY	671	826	946	785	3,228

Notes: *1. The decking (Item E) constitutes bracing level No. 1 for all estimates.

*2. Total steel bracing quantities of the station include an allowance for additional steel in the end bulkheads: 125 tons for 50' depth and 170 tons for 70' depths.

*3. The permanent steel framing of the station roof and mezzanine levels form: bracing levels 2 and 3 for the 50' depths, and bracing levels 3 and 4 for the 70' depths. Notes for Precast Panels:

COMMENTS ON PRECASTING OPERATION

(To be used with preparing estimate variations as illustrated in Table 16, page 94, Item F)

Assumed casting yard progress:

Sites 1, 2 and 3

2 x 12 panels for 30' depth @ 8 per day

3 x 9 panels for 50' depths @ 5 per day

3 x 6 panels for 70' depths @ 4 per day

Site 4

All sizes for all depths @ 5 per day

(All lengths approximately equal)

Site 5

4 x 6 panels for 30' depths @ 6 per day

4 x 6 panels for 50' & 70' depths @ 5 per day

Note: For details of panels, see Figure 27, page 176

Structural steel required for top soldier beams:

1.3 Tons per panel (3 x 6 and 4 x 6)

1.6 Tons per panel (3 x 9 and 2 x 12)

APPENDIX C

SUMMARIES OF COST ESTIMATES

176 CUT-AND-COVER TUNNEL SITUATIONS

A summary tabulation of 176 estimates prepared for the study is presented in this appendix. Each gives the total cost of eleven direct cost activities, four indirect cost activities and appropriate contractors markup to cover contingencies and profit. The tables are arranged in order to compare different construction methods with varying site conditions for a particular transit structure. The estimates were prepared as discussed in Sections 3 and 4 of this volume of the report.

Tables 56 through 58 (15 pages) summarize estimates for the four lane highway tunnel. Each sheet presents comparative estimates for a particular site conditions of soil, groundwater, and depth of structure. The five pages of Table 56 are for 30-foot (9.1m) depths at sites 1 through 5 respectively. Likewise, the five pages of Table 57 are for 50-foot (15.2m) depths and the five pages of Table 58 for 70-foot (21.3m) depths. Where applicable, (sites 1 and 2) six estimates on each sheet show variations using internal or tieback bracing for each of the three types of ground support systems: soldier piles and lagging, cast-in-slurry, and precast concrete panel ground support. At sites 3 and 4 only four combinations of ground support and bracing systems are compared as applicable. Since tiebacks are not practical at site 5 only two candidate systems are compared on those sheets. Tables 59 through 60 and 61 through 63 present similar comparison tables for the rapid transit station and rapid transit line section respectively.

All estimates are identified by code as given on Table 6, page 61, in a similar order of presentation. This same order of presentation is followed in Table 19, page 107, which summarizes total project costs of the 176 estimates presented here in Tables 56 through 63.

A more detailed breakdown of costs is given in Volume 3 of this report. These computer estimate summaries include 12 representative cut-and-cover situations and 3 estimates comparing under-the-roof construction techniques. They summarize all component work operations of the eleven direct and four indirect cost activities. The operations and activities are further detailed by component costs (i.e. labor, equipment, materials) and unit costs of each.

Printouts of the four basic computer estimates described in paragraph 3.3.3, page 64, are presented in a supplemental volume. For these estimates, all details generated in preparation and execution are shown. Each work operation shows a breakdown of labor, equipment and materials used and rates of progress for those interested in such details. Samples of these details are given in Tables 8 through 11, pages 67-74.

Estimates for situations differing from those assumed for the study can be made by adjusting individual activity costs as discussed in paragraph 4.3, page 92.

Table 56. ESTIMATE COMPARISON TABLES OF ACTIVITY CONSTRUCTION COSTS
FOUR LANE HIGHWAY TUNNEL - 30' DEPTH

Site 1: Alluvial soils - high water table, lowered during construction

	GROUND SUPPORT	SOLD. PILES & LAGGING		CAST-IN-SLURRY (SPTC)		PRECAST CONC. PANELS	
	TYPE OF BRACING	INTERNAL	TIEBACK	INTERNAL	TIEBACK	INTERNAL	TIEBACK
	EST. DESIGNATION	1-1GT	1-1HT	1-1JT	1-1KT	1-1LT	1-1MT
A	TRAFFIC CONTROL	158,000	158,000	158,000	158,000	158,000	158,000
B	UTILITY WORK	1,643,000	1,643,000	2,144,000	2,144,000	2,144,000	2,144,000
C	PROTECT ADJ.STRUCT.	193,000	193,000	193,000	193,000	193,000	193,000
D	GROUNDWATER CONTROL	565,000	565,000	565,000	565,000	539,000	539,000
E	DECKING	2,795,000	2,795,000	2,779,000	2,779,000	2,745,000	2,745,000
F	GROUND WALL SUPPORT	841,000	755,000	1,806,000	1,807,000	2,198,000	2,198,000
G	BRACING	483,000	389,000	490,000	417,000	479,000	417,000
H	EXCAVATION	961,000	919,000	930,000	887,000	901,000	860,000
I	CONST.PERM.STRUCT.	5,854,000	5,854,000	5,472,000	5,472,000	5,166,000	5,166,000
J	BACKFILL	125,000	119,000	117,000	123,000	113,000	113,000
K	RESTORATION	373,000	373,000	373,000	373,000	373,000	373,000
	SUB TOTAL - DIRECT	13,991,000	13,763,000	15,027,000	14,918,000	15,008,000	14,906,000
N	OVERHEAD (FIXED)	259,000	258,000	262,000	261,000	263,000	262,000
O	OVERHEAD (TIME REL)	2,101,000	2,101,000	2,266,000	2,266,000	2,347,000	2,347,000
P	PLANT (FIXED)	206,000	206,000	206,000	206,000	206,000	206,000
Q	PLANT (TIME REL)	143,000	143,000	154,000	154,000	160,000	160,000
	SUB TOTAL - INDIRECT	2,709,000	2,708,000	2,888,000	2,887,000	2,976,000	2,975,000
	TOTAL COST	16,700,000	16,471,000	17,915,000	17,805,000	17,984,000	17,881,000
	MARKUP	2,505,000	2,471,000	2,687,000	2,671,000	2,698,000	2,682,000
	BID PRICE	19,205,000	18,942,000	20,602,000	20,476,000	20,682,000	20,563,000

Table 56. ESTIMATE COMPARISON TABLES OF ACTIVITY CONSTRUCTION COSTS
FOUR LANE HIGHWAY TUNNEL - 30' DEPTH (Continued)

Site 2: Alluvial soils - permanently low water table

	GROUND SUPPORT	SOLD. PILES & LAGGING		CAST-IN-SLURRY (SPTC)		PRECAST CONC. PANELS	
	TYPE OF BRACING	INTERNAL	TIEBACK	INTERNAL	TIEBACK	INTERNAL	TIEBACK
	EST. DESIGNATION	2-1GU	2-1HU	2-1JU	2-1KU	2-1LU	2-1MU
A	TRAFFIC CONTROL	158,000	158,000	158,000	158,000	158,000	158,000
B	UTILITY WORK	1,643,000	1,643,000	2,144,000	2,144,000	2,144,000	2,144,000
C	PROTECT ADJ.STRUCT.	193,000	193,000	193,000	193,000	193,000	193,000
D	GROUNDWATER CONTROL	-	-	-	-	-	-
E	DECKING	2,778,000	2,778,000	2,779,000	2,779,000	2,745,000	2,743,000
F	GROUND WALL SUPPORT	841,000	755,000	1,806,000	1,807,000	2,198,000	2,198,000
G	BRACING	483,000	389,000	490,000	417,000	479,000	417,000
H	EXCAVATION	961,000	919,000	930,000	887,000	901,000	860,000
I	CONST.PERM.STRUCT.	4,870,000	4,870,000	4,720,000	4,720,000	4,414,000	4,414,000
J	BACKFILL	244,000	239,000	238,000	239,000	225,000	225,000
K	RESTORATION	373,000	373,000	373,000	373,000	373,000	373,000
	SUB TOTAL - DIRECT	12,544,000	12,317,000	13,831,000	13,717,000	13,830,000	13,725,000
N	OVERHEAD (FIXED)	261,000	262,000	265,000	264,000	266,000	266,000
O	OVERHEAD (TIME REL)	2,101,000	2,101,000	2,266,000	2,266,000	2,347,000	2,347,000
P	PLANT (FIXED)	206,000	206,000	206,000	206,000	206,000	206,000
Q	PLANT (TIME REL)	143,000	143,000	154,000	154,000	160,000	160,000
	SUB TOTAL - INDIRECT	2,711,000	2,712,000	2,891,000	2,890,000	2,979,000	2,979,000
	TOTAL COST	15,255,000	15,029,000	16,722,000	16,607,000	16,809,000	16,704,000
	MARKUP	2,288,000	2,254,000	2,508,000	2,491,000	2,521,000	2,506,000
	BID PRICE	17,543,000	17,283,000	19,230,000	19,098,000	19,330,000	19,210,000

Table 56. ESTIMATE COMPARISON TABLES OF ACTIVITY CONSTRUCTION COSTS
FOUR LANE HIGHWAY TUNNEL - 30' DEPTH (Continued)

Site 3: Alluvial soils - high water table, maintained during construction

GROUND SUPPORT		SOLD. PILES & LAGGING		CAST-IN-SLURRY (SPTC)		PRECAST CONC. PANELS	
TYPE OF BRACING		INTERNAL	TIEBACK	INTERNAL	TIEBACK	INTERNAL	TIEBACK
EST. DESIGNATION		-	-	3-1JT	3-1KT	3-1LT	3-1MT
A	TRAFFIC CONTROL			158,000	158,000	158,000	158,000
B	UTILITY WORK			2,144,000	2,144,000	2,144,000	2,144,000
C	PROTECT ADJ.STRUCT.			193,000	193,000	193,000	193,000
D	GROUNDWATER CONTROL			697,000	697,000	670,000	670,000
E	DECKING			2,779,000	2,779,000	2,745,000	2,745,000
F	GROUND WALL SUPPORT			1,824,000	1,824,000	2,337,000	2,337,000
G	BRACING	N.A.	N.A.	495,000	613,000	479,000	613,000
H	EXCAVATION			930,000	887,000	901,000	860,000
I	CONST.PERM.STRUCT.			5,472,000	5,472,000	5,166,000	5,166,000
J	BACKFILL			117,000	123,000	112,000	113,000
K	RESTORATION			373,000	373,000	373,000	373,000
SUB TOTAL - DIRECT				15,182,000	15,263,000	15,278,000	15,372,000
N	OVERHEAD (FIXED)			263,000	263,000	265,000	265,000
O	OVERHEAD (TIME REL)			2,266,000	2,266,000	2,347,000	2,347,000
P	PLANT (FIXED)			206,000	206,000	206,000	206,000
Q	PLANT (TIME REL)			154,000	154,000	160,000	160,000
SUB TOTAL - INDIRECT				2,889,000	2,889,000	2,978,000	2,978,000
TOTAL COST				18,071,000	18,152,000	18,256,000	18,350,000
MARKUP				2,711,000	2,723,000	2,738,000	2,753,000
BID PRICE				20,782,000	20,875,000	20,994,000	21,103,000

Table 56. ESTIMATE COMPARISON TABLES OF ACTIVITY CONSTRUCTION COSTS
FOUR LANE HIGHWAY TUNNEL - 30' DEPTH (Continued)

Site 4: Sand, silt & rock - high water table, maintained during construction

	GROUND SUPPORT	SOLD. PILES & LAGGING		CAST-IN-SLURRY (SPTC)		PRECAST CONC. PANELS	
	TYPE OF BRACING	INTERNAL	TIEBACK	INTERNAL	TIEBACK	INTERNAL	TIEBACK
	EST. DESIGNATION	-	-	4-1JT	4-1KT	4-1LT	4-1MT
A	TRAFFIC CONTROL			158,000	158,000	158,000	158,000
B	UTILITY WORK			2,144,000	2,144,000	2,144,000	2,144,000
C	PROTECT ADJ.STRUCT.			193,000	193,000	193,000	193,000
D	GROUNDWATER CONTROL			261,000	261,000	248,000	248,000
E	DECKING			2,779,000	2,779,000	2,745,000	2,745,000
F	GROUND WALL SUPPORT			2,450,000	2,450,000	3,126,000	3,126,000
G	BRACING	N.A.	N.A.	500,000	1,234,000	470,000	1,234,000
H	EXCAVATION			1,084,000	1,065,000	1,051,000	1,034,000
I	CONST.PERM.STRUCT.			5,472,000	5,472,000	5,166,000	5,166,000
J	BACKFILL			117,000	123,000	112,000	113,000
K	RESTORATION			373,000	373,000	373,000	373,000
	SUB TOTAL - DIRECT			15,531,000	16,252,000	15,786,000	16,534,000
N	OVERHEAD (FIXED)			265,000	269,000	267,000	272,000
O	OVERHEAD (TIME REL)			2,266,000	2,266,000	2,347,000	2,347,000
P	PLANT (FIXED)			206,000	206,000	206,000	206,000
Q	PLANT (TIME REL)			154,000	154,000	160,000	160,000
	SUB TOTAL - INDIRECT			2,891,000	2,895,000	2,980,000	2,985,000
	TOTAL COST			18,422,000	19,147,000	18,766,000	19,519,000
	MARKUP			2,763,000	2,872,000	2,815,000	2,928,000
	BID PRICE			21,185,000	22,019,000	21,581,000	22,447,000

Table 56. ESTIMATE COMPARISON TABLES OF ACTIVITY CONSTRUCTION COSTS
FOUR LANE HIGHWAY TUNNEL - 30' DEPTH (Continued)

Site 5: Clay soils - high water table, maintained during construction

GROUND SUPPORT	SOLD. PILES & LAGGING		CAST-IN-SLURRY (SPTC)		PRECAST CONC. PANELS	
TYPE OF BRACING	INTERNAL	TIEBACK	INTERNAL	TIEBACK	INTERNAL	TIEBACK
EST. DESIGNATION	-	-	5-1JT	-	5-1LT	-
A TRAFFIC CONTROL			160,000		160,000	
B UTILITY WORK			2,144,000		2,144,000	
C PROTECT ADJ.STRUCT.			193,000		193,000	
D GROUNDWATER CONTROL			297,000		285,000	
E DECKING			2,779,000		2,745,000	
F GROUND WALL SUPPORT			4,288,000		5,747,000	
G BRACING	N.A.	N.A.	805,000	N.A.	775,000	N.A.
H EXCAVATION			1,329,000		1,288,000	
I CONST.PERM.STRUCT.			5,472,000		5,166,000	
J BACKFILL			117,000		112,000	
K RESTORATION			373,000		373,000	
SUB TOTAL - DIRECT			17,957,000		18,988,000	
N OVERHEAD (FIXED)			279,000		287,000	
O OVERHEAD (TIME REL)			2,345,000		2,426,000	
P PLANT (FIXED)			206,000		206,000	
Q PLANT (TIME REL)			159,000		165,000	
SUB TOTAL - INDIRECT			2,989,000		3,084,000	
TOTAL COST			20,946,000		22,072,000	
MARKUP			3,142,000		3,311,000	
BID PRICE			24,088,000		25,383,000	

Table 57. ESTIMATE COMPARISON TABLES OF ACTIVITY CONSTRUCTION COSTS
FOUR LANE HIGHWAY TUNNEL - 50' DEPTH

Site 1: Alluvial soils - high water table, lowered during construction

	GROUND SUPPORT	SOLD. PILES & LAGGING		CAST-IN-SLURRY (SPTC)		PRECAST CONC. PANELS	
	TYPE OF BRACING	INTERNAL	TIEBACK	INTERNAL	TIEBACK	INTERNAL	TIEBACK
	EST. DESIGNATION	1-1GV	1-1HV	1-1JV	1-1KV	1-1LV	3-1MV
A	TRAFFIC CONTROL	163,000	163,000	163,000	163,000	163,000	163,000
B	UTILITY WORK	1,643,000	1,643,000	2,144,000	2,144,000	2,144,000	2,144,000
C	PROTECT ADJ.STRUCT.	1,419,000	1,419,000	193,000	193,000	193,000	193,000
D	GROUNDWATER CONTROL	864,000	864,000	864,000	864,000	835,000	835,000
E	DECKING	2,871,000	2,871,000	2,857,000	2,857,000	2,827,000	2,827,000
F	GROUND WALL SUPPORT	1,374,000	1,382,000	2,639,000	2,640,000	3,377,000	3,377,000
G	BRACING	1,169,000	1,325,000	1,383,000	1,361,000	1,326,000	1,361,000
H	EXCAVATION	1,474,000	1,347,000	1,410,000	1,286,000	1,366,000	1,247,000
I	CONST.PERM.STRUCT.	6,432,000	6,432,000	5,873,000	5,873,000	5,567,000	5,567,000
J	BACKFILL	884,000	782,000	844,000	756,000	811,000	709,000
K	RESTORATION	373,000	373,000	373,000	373,000	373,000	373,000
	SUB TOTAL - DIRECT	18,666,000	18,601,000	18,743,000	18,510,000	18,982,000	18,796,000
N	OVERHEAD (FIXED)	288,000	288,000	285,000	284,000	288,000	286,000
O	OVERHEAD (TIME REL)	2,339,000	2,339,000	2,506,000	2,506,000	2,587,000	2,587,000
P	PLANT (FIXED)	206,000	206,000	206,000	206,000	206,000	206,000
Q	PLANT (TIME REL)	159,000	159,000	170,000	170,000	176,000	176,000
	SUB TOTAL - INDIRECT	2,992,000	2,992,000	3,176,000	3,166,000	3,257,000	3,255,000
	TOTAL COST	21,658,000	21,593,000	21,910,000	21,676,000	22,239,000	22,051,000
	MARKUP	3,249,000	3,239,000	3,287,000	3,251,000	3,336,000	3,308,000
	BID PRICE	24,907,000	24,832,000	25,197,000	24,927,000	25,575,000	25,359,000

Table 57. ESTIMATE COMPARISON TABLES OF ACTIVITY CONSTRUCTION COSTS
FOUR LANE HIGHWAY TUNNEL - 50' DEPTH (Continued)

Site 2: Alluvial soils - permanently low water table

	GROUND SUPPORT	SOLD. PILES & LAGGING		CAST-IN-SLURRY (SPTC)		PRECAST CONC. PANELS	
	TYPE OF BRACING	INTERNAL	TIEBACK	INTERNAL	TIEBACK	INTERNAL	TIEBACK
	EST. DESIGNATION	2-1GW	2-1HW	2-1JW	2-1KW	2-1LW	2-1MW
A	TRAFFIC CONTROL	163,000	163,000	163,000	163,000	163,000	163,000
B	UTILITY WORK	1,643,000	1,643,000	2,144,000	2,144,000	2,144,000	2,144,000
C	PROTECT ADJ.STRUCT.	1,419,000	1,419,000	193,000	193,000	193,000	193,000
D	GROUNDWATER CONTROL	-	-	-	-	-	-
E	DECKING	2,852,000	2,852,000	2,857,000	2,857,000	2,827,000	2,827,000
F	GROUND WALL SUPPORT	1,374,000	1,382,000	2,639,000	2,640,000	3,377,000	3,377,000
G	BRACING	1,169,000	1,325,000	1,383,000	1,361,000	1,326,000	1,361,000
H	EXCAVATION	1,474,000	1,347,000	1,410,000	1,286,000	1,366,000	1,247,000
I	CONST.PERM.STRUCT.	5,623,000	5,623,000	5,311,000	5,311,000	5,005,000	5,005,000
J	BACKFILL	884,000	782,000	844,000	756,000	811,000	709,000
K	RESTORATION	373,000	373,000	373,000	373,000	373,000	373,000
	SUB TOTAL - DIRECT	16,974,000	16,909,000	17,317,000	17,084,000	17,585,000	17,399,000
N	OVERHEAD (FIXED)	284,000	284,000	284,000	283,000	286,000	287,000
O	OVERHEAD (TIME REL)	2,339,000	2,339,000	2,506,000	2,506,000	2,587,000	2,587,000
P	PLANT (FIXED)	206,000	206,000	206,000	206,000	206,000	206,000
Q	PLANT (TIME REL)	159,000	159,000	170,000	170,000	176,000	176,000
	SUB TOTAL - INDIRECT	2,988,000	2,988,000	3,166,000	3,165,000	3,255,000	3,256,000
	TOTAL COST	19,962,000	19,897,000	20,483,000	20,249,000	20,840,000	20,655,000
	MARKUP	2,994,000	2,985,000	3,072,000	3,038,000	3,126,000	3,098,000
	BID PRICE	22,956,000	22,882,000	23,555,000	23,287,000	23,966,000	23,753,000

Table 57. ESTIMATE COMPARISON TABLES OF ACTIVITY CONSTRUCTION COSTS
FOUR LANE HIGHWAY TUNNEL - 50' DEPTH (Continued)

Site 3: Alluvial soils - high water table, maintained during construction

GROUND SUPPORT	SOLD. PILES & LAGGING		CAST-IN-SLURRY (SPTC)		PRECAST CONC. PANELS	
TYPE OF BRACING	INTERNAL	TIEBACK	INTERNAL	TIEBACK	INTERNAL	TIEBACK
EST. DESIGNATION	-	-	3-1JV	3-1KV	3-1LV	3-1MV
A TRAFFIC CONTROL			163,000	163,000	163,000	163,000
B UTILITY WORK			2,144,000	2,144,000	2,144,000	2,144,000
C PROTECT ADJ.STRUCT.			193,000	193,000	193,000	193,000
D GROUNDWATER CONTROL			920,000	920,000	889,000	889,000
E DECKING			2,857,000	2,857,000	2,828,000	2,827,000
F GROUND WALL SUPPORT			3,122,000	3,199,000	3,902,000	3,902,000
G BRACING	N.A.	N.A.	1,494,000	1,994,000	1,437,000	1,994,000
H EXCAVATION			1,410,000	1,286,000	1,366,000	1,247,000
I CONST.PERM.STRUCT.			5,873,000	5,873,000	5,567,000	5,567,000
J BACKFILL			844,000	756,000	811,000	709,000
K RESTORATION			373,000	373,000	373,000	373,000
SUB TOTAL - DIRECT			19,393,000	19,758,000	19,673,000	20,008,000
N OVERHEAD (FIXED)			289,000	291,000	292,000	293,000
O OVERHEAD (TIME REL)			2,506,000	2,506,000	2,587,000	2,587,000
P PLANT (FIXED)			206,000	206,000	206,000	206,000
Q PLANT (TIME REL)			170,000	170,000	176,000	176,000
SUB TOTAL - INDIRECT			3,171,000	3,173,000	3,261,000	3,262,000
TOTAL COST			22,564,000	22,931,000	22,934,000	23,270,000
MARKUP			3,385,000	3,440,000	3,440,000	3,491,000
BID PRICE			25,949,000	26,371,000	26,374,000	26,761,000

Table 57. ESTIMATE COMPARISON TABLES OF ACTIVITY CONSTRUCTION COSTS
FOUR LANE HIGHWAY TUNNEL - 50' DEPTH (Continued)

Site 4: Sand, silt & rock - high water table, maintained during construction

GROUND SUPPORT	SOLD. PILES & LAGGING		CAST-IN-SLURRY (SPTC)		PRECAST CONC. PANELS	
TYPE OF BRACING	INTERNAL	TIEBACK	INTERNAL	TIEBACK	INTERNAL	TIEBACK
EST. DESIGNATION	-	-	4-1JV	4-1KV	4-1LV	4-1MV
A TRAFFIC CONTROL			165,000	165,000	165,000	165,000
B UTILITY WORK			2,144,000	2,144,000	2,144,000	2,144,000
C PROTECT ADJ.STRUCT.			193,000	193,000	193,000	193,000
D GROUNDWATER CONTROL			326,000	326,000	313,000	313,000
E DECKING			2,857,000	2,857,000	2,828,000	2,828,000
F GROUND WALL SUPPORT			3,087,000	3,087,000	4,017,000	4,017,000
G BRACING	N.A.	N.A.	1,608,000	3,433,000	1,558,000	3,433,000
H EXCAVATION			1,860,000	1,762,000	1,803,000	1,709,000
I CONST.PERM.STRUCT.			5,873,000	5,873,000	5,567,000	5,567,000
J BACKFILL			844,000	756,000	811,000	709,000
K RESTORATION			373,000	373,000	373,000	373,000
SUB TOTAL - DIRECT			19,330,000	20,969,000	19,772,000	21,451,000
N OVERHEAD (FIXED)			289,000	299,000	293,000	302,000
O OVERHEAD (TIME REL)			2,586,000	2,586,000	2,667,000	2,667,000
P PLANT (FIXED)			206,000	206,000	206,000	206,000
Q PLANT (TIME REL)			175,000	175,000	181,000	181,000
SUB TOTAL - INDIRECT			3,256,000	3,266,000	3,347,000	3,356,000
TOTAL COST			22,586,000	24,235,000	23,119,000	24,807,000
MARKUP			3,388,000	3,635,000	3,468,000	3,721,000
BID PRICE			25,974,000	27,870,000	26,587,000	28,528,000

Table 57. ESTIMATE COMPARISON TABLES OF ACTIVITY CONSTRUCTION COSTS
FOUR LANE HIGHWAY TUNNEL - 50' DEPTH (Continued)

Site 5: Clay soils - high water table, maintained during construction

	GROUND SUPPORT	SOLD. PILES & LAGGING		CAST-IN-SLURRY (SPTC)		PRECAST CONC. PANELS	
	TYPE OF BRACING	INTERNAL	TIEBACK	INTERNAL	TIEBACK	INTERNAL	TIEBACK
	EST. DESIGNATION	-	-	5-1JV	-	5-1LV	-
A	TRAFFIC CONTROL			166,000		166,000	
B	UTILITY WORK			2,144,000		2,144,000	
C	PROTECT ADJ.STRUCT.			193,000		193,000	
D	GROUNDWATER CONTROL			359,000		346,000	
E	DECKING			2,857,000		2,827,000	
F	GROUND WALL SUPPORT			5,096,000		5,959,000	
G	BRACING	N.A.	N.A.	2,958,000	N.A.	2,869,000	N.A.
H	EXCAVATION			2,105,000		2,040,000	
I	CONST.PERM.STRUCT.			5,873,000		5,567,000	
J	BACKFILL			844,000		811,000	
K	RESTORATION			373,000		373,000	
	SUB TOTAL - DIRECT			22,968,000		23,295,000	
N	OVERHEAD (FIXED)			310,000		314,000	
O	OVERHEAD (TIME REL)			2,666,000		2,747,000	
P	PLANT (FIXED)			206,000		206,000	
Q	PLANT (TIME REL)			180,000		186,000	
	SUB TOTAL - INDIRECT			3,362,000		3,453,000	
	TOTAL COST			26,330,000		26,748,000	
	MARKUP			3,950,000		4,012,000	
	BID PRICE			30,280,000		30,760,000	

Table 58. ESTIMATE COMPARISON TABLES OF ACTIVITY CONSTRUCTION COSTS
FOUR LANE HIGHWAY TUNNEL - 70' DEPTH

Site 1: Alluvial soils - high water table, lowered during construction

	GROUND SUPPORT	SOLD. PILES & LAGGING		CAST-IN-SLURRY (SPTC)		PRECAST CONC. PANELS	
	TYPE OF BRACING	INTERNAL	TIEBACK	INTERNAL	TIEBACK	INTERNAL	TIEBACK
	EST. DESIGNATION	1-1GY	1-1HY	1-1JY	1-1KY	1-1LY	1-1MY
A	TRAFFIC CONTROL	168,000	168,000	168,000	168,000	168,000	168,000
B	UTILITY WORK	1,643,000	1,643,000	2,144,000	2,144,000	2,144,000	2,144,000
C	PROTECT ADJ.STRUCT.	2,633,000	2,633,000	193,000	193,000	193,000	193,000
D	GROUNDWATER CONTROL	1,069,000	1,069,000	1,069,000	1,069,000	1,037,000	1,037,000
E	DECKING	2,946,000	2,946,000	2,914,000	2,914,000	2,894,000	2,894,000
F	GROUND WALL SUPPORT	1,914,000	1,985,000	3,822,000	3,607,000	5,181,000	5,181,000
G	BRACING	2,516,000	2,713,000	3,052,000	3,495,000	2,964,000	3,515,000
H	EXCAVATION	2,062,000	1,790,000	1,943,000	1,686,000	1,882,000	1,634,000
I	CONST.PERM.STRUCT.	7,838,000	8,157,000	7,047,000	7,047,000	6,741,000	6,741,000
J	BACKFILL	1,455,000	1,249,000	1,371,000	1,197,000	1,328,000	1,140,000
K	RESTORATION	373,000	373,000	373,000	373,000	373,000	373,000
	SUB TOTAL - DIRECT	24,617,000	24,726,000	24,096,000	23,893,000	26,905,000	25,020,000
N	OVERHEAD (FIXED)	324,000	325,000	317,000	316,000	323,000	324,000
O	OVERHEAD (TIME REL)	2,580,000	2,580,000	2,747,000	2,747,000	2,828,000	2,828,000
P	PLANT (FIXED)	206,000	206,000	206,000	206,000	206,000	206,000
Q	PLANT (TIME REL)	174,000	174,000	185,000	185,000	191,000	191,000
	SUB TOTAL - INDIRECT	3,284,000	3,285,000	3,455,000	3,454,000	3,548,000	3,549,000
	TOTAL COST	27,901,000	28,011,000	27,551,000	27,347,000	28,453,000	28,569,000
	MARKUP	4,185,000	4,202,000	4,133,000	4,102,000	4,268,000	4,285,000
	BID PRICE	32,086,000	32,213,000	31,684,000	31,449,000	32,721,000	32,854,000

Table 58. ESTIMATE COMPARISON TABLES OF ACTIVITY CONSTRUCTION COSTS FOUR LANE HIGHWAY TUNNEL - 70' DEPTH (Continued)

Site 2: Alluvial soils - permanently low water table

	GROUND SUPPORT	SOLD. PILES & LAGGING		CAST-IN-SLURRY (SPTC)		PRECAST CONC. PANELS	
	TYPE OF BRACING	INTERNAL	TIEBACK	INTERNAL	TIEBACK	INTERNAL	TIEBACK
	EST. DESIGNATION	2-1GZ	2-1HZ	2-1JZ	2-1KZ	2-1LZ	2-1MZ
A	TRAFFIC CONTROL	168,000	168,000	168,000	168,000	168,000	168,000
B	UTILITY WORK	1,643,000	1,643,000	2,144,000	2,144,000	2,144,000	2,144,000
C	PROTECT ADJ.STRUCT.	2,633,000	2,633,000	193,000	193,000	193,000	193,000
D	GROUNDWATER CONTROL	-	-	-	-	-	-
E	DECKING	2,928,000	2,928,000	2,914,000	2,914,000	2,894,000	2,894,000
F	GROUND WALL SUPPORT	1,914,000	1,985,000	3,822,000	3,607,000	5,181,000	5,181,000
G	BRACING	2,516,000	2,713,000	3,052,000	3,495,000	2,964,000	3,515,000
H	EXCAVATION	2,062,000	1,790,000	1,943,000	1,686,000	1,882,000	1,634,000
I	CONST.PERM.STRUCT.	7,201,000	7,520,000	6,675,000	6,675,000	6,369,000	6,369,000
J	BACKFILL	1,455,000	1,249,000	1,371,000	1,197,000	1,328,000	1,140,000
K	RESTORATION	373,000	373,000	373,000	373,000	373,000	373,000
	SUB TOTAL - DIRECT	22,893,000	23,002,000	22,655,000	22,452,000	23,496,000	23,611,000
N	OVERHEAD (FIXED)	315,000	315,000	312,000	311,000	317,000	319,000
O	OVERHEAD (TIME REL)	2,580,000	2,580,000	2,747,000	2,747,000	2,828,000	2,828,000
P	PLANT (FIXED)	206,000	206,000	206,000	206,000	206,000	206,000
Q	PLANT (TIME REL)	174,000	174,000	185,000	185,000	191,000	191,000
	SUB TOTAL - INDIRECT	3,275,000	3,275,000	3,450,000	3,449,000	3,542,000	3,544,000
	TOTAL COST	26,168,000	26,277,000	26,105,000	25,901,000	27,038,000	27,155,000
	MARKUP	3,925,000	3,942,000	3,916,000	3,885,000	4,056,000	4,073,000
	BID PRICE	30,093,000	30,219,000	30,021,000	29,786,000	31,094,000	31,228,000

Table 58. ESTIMATE COMPARISON TABLES OF ACTIVITY CONSTRUCTION COSTS FOUR LANE HIGHWAY TUNNEL - 70' DEPTH (Continued)

Site 3: Alluvial soils - high water table, maintained during construction

	GROUND SUPPORT	SOLD. PILES & LAGGING		CAST-IN-SLURRY (SPTC)		PRECAST CONC. PANELS	
	TYPE OF BRACING	INTERNAL	TIEBACK	INTERNAL	TIEBACK	INTERNAL	TIEBACK
	EST. DESIGNATION	-	-	3-1JY	3-1KY	3-1LY	3-1MY
A	TRAFFIC CONTROL			168,000	168,000	168,000	168,000
B	UTILITY WORK			2,144,000	2,144,000	2,144,000	2,144,000
C	PROTECT ADJ.STRUCT.			193,000	193,000	193,000	193,000
D	GROUNDWATER CONTROL			1,091,000	1,091,000	1,059,000	1,059,000
E	DECKING			2,914,000	2,914,000	2,894,000	2,894,000
F	GROUND WALL SUPPORT			5,019,000	4,485,000	5,996,000	5,996,000
G	BRACING	N.A.	N.A.	3,475,000	4,366,000	3,377,000	4,366,000
H	EXCAVATION			1,943,000	1,686,000	1,882,000	1,634,000
I	CONST.PERM.STRUCT.			7,047,000	7,378,000	6,741,000	7,072,000
J	BACKFILL			1,371,000	1,197,000	1,328,000	1,140,000
K	RESTORATION			373,000	373,000	373,000	373,000
	SUB TOTAL - DIRECT			25,738,000	25,995,000	26,155,000	27,039,000
N	OVERHEAD (FIXED)			327,000	328,000	331,000	336,000
O	OVERHEAD (TIME REL)			2,747,000	2,747,000	2,828,000	2,828,000
P	PLANT (FIXED)			206,000	206,000	206,000	206,000
Q	PLANT (TIME REL)			185,000	185,000	191,000	191,000
	SUB TOTAL - INDIRECT			3,465,000	3,466,000	3,556,000	3,561,000
	TOTAL COST			29,203,000	29,461,000	29,711,000	30,600,000
	MARKUP			4,380,000	4,491,000	4,457,000	4,590,000
	BID PRICE			33,583,000	33,880,000	34,168,000	35,190,000

Table 58. ESTIMATE COMPARISON TABLES OF ACTIVITY CONSTRUCTION COSTS
FOUR LANE HIGHWAY TUNNEL - 70' DEPTH (Continued)

Site 4: Sand, silt & rock - high water table, maintained during construction

	GROUND SUPPORT	SOLD. PILES & LAGGING		CAST-IN-SLURRY (SPTC)		PRECAST CONC. PANELS	
	TYPE OF BRACING	INTERNAL	TIEBACK	INTERNAL	TIEBACK	INTERNAL	TIEBACK
	EST. DESIGNATION	-	-	4-1JY	4-1KY	4-1LY	4-1MY
A	TRAFFIC CONTROL			171,000	171,000	173,000	173,000
B	UTILITY WORK			2,144,000	2,144,000	2,144,000	2,144,000
C	PROTECT ADJ.STRUCT.			193,000	193,000	193,000	193,000
D	GROUNDWATER CONTROL			376,000	376,000	364,000	364,000
E	DECKING			3,230,000	3,230,000	3,298,000	3,298,000
F	GROUND WALL SUPPORT			3,461,000	3,240,000	5,025,000	5,025,000
G	BRACING	N.A.	N.A.	2,193,000	4,611,000	2,192,000	4,611,000
H	EXCAVATION			2,961,000	2,824,000	2,961,000	2,824,000
I	CONST.PERM.STRUCT.			7,636,000	7,967,000	7,428,000	7,428,000
J	BACKFILL			1,539,000	1,321,000	1,539,000	1,321,000
K	RESTORATION			373,000	373,000	373,000	373,000
	SUB TOTAL - DIRECT			24,277,000	26,450,000	25,690,000	27,754,000
N	OVERHEAD (FIXED)			319,000	332,000	327,000	339,000
O	OVERHEAD (TIME REL)			2,914,000	2,914,000	2,996,000	2,996,000
P	PLANT (FIXED)			206,000	206,000	206,000	206,000
Q	PLANT (TIME REL)			196,000	196,000	202,000	202,000
	SUB TOTAL - INDIRECT			3,635,000	3,648,000	3,731,000	3,743,000
	TOTAL COST			27,912,000	30,098,000	29,421,000	31,497,000
	MARKUP			4,187,000	4,515,000	4,413,000	4,725,000
	BID PRICE			32,099,000	34,613,000	33,834,000	36,222,000

Table 58. ESTIMATE COMPARISON TABLES OF ACTIVITY CONSTRUCTION COSTS
FOUR LANE HIGHWAY TUNNEL - 70' DEPTH (Continued)

Site 5: Clay soils - high water table, maintained during construction

GROUND SUPPORT	SOLD. PILES & LAGGING		CAST-IN-SLURRY (SPTC)		PRECAST CONC. PANELS	
TYPE OF BRACING	INTERNAL	TIEBACK	INTERNAL	TIEBACK	INTERNAL	TIEBACK
EST. DESIGNATION	-	-	5-1JY	-	5-1LY	-
A TRAFFIC CONTROL	N.A.	N.A.	173,000	N.A.	173,000	N.A.
B UTILITY WORK			2,144,000		2,144,000	
C PROTECT ADJ.STRUCT.			193,000		193,000	
D GROUNDWATER CONTROL			424,000		411,000	
E DECKING			2,914,000		2,894,000	
F GROUND WALL SUPPORT			5,310,000		6,378,000	
G BRACING			3,965,000		3,852,000	
H EXCAVATION			2,930,000		2,839,000	
I CONST.PERM.STRUCT.			7,047,000		6,741,000	
J BACKFILL			1,371,000		1,328,000	
K RESTORATION			373,000		373,000	
SUB TOTAL - DIRECT			26,862,000		27,326,000	
N OVERHEAD (FIXED)			335,000		339,000	
O OVERHEAD (TIME REL)			2,999,000		3,069,000	
P PLANT (FIXED)			206,000		206,000	
Q PLANT (TIME REL)			202,000		207,000	
SUB TOTAL - INDIRECT			3,742,000		3,821,000	
TOTAL COST			30,604,000		31,147,000	
MARKUP			4,591,000		4,672,000	
BID PRICE			35,195,000		35,819,000	

Table 59. ESTIMATE COMPARISON TABLES OF ACTIVITY CONSTRUCTION COSTS
RAPID TRANSIT STATION - 50' DEPTH

Site 1: Alluvial soils - high water table, lowered during construction

	GROUND SUPPORT	SOLD. PILES & LAGGING		CAST-IN-SLURRY (SPTC)		PRECAST CONC. PANELS	
	TYPE OF BRACING	INTERNAL	TIEBACK	INTERNAL	TIEBACK	INTERNAL	TIEBACK
	EST. DESIGNATION	1-2GV	1-2HV	1-2JV	1-2KV	1-2LV	1-2MV
A	TRAFFIC CONTROL	92,000	92,000	92,000	92,000	92,000	92,000
B	UTILITY WORK	563,000	563,000	689,000	689,000	689,000	689,000
C	PROTECT ADJ.STRUCT.	512,000	512,000	69,000	69,000	69,000	69,000
D	GROUNDWATER CONTROL	857,000	857,000	857,000	857,000	773,000	773,000
E	DECKING	974,000	974,000	941,000	941,000	941,000	941,000
F	GROUND WALL SUPPORT	527,000	649,000	1,170,000	1,147,000	1,505,000	1,503,000
G	BRACING	1,133,000	481,000	1,144,000	540,000	1,146,000	527,000
H	EXCAVATION	497,000	453,000	458,000	418,000	446,000	401,000
I	CONST.PERM.STRUCT.	3,294,000	4,079,000	2,836,000	3,621,000	2,419,000	3,204,000
J	BACKFILL	149,000	147,000	137,000	135,000	132,000	131,000
K	RESTORATION	134,000	134,000	134,000	134,000	134,000	134,000
	SUB TOTAL - DIRECT	8,732,000	8,941,000	8,527,000	8,643,000	8,346,000	8,464,000
N	OVERHEAD (FIXED)	353,000	353,000	352,000	351,000	352,000	355,000
O	OVERHEAD (TIME REL)	2,901,000	2,901,000	3,095,000	3,095,000	2,804,000	2,804,000
P	PLANT (FIXED)	290,000	290,000	290,000	290,000	290,000	290,000
Q	PLANT (TIME REL)	218,000	218,000	231,000	231,000	211,000	211,000
	SUB TOTAL - INDIRECT	3,762,000	3,762,000	3,968,000	3,967,000	3,657,000	3,660,000
	TOTAL COST	12,494,000	12,703,000	12,495,000	12,610,000	12,003,000	12,124,000
	MARKUP	1,874,000	1,905,000	1,874,000	1,892,000	1,800,000	1,819,000
	BID PRICE	14,368,000	14,608,000	14,369,000	14,502,000	13,803,000	13,943,000

Table 59. ESTIMATE COMPARISON TABLES OF ACTIVITY CONSTRUCTION COSTS RAPID TRANSIT STATION - 50' DEPTH (Continued)

Site 2: Alluvial soils - permanently low water table

	GROUND SUPPORT	SOLD. PILES & LAGGING		CAST-IN-SLURRY (SPTC)		PRECAST CONC. PANELS	
	TYPE OF BRACING	INTERNAL	TIEBACK	INTERNAL	TIEBACK	INTERNAL	TIEBACK
	EST. DESIGNATION	2-2GW	2-2HW	2-2JW	2-2KW	2-2LW	2-2MW
A	TRAFFIC CONTROL	92,000	92,000	92,000	92,000	92,000	92,000
B	UTILITY WORK	563,000	563,000	689,000	689,000	689,000	689,000
C	PROTECT ADJ.STRUCT.	512,000	512,000	69,000	69,000	69,000	69,000
D	GROUNDWATER CONTROL	-	-	-	-	-	-
E	DECKING	955,000	955,000	941,000	941,000	941,000	941,000
F	GROUND WALL SUPPORT	527,000	649,000	1,170,000	1,147,000	1,505,000	1,503,000
G	BRACING	1,133,000	481,000	1,144,000	540,000	1,146,000	527,000
H	EXCAVATION	497,000	453,000	458,000	418,000	446,000	401,000
I	CONST.PERM.STRUCT.	2,822,000	3,607,000	2,653,000	3,438,000	2,236,000	3,021,000
J	BACKFILL	149,000	147,000	137,000	135,000	132,000	131,000
K	RESTORATION	134,000	134,000	134,000	134,000	134,000	134,000
	SUB TOTAL - DIRECT	7,384,000	7,593,000	7,487,000	7,603,000	7,390,000	7,508,000
N	OVERHEAD (FIXED)	349,000	349,000	350,000	348,000	349,000	353,000
O	OVERHEAD (TIME REL)	2,901,000	2,901,000	3,095,000	3,095,000	2,804,000	2,804,000
P	PLANT (FIXED)	290,000	290,000	290,000	290,000	290,000	290,000
Q	PLANT (TIME REL)	218,000	218,000	231,000	231,000	211,000	211,000
	SUB TOTAL - INDIRECT	3,758,000	3,758,000	3,966,000	3,964,000	3,654,000	3,658,000
	TOTAL COST	11,142,000	11,351,000	11,453,000	11,567,000	11,044,000	11,166,000
	MARKUP	1,671,000	1,703,000	1,718,000	1,735,000	1,657,000	1,675,000
	BID PRICE	12,813,000	13,054,000	13,171,000	13,302,000	12,701,000	12,841,000

Table 59. ESTIMATE COMPARISON TABLES OF ACTIVITY CONSTRUCTION COSTS
RAPID TRANSIT STATION - 50' DEPTH (Continued)

Site 3: Alluvial soils - high water table, maintained during construction

GROUND SUPPORT	SOLD. PILES & LAGGING		CAST-IN-SLURRY (SPTC)		PRECAST CONC. PANELS	
TYPE OF BRACING	INTERNAL	TIEBACK	INTERNAL	TIEBACK	INTERNAL	TIEBACK
EST. DESIGNATION	-	-	3-2JV	3-2KV	3-2LV	3-2MV
A TRAFFIC CONTROL			92,000	92,000	92,000	92,000
B UTILITY WORK			689,000	689,000	689,000	689,000
C PROTECT ADJ.STRUCT.			69,000	69,000	69,000	69,000
D GROUNDWATER CONTROL			862,000	862,000	772,000	772,000
E DECKING			941,000	941,000	941,000	941,000
F GROUND WALL SUPPORT			1,306,000	1,309,000	1,700,000	1,700,000
G BRACING	N.A.	N.A.	1,178,000	781,000	1,180,000	772,000
H EXCAVATION			458,000	418,000	446,000	401,000
I CONST.PERM.STRUCT.			2,836,000	3,621,000	2,419,000	3,204,000
J BACKFILL			137,000	135,000	132,000	131,000
K RESTORATION			134,000	134,000	134,000	134,000
SUB TOTAL - DIRECT			8,702,000	9,051,000	8,574,000	8,905,000
N OVERHEAD (FIXED)			353,000	353,000	354,000	358,000
O OVERHEAD (TIME REL)			3,095,000	3,095,000	2,804,000	2,804,000
P PLANT (FIXED)			290,000	290,000	290,000	290,000
Q PLANT (TIME REL)			231,000	231,000	211,000	211,000
SUB TOTAL - INDIRECT			3,969,000	3,969,000	3,659,000	3,663,000
TOTAL COST			12,671,000	13,020,000	12,233,000	12,568,000
MARKUP			1,901,000	1,953,000	1,835,000	1,885,000
BID PRICE			14,572,000	14,973,000	14,068,000	14,453,000

Table 59. ESTIMATE COMPARISON TABLES OF ACTIVITY CONSTRUCTION COSTS
RAPID TRANSIT STATION - 50' DEPTH (Continued)

Site 4: Sand, silt & rock - high water table, maintained during construction

	GROUND SUPPORT	SOLD. PILES & LAGGING		CAST-IN-SLURRY (SPTC)		PRECAST CONC. PANELS	
	TYPE OF BRACING	INTERNAL	TIEBACK	INTERNAL	TIEBACK	INTERNAL	TIEBACK
	EST. DESIGNATION	-	-	4-2JV	4-2KV	4-2LV	4-2MV
A	TRAFFIC CONTROL			94,000	94,000	94,000	94,000
B	UTILITY WORK			689,000	689,000	689,000	689,000
C	PROTECT ADJ.STRUCT.			69,000	69,000	69,000	69,000
D	GROUNDWATER CONTROL			360,000	360,000	324,000	324,000
E	DECKING			941,000	941,000	941,000	941,000
F	GROUND WALL SUPPORT			1,328,000	1,328,000	1,743,000	1,743,000
G	BRACING	N.A.	N.A.	1,205,000	1,307,000	1,199,000	1,307,000
H	EXCAVATION			605,000	573,000	587,000	550,000
I	CONST.PERM.STRUCT.			2,836,000	3,621,000	2,419,000	3,204,000
J	BACKFILL			137,000	135,000	132,000	131,000
K	RESTORATION			134,000	134,000	134,000	134,000
	SUB TOTAL - DIRECT			8,398,000	9,251,000	8,331,000	9,186,000
N	OVERHEAD (FIXED)			352,000	355,000	353,000	360,000
O	OVERHEAD (TIME REL)			3,185,000	3,185,000	2,895,000	2,895,000
P	PLANT (FIXED)			290,000	290,000	290,000	290,000
Q	PLANT (TIME REL)			237,000	237,000	217,000	217,000
	SUB TOTAL - INDIRECT			4,064,000	4,067,000	3,755,000	3,762,000
	TOTAL COST			12,462,000	13,318,000	12,086,000	12,948,000
	MARKUP			1,869,000	1,998,000	1,813,000	1,942,000
	BID PRICE			14,331,000	15,316,000	13,899,000	14,890,000

Table 59. ESTIMATE COMPARISON TABLES OF ACTIVITY CONSTRUCTION COSTS
RAPID TRANSIT STATION - 50' DEPTH (Continued)

Site 5: Clay soils - high water table, maintained during construction

	GROUND SUPPORT	SOLD. PILES & LAGGING		CAST-IN-SLURRY (SPTC)		PRECAST CONC. PANELS	
	TYPE OF BRACING	INTERNAL	TIEBACK	INTERNAL	TIEBACK	INTERNAL	TIEBACK
	EST. DESIGNATION	-	-	5-2JV	-	5-2LV	-
A	TRAFFIC CONTROL			95,000		95,000	
B	UTILITY WORK			689,000		689,000	
C	PROTECT ADJ.STRUCT.			69,000		69,000	
D	GROUNDWATER CONTROL			387,000		351,000	
E	DECKING			941,000		941,000	
F	GROUND WALL SUPPORT			2,052,000		2,508,000	
G	BRACING	N.A.	N.A.	1,269,000	N.A.	1,260,000	N.A.
H	EXCAVATION			684,000		663,000	
I	CONST.PERM.STRUCT.			2,836,000		2,419,000	
J	BACKFILL			137,000		132,000	
K	RESTORATION			134,000		134,000	
	SUB TOTAL - DIRECT			9,293,000		9,261,000	
N	OVERHEAD (FIXED)			358,000		359,000	
O	OVERHEAD (TIME REL)			3,275,000		2,983,000	
P	PLANT (FIXED)			290,000		290,000	
Q	PLANT (TIME REL)			244,000		224,000	
	SUB TOTAL - INDIRECT			4,167,000		3,856,000	
	TOTAL COST			13,460,000		13,117,000	
	MARKUP			2,019,000		1,968,000	
	BID PRICE			15,479,000		15,085,000	

Table 60. ESTIMATE COMPARISON TABLES OF ACTIVITY CONSTRUCTION COSTS
RAPID TRANSIT STATION - 70' DEPTH

Site 1: Alluvial soils - high water table, lowered during construction

	GROUND SUPPORT	SOLD. PILES & LAGGING		CAST-IN-SLURRY (SPTC)		PRECAST CONC. PANELS	
	TYPE OF BRACING	INTERNAL	TIEBACK	INTERNAL	TIEBACK	INTERNAL	TIEBACK
	EST. DESIGNATION	1-2GY	1-2HY	1-2JY	1-2KY	1-2LY	1-2MY
A	TRAFFIC CONTROL	97,000	97,000	97,000	97,000	97,000	97,000
B	UTILITY WORK	563,000	563,000	689,000	689,000	689,000	689,000
C	PROTECT ADJ.STRUCT.	950,000	950,000	69,000	69,000	69,000	69,000
D	GROUNDWATER CONTROL	1,085,000	1,085,000	1,085,000	1,085,000	996,000	996,000
E	DECKING	995,000	995,000	962,000	962,000	962,000	962,000
F	GROUND WALL SUPPORT	734,000	762,000	1,659,000	1,560,000	2,267,000	2,267,000
G	BRACING	1,623,000	1,032,000	1,698,000	1,307,000	1,699,000	1,360,000
H	EXCAVATION	683,000	593,000	630,000	547,000	613,000	526,000
I	CONST.PERM.STRUCT.	3,492,000	4,483,000	3,018,000	4,009,000	2,602,000	3,593,000
J	BACKFILL	363,000	315,000	335,000	290,000	324,000	281,000
K	RESTORATION	134,000	134,000	134,000	134,000	134,000	134,000
	SUB TOTAL - DIRECT	10,719,000	11,009,000	10,376,000	10,749,000	10,452,000	10,974,000
N	OVERHEAD (FIXED)	366,000	367,000	365,000	365,000	366,000	371,000
O	OVERHEAD (TIME REL)	3,170,000	3,170,000	3,365,000	3,365,000	3,073,000	3,073,000
P	PLANT (FIXED)	290,000	290,000	290,000	290,000	290,000	290,000
Q	PLANT (TIME REL)	237,000	237,000	250,000	250,000	230,000	230,000
	SUB TOTAL - INDIRECT	4,063,000	4,064,000	4,270,000	4,270,000	3,959,000	3,964,000
	TOTAL COST	14,782,000	15,073,000	14,646,000	15,019,000	14,411,000	14,938,000
	MARKUP	2,217,000	2,261,000	2,197,000	2,253,000	2,162,000	2,241,000
	BID PRICE	16,999,000	17,334,000	16,843,000	17,272,000	16,573,000	17,179,000

Table 60. ESTIMATE COMPARISON TABLES OF ACTIVITY CONSTRUCTION COSTS
RAPID TRANSIT STATION - 70' DEPTH (Continued)

Site 2: Alluvial soils - permanently low water table

	GROUND SUPPORT	SOLD. PILES & LAGGING		CAST-IN-SLURRY (SPTC)		PRECAST CONC. PANELS	
	TYPE OF BRACING	INTERNAL	TIEBACK	INTERNAL	TIEBACK	INTERNAL	TIEBACK
	EST. DESIGNATION	2-2GZ	2-2HZ	2-2JZ	2-2KZ	2-2LZ	2-2MZ
A	TRAFFIC CONTROL	97,000	97,000	97,000	97,000	97,000	97,000
B	UTILITY WORK	563,000	563,000	689,000	689,000	689,000	689,000
C	PROTECT ADJ.STRUCT.	950,000	950,000	69,000	69,000	69,000	69,000
D	GROUNDWATER CONTROL	-	-	-	-	-	-
E	DECKING	982,000	982,000	962,000	962,000	962,000	962,000
F	GROUND WALL SUPPORT	734,000	762,000	1,659,000	1,560,000	2,267,000	2,267,000
G	BRACING	1,623,000	1,032,000	1,698,000	1,307,000	1,699,000	1,360,000
H	EXCAVATION	683,000	593,000	630,000	547,000	613,000	526,000
I	CONST.PERM.STRUCT.	3,029,000	4,020,000	2,775,000	3,766,000	2,358,000	3,349,000
J	BACKFILL	363,000	315,000	335,000	290,000	324,000	281,000
K	RESTORATION	134,000	134,000	134,000	134,000	134,000	134,000
	SUB TOTAL - DIRECT	9,158,000	9,448,000	9,048,000	9,421,000	9,212,000	9,734,000
N	OVERHEAD (FIXED)	358,000	359,000	358,000	359,000	360,000	366,000
O	OVERHEAD (TIME REL)	3,170,000	3,170,000	3,365,000	3,365,000	3,073,000	3,073,000
P	PLANT (FIXED)	290,000	290,000	290,000	290,000	290,000	290,000
Q	PLANT (TIME REL)	237,000	237,000	250,000	250,000	230,000	230,000
	SUB TOTAL - INDIRECT	4,055,000	4,056,000	4,263,000	4,264,000	3,953,000	3,959,000
	TOTAL COST	13,213,000	13,504,000	13,311,000	13,685,000	13,165,000	13,693,000
	MARKUP	1,982,000	2,026,000	1,997,000	2,053,000	1,975,000	2,054,000
	BID PRICE	15,195,000	15,530,000	15,308,000	15,738,000	15,140,000	15,747,000

Table 60. ESTIMATE COMPARISON TABLES OF ACTIVITY CONSTRUCTION COSTS
RAPID TRANSIT STATION - 70' DEPTH (Continued)

Site 3: Alluvial soils - high water table, maintained during construction

	GROUND SUPPORT	SOLD. PILES & LAGGING		CAST-IN-SLURRY (SPTC)		PRECAST CONC. PANELS	
	TYPE OF BRACING	INTERNAL	TIEBACK	INTERNAL	TIEBACK	INTERNAL	TIEBACK
	EST. DESIGNATION	-	-	3-2JY	3-2KY	3-2LY	3-2MY
A	TRAFFIC CONTROL			97,000	97,000	97,000	97,000
B	UTILITY WORK			689,000	689,000	689,000	689,000
C	PROTECT ADJ.STRUCT.			69,000	69,000	69,000	69,000
D	GROUNDWATER CONTROL			1,130,000	1,130,000	1,037,000	1,037,000
E	DECKING			962,000	962,000	962,000	962,000
F	GROUND WALL SUPPORT			2,021,000	1,814,000	2,515,000	2,515,000
G	BRACING	N.A.	N.A.	1,753,000	1,690,000	1,753,000	1,690,000
H	EXCAVATION			630,000	547,000	613,000	526,000
I	CONST.PERM.STRUCT.			3,018,000	4,009,000	2,602,000	3,593,000
J	BACKFILL			335,000	290,000	324,000	281,000
K	RESTORATION			134,000	134,000	134,000	134,000
	SUB TOTAL - DIRECT			10,838,000	11,431,000	10,795,000	11,593,000
N	OVERHEAD (FIXED)			367,000	369,000	368,000	375,000
O	OVERHEAD (TIME REL)			3,365,000	3,365,000	3,073,000	3,073,000
P	PLANT (FIXED)			290,000	290,000	290,000	290,000
Q	PLANT (TIME REL)			250,000	250,000	230,000	230,000
	SUB TOTAL - INDIRECT			4,272,000	4,274,000	3,961,000	3,968,000
	TOTAL COST			15,110,000	15,705,000	14,756,000	15,561,000
	MARKUP			2,267,000	2,356,000	2,213,000	2,334,000
	BID PRICE			17,377,000	18,061,000	16,969,000	17,895,000

Table 60. ESTIMATE COMPARISON TABLES OF ACTIVITY CONSTRUCTION COSTS
RAPID TRANSIT STATION - 70' DEPTH (Continued)

Site 4: Sand, silt & rock - high water table, maintained during construction

	GROUND SUPPORT	SOLD. PILES & LAGGING		CAST-IN-SLURRY (SPTC)		PRECAST CONC. PANELS	
	TYPE OF BRACING	INTERNAL	TIEBACK	INTERNAL	TIEBACK	INTERNAL	TIEBACK
	EST. DESIGNATION	-	-	4-2JY	4-2KY	4-2LY	4-2MY
A	TRAFFIC CONTROL			101,000	101,000	101,000	101,000
B	UTILITY WORK			689,000	689,000	689,000	689,000
C	PROTECT ADJ.STRUCT.			69,000	69,000	69,000	69,000
D	GROUNDWATER CONTROL			408,000	408,000	373,000	373,000
E	DECKING			1,089,000	1,089,000	1,089,000	1,089,000
F	GROUND WALL SUPPORT			1,449,000	1,364,000	2,070,000	2,070,000
G	BRACING	N.A.	N.A.	1,689,000	1,783,000	1,689,000	1,783,000
H	EXCAVATION			970,000	925,000	970,000	925,000
I	CONST.PERM.STRUCT.			3,262,000	4,368,000	2,929,000	4,035,000
J	BACKFILL			380,000	329,000	380,000	329,000
K	RESTORATION			134,000	134,000	134,000	134,000
	SUB TOTAL - DIRECT			10,240,000	11,259,000	10,493,000	11,597,000
N	OVERHEAD (FIXED)			367,000	373,000	366,000	372,000
O	OVERHEAD (TIME REL)			3,565,000	3,565,000	3,270,000	3,270,000
P	PLANT (FIXED)			290,000	290,000	290,000	290,000
Q	PLANT (TIME REL)			264,000	264,000	244,000	244,000
	SUB TOTAL - INDIRECT			4,486,000	4,492,000	4,170,000	4,176,000
	TOTAL COST			14,726,000	15,751,000	14,663,000	15,773,000
	MARKUP			2,209,000	2,363,000	2,199,000	2,366,000
	BID PRICE			16,935,000	18,114,000	16,862,000	18,139,000

Table 60. ESTIMATE COMPARISON TABLES OF ACTIVITY CONSTRUCTION COSTS
RAPID TRANSIT STATION - 70' DEPTH (Continued)

Site 5: Clay soils - high water table, maintained during construction

	GROUND SUPPORT	SOLD. PILES & LAGGING		CAST-IN-SLURRY (SPTC)		PRECAST CONC. PANELS	
	TYPE OF BRACING	INTERNAL	TIEBACK	INTERNAL	TIEBACK	INTERNAL	TIEBACK
	EST. DESIGNATION	-	-	5-2JY	-	5-2LY	-
A	TRAFFIC CONTROL	N.A.	N.A.	102,000	N.A.	102,000	N.A.
B	UTILITY WORK			689,000		689,000	
C	PROTECT ADJ.STRUCT.			69,000		69,000	
D	GROUNDWATER CONTROL			441,000		405,000	
E	DECKING			962,000		962,000	
F	GROUND WALL SUPPORT			2,178,000		2,741,000	
G	BRACING			1,805,000		1,813,000	
H	EXCAVATION			950,000		923,000	
I	CONST.PERM.STRUCT.			3,018,000		2,602,000	
J	BACKFILL			335,000		324,000	
K	RESTORATION			134,000		134,000	
	SUB TOTAL - DIRECT			10,683,000		10,764,000	
N	OVERHEAD (FIXED)			368,000		371,000	
O	OVERHEAD (TIME REL)			3,635,000		3,352,000	
P	PLANT (FIXED)			290,000		290,000	
Q	PLANT (TIME REL)			269,000		250,000	
	SUB TOTAL - INDIRECT			4,562,000		4,263,000	
	TOTAL COST			15,245,000		15,027,000	
	MARKUP			2,287,000		2,254,000	
	BID PRICE			17,532,000		17,281,000	

Table 61. ESTIMATE COMPARISON TABLES OF ACTIVITY CONSTRUCTION COSTS
RAPID TRANSIT TUNNEL - 30' DEPTH

Site 1: Alluvial soils - high water table, lowered during construction

	GROUND SUPPORT	SOLD. PILES & LAGGING		CAST-IN-SLURRY (SPTC)		PRECAST CONC. PANELS	
	TYPE OF BRACING	INTERNAL	TIEBACK	INTERNAL	TIEBACK	INTERNAL	TIEBACK
	EST. DESIGNATION	1-3GT	1-3HT	1-3JT	1-3KT	1-3LT	1-3MT
A	TRAFFIC CONTROL	115,000	115,000	115,000	115,000	115,000	115,000
B	UTILITY WORK	1,267,000	1,267,000	1,768,000	1,768,000	1,768,000	1,768,000
C	PROTECT ADJ.STRUCT.	36,000	36,000	36,000	36,000	36,000	36,000
D	GROUNDWATER CONTROL	539,000	539,000	539,000	539,000	513,000	513,000
E	DECKING	1,445,000	1,445,000	1,390,000	1,390,000	1,283,000	1,283,000
F	GROUND WALL SUPPORT	844,000	886,000	1,747,000	1,747,000	2,017,000	2,017,000
G	BRACING	313,000	367,000	290,000	411,000	276,000	411,000
H	EXCAVATION	489,000	464,000	459,000	437,000	430,000	410,000
I	CONST.PERM.STRUCT.	2,885,000	2,884,000	2,682,000	2,682,000	2,448,000	2,448,000
J	BACKFILL	260,000	244,000	241,000	231,000	225,000	216,000
K	RESTORATION	96,000	96,000	96,000	96,000	96,000	96,000
	SUB TOTAL - DIRECT	8,289,000	8,343,000	9,363,000	9,452,000	9,207,000	9,313,000
N	OVERHEAD (FIXED)	263,000	262,000	262,000	257,000	275,000	271,000
O	OVERHEAD (TIME REL)	1,770,000	1,770,000	2,010,000	2,010,000	2,103,000	2,103,000
P	PLANT (FIXED)	206,000	206,000	206,000	206,000	206,000	206,000
Q	PLANT (TIME REL)	122,000	122,000	139,000	139,000	145,000	145,000
	SUB TOTAL - INDIRECT	2,361,000	2,360,000	2,617,000	2,612,000	2,729,000	2,725,000
	TOTAL COST	10,650,000	10,703,000	11,980,000	12,064,000	11,936,000	12,038,000
	MARKUP	1,598,000	1,605,000	1,797,000	1,810,000	1,790,000	1,806,000
	BID PRICE	12,248,000	12,308,000	13,777,000	13,874,000	13,726,000	13,844,000

Table 61. ESTIMATE COMPARISON TABLES OF ACTIVITY CONSTRUCTION COSTS RAPID TRANSIT TUNNEL - 30' DEPTH (Continued)

Site 2: Alluvial soils - permanently low water table

	GROUND SUPPORT	SOLD. PILES & LAGGING		CAST-IN-SLURRY (SPTC)		PRECAST CONC. PANELS	
	TYPE OF BRACING	INTERNAL	TIEBACK	INTERNAL	TIEBACK	INTERNAL	TIEBACK
	EST. DESIGNATION	2-3GU	2-3HU	2-3JU	2-3KU	2-3LU	2-3MU
A	TRAFFIC CONTROL	115,000	115,000	115,000	115,000	115,000	115,000
B	UTILITY WORK	1,267,000	1,267,000	1,768,000	1,768,000	1,768,000	1,768,000
C	PROTECT ADJ.STRUCT.	36,000	36,000	36,000	36,000	36,000	36,000
D	GROUNDWATER CONTROL	-	-	-	-	-	-
E	DECKING	1,428,000	1,428,000	1,390,000	1,390,000	1,283,000	1,283,000
F	GROUND WALL SUPPORT	844,000	886,000	1,747,000	1,747,000	2,017,000	2,017,000
G	BRACING	313,000	367,000	290,000	411,000	276,000	411,000
H	EXCAVATION	489,000	464,000	459,000	437,000	430,000	410,000
I	CONST.PERM.STRUCT.	2,434,000	2,433,000	2,395,000	2,395,000	2,162,000	2,162,000
J	BACKFILL	260,000	244,000	241,000	231,000	225,000	216,000
K	RESTORATION	96,000	96,000	96,000	96,000	96,000	96,000
	SUB TOTAL - DIRECT	7,282,000	7,336,000	8,537,000	8,626,000	8,408,000	8,514,000
N	OVERHEAD (FIXED)	262,000	264,000	264,000	265,000	277,000	278,000
O	OVERHEAD (TIME REL)	1,770,000	1,770,000	2,010,000	2,010,000	2,103,000	2,103,000
P	PLANT (FIXED)	206,000	206,000	206,000	206,000	206,000	206,000
Q	PLANT (TIME REL)	122,000	122,000	139,000	139,000	145,000	145,000
	SUB TOTAL - INDIRECT	2,360,000	2,362,000	2,619,000	2,620,000	2,731,000	2,732,000
	TOTAL COST	9,642,000	9,698,000	11,156,000	11,246,000	11,139,000	11,246,000
	MARKUP	1,446,000	1,455,000	1,673,000	1,687,000	1,671,000	1,687,000
	BID PRICE	11,088,000	11,153,000	12,829,000	12,933,000	12,810,000	12,933,000

Table 61. ESTIMATE COMPARISON TABLES OF ACTIVITY CONSTRUCTION COSTS
RAPID TRANSIT TUNNEL - 30' DEPTH (Continued)

Site 3: Alluvial soils - high water table, maintained during construction

	GROUND SUPPORT	SOLD. PILES & LAGGING		CAST-IN-SLURRY (SPTC)		PRECAST CONC. PANELS	
	TYPE OF BRACING	INTERNAL	TIEBACK	INTERNAL	TIEBACK	INTERNAL	TIEBACK
	EST. DESIGNATION	-	-	3-3JT	3-3KT	3-3LT	3-3MT
A	TRAFFIC CONTROL			115,000	115,000	115,000	115,000
B	UTILITY WORK			1,768,000	1,768,000	1,768,000	1,768,000
C	PROTECT ADJ.STRUCT.			36,000	36,000	36,000	36,000
D	GROUNDWATER CONTROL			670,000	670,000	642,000	642,000
E	DECKING			1,390,000	1,390,000	1,283,000	1,283,000
F	GROUND WALL SUPPORT			2,755,000	2,755,000	2,114,000	2,114,000
G	BRACING	N.A.	N.A.	295,000	607,000	275,000	607,000
H	EXCAVATION			459,000	437,000	430,000	410,000
I	CONST.PERM.STRUCT.			2,682,000	2,682,000	2,448,000	2,448,000
J	BACKFILL			241,000	231,000	225,000	216,000
K	RESTORATION			96,000	96,000	96,000	96,000
	SUB TOTAL - DIRECT			9,507,000	9,787,000	9,432,000	9,735,000
N	OVERHEAD (FIXED)			263,000	259,000	276,000	273,000
O	OVERHEAD (TIME REL)			2,010,000	2,010,000	2,103,000	2,103,000
P	PLANT (FIXED)			206,000	206,000	206,000	206,000
Q	PLANT (TIME REL)			139,000	139,000	145,000	145,000
	SUB TOTAL - INDIRECT			2,618,000	2,614,000	2,730,000	2,747,000
	TOTAL COST			12,125,000	12,401,000	12,162,000	12,462,000
	MARKUP			1,819,000	1,860,000	1,824,000	1,869,000
	BID PRICE			13,944,000	14,261,000	13,986,000	14,331,000

Table 61. ESTIMATE COMPARISON TABLES OF ACTIVITY CONSTRUCTION COSTS
RAPID TRANSIT TUNNEL - 30' DEPTH (Continued)

Site 4: Sand, silt & rock - high water table, maintained during construction

	GROUND SUPPORT	SOLD. PILES & LAGGING		CAST-IN-SLURRY (SPTC)		PRECAST CONC. PANELS	
	TYPE OF BRACING	INTERNAL	TIEBACK	INTERNAL	TIEBACK	INTERNAL	TIEBACK
	EST. DESIGNATION	-	-	4-3JT	4-3KT	4-3LT	4-3MT
A	TRAFFIC CONTROL			115,000	115,000	115,000	115,000
B	UTILITY WORK			1,768,000	1,768,000	1,768,000	1,768,000
C	PROTECT ADJ.STRUCT.			36,000	36,000	36,000	36,000
D	GROUNDWATER CONTROL			185,000	185,000	173,000	173,000
E	DECKING			1,390,000	1,390,000	1,283,000	1,283,000
F	GROUND WALL SUPPORT			2,377,000	2,377,000	2,893,000	2,893,000
G	BRACING	N.A.	N.A.	299,000	1,119,000	273,000	1,119,000
H	EXCAVATION			536,000	525,000	501,000	492,000
I	CONST.PERM.STRUCT.			2,682,000	2,682,000	2,448,000	2,448,000
J	BACKFILL			214,000	231,000	225,000	216,000
K	RESTORATION			96,000	96,000	96,000	96,000
	SUB TOTAL - DIRECT			9,725,000	10,524,000	9,811,000	10,639,000
N	OVERHEAD (FIXED)			265,000	263,000	279,000	278,000
O	OVERHEAD (TIME REL)			2,010,000	2,010,000	2,103,000	2,103,000
P	PLANT (FIXED)			206,000	206,000	206,000	206,000
Q	PLANT (TIME REL)			139,000	139,000	145,000	145,000
	SUB TOTAL - INDIRECT			2,620,000	2,618,000	2,733,000	2,732,000
	TOTAL COST			12,345,000	13,142,000	12,544,000	13,371,000
	MARKUP			1,852,000	1,971,000	1,882,000	2,006,000
	BID PRICE			14,197,000	15,113,000	14,426,000	15,377,000

Table 61. ESTIMATE COMPARISON TABLES OF ACTIVITY CONSTRUCTION COSTS
RAPID TRANSIT TUNNEL - 30' DEPTH (Continued)

Site 5: Clay soils - high water table, maintained during construction

	GROUND SUPPORT	SOLD. PILES & LAGGING		CAST-IN-SLURRY (SPTC)		PRECAST CONC. PANELS	
	TYPE OF BRACING	INTERNAL	TIEBACK	INTERNAL	TIEBACK	INTERNAL	TIEBACK
	EST. DESIGNATION	-	-	5-3JT	-	5-3LT	-
A	TRAFFIC CONTROL	N.A.	N.A.	117,000	N.A.	117,000	N.A.
B	UTILITY WORK			1,768,000		1,768,000	
C	PROTECT ADJ.STRUCT.			36,000		36,000	
D	GROUNDWATER CONTROL			218,000		206,000	
E	DECKING			1,390,000		1,283,000	
F	GROUND WALL SUPPORT			4,139,000		5,456,000	
G	BRACING			447,000		413,000	
H	EXCAVATION			656,000		614,000	
I	CONST.PERM.STRUCT.			2,682,000		2,448,000	
J	BACKFILL			241,000		225,000	
K	RESTORATION			96,000		96,000	
	SUB TOTAL - DIRECT			11,790,000		12,662,000	
N	OVERHEAD (FIXED)			277,000		296,000	
O	OVERHEAD (TIME REL)			2,090,000		2,183,000	
P	PLANT (FIXED)			206,000		206,000	
Q	PLANT (TIME REL)			144,000		150,000	
	SUB TOTAL - INDIRECT			2,717,000		2,835,000	
	TOTAL COST			14,507,000		15,497,000	
	MARKUP			2,176,000		2,325,000	
	BID PRICE			16,683,000		17,822,000	

Table 62. ESTIMATE COMPARISON TABLES OF ACTIVITY CONSTRUCTION COSTS RAPID TRANSIT TUNNEL - 50' DEPTH

Site 1: Alluvial soils - high water table, lowered during construction

	GROUND SUPPORT	SOLD. PILES & LAGGING		CAST-IN-SLURRY (SPTC)		PRECAST CONC. PANELS	
	TYPE OF BRACING	INTERNAL	TIEBACK	INTERNAL	TIEBACK	INTERNAL	TIEBACK
	EST. DESIGNATION	1-3GV	1-3HV	1-3JV	1-3KV	1-3LV	1-3MV
A	TRAFFIC CONTROL	119,000	119,000	119,000	119,000	119,000	119,000
B	UTILITY WORK	1,267,000	1,267,000	1,768,000	1,768,000	1,768,000	1,768,000
C	PROTECT ADJ.STRUCT.	36,000	36,000	36,000	36,000	36,000	36,000
D	GROUNDWATER CONTROL	805,000	805,000	805,000	805,000	775,000	775,000
E	DECKING	1,464,000	1,464,000	1,358,000	1,358,000	1,320,000	1,320,000
F	GROUND WALL SUPPORT	1,376,000	1,513,000	2,620,000	2,620,000	3,231,000	3,231,000
G	BRACING	704,000	1,262,000	735,000	1,386,000	697,000	1,361,000
H	EXCAVATION	758,000	693,000	695,000	633,000	651,000	595,000
I	CONST.PERM.STRUCT.	3,416,000	3,415,000	3,058,000	3,058,000	2,825,000	2,825,000
J	BACKFILL	577,000	497,000	510,000	456,000	476,000	426,000
K	RESTORATION	96,000	96,000	96,000	96,000	96,000	96,000
	SUB TOTAL - DIRECT	10,618,000	11,167,000	11,800,000	12,335,000	11,994,000	12,552,000
N	OVERHEAD (FIXED)	277,000	280,000	277,000	274,000	292,000	290,000
O	OVERHEAD (TIME REL)	1,928,000	1,928,000	2,169,000	2,169,000	2,262,000	2,262,000
P	PLANT (FIXED)	206,000	206,000	206,000	206,000	206,000	206,000
Q	PLANT (TIME REL)	132,000	132,000	149,000	149,000	155,000	155,000
	SUB TOTAL - INDIRECT	2,543,000	2,546,000	2,801,000	2,798,000	2,915,000	2,913,000
	TOTAL COST	13,161,000	13,713,000	14,601,000	15,133,000	14,909,000	15,465,000
	MARKUP	1,974,000	2,057,000	2,190,000	2,270,000	2,236,000	2,320,000
	BID PRICE	15,135,000	15,770,000	16,791,000	17,403,000	17,145,000	17,785,000

Table 62. ESTIMATE COMPARISON TABLES OF ACTIVITY CONSTRUCTION COSTS RAPID TRANSIT TUNNEL - 50' DEPTH (Continued)

Site 2: Alluvial soils - permanently low water table

	GROUND SUPPORT	SOLD. PILES & LAGGING		CAST-IN-SLURRY (SPTC)		PRECAST CONC. PANELS	
	TYPE OF BRACING	INTERNAL	TIEBACK	INTERNAL	TIEBACK	INTERNAL	TIEBACK
	EST. DESIGNATION	2-3GW	2-3HW	2-3JW	2-3KW	2-3LW	2-3MW
A	TRAFFIC CONTROL	119,000	119,000	119,000	119,000	119,000	119,000
B	UTILITY WORK	1,267,000	1,267,000	1,768,000	1,768,000	1,768,000	1,768,000
C	PROTECT ADJ.STRUCT.	36,000	36,000	36,000	36,000	36,000	36,000
D	GROUNDWATER CONTROL	-	-	-	-	-	-
E	DECKING	1,445,000	1,445,000	1,358,000	1,356,000	1,320,000	1,320,000
F	GROUND WALL SUPPORT	1,376,000	1,513,000	2,620,000	2,620,000	3,231,000	3,231,000
G	BRACING	704,000	1,262,000	735,000	1,386,000	697,000	1,361,000
H	EXCAVATION	758,000	693,000	695,000	633,000	651,000	595,000
I	CONST.PERM.STRUCT.	2,948,000	2,947,000	2,771,000	2,771,000	2,538,000	2,538,000
J	BACKFILL	577,000	497,000	510,000	456,000	476,000	426,000
K	RESTORATION	96,000	96,000	96,000	96,000	96,000	96,000
	SUB TOTAL - DIRECT	9,326,000	9,875,000	10,708,000	11,243,000	10,932,000	11,490,000
N	OVERHEAD (FIXED)	273,000	277,000	276,000	279,000	290,000	291,000
O	OVERHEAD (TIME REL)	1,928,000	1,928,000	2,169,000	2,169,000	2,262,000	2,262,000
P	PLANT (FIXED)	206,000	206,000	206,000	206,000	206,000	206,000
Q	PLANT (TIME REL)	132,000	132,000	149,000	149,000	155,000	155,000
	SUB TOTAL - INDIRECT	2,539,000	2,543,000	2,800,000	2,803,000	2,913,000	2,914,000
	TOTAL COST	11,865,000	12,418,000	13,508,000	14,046,000	13,845,000	14,404,000
	MARKUP	1,780,000	1,863,000	2,026,000	2,107,000	2,077,000	2,161,000
	BID PRICE	13,645,000	14,281,000	15,534,000	16,153,000	15,922,000	16,565,000

Table 62. ESTIMATE COMPARISON TABLES OF ACTIVITY CONSTRUCTION COSTS
RAPID TRANSIT TUNNEL - 50' DEPTH (Continued)

Site 3: Alluvial soils - high water table, maintained during construction

	GROUND SUPPORT	SOLD. PILES & LAGGING		CAST-IN-SLURRY (SPTC)		PRECAST CONC. PANELS	
	TYPE OF BRACING	INTERNAL	TIEBACK	INTERNAL	TIEBACK	INTERNAL	TIEBACK
	EST. DESIGNATION	-	-	3-3JV	3-3KV	3-3LV	3-3MV
A	TRAFFIC CONTROL			119,000	119,000	119,000	119,000
B	UTILITY WORK			1,768,000	1,768,000	1,768,000	1,768,000
C	PROTECT ADJ.STRUCT.			36,000	36,000	36,000	36,000
D	GROUNDWATER CONTROL			858,000	858,000	826,000	826,000
E	DECKING			1,358,000	1,358,000	1,320,000	1,320,000
F	GROUND WALL SUPPORT			3,340,000	3,424,000	3,842,000	3,842,000
G	BRACING	N.A.	N.A.	797,000	2,019,000	756,000	1,994,000
H	EXCAVATION			695,000	633,000	651,000	595,000
I	CONST.PERM.STRUCT.			3,058,000	3,058,000	2,825,000	2,825,000
J	BACKFILL			510,000	456,000	476,000	426,000
K	RESTORATION			96,000	96,000	96,000	96,000
	SUB TOTAL - DIRECT			12,635,000	13,825,000	12,715,000	13,847,000
N	OVERHEAD (FIXED)			282,000	283,000	296,000	298,000
O	OVERHEAD (TIME REL)			2,169,000	2,169,000	2,262,000	2,262,000
P	PLANT (FIXED)			206,000	206,000	206,000	206,000
Q	PLANT (TIME REL)			149,000	149,000	155,000	155,000
	SUB TOTAL - INDIRECT			2,806,000	2,807,000	2,919,000	2,921,000
	TOTAL COST			15,441,000	16,632,000	15,634,000	16,768,000
	MARKUP			2,316,000	2,495,000	2,345,000	2,515,000
	BID PRICE			17,757,000	19,127,000	17,979,000	19,283,000

Table 62. ESTIMATE COMPARISON TABLES OF ACTIVITY CONSTRUCTION COSTS
RAPID TRANSIT TUNNEL - 50' DEPTH (Continued)

Site 4: Sand, silt & rock - high water table, maintained during construction

	GROUND SUPPORT	SOLD. PILES & LAGGING		CAST-IN-SLURRY (SPTC)		PRECAST CONC. PANELS	
	TYPE OF BRACING	INTERNAL	TIEBACK	INTERNAL	TIEBACK	INTERNAL	TIEBACK
	EST. DESIGNATION	-	-	4-3JV	4-3KV	4-3LV	4-3MV
A	TRAFFIC CONTROL			120,000	120,000	120,000	120,000
B	UTILITY WORK			1,768,000	1,768,000	1,768,000	1,768,000
C	PROTECT ADJ.STRUCT.			36,000	36,000	36,000	36,000
D	GROUNDWATER CONTROL			246,000	246,000	234,000	234,000
E	DECKING			1,358,000	1,358,000	1,320,000	1,320,000
F	GROUND WALL SUPPORT			3,145,000	3,027,000	3,953,000	3,953,000
G	BRACING	N.A.	N.A.	846,000	3.741,000	802,000	3,741,000
H	EXCAVATION			918,000	868,000	859,000	814,000
I	CONST.PERM.STRUCT.			3,058,000	3,058,000	2,825,000	2,825,000
J	BACKFILL			510,000	456,000	476,000	426,000
K	RESTORATION			96,000	96,000	96,000	96,000
	SUB TOTAL - DIRECT			12,101,000	14,774,000	12,489,000	15,333,000
N	OVERHEAD (FIXED)			280,000	289,000	296,000	307,000
O	OVERHEAD (TIME REL)			2,249,000	2,249,000	2,343,000	2,343,000
P	PLANT (FIXED)			206,000	206,000	206,000	206,000
Q	PLANT (TIME REL)			154,000	154,000	160,000	160,000
	SUB TOTAL - INDIRECT			2,889,000	2,898,000	3,005,000	3,016,000
	TOTAL COST			14,990,000	17,672,000	15,494,000	18,349,000
	MARKUP			2,249,000	2,651,000	2,324,000	2,752,000
	BID PRICE			17,239 000	20,323,000	17,818,000	21,101,000

Table 62. ESTIMATE COMPARISON TABLES OF ACTIVITY CONSTRUCTION COSTS
RAPID TRANSIT TUNNEL - 50' DEPTH (Continued)

Site 5: Clay soils - high water table, maintained during construction

	GROUND SUPPORT	SOLD. PILES & LAGGING		CAST-IN-SLURRY (SPTC)		PRECAST CONC. PANELS	
	TYPE OF BRACING	INTERNAL	TIEBACK	INTERNAL	TIEBACK	INTERNAL	TIEBACK
	EST. DESIGNATION	-	-	5-3JV	-	5-3LV	-
A	TRAFFIC CONTROL	N.A.	N.A.	122,000	N.A.	122,000	N.A.
B	UTILITY WORK			1,768,000		1,768,000	
C	PROTECT ADJ.STRUCT.			36,000		36,000	
D	GROUNDWATER CONTROL			276,000		264,000	
E	DECKING			1,358,000		1,320,000	
F	GROUND WALL SUPPORT			5,035,000		6,030,000	
G	BRACING			1,589,000		1,518,000	
H	EXCAVATION			1,037,000		972,000	
I	CONST.PERM.STRUCT.			3,058,000		2,825,000	
J	BACKFILL			526,000		492,000	
K	RESTORATION			96,000		96,000	
	SUB TOTAL - DIRECT			14,901,000		15,443,000	
N	OVERHEAD (FIXED)			296,000		313,000	
O	OVERHEAD (TIME REL)			2,329,000		2,423,000	
P	PLANT (FIXED)			206,000		206,000	
Q	PLANT (TIME REL)			159,000		165,000	
	SUB TOTAL - INDIRECT			2,990,000		3,107,000	
	TOTAL COST			17,891,000		18,550,000	
	MARKUP			2,684,000		2,783,000	
	BID PRICE			20,575,000		21,333,000	

Table 63. ESTIMATE COMPARISON TABLES OF ACTIVITY CONSTRUCTION COSTS
RAPID TRANSIT TUNNEL - 70' DEPTH

Site 1: Alluvial soils - high water table, lowered during construction

	GROUND SUPPORT	SOLD. PILES & LAGGING		CAST-IN-SLURRY (SPTC)		PRECAST CONC. PANELS	
	TYPE OF BRACING	INTERNAL	TIEBACK	INTERNAL	TIEBACK	INTERNAL	TIEBACK
	EST. DESIGNATION	1-3GY	1-3HY	1-3JY	1-3KY	1-3LY	1-3MY
A	TRAFFIC CONTROL	122,000	122,000	122,000	122,000	122,000	122,000
B	UTILITY WORK	1,267,000	1,267,000	1,768,000	1,768,000	1,768,000	1,768,000
C	PROTECT ADJ.STRUCT.	36,000	36,000	36,000	36,000	36,000	36,000
D	GROUNDWATER CONTROL	973,000	973,000	973,000	973,000	941,000	941,000
E	DECKING	1,482,000	1,482,000	1,358,000	1,358,000	1,320,000	1,320,000
F	GROUND WALL SUPPORT	1,637,000	1,845,000	3,417,000	3,584,000	4,595,000	4,595,000
G	BRACING	1,435,000	2,640,000	1,634,000	3,433,000	1,572,000	3,515,000
H	EXCAVATION	1,076,000	933,000	957,000	830,000	897,000	779,000
I	CONST.PERM.STRUCT.	3,863,000	4,067,000	3,342,000	3,342,000	3,109,000	3,109,000
J	BACKFILL	894,000	763,000	795,000	680,000	744,000	636,000
K	RESTORATION	96,000	96,000	96,000	96,000	96,000	96,000
	SUB TOTAL - DIRECT	12,881,000	14,224,000	14,498,000	16,222,000	15,200,000	16,917,000
N	OVERHEAD (FIXED)	291,000	298,000	294,000	298,000	312,000	316,000
O	OVERHEAD (TIME REL)	2,088,000	2,088,000	2,329,000	2,329,000	2,423,000	2,423,000
P	PLANT (FIXED)	206,000	206,000	206,000	206,000	206,000	206,000
Q	PLANT (TIME REL)	142,000	142,000	159,000	159,000	165,000	165,000
	SUB TOTAL - INDIRECT	2,727,000	2,734,000	2,988,000	2,992,000	3,106,000	3,110,000
	TOTAL COST	15,608,000	16,958,000	17,486,000	19,214,000	18,306,000	20,027,000
	MARKUP	2,341,000	2,544,000	2,623,000	2,882,000	2,746,000	3,004,000
	BID PRICE	17,949,000	19,502,000	20,109,000	22,096,000	21,052,000	23,031,000

Table 63, ESTIMATE COMPARISON TABLES OF ACTIVITY CONSTRUCTION COSTS
RAPID TRANSIT TUNNEL - 70' DEPTH (Continued)

Site 2: Alluvial soils - permanently low water table

	GROUND SUPPORT	SOLD. PILES & LAGGING		CAST-IN-SLURRY (SPTC)		PRECAST CONC. PANELS	
	TYPE OF BRACING	INTERNAL	TIEBACK	INTERNAL	TIEBACK	INTERNAL	TIEBACK
	EST. DESIGNATION	2-3GZ	2-3HZ	2-3JZ	2-3KZ	2-3LZ	2-3MZ
A	TRAFFIC CONTROL	122,000	122,000	122,000	122,000	122,000	122,000
B	UTILITY WORK	1,267,000	1,267,000	1,768,000	1,768,000	1,768,000	1,768,000
C	PROTECT ADJ.STRUCT.	36,000	36,000	36,000	36,000	36,000	36,000
D	GROUNDWATER CONTROL	-	-	-	-	-	-
E	DECKING	1,464,000	1,464,000	1,358,000	1,358,000	1,320,000	1,320,000
F	GROUND WALL SUPPORT	1,637,000	1,844,000	3,417,000	3,584,000	4,595,000	4,595,000
G	BRACING	1,435,000	2,640,000	1,634,000	3,433,000	1,572,000	3,515,000
H	EXCAVATION	1,076,000	933,000	957,000	830,000	897,000	779,000
I	CONST.PERM.STRUCT.	3,370,000	3,574,000	3,056,000	3,056,000	2,822,000	2,822,000
J	BACKFILL	894,000	763,000	795,000	680,000	744,000	636,000
K	RESTORATION	96,000	96,000	96,000	96,000	96,000	96,000
	SUB TOTAL - DIRECT	11,397,000	12,739,000	13,239,000	14,963,000	13,972,000	15,689,000
N	OVERHEAD (FIXED)	284,000	291,000	289,000	295,000	306,000	312,000
O	OVERHEAD (TIME REL)	2,088,000	2,088,000	2,329,000	2,329,000	2,423,000	2,423,000
P	PLANT (FIXED)	206,000	206,000	206,000	206,000	206,000	206,000
Q	PLANT (TIME REL)	142,000	142,000	159,000	159,000	165,000	165,000
	SUB TOTAL - INDIRECT	2,720,000	2,727,000	2,983,000	2,989,000	3,100,000	3,106,000
	TOTAL COST	14,117,000	15,466,000	16,222,000	17,952,000	17,072,000	18,795,000
	MARKUP	2,118,000	2,320,000	2,433,000	2,693,000	2,561,000	2,819,000
	BID PRICE	16,235,000	17,786,000	18,655,000	20,645,000	19,633,000	21,614,000

Table 63. ESTIMATE COMPARISON TABLES OF ACTIVITY CONSTRUCTION COSTS RAPID TRANSIT TUNNEL - 70' DEPTH (Continued)

Site 3: Alluvial soils - high water table, maintained during construction

	GROUND SUPPORT	SOLD. PILES & LAGGING		CAST-IN-SLURRY (SPTC)		PRECAST CONC. PANELS	
	TYPE OF BRACING	INTERNAL	TIEBACK	INTERNAL	TIEBACK	INTERNAL	TIEBACK
	EST. DESIGNATION	-	-	3-3JY	3-3KY	3-3LY	3-3MY
A	TRAFFIC CONTROL			122,000	122,000	122,000	122,000
B	UTILITY WORK			1,768,000	1,768,000	1,768,000	1,768,000
C	PROTECT ADJ.STRUCT.			36,000	36,000	36,000	36,000
D	GROUNDWATER CONTROL			996,000	996,000	964,000	964,000
E	DECKING			1,358,000	1,358,000	1,320,000	1,320,000
F	GROUND WALL SUPPORT			4,546,000	4,752,000	5,396,000	5,396,000
G	BRACING	N.A.	N.A.	1,797,000	4,564,000	1,693,000	4,366,000
H	EXCAVATION			957,000	830,000	897,000	779,000
I	CONST.PERM.STRUCT.			3,342,000	3,342,000	3,109,000	3,109,000
J	BACKFILL			795,000	680,000	744,000	636,000
K	RESTORATION			96,000	96,000	96,000	96,000
	SUB TOTAL - DIRECT			15,813,000	18,544,000	16,145,000	18,592,000
N	OVERHEAD (FIXED)			302,000	311,000	317,000	326,000
O	OVERHEAD (TIME REL)			2,329,000	2,329,000	2,423,000	2,423,000
P	PLANT (FIXED)			206,000	206,000	206,000	206,000
Q	PLANT (TIME REL)			159,000	159,000	165,000	165,000
	SUB TOTAL - INDIRECT			2,996,000	3,005,000	3,111,000	3,120,000
	TOTAL COST			18,809,000	21,549,000	19,256,000	21,712,000
	MARKUP			2,821,000	3,232,000	2,888,000	3,257,000
	BID PRICE			21,630,000	24,781,000	22,144,000	24,969,000

Table 63. ESTIMATE COMPARISON TABLES OF ACTIVITY CONSTRUCTION COSTS RAPID TRANSIT TUNNEL - 70' DEPTH (Continued)

Site 4: Sand, silt & rock - high water table, maintained during construction

	GROUND SUPPORT	SOLD. PILES & LAGGING		CAST-IN-SLURRY (SPTC)		PRECAST CONC. PANELS	
	TYPE OF BRACING	INTERNAL	TIEBACK	INTERNAL	TIEBACK	INTERNAL	TIEBACK
	EST. DESIGNATION	-	-	4-3JY	4-3KY	4-3LY	4-3MY
A	TRAFFIC CONTROL			125,000	125,000	127,000	127,000
B	UTILITY WORK			1,768,000	1,768,000	1,768,000	1,768,000
C	PROTECT ADJ.STRUCT.			36,000	36,000	36,000	36,000
D	GROUNDWATER CONTROL			296,000	296,000	284,000	284,000
E	DECKING			1,561,000	1,561,000	1,561,000	1,561,000
F	GROUND WALL SUPPORT			3,461,000	3,240,000	5,025,000	5,025,000
G	BRACING	N.A.	N.A.	1,433,000	4,550,000	1,433,000	4,550,000
H	EXCAVATION			1,609,000	1,534,000	1,609,000	1,533,000
I	CONST.PERM.STRUCT.			3,923,000	3,923,000	3,837,000	3,837,000
J	BACKFILL			993,000	849,000	993,000	849,000
K	RESTORATION			96,000	96,000	96,000	96,000
	SUB TOTAL - DIRECT			15,301,000	17,978,000	16,769,000	19,666,000
N	OVERHEAD (FIXED)			306,000	319,000	316,000	333,000
O	OVERHEAD (TIME REL)			2,500,000	2,500,000	2,582,000	2,582,000
P	PLANT (FIXED)			206,000	206,000	206,000	206,000
Q	PLANT (TIME REL)			170,000	170,000	176,000	176,000
	SUB TOTAL - INDIRECT			3,182,000	3,195,000	3,280,000	3,297,000
	TOTAL COST			18,483,000	21,173,000	20,049,000	22,963,000
	MARKUP			2,772,000	3,176,000	3,007,000	3,444,000
	BID PRICE			21,255,000	24,349,000	23,056,000	26,407,000

Table 63. ESTIMATE COMPARISON TABLES OF ACTIVITY CONSTRUCTION COSTS
RAPID TRANSIT TUNNEL - 70' DEPTH (Continued)

Site 5: Clay soils - high water table, maintained during construction

GROUND SUPPORT		SOLD. PILES & LAGGING		CAST-IN-SLURRY (SPTC)		PRECAST CONC. PANELS	
TYPE OF BRACING		INTERNAL	TIEBACK	INTERNAL	TIEBACK	INTERNAL	TIEBACK
EST. DESIGNATION		-	-	5-3JY	-	5-3LY	-
A	TRAFFIC CONTROL	N.A.	N.A.	127,000	N.A.	127,000	N.A.
B	UTILITY WORK			1,768,000		1,768,000	
C	PROTECT ADJ.STRUCT.			36,000		36,000	
D	GROUNDWATER CONTROL			337,000		325,000	
E	DECKING			1,358,000		1,320,000	
F	GROUND WALL SUPPORT			5,170,000		5,997,000	
G	BRACING			2,399,000		2,166,000	
H	EXCAVATION			1,442,000		1,352,000	
I	CONST.PERM.STRUCT.			3,342,000		3,109,000	
J	BACKFILL			795,000		744,000	
K	RESTORATION			96,000		96,000	
SUB TOTAL - DIRECT				16,870,000		17,040,000	
N	OVERHEAD (FIXED)			308,000		324,000	
O	OVERHEAD (TIME REL)			2,577,000		2,663,000	
P	PLANT (FIXED)			206,000		206,000	
Q	PLANT (TIME REL)			176,000		180,000	
SUB TOTAL - INDIRECT				3,267,000		3,373,000	
TOTAL COST				20,137,000		20,413,000	
MARKUP				3,021,000		3,062,000	
BID PRICE				23,158,000		23,475,000	

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FEDERALLY COORDINATED PROGRAM OF HIGHWAY RESEARCH AND DEVELOPMENT (FCP)

The Offices of Research and Development of the Federal Highway Administration are responsible for a broad program of research with resources including its own staff, contract programs, and a Federal-Aid program which is conducted by or through the State highway departments and which also finances the National Cooperative Highway Research Program managed by the Transportation Research Board. The Federally Coordinated Program of Highway Research and Development (FCP) is a carefully selected group of projects aimed at urgent, national problems, which concentrates these resources on these problems to obtain timely solutions. Virtually all of the available funds and staff resources are a part of the FCP, together with as much of the Federal-aid research funds of the States and the NCHRP resources as the States agree to devote to these projects.*

FCP Category Descriptions

1. Improved Highway Design and Operation for Safety

Safety R&D addresses problems connected with the responsibilities of the Federal Highway
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3. Environmental Considerations in Highway Design, Location, Construction, and Operation

Environmental R&D is directed toward identifying and evaluating highway elements which affect the quality of the human environment. The ultimate goals are reduction of adverse highway and traffic impacts, and protection and enhancement of the environment.

4. Improved Materials Utilization and Durability

Materials R&D is concerned with expanding the knowledge of materials properties and technology to fully utilize available naturally occurring materials, to develop extender or substitute materials for materials in short supply, and to devise procedures for converting industrial and other wastes into useful highway products. These activities are all directed toward the common goals of lowering the cost of highway construction and extending the period of maintenance-free operation.

5. Improved Design to Reduce Costs, Extend Life Expectancy, and Insure Structural Safety

Structural R&D is concerned with furthering the latest technological advances in structural designs, fabrication processes, and construction techniques, to provide safe, efficient highways at reasonable cost.

6. Prototype Development and Implementation of Research

This category is concerned with developing and transferring research and technology into practice, or, as it has been commonly identified, "technology transfer."

7. Improved Technology for Highway Maintenance

Maintenance R&D objectives include the development and application of new technology to improve management, to augment the utilization of resources, and to increase operational efficiency and safety in the maintenance of highway facilities.

FHWA

R&D