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# COMBINED UTILITY/TRANSPORTATION TUNNEL SYSTEMS - ECONOMIC, TECHNICAL AND INSTITUTIONAL FEASIBILITY

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16. Abstract

Although utility tunnels are common in Europe and Asia, United States use is largely confined to institutions where all utilities are under single ownership. Cut-and-cover transportation projects appear to display nearly ideal conditions for the use of utility tunnels. This project evaluated the economic, technical and institutional feasibility of incorporating utility tunnels into cut-and-cover transportation tunnel projects. Direct construction costs for the utility tunnel and conventional utility treatment options were projected and found to be comparable. In addition, significant reductions in urban disruption result when the construction of the utility tunnel and transportation tunnel is properly integrated. The combined tunnel system is the recommended option. The treatment of each utility, the structure of the tunnel operating entity and recommendations for implementation are included.

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# PREFACE

Recent years have seen an increased interest in the use of utility tunnels with urban cut and cover projects. Among the many contributing factors are congested underground space, disruption during utility maintenance, and the cost of handling utilities during the construction of transportation tunnels. Consideration of these and other factors resulted in a decision by the Department of Transportation - Office of the Secretary and the Transportation Systems Center to fund the study reported herein. The purpose of the study was to delineate the conditions under which utility tunnels might be advantageously used in cut and cover projects, and to detail how this should be done.

The area of study is not new. In addition to numerous notes in the technical literature, four recent efforts have been reported. These are two special reports by the American Public Works Association (APWA), and two feasibility studies conducted on a specific example in the City of Chicago. These efforts taken together provide an orderly evaluation of utility tunnels, and the design of a specific example. The effort reported herein, considering the integration of the utility tunnel and transportation tunnel, while generalizing the previous works to provide nationwide applicability, is a logical extension of previous efforts.

Individuals who gave additional assistance include:

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Preceding Page Blank

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Atlanta, GA
- Metropolitan Atlanta Rapid Transit Authority
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- Baltimore Gas and Electric.

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- Tone Boring Co., LTD.
- Chicago Urban Transportation District
- Consoer, Townsend and Assoc.
- Bureau of Sewers
- Bureau of Water
- Bureau of Streets
- Bureau of Street Traffic
- Illinois Bell Telephone Co.
- Peoples Gas Light and Coke Company
- Commonwealth Edison Company
- Western Union Company
- Edward McLean, Inc.

Denver, CO
- DeLeuw, Cather and Co.
- Regional Transportation District
- Denver Public Service Co.
- Steam Heat Public Service Co.
- Gas Public Service Co.
- Commercial and Industrial Services.

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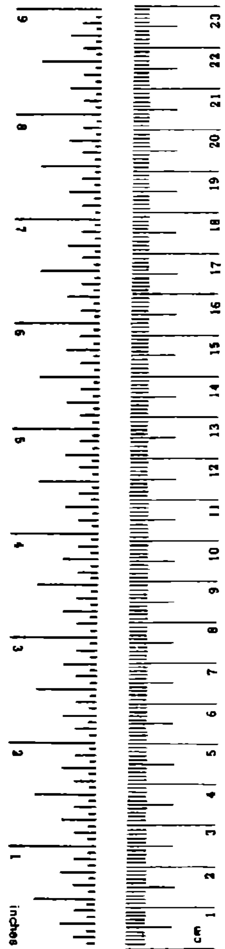
# METRIC CONVERSION FACTORS

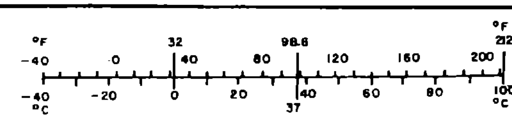
## Approximate Conversions to Metric Measures

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| in | inches | 2.5 | centimeters | cm |
| ft | feet | 30 | centimeters | cm |
| yd | yards | 0.9 | meters | m |
| mi | miles | 1.6 | kilometers | km |
| | | **AREA** | | |
| $in^2$ | square inches | 6.5 | square centimeters | $cm^2$ |
| $ft^2$ | square feet | 0.09 | square meters | $m^2$ |
| $yd^2$ | square yards | 0.8 | square meters | $m^2$ |
| $mi^2$ | square miles | 2.6 | square kilometers | $km^2$ |
| | acres | 0.4 | hectares | ha |
| | | **MASS (weight)** | | |
| oz | ounces | 28 | grams | g |
| lb | pounds | 0.45 | kilograms | kg |
| | short tons (2000 lb) | 0.9 | tonnes | t |
| | | **VOLUME** | | |
| tsp | teaspoons | 5 | milliliters | ml |
| Tbsp | tablespoons | 15 | milliliters | ml |
| fl oz | fluid ounces | 30 | milliliters | ml |
| c | cups | 0.24 | liters | l |
| pt | pints | 0.47 | liters | l |
| qt | quarts | 0.95 | liters | l |
| gal | gallons | 3.8 | liters | l |
| $ft^3$ | cubic feet | 0.03 | cubic meters | $m^3$ |
| $yd^3$ | cubic yards | 0.76 | cubic meters | $m^3$ |
| | | **TEMPERATURE (exact)** | | |
| °F | Fahrenheit temperature | 5/9 (after subtracting 32) | Celsius temperature | °C |




## Approximate Conversions from Metric Measures

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| mm | millimeters | 0.04 | inches | in |
| cm | centimeters | 0.4 | inches | in |
| m | meters | 3.3 | feet | ft |
| m | meters | 1.1 | yards | yd |
| km | kilometers | 0.6 | miles | mi |
| | | **AREA** | | |
| $cm^2$ | square centimeters | 0.16 | square inches | $in^2$ |
| $m^2$ | square meters | 1.2 | square yards | $yd^2$ |
| $km^2$ | square kilometers | 0.4 | square miles | $mi^2$ |
| ha | hectares (10,000 $m^2$) | 2.5 | acres | |
| | | **MASS (weight)** | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.2 | pounds | lb |
| t | tonnes (1000 kg) | 1.1 | short tons | |
| | | **VOLUME** | | |
| ml | milliliters | 0.03 | fluid ounces | fl oz |
| l | liters | 2.1 | pints | pt |
| l | liters | 1.06 | quarts | qt |
| l | liters | 0.26 | gallons | gal |
| $m^3$ | cubic meters | 35 | cubic feet | $ft^3$ |
| $m^3$ | cubic meters | 1.3 | cubic yards | $yd^3$ |
| | | **TEMPERATURE (exact)** | | |
| °C | Celsius temperature | 9/5 (then add 32) | Fahrenheit temperature | °F |



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# 1. INTRODUCTION AND SUMMARY

## 1.1 INTRODUCTION

A utility tunnel is defined as an underground structure containing one or more utility systems, permitting installation, maintenance, or removal of these systems without requiring excavation or street cuts. The concept seems particularly adaptable for use with cut-and-cover transportation tunnels, in which the initial excavation is provided at zero additional cost. During under-the-roof construction of a transportation tunnel, a utility tunnel does in fact exist on many transportation projects for brief periods. The question then is, should one proceed with conventional backfill operations, or instead add those appurtances necessary to maintain a utility tunnel as a permanent feature.

Many factors must be taken into account when considering the cost of a utility tunnel. The value of and need for a tunnel is less where few utilities exist. Regardless of the number of utilities included, the cost of a tunnel is much the same. It is therefore advantageous to include as many utilities as possible. This limits any study of tunnel feasibility to dense urban areas.

The initial cost of a tunnel is dependent upon the security and safety desired, as well as the cost of materials and labor. This tends to make the cost of a tunnel a function of the type of utilities included and the quality of monitoring instrumentation that is felt to be necessary. Therefore, it cannot be stated, even under specified conditions, whether a utility tunnel is cost effective when compared with conventional backfill. The cost of conventional backfill itself is highly variable. Preliminary results of a DOT/TSC study conducted by Birkmyer & Richardson (1974) indicate that in three BART and two WMATA cut-and-cover projects, utility handling costs ranged from 7.4 to 34.2 percent of total project costs. In addition to the amount of work done, the treatment of utility betterments significantly influences the cost of utility handling. On some projects, the entire utility plant may be replaced, while others may attempt to maintain the existing facilities. Consideration must be given to the type of treatment that conventional backfilled utilities will receive opposed to what is adequate treatment for those in a tunnel. As with most engineering decisions, the question of cost comparison has no answer except a range of approximations. A community can justify either answer depending on the goals and viewpoints of city designers and responsible executives, both public and private.

## 1.2 PROJECT BACKGROUND

The work reported herein is not an isolated study, but draws heavily on several previous efforts. It is good to identify at the outset this past related work. When mentioned in the body of this report, these works will be identified by the codes noted opposite the descriptions below.

SR39 Special Report 39 - Feasibility of Utility Tunnels in Urban Areas - funded by American Public Works Association and DOT/FHWA, pub. February 1971 by APWA.

This multi-sponsored two year effort indicated the need for and justification of utility tunnels in certain urban settings. It gave guidelines and described additional needed research.

SR41 Special Report 41 - Proceedings: Conference on Engineering Utility Tunnels in Urban Areas New England College, Henniker, New Hampshire, August 16-21, 1971, funded by APWA and Engineering Foundation.

This conference dealt with the technical impediments, research needs and implementation problems associated with common utility tunnels. Technical problems were felt to be readily solvable. Institutional, legal and right of way questions were considered to be more intractable, but still resolvable, and solutions were suggested. A call to action resulted - a demonstration project should be initiated to illustrate the economic and other benefits of the common utility tunnel.

CUTD Central Area Transit Project Utility Tunnel Feasibility Study, city of Chicago, Dept. of Public Works, Sept. 1973.

This was a two year effort to design a utility tunnel for construction in conjunction with Chicago's Central Area Transit Project (CCATP). The Monroe Street segment was selected as being most difficult and therefore the subject of detailed design. Incorporating input from all public and private utilities, preliminary design work was conducted and the costs estimated. The economic feasibility and benefits were not clearly established.

CT&A Utility Tunnel Economic Feasibility Analysis in Conjunction with the Construction of Subways by The Cut and Cover Method, funded by DOT and NSF, the study was conducted by Consoer Townsend and Associates for the CCATP general consulting firm of DeLeuw Novick.

This study was to consider the economic feasibility of the CUTD design, with particular emphasis on indirect economic benefits. The previously designed utility tunnel was treated as an add-on to the transportation tunnel, incorporating minimum modification to the structure or the construction procedures. Using this procedure, an unfavorable benefit/cost ratio resulted, and the report recommends that the utility tunnel not be implemented on Monroe Street. IITRI feels that integration of the utility and transportation tunnels would have resulted in a system with more favorable benefit/cost ratio.

It can be seen that many organizations and investigators have contributed to work that preceded and is incorporated in the present report. It will be further noted that, as the objectives of the preceding efforts were not identical to those of the current work, so also the conclusions may differ. It is not uncommon that engineering studies made under differing circumstances will result in different answers, so that this should not be a matter of great concern.

## 1.3 RESEARCH OBJECTIVES

The objectives of the research reported herein were broad. The utility tunnel concept was to be evaluated within the context of any cut-and-cover transportation project in any U.S. city. Flexibility was complete with respect to design, construction procedure, and utilities to be included. The technical problems associated with any utility were to be considered, including proposed future utilities now in the developmental stage. Concentration on economic and institutional problems was emphasized as these were of greatest concern in SR41. If the concept appeared to be viable, typical designs and guidelines were to be provided to ease implementation of a demonstration project, should such a project be incorporated into the recommendations.

## 1.4 SUMMARY OF RESULTS

The results of the study can be stated briefly.

The utility tunnel concept is technically feasible. Many examples of utility tunnels exist in this country, even more in Europe and Asia. These tunnels contain every type of utility, and their use is increasing in popularity and acceptance.

The use of utility tunnels in conjunction with cut-and-cover transportation tunnels can be technically and economically advantageous. When using utility tunnels, the transportation tunnel construction procedure may be modified. The effect is projected to decrease disruption and social costs to the community. The transportation project duration is decreased by 90 to 180 days by rescheduling of previously sequential tasks.

It is not necessary to consider indirect benefit elements to justify the use of the utility tunnel. Capital costs of the utility/transportation tunnel system are equal to corresponding conventional system costs.

The utility tunnel as proposed is as safe or safer than utilities using conventional backfill techniques. The safety of such a facility depends upon the type of instrumentation and controls. Because these costs are small in comparison to structure costs, there is little danger of inadequate installations being provided. The common attitude now among utility tunnel workers is that their facilities are overinstrumented.

The union utility workers interviewed do not fear working in a strange enviornment. The utility tunnel was viewed as a long manhole with multiple access. The working conditions were seen as superior. An event on the street cannot trap workers underground. Manhole pumping and ventilation are not required before entering. The advantages of working daytime hours in a shirt-sleeve environment appeared to outweigh the ten percent shift differential paid for night work in a manhole.

Security from vandals and saboteurs is superior in the utility tunnel as compared to conventional systems. It was felt that a determined and knowledgeable saboteur could not be stopped by any reasonable security system, but that the tunnel as designed by CUTD would be safer than conventional systems not having monitored access.

The utility tunnel is particularly useful when new utility types are installed. The economic benefits resulting from less expensive installation of new types of utilities at unknown future dates are indeterminate and cannot be incorporated in a B/C ratio. The needs of several future utilities were evaluated. It appears that new communications modes will be coming on-line within the next decade. Depending upon economic conditions, district heating and cooling may become more common.

Finally, utility tunnels are not universally applicable. Extremely restricted right-of-way, as at the Charles Street station in Baltimore, or very wide R/W, making possible total relocation of utilities, both operate against the economic justification for utility tunnels.

The decision to consider utility tunnels must be made by individual transportation agencies. The utility tunnel is neither the panacea claimed by its advocates nor the economic disaster feared by opponents. The concept is unusual if only for the remarkable volume of strongly expressed opinion it raises particularly in comparison to the general dearth of knowledge on the subject available in the engineering community. This state of affairs will continue until either many operating examples exist in this country, or the concept is finally discarded as non-viable.

## 2. REVIEW OF LITERATURE

The American Public Works Association's Special Report Number 39, "Feasibility of Utility Tunnels in Urban Areas," and Special Report Number 41, "Proceedings From the Conference on Engineering Utility Tunnels in Urban Areas", represent the most thorough treatment given the subject to date. Most of what is contained herein is taken from one or the other of those documents.

Utility location and installation practices have received considerable attention in recent years. Historically, the bulk of present utility systems, both above and below ground, were installed in days when land was cheap and sparsely settled, and environmental concerns were not receiving the attention they are today. Lately, the need to place utilities underground for reasons of safety, serviceability, and the increasing cost of above ground right-of-way has become widespread, with the result that a veritable maze normally exists under the street rights-of-way in most high density urban areas.

Far from becoming unobtrusive after installation underground, utility system presence is indicated by the seemingly ceaseless opening of the streets to effect repairs, provide new customer services, and to install new or larger systems. Consequential traffic interferences, noise and air pollution, street deterioration, and high cost to both the utility and governmental jurisdiction are equally obtrusive.

It is axiomatic to say that utility service requirements are undergoing rapid growth, both in kind and degree. Demands for all existing utility services are increasing. New types of utilities, such as Community Antennae Television (CATV), are being installed at increasing rates while other new services, such as data transmission via telephone circuits, are also adding to the requirements for more utility installations. Finally, prototype utilities, such as secondary quality water systems and pneumatic solid waste collection systems, are being proposed, tested, and in some cases, installed.

The appropriateness of past and present utility installation practices is being questioned, particularly when the following factors are considered: aesthetics, proliferation of utility types, services, and expansions; the shortening of pavement life; the scarcity and cost of available rights-of-way; the effect of street cuts on traffic, commerce, and people; the increasing population densities of urban areas; and many others.

Increasing interest in the use of utility tunnels in conjunction with new underground transportation system construction, expansion, or renovation as one solution to preceived unsatisfactory utility installations methods in dense urban areas has recently been generated. In this context, a utility tunnel is defined as an underground structure containing one or more utility systems, permitting the installation, maintenance, or removal of these systems without requiring excavations or street cuts.

The utility tunnel concept is not new. Utility tunnel use dates back to more than a century when the first water pipe or electric cable was added to the sewers of Paris. Today, many countries have walk-through tunnels which house one or more urban utility lines.

While institutional use (i.e., hospitals, industrial complexes, and universities) of utility tunnels in the United States is not uncommon, municipal utility tunnel application is rare. The most notable municipally owned utility tunnel systems of importance in North American are located at Fairbanks and Nome, Alaska; both were designed primarily to keep water and sewer lines from freezing. Utility tunnel use by universities and government institutions was documented by the Oak Ridge National Laboratory (ORNL) in a survey of 26 institutions -- 20 reported utility tunnel use. Table 2-1, "Summary of Utility Tunnel Information From Universities and Government Installation", summarized the results of the Oak Ridge study. A very recent illustration of utility tunnel construction and use can be found at Walt Disney World in Florida. A 24 foot utility tunnel was planned for the "interama" project in Miami, Florida, as well.

Motivation for past utility tunnel installation in foreign countries varies. The principal motivation for the comprehensive systems that exist has been to eliminate the ever increasing utility cuts. Motivation for universities and other institutional systems, on the other hand, was orginally based on central steam heating systems and the problems of maintaining directly buried steam lines. In examples of comprehensive utility tunnel installation from Japan and the German Democratic Republic, motivation for their continued use is based on three principal factors:

a. Both countries suffered extensive World War II damage requiring essentially complete reconstruction of utilities. It was concluded that it would be more economical to reconstruct utilities in tunnels than by the traditional practice of direct burial.

b. In both countries, rapid social and economic growth is occuring, producing large increases in demand for utility services.

c. Both countries wanted to reduce the incidence of street cuts occasioned by the great increases in demands for utility services.

Within the last decade, several studies related to the utility tunnel concept for urban application have been completed. The recent increase in the number of studies being done indicates the mounting concern over the inadequacies of direct utility burial. None of the studies

TABLE 2-1 - SUMMARY OF UTILITY TUNNEL INFORMATION FROM UNIVERSITIES AND GOVERNMENT INSTALLATIONS

| Institution | Heating System | Cooling System | Potable Water | Fuel Gas | Electric Power | Communi-cations | Typical Size[a] (ft) |
|---|---|---|---|---|---|---|---|
| Eielson Air Force Base | Steam | No | Yes | No | No | No | 4.5 x 5 |
| Fort Wainwright | Steam | No | Yes | No | No | Yes | 5 x 5 |
| University of Alaska | Steam | No | Yes | No | Yes | No | 6 x 6.5 |
| University of Arizona | Steam | Yes | Yes | No | Yes | Yes | 4 x 6.5 |
| University of California | Hot Water | Yes | No | Yes | No | No | 8.5 x 11.5 |
| Civic Center Area, Denver | Steam | Yes | Yes[b] | No | Yes | No | 9 x 14 |
| U.S. Air Force Academy | Hot Water | No | Yes | No | Yes[c] | Yes | - |
| City & County Buildings, Denver | Steam | No | Yes | Yes | No | No | - |
| State Capitol Buildings | Steam | No | Yes | No | Yes | Yes | 5 x 7 |
| Florida Atlantic University | Hot Water | Yes | No | No | Yes | Yes | 20 x 6.25 |
| Georgia Institute of Technology | Hot Water | No | No | No | Yes | No | - |
| Purdue University | Steam | No | Yes[d] | No | Yes[d] | Yes | 6.67 x 6.67 |
| Michigan State University | Steam | Yes | No | No | No | No | 6 x 6.75 |
| University of Minnesota | Steam | Yes | No | No | Yes | Yes | 5 to 7 x 7 |
| University of Missouri | Steam | No | No | No | No | No | - |
| University of Oklahoma | Steam | Yes | Yes | No | Yes | No | 4.5 x 6.5 |
| University of Oregon | Steam | Yes | Yes | No | Yes | Yes | 6 x 7 |
| University of Texas | Steam | Yes | No | No | No | No | 6 x 6.5 |
| NASA, Houston | Steam | Yes | No | No | Yes | Yes | 6.5 to 13 x 7.4 |
| University of Washington | Steam | Yes | No | No | Yes | Yes | 5 x 6.5 |

[a]First dimension is tunnel width and second dimension is tunnel height for rectangular sections.

[b]Six-inch cold soft water supply in copper pipe.

[c]Primary electric power not included. Secondary power only.

[d]New tunnels do not have water and electric power. Water lines are being removed from old tunnels for lack of space.

Source: Oak Ridge National Laboratory

conducted in the United States have found economic justification, based on tangible factors, to construct utility tunnels. This is in direct contrast to foreign experience with utility tunnels where tangible economic justification is claimed to have been documented and proven.

Existing utility tunnels generally accommodate potable water, steam, hot water, chilled water, electric power, telephone, telegraph, television coaxial cable and other communication circuits. Gas lines are included less frequently in utility tunnels. Inclusion of storm and sanitary sewers is generally limited to situations where gravity flow is possible. Utility tunnels may also contain services found in institutional systems, such as compressed air, clock and bell systems, fire alarm and closed circuit TV systems, fuel oil, raw material, process, intermediate and finished product liquids and gases. Tunnels in hospital installations have also included medicinal gas distribution systems. Table 2-2, "Degree of Accomodation of Utility Services in Existing Utility Tunnels", summarizes the experiences of many countries in accomodating utility systems in a tunnel environment. Information in Table 2-2, was presented by F. Josa to the 5th International Congress on Underground Techniques and Town Planning which was held in 1969 at Madrid, Spain.

As Table 2-2 illustrates, many of the most common objections to utility tunnels cited by utility and governmental executives based on system incompatibility have been overcome in a number of instances abroad. Referring to problems of utility system compatibility, the most often mentioned problems are:

> Possibility of gas explosions resulting from leaking gas lines and consequent damage to other systems.
>
> Potential of electric and electromagnetic interference in telephone and other communication

TABLE 2-2 - DEGREE OF ACCOMMODATION OF UTILITY SERVICES IN EXISTING UTILITY TUNNELS (1)

| Utility Tunnel Application | Utility Service: Central Heating | Central Cooling | Water | Sewer | Gas | Electric Power | Telephone and Telegraph | Other Communi-cations |
|---|---|---|---|---|---|---|---|---|
| 1. U. S. Institutional | General | General | General | Limited | Limited | General (2) | General | General |
| 2. Cold Climate Municipal and Government | General | N.A. (3) | General | General | N.A. | Limited | Limited | Limited |
| 3. U. S. Utility Owned | N.A. (4) | N.A. | Limited | N.A. | Limited | General | General (5) | N.A. |
| 4. Foreign: | | | | | | | | |
| a. England | Limited | Limited | General | Limited | General | General | General | General |
| b. France | N.A. | N.A. | General | General | Prohibited | Limited | General | General |
| c. Spain | N.A. | N.A. | General | Limited | Prohibited | General (2) | General | General |
| d. East Germany | General | N.A. | General | Limited | General | General (6) | General | General |
| e. Russia | General | N.A. | General | Limited | Prohibited | General | General | General |
| f. Japan | N.A. | N.A. | General | Limited | General | General | General | General |

(1). Accommodation by degree is defined as follows:
- A. General - the utility is installed as a matter of general practice where the service is required in the area served by the utility tunnel.
- B. Limited - the utility is installed only where conditions are appropriate such as in the case of sewers.
- C. Prohibited - the utility is excluded as a matter of policy.
- D. N.A. (Not Applicable) - utility not present in the area served.

(2). Generally limited to medium (~14 kv) distribution voltages.
(3). Not Applicable. Utility not present in area served.
(4). High pressure steam lines are included.
(5). Including transmission voltages to 345 kv.
(6). To 30 kv.

circuits and the temperature of potable and chilled systems.

The American Public works Association's Special Report Number 39, "Feasibility of Utility Tunnels in Urban Areas", concluded:

> An overview of past experiences and recent studies weighs heavily in favor of compatibility of all common utilities; especially for the controlled utility tunnel environment that is possible with current technology.

This report gives the most comprehensive treatment to the subject of utility tunnels. The basic nature of the utility system and its in-tunnel requirements, tunnel operational, maintenance and safety problems, and tunnel ownership, financing, legal and management concerns have been examined. Because there are no comprehensive standards pertaining to the combined installation of several utility systems in one tunnel, identification of these characteristics and requirements is not easily accomplished.

Tunnel feasibility from the technical, economic, institutional, and financial points of view was studied. In general, the study concluded the following for each area of feasibility considered:

a) Technical Feasibility - No serious technical problems were uncovered that would limit the feasibility of the utility tunnel concept.

b) Economic Feasibility - Economic justification will most likely be found in the higher density urban districts and in situations where massive reconstruction of streets, utility systems, and buildings is performed. Lack of available data at present poses many problems in determining economic justification.

c) Institutional Feasibility - Although complex, the legal, ownership, regulatory, and management problems are solvable. Until utility tunnel experience is gained, liability problems cannot be fully resolved.

d) Financial Feasibility - No financial problems are anticipated if economic feasibility is proven.

## 2.1 SUMMARY

In recent years, attention has been focused on the concept of locating utility systems in tunnels. Although not a new idea, applications in the United States have been limited to large educational, industrial, and commercial complexes. This is in contrast to the European and Japanese experience where utility tunnels have been used extensively and effectively in many urban settings.

The chief benefit attributed to the utility tunnels in use has been the reduction in necessary street cuts, reduction in traffic interference, noise and air pollution, street deterioration, and high cost to the utilities, government, and consumer. In addition, the growing shortage and cost of available rights-of-ways together with the proliferation of utility services increases the emphasis of the need for improved location and placement of utilities in urban streets, possibly in utility tunnels.

Past research on the subject has been generally limited to surveys of utility tunnel practices in the United States and abroad. Previous studies also seem to indicate that no insurmountable technical problems associated with the utility tunnel concept exist; that sewerage systems generally cannot be included in utility tunnels; that economic justification is unlikely except for high density urban areas; and that many of the questions raised about the merits and demerits of utility tunnels cannot be satisfactorily answered until a tunnel is built and put into operation.

## 2.2 PREVIOUS MONROE STREET RECOMMENDATIONS

Two investigations of interest with respect to the work reported herein were the CUTD report dated September 1973 and the CT&A (Consoer Townsend & Assoc.) report dated March 1975. The first effort was a design feasibility study conducted by the city of Chicago. Over a two year period the CUTD project team in collaboration with many representatives of private utility companies and public agencies selected a study segment, designed a utility tunnel and estimated its cost. The design was comprehensive, extending to the detailed planning of utilities passing through each intersection. This design was reported to be satisfactory to each utility except the gas company, which was finally excluded from the tunnel.

Because the projected cost of the proposed utility tunnel design was estimated at $21 million, compared with $15 million for conventional utility handling, it was decided to consider intensively the indirect benefits that might result from a utility tunnel. The CT&A economic feasibility analysis was initiated for this purpose.

The CT&A study was funded jointly by DOT and NSF, through the CCATP and its chief consultant, Deleuw-Novick. This program paralleled the IITRI effort in both subject and time, so that cooperation and data sharing was possible. The CT&A objective was to conduct a full economic analysis, with particular emphasis to be paid to the indirect benefits that might be realized. The final recommendation of the CT&A report is that the utility tunnel should not be constructed. Because IITRI disagrees strongly with this recommendation, and both evaluations are based on the same tunnel segment, a brief discussion is in order.

The basic area of disagreement is economic, which results directly from the different constraints on the

IITRI and CT&A contracts. CT&A was directed to evaluate a specific design. IITRI was directed to determine what the best design would be, and then to evaluate it. The broader scope of the IITRI contract had significant effect. Using its own resources and the assistance of consultants from design and construction, a construction procedure was assembled that treats the utility tunnel and transportation tunnel as a single system, resulting in substantial savings.

The utility tunnel must be maintained and operated by some agency. This subject was one discussed in a number of joint meetings between CT&A, IITRI and the various public and private utilities. The organizational structure recommended in the CT&A report is an excellent model. After the conclusion of the CT&A effort, the recommended staffing levels were questioned, and IITRI was able to determine that the actual number of employees should be much smaller than had been thought. This is incorporated in the IITRI recommendations.

IITRI did not attempt a quantative treatment of the indirect and non-quantifiable benefits. This was felt to be unnecessary since the economic analysis itself favored the use of the tunnel, and qualitative treatment of the non-quantifiable elements indicates that they also favor the utility tunnel. It should not be assumed, however, that the non-quantifiable factors are unimportant. The construction procedure recommended by IITRI will reduce the economic impact of the construction project on the business community by nearly one full order of magnitude. With traditional cut-and-cover methods, these losses are large in comparison to the actual project construction cost. This should be a matter of concern for the engineering community.

In short, the difference in the IITRI and CT&A

recommendations are solely the result of the broader scope of the IITRI contract. It is felt that the CT&A project team performed competently within their own contractual constraints. Many of the IITRI recommendations are the direct result of collaboration between the two teams, and much of the data on construction costs is taken directly from the CT&A and CUTD reports. In particular, the design features discussed in section 3.2 are nearly identical with the design recommendations made by CUTD.

## 3. TECHNICAL FEASIBILITY

The concept of placing utilities in a utility tunnel is not new to the engineering community. The motivation to put this concept into practice has increased in recent years with the widespread construction of underground mass transit. Many subway projects use cut-and-cover construction in the major arterial right-of-ways of downtown urban areas. This affords an excellent opportunity to take advantage of the excavation and location to install a tunnel to house the utilities found there. The methods that would be used to construct such a tunnel would be the same as those used to build a subway. The subway construction, therefore, could be easily extended to include the utility tunnel. In most cases, the tunnel would be an integral part of the structure, with the roof of the subway also serving as the floor of the utility tunnel. The design in this study uses the subway walls as the sidewalls of the utility tunnel as well. Attempts should be made to integrate as many of the subway and tunnel features as possible. For example, a single source of power could be used for illumination and ventilation power in both the subway and utility tunnel. Drainage systems might also be combined. Although separate, work access stairs to the tunnel and pedestrian subway access should be parallel. Any monitors located in the subway could be controlled by the utility tunnel central control panel. Every opportunity to reduce the cost of the two systems by treating them as one should be used, provided that this can be safely accomplished.

It is important to emphasize the point that the utility tunnel should not be considered as a separate structure from the subway. Cost figures are not appropriate where estimates of the utility tunnel are added to the costs of a subway structure. Construction procedures in this study have been carefully detailed and designed so that the additional cost of a utility tunnel that is built during a cut-and-cover subway construction project is minimal.

Subway designs are well known. A detailed utility tunnel design, construction procedures, utility configurations, and tunnel operation procedures are discussed in this chapter. The proposed utility tunnel will be located in a right-of-way that is 66 feet from property line to property line. This restricted right-of-way, which is found in most densely populated urban areas, is the reason that the tunnel will be located above the subway as opposed to along the side. The utility tunnel will be the shallower of the two structures because the utilities are presently located very near the street surface. In cities where the street right-of-ways are wider, other configurations may be used.

The tunnel design proposed in this report is appropriate for the entire length of the subway system, if it is desired. Modifications might be considered in tunnels of exceptional length. These modifications might include sectionalization of the tunnel to prevent the spread of fires, flooding, smoke, and toxic fumes, and additional space for auxiliary utility apparatus such as communications repeaters and pumping stations.

The tunnel will be continuous its entire length, so it will be possible for a person to walk from one end to the other. It is questionable whether a person should be able to traverse the entire width. The racking configurations of many of the utilities, cables in particular, present natural barriers. Additional devices, such as chain-link fences or concrete dividers, may be used as desired or necessary. In the proposed design transformer vaults provide isolation and protection for almost all of the power utility plant.

The tunnel will have a minimum internal clearance of 10.5 feet, and in most cases it will be over 12.5 feet. The width will also vary, depending upon the width of the subway. For the purposes of this study a width of 53.5 feet and height of 10.5 feet inside dimensions was used. These dimensions are based on the Monroe segment selected for analysis. This segment is continuous station. On other parts of the CCATP system a 32 ft. wide twin-tube configuration is used. In those segments, the utility tunnel will be reduced to the same width by placing transformer vaults outside the tunnel.

The roof of the utility tunnel will be constructed from precast concrete elements which will allow over two feet of space for laterals. Utility supports should not extend to the roof in most cases. Additional room for utility work space will be available in the form of side spaces. These are areas where the tunnel extends 20 feet into either side of the intersection to provide additional room for utility turning movements. These will occur at five of the seven intersections on the study segment.

The inside of the tunnel will be concrete. The walls will be constructed by the diaphragm wall technique, so that their surface is relatively smooth, but not finished. Other ground support methods would be equally applicable if found economically feasible. The floors and roof will be concrete, probably pre-cast elements. The floors will be sloped for drainage. Utility supports will be bolted into the roof, walls, or center columns, or will be self-supporting and bolted to the floor. In any case, they will be stationary. Illumination will be similar to that of an office, with additional lighting available for close work. There will be numerous electrical outlets for power tools. In general, the utility worker should find the tunnel a clean, well-lit, comfortable environment in which to work.

Safety in a utility tunnel is emphasized because it has been the major concern of many who have considered the concept. Safety details are discussed in Sections 3.1 to 3.3, both as individual utility hazards and the tunnel as a whole. Instrumentation is possible to detect and prevent many of the accidents that might occur from mechanical failure of the utility facilities or the tunnel structure. Ventilation and automatic shut-down will be used to prevent the spread of a hazardous condition to other parts of the tunnel. Fire fighting equipment and automatic sprinklers will also be provided. A minimum of two means of egress will be available to the workers at each intersection.

The construction and operation of the tunnel itself is technically feasible, as the next sections will demonstrate. The economic justification of a utility tunnel project is finally discussed in Section 5.

## 3.1 UTILITY CHARACTERISTICS AND REQUIREMENTS

a. The technical feasibility of locating utilities in tunnels associated with transportation tunnels depends upon many factors, including the tunnel design and the adequacy of the utility configurations. These configurations must provide for the optimum functioning of each plant, by means of proper working space for utility maintenance, adequate support structures, and provision for the protection of both the utility plants and tunnel environment.

The following sections discuss possible configurations and requirements for each utility. The basic existing network and procedures are described and the materials used for each type of facility enumerated. There are several procedural rules which will be followed by every utility in a tunnel. These common rules are also described in this introductory section. Because of its importance, a separate section of this report is devoted to the subject of safety.

An unusual aspect of the utility tunnel herein discussed is its size. It is most economical to make the utility tunnel width either one half of or equal to the transportation tunnel width. It follows that working room, safety, and possible future expansion of utility plant are much improved over smaller existing U.S. utility tunnels.

b. Compatibility problems are closely related to safety concerns in most instances. With the exception of sewer lines, every utility considered in this study may be included in a tunnel and, with the proper precautionary measures, interference between them will be negligible. The gravity flow sewer system is typically excluded because of grade requirements, but general sewer requirements are nevertheless discussed.

Experience demonstrates that many of the utilities once considered incompatible are now being housed together. Much of this is due to improved operating methods, shielding, pipe and cable materials, and insulations. Improved compatibility may also be a result of better monitoring techniques and environmental control in the tunnels.

Gas mains are thought to be incompatible with almost every other utility by many people. This concern stems primarily from safety considerations. Improved pipe joints and sophisticated monitoring techniques have made the inclusion of gas desirable. Existing conventional backfilled systems experience difficulty with leaking gas which may flood the conduits and manholes of other utilities. Small gas leaks currently are ignored. These could easily be identified and treated in a utility tunnel. In short, gas lines should be included in the utility tunnel to improve safety and reduce street openings. Whether it will be possible to include gas in any particular case depends mostly on the policy of the local gas company.

Power and communication lines were thought to be incompatible, but their location on opposite sides of the tunnel, along with shielding, insulation, and proper grounding provide adequate protection against conductive and inductive interference. Power cables pose the additional problem of heat dissipation. The temperature of the tunnel will be controlled by a forced air ventilation system and the heat generated by power cables will not be allowed to raise the air temperature above a specified level. In some cases, utility intake air is filtered and tempered.

Water mains in tunnels raised some concern about flooding. The possibility of flooding still exists, but is made remote by pumping and drainage systems, and water level detectors.

Occasional wetting of the utilities is not a problem. In at least one case, a utility tunnel is cleaned using fire hoses. A matter of concern would be a constant drip on another utility that might result in deterioration. To avoid this problem, water lines should not run long distances directly above other systems.

There should be little concern about the incompatibility of other systems. All of the systems in this study, except sewer, will be able to share a common tunnel.

c. Work space in the tunnel will be allotted on the basis of the methods of maintenance that presently exist. It is expected that new procedures will evolve with increasing utility tunnel experience to specifically fit the new space requirements.

Basic work space requirements may be subdivided into two groups, those for pipe utilities and those for cables. Specific requirements are described in the utility configuration sections of this report, but the general requirements are as follows:

Space must be provided for cable pulling and splicing operations of cable utilities.

Space, at least one pipe diameter along the pipe and two diameters at valves, must be allowed for tapping and maintenance of pipe utilities.

The basic requirements also include additional space for lateral and cross-connections.

d. Laterals and service connections will be similar for all the utilities. Efforts will be made to position piped utilities in the tunnel to shorten the length required for laterals and thereby provide a substantial savings when either side of the street must be serviced. In a tunnel situation, laterals may branch off the distribution line at any spot along the entire plant length instead of being restricted exclusively to manhole locations. Utilities on racks or on the floor will require laterals to travel vertically until the tunnel roof is reached. The laterals will be supported at this junction from the roof structure. The roof is composed of precast concrete sections in the shape of concrete box beams. Double tees were also considered, but it was shown that concrete beams are structurally more competent and provide more clearance for utility lateral cross-overs. The laterals will run along the underside of the roof structure. All laterals will be encased in ducting where they cross the tunnel to protect both the laterals and the utilities below.

The laterals will pass through the utility tunnel side walls by means of caulked sleeves or grouted voids. The caulking or grout will securely hold the lateral in place and prevent soil or groundwater from entering the tunnel. The lateral will then travel through soil as in conventional systems to its service connection. The tunnel wall may either be provided with knock-outs at frequent intervals, or a small drill can be used to punch a four inch diamenter hole in less than five minutes.

e. Properly designed support structures will prevent failures that result from vibration or movement. This will keep cables properly spaced to prevent short circuiting and overloading, and will provide easy access to the utilities for maintenance. Support system that might be found in a tunnel are spring devices from the roof, concrete pedestals secured to the floor, or tray racks or supports for cables. Cables need to be supported at 3-foot intervals or almost continuously. Pipes must be supported at junctions or 20-foot intervals. Some companies request thrust restraints at sharp bends in pipe.

Cable racks might be of several varieties, depending upon the specific requirements of the utility plant. The racks may be secured to the wall or self-supporting. They might provide for cables to be located all on one side of the support, or a center racking scheme may be preferable. The rack might support the cables at intervals, or might support split conduit, or may even support cable trays in which the cables may rest. The decision as to which type of rack is most appropriate in a given situation will depend upon the number and size of the cables, space requirements, and the cost of materials.

Relative merits of different utility configurations must be weighed according to the situation. Opinions may vary from utility to utility and city to city. The following sections discuss each utility and the advantages and disadvantages of each alternative configuration. In most cases, any of several alternatives are technically feasible, and the choice should then be based on the opinion of the utility company concerned.

### 3.1.1 Natural Gas Configuration

In densely populated urban areas the natural gas distribution system is in a grid pattern, generally following the street layout. These layouts include branched and looped patterns to provide service in case of a failure of one portion of the system. Gas mains are presently laid by direct burial methods, generally under streets and sidewalks. Gas systems do not use manholes so that main inspection is impossible without excavation.

The gas mains under consideration for inclusion in a utility tunnel are generally low pressure (from 1/4 to 100 psi) mains made of welded steel pipe. Low pressure gas systems commonly require pipes four to twenty-four inches in diameter. Service connections are accomplished by means of taps or valved branches, depending upon the customer requirement. Metering and pressure reduction is provided on the customer's property. A typical service connection consists of welded branches which run under the sidewalk and through the wall of the customer's building.

Valves are used to sectionalize the line and service tees may be installed while the line is in service. Auxilliary equipment, such as telemeters, pressure regulators, and recording gages are also required in a gas distribution system (Holder, 1971).

Corrosion protection is a principal concern. Where mains are in contact with soil, protection is provided by the extensive use of coatings. Pipe is also cathodically protected. Mains in contact with air could be covered with a film coating of a material such as epoxy resin (Mork, 1971).

The inclusion of gas lines in a utility tunnel must be given careful consideration. Opposition to such a plan has been expressed and fear of gas explosions prevades the utility community. This fear has not been borne out by past experience. Utility tunnels including gas mains exist at the present time, and there has been little evidence to indicate that this configuration is more dangerous than direct burial. A discussion of some examples of gas lines successfully being included in tunnels with other utilities follows.

Consolidated Edison Company of New York, Inc., has built six utility tunnels used for river crossings. The oldest has been in service since 1895. High-pressure gas transmission lines, along with high-tension electric power cables, high-pressure steam, fuel oil, telephone cables, and air lines all have been operating in the same tunnel without serious problems. The original cast iron mains have been replaced with 20 to 24 in. welded steel, operated at pressures up to 350 psi (Mork, 1971).

Gas lines have been included in England, East Germany, and Japan. For over a century, skeptics in England have been waiting for the first explosion of utility tunnel gas lines. There is hesitation to include gas lines in tunnels in other countries, including France and Spain as well. About 10 percent of Japan's utility tunnels include gas lines. Although Japanese gas companies think that there is no suitable detection equipment and an explosion is inevitable, there have been no explosions in tunnels to date (SR39).

East Germany went to great lengths to study the feasibility of including gas mains in utility tunnels. Their inclusion was finally approved in the 1960's. The installations are strictly regulated and specifications concerning ventilation and emergency shut-off valves have been stipulated (SR39).

The U. S. Department of Transportation has determined that a high percentage of gas main ruptures are the result of damage due to the activities of other utilities.

Unfortunately, contractors have often unwittingly damaged gas mains which were than backfilled without being repaired. Many times damage is caused by exploration or repair procedures conducted by other utilities. Earth settlement of backfilled sections or movement caused by a change in the soil stress field may also cause rupture (SR39).

Poor quality pipe or inadequate pipe jointing will allow gas to escape into the surrounding soil. Gas can travel through soil interstices where the odorizing agent may be leached out. In this instance gas leaks are more difficult to detect and buried gas mains are extremely hazardous.

There is instrumentation available, provided adequate precautions are taken, that will allow gas mains to be safely included in a utility tunnel with other utility plants. There are several configurations that may be used for natural gas that would adequately meet the needs of a distribution system. These are designed for a low-pressure system, utilizing welded steel pipes 20 to 24 inches in diameter. Valved laterals will be used at service connections. Different alternative configurations for a natural gas utility in a tunnel are discussed below.

Alternative 1. The gas main in this configuration will be in direct contact with the tunnel atmosphere. There will be no separate compartment provided for the pipe. The pipe itself will be either secured to the floor by means of a concrete base or will be suspended from the ceiling or a column. This latter position has certain advantages over the former. A pipe resting on a concrete base will be submitted to traffic vibrations from the street above which are transmitted through the tunnel walls and floor. These vibrations are known to have caused gas pipe ruptures during subway construction projects. It has been suggested that the gas mains be positioned as high as possible in the tunnel, above most of the possible sources of fire, because any gas leaking from the pipe would accumulate at the roof and be more easily vented out of the tunnel.

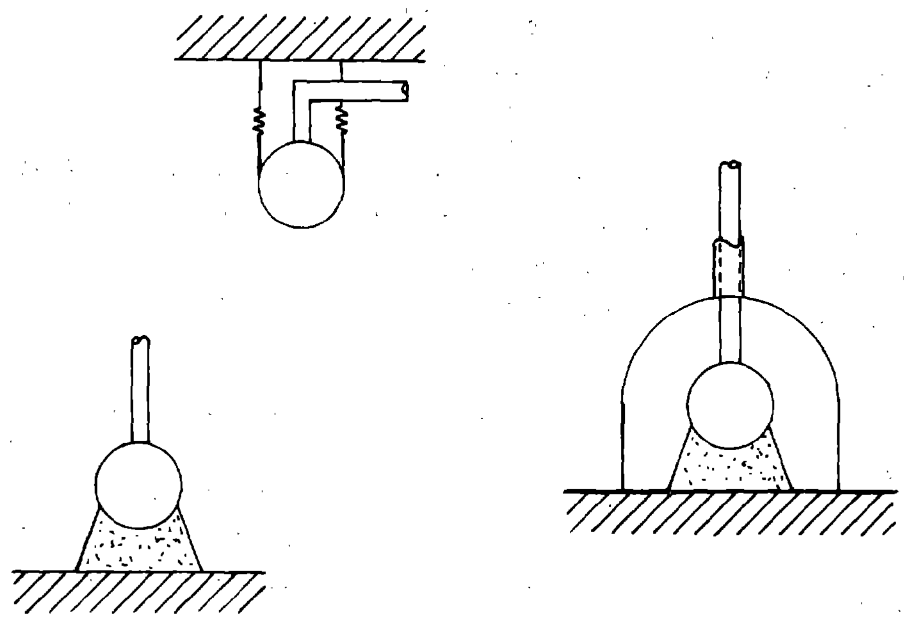
Corrosion protection in either case would probably be provided by a thin coat of epoxy resin. Such protection is merely a precaution, since the tunnel atmosphere will be precisely controlled to eliminate moisture and corrosive agents.

Support in the case of a suspended pipe will be provided at 20-foot intervals. Ceiling or wall supports will allow for thermal expansion or contraction of the pipe, eliminating the need for the pipe to rest on rollers. Thrust restraints may be necessary at pipe bends on high pressure lines.

If the pipe is to be supported on a concrete base, rollers at 20-foot intervals will be necessary to handle the thermal expansion effects. (See Figure 3-1).

Service connections will be taken from the top of the pipe, as laterals with valved connections of welded steel, and out through the wall of the tunnel. All auxiliary equipment will be supported by the tunnel structure as needed.

The advantages of having the gas main exposed to the tunnel environment are significant. Gas surveillance instrumentation will be installed in the tunnel to monitor the tunnel atmosphere and detect gas leaks. If a significant leak is detected, the tunnel emergency ventilation system will change the air as quickly as possible before the gas has time to accumulate in large quantitites. Gas utility workers will then be summoned to inspect the pipe and locate the leak. Direct access to the pipe will greatly reduce the amount of time required to locate and repair a leak. The gas utility will take advantage of the forced air ventilation system of

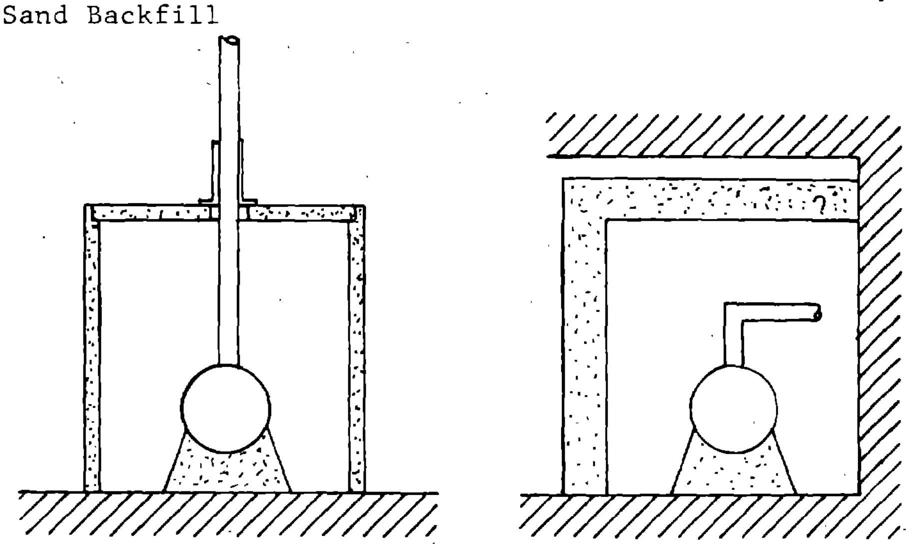


Alternative 1: Pipe Exposed

Alternative 2: Multi-Plate Shell

Alternatives 3 and 4: Removeable Lid With and Without Sand Backfill

Alternative 5: Protective Compartment



Note: independent ventilation required for alternatives 2 through 5.

Figure 3-1. Natural Gas Alternatives 1-5 the tunnel which is considerably less expensive than isolating the gas main and installing separate ventilation.

Alternative 2. The gas main in this configuration will be resting on a concrete base, similar to that in the first alternative, but enclosed in an arched shell of corregated 12 gage steel. The steel will be bolted to the floor at either side. It will be composed of standard multiplate arch so that one section at a time may be removed to inspect the gas main. In this way, any gas leaking from the pipe will be contained within the small area between the pipe and its surrounding shell. The enclosure will be tightly sealed and ventilated. (See Figure 3-1.)

Service connections will be taken from the top of the pipe through sleeved or sealed laterals. These lateral sleeves will be bolted to the main shell so that no gas will escape and vented to the air outside the tunnel by free air circulation, or a ventilation system completely separate from that of the tunnel.

The advantage of having the pipe encased in corrigated steel is that it would prevent or retard a gas leak from permeating the tunnel atmosphere. The shell interior would be equipped with gas monitoring instrumentation to detect excessive vapor build-up. The shell would render no protection in the case of a gas explosion, but it would serve as a shield against accidental damage by workers of other utilities. Because of the small enclosure volume, dilution of leaking gas is easily accomplished.

Alternative 3. The third alternative consists of a permanent structure with 6-inch concrete walls at least 2 feet from either side of the gas main. The walls are securely fastened to the tunnel floor, with notches for a removable cover. The cover would also be 6-inch thick concrete sections, approximately 6-1/2 feet wide and in about 4 to 8 foot segments. Each segment would be secured to form an airtight chamber with two feet of clearance on all sides in which the gas main could be housed, but from which the cover can be easily removed.

The main would be supported on a concrete base, as in alternatives one and two. Sleeved service connections would be taken from the top of the pipe and up through the cover to the tunnel roof. The compartment interior would require the special gas instrumentation and ventilation of alternative two. (See Figure 3-1.)

The advantages to this configuration are similar to those of alternative two. The cost of materials is considerably less for this arrangement than for that of a main in a steel shell, but what is saved in cost is most probably sacrificed in the limited working space that would result from walls in a fixed position. Hence, this alternative most likely will occupy a considerably larger space in the tunnel than any configuration considered thus far. Another disadvantage to this alternative is the probability that special tapping tools and other equipment might have to be designed to work in restricted space. As in alternative two, the concrete structure would not provide any explosion protection.

Alternative 4. This configuration is exactly the same as the preceeding one with the exception that the area within the concrete structure will be filled with soil, probably sand. Although this seems cumbersome when repairs are necessary, the rationale behind the design is the strong opinion expressed by some gas companies that leaking gas should be prevented from coming in contact with air at any cost. This configuration, it is hoped, will reduce the likelihood of a gas explosion by preventing a direct air-gas mix.

There are several functional problems that come immediately to attention. A section of pipe needing inspection or repair will require excavation, with the soil being stored within the tunnel while the utility work is in progress. There would be little benefit to the gas utility with this configuration, since inspection and repair methods would be the same as if the pipe were buried directly in the ground. Accidental dig-in damage would be eliminated.

Alternative 5. The fifth gas system configuration provides the main with a separate compartment. The compartment incorporates the side wall and floor of the utility tunnel and would isolate gas from the rest of the utilities by means of a 2-foot thick wall and roof. The gas compartment would be located about two feet below the roof structure of the tunnel to allow the laterals of other utilities to pass above the gas without sharing the same air or space. Support for the gas main could be modeled after alternative one; it could either be suspended from the roof of the compartment or rest on a concrete base. The compartment would be equipped with a separate ventilation system and instrumentation. Gas detectors and monitoring equipment would be located within the chamber. Laterals would be taken directly out through the sidewall on the near side of the utility tunnel or carried in sleeves to the far side.

Access to the gas compartment must be provided. This could be accomplished either through hatches directly form the surface or through the tunnel by means of sealed doors. Regardless of the access, the working space must be at least seven feet in height and at least two feet on either side of the pipe.

The major advantage of this configuration is that it not only prevents gas from leaking into the tunnel, but it provides explosion protection to the other utilities. The compartment would have to exist almost as a separate entity from the rest of the tunnel, with separate ventilation, lighting, drainage, and in some cases, access. The major drawbacks would again be associated with space limitations and new tool development.

Alternative 6. This configuration is that of a double-walled pipe. Both pipes will consist of the typical welded steel pipe used in natural gas distribution systems. The annular space of about one inch between the pipes will be filled with water. The advantage to this is to prevent the gas that might leak from the inner pipe from coming in contact with the tunnel air. The water will only be pressurized enough to eliminate any trapped air in the annulus. The inner pipe will be supported by flexible material at 20-foot intervals within the larger pipe. The entire system will rest on a concrete base or will be suspended from the tunnel roof. The support structures and laterals will be handled as those in alternative one. Tapping will be accomplished by the insertion of cut-off material such as a large seal ring to isolate a segment of the pipe which may then be pumped dry. Special tools have to be developed to work within a larger pipe.

The double-walled pipe will not provide protection against explosion and it will be housed in the tunnel proper along with all of the other utility plants. The high points in the pipe will have risers so that escaping gas can be detected by the rise of bubbles in the water. Gas detectors will also be necessary within the tunnel itself. Although this design prevents escaped gas from mixing with air, it seems more reasonable to use the first alternative of a single pipe thickness and spend the money it would cost to use a double-wall on more sophisticated gas detection equipment for the tunnel as a whole.

Alternative 7. The final alternative for a natural gas system would be that of conventional direct burial outside of the utility tunnel. This would dispel some of the concern expressed by many utilities, but would not eliminate the disadvantages of the direct burial method, which is also hazardous to the tunnel.

One of the most common causes of gas main rupture is damage by accidental puncture and damage by ground movement. Although many utilities would be housed in a tunnel and the need for many street cuts would be eliminated, excavation of the gas main would still be necessary when repairs are required. With excavation there is always a chance of puncture or damage unless the location of the utility is precisely known. Once excavated, the gas utility must be backfilled and, with time, backfill may settle resulting in rupture.

If a gas main is ruptured or if gas is leaking from a joint connection and goes undetected, gas will travel through the soil interstrices and will fill any voids in the immediate area. This may either be a void in the soil or a nearby utility tunnel. Regardless of the actual pipe location, if gas enters the tunnel from the soil outside, it may accumulate in large enough concentrations to cause an explosion. The danger of a buried gas main is that the odorizing agent may be leached out in the soil and the gas may go undetected by its odor. For this reason it will be necessary to install gas sensing instrumentation within a utility tunnel, regardless of whether the gas pipe is inside the tunnel structure or not.

Natural Gas Summary. Past experience has demonstrated that gas lines may be incorporated into a utility tunnel without serious problems, despite opinion to the contrary. It has been successfully accomplished in Japan, East Germany, and England. The requirements of a modern natural gas distribution grid closely parallel to those of most major utilities, so that joint occupancy in a tunnel appears to be a reasonable concept, provided that the other utilities are not unduely endangered or that the costs are not prohibitive.

In speaking with gas company representatives, many configurations were suggested but only the most feasible alternatives have been discussed in this report. Although seven alternatives have been identified, all with seemingly different requirements, a general statement as to the configuration criteria that must be met for natural gas systems can be outlined at this point.

a) Sophisticated gas vapor detection equipement in the tunnel is necessary, regardless of whether the gas line is located inside or outside of the tunnel.

b) The prevention of a gas-air mixture must be a prime objective in the selection of a high quality pipe and the method of joining pipe segments.

c) The complete isolation of gas and air is not as imperative as the need to quickly detect a leak and prevent the tunnel atmosphere from becoming toxic or explosive.

d) The complete protection of other utility plants from a gas explosion is nearly impossible as long as the gas main is housed in the tunnel, but adequate shielding from accidental damage by other utility workers should be provided. This may be accomplished by partial or complete isolation, or by chain-link fence partitions, etc.

There now exists instrumentation so that the inclusion of a gas main in a utility tunnel, rather than resulting in unduely hazardous conditions will be safer provided that the proper precautions are taken.

### 3.1.2 Electric Power Configuration

Primary electric power distribution systems are generally of the grid pattern, conforming to the street lay-out in most urban areas. This system of conductors serves distribution transformers from distribution substations. These transformers reduce the bulk power of the 2.4 to 46 kv primary cables to below 600 volts, which is used in secondary cables that service customer premises.

There are five types of power cable construction, but only three are found in a primary distribution system. These are:

a. Those insulated with oil/paper or lead sheath jackets, 2-4 inches in diameter used for voltage between 5 and 27 kv, primary cables.

b. Those solid dielectric, insulated with polyethylene or rubber, 1-5 inches in diameter, used for voltage between 5 and 69 kv, primary cables.

c. Those solid dielectric, insulated with polyethylene or rubber 3/8 to 1-1/2 inches in diameter, used for voltage up to 600 volts, secondary service cables.

The choice of cable and insulation type depends on voltage, installation conditions, load, and other factors, but generally the higher capacity cables have lead sheaths and those of lower capacity are insulated with rubber or plastic.

There are many examples of both primary and secondary electric power lines successfully housed in tunnels through-out the world. Electric cables up to 30 kv are now included in tunnels in East Germany. In Madrid, lines up to 138 kv are permitted. The 345 kv electric cables installed in oil-filled pipes in the Consolidated Edison Utility tunnel in New York are likely the largest existing in a multi-service tunnel. No interference with communications or over-heating of the tunnel has occurred. In London, electric power and communications cables are housed in the same tunnel with no compatibility problems. There seems to be confidence in new materials and a growing conviction that higher voltage cables can be installed in a common tunnel without mishap or interference problems.

The majority of service interruptions in conventionally buried electric power lines are the result of accidental damage by contractors or other utilities doing their own excavation. Power lines may also fail due to corrosion, sheath fatigue, and high side wall pressure.

There are various general requirements which must be met if electric power cables are to be housed in a utility tunnel structure. Space requirements are easily identifiable. Space must be applied for splicing and repair operations of the cables. One cable must be able to be withdrawn so that it can be hung with at least one foot of space around it to perform splicing operations. Provisions must also be made for cable pulling eyes and cable bends in secondary laterals. Auxiliary equipment and transformers are housed in vaults. During the CUTD study, the transformers were redesigned to fit into an area 7 x 11 feet in cross-sectional dimension.

The tunnel environment must be relatively dry and of moderate temperature. High temperatures will reduce the capacity of the cables. Because of this concern, careful attention must be paid to the heat generation of the cables used. The heat dissipation for cables used in a primary distribution network ranges from 2 to 25 watts/circuit foot. The thermal effects of placing distribution cables in a utility tunnel were estimated by a private electrical utility company using the following assumptions to obtain maximum summer air temperatures in the tunnel:

Outside air temperature is 35°C (95°F)

Average ambient ground temperature is 27.5°C (82°F)

Two-thirds of the cables installed are 12 kv, one third are secondaries

A system average loading on cables is assumed.

Based upon using cables sized to their ratings in conduits, the following temperatures were estimated for the tunnel air:

28-12 kv and 14 secondaries will cause an air temperature of 104°F without air circulation.

16-12 kv cables and 9 secondaries would cause an air temperature of 95°F in the tunnel without air circulation.

Oversizing the cables will decrease the temperature or increase the number of cables permissible in a direct ratio to the circular mil size. For example, using 750 MCM cables for a 500 MCM secondary rating would allow 50 percent more secondaries, or would drop the air temperature 0.24°F for each cable used.

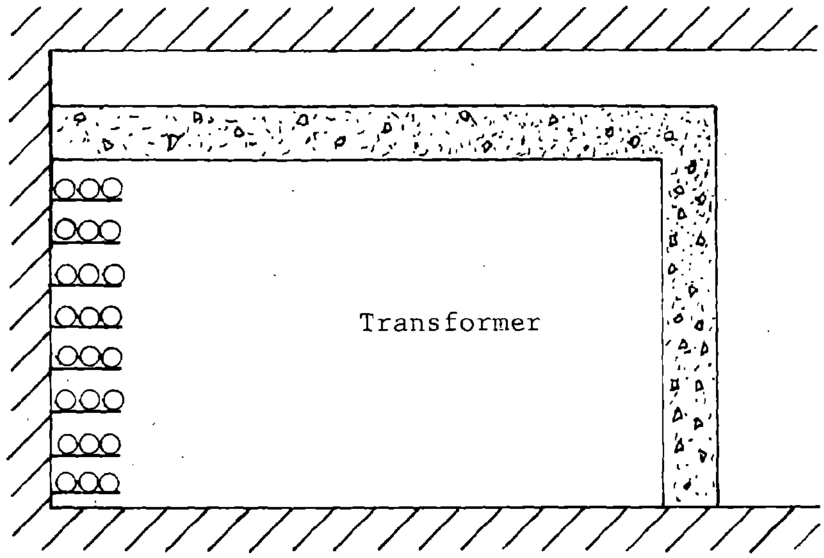
This means that ventilation of the tunnel is a primary concern. If circulating fans run all night during the cooler air period, it would give enough extra thermal capacity to the surroundings to drop the peak daytime temperatures about 5°F. This means that forced air ventilation would be required in the tunnel for reasons other than the inclusion of the gas mains.

Safety requirements must also receive attention. High voltage cables must be readily identifiable and situated so that no danger exists to other utility workers. Transformers must be housed in vaults that provide protection to the rest of a tunnel in the case of an explosion. Cables should be checked for faults periodically to avoid the possibility of fire and explosion. Gas and electric power should be separated in the tunnel and any power cables crossing another utility plant must be encased in ducting.

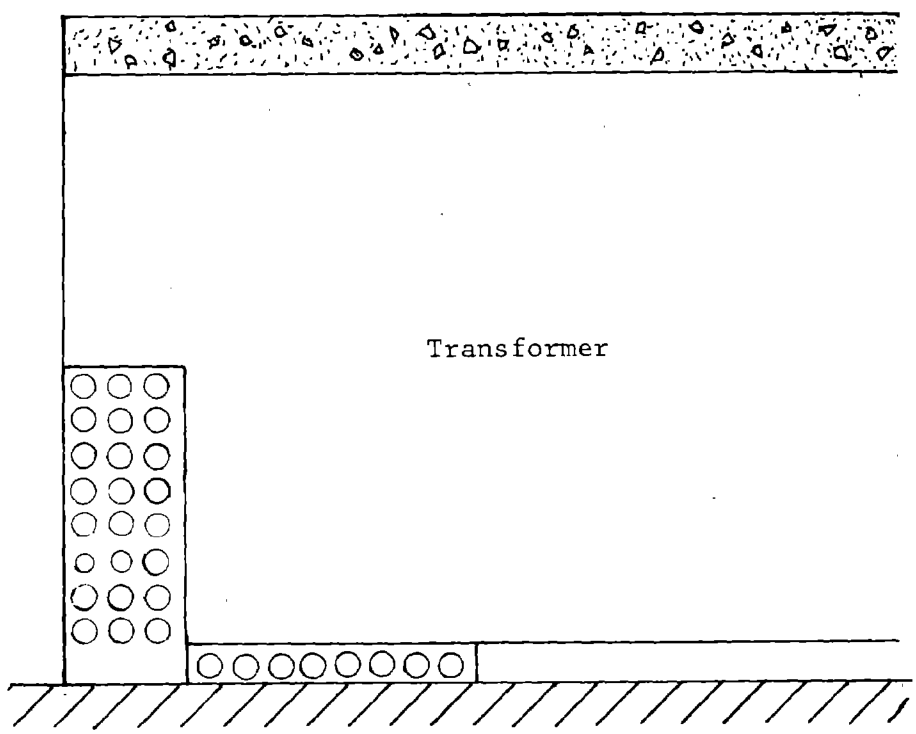
Many questions have been raised as to the compatibility of power cables and communications lines. Even though magnetic and electric induction interference is a possibility, experience (particularly in the German Democratic Republic) has demonstrated that adequate insulation exists so that interference problems can be easily eliminated. (Refer to Section 3.1.3-Wire Communications.)

Several options exist concerning electric power cable and auxiliary equipment placement within a utility tunnel. Generally, power cables will be placed on the opposite side of the tunnel from gas and communication utilities to minimize the possibility of explosion or inductive interference. Transformers will be located in closed vaults along one side of the tunnel. Power cables using oil impregnated paper as insulation must be kept essentially flat to prevent the migration of oil. Full length support of cables is necessary, and those in pipe must be supported every 20 feet on rollers. Secondary and primary cables will be separated. Various alternatives are described in the following sections.

<u>Alternative 1</u>. Power cables may be exposed their full length and provided with cable racks at the three-foot intervals. Primary and secondary cables will be separated so that the secondary cables having service connections and laterals will be closer to the tunnel roof. The cable racks will support three cables each and will be fastened to the tunnel wall. The vault will utilize both the floor and sidewall of the tunnel as part of its structure. Room will be allowed for one 10 x 12 inch splice on each rack so that any more than one splice per rack will have to be staggered. There will be a three-foot working aisle between transfomer and cable racks to provide for repair and splicing. (See Figure 3-2.)




Alternatives 1 and 2: Exposed Full Length or in Ducting Between Vaults




Alternative 3: Concrete Duct Banks

Figure 3-2. Electric Power Alternatives 1-3

A modification of this exposed cable design would be to have cable laying in split ducting on racks. This configuration would have the advantage of keeping the cables separate and in proper spacing to prevent short circuits and overloading, would serve as additional insulation to protect against overheating, and prevent flammable liquid spills should one of the cables cooled with gas or oil fail. These trays may be lined with fire-resistant material to further limit the spread of fire.

Alternative 2. The second configuration is much like that of alternative one, except where the cables pass between the transformer vaults and along the tunnel wall they will be housed in steel conduit. The steel conduit will be supported on rollers at 20-foot intervals to allow for thermal expansion and contraction. High voltage cables may be cooled with a harmless gas pressurized within the pipe, but cables in a primary distribution network are restricted to lower voltages and the gas is not necessary. The steel conduit may be fastened to the wall, rest on racks, or may hang from the roof depending upon the arrangement of cables within the vaults. Normally, pipe sections are from 20 to 40 feet in length. Cable pulling will be executed from the point where the cables enter the vaults. Pulling up to 1000 feet of cable is now possible, so that pipe sections may be joined once they are in the tunnel and the cables pulled through the longer sections with no difficulty.

The advantages of having cable exposed in transformer vaults and in steel conduit between vaults are due to the increased safety aspect of eliminating exposed cables in the tunnel proper. The conduit will guard against accidental damage, overloading, bunching, etc., of the cables. Having the cable exposed in the transformer vaults will facilitate inspection and failure detection, cable pulling operations, splicing, and repair work. This arrangement will also reduce the possibility of interference with communication utilities. All laterals crossing other utility plants will be in ducting.

Alternative 3. In this configuration, the power cables would be located in steel pipe in concrete duct banks with the primary and secondary cables occupying distinct positions. The banks might be located anywhere there is room. Basically nothing would change for the power utilities from the present conventional burial except that work could be done at any time in the tunnel and damage from dig-ins would be eliminated. Laterals would be taken from the transformer vaults and across the roof structure to a service connection. (See Figure 3-2.)

The advantage to this configuration is that it is the safest, least conspicuous arrangement for power cables. Induction interference would not be a problem; cable failures, short circuits and overloads would not present the fire hazard that it would were the cables exposed or in steel pipe. The possibility of damage from other utility workers would be remote, and the problem of heat dissipation would be reduced.

Alternative 4. This alternative consists of conventionally burying the cable outside of the tunnel. This would also include the location of transformer vaults and all power utility auxiliary equipment either in the basement of the buildings they service or somewhere in the street right-of-way outside the tunnel. This arrangement may result in crowding, since the location of transformer vaults outside the tunnel walls would take up a considerable portion of the space reserved for sewer lines.

Excavation or manhole work would be necessary to repair or install new facilities. This work could only be done at night unless an emergency dictates otherwise.

Manhole work is restrictive and is likely more dangerous than working in the carefully monitored environment of a tunnel.

Primary Power Summary. The configuration of a primary distribution system, unlike gas and water utilities, has the advantage of not being restricted to one design within a given tunnel section. The choice of power cable arrangement is dependent upon the conditions at a specific location within the tunnel, such as the amount of space available, the number of primary and secondary cables, other utilities included in the tunnel, the complexity of intersections and the number of laterals and service connections required at a given point. Where wall space is deemed insufficient, additional cables may be hung in ducting from the roof or may be encased in concrete in the floor.

Although the actual configuration of the electric power cables is determined by the needs at any one location in the tunnel, several general statements can be made at this point.

a) Sophisticated heat detection and sensing equipment must be installed in the tunnel which can trigger the emergency ventilation system if the temperature increases beyond a specified level.

b) Fire and smoke detection instrumentation must be employed to guard against the spread of electrical fires.

c) Adequate space must be provided for cable splicing and pulling operations.

d) Adequate space must be provided for proper heat dissipation and forced ventilation should be used, when necessary, to keep the tunnel temperature at a suitable level.

e) Transformer vaults must be housed in a separate compartment which would shield other utilities from a possible explosion.

f) Identification of high voltage power cables must be provided.

Whatever the configuration within a given tunnel, there is a consensus that there are no technical reasons which would prohibit the incorporation of electric power distribution systems in the utility tunnels shared by other utilities.

### 3.1.3 Wire Communications Configurations

Wire communications systems include those of telephone, telegraph, fire and traffic signal controls, security service, data transmission and cable antenna television (CATV). The largest to consider is the telephone system and will serve as a basis for this discussion. All other wire communications will often share ducts and will follow the telephone's pattern of distribution so their requirements are essentially the same.

The telephone system that would be incorporated in a utility tunnel consists of intercity and local interoffice truck circuits, which seek the shortest distance between two offices, and local customer loop circuits. Circuitry in urban areas is in the form of multi-pair cables encased in lead, rubber, or plastic sheath. Each customer has one or more individual pairs of wires from her property to a switching machine or central office. The largest cable currently in use is 3.1 inches in diameter and composed of 2700 pairs of individual insulated wires. The large urban areas feeder routes are composed of 25 to 50 cables. Disruption of a branch or feeder may put a large number of people out of service, which can only be restored when the cable is replaced or wires reconnected (Lowe, 1971). Telephone lines are incorporated in practically every utility tunnel in existence. They are housed with electric power lines, gas mains, steam lines, oil lines, and water lines with no apparent difficulty.

The space requirements of the telephone system located in a utility tunnel are difficult to enumerate. They are a function of the location of the tunnel relative to the telephone system. There must be room for cable splicing and installation, as well as vault space for loading coils and electronic amplification apparatus. These vaults occupy about 1000 cu. ft. and must be spaced at one-mile intervals. Space must be provided for up to 100 cables in some instances. Individual cables must be able to be separated from their support and be surrounded by at least one foot of working space for splicing operations (Lowe, 1971).

Most telephone and other wire communications systems fail due to accidental damage by other utilities (SR39). Since the cables are somewhat flexible, minor earth movements have no effect on the operation of the system. Corrosion protection is a major concern. Telephone cable electrolysis is the result of the cable being exposed to moisture so that an electro-chemical reaction takes place. To resolve this problem, humidity control, coatings, and cathodic and anodic protection may be used.

Perhaps the primary reason that the idea of installing wire communications in a utility tunnel has met any opposition has been anticipated interference from the power utility plant. Without special treatment, the interference may range from low level noise to voltages or currents high enough to damage communications equipment and result in personal danger. The magnitude of induced voltage increases with longer exposure lengths, smaller separations, and larger amounts of electrical power. It relates to the electric and magnetic fields surrounding electric power conductors. Inductive fields may be minimized through configuration design and conductor shielding (Granquist, 1971).

Conductive interference is the result of conductive coupling, which is caused by an existing potential gradient between the ground contacts of the power and telephone systems. It may cause heating and subsequent failure of the communication system, or an intolerable noise level. Several methods are available to decrease conductive interference, including resizing of the power conductor, addition of blocking circuitry, better grounding, and maintenance of proper impedances (Granquist, 1971).

If these interference problems are not corrected, sufficient voltage levels may accumulate to endanger communications workers. One way in which these problems may be reduced is to put either electric power cables or telephone cables in ducting. Proper three-phase balancing of the systems and filters to reduce harmonics also serve to relieve the problem. With proper operating procedures, power and communications systems are compatible, as evidenced by many existing utility tunnels and other shared facilities.

The requirements of the wire communications are similar to those of electric power in many respects. The alternatives for telephone cables are discussed below.

Alternative 1. Telephone cables may be hung on racks or may rest in split ducting which is hung on racks. There is little that exposed telephone cables can do to endanger other utility plants, so that having exposed communications cables is not hazardous to the tunnel. The cables are flexible and will require support every three feet.

Racking arrangements will place five cables on each extension, with enough space on each rack for at least one 12-inch diameter splice. The racks will remain at least two feet from the precast roof beams to allow for room for laterals which must cross above the communications plant. The racks will either rack five three-inch cables on each shelf on one side or will utilize the center racking arrangement of three cables on either side of the rack support.

This racking would reduce the difficulties which might occur by having to retrieve the innermost cable when the cables are five-deep on a shelf. The outside of the double racking arrangement would support other wire communications, so that telephone cables would be racked on either side of one aisle. Space requirements and utility worker preference will determine which racking arrangement will make optimum use of tunnel space and repair time. (See Figure 3-3.)

The advantages of having exposed cable the entire length are apparent. Inspection and repair work will be easier and less costly than when cable is in ducting. Laterals and splices may be located anywhere along the entire cable length, which will relieve the congestion that is now found in manholes. This design allows the telephone cables to remain exposed within the tunnel without fear of interference from exposed power cables, since one or the other must be in ducting to reduce inductive interference.

One hazard of having exposed telephone cables in the tunnel is that they are vulnerable to accidental or deliberate damage. This becomes a concern when the complexity of multi-pair cable repair or the number of customers without service in the event of damage is considered. A chain-link fence or similar device could be used to isolate the plant if such measures are deemed necessary.

Alternative 2. This alternative consists of housing the telephone cables in ducting, most likely PVC pipe. Laterals would travel along the precast roof sections and exit through the tunnel walls. The racking configuration would resemble that of the first alternative and would depend upon the amount of space available in the tunnel and the worker preference. Room for cable pulling and the devices that are involved in the operation will be a function of the racking arrangement. Splicing will be done at conduit junctions. (See Figure 3-3a.)

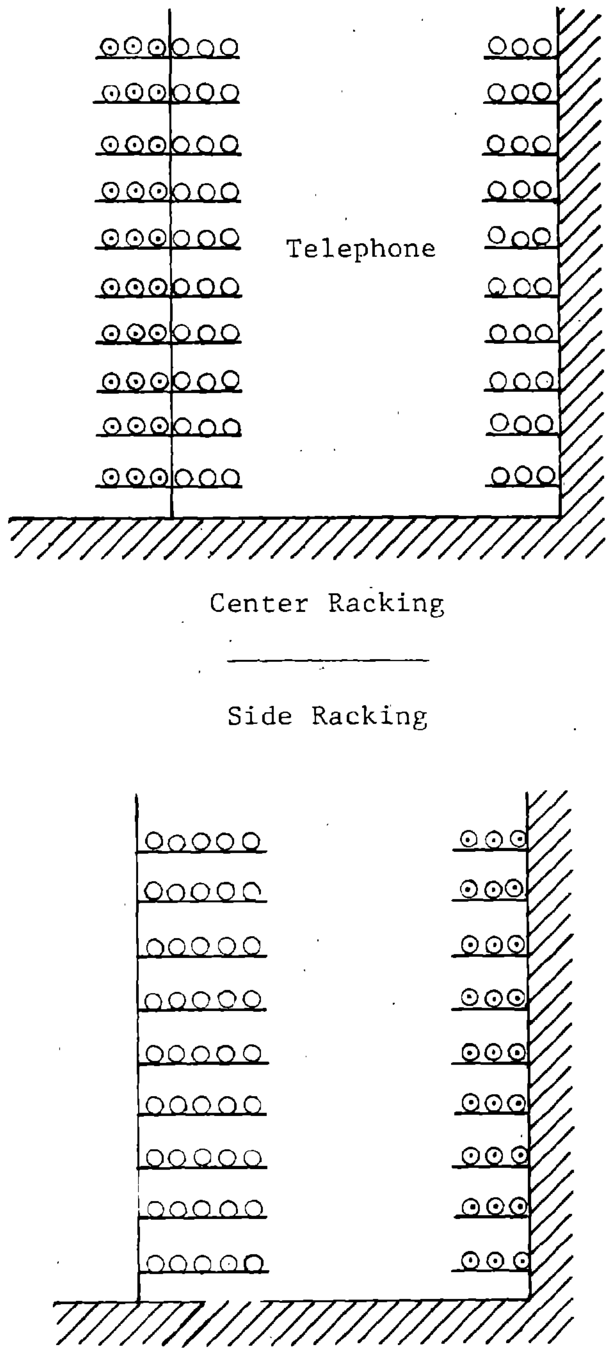



Figure 3-3. Communications Alternatives 1 and 2

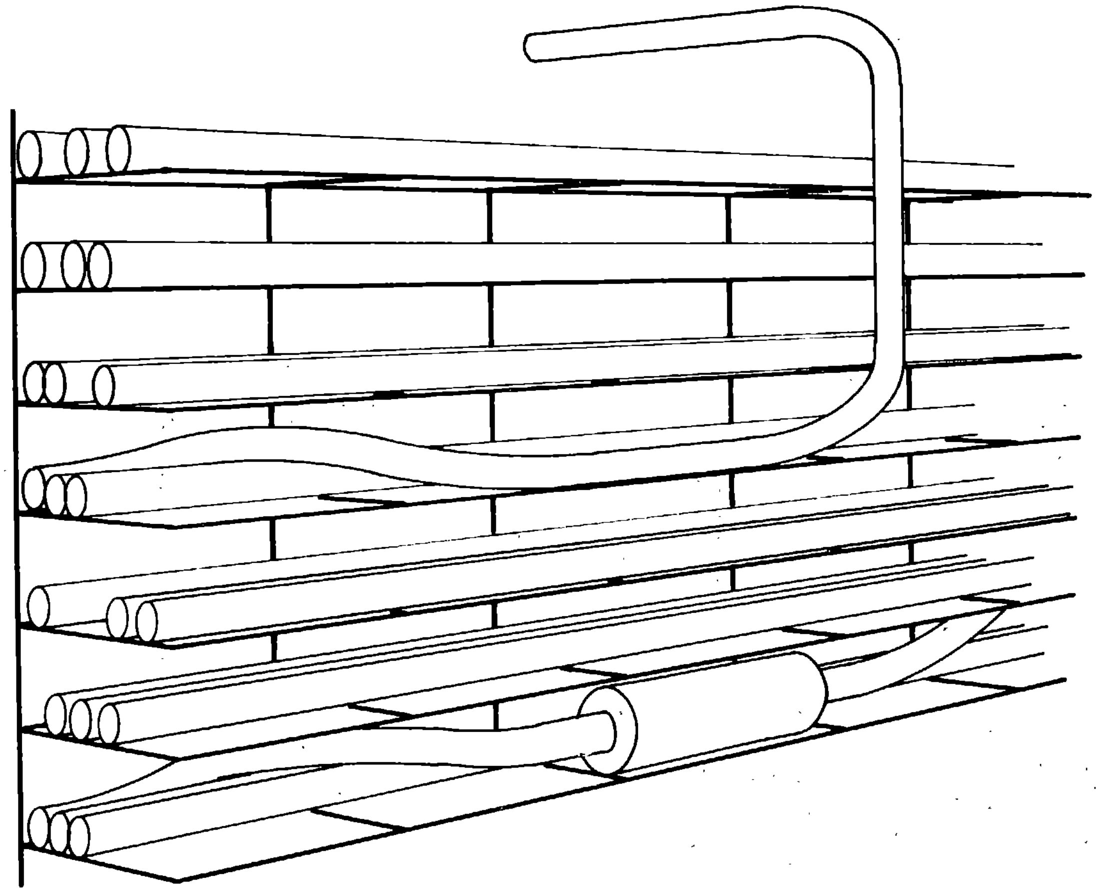


Figure 3-3a   Details of Cable Lateral and Splice

The advantage of this configuration is the additional protection against electrical interference and damage provided by the ducting. This alternative would definitely be more costly than having exposed cables in the tunnel, but the extra protection might prove to be worth the additional expense.

Alternative 3. This alternative finds the telephone cable conventionally buried in the ground. Usually the cable is encased in concrete duct banks to guard against moisture and confusion. Cable inspection is done either in manholes or after excavation. Splicing is restricted to the manholes from where all cable pulling takes place. Quite often in populated urban areas, the manholes are so crowded with ducts crossing through them that the use of the bottom ducts is lost because they become impossible to reach. In some cases, communications and power utilities share split manholes, where there is isolation of each plant within a manhole.

Wire Communications Summary. There is no technical reason which would prevent the inclusion of the wire communication systems in a utility tunnel. Past experience has shown that modern insulation and minor adjustments may be made to reduce the liklihood of electrical interference. Communication cables, themselves, have very little effect on the other utilities in a tunnel. Moderate temperature and humidity are required for optimum performance, but these requirements are common to most utilities. The cables may be protected against corrosion by various methods now in use.

A general statement may be made about the wire communications configuration at this point.

a) Specific racking arrangements will be determined by the number of cables being used, the amount of space available, and the most efficient method of inspection and repair.

b) Telephone and communication cables will be located on opposite sides of the tunnel from electric power lines. Protection from electric inductive and conductive interference must be provided.

c) Space must be provided on each rack for at least one splice and working space must be available for these operations.

d) Adequate space must be provided for cable pulling operations.

### 3.1.4 Water Supply System Configurations

Water supply systems in urban areas that will be of interest to this study are composed of distribution mains, reserve reservoirs, pumping stations, and service connections. Most systems supply domestic, industrial, and fire fighting needs from the same network. There are, however, many systems which have separate high pressure fire mains. Distribution networks can be either branched or a grid pattern, with grids predominating in urban areas, and the choice of pattern depending upon urban density, street plans, or topography. Dual main systems are most prevalent in urban areas because of the cost of extra service length.

Pipe materials include cast iron, welded steel, asbestos-cement, and ductile cast iron. Plastic pipe is being introduced for smaller sizes. Various coatings, both internal and exterior, are available to resist corrosion. The minimum size is 8 inches; 24-inch pipe will be used for the purposes of this report, although pipes up to 48 inches may be encountered. (Amory, 1971)

Auxiliary equipment required for a water distribution system includes valves, pressure controls, surge protection devices, and pump stations. Valves are spaced so that no single break in the line will affect more than a 500-foot section of main. This means valves at every branch connection and at least two at cross-connections. Fire hydrants are generally spaced 150 feet apart. (Amory, 1971)

Support is required at every pipe joint, which is about every 20 feet. Thrust supports will be required at short bends for some pipe configurations. Expansion and contraction supports are generally not required.

The temperature of potable water must not exceed a certain level, as it will become undersirable for drinking purposes. Most palatable water is from 40°F to 50°F and should not exceed 70°F. The allowable tunnel temperature will depend upon initial water temperature, minimum flow, and other factors, but must not show an increase of more than 5°F in excess of that caused by exterior ambient conditions. To minimize the fluctuating temperatures in a tunnel, the water line should be insulated, and proper tunnel ventilation should also be provided. Many of these same considerations also apply to pipelines buried in the ground. (Amory, 1971)

Safety concerns have been expressed, both for the pipeline and for the tunnel. The pipeline must itself be protected against corrosion, rupture, extreme temperature change, and possible contamination. The tunnel must be protected from flooding. It is felt that main leaks or ruptures may not pose a serious problem. This assumption stems from several reasons:

a) The volume of the tunnel is extremely large in comparison to the volume of water that would flow into it before emergency measures could be taken.

b) Adequate drainage will be provided in a tunnel, sump pumps will be employed, and an emergency overflow system will be available for the flow in excess of what the pumps can handle.

c) Many utilities will be hung and all are immursible, at least for brief periods of time, so that no serious damage would result from an exposure to water. Transformers will be located in waterproof vaults. (SR39)

Several options are available for the design of pipe utilities in a utility tunnel, and are discussed below.

Alternative 1. The water main may rest on a concrete base which is secured to the tunnel floor. This base may either be continuous or intermittent (at 20-foot intervals). Thrust restraints at sharp bends may be necessary with this design. The pipe will also be insulated against temperature change. (See Figure 3-4.)

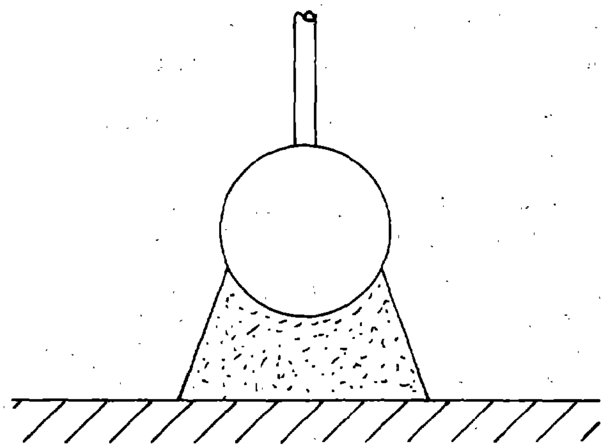
One of the disadvantages of having the water main resting on a concrete base is that trafic vibrations from above will be transmitted to the pipe and could cause a weakening or rupture.

Service connections will be tapped into the top of the line and will run along the roof sections and out through the tunnel. The insulation of service connections as well as ventilation and humidity control, will reduce any condensation which might form on the pipe and result in damage to other utility plants as water crosses over.

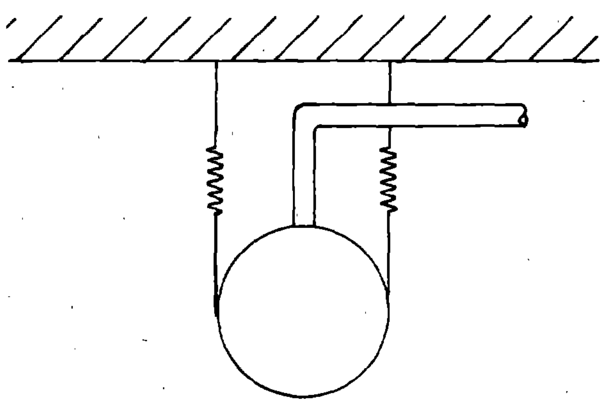
Alternative 2. The water main could be suspended from the tunnel roof. Flexible supports will be required every 20 feet. These support springs will dampen the effects of traffic vibration. Thrust restraints may be required at sharp bends. (See Figure 3-4.)

The pipe will be in close proximity to the tunnel roof, which will reduce the length of pipe needed for laterals and service connections. The space requirements for tapping, inspection, and pipe repair are the same for both configurations.

Alternative 3. This alternative finds the water mains conventionally buried in the ground. This configuration dampens the effects of vibration and drastic temperature change, but has disadvantages. Any pipe repair, inspection, or tapping can only be done once the pipe has been exposed by excavation. This makes inspection nearly impossible and repair very costly. If the water main is buried with a utility tunnel sharing the right-of-way, a dual main system is mandatory. The buried water main will also have to endure possible rupture as a re-



Alternative 1: Concrete Base Support



Alternative 2: Suspension Support

Figure 3-4. Water System Alternatives 1 and 2 sult of accidental damage of minor earth movements

Water System Summary. Several general statements about the water distribution system configuration in a utility tunnel may be made at this point.

a) Flood detection instrumentation must be installed in the tunnel.

b) Adequate drainage, emergency sump pumps and overflow system must be provided

c) The tunnel temperature must remain under a specified level to successfully house potable water. Heat detectors should be able to trigger emergency ventilation. The pipes must also be insulated against temperature change.

d) A forced air, 24-hour ventilation system must be installed in the tunnel.

Adequate tunnel alarm and drainage systems make the inclusion of a water distribution system within a utility tunnel a viable possibility.

3.1.5 Sewer System Configuration

Wastewater systems include both sanitary and storm collection. These exist as separate or combined facilities, with many modern cities switching to separate systems. Sewerage collection systems in urban areas are arranged in networks permitting gravity flow to treatment or disposal plants. Grades are generally between 0.5 and 2.0 percent. Abrupt grade changes are overcome by drop manholes or pumped lift stations. Collection networks must be deeper than the buildings that they service, so they are often the deepest utility found in the street right-of-way. (McPherson, 1971)

Sewer pipes vary in size from 8 inches to several feet in diameter. Vitrified clay, concrete, asbestos-cement, cast iron, corrugated metal, plastic, and lightweight fiberglass are all used as pipe material. The choice of material depends upon the pipe size and the composition of the material being transported. Often they are lined to resist corrosion.

Due to the short sections of pipe (around 7 feet), sewer lines require almost continuous support, or at each junction at the very least. Moderate temperatures are not as important to sewage as to potable water and no insulation would be needed. Careful attention should be paid to pipe junctions and connections, because leakage from sewer lines might contaminate the tunnel environment. This is not generally of concern, because welded pipe and modern technology have made leakage at junctions rare.

Since sewer collection systems are gravity flow systems, their grade requirements are relatively inflexible. This is the primary reason that sewers have seldom been included in utility tunnels in the past. Their inclusion is only possible where their grade is coincident with that of the tunnel, or where the tunnel is actually built with the grade required in the sewer lines. Another occurance of sewers in utility tunnels is in those cold regions where sewer lines would otherwise freeze. Aside from these rare instances, gravity sewers do not seem to be a likely candidate for inclusion in a utility tunnel (SR39)

A feasible method by which gravity flow systems may be included is to provide a separate compartment along the sides of the transportation/utility tunnel structure shown in Figure 3-5. This would require little additional structure, and would permit total access to the system while eliminating infiltration. To construct a structure such as that appearing in Figure 3-5, one must investigate the nature of the adjacent buildings to determine whether foundation problems would result.

Pressurized sewer lines might well be included in a tunnel, although their use is not widespread at the present time. They would require pumping and grinders, but this extra cost would partially be recovered in the reduced size of pipe that would be used. Pressurized systems should be considered as a future possibility.

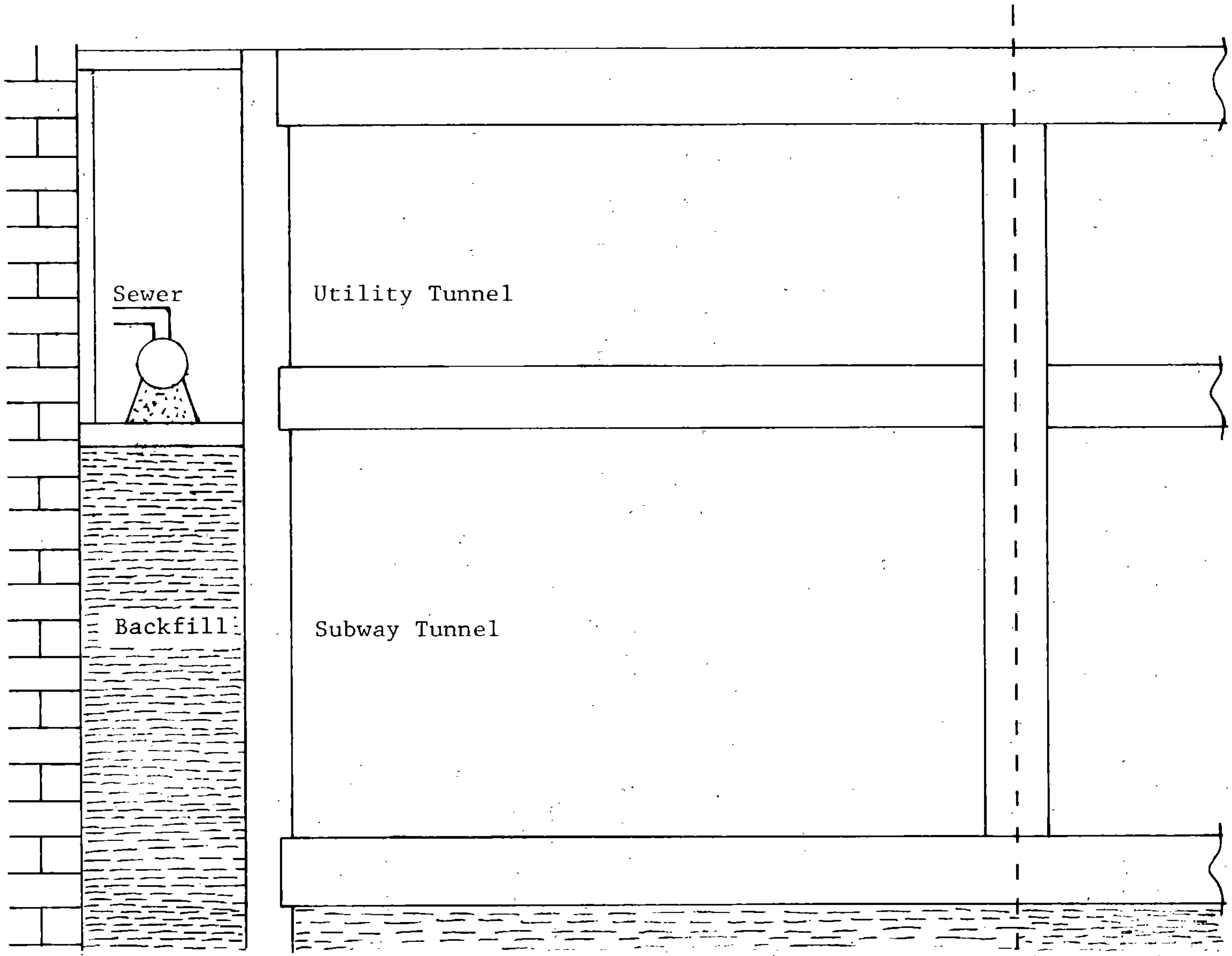



Figure 3-5. Gravity Flow Sewers in Supplementary Structure

Sewer System Conclusions. Gravity flow systems will seldom be included in utility tunnels. Where a utility tunnel is used, two sewer lines will be necessary in urban areas, one on either side of the rights-of-way. This will allow access to service connections at either side of the street.

Pressurized systems in a tunnel would follow the same criteria as that used for water utilities. Gravity flow systems housed in compartments on either side of the street are subject to the following criteria:

a) Adequate ventilation is essential.
b) Sewers must be vented to allow for escaping gas.
c) Gas detectors will be installed in the tunnel to monitor toxic fumes.
d) Underpinning requirements of adjacent buildings must be evaluated.

Pressurized systems can easily be included in tunnels with other utilities. The idea of housing gravity flow systems in separate compartments adjacent to tunnels is a viable possibility.

### 3.1.6 Other Utility Systems

A utility tunnel project should also consider inclusion of both smaller and less commonly used utilities. Among these are central heating and cooling (steam lines and chilled water), city power (electric), solid waste slurry, petroleum and chemical transport, secondary quality water, pneumatic mail handling and parcel delivery, and solid waste collection systems. These may be divided into cable utilities and piped utilities.

The cable utilities, basically city power, will demand little tunnel space and will operate at low voltages. It may be prudent for them to share ducting with electric power utilities, with some arrangement being made for city power workers to have access to transformer vaults to do repair and splicing work on their cables. All safety precautions dictated by electric power should adequately meet the needs of the city power.

The pipe utilities listed above will have many of the same requirements, such as support, thrust restraints, etc., as a water supply system. The largest, most common of these systems is central heating and cooling.

3.1.6.1 Central Heating and Cooling

Central "district" heating has a long history in older urban areas, but central cooling is relatively new. Heating pressures are on the order of 300 psi. Central cooling is accomplished by a chilled water system, operating at temperatures between 40°F and 55°F and pressures on the order of 125 psi. Both require supply and return lines. Return is generally a condensate requiring a smaller line in the case of a steam system. (Pohlkotte, 1971)

The network is entirely dependent upon the users, so no definite pattern has been established. A requirement for both is considerable insulation to prevent heat gain or loss. The thickness of the insulation varies from 1 to 6 inches, and it must be kept dry to keep its thermal conductivity at a minimum. (SR39)

The pipes are predominantly welded steel. Those buried in the ground are in conduit to protect the insulation. The primary concern is the prevention of moisture from coming in contact with the insulation. Provision for thermal expansion and contraction of the pipe is also necessary, and those on concrete bases will require rollers, while those suspended will employ spring-device supports.

Laterals will be tapped into the mains and provided with valved connections. Condensate traps are necessary every 300 to 400 feet for steam lines.

The effect of the inclusion of these lines on the tunnel environment will most probably be an increase in temperature, so adequate ventilation is extremely important. If the tunnel temperature is held below a maximum of 90°F, no temperature effects will be felt by most other utilities (electric power, gas, communications) as they are designed to operate at this level without loss of capacity. With sufficient insulation and ventilation, central heating and cooling lines can be housed in tunnels with other utilities without detriment. In fact, being high maintenance systems, their presence in an area is frequently a strong argument for a utility tunnel.

3.1.6.2 Other Pipe Systems

There are a few special requirements of the other pipe systems which might be included in a utility tunnel. Pneumatic mail handling systems and solid waste collection systems must avoid sharp bends. Petroleum and chemical pipe lines transporting hot material would need insulation. These systems, with the exception of the solid waste slurry system, are not new and have been used in Europe for many years. They would be treated in a similar manner to that of the conventional water supply system.

3.1.7 Future Utility Expansion

The expansion of a utility plant in a tunnel will be influenced by two factors, the growing need for service and the development of new and improved systems. This progress might either reduce or increase the space requirements of a particular utility, depending upon the mode of operation. For example, the communications industry is developing new methods of transmitting a greater quantity of information more efficiently. The work is being done primarily in the fields of fiber optics and waveguide systems. These systems will have the capability of carrying more information in a fraction of the space now required for multi-pair cables. This will result in greater transmitting capacities in a significantly reduced space, so that, although the communication plant would be expanding its capacity, it would actually be reducing its physical space requirements. These systems are particularly well suited to a tunnel environment.

The electric power utilities, on the other hand, could increase their capacities only by adding more wire to their cables. This would result in an expanded plant that would require more space in a tunnel. These factors must all be taken into account when space is reserved by various utilities.

The expected life of the tunnel is another essential parameter to consider when planning for future expansion. The designs studied in this report are expected to provide service indefinitely.

The inclusion of more utilities as they develop or as needs arise means that the existing space in the tunnel must be used to its best advantage. This may mean, for instance, that instead of using current methods for cable pulling, tapping, and insulating pipe, new designs will need to be developed so that utility maintenance may be accomplished in smaller space. This will allow utility plants to be positioned closer together and leave more room for new facilities.

### 3.1.7.1 Millimeter Waveguide Systems

Present intraurban communications networks are primarily comprised of cables containing unshielded, twisted copper wire pairs, originally designed for signal transmission at voice frequencies. Circular waveguide systems have been developed which enable broader band signal transmission. One waveguide system, underway in the United Kingdom, has an initial capacity of over 94,000 working telephone circuits, and will be expanded to 250,000 circuits at a later date.

The waveguide is formed from glass-reinforced plastic with helical winding. There is also a dielectric-lined waveguide. The waveguide is encased in ducting (usually PVC pipe) which is then pressurized with a harmless dry gas to improve its performance and protect against external moisture. Most consideration has been given to buried waveguides, and the construction procedures closely parallel those used for existing cable networks.

Some of the problems to consider when contemplating the installation of a waveguide system, whether buried or in a utility corridor, are listed below:

a) system requires precise alignment of transmission line, which accounts for a large portion of installation cost when underground

b) increased attenuation in circular waveguides is caused by bends

c) metallic waveguides are subject to corrosion, crevice corrosion, stress cracking, etc.

d) any local change in shape of a waveguide or obstruction creates a discontinuity

e) variation with temperature (100mm/10m waveguide section)

f) loss of 2dB/km for AlMgSi tubes when inserted in buried PVC ducts

g) cost of trenching, duct installation, and backfill are major expenses

h) paths for circular waveguide systems will be restricted to a bend radius > 100m

i) waveguides cost much less than coaxial cables of compariable traffic capacity

From the above considerations it is concluded that a utility tunnel offers a feasible location for future waveguide systems routing. Direct installation costs would be considerably reduced, and waveguide alignment facilitated. The bending radii of several hundred meters parallel those used in rapid transit facilities. The only equipment that would be located in the tunnel would likely be the waveguide/duct combination which must be aligned to within a few milliradians at each joint. It would be corrosion-proof and electrically insulated.

3.1.7.2 Optical Fiber Transmission

Optical fiber transmission systems use light as the carrier for communication signals. In 1972, optical fiber systems were developed which demonstrated their potential as being economically competitive with conventional communications systems. It is predicted that sometime around 1980, wide-band optical fiber links will become commercially available.

The advantage of optical fiber transmission is the large information capacity and relatively inexpensive material of which it is made. It also demonstrates a high quality which is needed for computer data transmission, cable television, and voice transmission.

The space requirements of an optical fiber system would be much smaller than that of conventional coaxial cables of multi-pair wires of the existing communications system. One hundred fibers could be bundled into a cable roughly one-quarter of an inch in diameter. This quarter-inch cable would have the same capacity as one million telephone wires.

Optical fibers could be easily incorporated in an existing utility tunnel. They are also exceptionally compatible with other systems. An optical fiber system can withstand temperture extremes of -55$^{o}$C to +85$^{o}$C, is resistant to vibrations, compaction, and is immune from humidity and immersion damage. The system is also immune to electrical disturbance. Optical fibers are difficult to splice and tap. There is no laser source capable of supplying an optical fiber system. These aspects are currently being investigated and are the primary reason optical fibers are not in common use at this time.

### 3.1.8 Conclusions and Recommendations

There is no technical reason that the utilities just described cannot be housed together in a utility tunnel. Past experience has demonstrated that tunnels are technically feasible and that the development of the industry is significantly advanced to be capable of providing materials and workmanship that will enhance utility compatibility. Instrumentation is available that will eliminate the hazards of housing utilities together.

From interviews with utility companies in cities around the country it has been found that views on methods of incorporating utilities in tunnels vary considerably. IITRI does not purport that a single utility configuration will satisfy all utilities for any situation, but will make general recommendations for an optimum utility arrangement which will satisfy major requirements. The following is an outline of those recommendations.

Recommended Configurations:

a. Gas - Alternative one of the gas distribution configuration is recommended. This arrangement finds gas located near the center line of the tunnel, supported by rigid fixtures from the center columns. Thrust supports are necessary at sharp bends. The pipe is made of welded steel which is coated to resist corrosion. Sophisticated gas detection systems and forced air ventilation is required.

b. Electric Power - Alternative two of the power distribution configuration is recommended. This finds electric cable either racked on the walls or suspended from the roof. Additional lines in conduit in the floor may be necessary, depending upon the size of the plant. Cables will be exposed (or insulated with oil/paper) in the transformer vault interiors and will be housed in steel conduit between the vaults, supported every 20 feet. Shielding, etc., to prevent electrical interference with communications is required. Forced air ventilation is necessary to maintain moderate tunnel temperatures.

c. Wire Communication - Alternative one of the wire communications distribution configuration is recommended. Telephone cables would be hung on two racks, supported every three feet. These racks would be separated by three feet working space. One rack would be secured to the wall and the other would be a center rack, with the other side occupied by other wire communication cables. Adequate shielding against electrical interference must be provided.

d. Water Supply System - Alternative two of the water supply system configuration is recommended. This finds water located near the center line of the tunnel, supported by rigid fixtures from the center columns. The pipe is made of welded steel which is coated to resist corrosion. Water level detectors, drainage system, and pumps are all required to guard against possible flooding. Forced air ventilation is necessary to maintain acceptable temperatures in the tunnel.

e. Sewer System - The recommendation for gravity sewer systems is that they be located outside of the tunnel and buried in the ground on either side. Forced sewers or pressurized systems might be included in the tunnel, but their use is not widespread. If included, pressurized sewers would be hung in the same configuration as water mains.

f. Central Heating and Cooling - Welded steel pipe is recommended, with support at 20-foot intervals. These pipes would be suspended from the tunnel roof and supported by a flexible steel spring device, with thrust restraints at sharp bends. Forced air ventilation and insulation is necessary, as well as adequate drainage provisions.

g. Other Systems - Effort must be made to include many of the minor utility systems. Cable systems will be racked and pipe systems will be suspended, and will follow the pattern of the other similar facilities.

A typical tunnel cross section employing these configurations is illustrated in Figures 3-6 and 3-7.

These recommendations are subject to change to better fit a given situation. Although tentative, they should be carefully considered as the configurations that most effectively satisfy safety, economic, and space concerns.

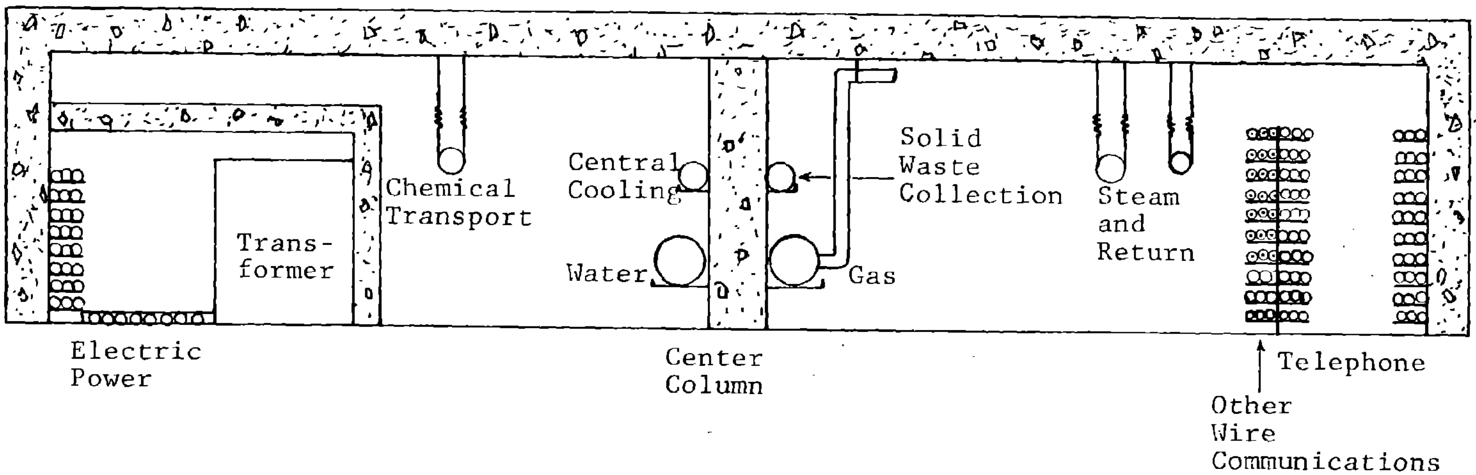



Figure 3-6. Transverse Tunnel Cross Section

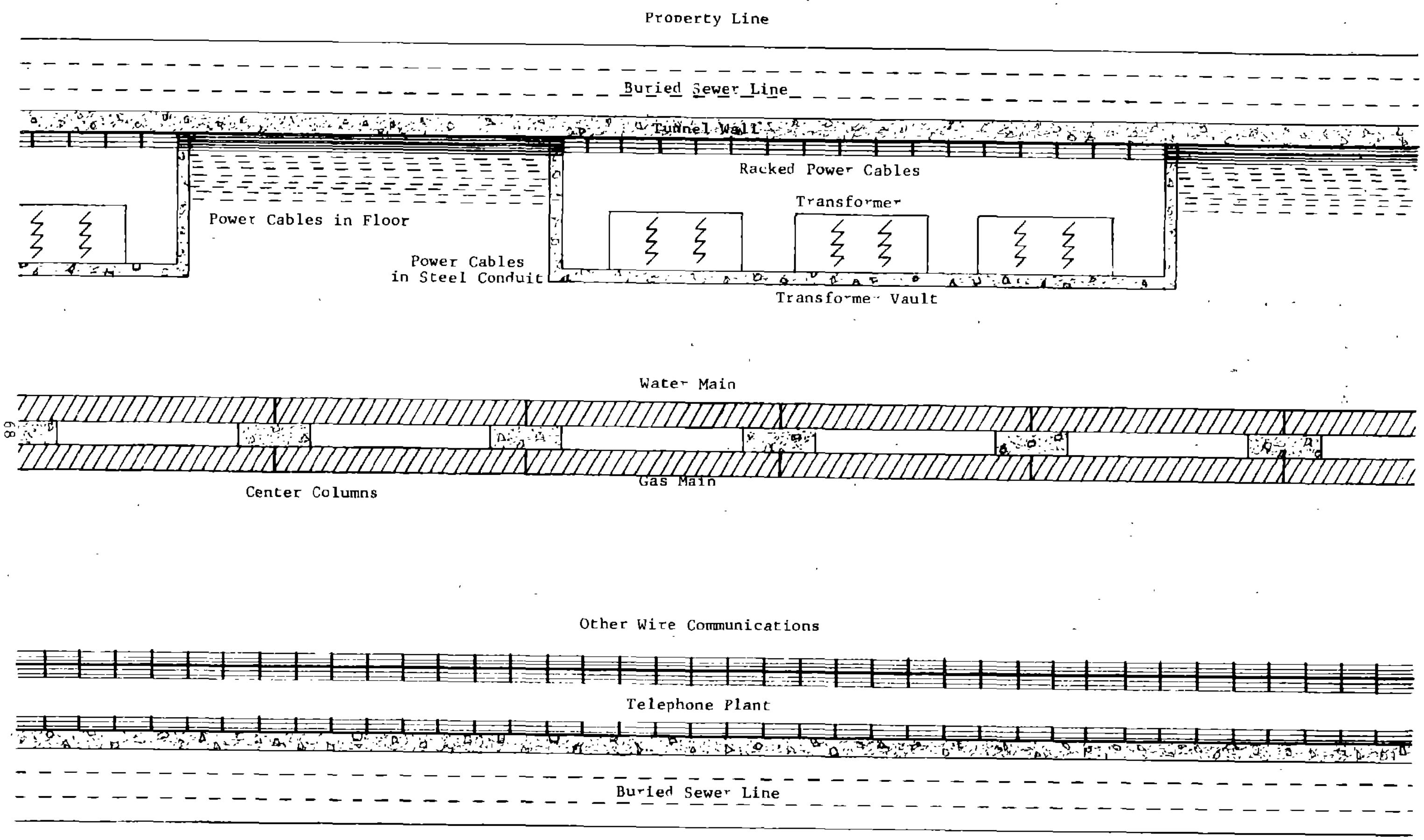



Figure 3-7. Plan View of Recommended Utility Tunnel

Table 3-1 summarizes the requirements for existing and future utilities when housed in a tunnel. Support intervals are stated. The possibility that the utility system will affect the tunnel environment due to leakage, rupture, condensation, heat dissipation, and electromagnetic interference is stated. The space needed for the facility and the working space needed for splicing and tapping is described. Service characteristics and the special requirements of each utility are stated. Finally, environmental provisions and controls needed for each utility to function most efficiently and safely are stated. These include humidity, temperature, and ventilation controls in the tunnel as well as insulation and tapping and splicing space for the utility plant.

## 3.2 TUNNEL SYSTEMS

Tunnel systems include those features which will provide for the efficient and safe functioning of a utility tunnel. The tunnel design includes provisions for the following tunnel systems:

a. Ventilation
b. Drainage
c. Emergency Overflow
d. Lighting
e. Communications
f. Fire Control
g. Vapor Detection
h. Access and Egress
i. Security Monitors and Control Center.

Much of the following discussion of these systems is taken from the CUTD and CT&A reports on the design for the Chicago utility tunnel (see Section 1.0-Introduction and Summary). The criteria used in these reports was felt to provide the "ideal" systems design and deviations from this design should be considered and are often desirable. The adequancy or excessiveness of the model will be determined

## TABLE 3-1 - SUMMARY OF REQUIREMENTS FOR EXISTING AND FUTURE UTILITIES IN A TUNNEL

| Utility Systems | Interval Support | Possible Effects on Tunnel | Space Requirements | Service Characteristics | Provisions* 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|---|---|---|
| Water | 20'; junct. | condensation, leak, rupture | 1 pipe dia. along pipe length 2 dia. around valves | potable water must be <70°F, 40°-50° desirable | | X | X | X | X | |
| Gas | 20'; junct. | leak, rupture, explosion (?) | 1 pipe dia. along pipe length 2 dia. around valves | low pressure 1/4 to 100 psi | X | | X | | X | |
| Power | 30-36" | heat, EM interference | room for splicing and cable pulling | primary 5 to 69 kv secondary up to 600 volts | X | X | X | X | | X |
| Communication | 30-36" | none | room for splicing and cable pulling | low voltage multi-pair cable | X | | | | | X |
| Heating and Cooling | 20'; junct. | condensation, leak, rupture | 1 pipe dia. along pipe length 2 dia. around valves | chilled water 40-55°F heating 250-400°+F | | X | | X | X | |
| City Power | 30-36" | heat, EM interference | room for splicing and cable pulling | primary 5 to 69 kv secondary to 600 volts | X | X | X | X | | X |
| CATV | 30-36" | none | room for splicing and cable pulling | low voltage | X | | | | | X |
| Sewer | 7-20' | leak, rupture | 1 pipe dia. along pipe length | gravity flow or pressurized | | | X | | X | |
| Chemical Transport | 20'; junct. | leak, heat rupture | 1 pipe dia. along pipe length 2 dia. around valves | depends on chemical | | X | X | X | X | |
| Secondary Water | 20'; junct. | condensation, leak, rupture | 1 pipe dia. along pipe length 2 dia. around valves | not potable | | | | | X | |
| Pneumatic Mail | 20'; junct. | none | 1 pipe dia. along pipe length 2 dia. around valves | no sharp bends | | | | | X | |
| Waveguide | 30-36" | none | 1 pipe dia. along pipe length | precise alignment, few bends | X | X | | X | | X |
| Waste Collection | 20'; junct. | leak, rupture | 1 pipe dia. along pipe length | no sharp bends | | | X | | X | |
| Optical Fiber | 30-36" | none | room for splicing and tapping | complicated splicing and tapping | X | | | | | X |

*1 - Humidity control of tunnel.
2 - Temperature control of tunnel.
3 - Ventilation of tunnel.
4 - Insulation required for utility.
5 - Tapping space required.
6 - Splicing space required.

by each city and they will adjust their plans accordingly.

The following details have been developed for the tunnel systems:

3.2.1 Ventilation

a) forced air
b) seven changes per hour
c) fan shafts at mid-block
d) automatic emergency capacities
e) 33 inch fans to move 10,000 CFM each
f) two air intakes at each intersection (air enters at intersection, exhaust at mid-block).

The ventilation system will be used for humidity, temperature, and vapor accumulation control. It will be integrated with the tunnel detector and sensors so that it may be automatically, remotely, or manually triggered.

3.2.2 Drainage

a) pumping stations at each intersection
b) automatically controlled emergency pumps
c) floors crowned transversely to drain to sides
d) floors sloped longitudinally to drain to pumping stations and overflow outlets
e) pumping stations to be incorporated with air intake and personnel entranceways
f) each pump station has sump basin with 1,500 gallon capacity (minimum)
g) two pumps per station with 1,200 CPM capacity able to move one quarter of the flow from a 24-inch water main in the event of rupture
h) flood detector alarms when sump basins fill
i) pumps discharge into external city sewers
j) two independent power supplies for pumps.

The drainage system will be used for flooding control from the rupture of water mains, central cooling mains, liquid chemical and petroleum transport pipes, and waste collection slurries.

### 3.2.3 Emergency Overflow

a) gravity overflow drains
b) three 30-inch in diameter outfall lines to handle flooding overflow quickly to avoid excess overloading of subway roof
c) tunnel floor sloped to several outlet points (such as to overflow sewers or river)
d) the lowest point of tunnel will have flooding held to four feet.
e) flooding alarm activated when water reaches top of sump basins.

The emergency overflow system is provided to accommodate any flooding that cannot be handled by the drainage system.

### 3.2.4 Lighting

a) continuous in general tunnel
b) each work aisle provided with separately controlled additonal lighting
c) power tool receptable located in all work corridors at 50-foot intervals
d) illuminated exist signs
e) emergency back-up system.

Lighting will be comparible to that found in an office situation, with supplementary lighting provided for intricate splicing and tapping operations.

### 3.2.5 Communications

a) telephone at all entrances
b) talkback speakers at all intersections.

Tunnel communications will be a separate system from the wire communications utility plant housed in the tunnel.

### 3.2.6 Fire Control

a) automatic sprinkler system
b) fire alarm activated by water flowing in sprinkler system
c) two fire extinguishers in each block for each aisle and one at each intersection
d) manual fan control at each exit for exhausting smoke
e) tunnel temperature monitor.

Fire control will be activated in the event of electrical fire or any other fire. The water that results from sprinkler activation will be drained from the tunnel through the drainage system.

### 3.2.7 Vapor Detection

Gas, smoke and safe air quality detectors will activate the ventilation system.

The vapor detection system will monitor the levels of gas vapors in the tunnel, as well as those resulting from ignited insulation, sewage leaks, leaks from the chemical transport systems, and smoke. It will act as a general air quality monitor.

### 3.2.8 Access and Work Hatches

Personnel access
a) located at each intersection
b) monitored at Control Center
c) two exit stairways per block
d) illuminated signs.

The entire length of the tunnel is continuous so that at least two means of egress are provided from any point in the tunnel. Personnel access will be provided by means of stairways that parallel the subway escalators.

Work hatches

a) provided for tools and equipment
b) for cable pulling
c) as water proof service connections to buildings
d) must be ventilated and locked
e) must allow water valves to be accessible from the street.

The general dimensions and spacing of work hatches are as follows:

a) two per block for power, rectangular 26 by 30 inches
b) one per block for water, rectangular 11 by 14 feet
c) two per block for wire communications, 24 to 30-inch diameter
d) one per block fcr Western Union, 24 to 30-inch diameter.

The spacing of electric power hatches will be 100 feet from an intersection and 200 feet between hatches. All others are staggered but located directly over the work aisles in the tunnel.

### 3.2.9 Security Monitors and Control Center

The control center will monitor all tunnel systems, including those provided for security, and will remotely control tunnel access hatches. The center will be located at some convenient point outside the tunnel and will have direct communications not only with tunnel personnel, but with the utility companies and city fire department, tunnel security forces, maintenance crews, and medical personnel. The control panel will operate 24 hours a day by a operator. This operator would alert the utility companies of any irregularities in their facilities, but tunnel personnel would never be allowed to maintain or repair the utilities. Walk through inspections will not be provided, in as much as maintenance and utility personnel will be in the tunnel.

Security would be provided by locked accessways and 24 hour surveillance by closed circuit television. Tunnel personnel and utility workers would have to check in and out. No one would be allowed to enter the tunnel who has not previously received clearance.

The amount of security and safety precautions taken in a utility may vary from city to city, depending upon several factors, including what types of utilities will be included and how much money is available to be spent on monitoring and sensing apparatus. Operations of successful tunnels in other locations should be evaluated and used as a comparison. Both CT&A and CUTD suggest an inspection crew of 16, with two inspectors conducting a walk-through investigation of the tunnel 24 hours a day. This is thought to be excessive. The central control panel should be manned, but this duty will be shared with other committments. One utility tunnel visited, six times longer than the design example, was monitored by a single control panel whose operator also handled other duties.

## 3.3 TUNNEL SAFETY

One of the most important aspects of utility tunnel operation is providing adequate safety for the utility plants and the workers that will be maintaining them. The tunnel systems must function to prevent a mishap from occuring, and the workers must work carefully and obey all safety rules. Beyond the avoidance of increased hazard during normal conditions, continuity of public service is of particular importance during disaster.

The tunnel systems are described in some detail in the preceeding section of this report, "Tunnel System". The specific problems that might be caused by the utilities were discussed in Section 3.1, "Utility Characteristics and Requirements," of this report. This section will expand both of the previous sections by detailing how the utility tunnel can provide a safe environment for all concerned.

Many types of failure can occur in a utility tunnel, either from structural failure, utility failure, or safety systems failure. These different types of failure are discussed in Table 3-2, Possible Failure Modes and Effects in Utility Tunnel. In this table are outlined the components or sources of failure, the basic cause or fault, the direct effect, and the general effect on the tunnel. One type of failure might have a number of effects on a variety of utility or tunnel systems which, in turn, might be manifested in different types of tunnel problems. For example, differential settling of the tunnel structure, depending upon its severity, might result in pipe rupture or cable failures. This, in turn, could possibly lead to tunnel flooding, gas leakage, fire, or a number of other events. Many of these failures can be avoided by adequate structural and tunnel system design. Some of the other ways to avoid these failures are discussed below.

The tunnel must be safe for the utility worker. He should not only be protected from such catastrophic events as explosion, fire, and asphyxiation, but also accidents that may result from falling objects, inadequate identification of utilities, and mishandling of tools and torches. The effects of these types of accidents are magnified in a tunnel situation, due to the close proximity of many different utility plants.

Tunnel accidents or failures may also be the result of allowing the tunnel to reach a generally deteriorated condition. Water and steam lines may drip on other utilities, cables may sag, and walkways may not be kept free of clutter. These things, although not an immediate threat to tunnel safety, may develop into a condition which is difficult to

## TABLE 3-2 - POSSIBLE FAILURE MODES AND EFFECTS IN UTILITY TUNNEL

| No. | Component or Source | Basic Cause or Fault | Direct Effect | Effect on System |
|---|---|---|---|---|
| 1 | Tunnel structure | Errors in structural design<br>Errors in construction | Inability to carry load | Tunnel collapse or distress |
| | | Explosion at street level<br>Earthquake | Excessive load on structure | |
| | | Nearby railroad or vehicular traffic | Excessive vibrations | |
| | | Insufficient space in tunnel | Inability to make simultaneous repairs on different utilities | Known faults continue longer than necessary |
| | | | Difficulty in transporting equipment | Personnel casualties<br>Damage to utilities |
| | | Projections from surfaces of tunnel | Obstructions to traffic | Damage to equipment being transported |
| | | Insufficient water tightness | Excessive seepage into tunnel | Frequent operation of sump pump<br>Humid atmosphere causes faster deterioration of materials |
| | | | Gross leak in crossing under river | Flooding of tunnel |
| 2 | Take-off or side outlet from tunnel | Uneven settling | Gas pipe breaks | Gas released into tunnel<br>Gas released into customer's premises |
| | | | Water pipe breaks | Flooding of tunnel<br>Flooding of customer's premises |
| | | | Electric cables break | Loss of power to customer<br>Arcing causes fire |

TABLE 3-2 (Continued)

| No. | Component of Source | Basic Cause or Fault | Direct Effect | Effect of System |
|---|---|---|---|---|
| 2 | Take-off or side outlet from tunnel (cont'd) | Uneven settling (cont'd) | Communications cables break | Loss of communications to customer |
| | | Inadequate sealing | Gas enters tunnel | Explosive atmosphere in tunnel |
| | | | Water enters tunnel | Flooding of tunnel |
| | | | Fire propagates into tunnel | Fire in tunnel |
| | | | Gas from tunnel propagates to customers' premises | Explosive atmosphere on customers' premises |
| | | | Fire from tunnel propagates to customers' premises | Fire on customers' premises |
| 3 | Entries and exits from tunnel | Insufficient number of entries and/or exits | Excessive time for emergency exit | Personnel casualties |
| | | Entries and/or exits fully or partially blocked<br><br>Entries and/or exits difficult to open<br><br>Entries and/or exits not marked<br><br>Personnel unfamiliar with entry and/or exit locations | Excessive time for repair crew to reach source of fault | Explosive atmosphere in tunnel<br><br>Flooding of tunnel<br><br>Excessive time to correct electrical failure<br><br>Excessive time to correct communications failure |
| | | Failure to close | Fire propagates into tunnel from outside | Fire in tunnel |
| | | | Toxic or flammable gases enter tunnel | Explosion and/or fire in tunnel<br><br>Toxic atmosphere in tunnel |

TABLE 3-2 (Continued)

| No. | Component or Source | Nasic Cause or Fault | Direct Effect | Effect on System |
|---|---|---|---|---|
| 3 | Entries and exits from tunnel (cont'd) | Access by unauthorized personnel | Inadvertent damage to utilities controls, detectors, or alarms<br><br>Sabotage | Explosion in tunnel<br><br>Fire in tunnel<br><br>Flooding of tunnel<br><br>Toxic atmosphere in tunnel |
| 4 | Ventilation system | Inadequate design | Gas can accumulate at high locations in tunnel or in adjacent vaults | Explosion and/or fire<br><br>Hypoxic atmosphere in vaults |
| | | Loss of power to blowers<br><br>Blockage of air intake openings by snow or malicious act<br><br>Short-circuiting of ventilation air by improper openings to tunnel<br><br>Lack or failure of emergency ventilation system | No ventilation or reduced ventilation increases temperature and humidity in tunnel | Heating of electric conductors reduces ampacity and causes cable burnout<br><br>Humid atmosphere causes faster deterioration of materials<br><br>Intolerable environment for workmen |
| | | | Smoke accumulation in case of fire causes loss of visibility and prevents access for fire fighting | Extensive fire in tunnel |
| | | Unprotected or poorly located air intakes | Fire propagates into tunnel from outside | Fire in tunnel |
| | | | Toxic or flammable gases enter tunnel | Explosion and/or fire in tunnel<br><br>Toxic atmosphere in tunnel |
| | | Failure of exhaust blowers to shut off in case of fire or flammable gas in tunnel (except blowers nearest source) | Increased spread of fire or flammable gas in tunnel<br><br>Reduced access to source by fire-fighting personnel | More extensive fire in tunnel |

## TABLE 3-2 (Continued)

| No. | Component or Source | Basic Cause or Effect | Direct Effect | Effect on System |
|---|---|---|---|---|
| 5 | Gas piping | Failure of pipe supports | Overstress of pipe wall | Gas leak in tunnel resulting from pipe failure |
| | | Differential settling of pipe supports | | |
| | | Restraint from thermal expansion | | |
| | | Earthquake | | |
| | | Vibrations from vehicular traffic | Fatigue stress in pipe | |
| | | Missing or damaged protective coating | Pipe corrosion | |
| | | Corrosive constituent in gas | | |
| 6 | Valves in gas piping | Failure of pressure regulating valve causes excessive pressure in pipe | Overstress of pipe wall | |
| | | Lack of shut off valves | Excessive time to stop gas leak | Accumulation of gas in tunnel; explosion and/or fire |
| | | Inoperative shut off valves | | |
| | | Inaccessible shut off valves and no provision to operate them from outside or remotely | | |
| 7 | Gas Detectors | Lack of gas detectors | No warning of gas leak | Accumulation of gas in tunnel; explosion and/or fire |
| | | Inoperative gas detectors | | |
| | | Insensitive gas detectors | | |
| | | Poor location of gas detectors | | |
| | | Fault in transmission line from detector to panel | | |
| 8 | Fire detectors/alarms | Lack of fire detectors | No warning of incipient fire | Extensive fire in tunnel |
| | | Inoperative fire detectors | | |

TABLE 3-2 (Continued)

| No | Component or Source | Basic Cause or Fault | Direct Effect | Effect on System |
|---|---|---|---|---|
| 8 | Fire detectors/alarms (cont'd) | Insensitive fire detectors<br>Poor location of fire detectors<br>Fault in transmission line from detector to panel | No warning of incipient fire | Extensive fire in tunnel |
| 9 | Sprinkler system | Lack of sprinkler system<br>Inoperative sprinkler system<br>Poor location of sprinkler heads | Inability to extinguish incipient fire | Assumulation of gas in tunnel; Explosion and/or fire |
| 10 | Fire extinguishers | Extinguishers not provided<br>Extinguishers not accessible<br>Extinguishers inoperative<br>Extinguisher too small<br>Worker not trained to use extinguisher | | |
| 11 | Water piping | Failure of pipe supports<br>Differential settling of pipe supports<br>Earthquake<br>Excessive pressure surges | Overstress of pipe wall | Flooding of tunnel resulting from pipe failure |
| | | Vibrations from vehicular traffic | Fatigue stress in pipe | |
| 12 | Valves in water piping | Lack of shutoff valves<br>Inoperative shutoff valves<br>Inaccessible shutoff valves and no provision to operate them from outside or remotely | Excessive time to stop water flow in emergency | Flooding of tunnel |
| 13 | Water leak detectors/alarms | Lack of pressure sensors or leak detectors<br>Inoperative pressure sensors or leak detectors | | |

## TABLE 3-2 (Continued)

| No. | Component or Source | Basic Cause or Fault | Direct Effect | Effect on System |
|---|---|---|---|---|
| 13 | Water leak detectors/alarms (cont'd) | Fault in transmission line from sensor to panel<br>Fault in transmission line to automatic shutoff valves | Excessive time to stop water flow in emergency | Flooding of tunnel |
| 14 | Electric cables | Failure of cable supports<br>Restraint from thermal expansion<br>Earthquake | Overstress causes pipe failure and loss of insulating oil or gas | Overheating and/or arcing of conductors, burnout, and fire in tunnel<br>High voltage on exposed surface and personnel casualties |
| | | Vibration from vehicular traffic | Fatigue stress causes pipe failure and loss of insulating oil or gas | |
| | | Leak in pipe from corrosion or other cause | Loss of insulating oil or gas | |
| | | Electric overload | Excessive heat generation in conductors | |
| | | Breakdown of electric insulation | Arcing or short circuit | |
| | | Sagging of electric cable tray | Oil migrates from impreguated paper and causes short circuit | |
| | | Faulty splice | Excessive heat generation at splice | |
| | | Inadvertent covering with thermal insulation | Reduced heat dissipation from surface | |
| | | Inadequate grounding | Pipe at high voltage | Arcing causes fire in tunnel<br>Personnel casualties |

## TABLE 3-2 (Continued)

| No. | Component or Source | Basic Cause or Fault | Direct Effect | Effect on System |
|---|---|---|---|---|
| 15 | Communications cables | Improper location in tunnel | Induced voltage from electric cables | Arcing causes fire in tunnel<br>Loss of service<br>Personnel casualties |
| 16 | Communication cable trays | Failure of tray supports | Wire breaks | Loss of service |
| | | Improper arrangement | Trays intercept water from fire sprinklers and prevent extinguishing incipient fire | Loss of service<br>Fire in tunnel |
| 17 | Water drains | Inadequate drains<br>Clogged drains | Accumulation of water in tunnel | Flooding of tunnel |
| 18 | Sump pumps | Power failure<br>Pump and/or motor failure<br>Level switch failure<br>Failure of high water alarm | | |
| 19 | Repair machinery and/or equipment | Lack of electric ground<br>Inadequate grounding | Equipment at line voltage | Arcing causes fire in tunnel<br>Personnel casualties |
| | | Poorly located power taps | Power cord is tripping hazard | Personnel casualties |
| 20 | Lighting in tunnel | Power failure<br>Inadequate lighting<br>No emergency lights<br>Inoperative emergency lights | Loss of light in tunnel | Personnel casualties<br>Inability to fight fire<br>Inability to make repairs |
| 21 | Maintenance and/or repair personnel | Loss of control in moving heavy equipment | Impact of equipment on electric cables causes insulation breakdown | Arcing and fire in tunnel<br>Personnel casualties |
| | | Unauthorized tampering with other utilities | Release of gas in tunnel | Explosion and/or fire |
| | | | Release of water in tunnel | Flooding of tunnel |

TABLE 3-2 (Continued)

| No | Component or Source | Basic Cause or Failure | Direct Effect | Effect on System |
|---|---|---|---|---|
| 21 | Maintenance and/or repair personnel | Unauthorized tampering with other utilities | Short-circuiting or overheating of cables | Arcing causes fire in tunnel<br>Personnel casualties |
| | | Improper use of torch or welding equipment | Ignition of flammable material | Fire in tunnel |
| | | | Release of gas in tunnel | Explosion and/or fire in tunnel |
| | | | Release of water in tunnel | Flooding in tunnel |
| | | | Breakdown of electric insulation by overheating | Arcing causes fire in tunnel<br>Personnel casualties |
| | | Faulty tap into gas pipe | Release of gas in tunnel | Explosion and/or fire |
| | | Faulty tap into water line | Release of water in tunnel | Flooding in tunnel |
| | | Faulty work on electric cables | Arcing causes ignition | Fire in tunnel |
| | | | High voltage on exposed surfaces | Personnel casualties |
| | | Smoking in unauthorized area | Ignition of flammable material | Fire in tunnel |
| | | Error in color coding pipes and/or electric cables | Release of gas | Explosion and/or fire |
| | | | Release of water | Flooding of tunnel |
| | | | Exposure to high voltage | Arcing causes fire in tunnel<br>Personnel casualties |
| 22 | Procedures for routine maintenance and repair | Lack of procedures | Release of gas | Explosion and/or fire |
| | | Inadequate or faulty procedures | Release of water | Flooding of tunnel |
| | | Lack of personnel training | Exposure to high voltage | Personnel casualties |

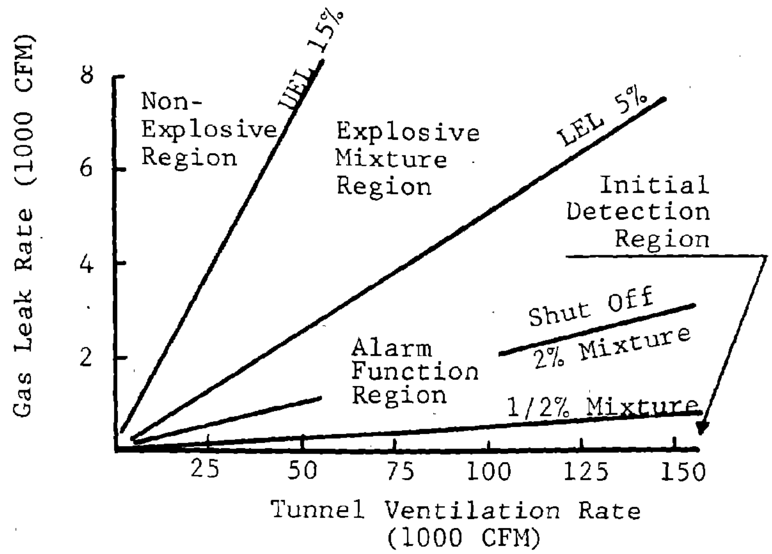
## TABLE 3-2 (Continued)

| No | Component or Source | Basic Cause or Fault | Direct Effect | Effect on System |
|---|---|---|---|---|
| 23 | Procedures for responding to emergencies | Lack of procedures | Delay in stopping gas leak | Explosion and/or fire |
| | | Inadequate or faulty procedures | Delay in stopping water flow | Flooding of tunnel |
| | | Lack of personnel training | Continued arcing and/or overheating of cables | Fire in tunnel |
| 24 | Communications to control center | Lack of cummunication system<br>Inoperative main and standby communication systems<br>Inadequate number and/or location of access points | Inability or delay in communicating under emergency conditions | Extensive damage in tunnel<br>Personnel casualties |

rectify. To prevent this, utilities must be periodically inspected by their workers and the tunnel itself must be maintained. Proper design will minimize hazards such as water lines placed over other utilities.

Failure of the tunnel safety systems may be avoided by periodic testing. Standards must be carefully established and the systems calibrated to verify their level of sensitivity. This point cannot be overstated. Questions such as how much smoke should be allowed to accumulate before the ventilation system is automatically triggered must be answered. Gas leaks are dangerous to the tunnel, but often difficult to detect. The lower explosive limit of a gas-air mixture is 5 percent, but detection instrumentation should be set as low as 0.5 percent so the ventilation system can easily and quickly dissipate any leakage and gas workers can repair the pipe. (See Figure 3-8) The tunnel operating entity should clearly set levels of sensitivity that will guarantee that no hazard is allowed to go undetected. (Newburger, 1971)

Figure 3-9 illustrates the probability of a simultaneous gas leak and power failure in the same one mile length of tunnel over a 50 year period. It should be noted that the range of the graph, 200 miles, is much longer than any tunnel that is presently being considered. The three lines on the graph represent (1) when there is no ventilation or monitoring in the tunnel, (2) when 95% of the leaks are diluted by the ventilation system, and (3) when 95% of those that are not diluted are detected and stopped by the monitoring system. As one can expect, the probability of such a disaster occuring increases as the number of miles of tunnel being considered increases, but the length of tunnel presently being considered is extremely small and chances of a simultaneous failure are negligible. In order to obtain a 50 percent probability of one such event occuring during a 50 year tunnel life, over 2 million miles of utility tunnels would have to be considered. (Newburger 1971)




L.E.L. = Lower Explosive Limit
U.E.L. = Upper Explosive Limit

Figure 3-8. Effect of Ventilation Rate in Keeping Minor Leaks Below the Lower Explosive Limit (After Newburger 1972)

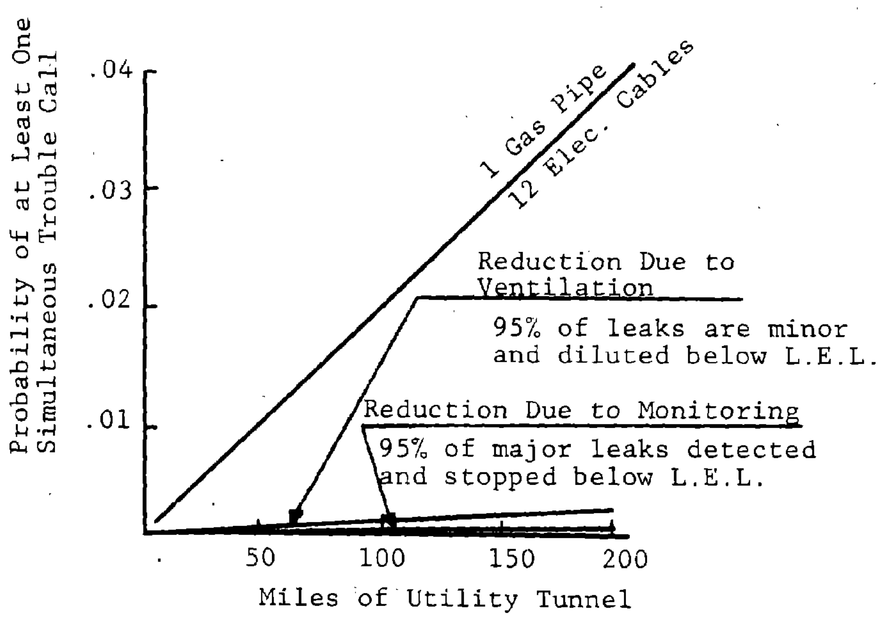



Figure 3-9. The Probability of Simultaneous (Same Day - Same Section) Gas and Electric Trouble Over a 50-Year Period (After Newburger 1972)

There are several criteria against which to measure pipe standards to assure their best performance in a tunnel. They are as follows:

a) pipe quality - made of high quality extra weight materials free from dents and gouges
b) pipe joints - welded joints tested by hydrostatic pressure or radiographic examination
c) pipe valved - to sectionalize the pipe in case of failure in one area, should also have remote surface controls
d) corrosion - carefully applied protection so that there are no gaps.

This will regulate the quality of pipe systems used in tunnels and will make the need for detectors infrequent. (Newburger, 1971)

Tunnel and utility personnel may or may not want to lock vaults, valves and accessways. If utilities are isolated by chain-link fence or the like, it may be unnecessary to lock such things as valves. If passage between utility plants is possible, some type of control center remote control of unlocking valves, etc. might be desirable in cases of emergency. No locks in the tunnel might be preferred. The final configuration will be decided by the operating entity, which includes input from the utilities.

Summary. The following is a list of ways to avoid or arrest tunnel accidents and establish safe operation:

a) Detection systems must be installed and periodically tested.
b) Statistical tests should be applied to the detection system design to insure full coverage in spite of the probability of individual component failure.
c) High standards for utility quality should be established and enforced.
d) At least two means of egress should be provided.
e) Entranceways and hatches should be identified and locked.

f) Workers should know exit locations and the location of first aid and fire fighting equipment.

g) Emergency exterior manual controls should be provided on steam and water utilities.

The most effective way to insure tunnel safety is to conduct a comprehensive hazards analysis during the design process itself. Awareness on the part of the designer can be of great significance. For example, one would intuitively think the safest configuration for gas is outside the tunnel, or, if inside the tunnel, behind a heavy, sealed partition. In fact, greater safety might be obtained by putting the gas line inside, and spending the money thus saved on heavier pipe and better leak detection systems. Putting the gas line outside the tunnel, subject to accidental dig-in or corrosion may expose the tunnel to worse hazards.

If greater safety is desired, modified designs should be considered that would provide such features as bulkheads to sectionalize the tunnel to prevent the spread of fires and flooding. It should be kept in mind that design should be used to provide optimum safety while maintaining a cost effective tunnel operation.

## 3.4 CONSTRUCTION SEQUENCE

Much of the economic advantage found with the utility tunnel results from a construction procedure that does not require a utility backfill stage. Without the need to backfill, temporary structures may be avoided and disruption greatly reduced. The recommended construction procedure is novel for the U.S., but is used in Europe and Asia with success.

Three designs were considered in the evaluation of the construction procedure and costs. A fourth design, that recommended by CUTD in 1969 is mentioned, but not evaluated. The prices of construction materials have changed radically since the CUTD design, making it no longer economic. The options evaluated by IITRI are:

| | |
|---|---|
| Option I | Transit tunnel designed for conventional utility handling |
| Option II | Transit tunnel designed with a utility tunnel, roof span full-street width |
| Option III | Transit tunnel designed with a utility tunnel, pre-founded center columns and half-street width roof spans. |

In all options the most economical design is attempted. Thus diaphram walls at $17/ft$^2$ are shown instead of the current $29/ft$^2$ for soldier pile and lagging. Either support method however, would be appropriate for the proposed design. Temporary elements are avoided when possible. Diaphram walls are incorporated into the final structure, and at appropriate levels permanent structural elements double as temporary bracing. The critical point to be considered in the utility tunnel options is the use of permanent roof decking to replace temporary timber decking. Not only are the costs of temporary decking and traffic control saved, but the early reestablishment of normal surface traffic is highly desirable.

The intent in the feasibility analysis is to compare the best conventional design with the best utility tunnel design. It would be unacceptable to take a transit tunnel designed for use with conventional utility handling and add to it a utility tunnel structure.

The following paragraphs describe the construction sequence for each of the options. In some cases a particular step may be moved from one stage to another with little effect. The sequence discussed below is not necessarily the best possible. That is a subject for detailed tunnel design, outside the scope of this investigation. What is important to this report is that the construction of the utility tunnel is possible using the procedures indicated.

OPTION I CONVENTIONAL SYSTEM

Stage 1

a. Adjust utilities and divert if necessary.

b. Construct guide walls to utility level. Size and dimensions to be decided by diaphragm wall contractor depending on type, size and equipment.

c. Cast diaphragm walls, terminating 3 to 4 feet above tunnel roof elevation. Short soldiers extending up to street level are cast into the top of the diaphragm walls.

Stage 2

d. Install soldier pile timber lagging and construct temporary steel and timber street decking.

Stage 3

e. Excavate to approximate tunnel roof level and install permanent steel beams to act as bracing.

Stage 4

f. Continue excavation and earth moving to second (temporary) bracing level, install walers and temporary tubular struts.

Stage 5

g. Continue excavation to underside of base slab and place bottom slab of the tunnel.

Stage 6

h. Construct intermediate columns and place the roof slab of the tunnel (cast-in-place concrete or precast sections).

i. Waterproof the roof of the tunnel.

Stage 7

j. Backfill area above tunnel - dismantle temporary decking, pull soldier piles, restore utilities, backfill and reconstruct street surface.

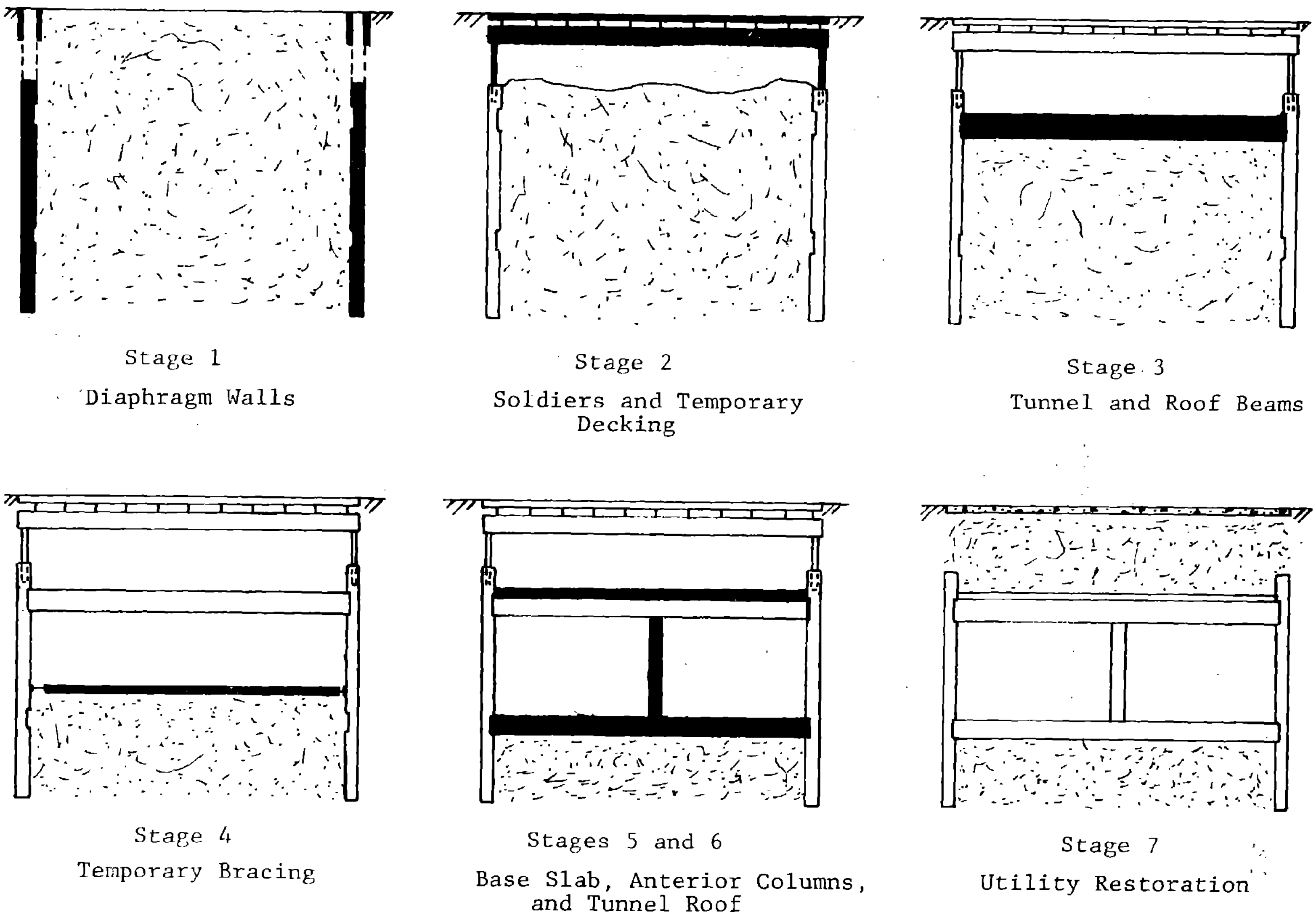



Figure 3-10. Construction Sequence For Option I

This option uses standard techniques throughout. The short soldier pile wall near the surface permits ground support to be maintained even during backfilling of the utilities. Currently, the diaphragm walls on 42nd Street in New York extend to the surface, and the upper eight feet will have to be cut off and removed.

OPTION II FULL-SPAN UTILITY TUNNEL SYSTEM

Stage 1

a. Adjust utilities and divert if necessary.

b. Construct guide walls to utility level. Size and dimension to be selected by diaphragm wall contractor to accomodate the size and type of equipment.

c. Build diaphram walls and terminate about 2 feet below finished street surface.

Stage 2

d. Excavate street to expose shallow utilities and install permanent street decking. Use new decking as erection platform. Permanent street decking to serve also as top bracing. Place wearing surface and open street to traffic.

Stage 3

e. Carry out excavation and earth moving under roof to first bracing level which is also the tunnel roof level. Install concrete beams connecting to the diaphram walls.

Stage 4

f. Continue excavation to third (temporary bracing) and install walers and bracing struts.

Stage 5

g. Continue excavation to underside of base slab and place bottom slab of tunnel.

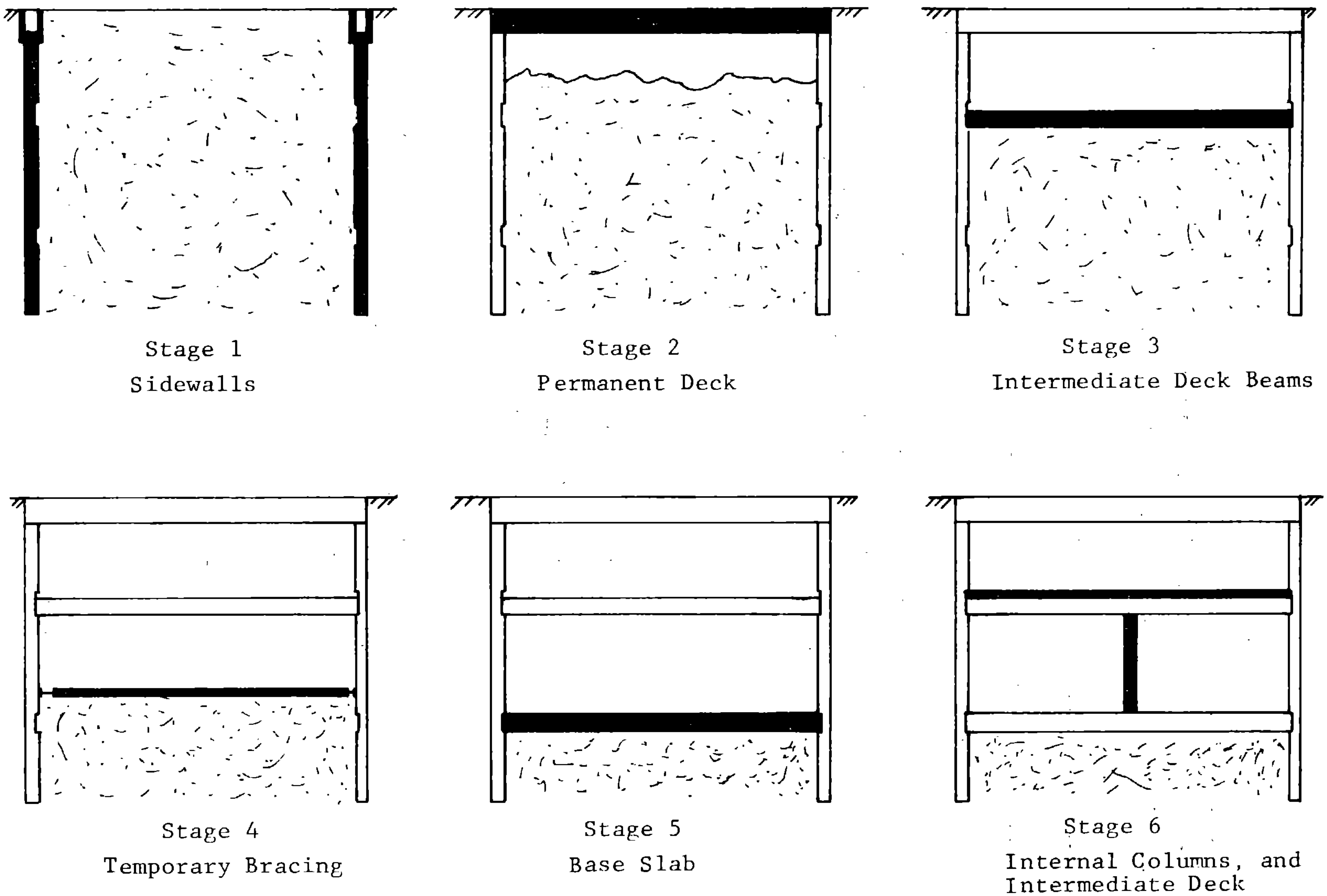



Figure 3-11. Construction Sequence For Option II

Stage 6

h. Construct intermediate columns and place the roof slab of the tunnel (cast-in-place concrete or precast sections).

i. Locate utilities in utility tunnel.

Note that utility restoration can be started earlier if a light work platform is provided and the utility trays and hangers are supported from the street decking or the beams installed in Stage 3. Surface disruption is eliminated after Stage 2. Construction scheduling will require consideration of contractor storage areas and work room. The most difficult point is the Stage 3 excavation. A small excavator would work a face below and adjacent to the existing utilities, casting spoil back to the closely following Stage 4 excavation. As each utility is exposed by the advancing face, any concrete encasement is broken up and hangers are attached to the street decking elements. Excavation under-the-roof, as opposed to clamming through the roof is not a new concept. This was used in Oakland and New York using a belt loader and Cat 977's loading trucks respectively. Europe and Asia have seen greater use of the method.

OPTION III HALF-SPAN UTILITY TUNNEL AND CENTER COLUMNS

Stage 1

a. Adjust utilities and divert if necessary.

b. Construct guide walls to utility level. Guide walls to be designed by the contractor for the type and size of excavating equipment.

c. Build exterior diaphragm walls as continuous units and the interior walls as a strip panel unit. Terminate walls at appropriate level.

Stage 2

d. Excavate street to expose utilities, and cast cap beam on top of strip panel wall. Install

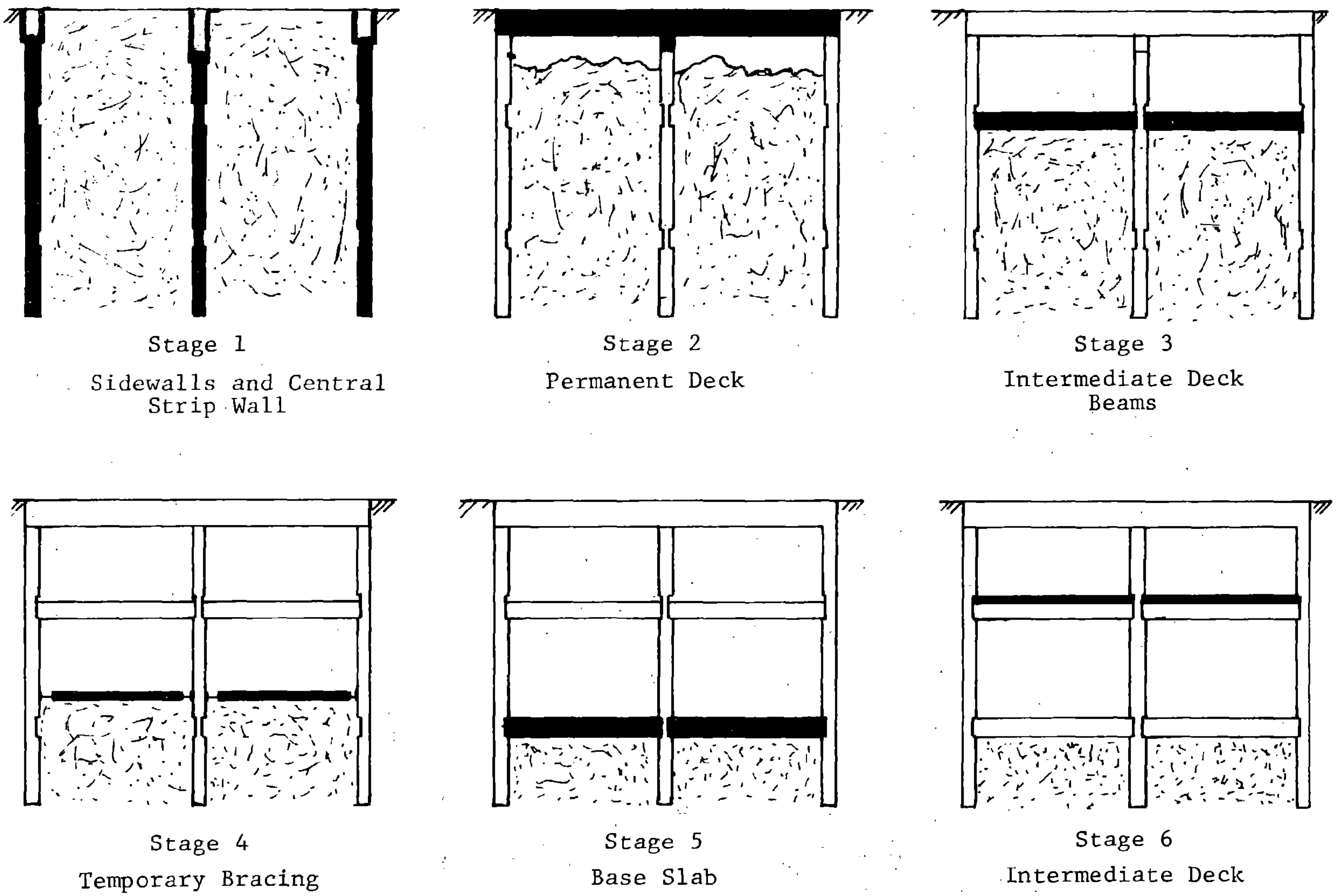



Figure 3-12. Construction Sequence For Option III

permanent street decking using existing street as erection platform. Permanent street decking to serve also as top bracing. Place wearing surface and open street to traffic.

Stage 3

e. Carry out excavation and earth moving under roof to first bracing level which is also the tunnel roof level.

f. Install permanent concrete beams connecting to the diaphragm walls.

Stage 4

g. Continue excavation to third (temporary) bracing and install walers and bracing struts.

Stage 5

h. Continue excavation to underside of base slab and place bottom slab of tunnel.

Stage 6

i. Place roof slab of the tunnel (cast-in-place concrete or precast sections).

j. Install utilities in utility tunnel.

Summary - Construction Sequence. The three options described above are not the only viable construction methods. For example, the conventional system (option I) has all excavation completed before construction of the transportation tunnel. It may be feasible instead to place the tunnel roof immediately following the stage 3 excavation. In this fashion, the utility restoration could parallel the stage 4 and 5 excavation, and backfill operations could start as soon as the interior columns are placed in stage 6. The lower excavation would then be conducted under the roof, just as in options II and III. Traffic disruptions would continue nearly until the end of the contract. It was not felt that the greater excavation costs would be offset by any significant reduction in project duration or disruption.

Many features are shown in these options that do not strongly effect the utility tunnel decision. In general, attempts were made to avoid the use of temporary structural components. Recent advances in the cost of steel prompted the use of slurry wall sidewalls. The methods and materials chosen provided a comparison between two systems thought to represent good engineering practice, and providing similar structures and services. No methods or materials were suggested that have not been proven in practice in this country or Europe.

It is well to establish clearly just which elements of the suggested procedures are actually important to the utility tunnel concept.

a) The procedures for the utility tunnel and the conventional systems are identical up to the placing of street decking. Both require initial utility handling and relocation, initial excavation of the street surface and placing load-bearing side walls.

b) The utility tunnel procedure as proposed denies the contractor some access to the street surface. The CUTD utility tunnel design does, of course, have six work hatches per block, ranging in size from 24 inch diameter to 11 by 14 feet. Additional hatches could be provided if this were desirable. For this program, however, the more severe condition of no access except an adit at the end of the project was assumed.

c) Placing the permanent deck early requires that the remaining excavation be conducted without claming. Although this option has been used in the past, it is not common in the U.S. and new excavation costs were computed for this work.

## 3.5 TECHNICAL CONCLUSIONS

It has been clearly shown that the construction and safe operation of a utility tunnel is technically feasible. Designs of other tunnels around the world, including that proposed by CUTD, were studied. The best features of these tunnels were incorporated into a recommended IITRI design, which is felt to optimize the use of space, time, and safety methods. The recommended configurations and procedures should be generally applicable to any city in the world. Each city will then modify the designs according to their specific conditions and requirements.

Technical feasibility is only part of the study to determine whether utility tunnels should be used in urban areas. The institutional impact and economic analysis must also be considered, and the next two chapters of this report will be devoted to these factors.

## 4. INSTITUTIONAL FACTORS

Institutional factors play an important role in the feasibility study of locating utilities in transportation tunnels. Institutional considerations consist of several major elements:

a. utility company and union attitudes and the effect the tunnel project will have on them,

b. the type of tunnel ownership and financing of the project,

c. the tunnel operating entity that is established and the responsibilities of operation,

d. the effect of a utility tunnel project on public opinion and the functioning of the central business district.

The final element is touched upon in this section of the report, but a more detailed discussion of this aspect can be found in Section 5, Socio-Economic Impacts.

Meetings were conducted by IIT Research Institute and APWA in cities across the country to investigate the various opinions held about the utility tunnel concept by city authorities, public and private utility companies and their unions, and merchants and the general public. Consideration was given to the effects of a cut-and-cover subway project, with conventional utility restoration, in an urban area. Proposed utility tunnel designs were then discussed. Efforts were made by IITRI and APWA not to influence those interviewed either for or against the concept; the purpose of the meetings was simply to gather information. Many of the changes suggested by those interviewed have been incorporated into the final recommended utility tunnel design appearing in this report. Suggestions from the construction community and public were used in regards to the best way to schedule a construction project of this type.

Material used in the Tunnel Ownership and Operation (4.1) section was taken both from the literature and from information obtained from these interviews. Recommendations are based upon a thorough review of the literature plus utility company and public opinion.

The impact of a utility tunnel project associated with subway construction is difficult to evaluate. Anger was expressed by merchants and the public which is impossible to quantify. Many objections were voiced out of ignorance or conservatism, but there was a great deal of genuine concern expressed about the growing tangle of utilities in public rights of way and a spirit of cooperation sometimes prevailed.

A representative attitude of any particular group of utilities or engineers was not readily obtainable. The attitude of any given utility from city to city ranged from skepticism to unrealistic optimism. The following sections concentrate on objective facts as much as possible.

## 4.1 TUNNEL OWNERSHIP AND OPERATION

The construction and operation of an urban area utility tunnel is a legally and financially challenging proposition. The requirements of tunnel ownership and operation can be defined according to the legal regulations and utility company attitudes at a particular location. There are certain prerequisites which must be met before these roles can be filled. Tunnel ownership must be based on the ability of the owning party to raise necessary capital for such a project. The utility tunnels under consideration will be associated with transportation projects. If the cost of constructing a utility tunnel is demonstrated to be roughly that of the cost of conventional utility restoration for a cut-and-cover subway project in a particular city, the amount of capital needed to be raised might be insignificant.

The tunnel management would be established by the owner, and must meet the approval of all of those participating in the project. Agreement between public and private utilities and municipal government could be expedited by a judiciously designed program of management and ownership. Feasible avenues for financing and managing a tunnel, along with the legal precedents which may be set by the creation of such an entity must be investigated for each city, and an equitable arrangement must be made for financial and operational responsibilities.

Several ownership options exist, depending upon the particular situation. These are ownership by civic government, private party, or by joint-agreement of utility companies. These are apparent reasons why the municipal government is the most feasible tunnel owner. Working relationships between city government and utility companies have been established out of past necessity. These channels could easily be extended to include methods for financing and operating a utility tunnel. Street rights-of-way are already owned by the city, except in such rare cases where utility companies have jointly purchased them. The city has the authority to regulate the positions the utilities must occupy in the street (refer to legal discussion) and may also determine the role of non-users who would benefit from the tunnel. Public hearings or political action would determine the zone of benefit and those occupying this zone would be compelled to financially contribute to the support of the tunnel in some way.

The matter of financing the construction of a tunnel by means of revenue or special assessment bonds would be under civic jurisdiction. Revenue bonds qualify for federal tax exemption, thereby reducing interest rates. The project may also be qualified to receive federal, state, or provincial grants through such agencies as the Federal Highway

Administration and the Department of Housing and Urban Development. The civic government is usually more able to withstand a debt than a private or joint-utility owner. Payment of interest and bond retirement would be financed in part by the rentals collected from the utilities, who would guarantee payment by underwriting bonds, and the financial support of the direct and indirect non-utility beneficiaries.

Examples of civic ownership of common duct systems in North America exist. The cities of Baltimore and Montreal constructed common duct systems in the early 1900's. The municipal authorities own the conduit and rent space to utility users. The rent covers all cost of owning, operating, and maintaining the system. In Montreal, the system is managed by a commission of three engineers. The commission is authorized to fix and collect rentals from both participating private and public utilities. This rent not only pays the operating cost (salaries, etc.) but pays the interest and redemptions over the 40 year period of the city debt. Rentals cease to include interest when redemption is paid in full.

Civic ownership is advisable, due to the complexity of ownership of various utilities and the relative ease by which the utility tunnel could be financed and managed through existing procedures. Government has an unfortunate reputation for being inefficient, and some private utilities have expressed fear of increased rental rates once the tunnel is in operation. It must be emphasized at this point that rental rates and the managing body will not be established at the whim of the tunnel owner, but will be designed to fit the requirements of the utility needs at each particular city. Nevertheless, other ownership options must be explored before a decision is reached.

Joint ownership by the participating utility companies would be one way of assuring adequate utility representation in a managing entity. It may also alleviate much fear of red tape encountered in government operations, but this type of ownership has several disadvantages.

One obstacle to joint ownership is that there is no existing legislation that enables a body as such to raise capital or operate a tunnel. This would mean costly delays while such legislation is enacted. The utility companies lack the authority of the municipal government, particularly where beneficiaries might have to support the project. Private money costs more than civic money, and the tunnel would have to be financed through the issuance of stocks and bonds, the interest on which would have no tax exemption status. Excess costs that are not covered by stock and bonds would have to be covered by rate increases to the consumer.

There are also disadvantages to joint-ownership which come from within the utility corporate structure. Utility company investment and rate making are already explicitly established and regulated, so that a major funding such as a utility tunnel would mean a change in corporate policy. This process is a slow and arduous one. It involves changing attitudes, which is bound to be time consuming.

Some difficulty might arise concerning the incorporation of new utilities, not in common use at this time, in a tunnel. Tunnel design provides space for utility expansion. This space may not all be rented by the time the tunnel is put into operation, so that those utilities in the tunnel may be indirectly paying for this extra space with their rent. There might be hesitation on the part of one of the utility/owners to allow a new utility in a competing field into the tunnel, particularly if the tunnel is more than a few years old and the utilities have been paying rent during that time.

Private ownership of a utility tunnel faces many of the same problems that joint-ownership encounters, such as lack of authority and means to obtain capital. Compounding these problems is the fact that the government is hesitant to provide grants for private ownership.

Consoer, Townsend, and Associates, in a report on the feasibility of mass transit utility tunnels in the City of Chicago, conducted a study for the Department of Transportation and the National Science Foundation. In their report they advised that the tunnel be owned by the City of Chicago and operated by the Department of Public Works.

The tunnel operating entity will be established by the tunnel owner, subject to approval from the utilities involved. CT&A suggests that the Department of Public Works operate the tunnel, with the Bureaus of Engineering and Construction both being involved in tunnel operation and maintenance. The Chief Engineer would operate the tunnel; the Bureau of Construction would provide maintenance and repair services. A crew of operators and inspectors is suggested by Consoer and Townsend, with walk-through inspection and control panel monitoring. The ancillary services would also be operated by the Department of Public Works.

An advisory committee of utility company representatives would cooperate with the managing entity on setting policy for tunnel operation, as well as coordinate utility expansion and repair work.

In general, the operating entity must meet the following criteria:

a) have an organizational structure flexible enough so that rigid utility control is not necessary and disagreement will not cause administration breakdown,

b) have authority to procure permits and easements for tunnel construction, approve design criteria, installation and operation of utilities,

c) coordinate the utility tunnel construction with state and local authorities,

d) coordinate the utility installation and future expansion plans,

e) operate and maintain ancillary systems,

f) provide maintenance crew, operation and inspection crew, security and access control,

g) establish rental rates and their collection,

h) approve tools and equipment used by leasess, and

i) establish tunnel operation and work rules.

A careful balance between utility representation and the operating entity must be maintained to provide for the successful operation of the tunnel. This method of cross-checking will prevent one body from domination over another party involved in the tunnel project.

4.2 UTILITY COMPANIES

Cooperation and coordination of effort between utility companies in a common tunnel is imperative. Although utility companies may have joint-pole and common trench agreements and like-utilities (eg. communications) will share ducting on occasion the utility companies, by and large, operate independently. This type of operation leads to wastefulness and duplication of effort which might prove costly to the consumer as well as the utility company itself.

Utilities and streets traditionally share rights of way, especially in central business districts of large urban areas. Unfortunately, the planning for these utility locations has been poorly coordinated and there is a severe lack of information about existing utility configurations. Hence, the rights-of-way in central business districts are usually a tangle of cables and pipes, making servicing and planning for future expansion difficult.

Repair of these utilities or the installation of new facilities invariably leads to disruption of street traffic. Sixty percent of the street opening permits granted in the City of Chicago have been to utility companies alone. Union work rules generally prevent one type of utility worker from exposing another utility plant unless it is necessary for the repair or installation of their own facilities. This leads to a multiplicity of street openings if several utilities are working in the same area. Exceptions to this procedure exist, but are usually associated with development of new areas where few previously existing utilities can be found. An example of this type of cooperation is the common trenching that is sometimes practiced by power and communication utilities. When all new utilities are to be installed in an area and both power and telephone cables will be occupying the same pathways, sometimes one or the other company digs a common trench and lays both cables. The number of feet laid is carefully recorded and the utilities take turns so that no one company does more work in common trenches.

The location of utilities in urban areas is unpredictable. In the existing tangle of utilities there is always a likelihood that some will be damaged from installation and repair operations, soils exploration, or drilling to determine footing conditions. The expansion, addition of laterals, splicing, restoration and relocation of utilities compounds the problem. Support of utilities during a construction project may also severely damage utilities. This may be the result of vibrations from street traffic or construction equipment, or the age and deteriorated condition of the plant.

In most cities, there exists no administrative body to coordinate installation and repair activities or to plan for future utility expansion. Occasionally utility companies meet informally to discuss problems and voice complaints, but the groups lack power and their accomplishments are variable. Cooperation between utility companies must be internally motivated and, unfortunately, this does not often occur. Utility companies experience considerable dialogue when subway projects are being proposed and the space available to the utilities in the street right-of-way has been reduced.

Utility companies were interviewed by IITRI and APWA to learn their views of the utility tunnel concept and whether they considered it an economically viable proposal. There was also discussion of utility compatibility, space requirements, utility benefits, restoration problems and future plans.

The utilities most likely to be included in a utility tunnel are communications (telephone and telegraph), power (electricity), gas, and water. Those that were excluded due to incompatibility or technical limitations are sanitary and storm sewers and possibly gas. Some of the smaller utility systems might also be included in a utility tunnel, such as city electricity (street lights, traffic signals, police alarms), and pneumatic parcel and mail transport. Consideration should be given to the systems in the developmental stages and those which are not yet in common use, such as chemical transport, pneumatic sanitary waste disposal, chilled and heated water, millimeter waveguide systems, and optical fiber communication systems. Only the major utilities most likely to be initially included in a utility tunnel were consulted in this study. Those include telephone, telegraph, electricity, steam, gas and water. The sanitary utilities (sewers) were also interviewed, but felt that the construction of a utility tunnel would have little direct effect on their plant.

A statement must be made as to the attitude of the utility representatives that were interviewed. They spoke for both public and private utilities. Since the concept of the utility tunnel is not a new one, most of those interviewed had been exposed to the idea prior to their meetings with IITRI and APWA, and already held strong opinions about the desireability of utility tunnels. Some of the commonly held beliefs are listed here.

a) Utility tunnels are good only for point to point systems, but buildings along the way cannot be efficiently serviced.

b) The risk of accidental or deliberate explosion is much greater.

c) Costs are excessive.

d) Utility workers will fear working in a strange environment near other utilities.

e) It will never work.

f) It will solve most utility problems.

There was a variation of opinion from city to city for similar utilities, so that statements about the feasibility of including a particular utility in the tunnel are nearly impossible to make. Some of the mixed responses experienced in the interviews from city to city are:

Power cables must be in/open trays - PVC - steel - fiber - split - seamless ducting/to operate effectively in a tunnel.

Communications cables should be/near power cables but as far as possible from the gas main - as far as possible from power cables and steam lines/to operate effectively.

A water main rupture resulting in flooding of the tunnel would/destroy all communications cables - cause no damage since the cables are submersible.

The gas utility must be/buried outside of the tunnel to prevent explosion and unconfinable leakage - located inside of the tunnel to be provided with adequate vapor detection instrumentation/to prevent explosion.

The response of city owned services was typically more favorable to the tunnel idea than the private companies in the same cities.

Utility companies have several major concerns about the utility tunnel concept. These are primarily economic, safety-oriented, and space-oriented. A discussion of each area follows.

Economic Concerns. Many questions arose concerning the funding of a tunnel project. Who will pay the capital and operating costs? How will rent be determined? What are conventional (buried) versus utility tunnel restoration costs? There is a general hesitation on the part of the utility companies to view the tunnel concept as economically beneficial. A detailed comparison of conventional burial vs. utility tunnel costs can be found in the economic analysis section of this report. There was concern expressed by some electric power companies that putting cables on racks as opposed to putting them in ducting would require more expensive equipment, but the majority of the other cable utilities disagreed. Concern was expressed by some utilities, electric in particular, that their extended cable life (up to 40 years) made cable replacement less frequent resulting in fewer street cuts than the gas company normally makes, therefore a tunnel which excluded gas mains would not really be of any benefit. One expressed a desire to include all possible utilities so that the cost of constructing and operating a tunnel would be divided among more parties.

Concern over tunnel ownership was expressed. If the tunnel is owned by the city then the rental rate might increase with the rising cost of city operations. Many utilities see joint-ownership of the tunnel by utility companies as the most efficient and economical means of financing tunnel operations. Some utilities presently own their rights-of-way and pay on the order of 3 percent of their revenues in franchise tax on anything over 10,000 kw hours.

Generally, the economic concerns centered around (1) initial and operating costs, (2) utility restoration costs, and (3) renting space and billing procedures. The first two concerns will have to be weighed from the economic analysis. The renting and billing concerns can only be resolved by serious open discussion and reference to similar existing situations where utilities have shared space.

<u>Safety Oriented Concerns</u>. Safety in the tunnel is a common concern of the utility companies. Two major decisions to be made concern the question of whether to include gas or power transformer vaults in the tunnel. The monitoring systems provided for in the tunnel design seem to satisfy most other safety needs, including that of adequate security, although the suggested system seemed elaborate and expensive to the utilities. Inclusion of gas and transformer vaults seems to generate a fear of an increased possibility of explosion. The transformer vaults comprise compartments in the tunnel design, with a concrete wall at least one foot thick between the transformers and the other utilities. (See utility configurations for details.)

Inclusion of the gas line poses a serious problem. One gas company refused to be included in a utility tunnel unless they are provided with a separate compartment and at least two feet of sand backfill around the main. Mr. Edward McLean, a consulting industrial engineer with over 30 years experience in the natural gas and liquefied petroleum gas industries expressed the opinion that, with the proper safeguards, there is no reason why a gas main cannot be housed in a tunnel. He described industrial installations where thousands of feet of gas main were run in tunnels without mishap. He felt that gas detection equipment is available to adequately safeguard a tunnel installation. The conclusion reached by IITRI and APWA is that the gas lines should be included within the tunnel, but that it is more important to respect the opinions held by the local utilities in any given situation. The design and operation of a utility tunnel requires active cooperation from all participants.

The primary objection of the gas utility in Philadelphia is concern over gas leaks permeating the separate compartment in the tunnel or flooding sleeved laterals, but it was felt that these problems could be solved by providing adequate safety measures. They question the cost effectiveness of such measures.

Considering that natural gas utility makes most of the street openings for repairs seems to indicate that the issue of gas inclusion in a tunnel is one of significant importance so that all attempts should be made to find a satisfactory configuration which will include gas within the tunnel.

There was a consensus among the utilities that any laterals passing over another utility's plant should be housed in ducting for safety purposes.

Space Oriented Concerns. More cooperation and flexibility from the utility companies has been encountered concerning the space limitations of a tunnel than in any other aspect of the project. Side spaces for splicing and cable pulling are viewed as adequate. There was concern expressed about the tremendous space occupied by transformer vaults, but one power company redesigned their vaults to make better use of available space in the tunnel. They also consented to move all vaults to one side of the street, which would facilitate space allotments and planning for the other tunnelled utilities.

There was concern expressed that the bending radius of telephone cables might be too large for tunnel conditions, or that there might not be a space or provision to place pulling eyes. Alternative methods of cable pulling have been discussed and it is felt that these space problems can be easily resolved.

The specific space and racking requirements for each utility is covered in section 3.1 of this report.

Utility Opinion Summary. In some cities, the utility companies were unanimous in condemning the utility tunnel concept as impossible. In other cities they were eager to begin construction of the project, but the general feelings expressed by most of the utility company representatives are those of wary hesitation. They would like to have full knowledge of the necessary investments required of them and the benefits they will receive before making any kind of definite commitment. The outstanding exception to this feeling was AT&T. Although concerned about cost and compatibility problems, they are even more concerned about growing congestion in underground rights of way. Most representatives feel that utility tunnels are good and desireable. They also feel that they are inevitable and AT&T will help in whatever way they can to create a liaison between different utilities on right of way practices and use of utility tunnels.

It is felt that utility tunnels will be most feasible in heavily congested urban areas. The concept is especially applicable in those areas where subway construction necessitates a "support and maintain in place" method of operation. In those cases where there are few operating utilities or where it would be easy or cost effective to abandon or relocate utilities from underground transit rights of way, utility tunnels are viewed as undesirable.

The utilities expressed the opinion that there are no insurmountable technical difficulties associated with housing most utilities in a tunnel, but the benefits of such a configuration must be clearly demonstrated before utilities will change their mode of operation.

## 4.3 UNIONS

The utility tunnel represents a change in the working environment of utility union members. The tunnel would present an unfamiliar work environment and cooperation between unions who normally do not work together would be necessary. Therefore, consideration of union opinion concerning the utility tunnel concept is essential.

The major factors influencing union members are the change in working conditions, procedures, and work rules that would result from utilities existing in a free-access location. Most utility work, such as cable pulling and splicing, is now being done in manholes between 7 p.m. and 7 a.m. because traffic conditions during the day restrict manhole access. Since most utilities pass through the same manholes, different work rules often apply to the same area. For example, some communication workers in Chicago are prohibited from using open flame underground, whereas power cable splicing frequently involves the use of torches, even in the vicinity of gas mains which might be passing through the manhole. This conflict in work rules would also exist in a utility tunnel, and steps would have to be taken to outline standard procedures which would be agreeable to all unions involved.

Working conditions in a utility tunnel have definite advantages over working underground, according to the unions. The atmosphere would be controlled and adequate lighting would always be available. A great advantage would be that the entire length of the utility would be exposed in the tunnel. The only exception would be power lines that might be located in ducting in the tunnel floor. Cable pulling, in this case, would probably be easier, although more workers might be required. The task of cable pulling would be eliminated for those cables which are racked, and the only additional task would involve racking these cables. Additional safety is provided by the tunnel monitoring systems, which is particularly significant if open flames is to be used in the vicinity of gas lines. A manhole provides only one means of egress, which might prove fatal if an event on the surface should block the opening. The utility tunnel would not only have numerous access hatches, but the entire length would be available as a means of egress should an emergency arise.

Union members anticipate no interference from the other utilities in the tunnel, as they now operate with a "two-way street" attitude. Joint-pole agreements and the sharing or leasing of ducts exists to some extent between utilities at the present time. Previous studies have stressed the fact that difficulties would arise when different utility union members work in a common structure, but union members agree that they have worked around other utilities in the restricted space provided by manholes with no problems.

The unions would object to the utility tunnel concept if it meant a decrease in jobs, but they anticipate that the money saved by reduced maintenance costs would be spent by the utility companies on expanding existing facilities and developing future utility systems. The job of utility inspection in a tunnel would still be the domain of the union members and utility workers. Any walk-through inspection of the tunnel would not provide for utility inspection, although any utility malfunction discovered during tunnel inspection would be immediately reported to the utility companies.

Utility unions should be consulted during the designing stage and when plans for tunnel operation are being formulated. They will be the force who ultimately decides how much space each utility will require and whether the designs are adequate to meet their needs.

The consensus among the utility union members is that any disadvantages encountered while working in a tunnel would be far out-weighed by the advantages. They feel that they would not be exposed to an environment any more hazardous than that encountered in manholes, and the monitoring systems provided for the tunnel design would perhaps furnish more safety. Cooperation between utility union members can be expected in the evaluation of institutional factors concerning the utility tunnel concept.

## 4.4 THE PUBLIC

The one group experiencing both the advantages and inconveniences of a particular construction mode or utility configuration in urban areas most acutely is the public. The public is effected both as consumer and merchant. Traffic delays, service disruption, noise pollution, parking space reduction, and dirt all result from utility repair in the street rights-of-ways. The consumer is reluctant to patronize a store that is inconvenient to reach and the merchant experiences a drop in business. The problems are compounded by cut-and-cover or open cut construction. Radical utility relocations, or installation and repairs may close a street or portion of the street for weeks. Many utilities are located near the curb or under the sidewalks, which make access to a store or business not only inconvenient but dangerous, both in fact and appearance. Dirt may be tracked into the store. Broken pavement by the side of an excavation provides material for vandals to throw at nearby windows. Timber walkways are unstable and become slippery when wet.

Public frustration and outcry follow closely from daily inconvenience. The public is angered when freshly paved streets are violated by the later addition of an underground cable traversing the road. They have been motivated to form citizen action groups to have a voice in the disruption of their streets.

In Washington D.C., an ad hoc group composed of local merchants works closely with the Washington D.C. Highway Department concerning such things as utility relocation, construction plans, and street opening permits. Their interests are considered when proposed street and utility work is still in the planning stages. The two groups work together to devise plans that will cause the least disruption possible to the public while satisfying the utility companies and city planners. The merchants in Washington seem to prefer an intense disruption of business for a short time as opposed to prolonged inconvenience and repeated street cuts.

## 4.5 INSTITUTIONAL FACTORS SUMMARY AND CONCLUSIONS

Several preliminary conclusions can be drawn from this study of the institutional factors related to the construction of a utility tunnel. Civic owership appears to be the most feasible option for a utility tunnel. In this way, whatever capital needs to be raised will be done at the least cost to the consumers and utility companies and the least amount of new legislative action. The tunnel operating entity would be established by the tunnel owner with frequent input and approval from the utility companies. This entity would likely follow the suggestion of Consoer, Townsend, and Associates and be under the jurisdiction of the local Department of Public Works, if the tunnel is civically owned. The entity would establish tunnel operation and maintenance procedures, coordinate utility work, and fix and collect rentals.

Interviews with representatives from public and private utility companies, the engineering community, and merchants and general public were conducted. Their opinions aided in establishing some of the guidelines for tunnel design and operation in this report.

The utility companies showed the widest range of opinion, from strong disapproval to strong support for a tunnel project. They were generally more willing to volunteer the cooperation of other utilities than themselves, but with the exception of the gas companies, outright rejection of the idea was rare. Public utilities exhibited more enthusiasm than private utilities. Gas companies generally did not want to participate, while power and the telephone were usually the most cooperative. Water and steam representatives generally felt that they could be included if a tunnel was built.

There was concern expressed by the utilities on three major issues: economics, space available, and safety measures. It was felt, after discussion of the tunnel configuration and systems, that if the project is economically justifiable then the technical and physical limitations are not a serious impediment.

The utility union personnel felt that any disadvantages encountered while working in a tunnel would be far out-weighed by the advantages. The tunnel environment would provide pleasant working conditions. The monitoring systems would make the tunnel a safer place to work in than a manhole. Work could be done at anytime during the day, instead of 7 p.m. to 7 a.m., as is done presently. Cables and pipes would be easier to care for with the free access that the tunnel provides.

Public opinion is opposed to street disruption of any kind or at any time. Prolonged disruption has devastating effects on stores and business. If utilities must be repaired, the public would rather not be aware of the repair work as it is being done. If a subway must be built they would rather see it under decking as soon as possible. They would be justifiably enraged if poor planning of utility repair or expansion id anything to hinder the rapid completion of the construction project, or required street cuts in new pavement. Merchants feel that there is a rational method by which a dialogue between the public and the urban planners can be established. This communication would aid in the future developement of city and private services and would benefit all concerned.

# 5. SOCIO-ECONOMIC IMPACTS

## 5.1 SOCIETAL FACTORS

The cut-and-cover construction of a subway or utility project will subject various areas of the central business district of a city to immediate and undesirable conditions of varying duration. These conditions affect the social and economic vitality of the business district. Any responsible project will make "all available effort" to minimize the harm to the area. The adjustments, which are possible, will vary with the type of construction method employed.

In evaluating the utility tunnel versus conventional backfill options, merchants and engineers face major differences in surface disruption time and the resultant socio-economic impacts.

The utility tunnel configuration would permit complete surface restoration of a half mile project within a total of one year, totally disrupting only one block sections for a maximum of six weeks each. Conventional cut-and-cover construction would disrupt each one block section for four weeks, but surface disruption would continue for two years. Thus, the alternatives are six weeks total disruption of only one block at a time to completion of surface work in one year, as opposed to four weeks per block plus disruption along the entire length of the project for two years to complete.

The socio-economic results of two years of stress and inconvenience are the differences compounded during 24 months versus 1-1/2 months.

Pedestrians, motorists, merchants and workers all oppose street disruption. Sidewalks are lost for periods of time, street detours impair mobility and the whole nature of the downtown area changes during construction from an active urban area to a dirty job site.

Noise and vibrations interfere with peace of mind and normal activity patterns within adjacent buildings. This lasts for six weeks with utility tunnel construction, and 18 months longer using conventional backfill methods.

The worker or shopper is confronted with the problems of:

a) How much more time will it take me?
b) Where is the new entrance located?
c) Is the business open?
d) How much further will I have to go?
e) Is it worth all this extra bother?

These feelings result in an avoidance of the downtown area, and consequently a loss of sales and economic vitality. It is difficult to measure the cost of the loss of patronage, but the more consumers become frustrated with the inconvenience the longer it will take them to return to the downtown area.

The physical disruptions inherent in utility and subway projects are as follows:

street excavation
sidewalk excavation
noise
fumes
dust, dirt
debris
barriers (visual and physical disruptions)
blocked entrances.

There are several immediate physical and socio-economic impacts due to the above disruptions.

Mobility

Cars, trucks, buses, taxis, must detour the construction site. No parking is allowed on the timber-decked streets. The available number of lanes are reduced and subject to rerouting, which may result in congestion and confusion. Shipping and delivery of goods and freight becomes more difficult in terms of blocked entrances and additional time (labor costs). Pedestrians are discouraged by the conditions they are confronted with and patronize the disrupted streets to a lesser extent. (In normal times pedestrians walk only two to three blocks for shopping; under stress conditions they are not likely to want to walk in the disrupted area at all.)

Outdoor Activities

Gardens, restaurants, parks, plazas lose their attractiveness during the construction period.

Visual Blight

The presence of barriers, machines, dirt, etc. decrease the emotional and esthetic appeal of the area.

Hazards and Possible Accidents

Physiological Stress

The pollutions of fumes, dust, dirt, and noise subject the body to irritation.

Psychological Stress

The excess time, distance and confusion resulting from the construction project distrubs both shoppers and employees alike. Irritability of sales people results in loss of good will and sales.

Institutions and Other Business Requiring Low Noise Levels

Schools, hospitals, theaters, museums must operate in quiet areas, which becomes increasingly difficult during construction.

Hotels

Hotels, tourist attractions, and convention centers suffer from lack of accesibility as well as from the noise, and dirt. Loss of entrances create delays and aggrevations.

Restaurants and Other High Volume Traffic Dependent Trades

These establishments are hardest hit, being dependent on street access and foot traffic for their business.

Crime and Vandalism

Exposed construction material and scattered debris are open invitations to vandals to destroy property.

Public Service

Police patrol, fire, ambulance, and mail services, are all curtailed due to street disruption.

Leases

If the construction period extends for several months (4-12) the loss of store front and office tenants will adversely affect the real estate industry.

Retail Trade

The stores on the streets being excavated will exhibit definite sales losses. Adjacent streets will suffer less, depending on the amount of congestion and the length of time for which intersections are blocked. Marginal stores will be unable to stay in business if the construction period extends much beyond six months time.

Marginal Small Business

If duration exceeds six months, 20 to 30 percent will fail.

Employment

If retail trade loses business, unemployment will increase. The number of construction jobs generated by the project will not offset these figures. This also means increased unemployment and welfare claims.

Tax Bases

Lower sales and unemployment mean lower sales tax, city tax, employee head tax, and federal income tax. The property values may not lower, but any loss of tenants will make it more difficult for landlords to pay property tax.

General Ambience of CBD and Its Competitive Position

As the disruptions of the project increase the CBD becomes less attractive. Ninety percent of the retail sales lost from the CBD goes to suburban stores. In recent years, this loss has been somewhat less, but it is essential to the survival of the innercity that consumers are encouraged to patronize downtown stores.

One of the problems found in researching the economic impact on area merchants is that there is an unfortunate lack of information on the direct costs of these disruptions. Little has been written on the subject of what happens to the CBD during the construction period. By reviewing impact statements on other projects and through discussions with merchants affected by previous construction projects the following conclusions may be offered:

> Retail sales will lose 20 to 30 percent of their business; the higher figure reflecting two year construction disruption.
>
> Offices and store fronts may be vacated if construction goes beyond 12 months. If construction lasts six months or less, no appreciable decline in leases will occur (with the exception of small marginal operations).
>
> Marginal operations could go bankrupt - losing 20 percent or more of their sales if the project last more than several months. Since this 20 percent is their profit, losses over a two year period would probably render them unable to repay even emergency small business loans.
>
> Banks will have to erect temporary windows or new entrances to maintain their walk-in business. Although much business could be transacted through the mails, some damage is inevitable.
>
> Hotels and tourist attractions would show moderate losses on the whole - direct inconvenience might result in losses of 15 to 20 percent.
>
> Professional services, doctors, lawyers, accountants would lose some business, especially if the disruption lasts more than six months.

> Restaurants and high volume stores would be hardest hit. From 50-75 percent of their business would disappear until their accessibility is restored.

The dollar amount of these losses to individual businesses is a function of the duration of the surface disruptions. A brief disruption may be endured; longer disruptions will possibly result in business failure. The loss to the business district as a whole is based on the duration, and percentage of the total area blocked.

Much of the new office space in Chicago is leased but not yet occupied. Only 30 percent of the tenants in these new buildings are now paying rent. If a project lasted more than a year, offices with flexible location needs would shift to a more attractive suburban location. Only 85 percent of the more prestigious locations are leased. Office leasing has lagged behind the economy, and some urban landlords have lowered lease rates to compete with suburban areas. Any extended disruption to the area will damage these attempts to regain part of the market.

General office activity and recreational activity would be distrubed. Some of the noise can be reduced but the lack of patronage of area theaters and parks will damage this industry, as well.

A secondary aspect of the change in patronage is the resulting change in social mixture of the CBD. The lower class ethnic groups have fewer alternatives for shopping or movie theaters and they will continue patronage of the area. This makes a visible difference in the quality of the downtown area life and defeats the efforts to fully integrate the city. These hidden costs are not directly quantifiable, but affect the ability of an area to recover from disruption.

A stronger, and more rapid recovery is possible when the construction lasts less than one year. Second year losses may increase by five to ten percent. Recovery based on an operational transit system is optimistic. This would reinstate accessibility but that alone is not sufficient to revitalize the economy of the CBD. Obviously, there are serious socio-economic problems to be faced by any city considering a massive disruption to the CBD. The public benefits when the project affects smaller areas for a shorter period of time. Project planning should strive to increase accessibility to businesses that offer essential retail goods and social services without harming the health and economic welfare of the citizens.

The perceived quality of the district is essential to market capture and maintenance of the desired ethnic and economic mix of the people patronizing the area. Retailers and large companies, as well as private professionals, will take these general qualities into consideration when selecting a suitable location for their business. Shorter term disruption will minimize the loss to the area. The total recovery of an area after construction has been completed is a complex issue involving many factors other than simply the duration of the project. Recovery is also based on the economic cycle of the nation as a whole. Nevertheless, every effort on the part of the urban planners and engineering community should be made to employ innovative construction techniques to minimize the disruption to urban areas and thereby reduce the severity of the impact.

TABLE 5-1 - SUMMARY OF LOSSES FOR EACH CONSTRUCTION PERIOD

| Time | Type | Percent |
|---|---|---|
| 1-1/2 months | Retail Sales | 20 |
| | Marginal Business | 10-25 |
| | Banks | 1-3 |
| | Postal Delivery | |
| | Hotels | 10-15 |
| | Restaurants | 50-75 |
| 6 months | Retail Sales | 25 |
| | Marginals | 20-30 |
| | Restaurants | 50-75 |
| | Professionals | 10 |
| | Hotels | 20 |
| | Banks | 3-5 |
| 1 year | Retail Sales | 25 |
| | Marginals | 30 out of business |
| | Leases | not remewed |
| 2 years | More leases lost | |
| | Retail Sales | 30 |
| | Professionals | 15 |
| | Restaurants | (in debt) |
| | Marginals | bankrupt |

## 5.2 LEGAL IMPLICATIONS OF A UTILITY TUNNEL

The construction of large scale general public improvements such as a cut-and-cover transportation tunnel represent a wholesale disturbance of complex and sometimes delicate utility systems found in the rights of way. Utility handling, while assuring the continuity of utility service to adjacent customers, is an important and expensive aspect of any such construction. The decision to construct a cut-and-cover transportation tunnel, however, is also a decision for the overall relocation of utilities. As such it affords an opportunity for the reordering of the central area rights of way to better fulfill the future space needs of existing and new utility facilities. It was noted in APWA Special Report No. 44, Accommodation of Utility Plant Within The Rights Of Way of Urban Streets and Highways: State of the Art, that...

> ...Urban redevelopment project offers some cities the opportunity to correct R/W utility accommodation practices made in central areas and CBD's when they were originally developed.

Prudence would suggest that opportunities to more rationally reorder the allocation of space to utilities in congested rights of way should be exercised whenever possible.

This discussion will be directed to various aspects attendant upon the use of utility tunnels. These will include an overview of legal implications, cost sharing, past joint use experiences and other relevant considerations. It is not meant to be a comprehensive legal statement, but is a reiteration of the research done by APWA on the matter of the legal implications of a utility tunnel.

States and their delegated political subdivisions or agencies possess and exercise sovereign and complete control over public rights of way within their respective jurisdictions. It is generally accepted and often codified that public utilities designed to serve public purposes may also make use of designated classes of public right of way subject to various qualifications and regulations.

When the utility obtains the express or implied consent of the legal authority having jurisdiction over the right of way and expends money on the basis of that consent, it gains a legal interest or privilege in its location for limited purposes and is also subject to corresponding duties or obligations. Thus, the legal jurisdiction may not rescind its consent and obligate the utility to move its facilities without a valid reason. No utility however, can exercise a vested right to remain in a given location within a public right of way in the face of a valid reason---regardless of local franchise agreement conditions or expense. Government may not agree to limit or impair its 'police power'---its power to make all reasonable regulations necessary to preserve the health, safety, welfare and convenience of the public. The control of public rights of way are generally recognized within the scope of 'police power'.

The courts have uniformly held that legally authorities can require utilities to relocate any facilities within a right of way to another position within the right of way at their own expense, whenever the necessities of street improvement or betterment require. Utilities may also be required to relocate when governmental functions other than street betterments are involved as long as they are not merely the "proprietary" activities of the legal authority or are to benefit other privately owned utilities. Definition of 'proprietary' activities in this case is not uniformly interpreted in the courts. Federal participation in betterments or improvement is not an inhibition of the local exercise of 'police' powers.

The exercise of police power by a local authority must be determined by the balance of the burden imposed upon a private individual (or utility) against the benefit accruing to the public through the limitation of his rights. Some exercise of this power in connection with the relocation of utilities at their own expense to make way for the construction of subways have been upheld in the courts.* Subway construction in these cases were classified as governmental functions. In at least one case, utility relocation costs were found to be payable by a transportation authority for subway entrance changes in a public right of way because the construction was defined as a proprietary function of the city.**

In the case of Peoples Gas Light and Coke v. Chicago (413 Ill. 457,109 N.E. 2nd 777, 1953), the following ruling was made:

> The Supreme Court of Illinois affirmed the Circuit Court which had dismissed the company's complaint, holding that providing ways for travel below the surface of the streets of a municipality is a proper street use and that the same principles apply as would apply on the surface - namely, that the city was acting in its governmental, not proprietary, capacity, and that the utility is required by common law principles to move its

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*People Gas Light and Coke Co. v. Chicago, 413 Ill. 457,109 N.E. 2d 777 (1953)

New Jersey Bell Tel. Co. v. Delaware River Joint Comm'n, 125 NJ L 235 15 A 2d 221 (1940)

Philadelphia Electric Co. v. Philadelphia, 301 Pa 291, 152 Atl 23 (1930).

**City of New York v. New York Tel Co. 278 NY 9, 14 N.E. 2d 831 (1938).

> facilities at its own cost. Such a requirement does not violate the company's property or contract rights or deny it equal protection of the laws.

The foregoing indicates that legally authorized local jurisdictions may exercise the power to require utilities to relocate their facilities within public rights of way. The expense of relocation may be an obligation on the utility when the local jurisdiction so elects in the exercise of its "governmental" functions. The expense of relocation may not be an obligation of the utility if the local authority requires relocation to serve its "proprietary" functions. A case on behalf of the local authority in the case of a utility relocation for a subway construction at utility expense is found in the case of Philadelphia (301 Pa. 291, 152 Atl. 23, 1930), in which the following ruling was made:

> The Supreme Court of Pennsylvania reversed the Common Pleas Court and held that the company could not abrogate its contractual obligation to comply with the condition compelling it to pay for the construction of a municipal work such as a subway.

In this case the findings of the court were based upon the franchise agreement under which the utility operated in public rights of way as it was interpreted as a contract.

Franchise agreements are the most popular and prevalent tool used for the regulation of public utilities by governments. As noted in the previous legal citation, franchise agreements may have some implications for the integration of utilities in transportation tunnels. Most notably, the issue of allocation of utility relocation costs is of concern to both governments and utilities. In general, most franchise agreements between governments and utilities require the utility to relocate at the jurisdiction's request, and at the utility's expense. One example of the wording of a franchise granted by the Phoenix, Arizona is as follows...

A. The entire cost of relocation shall be borne by the City if the Grantee is required by the City to relocate facilities which are located in private easements or rights of way obtained by the Grantee prior to the dedication of the public street, alley or easement from which the facilities must be relocated. These prior rights of the Grantee would also be unaffected by any subsequent relocation.

B. Except as covered in paragraph A above, the Grantee shall bear the entire cost of relocating facilities located on public rights of way, the relocation of which is necessitated by the construction of improvements by or on behalf of the City in furtherance of its governmental functions. The City will bear the entire cost of relocating any facilities, the relocation of which is necessitated by the construction of improvements by or on behalf of the City of Phoenix in furtherance of a proprietary function. The following items are clearly governmental functions of the city:

   1. Any and all improvements to City streets, alleys and avenues designed to improve the flow of vehicular and pedestrian traffic;
   2. Installation of sewers and storm drains and related facilities;
   3. Installation of pipe and other facilities to serve domestic and municipal water to the extent that those facilities are used to serve municipal facilities utilized in furtherance of the City's governmental functions;
   4. Establishing and maintaining municipal parks;
   5. Providing fire protection;

C. With respect to all other instances requiring relocation of utility facilities or necessitating protecting the utility facilities or providing temporary service where the improvements being installed by or on behalf of the City do not require relocation, the cost of relocation or providing temporary service or protecting facilities will be resolved on a case by case basis.

This example was selected because it clearly defines the relationship of "governmental" and "proprietary" functions of the jurisdiction. In this case, if subway construction was planned, the costs of utility relocation would be clearly those of the affected utilities.

The use of franchise agreements is a commonplace tool for the control of utility usage of the public rights of way. The 1973 APWA survey findings, indicated in Table 5-2 demonstrates that locally negotiated franchises are most prevalent, while state-wide franchises are second. The responsibilities for utility relocation and the expenses of relocation were surveyed for a number of jurisdictions. The results of this effort appear in Table 5-3. In the majority of the franchises reviewed, the local authority clearly spelled out its right to require the relocation of utility facilities for good cause. The majority also stated that the obligation for the cost of relocation would be that of the utility involved.

Because standards for utility location have been developed in a number of jurisdictions, some information exists to suggest that utilities may be required to locate their facilities at a specific location within the right of way. The 1973 APWA survey indicated that 41 percent of the respondent communities have some form of utility location standards; 38 percent have not developed standards; and 21 percent are now working on these criteria. Of the communities with firm criteria, 31 percent require mandatory compliance while 69 percent employ their standards only as guidelines.

In conclusion, sufficient legal documentation exists to suggest that utility/transportation tunnel integration is possible, and under the proper conditions, enforceable by local governments and governmental authorities. Indeed, where specific statutes, state constitutional provisions, or franchise contract stipulations do not expressly address this issue one way or the other, there appears to be little

TABLE 5-2 - AUTHORITY BY WHICH UTILITIES OCCUPY PUBLIC STREETS RIGHTS OF WAY

(214 replies)

| Authority | Percent |
| --- | --- |
| Franchise By State | 25.2 |
| Franchise By Municipality | 62.6 |
| State Legislation | 20.6 |
| Municipal Ordinances | 57.0 |
| Other | 4.2 |

TABLE 5-3 - RELOCATION RESPONSIBILITY

| Jurisdictions | Franchise Requirement | | | |
|---|---|---|---|---|
| | Responsible For Relocation At Jurisdiction Request | | Relocation At Utility Expense | |
| | Yes | No | Yes | No |
| San Diego County CA | X | | X | |
| San Diego CA | X | | X | |
| Oakland CA | X | | X | |
| Austin TX | X | | X | |
| Fremont CA | X | | X | |
| Bellevue NC | X | | X | |
| Decatur GA | X | | X | |
| Portland OR | X | | X | |
| Minneapolis MN | X | | X | |
| Travis TX | X | | X | |
| Tempe AZ | X | | X | |
| Phoenix AZ | X | | Depends on Conditions | |
| Wichita KS | X | | X | |
| Montgomery County AL | X | | X | |
| Hammond IN | X | | X | |
| Covington KY | X | | X | |
| Louisville KY | X | | X | |

TABLE 5-3 (Continued)

| Jurisdictions | Franchise Requirement | | | |
|---|---|---|---|---|
| | Responsible For Relocation At Jurisdiction Request | | Relocation At Utility Expense | |
| | Yes | No | Yes | No |
| Natick MA | X | | X | |
| Stillwater MN | X | | X | |
| Paterson NJ | X | | X | |
| Camden NJ | X | | X | |
| New York NY | X | | Depends on Conditions | |
| Syracuse NY | X | | X | |
| Cheektowaga NY | X | | X | |
| Raleigh NC | X | | X | |
| Chester PA | X | | X | |
| Scranton PA | X | | X | |
| Boroughs of Alden and Clifton Heights PA | X | | X | |
| Philadelphia PA | X | | X | |
| Pittsburgh PA | X | | X | |
| Mifflin County PA | X | | X | |
| Nashville TN | X | | X | |
| Bremerton WA | X | | X | |
| White County WV | X | | X | |

TABLE 5-3 (Concluded)

| Jurisdictions | Franchise Requirement | | | |
|---|---|---|---|---|
| | Responsible For Relocation At Jurisdiction Request | | Relocation At Utility Expense | |
| | Yes | No | Yes | No |
| Benwood WV | X | | X | |
| Merced CA | X | | X | |
| Tampa FL | X | | X | |
| Macon GA | X | | X | |
| Chicago IL | X | | X | |
| New Orleans LA | X | | X | |
| Lafayette LA | X | | X | |
| Belfast ME | X | | X | |
| Detroit MI | X | | X | |
| Los Angeles CA | | X | | X |
| Kansas City KS | X | | X | |
| Westchester County NY | | X | | X |
| Milwaukee WI | | X | | X |
| Hannibal MO | | X | | X |
| Plattsmouth NE | | X | | X |
| Teague TX | X | | X | |

doubts that governments reserve the right, under common law, to regulate the use of public right of way if it is to the benefit of life, health, property, safety, or convenience of the public. In Port of New York Authority vs. Hackensack Water Company, Public Service Electric and Gas Company, and New Jersey Bell Telephone Company (1963), the Court held that: (1) the utility's interest in public right of way is subordinate to the public's enjoyment of it and the utility runs the risk that public welfare may require changes calling for the relocation of utility facilities; and (2) the true connection between police power and relocation of utility facilities is not that the duty to relocate is generated in each specific instance by decision under police power to impose it but rather the meaning is that the utility interest in the street was intended to be subordinate to police power, that is, that the government's authority to exert police power in the street for public welfare was not bargained away by grant to the utility company. As in the case of Philadelphia Electric Company vs. Philadelphia, this doctrine should equally apply to subsurface public right of way.

In short, if the building of a subway transportation system could be proven to be a necessary "governmental" function for the benefit of life, health, property, safety, or convenience of the public, utilities, it would appear, could be required to relocate at their expense in a manner to be determined by the governmental authority. This could mean relocation in a joint-use transportation/utility tunnel where tranditional relocation methods were proven to be not feasible, as in the case of limited right of way space resources in densely populated CBD's.

It is likely that related federal government monetary policies will have a substantial impact on decisions to fund projects involving utility systems and transportation tunnel integration as well. In the case of federally funded highway projects, for example, the Code of Federal Regulations, Title 23, Highways, Subpart A, Section 645.103, states:

> Federal funds may participate, at the pro rata share applicable, in an amount actually paid by a State, or political subdivision thereof, for the costs of utility relocations under one or more of the following conditions:
>
> 2) where the utility occupies either publicly owned or privately owned land or public right of way, and the State's payment of the costs of relocation is made pursuant to State law and does not violate any legal contract between the utility and the State, provided an affirmative finding has been made by FHWA that such a law forms a suitable basis for Federal-aid fund participation...

Thus, federal money can be used for utility relocation on highway projects if state or local contracts with utility companies (franchises) do not stipulate that utilities must bear the brunt of relocation and the costs incidental thereto. In Phoenix, Arizona, for example, where the costs of utility relocation is clearly the responsibility of the City, the City is eligible for reimbursement of utility relocation costs under prevailing federal regulations for federally approved highway construction projects.

## 5.3 ECONOMIC ANALYSIS

This section summarizes the economic analyses conducted for the tunnel designs previously described. The comparison between options was made by estimating the cost of the entire basic structure plus the costs of utility handling. Common elements in the total system, such as trackwork, street paving and others were ignored. Construction estimates were obtained from contractors, bid prices from transit systems under construction, and the literature. The utility tunnel appurtenances and utility loading were adapted from the CUTD (1973) report on a detailed utility tunnel design proposed for Monroe Street in Chicago, It was felt that this proposed utility tunnel design and the utilities therein provide an excellent example that can easily be generalized for application in any urban area.

Emphasis is placed on quantifying the direct costs accruing to the tunnel owner and other organizations involved in the project. The benefit analysis has been accepted from previous work (CT&A, 1975) with little change. The traffic delay cost for the construction period was not considered in the CT&A study, which assumed traditional construction methods. This element was therefore quantified using numerical relaxation techniques as shown in Appendix B. Throughout, dollar figures are indexed to 1975.

Three design options were evaluated in this analysis. Option I (Figure 5-1) is a conventional subway design in which the utilities are located in the backfill above the subway roof. Twenty-four inch thick slurry walls are provided to function as outer walls of the transportation tunnel and for roof support. The roof of the transportation tunnel could be either precast concrete panels or a cast-in-place slab. The choice would be determined by economics. Steel plate girder and precast roof elements were selected for this estimate. The floor of the tunnel is a cast-in-place concrete slab. Center columns are provided to support the roof.

Option II (Figure 5-2) incorporates a clear span utility tunnel above the transportation tunnel. Slurry walls of the same thickness as Option I are provided to support the permanent street level roof deck and to function as outer walls for the transportation and utility tunnel. The permanent street level deck consists of precast concrete elements. Concrete beams running across the width of the tunnel are provided to support the intermediate deck, which

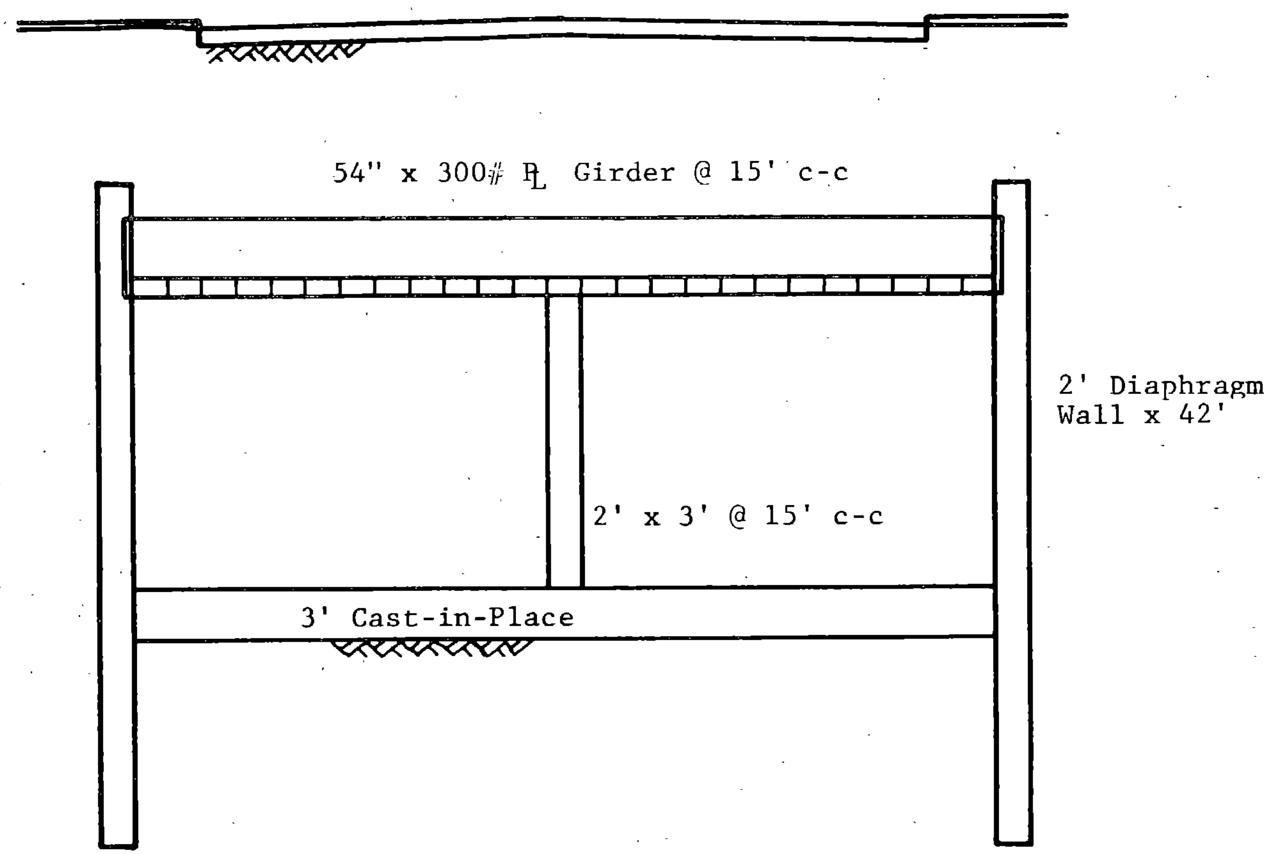


Figure 5-1. OPTION I - Conventional Design

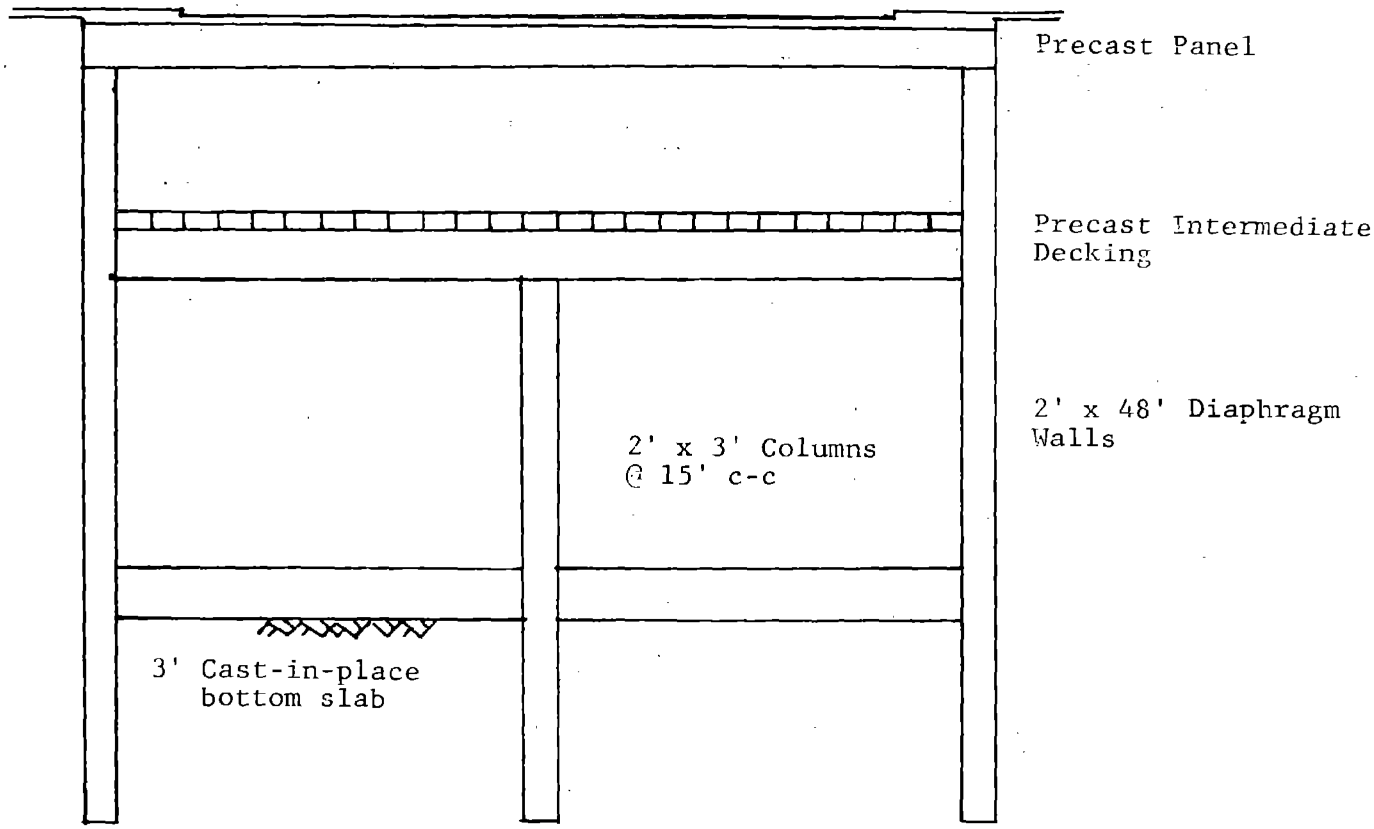


Figure 5-2. OPTION II - Utility Tunnel With Center Columns

is also precast concrete elements. The base slab and center columns are the same as in Option I. Option II was eliminated during preliminary analysis as the design required a very expensive roof deck.

Option III (Figure 5-3) is similar to Option II. The major design variation is the incorporation of central strip panel walls extending to the roof deck to replace the center columns. The strip panel wall is a two feet by six feet slurry wall that extends to three feet below the roof deck. Cap beams are provided on top of the strip panel walls and run the entire length of the tunnel. By providing a central support to the roof deck (street level) the unsupported width of the deck is reduced to half and the thickness of the roof deck is also reduced. The roofs of the utility (deck at street level) and transportation tunnel are precast concrete panels. The base slab is the same as in Option I.

The cost of under roof excavation as proposed in Option II and III is \$13.26 per cubic yard, \$1.96 per cubic yard more than the cost used for common excavation. A detailed breakdown of the structural costs for Option I and III is presented in Table 5-4. Sources of unit cost elements are listed in Table 5-5.

Utility Handling (Options I and III

Utility handling costs were estimated for the following cases:

Option I - Replace 20 percent of power and communications cables, replace 100 percent of gas and city services.

Option I - Replace 100 percent of all utilities.

Option III - Replace 100 percent of all utilities.

Depreciation of existing utilities scheduled for replacement was not considred. The question of what constitutes a utility

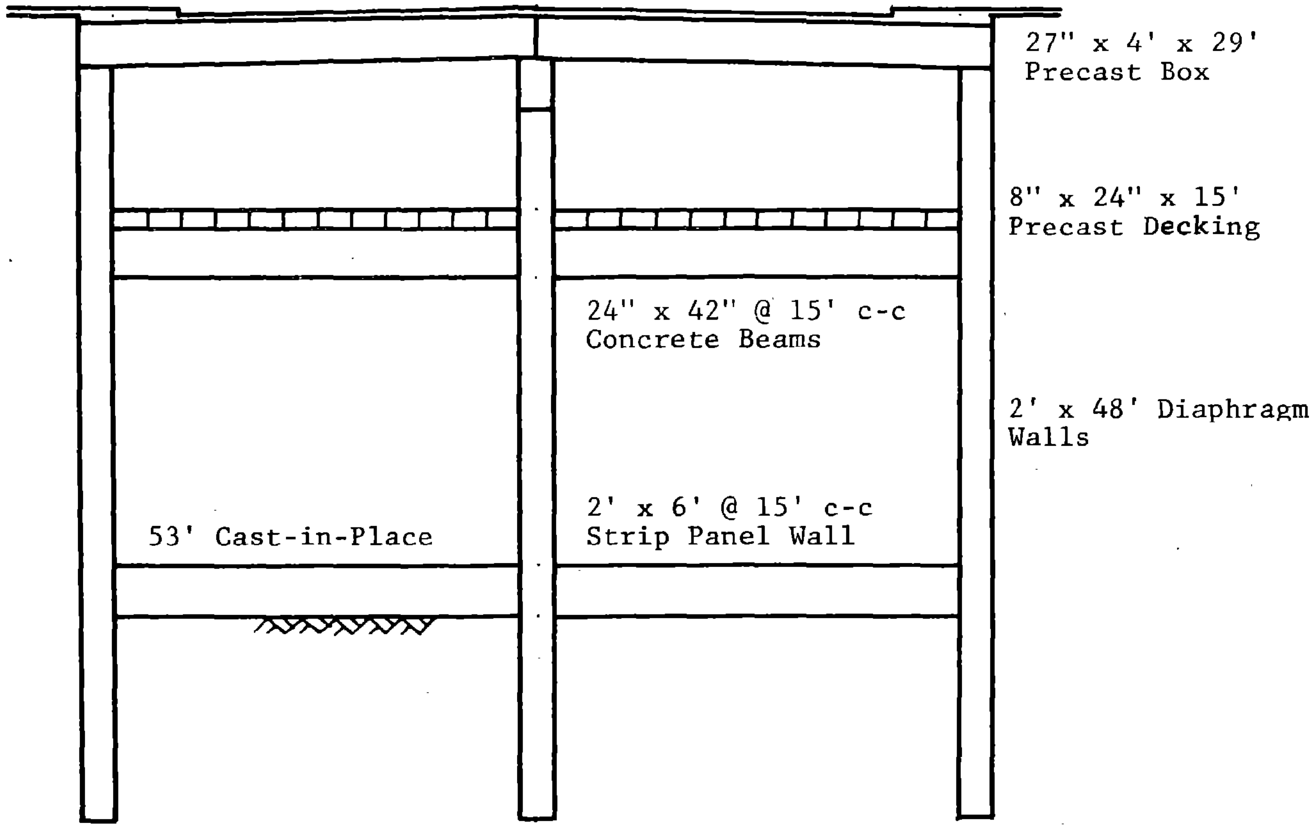


Figure 5-3. OPTION III - Utility Tunnel With Strip Panel Wall

## TABLE 5-4 - STRUCTURAL COST - OPTIONS I AND II

| | OPTION I - Conventional | | | OPTION III - Utility Tunnel | | |
|---|---|---|---|---|---|---|
| Element | Description | Unit Cost or Source | Cost | Description | Unit Cost or Source | Cost |
| Side Walls and Bracing | 2' diaphragm wall<br>42' x 2 (2880') | (3)<br>17/SF | $ 4,112,640 | 2' diaphragm wall<br>48' x 2 (2880') | (3)<br>16/SF | $ 4,423,680 |
| | Soldiers and Lagging | (6) | $ 564,480 | Not applicable | | |
| | WF 36 x 135 walers<br>2(2880) x 135 ÷ 8 | (7)<br>2.10/lb | $ 204,120 | Same as Option I | | $ 204,120 |
| | 140 lb/ft struts at 15' C-C .44 ft long<br>2880 ÷ (15 x 8) x 44 x 140 | (7)<br>1.86/lb | $ 274,982 | Same as Option I | | $ 274,982 |
| Street Deck | 36 WF w/10" planking (temporary)<br>56 x 2880 ÷ 9 | (8)<br>130/SY | $ 2,329,600 | 4' x 27" precast box<br>57.5 x 2880 | (9)<br>13.5/SF | $ 2,235,600 |
| | | | | 2' x 3' cap beam<br>140 lb/CY steel<br>2880 x 2 x 3 ÷ 27 = 640 | (1)<br>200/CY | $ 128,000 |
| | | | | 640 x 140 | 0.45/lb | $ 40,320 |
| | Page Total | | $ 7,485,822 | | | $ 7,306.702 |
| | Total | | $ 7,485,822 | | | $ 7,306,702 |

TABLE 5-4 (Continued)

| | OPTION I - Conventional | | | OPTION III - Utility Tunnel | | |
|---|---|---|---|---|---|---|
| Element | Description | Unit Cost or Source | Cost | Description | Unit Cost or Source | Cost |
| Intermediate Deck | 300 lb/ft Pl. girder | | | 24" x 42" conc. beam | | |
| (transportation tunnel roof) | @ 15' C-C | (4) | | 170 lb/CY steel | (1) | |
| | 300 x 54 x 2880 ÷ 15 | 0.50/lb | $ 1,555,200 | 2 x 3.5 x 54.5 x 2880÷(15 x 27) | 200/CY | $ 542,578 |
| | | | | 2713 x 170 | 0.45/lb | $ 207,545 |
| | Pre-cast 12" x 24" | | | | | |
| | hollow core | (9) | | Pre-cast 8" x 24" | | |
| | 53.5 x 2880 | 3.10/SF | $ 477,648 | hollow core | (9) | |
| | | | | 53.5 x 2880 | 2.80/SF | $ 431,424 |
| Interior Columns | 2' x 3' w/200 lb/CY | (1) | | 2' x 6' @ 15' C-C slurry | (3) | |
| | 2' x 3' x 17 x 2880 ÷ (15 x 27) | 200/CY | $ 145,067 | 2880 x 45 x 6 ÷ 15 | 16.60/SF | $ 860,544 |
| | 725 x 200 | 0.45/lb | $ 65,250 | | | |
| Base Slab | 3' cast in place | | | | | |
| | w/150 lb/CY steel | (2) | | Same as Option I | | |
| | 2880 x 3 x 53.5 ÷ 27 | 80/CY | $ 1,369,600 | | | $ 1,369,600 |
| | 17,120 x 150 | 0.45/lb | $ 1,155,600 | | | $ 1,155,600 |
| | Page Total | | $ 4,768,365 | | | $ 4,567,291 |
| | Total | | $12,254,187 | | | $11,873,993 |

TABLE 5-4 (Continued)

| | OPTION I - Conventional | | | OPTION III - Utility Tunnel | | |
|---|---|---|---|---|---|---|
| Element | Description | Unit Cost or Source | Cost | Description | Unit Cost or Source | Cost |
| Excavation | Upper six feet<br>53.5 x 6 x 2880 ÷ 27 | (5)<br>12.50/CY | $ 428,000 | Same as Option I | | $ 428,000 |
| | Common excavation<br>53.5 x 30 x 2880 ÷ 27 | (5)<br>11.30/CY | $ 1,934.560 | Common excavation<br>53.5 x 30 x 2880 ÷ 27 | (5)<br>13.26/CY | $ 2,270,112 |
| Excess Backfill | Granular material<br>12 x 53.5 x 2880 ÷ 27 | (10)<br>9.80/CY | $ 671,104 | Not applicable | | |
| | Page Total | | $ 3,033,664 | | | $ 2,698,112 |
| | Total | | $15,287,851 | | | $14,572,105 |

( )Numbers indicated in parentheses are referenced in Table 5-5

TABLE 5-5 - PRICE REFERENCES

| Ref. # | Materials | Unit Price | Source |
|---|---|---|---|
| 1. | Cast-in-place concrete reinforcement | $200/cy.<br>$0.45/lb. | P.P. Xanthakos, Inc.<br>P.P. Xanthakos, Inc. |
| 2. | Cast-in-place concrete for base slab (no form work) | $80/cy. | P.P. Xanthakos, Inc. |
| 3. | Slurry walls:<br>Option I: | $17/sq.ft. | Sumitomo Construction America, Inc. |
| | Option II: Sidewalls<br>Stripwalls | $16/sq.ft.<br>$16.60/sq.ft. | Sumitomo Construction<br>Sumitomo Construction |
| 4. | Steel plate girders | $0.50/lb. | P.P. Xanthakos, Inc. |
| 5. | Utility Excavation<br>Common Excavation | $12.5/cy.<br>$11.3/cy. | IITRI projection<br>Abstract of Washington Metro Area Transit Authority Bid |
| | Under Roof Excavation | $13.26/cy. | IITRI projection |
| 6. | Steel soldier piles & lagging | $14/sq.ft. | P.P. Xanthakos, Inc. |
| 7. | Temp. bracing-<br>1. Cost of steel tubes<br>2. Installation & removal chrgs.<br>3. Steel walers | $0.26/lb.<br>$0.20/lb.<br>$0.5 lb/ | P.P. Xanthakos, Inc.<br>P.P. Xanthakos, Inc.<br>P.P. Xanthakos, Inc. |
| 8. | Temp. wooden decking & traffic control | $130/sq.yd. | Avg. bid price (Bechtel) |

. . . continued . . .

TABLE 5-5 (Concluded)

| Ref. # | Materials | Unit Price | Source |
|---|---|---|---|
| 9. | Precast panels: | | |
| | Option I: 12" x 2' hollow core sections | $3.10/sq.ft. | Midwest Precast - Chicago |
| | Option III: | | |
| | Street decking: 27" x 4' box beam panels | $13.50/sq.ft. | Midwest Precast - Chicago |
| | Tunnel Roof: 8" x 2' hollow core sections | $ 2.80/sq.ft. | Midwest Precast - Chicago |
| 10. | Backfill | $ 9.80/sq.ft. | Avg. bid price - (CUTD, Bechtel) |

betterment is not treated uniformly throughout the country. Here we assume that new cable does not constitute a betterment, thus giving an artificial economic advantage to the conventional 20% replacement case, and making this economic feasibility analysis somewhat conservative.

Table 5-6 gives a detailed cost comparison for the options. The utility handling costs for the three schemes are:

| | |
|---|---|
| Option I (20% replacement) | $12,979,588 |
| Option I (100% replacement) | $14,473,132 |
| Option III | $12,819,288. |

It can be concluded from the analysis that the cost of relocating utilities in a utility tunnel with total replacement of all utilities is similar to replacing 20% of the cable utilities and 100% of the public utilities in the conventional scheme.

Utility Tunnel Requirements (Option III)

1. Appurtenances

The utility tunnel is well lit and adequately furnished with fire sprinklers, extinguishers, etc. for emergencies. Cable racks are provided for telephone and telegraph cables. Provision is made to handle the 24" diameter gas and water mains. The total estimated cost for appurtenances in $895,980.

2. Auxiliary Systems

The auxiliary system requirements for the utility tunnel are:

Pumping stations:

Six pumping stations are provided. Each station has two 1,200 gpm pumps.

TABLE 5-6 - COST ESTIMATES FOR THE OPTIONS

| Cost Elements | Option I (20% replacement) | Option II (100% replacement) | Option III |
|---|---|---|---|
| | Cost $ | Cost $ | Cost $ |
| 1. Electric | | | |
| a. Work common to three alternatives | $3,358,421 | $3,358,421 | $3,358,421 |
| b. 100% replacement of cables | - | 1,050,000 | 1,050,000 |
| c. 20% replacement of cables (due to accidental damages) | 210,000 | - | - |
| d. Conventional method requirements | 2,008,805 | 1,568,000 | - |
| e. Additional vaults | 330,000 | 330,000 | 500,000 |
| 2. Telephone | | | |
| a. Work common to three alternatives | 1,549,136 | 1,549,136 | 1,549,136 |
| b. 100% replacement of cables | - | 1,430,000 | 1,430,000 |
| c. 20% replacement of cables (due to accidental damages) | 286,000 | - | - |
| d. Conventional method requirements | 256,065 | 94,500 | - |
| 3. Telegraph | | | |
| a. Work common to three alternatives | 246,599 | 246,599 | 246,599 |
| b. 100% replacement of cables | - | 182,754 | 182,754 |
| c. 20% replacement of cables (due to accidental damages) | 36,550 | - | - |
| d. Conventional method requirements | 97,260 | 63,000 | - |
| 4. Gas | | | |
| a. Work common to three alternatives | 2,549,370 | 2,549,370 | 2,549,370 |
| 5. City Sewers | | | |
| a. Work common to three alternatives | 582,306 | 582,306 | 582,306 |

TABLE 5-6 (Concluded)

| Cost Elements | Option I (20% replacement) | Option I (100% replacement) | Option III |
|---|---|---|---|
| | Cost $ | Cost $ | Cost $ |
| 6. <u>City Water</u> | | | |
| a. Work common to three alternatives | $ 778,000 | $ 778,000 | $ 778,000 |
| b. Conventional method requirements | 25,000 | 25,000 | - |
| c. Utility tunnel installation | - | - | 55,000 |
| 7. <u>City Electric</u> | | | |
| a. Work common to three alternatives | 223,151 | 223,151 | 223,151 |
| b. Conventional method requirements | 442,895 | 442,895 | - |
| c. Utility tunnel installation | - | - | 314,551 |

Ventilation System:

The ventilation system essentially consists of 14 fan shafts and 13 air intakes capable of handling air at the rate of 10,000 C.F.M.

Flooding Overflow:

This consists of gravity overflow drains and three 30 inch diameter outflow lines.

Hatches:

49 - medium sized roadway hatches

7 - gas section hatches

The total cost for the auxiliary system is $434,950.

3. Detection and Communication Systems

Automatic dial telephones and talk back speakers are installed at each intersection for communication. Thermostats, detection sensors, alarms for gas sections, etc. is provided for sensing hazardous conditions in the utility tunnel when and if they occur and warning the control panel operator.

4. Control Center Allowance

The control center monitors the detection system, communication system, etc. One center can control about 5 miles of the tunnel. The cost of the control panel depends on the length of the tunnel to be monitored. Costs estimated by CT&A (1975) for the panel are adapted and distributed in this study.

A detailed cost breakdown for the utility tunnel requirements is presented in Table 5-7.

TABLE 5-7 - UTILITY TUNNEL REQUIREMENTS: OPTION III

| Item | Unit | Unit Cost | Quantity | Cost |
|---|---|---|---|---|
| 1. Appurtenances | | | | |
| lighting | l.f. | $ 30(1) | 3,080 ft. (2,800' tunnel + 200' side space) | $ 92,400 |
| automatic fire sprinklers and extinguishers | l.f. | $ 35(1) | 3,080 ft. | $107,800 |
| contingencies | l.f. | $ 160(1) | 3,080 ft. | $492,800 |
| cable racks (excluding duct banks) | total | project | | $142,000(1) |
| additional cost for gas section | total | project | | $ 60,980(2) |
| 2. Auxiliary System | | | | |
| pumping stations | each | $25,000* | 6 | $150,000 |
| fan shafts | each | $11,000* | 14 | $154,000 |
| air intakes | each | $ 6,000* | 13 | $ 78,000 |
| flooding overflow | total | project | | $ 36,150* |
| roadway hatches | each | $ 200* | 49 | $ 9,800 |
| hatches for gas sections | each | $ 1,000* | 7 | $ 7,000 |
| 3. Detection and Communication Systems | | | | |
| automatic dial telephones | total | project | | $ 20,000 |
| talk back speakers | total | project | | $ 20,000 |
| detection sensors, etc. | total | project | | $ 45,000 |
| exit signs | each | $ 150 | 14 | $ 2,100 |

TABLE 5-7 (Concluded)

| Item | Unit | Unit Cost | Quantity | Cost |
|---|---|---|---|---|
| 4. Control Center Allowance | total | project | | $172,000 |
| Total Cost Utility Tunnel Requirements | | | | $1,590,030 |

(1)Projected CUTD costs for 1975.

(2)Projected CT&A costs for 1975.

*CUTD Costs projected to 1975. No significant changes in bid prices of these items was noticed from 1973 prices.

## Operating and Maintenance Costs for the Utility Tunnel

### A. Operating Costs

#### 1. Salaries

No staff will be required for full time duties on the first tunnel segment. City staff will be assigned part-time responsibilities for the successful operation of the utility tunnel. A console operator will be shared with other legs of the tunnel when built.

#### 2. Ancillary Services

The administrative support services required for the operation of the utility tunnel are the Finance Department, Civil Service Department, Purchasing Department, Law Department and Engineering Department. The services of these departments will be hired from the city on a part-time basis.

#### 3. Rentals

Telephone lines will be leased from the telephone company for transmittal of signals to the control room. The rental charges for these lines have been adapted from the CT&A (1975) calculations. Control room space rental charges have been computed at $5 per sq.ft., which is a competative price for a downtown area.

#### 4. Utilities

The utility tunnel will require electric power for lighting pumps, ventilation, etc., and water supply for testing fire sprinklers and sump pump systems. The cost estimates for the utilities has been adapted from CT&A estimates.

### B. Maintenance Costs

Contract maintenance services will be obtained as and when required to service the mechanical and electrical equipment in the tunnel. Estimates for these services has been made based on the CT&A estimate.

Table 5-8 gives a detailed cost estimate for O&M elements. The total operating and maintenance cost is estimated at $113,620 per annum.

Economic Summary

1. Construction Costs

The structural costs of Option I and III are:

| | |
|---|---|
| Structural Cost Option I: | $15,287,851 |
| Structural Cost Option III: | $14,572,105. |

Structural Costs for Option III is about $700,000 less than I, not including the cost of repaving the street and waterproofing. It is anticipated that the cost of a waterproof membrane and wearing surface for Option III will be comparable to base and paving for Option I.

2. Traffic Delays

Detailed analysis of traffic delay and the associated costs are presented in Appendix B of this report.

The estimated traffic delay costs during construction for the proposed options are:

Option I . . . . . . . . . . $9,090,000
Option III . . . . . . . . . $4,415,000.

The benefits realized by adopting Option III are $4,675,000. These are short-term benefits to the society during construction.

The long-term benefits realized during the economic life of the tunnel (40 years) due to the absence of street dig-ins are adapted from the benefit study conducted by CT&A.

TABLE 5-8 - OPERATION AND MAINTENANCE COST

| A. | Operating Costs(*) | Per Annum |
|---|---|---|
| | 1. Salaries | |
| | | $ 11,000 |
| | 2. Ancillary Services | |
| | • Finance Department | 1,600/ |
| | • Civil Service Department | 2,100/ |
| | • Purchasing Department | 3,500/ |
| | • Law Department | 1,900/ |
| | • Engineering Department | 550/ |
| | Total Ancillary Services | $ 9,650 |
| | 3. Rentals | |
| | • Telephones and leased line facilities | 2,400/ |
| | • Control room rent | 1,800/ |
| | Total Rentals | $ 4,200 |
| | 4. Utilities | |
| | • Electric power | 20,750/ |
| | • Water | 1,000 |
| | Total Utilities | $ 21,750 |
| | 5. Supplies | |
| | | 1,000 |
| | Total Operating Costs | $ 47,600 |
| **B.** | **Maintenance Costs(*)** | **Per Annum** |
| | a. Contract Services | |
| | 1. Control console (incl. sensors & alarms) $5,000 | |
| | 2. Fire sprinkler system $2,640 | |
| | 3. Ventilation system $3,500 | |
| | 4. Sump pumps $3,750 | |
| | Total Contract Services | $ 14,890 |

*The costs calculated by CT&A have been modified and adapted.

TABLE 5-8 (Concluded)

| B. | Maintenance Costs (Cont'd) | | Per Annum |
|---|---|---|---|
| | b. Electrical | | |
| | 1. Electricians | $5,700 | |
| | 2. Foreman to supervising electricians | $1,630 | |
| | 3. Material costs | $4,800 | |
| | Total Electrical | | $ 12,130 |
| | Total Maintenance Cost | | $ 27,020 |
| | c. Insurance Cost | | 39,000 |
| | Total Operating & Maintenance Costs | | $113,620 |

3. Utility Handling

The total savings realized by locating the utilities in the utility tunnel as opposed to direct burial, assuming total replacement of cable utilities in both cases is $1,653,832. Cost analysis based on 20% replacement of cable utilities for the conventional option and total replacement in the utility tunnel results in a savings of $160,300 for the utility tunnel.

The cost of disruption to the business community during construction is truly significant. Attempts were not made in this study to quantify these costs. However, review of gross receipts of several retail stores located on existing cut and cover projects indicates that annual losses may be as high as several million dollars for some business types. If it could be quantified in dollars the cost of Option I would be significantly more than III.

Additional savings in utility tunnel appurtenances could be achieved by combining the requirements of the subway system and the utility tunnel. For example, the pumping system of the subway could be combined with that of the utility tunnel at lower costs than two separate sets of pumps.

Table 5-9 gives a summary of the total direct and indirect costs for the project for Options I and III. The annual O&M, street dig-ins and utility tunnel repair costs have been capitalized for 40 years based on 6% interest rate. (Cost treated as an annuity.) Both the CT&A studies and IITRI studies concluded that 6% interest for public works using civic money was a fair choice. It can be concluded that the savings to the taxpayer by adopting Option III is about $4,245,000.

TABLE 5-9 - COST SUMMARY

| Cost Elements | | Option I (20% replacement) | Option I (100% replacement) | Option III |
|---|---|---|---|---|
| Direct Costs | | | | |
| 1. Construction (Structural)[1] | | $15,287,851 | $15,287,851 | $14,572,105 |
| 2. Utility Tunnel Requirements | | - | - | 1,590,030 |
| 3. Utility Handling | | 12,979,588 | 14,473,132 | 12,819,288 |
| 4. Utility Tunnel O&M | | - | - | 1,709,561 |
| | Sub-Total | $28,267,439 | $29,760,983 | $30,690,984 |
| Indirect Costs | | | | |
| 5. Traffic Delay:[3] | | | | |
| a. Construction | | 9,090,000 | 9,090,000 | 4,415,000 |
| b. Street Dig-Ins[2] | | 30,093 | 30,093 | - |
| 6. Utility Repairs (Underground vs Utility Tunnel)[2] | | 469,829 | 469,829 | - |
| | Total Cost | $37,857,361 | $39,350,905 | $35,105,984 |
| Note: A 40 year tunnel life assumed. | | | | |

(1) Does not include cost of street resurfacing, waterproofing, sidewalks, subway tunnel appurtenances, etc.

(2) Cost adapted from CT&A report.

(3) Traffic delay - Appendix B.

## Summary

This analysis indicates that the usual approach to economic feasibility analysis of utility tunnels is incorrect. Typically great effort is devoted to consideration of indirect benefits to ascertain whether they equal the high cost of a utility tunnel. IITRI, instead, reviewed the cost of utility tunnels, and found that a minor change in cut and cover construction procedure, i.e., excavation below the roof, resulted in significantly reduced construction disruption and elimination of temporary decking. The effect is that the utility tunnel, rather than being an expensive luxury, is not significantly different in cost from the conventional option. The basic analysis includes a rather large penalty for excavation under the roof. Even if the existing utilities are maintained in place, the total cost still favors the utility tunnel. Therefore, on the basis of economics alone, the integrated utility/transportation tunnel system is recommended. In addition, numerous environmental and non-quantifiable factors not accounted for by dollar costs all argue for the utility tunnel.

## 6. RECOMMENDATIONS FOR IMPLEMENTATION

A valid and convincing test of the combined utility/transportation tunnel concept will require its application in an actual transit project. The implementation of a demonstration project is now well within the state of the art. Contractors who have used construction techniques similar to those presented in this report are active in this country. Operating examples of utility tunnels may be found in many major U.S. cities. It is believed that the next step should be the design and construction of a demonstration project.

In any selection of alternative civil engineering design concepts the total impact upon society should be considered. The economic analysis presented in the example design presented in this report indicates a difference in traffic delay costs between the conventional and the combined systems of 8.5 million dollars per mile. Extensive literature exists on traffic costs, they can be well defined, and should not be ignored. Instead, mechanisms for treating such non-recoverable costs should be evolved. Other impact elements are less well defined. For example, utility companies take advantage of cut and cover projects to install excess capacity in anticipation of future growth. The allocation of these costs is not an easily treated subject. The utility company is given an opportunity to avoid the cost of future excavation. Perhaps this savings should properly be shared with the transportation agency that makes it possible. Traditionally, it is not. In the case of a utility tunnel, the additional capacity could be deferred until needed. The cost of this hardware over the time period it remains unused represents a benefit to the utility tunnel. This was not included in the economic analysis since the allocation of such benefits in actual practice appears to be based on factors other than engineering economics. For example, a consistant definition of what constitutes a utility betterment has not emerged. Since a conservative approach should be taken in the evaluation of new construction techniques, this and similar benefits to the utility tunnel are not claimed in the economic evaluation.

General recommendations regarding the implementation of the combined utility/transportation tunnel can be made.

* A consensus regarding the proper role of utility tunnels in transportation systems will result only from the construction and operation of actual examples. It is not felt that additional feasibility analyses are required at this time to display the benefits to be derived. The combined system should be implemented as a demonstration on an urban transportation system.

* When so implemented, all possible societal impacts should be considered. Non-recoverable cost elements should be incorporated into benefit/cost ratios, and a mechanism for dealing with them should be evolved and incorporated into the financing of transportation projects.

* Federal assistance should be provided in the implementation of the demonstration project. This should include funding, coordination of the independent tunnel users and technical assistance.

* The local agencies and private organizations that would be involved should be exposed to utility tunnel operations and users. This will resolve questions and identify useful solutions to problem areas.

* The design of the utility tunnel and its operational procedures should reflect input from all the potential users. The designer should retain the flexibility to accept reasonable requests and suggestions from the ultimate users.

* The designer should be familiar with the concept and its application. This might include personal visits to operating tunnels, access to specialized consultants and discussions with contractors who have actually used the early closure techniques elsewhere in the world.

* The demonstration tunnel should be of such length as to make efficient use of operating personnel and ancillary equipment. This is longer than a single construction contract.

It is believed that the combined utility/transportation tunnel concept is an attrative alternative to conventional cut and cover tunneling in areas where construction disruption may be severe. Demonstration of this concept will require physical implementation in the real world.

## 7. CONCLUSIONS

The primary finding of this study is that the utility/transportation tunnel concept is economically feasible. Different types of utility tunnels have existed for decades, and experienced successful operation. The statement is frequently found in the literature that "no insurmountable technical problems exist" that would prohibit the use of utility tunnels. In light of the facility with which these problems have been solved around the world, this statement may only be described as overly-conservative. The solution of safety and compatibility problems are primarily economic in nature; one can construct an "ideally" safe tunnel if funds are available for such a purpose. Whether the construction of a tunnel is of actual benefit to the community and utility companies should be the determining factor.

In the economic analysis, two utility handling options were evaluated for an example project 2900 feet in length. The options were subway with conventional utility treatment, and subway with utility tunnels. Although two methods of construction were considered for the latter option, the system without center columns was discarded due to the prohibitive cost of the free span roof elements. Both the conventional and utility tunnel options discussed in this report employ the most economical and innovative construction techniques available at this time. The basic direct costs of these options were identified by IITRI consultants as the cost of labor and materials. The economic analysis reveals that the construction of a utility tunnel, rather than being much more expensive than a conventional cut and cover project, is actually comparable in cost. The outstanding economic benefits are derived from non-quantifiable and indirect cost savings. The indirect costs are identified as traffic delays, lost business and the like. The non-quantifiable costs, such as strife and disruption of urban area business routine during construction, are intangible. Benefit, then, would be a direct result of a decrease in these disruptions.

The two options are completed in approximately the same length of time, with the utility tunnel option III being somewhat briefer. The major difference between the two schemes, is that conventional utility treatment calls for the street to be partially closed to traffic at least 18 months longer than the utility tunnel option. This is reflected in the indirect and non-quantifiable costs. The ramifications of this period of street closure are significant. The effects of reduced traffic delays and sociological impact of this shortened closure period are discussed in the body of this report. Briefly, the savings in decreased traffic delay during construction is estimated at 4.5 million dollars. The benefits accrued to the utilities such as longer cable life, etc., in the utility tunnel option would result in another one million dollar savings over conventional burial. The non-quantifiable benefits to business, industry, the consumer are also apparent. Business could resume its normal operation sooner as a result of shorter street closure. Protection of the utilities in a tunnel would also mean fewer service disruptions due to accidental damage, which is a common occurrence when utilities are buried. Although the details of the economic benefits of utility tunnels are discussed throughout this report, particularly in Section 5, it can be simply stated in these conclusions that over 5.5 million dollars can be saved in indirect benefits alone by the use of utility tunnels. Add to these the massive non-quantifiable benefits to the consumer and central business district, and a strong case supporting the construction and use of utility tunnels emerges.

The early demonstration of the utility/transportation tunnel system in actual practice is therefore recommended.

## 8. REFERENCES


1) American Public Works Assoc. (1971), (SR39) Feasibility of Utility Tunnels in Urban Areas, APWA Special Report No. 39, Feb. 1971, 167p.

2) Amory, W., "Utility Tunnel Concept For Water (A Summary)", APWA Special Report No. 41, Aug. 1971 p. 53.

3) Amory, W., "Safety and Temperature Considerations For Water Pipelines in Utility Tunnels," APWA Special Report No. 41, Aug. 1971, p 91-92.

4) Chicago Urban Transportation District (1973), Central Area Transit Project, Utility Tunnel Feasibility Study, City of Chicago, Dept. of Public Works, Sep. 1973, 165p.

5) Gaulin, J. (1971), "Management of Utility Tunnels," APWA Special Report No. 41, Aug. 1971, p. 121-124.

6) Granquist, T. A., "Communications, Power, and Tunnels," APWA Special Report No. 41, Aug. 1971, p. 80-82.

7) Holder, R. H.,"Utility Tunnel Concepts for Gas," APWA Special Report No. 41, Aug. 1971, p. 50-52.

8) Lowe, A. F., "Utility Tunnel Concepts for Telephone," APWA Special Report No. 41, Aug. 1971, p. 44-47.

9) McCoy, C., "Sewerage Pipeline Safety and Grade Elevation Considerations," APWA Special Report No. 41, Aug. 1971, p. 93-94.

10) McPherson, M. B., "Utility Tunnel Concepts for Sewers," APWA Special Report No. 41, Aug. 1971, p. 54-58.

11) Meese, W. J., "Safety and Safety Standards for Electric Supply and Communication Facilities in Utility Tunnels," APWA Special Report No. 41, Aug. 1971, p. 95-98.

12) Midwest Precast Co., 1975, personal communication.

13) Mork, N. A., "Gas Pipeline Safety in Utility Tunnels," APWA Special Report No. 41 Aug. 1971, p. 83-90.

14) Newburger, J. A, "Reliability and Emergency Procedures for Joint Utility Tunnels," APWA Special Report No. 41, Aug. 1971, p. 139-145.

15) Outlaw, E. G., "Utility Tunnel Concepts for Electricity," APWA Special Report No. 41, Aug. 1971, p. 48-49.

16) Pohlkotte, R. H. "Utility Tunnel Concepts for Cooling and Heating," APWA Special Report No. 41, Aug. 1971, p. 59-62.

17) Sumitomo Construction America, Inc., 1975, personal communication.

18) Newburger, J. A., "Reliability and Emergency Procedures for Joint Utility Tunnels," APWA Special Report No. 41, Aug. 1971, p. 139-145.

19) Wenger, D. (1971), "Utility Tunnel concept Organization and Jurisdiction," APWA Special Report No. 41, Aug. 1971, p. 172-177.

20) Xanthakos, Petros P., 1975, personal communication.

# APPENDIX A

## ANNOTATED BIBLIOGRAPHY

The following bibliography is the result of a literature search conducted by APWA concerning the feasibility of utility tunnels and related areas and systems. Each reference contains an abstract and key words along with the usual information. It is arranged alphabetically by author.

Abbott Jr., Actor T., "Joint Utility Corridors Pros and Cons," Right of Way (June 1970), p. 47-50.

Kinds of joint corridors are discussed. Advantages cited are: capital cost saving, space conservation, and aesthetics. Disadvantages suggested are: construction coordination requirements, non-coincident routing, mutual interference, and (particularly in utilidors) hazard to other plant.

Key Words: Utility corridors, types, space conservation, capital cost saving, construction, routing, mutual interference, hazards.

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Abbott, Arthur Vaughan, "Construction of Underground Conduits," Telephony, Part II (New York: McGraw Publishing Company, 1903), 180p.

Better duct construction can allow lower cost cable to be used. One cable per duct is preferred. Wood, cement, clay duct materials are discussed. Originally iron pipe encased in concrete was used, then a mandrel for casting was developed. Various cross-section for multi-duct clay units are discussed. Joint experiments are traced. Concrete bedding (capping and other laying techniques are mentioned). Manhole design/construction emphasizes the trade-off between working space needs and economy. Various frame and cover designs are discussed. Aerial distribution systems are evaluated. Obstacles and congestion facing underground installations, cost estimates, annual charges (depreciation and maintenance) and a sample construction contract are included. Illustrations are provided throughout.

Key Words: Underground conduits, low cost cable, duct materials, laying techniques, construction, space needs, underground congestion, cost estimates, construction obstacles, construction contract, aerial distribution systems.

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Allee, K.M., "The Incorporation of Existing Underground Mains Into Modern Construction of Housing Centres in the City---Described by the Example of the Housing Area," Hilmar Barthel, Ing. Dipl.-Ing. Dec., p. 176-193.

The report described the reconstruction works of heavily damaged housing areas in Berlin, gives an analysis of required mains for sewers, water and gas supply and discusses the possibility and benefit of using partly the old pre-war equipment. Difficulties encountered in the formation and connection of network sections are also presented.

Key Words: Reconstruction, sewer mains, town planning, installation, housing area network.

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Almy, Richard R., Valuation Considerations of Utilidor Feasibility as they Relate to Finance, Management and Taxation, A.P.W.A. Research Foundation Project 68-2 (Chicago: APWA, July 31, 1970), 14p.

Assuming that financial and technical feasibility have been established in a given case, the necessary cost sharing should be apportioned according to benefit. Elements and kinds of costs and benefits are discussed, and value is distinguished. The problem is to identify the beneficiaries, the type of benefits, and their quantification. Nine financing possibilities are discussed.

Key Words: Utilidor feasibility, finance, management, taxation, cost sharing, cost benefits, financing possibilities.

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American Public Works Association, 1972, I.M.E. Policy Statement on Pipeline Safety (unpublished).

This report summarizes the data received from the following: (a) Chapters - Oklahoma, New England, Oregon, Northern California, Southern California, Hawaii, Central California, Florida, Ontario, Washington State, Nebraska. (b) Municipalities - Baton Rouge, La; Los Angeles, Ca; King County, Wash; West Hartford, Conn; Sparks, Nevada; Akron, Ohio; Birmingham, Mich. (c) North Dakota State Department of Health: Information is given concerning accident statistics, required practices, and "one call" programs.

Key Words: Accident statistics, required practices, "one-call" programs.

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American Public Works Association. 1960. Specifications for Trench Excavation and Backfill and Restoration of Pavement and Sidewalks. July 20, 1960: p. 1-8.

These specifications cover all work undertaken in public streets or easements. Stipulations are: required safety measures, maximum amount of open trench, expenditious cleanup, backfill and cover requirements, methods of removal and replacement of existing works.

Key Words: Specifications, streets, easements, safety measures, cleanup, backfill and cover requirements, methods of removal and replacement.

American Public Works Association for the Symposium on Pipeline Safety. 1972. Statement on Pipeline Safety. April 18, 1972: p. 1-9.

The longtime close connection of APWA with pipeline protection interests is noted. Responses from its chapters to a request for definitions and solutions are presented. Four main causes of damage are noted. The key need is utility coordination. Also required are: call-before-you-die promotions; improved permit programs; more adequate records. Model legislation and nine improvements are proposed.

Key Words: Pipeline safety, damage causes, utility coordination, model legislation, proposed improvements, permit program.

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Anderson, Howard M., "Looking Downward with Radar," Chiltons GAS (May 1973), 3p.

Electromagnetic subsurface profiling is accomplished by transmitting/receiving on a sled that can be drawn across a grid pattern. Changes in subsurface composition modify the extent and nature of signal reflection.

Key Words: Electromagnetic subsurface profiling, signal reflection, subsurface composition.

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Anon, "Damage to Post Office Cables by Fire in London Subways," Post Office Elec. Eng. Journal, V. 22 (Oct. 1929), p. 213-219.

The report describes causes and damages of the recent serious breakdowns of cables due to fire and explosion in London subways. And it is the tidal flood in the subway that causes the damage and leakage of the gas lines. Then it ends up with the explosion in the subway.

Key Words: Post office cables, restoration work, pipe subway.

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Apple, M.K. and E.L. Isaac, "Special Equipment Required for Laying and Pulling Cables in Conversion of Overhead to Underground," Pacific Coast Elect. Asso. Ann. Conf. Eng. Oper. Section, San Francisco, CA. (Mar. 26, 1970), 32p.

The report presents the research on new equipment and tools during the past year that has been in the development for installing underground pipe type transmission cable for 115 KV and 230 KV lines. A series of pictures that show the operation and the outline figure of new equipment are also attached along with this report.

Key Words: Equipment, overhead cable, pipe installation, cable conductor, pulling sheave, guide wheel, reel carrier, transmission cable, underground circuit.

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Artingstall, Wm., "Design and Construction of the Telephone and Telegraph Tunnel Under the Chicago River at Harrison Street," Municipal and County Engineering, Vol. LVII, No. 2 (Aug. 1919), p. 58-59.

The author describes one of the engineering exceptions that, in laying conduit for cables, it is not always true that the near the conduits are kept to the surface of the ground, the less will be the cost of the installation. This exception has just been completed by the Chicago Plant Division of the Western Union Telegraph Company.

Key Words: Conduit, cable, trunk lines, cost of installation.

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Ayers, F.E., "Plotting Underground Utilities in the City of Ottawa," The Engineering Journal (Feb. 1963), p. 30-32.

In 1957 a committee, including gas, telephone, electric, city roads, sewers, and water, was set up to arrange ideal locations, utility problem discussion, and production of composite plans. A section was established in the city department (of Works and Planning) to make surveys and drawings at a scale of 1" = 20 ft. Cost sharing is based upon volume of underground owned by each participant. Updating arrangements operate.

Key Words: Underground utilities, planning, cost sharing, problem discussion, utility locations.

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Bagge, Carl E., "A Challenge to the Past: Multiple Use of Rights of Way," Right of Way (Dec. 1969), p. 17-23.

Various disciplines are involved and are interdependent. The gap must be bridged between systems planning and environmental planning. The various reasons for past reluctance to multiple use, present modest efforts toward joint use, public concern for the environment, and land shortage are each discussed. Planning previously covert, must be done overtly so as to avoid wastage. Services planning must be included in comprehensive regional planning.

Key Words: Systems planning, environmental planning, multiple use, joint use, land shortage, regional planning.

Bahniak, F.T., "Con Edison's Newest EHV Conduit," Transmission and Distribution (Jan. 1964), inquiry number T&D 7719, p. 31-35.

The Hudson Avenue Tunnel is a multi-purpose transmission structure. It is a huge tunnel through solid rock under New York's East River. It houses 345-kv cables, steam lines and fuel oil pipes. The author gives general descriptions on the usage of electricity, steam and fuel oil. Design figures and construction methods for the tunnel are presented in this report.

Key Words: Conduit, utility, gas pipe, steam pipe, fuel oil main, electric cable, installation, facility, transmission lines, multi-purpose transmission tunnel, transmission system.

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Bardout, M.G., "Construction of a Tunnel for Telephone Crossing Under the Seine Between Saint Michel Place and Place Du Chatelet," Records of the Technical Institute of Building Trades and Public Works, Vol. 9, No. 6 (Oct. 1956), p. 924-945.

Owing to underground congestion by sewer, electric, gas and multi-duct telephone installations, crossing location is difficult to obtain. Consideration was given to laying the installation in prefabricated units in a trench on the river bed, but a tunnel of 2.2 m (7.2 ft) diameter was selected having a length of 630 m (2079 ft.). Construction is described in detail. (The article does not indicate whether other utilities were also included in the tunnel (does it?)).

Key Words: Tunnel construction, underground utility congestion, prefabricated units.

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Barnes, C.C., "Power Cables: Their Design and Installation," (Second Edition; New York: Barnes & Noble, Inc., 1966), author's preface, p. vii.

Noting increased demands upon distribution cables, the book covers basic design procedures and important recent developments.

Key Words: Power cables, design, installation, recent developments.

Barron, D.A., "Post Office Cabling in the Mersey Tunnel," (Part 2), The Post Office Electrical Engineers' Journal, Vol. XXXII (July 1939), p. 79-84.

The author describes the cabling and jointing work recently included in the Mersey Tunnel. This work presented many unusual difficulties due to limited times and access, restricted space, and the cold air current necessary for the ventilation of the tunnel.

Key Words: Mersey Tunnel, cabling tunnel, jointing work.

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Bartlett, Vernon Ferdinand, and William Henry Cadwell, "The Coaling-Jetty, Circulating-Water System and Cable-Tunnels at the Battersea Power Station of the London Power Company," Minutes of Proceedings, p. 74-120.

Design of a jetty to serve two-2000 ton ships per tide and its construction using Coffer-Dam are discussed, including intake screening provisions (pp. 74-82). 16.5 million gal/hour of cooling water is required (from the 500 MGPH flow in the Thames); intake chambers, screening chambers, culvert, suction chamber, pump house, and outlet are described (p. 82-90). 66 kv cables in a ten foot tunnel under the Thames serve northward, and a seven-foot square reinforced concrete tunnel to the transformer station at the southern corner of the site then branches to ducts under the road (p. 90-93). Cost data is provided. Discussion by Sir Henry Japp, emphasizes the careful soils investigation that preceeded design. Discussion also deals with architectural, structural, and urban siting matters.

Key Words: Jetty, design, screening, provisions, intake chambers, pump house, soils investigation, architectural, structural, construction.

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Benson, Edmond K., "Rapid Duct Survey," Materials Protection (Feb. 1963), p. 59-62.

Using a standard lead slug, new type reference electrode, and a strip chart recorder, quicker and more accurate surveys can be made of corrosion in a multiple-duct (non-stray current area) network.

Key Words: Rapid duct survey, strip chart recorder, corrosion, multiple duct network.

Blain, Ray, "Underground Cable Construction," Telephone Engineer, Vol. 34, No. 3 (Mar. 1930), p. 32-36.

Manhole design and construction, duct material and laying techniques, and lateral runs are each discussed.

Key Words: Underground cable construction, manhole design, duct material, laying techniques.

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Blain, Ray, "Underground Conduit Construction," Telephony (Apr. 20, 1935), p. 15-18.

Urging consideration of undergrounding, the use of clay runs with from one to nine ducts is recommended. Construction details and precautions and manhole requirements are discussed.

Key Words: Underground conduit construction, clay runs, construction details, precautions, manhole requirements.

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Boegley Jr., W.J., and W.L. Griffith, Feasibility of Retrieving Utility System Capital and Maintenance Costs from Annual Reports (Oak Ridge, TN: Oak Ridge National Laboratory, June 1970), 50p.

Need for uniform accounting systems, such as developed by the National Association of Railroad and Utility Commissions, is stressed. While the reports required by the FPC have more uniformity than those required by individual states, less (useable) detail is provided for urban distribution systems.

Key Words: Utility system, cost recovery, uniform accounting systems.

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Boegley, W.J., & Griffith, W.L., 1970, The Potential Use of Utility Tunnels in Urban Areas. The American Society of Mechanical Engineers, Aug. 3, 1970: 9p.

(Essentially the same as Boegley Jr., W.J., and W.L. Griffith, "Underground Utility Tunnels," Mechanical Engineering (Sep. 1971), p. 27-32.

Key Words: Utility tunnels, urban areas.

Boegley Jr., W.J., and W.L. Griffith, "Underground Utility Tunnels," Mechanical Engineering (Sep. 1971), p. 27-32.

Reference is made to their study of feasibility of walk-through utility tunnels that could also serve as nuclear attack shelters. Discussion of early tunnels (Paris 1851; Nottingham, 1861) mentions various included utilities. A survey of 19 cities and 27 universities indicated that 21 use tunnels. The White Plains, N.Y., Utility Tunnel Study includes costs, cross-sections, and cost recovery proposals.

Key Words: Utility tunnels, feasibility, nuclear attack shelters, utility tunnel examples, costs, cost recovery.

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Boegley, Jr., W.J., and W.L. Griffith, "Utility Tunnels Enhance Urban Renewal Areas," The American City (Feb. 1969).

Consolidation of utilities underground is suggested in conjunction with urban renewal projects. Three advantages and four disadvantages are listed. Oversizing to accomodate future expansions is urged.

Key Words: Utility tunnels, urban renewal, future utility expansions.

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Bogdanowski, J., "Boring Beats Trenching for UC Construction in Congested Areas," Electric Light and Power (Oct. 15, 1957), p. 136-140, 169.

Congested conditions preclude open cut installations, and most jobs involve rock in New York City. Several different sized machines are in use. Cost is usually less than for trenching under railroads, parkways, and congested city streets.

Key Words: Boring, trenching, costs, congested conditions.

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Boryer, W.T., "Some Features of Deep Level Tunnelling in London," Engineering Services, p. 14-18.

130 cable accomodations in 7 and 12 foot diameter tunnels for the Post Office Department is described. Seepage and bulkheading are discussed. Stairways, eating, and wash-room facilities are provided for staff. Cost calculations lead to the conclusion that tunnels are economic in London on any street having 60 more cables.

Key Words: Tunnelling, seepage, bulkheading, cost calculations, economic feasibility.

Bray, Oscar S., "The Mystic Cable Tunnel Design and Construction," Meeting 17, Dec. 1945, p. 68-81.

Tunnel was selected over cable or overhead choices to carry 18 circuits under the river. Eight foot inside diameter, thirty feet below low water, 1100 feet long, the tunnel design and construction is described.

Key Words: Tunnel, design, construction.

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Bredemeier, Kenneth, "Industry, Unions, Eye Safety Measures," The Washington Post (Apr. 19, 1972), p. C2.

62% of serious gas line accidents are caused by earthmoving work. Hand excavation, and "one call" improvements were suggested at a National Transportation Safety Board Conference.

Key Words: Gas line accidents, "one call," hand excavation, earthmoving.

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Brown, Verne R., "Our Public Rights of Way," Right of Way (Apr. 1973), p. 11-13.

Private right of way acquisition is impracticable. Public rights of way first accomodate the travelling public, then the general public (emphasizing aesthetics) then mass transportation and finally utilities. The ten research needs developed by the APWA June, 1967 Symposium, are listed.

Key Words: Private right of way, acquisition, public right of way, research needs.

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Brown, Verne R., "Utility Space Allocations on Public Rights of Way," Right of Way (Feb. 1973), p. 14-18.

In November 1971, a subcommittee of the Florida Utilities Coordinating Committee (established in 1932) was appointed to study standardized utility space allocations. Urban and Rural designs were considered so as to provide sufficient space for future expansions and to adhere to safety requirements. Sidewalks "troughs" and "conduits" were designed. The recommendation is for a fifteen-foot minimum utility zone.

Key Words: Utility space allocation, public right of way, standardization, design, safety requirements, utility zone.

Brush, Edward E., "Electronics See Beneath the Surface," American Road Builder (July 1973), p. 10, 11.

Great potential costs from unknown subsurface conditions can be attenuated by use of electronic equipment for subsurface surveying. Seismic equipment (shock waves travel at different speeds in different materials) and resistivity measurement can provide more complete and reliable information at less cost than borehole techniques.

Key Wrods: Subsurface surveying, seismic equipment, resistivity measurement, borehole techniques.

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Buller, F.H., "Artificial Cooling of Power Cable," (Aug. 1952), p. 634-641.

Noting that congestion is forcing consideration of smaller cables, better cooling is required. Several formulae are developed for various types of duct and tunnel installations.

Key Words: Power cable cooling, duct installations, tunnel installations.

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Buller, F.H., "Pulling Tension During Cable Installation in Ducts or Pipes," General Electric Review (Aug. 1949), p. 21-23.

Increased costs have invoked desire to have fewer manholes. The resultant longer runs require application of additional friction formulae.

Key Words: Cable installation, pulling tension, ducts, pipes.

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Buller, F.H. and J.H. Neher, "The Thermal Resistance Between Cables and a Surrounding Pipe or duct Wall," A.I.E.E. Transactions, Vol. 69 (1950), p. 342-349.

Noting that present semi-empirical methods are not adequate (especially for oil or gas filled pipe-cables), theory is developed and tests run to provide formulae for calculating the connection, conduction, and radiation heat transfer from cables to ducts.

Key Words: Cables to ducts, connection, conduction, radiation, heat transfer.

Burden, B.C., "The Buried Underground Cable Plant," Telephony (Sep. 6, 1930), p. 16-20.

Survey data from using companies lists five advantages and four disadvantages of buried vs. aerial, and discusses steps to improve these conditions. Six types of burial (ranging from direct burial to steel armored) are evaluated.

Key Words: Cable plant, buried, aerial, advantages, disadvantages, types of burial.

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Burden, B.C., "Miscellaneous Features of Conduit Construction," Fortnightly Telephone Engineer (June 1, 1941) p. 7-10.

Reasons for undergrounding are considered. Various types of duct materials and multipe-duct configurations are discussed.

Key Words: Conduit construction, undergrounding, duct materials, duct configurations.

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"Cable in Shafts and Tunnels," Underground Systems Reference Book, p. 8-58.

Economically justified tunnel installations may be: near power plants; under rivers, under interchanges, etc. Types of armor, installation method, and supports are discussed.

Key Words: Tunnel installations, economic justification, methods, materials, supports.

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"Cable Tunnel Under the Thames," Engineering (Dec. 24, 1948), p. 619.

A fifteen year old ten-foot tunnel under the Thames is filled and so a new one of eight-foot diameter has been added. Dimensional details are given.

Key Words: Cable tunnel, dimensions.

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Carcich, Italo G., Leo J. Hetling, and R. Paul Farrell, "The Pressure Sewer: A New Alternative to Gravity Sewers," Civil Engineering - ASCE (May, 1974), p. 50-53.

By installing grinder pumps in individual houses, a small diameter sewage collection system can be installed that avoids the excessive deep cuts inherent in gravity systems in hilly terrain. Costs are claimed to be much lower for initial installation.

Key Words: Pressure sewer, cost reduction, grinder pumps, gravity sewer systems.

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Carter, H.G., "Total Underground Research and Development," Transmission & Distribution (Sep. 1966), p. 40-42.

The author points out that a successful study program of public opinion and desires, of equipment, tools and materials has resulted in a significant reduction in underground costs and high public acceptance. The report begins with a joint marketing survey and an equipment methods study. And finally, an extensive testing program is presented.

Key Words: Installation cost, construction technique.

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Caye, Weyant D., "Harlem River Submarine Conduit Crossing," The Municipal Engineers Journal, Paper 170 (Oct. 25, 1933), p. 96-112.

"Nerve cables" serving police alarm systems, burglar and protection, signal, quotation tickers, telephone and telegraph, are all housed in a crossing operated by the Empire City Subway Company. A seven foot diameter cast iron pipe housing 206 ducts was designed for this 600 foot long, 27 foot below mean low water, crossing. Existing gas and power crossings in the area required cooperation and assistance from some nine agencies.

Key Words: Utility ducts, utility cooperation, iron pipe housing.

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"Chapter VII--Conduit, Ducts, Galleries, and Cable Chambers," Int. Telegraph and Telephone Consultive Committee, Ch. 7 and 7A of Recommendations for the Protection of Underground Cables Against Corrosion, Int. Telecomm. Union, Geneva, 1961 and 1965.

At the beginning of this chapter the author gives brief descriptions on the various systems of duct, galleries, and cable chambers. Then it follows discussions of precautions that should be taken during the construction of ducts or the laying of cables in ducts. In addition, an Annex which discusses the protective measures against explosive gases and toxic gases that may be encountered in cable chambers for telecommunications cables is also attached.

Key Words: Galleries, multi-way duct, cable netowrk, conduit, cable chambers, telecommunication cables.

Chilberg, G.L., "New Aspects of Buried Urban Telephone Distribution," Electrical Engineering (Nov. 1963) p. 677-683.

Reasons given for undergrounding are appearance, serviceability, lower first cost, reduced maintenance. Design discussion includes location, joint trench, code separation. Modern construction tools, materials, and methods are described. The increasing usage of underground is noted.

Key Words: Undergrounding, methods, materials, construction tools, design, location, serviceability, maintenance, costs.

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City Engineer Attebery, APWA Underground Accident Report, (Phoenix, Arizona; Apr. 4, 1972), unpublished.

Information was obtained from Gas, Water, Sewer, Telephone, Electric Agencies, and includes some dig-in data (including reasons); breakages; damage costs. Steps are suggested to reduce dig-ins/damages.

Key Words: Underground utility accidents, breakages, damage costs, damage reduction.

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"City-Within-A-City Rising in Dallas," Engineering News-Record (Mar. 28, 1957), p. 45 and 46.

Business offices, stores, and a hotel on a 120-acre site near downtown will be served by underground utility tunnels housing chilled water, steam, and return lines in a 7-1/2 foot high, 12 foot wide structure. Truck tunnels 32 feet wide by 14 feet high also serve each building. Where locations coincide, utility tunnel is under truck tunnel.

Key Words: Utility tunnel, truck tunnels, location conflict.

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Cole, Russell A., "Concrete Cable Tunnels Show Economy," Electrical World (Sep. 27, 1930), p. 586-588.

Along Detroit streets too crowded for regular conduits, a tunnel system 1100 feet long with 400 feet of branch tunnels was designed so that tunnel wall and conduit were monolithic. Depth was about 67 feet.

Key Words: Cable tunnels, economics, utility overcrowding.

"Conduit and Manhole Construction," Report No. 130, Underground Systems Committee, p. 1077-1088.

Types of duct materials, manhole designs, underground structures, for transmission and for distribution are discussed in detail. Tests for expansion effects are described.

Key Words: Conduit construction, manhole construction, materials, design, structures, expansion effects.

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"Construction Notes from Here and There," Concrete Pipe News (Apr. 1956), p. 45.

Illustrations of utilidor cross-sections show water, sewer, steam, and other utilities accommodated in Alaska.

Key Words: Utilidor, utility accommodation, construction notes, illustrations.

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Corey, John B.W., "Feasibility of Utility Tunnels," A.W.W.A. Journal, p. 226-229.

A.P.W.A. Special Report No. 39 is used as a basis for this article which emphasizes the chambers for valves and appurtenances are cited as requirements, as is security against vandalism, sabotage, and acts in ignorance by different utility employees.

Key Words: Utility tunnel, feasibility, valve chambers, security measures.

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"Corridor Manholes Serve as Cable Room," Electrical World (1932), p. 99.

Lack of space for a cable room was overcome by construction of a three-compartment manhole under a hallway.

Key Words: Corridor manholes, cable room, construction, design.

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Davis, Telford R., "New Heating Tunnels Laid at Indiana University," Heating & Ventilating (May 1937), p. 45-46.

Thirty year old tunnel replaced with larger new layout, for steam and power distribution to the expanding campus.

Key Words: Heating tunnels, expansion.

"Deep Underground Conduit Installation," Edison Electric Institute Bulletin (Jan. 1942).

Employment of a casing and soil removal is recommended when pushing large duct lines. Better control of direction is among the listed advantages.

Key Words: Conduit installation, soil removal, large duct lines, listed advantages.

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DeWolf, R.D., "Chicago Tunnel Development--and Unusual District Heating Plan," Heating and Ventilation (June 1934), p. 28-30.

The author describes the tunnel system development in Chicago. The system is a district heating plan in the famous Loop area of Chicago. A series of problems encountered with the development of the tunnel system and the ways to overcome the difficulties are discussed. And, a possible solution to meet with the increase transportation demand for the heating purpose, an assignment to separate the usage of the tunnels is recommended.

Key Words: Chicago tunnel system, central heating plant, transmission, steam transmission system, pipe relocation, franchise.

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Dillon, W.E., H.A. Bunting, and M.S. Chen, "Thermal Network Technique for Calculating the Temperature Rise of Duct Bank Cable System," p. 24A1-24A4.

This paper investigates the steady state and transient temperature rise of a cable system in a duct bank. Thermal resistances and capacitances of ducts are defined and analog network is developed. Calculating load capacities and thermal responses of cables is accomplished by a digital computer program.

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Dorsey, J.S., "Design to Avoid Interference," Gas (Mar. 1969), p. 67-72.

The greatly increasing use of cathodic protection for pipelines can be harmful to other substructures. Recommendations are: remoteness, low voltage, deep anodes, design cognizant of potential interferences, corrosion engineer and pipeline designer work together.

Key Words: Pipelines, cathodic protection, safeguards to other substructures.

Dove, Lloyd A., "Utility Tunnels: Underground Movement with Revolutionary Potential," APWA Reporter (Jan. 1971), p. 20-25.

This is an interim report on the APWA Research Foundation study of the feasibility of utility tunnels in urban areas. European practice is noted as a guide for U.S. and Canadian application but generalization is not possible owing to individual circumstances. The compatibility aspect is considered as between highway systems and utilities and between various utilities themselves. Operational, engineering economics and legal considerations are listed. Demonstration projects are called for.

Key Words: Utility tunnels, feasibility, urban areas, operational, engineering, economic, and legal considerations.

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Dunn, G.P. and J.C. Nash, "Toll Conduit Construction on Private Property," Bell Telephone Quarterly, p. 39-56.

Some reasons for using private right-of-way instead of public highways are: traffic interference; other utilities (especially electric) with potential interference; potential future highway widening; better alignment capability (shorter, obstruction avoidance). Underground design was felt to simplify property acquisition from what overhead would involve. Special problems and construction techniques are detailed.

Key Words: Conduit construction, private property, interference factors, construction techniques, special problems, property acquisition.

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Egan, A.J., "Communication Conduits and Cables," Engineers & Engineering (Feb. 1932), p. 17-19.

Underground plant is described as being as large as 102 ducts and cables of up to 1800 pairs. Use of terra cotta multiple ducts on a concrete base is preferred. Detailed discussion of installation, maintenance, and testing follows.

Key Words: Communication conduits, cables, underground, multiple use ducts, installation, maintenance testing.

Feasibility of Utility Corridors, Report No. 1, Technical Aspects, Utility Corridors Task Force (May 4, 1971), p. 1-19.

The study initially addresses transmission facilities only, in an area eighteen miles square adjacent to Detroit. The problems and advantages of utilidors are listed. Technical solutions appear available, but implementation will require solving legal, economic, planning, and administrative aspects.

Key Words: Utility corridors, feasibility, transmission facilities implementation.

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Fehner, E.C., "Titan Termination Data Control and Interconnection Cabling," IEEE Transactions on Aerospace-Support Conference Procedures, p. 1161-1174.

Title I ICBM hardsites require 52 miles of cabling, 1350 multiconductor cable configurations, 6600 different cables, and over 700,000 terminations. Interconnection data handling was automated; prefabrication of cables was maximized to simplify installation. These techniques speeded successful completion.

Key Words: Multiconductor cable configurations, prefabricated cables, installation.

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Fox, A.L., "Some Recent Developments in Underground Conduit Construction in the Bell System," Bell Telephone Quarterly, p. 216-227.

Whereas total waterproofing is deemed unnecessary for telephone lines, small joint openings allow entry of silt which may create a problem for installation of cable in future years into such "spare" ducts. A mortar bandage was developed for the jointing of tile duct runs.

Key Words: Underground conduit construction, telephone, silt, duct jointing.

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Frost, G., "Service Tunnels in German Democratic Republic," 4th Int. Conf. on Underground Town Planning and Construction, Warsaw (1965, in French), V.4, p. 259-268.

The paper contains a critical examination of advantages connected with service tunnels and presents some tunnels constructed in German Democratic Republic.

Key Words: Service tunnel, advantage.

"Gas Explosion Problems May Get HUD Funds," E.N.R. (July 12, 1973), p. 16.

U.S. Senate Bill ($1 million) for research jointly by HUD and National Transportation Safety Board.

Key Words: Gas research, explosions.

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Gaulin, Jacques, "Controlling Urban Excavation," APWA Reporter (Feb. 1974), p. 18-19.

Montreal's by-law and procedure for regulation of temporary street occupation and retaining wall tie-back installations are discussed.

Key Words: Urban excavations, control, regulation.

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Goeller Jr., R.A., "Flexible Electrical Design at Fordham," Electrical Construction and Maintenance (Mar. 1965), p. 124-125.

Underfloor electrical ducting was employed in the renovation and expansion of Dealy Hall at Fordham University.

Key Words: Underfloor electrical ducting, design, expansion.

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Halmos Jr., E.E., "Underground Construction: A Safety Problem," Contractors & Engineers Magazine (July 1972), p. 35

Referring to the tremendous cost and danger of accidents to underground utilities, it is suggested that inaccurate or incomplete drawings, insufficient location detail, and contractor carelessness are main causes. Utilidor concepts are held forth as a hope for improvement. Interest by government or technical societies is weighted, and increased Congressional interest in safety is noted.

Key Words: Underground construction, safety problems, utilidor concepts, cost and danger of accidents.

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Harrison, G.B.W. and A. Miller, "A New 54-Way Duct Route in Central London," Post Off. Elec. Eng. Journal, V. 31 (1938), p. 142-146.

A description is given of the difficulties encountered in providing a new heavy duct route in busy West End

thoroughfares, and also of the special measures taken to anticipate and overcome difficulties both above and below ground.

Key Words: Duct route, open trench, tunnelling shaft, manhole, main trunk cable.

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Higgins, P. Kerr, "Some Tips on Conduit Work," Telephone Engineer (June 1925), p. 24-28.

Manhole construction, including manufacture of brick, is discussed. Pulling-in and handling of cable emphasizes care to avoid kinking, spreading, racking, and eplicing of cables in manholes emphasizes need for maintenance accessibility.

Key Words: Conduit construction, manhole construction, construction methods, maintenance accessibility.

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Hiller, Stanley, "New Concepts for Consolidation of Utility Lines," APWA Yearbook (1962), p. 162-165.

A group of utilities on each side of the street in the sidewalk area share service lateral trenches to pairs of lots. One excavation is made and each utility is installed one above the other. Comments by James E. McCarty emphasize that the key is coordination through consolidation: the resultant cost makes undergrounding acceptable to developers.

Key Words: Utility line consolidation, cost factors, coordination, shared service areas.

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Hock, Irving, "The 3-D City," APWA Reporter (Jan. 1971), p. 26.

Referring to underground shopping concourses in Russia, Sweden, Canada, and some U.S. cities, it is noted that undergrounding of utilities is cheaper in conjunction with such commercial projects.

Key Words: Utility undergrounding, cost reduction, underground commercial projects.

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Hoffer, William, "Gas Explosions: The Rising Toll," Washington Post (Sunday, Mar. 25, 1973), p. C5.

Citing the great number of gas explosions, most from careless construction work damage, a call is made for greater safety procedures. The call-in program must be supported by better records and emergency procedures.

Key Words: Gas explosions, recommended safety procedures, improved location records, emergency procedures.

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Hoffman, Robert J., "Engineering Utility Tunnels In Urban Areas," Conference on the Urban Environment (Storrs, CT: The University of Connecticut), p. 41-55.

The great and increasing number of underground utilities, congestion, street repair requirements, accident hazards are noted. The cost of locating and staking existing lines is observed as is delay costs to motorists. The systems approach is introduced with examples of utility tunnels throughout the world and favorable maintenance experience with them. Advantages and disadvantages are listed and discussed. Economic, financial, legal factors are the major problem.

Key Words: Utility tunnel engineering, urban areas, utility tunnel system examples, cost factors, legal factors, financial factors.

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Hoffman, Dr. Z., "Pipeline Damage - Service Time and Repair Cost," Water and Sewer Works (date unknown), p. 60.

A twelve-year study notes the kinds of failures and their causes for water mains of various materials.

Key Words: Pipeline damage, causes of pipe failure, repair costs.

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Holder, DAvis C., "Utility Tunnels as Public Shelters," (Boulder, CO: University of Colorado, School of Architecture, review copy Dec. 1968), 52p.

The desirability of providing distributed interconnected shelters for people, and protection of utilities in time of attack, is discussed. The compatibility of the two uses is arranged, and cost estimates are developed, revenues and rates discussed.

Key Words: Utility tunnels, bomb shelters, utility protection, joint-use compatibility, cost estimates, revenue.

Hubbard, C.H., "Utility Chooses Pre-Cast Cable Ducts for Substations," Power Engineering (Dec. 1962), p. 62.

Instead of previously used creosoted lumber ducts, the Public Service Company of Indiana is now using six-foot long pre-cast sections with dry tongue and groove-end joints. The ducts have drain holes; a lid fits into grooves in the sides; the finished surface serves as a sidewalk.

Key Words: Pre-cast cable ducts, utility use of.

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Huelsman, Albert W., "Joint Utility Tunnel," Concrete Pipe News, p. 73-75.

200 lineal feet of 54" diameter concrete pipe houses sewer, water, and electric power, crossing I-94 near Waukesha. Cost was apportioned to the users.

Key Words: Joint utility tunnels, cost apportionment.

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Ito, K., "Cable Tunnel Construction by Shield Method," Japanese Telecommunication Rev., 8, (4), p. 191-197.

The author introduces the application Shield Method to the construction of the cable tunnel. He also points out that when a large number of cables are laid on one route the cable tunnel is more economical than a conduit, and the cable tunnel is preferable because of ease of cable installation and maintenance. An economic comparison between the shield method and the open-cut method is also attached.

Key Words: Cable tunnel, shield method, underground conduit construction, shield machine, advantage, communication cable tunnel, segment material.

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Jepson, Thomas S., "Precast Duct Underground Saver," Electric World (June 6, 1960), p. 57-58.

Four-duct runs of 4-1/2 in. diameter are precast. Manufacture and laying procedure are described. The larger diameter was chosen because of the trend to larger compound-insulated conductors.

Key Words: Pre-cast duct, laying procedures, compound insulated conductors.

Jervey, W.T., "Concrete for Cable Conduit," Bell Laboratories Record (Nov. 1961), p. 407-409.

Clay had been widely used but breakage and jointing problems lead to new studies. Plastic sheathing of cables eliminates the hazard of concrete reacting with lead sheathing. Several joint designs were tested, and a double tenon with plastic sleeve was selected.

Key Words: Concrete cable conduit, joint design testing, plastic sheathing of cables.

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Johnson, B.R., "New Underground Telephone System for Atlantic Steel, Atlanta, Ga.," Southern Power & Industry (Apr. 1950), p. 74-75.

Damage from construction crews, electrolysis, and overloading were eliminated by installation under 30" cover of two-inch diameter asbestos-cement duct runs, with manholes.

Key Words: Underground telephone system, installation, justification for.

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Jones, G.W., T.H. Haines, T.F. Smith, and W.J. Huff, "Investigations During 1938, 1939, and 1940 of Combustibles in Manholes in Boston, Massachusetts," R.I. 3604 (United States Department of the Interior and Bureau of Mines, Jan. 1942), 33p.

In cooperation with Edison Electric of Boston, these government agencies had made continuous surveys since 1929 to determine the general hazards of combustibles in a typical large city and to establish the value such surveys may have in hazard elimination. Key manholes in the system of 19,000 total manholes were chosen for sampling, and tests are now limited to areas that have shown trouble in the past. Experience has shown that explosions can be virtually eliminated through surveys and corrections. Over the years of the testing program, percentage showing combustibles dropped from 4.8 to 0.7. Gas leak repairs have been made as a reuslt of cooperative testing. The value and need of coordinated, systematic, and continuous testing has been shown.

Key Words: Research, manholes, combustibles therein, hazards.

Kassner, John J., "Relocating Substreet Utility Lines," Civil Engineering - ASCE (Apr. 1968), p. 86-88.

The mass of underground installations demands a coordinated undertaking when redevelopment projects require relocations. Owing to the multiple ownerships, the city should coordinate the work which should be undertaken as a single project. The consultant should play a key role, and an example of this is given in the N.Y.C. new Police Headquarters project.

Key Words: Utility relocation, coordination.

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Kearney, Stephen, "Underground Services Mapped for Emergency Needs," Engineering News - Record (July 3, 1941), p. 67-68.

Maps at 50 ft. to 1 inch show sewers, water, gas, telephone, electric, and other underground works. Complicated intersections are mapped at 20 ft. to 1 inch.

Key Words: Underground services, mapping.

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Kent, Erwin, "An APWA Interview with Erwin Kent and Consolidated Edison," (Jan. 1970), 5p.

Strongly advocates joint usage of right-of-way and of tunnels. Electric, gas, water, telephone, steam, oil, are all seen as compatible. Highway lands should be used except on scenic parkways.

Key Words: Joint-use utility tunnels, utility systems, compatibility, feasibility.

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Kovacshazy, F., "Some Problems Concerning the Development of the Budapest Public Utility Conduits," V. 2, of Int. Conf. on Underground Town Planning and Construction, 4th, Warsaw, 1965, p. 53-70.

The author discusses the standard Hungarian system developed for locating the town underground public utility conduits and lines, -- he is treating in detail the developments in methods of laying them without using the open working separate trenches and without any disturbance of the pavement and the soil surface.

Key Words: Public utility conduits, trench, inadequacy of capacity, duct, standard order of location.

Krakauer, Jay F., "Some Geographic Factors in the Development of Utility Substructures in New York City and a Plan for Directory Subsurface Expansion," The Municipal Engineers Journal (Sep. 23, 1942), p. 28-44.

Noting that New York has a multitude of independent utilities with no planned coordination, their history is traced from the time of New Amsterdam being laid out on a long narrow peninsula with a street pattern suited to it. The subsequent services required to follow that pattern, with major concentrations on the longitudinal streets rather than on the cross streets. Lack of accurate records costs contractors and the city huge amounts because of the uncertainty of relocational/maintain in place requirements. Recommendations include coordinated planning and centralized control (subsurface zoning), comprehensive substructure records and maps.

Key Words: Utility location, problems, insufficient coordination, historical review, insufficient records, cost factors, coordinated planning, centralized control, mapping.

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Kranz, H.H., "Principles of Subsurface Utility Planning," Civil Engineering (Oct. 1937), p. 705-708.

Noting the complication of underground installation, the author suggests four rubrics for planning: designating the authority or agency to administer the plan; mapping of existing installations; location assignment; and future major installation plans. Discussion then focuses on the progress that Cincinnati had made to date.

Key Words: Subsurface utility planning, necessary requirements, problems.

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Kugelman, C.W., "Recent Bridge Construction at Portsmouth, OH," Telephone Engineer, p. 38-39.

Special clamps and fittings were obtained in order to carry 1700 feet of cable over a new suspension bridge. Four 4 inch ducts were run under the sidewalk in a concrete arch bridge of 160 ft. span.

Key Words: Special cable clamps, special cable fittings.

Lande, Kent O., "Underground Utility Coordination " (1971), p. 15-18.

Cooperation and coordination in usage of common rights-of-way, adequate records, custom made standards for each community, and coordinating committee are recommended.

Key Words: Underground utility coordination, right of way use, adequate records, coordination committee.

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Lane, Richard A., and G.D. Schrader, "Cable Tunnel Under Schulykill River," Electric Light and Power (July 1949), p. 54-58, 60-61, 96.

Two existing 66 kv overhead crossings and a 13.2 kv submarine cable were in hazard from crossing another 66 kv line and river improvements (dredging). A study was made to determine what ultimate accommodation should be provided in what cross-section of tunnel. It is noted that three of the four 66 kv positions and eleven of the eighteen 13.2 kv positions are already occupied, and operating well. Detailed description is given of the construction.

Key Words: Electric cable tunnel, construction description.

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"Largest Single Construction Job Ever Carried Out In Quebec City," Roads & Engineering Construction (Dec. 1950), p. 79-83, and 112.

Detailed description of the construction and construction equipment is given on this 12,000 feet of 10 ft. x 7 ft. utility tunnel for the new canyons of Laval University. The tunnel will house electrical, telephone, watermains, storm sewers, and heating. Junction chambers are spaced about 400 ft. apart for future lateral tunnels to each building.

Key Words: Utility tunnel, construction description, construction equipment.

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Lawrie, Robert J., "Precast Concrete Duct Speeds Underground Work," Electrical Construction and Maintenance (Mar. 1970), p. 118-120.

Installation speed, inventory control, less coordination requirements are cited as advantages. Snagging problem at joints was overcome by placing a rolling ball at the head of the pull-in lead.

Key Words: Precast concrete duct, installation speed, inventory control, coordination requirements, snagging problems.

"Legal Problems Encountered in Street Cuts and Restoration," Pennsylvanian (May 1973), p. 24-25.

Pennsylvania Department of Transportation controls installations in State highways, and on occasion permits the municipality to exercise the control in the highways that pass through them. Problems with this have been failure to obtain a permit, requirements for the utility to obtain a certificate of public convenience, improper signing, blasting, restoration, and recording.

Key Words: Street cuts and restoration, legal problems.

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Location of Underground Utilities, (New York: City Planning Division), (July 1937), 15p.

A committee prepared this manual which emphasizes planning and recording of underground plant. Eleven "General Principles" include: Having such plans as an adjunct to the master plan; standards and minimum scale for plan; data obtaining procedure; minimization of street openings. Ten "Standards for Plans" detail drawing materials, details to include, referencing of sheets, use relative to permit issue. Ten "General Standards of Design" include discussion and illustration of location assignment, potential for combined tunnels, anticipation of future requirements such as service expansion and pedestrian tunnels.

Key Words: Underground utility location, manual of planning, planning principles, design standards.

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Luthim, John C., "Financial Aspects of Water Main Extension," Journal of the AWWA (Oct. 1971), p. 661-670.

Policy committee report concerning economic investment by publicly and privately owned utilities. Practices and rules in the various states were surveyed, including the matter of payments by developers. A mathematical model is presented which considers utility plant (in-tract and back-up facilities), depreciation construction advances (with and without refunds), to meet cash-flow and revenue requirements.

Key Words: Water main extension, financial concerns, state financial practices, revenue requirements.

Manson, R.E., "Utility Tunnel STudy for the Central Business District," City of Akron, Dept. of Planning and Urban Renewal (Apr. 1966), 34p.

This report presents the results of a study which contains a discussion of the advantages, disadvantages, and problems which may be encountered in the construction and maintenance of a downtown utility tunnel in the City of Akron. And the purpose of this study is to investigate the adaptibility of the utility tunnel to the future development of the Central Business District.

Key Words: Utility tunnel, adaptibility, advantage, disadvantage, maintenance, feasibility.

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Matheson, Donald Stewart, "Subaqueous Tunnelling in Compressed Air, with Reference to the Barking Power Station Cable Tunnel Under the River Thames," Selected Engineering Papers (London; The Institution of Civil Engineers, 1927), 26 p.

The alternative to tunnel would have required an additional 30 miles of land cable, to cross on an existing bridge, so the cost was too great. Twelve-foot diameter shafts and seven foot diameter tunnel about 2,500 feet long was chosen. The paper details the field layout, construction progress, and medical data concerning work under 35 psi air.

Key Words: Subaqueous tunnelling, cable, field lay-out, construction progress, medical worker data.

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McCombs, Philip A., "Gas Leaks Deadly Peril in D.C. Area," (The Washington Post, July 18, 1973), p. A6.

Of 80,000 leaks reported annually, 20,000 could be serious. Contractors are responsible for about 15,000 damaging accidents. Call-in system is urged.

Key Words: Gas leaks, responsibility for, call-in systems.

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McKelway, G.H., "Submarine Conduit Line," Electrical World, Vol. 86., No. 15 (Oct. 10, 1925), p. 752-753.

Requiring additional crossing under the Wallabout Canal, New York telephone decided to install a 24 duct conduit line to allow for future increase in service.

Key Words: Submarine conduit line, utility service demands.

McFalls, R.K., "Engineering Considerations for Joint-Use Utility Tunnels," Paper presented at the International Symposium on Systems Engineering and Analysis, Purdue University, Oct. 23-27, 1972.

Major aspects of utility tunnels are discussed, including their history and current practice, motivating factors for joint-use utility tunnels, advantages, problems, and the current status of utility tunnels; characteristics of utilities as they would apply to placement in a utility tunnel, including district heating, district cooling, electric power, gas, sewers, telephone, and water; operation of a utility tunnel system, including corrosion protection, electrical protection, electromagnetic interference, fire protection, safety, reliability, and maintenance and ventilation. Finally, several sample utility tunnel configurations are presented along with the author's overall conclusions about the utility tunnel concept.

Key Words: Utility tunnels, history, current practice, advantages, problems, utility characteristics in tunnel, district heating and cooling, electric power, gas, sewers, telephone, water, utility tunnel system requirements, corrosion and electrical protection, electromagnetic interference, fire protection, safety, reliability, maintenance, ventilation, sample utility tunnel configurations.

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Mellanby, J., "Cable Capacity of Conduits," Electrical Times (Jan. 31, 1963), p. 175-176.

The number of cables that can be theoretically and practicably installed in a conduit, and the radius requirements of bends, are discussed.

Key Words: Conduit cable capacity, bend radius requirements, cable installation.

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Mermel, T.W., "Joint Use of Rights-of-Way Can Reduce Costs of Services," Civil Engineering - ASCE (Mar. 1969), p. 56-59.

Greater planning and coordination for joint use of rights-of-way is required with emphasis on undergrounding rather than cosmetics for overhead installation. Efficient cooperative use can make underground installation cost-competitive, especially in urban areas. Community convenience and values must take precedence.

Key Words: Joint-use right-of-way, reduced costs, planning requirements, coordination requirements, cost effectiveness realization.

Miller, Leroy W., "Utility Tunnel Ownership and Right of Way Considerations," Public Works (Dec. 1972), p. 67-69.

Utility occupancy (by franchise or agreement) of public right-of-way may be a deterent to getting relocations into tunnels. Who bears relocation costs, who is given authority to construct tunnels, purposes of regulation and denials, whether tunnel ownership is a proprietary or governmental function, liability, are some of the legal questions raised.

Key Words: Utility tunnel ownership, right-of-way considerations, legal implications, utility relocation.

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"Minnegasco Reports on Urban Plastic Plow-In," Gas Age, (Oct. 1964), p. 29.

Plowing-in plastic pipelines cuts installation time to less than a third, and costs less, than conventional excavation for steel pipe.

Key Words: Plastic pipeline plowing-in, installation, cost reduction, steel pipe.

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Minor, H.H., and E.S. Dreischmeyer, "New-Underground Distribution Utilizes Non-Leaded Cables," Electrical West, Vol. 88, No. 4 (Apr. 1942), 3p.

Overload on the system required replacement, and underground was selected using multiple soapstone duct; the downtown of Fresno was done in two steps.

Key Words: Underground distribution, non-leaded cables, multiple soapstone duct, construction phases.

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Missimer, Hertel C., "Avoiding Utility Interference Underground," Civil Engineering - ASCE (Sep. 1965), p. 36-38.

To avoid large scale utility structure replacement, foresight cooperation, and coordination are required. The Planning Commission in Philadelphia is charged with preparation of long range plans and so plays an important role in utility coordindation activities; a Municipal Board of Highway Supervisors does the fine tuning relative to short range plans and current undertakings. Maps are at a scale of 1" = 20 ft; utilities can "reserve" future locations. Construction phase is handled by a Utilities Technical Committee.

Key Words: Underground utility, interference, planning, coordination, reserved utility locations, construction phases.

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"Modern Methods Speed Underground Duct Work," Electrical Construction and Maintenance (Nov. 1960), p. 86-88.

Two and one-half million feet of 4" fibre duct installed for power, lighting, and communications at O'Hare International Airport. Ten foot lengths (instead of 8 foot), 85 piece palletized delivery, machine handling, steel strapping of placed ducts to hold configuration pending concreting, expedited the project.

Key Words: Underground duct, construction methods, design.

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Morgan, N.L., "Temperature Survey of Power Cable Ducts," The Engineering Journal, Volume XV, No. 11 (Montreal: Nov. 1932), p. 497-511.

Temperature affects the life of a cable, so this survey in London, Ontario was made to determine temperatures of various parts of the system. Underground temperature of the earth was related to maximum and minimum surface temperature times and to peak load times. Varying thermal resistivity of the surrounding soil was seen as being a factor that could limit a particular section of the system.

Key Words: Power cable ducts, temperature survey, thermal resistivity, cable life.

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Mourawiow, I.N., "Complex Constructing and Designing of Underground Conduit Nets in Moscow," Int. Conf. on Underground Town Planning and Construction, 4th, Warsaw, V4, p. 281-296 (1965), USSR.

The paper explains methods of complex arrangement of underground public utility nets either in common trenches or in collectors laid under streets or introduced amidst housing terrains. The modern methods of execution of works are presented.

Key Words: Common trenching, utility location, utility collectors, methods of work, design.

Mudie, Jerry G., "Utilidor Problems, Possibilities, Revealed in Detroit Urban Study," APWA Reporter (June 1972) p. 12-14.

The Urban Detroit Area (defined as 35 counties in Michigan, Ohio, and Ontario) was studied by Dr. Constantine Doxiadis relative to its continued urban development and the resultant utility needs. The technical feasibility of shared corridors in a grid pattern was confirmed. Cost will limit utilidor applications. Several legal/administrative problems are listed. Four study committees are operating on legal, economic, planning and administrative aspects. Comprehensive planning is emphasized.

Key Words: Utilidor, problems, possibilities, technical feasibility, cost, legal/administrative problems.

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"Multiple Use Explored for Shrinking Rights-of-Way," Electrical World (Sep. 1, 1969), p. 26 and 31.

More usage of highway lands for utilities is urged. Joint development by the highway authority and the utilities must start at the early planning stages. Environment preservation is stressed.

Key Words: Shrinking right of way, multiple use, planning, environmental preservation.

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"Municipal Conduct System of the City of Baltimore, Md.," Electrical World (Jan. 4, 1908), p. 13-16.

In order to force the removal of overhead wiring, the city provided duct space in tunnels, with the upper part reserved for electric and power, and the lower for telegraph and telephone. Sixteen users are listed with a tabulation of lease rates. Generous manhole provisions aids installations and maintenance. Construction and design are described in detail.

Key Words: Municipal conduit systems, construction, design, lease rates, maintenance.

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Neck, L., "Modern Cable Layout in Manholes and Cable Chambers," Post Off. Elec. Eng. Journal, 29 (Apr. 1936, pt. 1), p. 29-33.

In this article the author shows how recent new designs for manholes have enabled improved accomodation to be provided therein for cables. Easy access to all joints is afforded and the result is neat and efficient. He suggests that similar methods might, with advantage, be applied to cable chambers.

Key Words: Cable chamber, junction manhole, advantage, cable layout, conduit.

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Nettleton, L.A., "Heat Dissipation from Network Manholes," Electrical World (Sep. 16, 1933), p. 369-372.

Better design of manholes and covers can provide enough ventilation for transformers, without forced air systems. Load variations relative to seasons of the year dictate the maximum requirement. Formulae are given for calculation of heating.

Key Words: Manholes, heat dissipation, design, heat calculation formulae.

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Neyens, James F., "Pump Station Explosion at Moline, Illinois - A Reminder of Gas Hazards," Digester (Winter 1967-68), p. 11-13.

Pumping station destroyed by explosion of apparent gasoline infiltration to sewer system emphasizes the hazard in sewerage.

Key Words: Pump station explosion, sewage hazards, gasoline infiltration.

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Nicholson, C.T. and T.J. Brosnan, "An Investigation of the Relationship Between Temperature and Movement of Cables in Ducts," Transactions, AIEE, Vol. 63 (Oct. 1944), p. 723-728.

Sheath temperature rise was measured as electrical load was applied to the cable and corresponding physical change measured in terms of longitudinal expansion and of change in configuration of bends in manholes. Influence of the degree of "bond" between cable and sheath was also studied.

Key Words: Cables, ducts, sheath temperature, cable movement, cable sheath bond.

Norrie, Charles Matthew, "The River Hooghly Tunnel," Minutes of Proceedings, Institute of Civil Engineers, p. 281-326.

Reasons for selecting tunnel instead of overhead crossing of electric power lines in this Calcutta installation are touched upon. Illustrations and detailed discussion of safety measures, compressed air systems, construction progress and medical experience, are included. Inside diameters of 8 feet for shafts and 6 feet for tunnel were questioned as to adequacy and convenience of cable installation, but operation was reported as being quite satisfactory. It was also observed that in the future (when operating consolidations occurred as with the Post Office Department in the United Kingdom) other lines such as telephone would be added to the tunnel usage.

Key Words: Tunnel, safety measures, construction, compressed air systems.

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Novotny, John J., "Steam Tunnels at the University of Wisconsin," Power Plant Engineering (Oct. 1, 1930), p. 1092-1095.

First consideration is given to potential future expansion of the campus buildings. The tunnels house steam, electric, telegraph, telephone, compressed air lines. Design pays attention to adequate drainage. Tunnel lighting is suspended from the roof rather than being imbedded in it. Brackets and pipe chairs were designed to accomodate the various lines. Cost figures are supplied.

Key Words: Steam tunnels, costs, joint-use.

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"Oil-Filled Cables, 66 kv Installation in Tunnel Under the River Tyne at Newcastle."

Part of a nine mile route for this connection between a switching station and transformer station is through an existing six foot diameter utility tunnel 1000 ft. long under the river. Design and installation of the cable is described.

Key Words: Utility tunnel, cable installation, tunnel design.

Olmsted, Leonard M. Editor, "Trends in Underground Distribution," Electrical World (Aug. 12, 1957), p. 87-102.

Results of a survey show the practices and requirements of 42 utilities concerning underground electric, including service connection mains, transformers, and networks. The experience, and cost-reduction efforts, of Commonwealth Edison Co, Chicago, includes cable burial and transformer vault installations for residential distribution. Fused cutouts used by calectric for sectionalizing 4000v distribution, and conversion of aerial radial systems to network, for future undergrounding in Elizabethton, Tenn. are described. Conversion to aluminum and interchangeability with copper, is discussed under Consolidated Edison Company experiences.

Key Words: Underground distribution, cable burial, transformer installation, cost reduction.

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Papamarcos, John, "Sharing Rights of Way," Power Engineering (June 1970), p. 26-33.

Notwithstanding the Deerfield conference of a year earlier, little cooperative inter-utility planning is being done. "Energy Coordiors" are advocated. The Regional Planning Authority is seen as the key to coordination. Recreational uses should be made of lands occupied by utilities. The APWA Research Foundation study of Utilidors is well reported. Bell System advises that it is looking at extra shielding to increase compatibility. Better sharing arrangements have been made with railroads than with highways.

Key Words: Right of way sharing, utility planning.

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Paul, James C., "Feasibility of Utilidors," Engineering Foundation Research Conference (Deerfield, MA. July 28 - Aug 1, 1969), 9p.

The Toronto, Canada Utility Coordinating Committee, which has existed for thirty-five years and already has done such things as establish standard locations for various utilities, presently considers the cost and other problems of utilidors to be excessive at this time. Provision for expansion (foreseeable for twenty or thirty years) should be made when a utility is undergrounded. Separate locations are the best guarantee of service continuity. But continued study with open mind is required owing to urban development magnitude, demand for improved environment by the public, and labours demand for improved working conditions.

Key Words: Utilidors, feasibility, cost, utility expansion.

Pegg, R.N., "The Principles and Theory of Underground Town Planning," Public Utilities.

The author presents principles and theories for the purpose of underground utility design and constructions. Some design and constructive examples that had been conducted in the City of London are also illustrated.

Key Words: Public utility plant, cable, distribution network, cable duct, subway.

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Pequignot, C.A. Editor, "Tunnels and Tunnelling," (London: Hutchinson and Co. (Publishers) Ltd. 1963), 540p.

The chapters deal with: historical development, geology, surveying, rock, soft ground, compressed air, prestressed concrete, economics; railway, road, electric, sewer, mining, military, and canal applications.

Key Words: Tunnels, construction, historical development, electric & sewer applications.

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Pickering, Ellis E. 1970. Feasibility of Utility Tunnels (Utilidors) In Urban Areas. American Public Works Association. Sept. 29, 1974: 1-16.

Reporting on the study being conducted by the Stanford Research Institute for the APWA Research Foundation to determine feasibility of constructing utilidors in conjunction with transportation facilities, four factors emphasizing the, and eight issues requiring investigation, are listed. Experience in England, Spain, France, Japan and elsewhere are cited and illustrated. Absence of utilidors in Canada and the United States is attributed to fragmented utility ownership. Likely economic areas, potential benefits, and problems are listed.

Key Words: Utility tunnels, feasibility, problems, economics, benefits.

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Poertner, Herbert G., "Feasibility of Utilidors in Urban Areas," American Public Works Association. Presented July 31, 1969 at the Conference on Joint Utilization of Right-of-Way for Utilities and Municipal Services in Urban, Suburban and Rural Environments, sponsored by the Engineering Foundation.

This pre-study discussion of APWA research project No. 68-2, lists specifics to be investigated, justification, potential opportunities, scope of the first phase of the study, methodology, and anticipated results. (Subsequent reports on this project were abstracted earlier).

Key Words: Utilidors, feasibility.

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Porter, J.W., "Its Just as True Today," Concrete Pipe News (Dec. 1956), p. 135-137.

Specification of precast conduits and especially the bedding requirements is discussed. The need for full enforcement in the field is stressed.

Key Words: Precast conduit specifications, bedding requirements.

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"Precast Duct Entrances," Electrical World (1928), p. 629.

Great reduction in cable sheath troubles after 16 months experience with special cable entrances in 75 manholes.

Key Words: Pre-cast duct entrances, cable sheath problems.

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"A Preliminary Survey Summary of Current Practice in Managing Utility Locations in 12 Metropolitan Areas,"

The need and efforts to effectively use urban space, on a community-wide basis, are reported from selected communities. Partially coordinated master and accident record systems are given. Some cost estimates are included for various constructions.

Key Words: Utility location management, reporting system, need for coordination.

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"Prevention of Damage to Pipelines," Report No. NTSB-PSS-73-1 (Washington DC: National Transportation Safety Board, June, 1973), 32 p.

The need for completeness in a damage program is emphasized: all facets must be covered. Special merit of Utility Coordinating Committees includes the communication and cooperation developed among the various agencies by such joint participation.

Key Words: Pipeline damage prevention, programs, cooperation.

"Public Improvements for the Permanent Headquarters of the United Nations," The Municipal Engineers Journal, p. 132-148.

Vehicular tunnel 1377 ft long on 1st Avenue provided space above for steam, power, and other utilities, and a future interceptor sewer below. Heavy existing utility installations had to be relocated before construction started, and was by a joint contract. Much consolidation was achieved, into a trench on each side of the street.

Key Words: Vehicular tunnel, utility accommodation, utility relocation, utility trench consolidation.

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Radnai, F., "The Practice of Laying Public Utility Conduit into Service Tunnels in Budapest," of Int. Conf. on Underground Town Planning and Construction, 4th, Warsaw, V1 (1965), p. 23-52.

The paper explains the natural characteristics of Budapest, its technical underground equipment, the expected long term development of public facilities, and emphasizes in a motivated examination the necessity of introducing the public service tunnels as a remedy against the difficulties arising nowadays with the operation of underground public utilities.

Key Words: Public utility conduit, tunnel network of public services, traffic junction.

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Radnai, F., "Questionnaire on the Laying of Public Utility Ducts in Common Public Service Tunnels," of Int. Conf. on Underground Town Planning and Construction, 4th, Warsaw, V2 (1965), p. 207-212.

The author collected a great quantity of practical questionnaire arising at design and exploitation of service tunnels. The questionnaire includes categories about technology, safety rules, service cable connections, construction, operation, questions of economy, and so forth.

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Rattay, Wolfgang, "Planning, Building and Operation of Collecting Channels for Supply Mains in Towns of the German Democratic Republic," (Berlin: German School of Architecture, unpublished), 10p.

Urban development and increased service demands are increasing the desirability of combined use facilities,

and three examples are described. The school is undertaking an extensive study of: thermal effects on lines; electric influence on lines; the effects of escaping gas.

Key Words: Joint-use utility facilities, thermal affects, electric influence, escaping gas.

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Reiter, Glenn M. and Lawrence Hirsch, "Use of Plastic Pipe for sewers," Public Works, (Apr. 1973), p. 88-91.

Increasing costs of a sewer system installation led to the investigation and substitution of (ABS) plastic pipe, with a cost saving of as much as 30%.

Key Words: Plastic sewer pipe, cost saving.

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Report of Joint Committee of Institution of Civil Engineers and Institution of Municipal Engineers. "Location of Underground Services," (Westminister: the Institution of Civil Engineers, revised edn. July 1963), 13p.

Interest in developing standard practice led to locational and installation order proposals for electricity, gas, water, telecommunications. Installations under the pavement, except for sewers is discouraged. Pros and cons of "subways" are cited, with the conclusion that owing to hazards and costs they should be used only in crossing major traffic intersections. Coordination of work and competent standard drawings (records) are urged.

Key Words: Underground utility location, standardization practices, records.

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Riddle, William G., "Minimum Size for Water Mains and Standards for Future Growth," Public Works (Nov. 1972), p. 81-83.

Anticipating growth, meeting fire flow requirements, maintaining carrying capacity, are discussed to support a plea for larger sized mains.

Key Words: Water mains, standards.

"Rig and Wrench Speed Tunnel Conduit Installation," Electrical Construction and Maintenance (Jan. 1970), p. 92-95.

Five inch diameter rigid steel conduit for 12 kv and 4160 volt feeders were installed in 2,300 feet of 9-1/2 ft. tunnel at the rate of 500 feet per 8 hour shift with three men.

Key Words: Tunnel conduit installation, installation rate.

Robinson, C.F., "Ferman Underground Installations," The Military Engineer, Vol. 39, No. 265 (Nov. 1947), p. 469-474.

Placing of aircraft, oil and other critical production facilities underground is described. Various geological conditions, and existing mines and other underground space were employed. The susceptibility of railroads to bomb damage detracted from the success of the underground program, as all supplies and products relied on this type of transportation.

Key Words: Underground facilities, space uses.

Ross, Everett C., "Engineered Work Measurement Program Brings Savings to Municipal Utility," Public Power (July 1970), p. 6-10.

Conversion from 4 kv to 12 kv distribution, and use of Methods-Time-Measurement are discussed. "How Riverside achieves economies in underground construction" lists five points concerning substructures, trenches, conduits, six points on cable, splices, terminals, five points on transformers, sectionalizing, protective devices.

Key Words: Underground construction economics, work measurement program.

"Rules and Regulations Governing Private Development of Sanitary or Storm Sewers in the Atlanta Metro Sewer System," (Atlanta, GA: Dept. of Public Works, Water Pollution Control Division), p. 10-13, 18.

Easements, house connections, permits, fee assessed (for usage, pavement restoration and inspection), construction specifications, storm design, flood works, are covered.

Key Words: Sanitary storm sewers, construction specifications, design, flood control, pavement restoration, fees.

Safety Rules for the Installation and Maintenance of Electric Supply and Communication Lines, N.B.S. Handbook 81 (Washington D C: U.S. Government Printing Office, Nov. 1, 1961).

"Saving Time and Expense in Underground Work," Electrical World (Aug. 27, 1932), p. 274-275.

A cylindrical air motor with brush, ream, or carborundum wheel attachment, may be used to clean out silted or obstructed ducts.

Key Words: Obstructed ducts, cleaning.

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Scott, Hugh P., "The Swing to URB," Electrical Construction and Maintenance (Feb. 1970), p. 100-105.

Underground residential distribution is increasing and has several attractions. Problems discussed are: non-standardization of components, separate v. packaged components, cable splices, front-lot v. rear lot locations, damage from subsequent excavations, and joint usage installations.

Key Words: Underground residential distribution, problems, attractions.

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Scott, Hugh P., "The Swing to URD," Electrical Construction and Maintenance (Jan. 1970), p. 87-91.

Consulting electrical engineers Ken Oliphant and Carl Martineau, who have designed over twenty major URD projects, were interviewed. Underground transformers specifically designed for such use and "packaged" transformer-vault combinations, are discussed. Secondary runs being shortened, direct burial cable, above ground connections, type of conductor, are also assessed.

Key Words: URD projects, design, assessment of.

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Seigel, Max H., "Network of Uncharted Utility Lines is ...," The New York Times (Feb. 18, 1973).

Considerable hand digging required in the Second Avenue subway construction owing to lack of information on old underground installation.

Key Words: Locating underground installations.

Selbe, Rex L., "New Fast-Setting Cement: the Road to a Motorists' Heart," American City (Nov. 1972), p. 63.

"Development of Duracal" by U. S. Gypsum - setting time 30 to 45 minutes, 3000 psi in one hour.

Key Words: Fast-setting cement.

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Shae, C. H., "Cable Sheath Troubles at Duct Edges," Electrical World (Apr. 7, 1928), p. 706.

More careful design of manholes (allowing expansion room) or duct edge protectors in old manholes, is recommended to eliminate the abrasion of the sheath caused by expansion and contraction.

Key Words: Manhole design, duct edge protectors.

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Shugrue, J. F., "Multiple Use of Rights of Way," Right of Way (Feb. 1970), p. 10-12.

The past practice of arbitrarily proscribing utilities from highway rights-of-way, modern relocation cost sharing legislation, and studies for coordinated highway and utility usage, are discussed.

Key Words: Right of way, joint utility use.

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Sillers, Thomas J. and Homer J. Vick, "Underground Distribution - Present and Future," Proceedings of the American Power Conference 1964 Vol. XXVI (Chicago: Illinois Institute of Technology, 1964), p. 1038-1040.

Description of a turnkey project for Wisconsin Power and Light Company, involving "random lay" joint use with telephone for a 108 lot subdivision.

Key Words: Underground distribution, joint-use "random lay."

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Soons, A. T., "Tunnelling Work in Underground Line Construction," Post Off. Elec. Eng. Journal, V. 30 (July 1937, Pt. 2), p. 94-98.

A description is given of a scale model used to demonstrate underground tunnelling construction. The conditions required for tunnelling as an alternative to trenching and the practical considerations for the tunnel constructions are presented. The author also describes the method of construction of tunnels for underground duct work.

Key Words: Tunnelling, underground line construction, pilot-holes, working shafts, trenching, excavation.

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Soons, A. T., "Slewing and Lowering Existing Ducts and Cables."

The author describes a practical method of slewing and lowering a cable route in self aligning earthenware ducts and stresses the precautionary measures necessary.

Key Words: Ducts, cables, slewing, lowering precautions.

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Springer, G. B., "Chicago's Tunnels for Electric Light and Power Cables," Engineering World (Aug. 1, 1919), p. 53-58.

The report describes the details of Commonwealth Edison Company's tunnels in the City of Chicago. In some of these tunnels, it is most desirable to build in clay both from the standpoint of obtaining a dry tunnel and also from the economical point of view. Construction methods employed and the experiences in constructing Chicago tunnels are presented. In addition, relative advantages of building tunnels are also attached.

Key Words: Power cable, advantages of tunnel and conduit, economical point of view, expense of repair, cost of reinstallation, submarine cable.

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Stastny, Francis J., "Joint Utilization of Rights-of-Way," Transportation Engineering Journal - ASCE (May 1972), p. 299-302.

Increased interest in the long-time practice of joint usage of right-of-way is prompted by increasing land costs. But in rural areas, lower costs and less coincidence of routing reduce this interest. Several problems arising from joint usage are discussed.

Key Words: Right of way, joint-use, justification, special problems.

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Standard Specifications for Construction of Public Improvements, Div. 3, Sect. 47 (Des Moines: Bureau of Engineering, City of Des Moines, March 1972).

A two year maintenance period for contracts is prescribed, except where the cause for repairs is beyond the contractor's control.

Key Words: Maintenance contracts, prescribed period.

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"Statement of Facts Concerning a Gas Explosion Occurring December 21, 1962," (Grand Island, Nebraska, unpublished).

Rupture of a gas connection during excavation for a watermain installation permitted gas to seep into the basement of 594 East Texas Street.

Key Words: Gas explosion, causes.

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Stoppoloni, Mario, "Venice Has Success With Prefabricated Duct Line," Electrical World (Nov. 23, 1946), p. 80, 81.

Concrete pad is placed in bottom of excavated trench, prefabricated rings (about 2 in. long) are set at about 20 inch centers, sidewalls poured, and prefabricated (sidewalk) slab covers are used. The rings are set above the pad to allow drainage. Less pulling pressure is required to install the cables than required in the case of a continuous duct.

Key Words: Prefabricated duct line, construction description.

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Suloway, Marshall, "Utility Problems in the Designing and Construction of Urban Highways," 50th Annual meeting, p. 11-24.

The Board of Underground Work of Public Utilities of Chicago (organized in 1910) involves twelve private and public agencies in the coordination of work pre-planning. The system is described, with emphasis on the planning of the Transit projects, noting that required utility relocations will likely require to be done by the prime contractor under the supervision of the various utilities engineers. The effectiveness of the Board rests on a sense of common cause.

Discussion of the paper includes the jurisdictional problems with unions, and the advantages of the coordinated record-keeping.

Key Words: Utility location coordination, records, jurisdictional problems, pre-planning.

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"Summary Report on the Use of Underground Space to Achieve National Goals," (New York: American Society of Civil Engineers, 1973), p. 16.

Noting that many billions of dollars could be saved annually by installing life-support services underground, a policy pronouncement by government is urged so that sufficient (private) funds will be devoted to the Research and Development programs needed to make underground construction competitive. Required R&D includes: equipment improvement, better ground treatment and excavation disposal, standardization of tunnel sizes, better work safety, better space management arrangements.

Key Words: Underground construction, equipment improvement, ground treatment, excavation disposal, work safety, space management, standardization tunnel sizes.

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Systems Approach to Flexible Pavement Design and Management, Research Results Digest No. 62 (Washington DC: Transportation Research Board, July 1974).

Twelve classes of input variables for a computer program are described, for staged overlay pavement design.

Key Words: Computer program, input variables, overlay pavement design.

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Templeman, G. E., "The Municipal Underground Conduit System of Montreal," The Engineering Journal, V. VIII, No. 9 (Montreal: Sep. 1925), p. 367-376.

Noting that some thirty companies had the right to install lines, civic authorities obtained legislation in 1899 permitting them to compel undergrounding. Telephone had previously gone underground, but all others are included in a planned joint system. Each must advise of its quantity requirement for reservation of duct space. Typical cross sections are illustrated; construction is described, operation features are mentioned. Cooperation between the Commission and various utilities is called excellent.

Key Words: Montreal conduit system, duct space coordination, construction, operation, design.

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"Tunnelers Hole Through East River Utility Bore," Engineering News-Record (Nov. 28, 1963), p. 21.

Reference is made to construction progress on a 12 ft. by 12 ft. tunnel of 1,823 ft. length-initially to carry fuel-oil and steam lines and water high-voltage transmission lines.

Key Words: East River utility bore, construction progress.

Turley, T. G., "Cabling Problems in Subways and Tunnels," The Institution of Post Office Electrical Engineers, No. 187 (June 1945).

History and Post Office usage of underground in London, cabling operations, and tunnel maintenance are discussed at length. Noting that some municipally owned tunnels now exist, that rent to various users, and that extensive rebuilding of towns affords an opportunity to consider tunnel alternatives to congested underground multiple installations, the author favors rectangular concrete tunnels to house gas, water and various cables. Coordinated planning would still enable "piecemeal" construction.

Key Words: Tunnels, subways, cabling problems, tunnel maintenance, cabling operations, space rental, coordinated planning.

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"UHV Joint Research Program Moves Into Second Stage After Encouraging Results," Electrical World (Jan. 1, 1971). p. 41.

Joint research by ASEA and AEPS on 765 kv lines and transformers.

Key Words: Transmission lines, transformers.

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"Underground Conduit and Manhole Construction," The Electrical News, Vol. 35, No. 15, Toronto (Aug. 1926), p. 29-33.

This news report presents the recent tendency (1926) toward the increase in duct deparation as they enter the manhole in order to provide better training of the cables in the manholes. Higher voltages and concentrations of larger amounts of power in a single cable is widely applied. Manhole constructions concerning the position of duct entrances on the sides of manholes are discussed. And, according to the discussion, round covers for the manhole design are favored by this report.

Key Words: Duct, conduit, manhole, power cable, duct.

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"Urban and Public Utility Tunnels Constructed at a Shallow Depth," Construction and Design of Tunnels, Section 4, Chapter 6, p. 811-828.

This article is a section of a chapter in the book of "Construction and Design of Tunnels." In this section, the author presents the constructing methods of public utility tunnels especially the constructions under heavy traffic and dense pedestrian area in big cities. Samples of construction in cities of Vienna and Budapest are discussed in this section.

Key Words: Utility tunnel, urban, conduit, subway, shielf tunnelling, open trench, closed monolithic reinforced-concrete frame, jamming effect.

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"URD Components Maintain High Reliability," Electrical World (Jan. 5), p. 42.

Good performance is reported on such underground residential distribution equipment as plug-in elbows.

Key Words: Underground residential distribution, equipment reliability.

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"Utilities Put R/W in Land Bank," Electrical World (Jan. 1, 1971).

Two Connecticut power companies will purchase approximately 40 miles of abandoned railroad rights-of-way, turn them over to the state, for a "transportation" corridor to include transmission line installations.

Key Words: Transportation corridor, transmission line installations.

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"Utility Trench at Sea-Toe Airport," Western Construction (July 1969), p. 60, 62.

Describes construction progress on a 14 ft. by 13 ft. utility trench 1500 ft. long to serve the air terminal.

Key Words: Utility trench.

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"Utility Tunnel Conference," Pipeline (Autumn 1971).

Allocation of space vertically is discussed from the safety viewpoint during repairs. Systematic placement of utilities within tunnels is advocated.

Key Words: Utility space allocation, safety during repairs, systematic utility location.

"Utility Tunnel Status Described," American Public Works Association, Reporter,

A report made to AWWA by John B.W. Corey based upon APWA study of feasibility of utility tunnels notes: utility tunnels are not new, most needed in congested parts of the United States, a proposed system is under consideration for White Plains, New York.

Key Words: Utility tunnel, feasibility, White Plains, New York system.

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Warren, Bacil B., "Arizona Subway," Power (Mar. 1938), p. 70-72.

Replacement of old "helter-skelter" mains with 5773 feet of tunnel for steam, water, electricity, telephone and gas, has given a savings of 50% in cost from corrosion and heat loss. Serving a much expanded campus has been simple by including lateral tunnels in the new buildings contracts.

Key Words: Utility tunnel, cost savings, lateral tunnels.

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1972 Western Regional Conference, APWA, San Diego, May 7-10, 1972, "Economic and Fianancial Considerations for Utility Tunnels," by M.A. Nishkian, 5p.

Three classes of benefits are suggested; (1) quantifiable for monetary evaluation, (2) quantifiable but insufficient data to assign monetary value, (3) identifiable but non-quantifiable. Advantages outweigh disadvantages in particular urban (high density) districts.

Key Words: Utility tunnels, financial considerations, economic considerations, benefits, utility tunnel advantages.

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1972 Western Regional Conference, APWA, San Diego, May 7-10 1972, "Technological and Legislative Needs," by R.L. Johnson, 14 p.

Motivation for early tunnel installations (Paris, London, etc.) are examined, along with ten technological problems then being faced. It is noted that, whereas the same problems are still in existence, much technology has been advanced in the matter of equipment, materials, and applications to various types of utilities. Electric, gas oil, improvements are cited. Government interest, shortage of space, traffic interference, should involve legislative interest---starting with, development of a planning process and support from APWA.

Key Words: Utility tunnel, ownership, right of way considerations, planning, right of way regulation, legal considerations.

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1972 Western Regional Conference, APWA, San Diego, May 7-10, 1972, "Utility Tunnel Ownership and Right-of-Way Considerations,"by Leroy W. Miller, 20p.

While utilities are used to share space, joint tunnel ventures may be dubious because of requirements to relocate if the government so requires. Joint comprehensive planning, and government construction of tunnels with requirement on utilities to use them is not a new concept, but government financing may have legislative problems. The utility right to occupy streets and the government right to regulate it is discussed. Easement and private lease occupancy, establishment of fee or costs, relocation requirements, liability exposure, and the Doctrine of Sovereign Immunity, are dealt with. It is concluded that no legal problems should preclude usage of utility tunnels.

Key Words: Utility tunnel, ownership, right of way considerations, planning, right of way regulations, legal considerations.

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"When Gas Pipelines Blow Up," Business Week (Aug. 4, 1973), p. 50.

Noting the increase in fatal accidents from gas line explosions, the Transportation Department's Office of Pipeline Safety contends that its power is restricted to regulation of the utility operators whereas the problem is with contractor's excavation. Model legislation was objected to.

Key Words: Gas pipelines, explosions, model legislation.

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"Why Not Put Power Lines in Tunnels?" American Water Works Association News (June 14, 1971), 2p.

Electric and telephone lines may soon be included in utility tunnels. Previous economic analysis has not included monetary value for traffic delays/street damage, noise, and protection of the facilities.

Key Words: Utility tunnels, electric, telephone, economic analysis.

Zwerling, Stephen, "BART: Manhattan Rises on San Francisco Bay," Environment, Vol. 15, No. 10 (Dec. 1973), p. 14-19.

The contention is that the system was really intended to re-vitalize downtown San Francisco whereas the public was told it was to relieve traffic congestion. The lack of examining alternatives to rapid rail, and the ignoring of public views, are criticized.

Key Words: BART, public opinion, alternatives to rapid rail.

# APPENDIX B

## TRAFFIC DELAY DURING CONSTRUCTION

The characterization of area-wide traffic delay in a very densely traveled area such as the Chicago CBD requires a highly heuristic approach. The intersection spacing and traffic signal timing presents a traffic network that is interrelated both in upstream and downstream conditions. The signal timing scheme is a fixed time, double offset system designed to move traffic in platoons two blocks long. However, midway through the proposed construction period the city will install a computer controlled fully demand actuated signal system.

The traffic flow is operating at very high levels of service (D&D) throughout the period from 7 a.m. to 7 p.m. Parking and standing vehicles are encountered in every block with random pedestrian interference throughout the area. The impact area is taken as that area bounded by Franklin Street and Michigan Avenue on the west and east and Randolph and Van Buren Streets on the north and south. This impact zone contains 84 street links and over 45 signal controlled intersections.

Two basic construction schemes have been considered the first is characterized as:

SCHEME I

timber decking of Monroe Street - 2ft above grade

reduction of traveled way to two 9-1/2 foot lanes

uni-directional optimization of traffic signals

manual control at all Monroe Street intersection.

This construction phasing would last for two years at which time Monroe Street would be restored to these lanes. The second scheme would be:

SCHEME II

Reduction of traveled way on Monroe Street to two 9-1/2 foot lanes for 60 days - to permit construction of side-walls.

Complete closure of Monroe Street - one block at a time - for permanent decking operation. Twenty days per block closure for decking.

Timber decking of cross streets during decking operations.

Uni-directional optimization of traffic.

Manual control at all Monroe Street intersections.

In addition to the revised traffic operation on Monroe Street it is assumed that State Street will become a transit Mall prior to initiation of this project.

Using these basic assumptions it is possible to perform a numerical relaxation of displaced traffic volume and estimated travel speed during any particular construction phase. The traffic volume displaced is assumed to take the form of a negative exponential decay function with an average stabilization period of two weeks. The travel demand is a tri-maximum distribution with peaks at both rush periods as well as at mid-day. Presented in Table B-1 are the existing traffic volumes and speeds in the impact area. The source for the data was the City of Chicago 1974 Loop Traffic Study and various other city studies factored to 1975 levels. These conditions represent the typical weekday operation for the area. The impact of the first construction scheme is presented in Table B-2. There is an obvious increase in traffic volumes throughout the area and a net reduction in travel speeds. Table B-3 presents the impacts of the second construction alternative and depicts a similar condition although with higher localized congestion.

Summarizing the increase in traffic congestion the results are: Scheme I - Reduction to 2 lanes

3,560 $\frac{\text{Vehicle-hours}}{\text{day}}$ additional delay

1,425,000 vehicle hours delay throughout duration of project.

Scheme II - Permanent Decking Operation

5,495 $\frac{\text{Vehicle-hours}}{\text{day}}$ additional delay

692,000 Vehicle-hours delay throughout duration of project.

It can readily be seen that although the daily delay is substantially higher for the second scheme due to localized effects the traffic operation are returned to normal in a much shorter time frame resulting in approximately a 50 percent reduction on total delay.

In order to quantify this travel delay in terms of economic impact the values shown in Table B-4 were used to represent typical vehicle operating costs. The hourly value for a passenger automobile (occupancy 1.4 people) is $6.12, a single unit truck is $9.86 and a taxi $7.64. The resulting cost of the motoring public of either of the construction alternatives is:

Scheme I - $9,090,000

Scheme II - $4,415,000.

While these costs are not realizable in terms of reducing or increasing construction costs, they do represent a real economic burden to the metropolitan area.

TABLE B-1 - EXISTING TRAFFIC OPERATIONS IN IMPACT ZONE

| Street Link | | Current Traffic Volumes | | | | Travel Speeds | | | Average Link Transit Time |
|---|---|---|---|---|---|---|---|---|---|
| | | A.M. | Noon | P.M. | ADT | A.M. | Noon | P.M. | |
| | | | | | | (mph) | (mph) | (mph) | (min.) |
| Franklin Street | NB | 490 | 400 | 425 | 6,240 | 9.0 | 7.0 | 7.0 | 3.91 |
| " " | SB | 590 | 420 | 540 | 6,760 | 9.0 | 8.0 | 9.0 | 3.46 |
| Wells Street | NB | 370 | 300 | 330 | 4,800 | 9.0 | 8.0 | 10.0 | 3.33 |
| " " | SB | 450 | 320 | 410 | 5,200 | 9.0 | 8.0 | 10.0 | 3.33 |
| LaSalle Street | NB | 750 | 610 | 660 | 9,600 | 8.0 | 7.0 | 9.0 | 3.75 |
| " " | SB | 910 | 650 | 830 | 10,400 | 10.0 | 9.0 | 10.0 | 3.10 |
| Clark Street* | SB | 1,150 | 820 | 1,050 | 13,200 | 10.79 | 9.20 | 9.75 | 3.03 |
| Dearborn Street* | NB | 1,050 | 860 | 920 | 13,500 | 7.72 | 6.68 | 6.54 | 4.30 |
| State Street | NB | 595 | 490 | 520 | 7,640 | 8.0 | 7.0 | 8.0 | 3.91 |
| " " | SB | 730 | 520 | 665 | 8,360 | 10.0 | 9.0 | 10.0 | 3.10 |
| Wabash Avenue | NB | 670 | 550 | 590 | 8,640 | 8.0 | 7.0 | 7.0 | 3.91 |
| " " | SB | 815 | 580 | 750 | 9,360 | 10.0 | 8.0 | 10.0 | 3.22 |
| Michigan Avenue | NB | 1080 | 890 | 950 | 13,920 | 8.0 | 7.0 | 7.0 | 3.91 |
| " " | SB | 1,320 | 940 | 1,200 | 15,080 | 10.0 | 9.0 | 10.0 | 3.10 |
| VanBuren Street* | WB | 525 | 480 | 540 | 6,790 | 9.94 | 11.56 | 12.79 | 3.15 |
| Jackson Blvd.* | EB | 1,500 | 1,250 | 1,260 | 17,250 | 8.30 | 8.51 | 6.28 | 4.68 |
| Adams Street* | WB | 790 | 650 | 920 | 11,200 | 9.61 | 8.75 | 9.40 | 3.89 |
| Monroe Street* | EB | 950 | 750 | 770 | 11,000 | 9.79 | 5.66 | 4.66 | 4.51 |
| Madison Street* | WB | 890 | 890 | 760 | 12,400 | 10.03 | 7.16 | 9.86 | 3.98 |
| Washington Street* | EB | 790 | 890 | 960 | 13,550 | 9.20 | 5.99 | 6.38 | 5.00 |
| Randolph Street* | WB | 1,120 | 1,050 | 960 | 14,800 | 11.33 | 8.81 | 9.76 | 3.61 |

NB - Northbound SB - Southbound EB - Eastbound WB - Westbound

* Existing data supplied by City of Chicago - 1974 Loop Study.

TABLE B-2 - CONSTRUCTION SCHEME I - REDUCTION OF TRAVELED WAY TO TWO LANES

| Street Link | | ADT | Average Travel Speed | Average Link Transit Time |
|---|---|---|---|---|
| | | | (mph) | (min.) |
| Franklin Street | NB | 7,490 | 6.15 | 4.89 |
| " " | SB | 8,110 | 6.95 | 4.32 |
| Wells Street | NB | 5,520 | 7.65 | 3.92 |
| " " | SB | 5,980 | 7.65 | 3.92 |
| LaSalle Street | NB | 10,560 | 7.20 | 4.17 |
| " " | SB | 11,440 | 8.70 | 3.45 |
| Clark Street | SB | 14,520 | 8.90 | 3.36 |
| Dearborn Street | NB | 14,850 | 6.30 | 4.78 |
| State Street | NB | -- | -- | -- |
| " " | SB | -- | -- | -- |
| Wabash Avenue | NB | 9,930 | 6.50 | 4.60 |
| " " | SB | 10,760 | 7.90 | 3.78 |
| Michigan Avenue | NB | 16,710 | 6.15 | 4.89 |
| " " | SB | 18,100 | 7.75 | 3.88 |
| VanBuren Street | WB | 7,470 | 10.30 | 3.50 |
| Jackson Blvd. | EB | 20,700 | 6.15 | 5.84 |
| Adams Street | WB | 12,880 | 7.90 | 4.58 |
| Monroe Street | EB | 4,400 | 3.20 | 11.29 |
| Madison Street | WB | 14,260 | 7.70 | 4.69 |
| Washington Street | EB | 16,260 | 5.75 | 6.25 |
| Randolph Street | WB | 16,280 | 8.95 | 4.01 |

NB - Northbound
SB - Southbound
EB - Eastbound
WB - Westbound

TABLE B-3 - CONSTRUCTION SCHEME II - PERMANENT DECKING - BLOCK BY BLOCK

| Street Link | | ADT | Average Travel Speed (mph) | Average Link Transit Time (min.) |
|---|---|---|---|---|
| Franklin Street | NB | 8,110 | 5.37 | 4.59 |
| " " | SB | 8,790 | 6.07 | 4.94 |
| Wells Street | NB | 5,760 | 7.20 | 4.17 |
| " " | SB | 6,240 | 7.20 | 4.17 |
| LaSalle Street | NB | 11,040 | 6.80 | 4.41 |
| " " | SB | 11,960 | 8.22 | 3.65 |
| Clark Street | SB | 15,180 | 8.42 | 3.56 |
| Dearborn Street | NB | 15,530 | 5.93 | 5.06 |
| State Street | NB | -- | -- | -- |
| " " | SB | -- | -- | -- |
| Wabash Avenue | NB | 10,370 | 6.14 | 4.89 |
| " " | SB | 11,230 | 7.46 | 4.02 |
| Michigan Avenue | NB | 18,100 | 5.37 | 5.59 |
| " " | SB | 19,600 | 5.77 | 4.43 |
| VanBuren Street | WB | 7,810 | 9.72 | 3.70 |
| Jackson Blvd. | EB | 22,430 | 5.39 | 6.68 |
| Adams Street | WB | 13,440 | 7.40 | 4.86 |
| Monroe Street | EB | 0 | -- | -- |
| Madison Street | WB | 14,880 | 7.23 | 4.98 |
| Washington Street | EB | 17,620 | 5.04 | 7.14 |
| Randolph Street | WB | 17,020 | 8.48 | 4.25 |

NB - Northbound
SB - Southbound
EB - Eastbound
WB - Westbound

TABLE B-4 - VEHICLE OPERATING DELAY COSTS
(Dollars/Min.)

| | Private Passenger Automobile | Single-Unit Truck | Taxi |
|---|---|---|---|
| Fuel | 0.04 | 0.04 | 0.04 |
| Tire, Oil and Routine Maintenance | 0.001 | 0.0025 | 0.001 |
| Depreciation | 0.001 | 0.0018 | 0.0013 |
| Time Cost* | 0.06 | 0.12 | 0.085 |
| TOTAL | 0.102 | 0.1643 | 0.1273 |

*Driver/Passenger Waiting Time.

Source: HRB Research Record, Number 314, 1970 - A general - purpose model for motor vehicle operating costs.

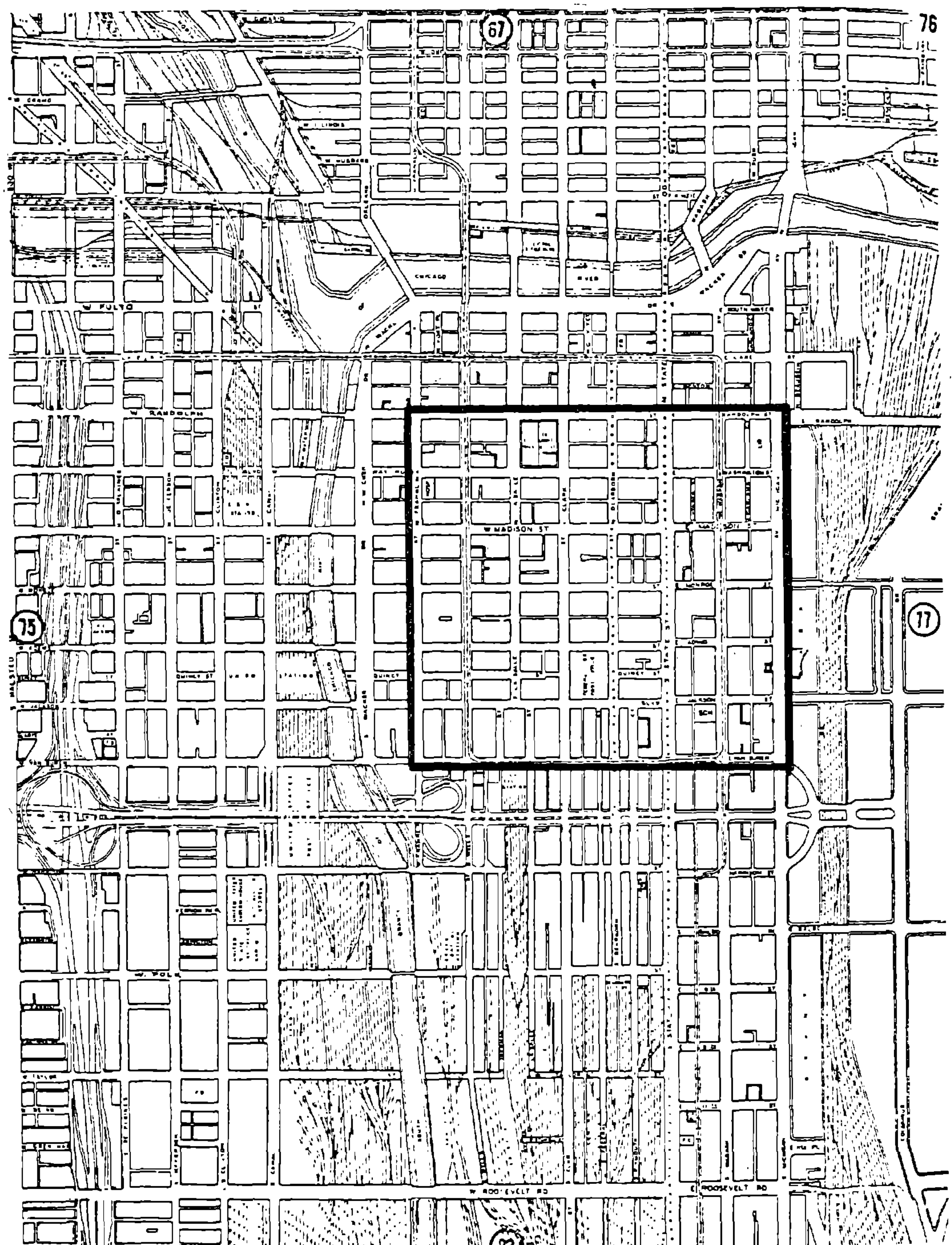


Figure B-1 Location of Impact Zone