Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
UMTA-MA-06-0100-80-2		

4. Title and Subtitle	5. Report Date / 6. Performing Organization Code
PROCEEDINGS - WORKSHOP ON TUNNEL LINING DESIGN MARCH 12 & 13, 1979	5. December 1979 6.
7. Author(s) *Gary S. Brierley, Editor	8. Performing Organization Report No. DOT-TSC UMTA-80-7
9. Performing Organization Name and Address *Under Contract to: Pacific Consultants 575 Boylston Street Boston MA 02116	10. Work Unit No. (TRAIS) UM-948/R9745 11. Contract or Grant No. DOT-TSC-1526
12. Sponsoring Agency Name and Address U.S. Department of Transportation Urban Mass Transportation Administration Office of Technology Development and Deployment Office of Rail and Construction Technology Washington DC 20590	13. Type of Report and Period Covered Workshop Proceedings March 12, 13, 1979 14. Sponsoring Agency Code UMTA (UTD-30)

15. Supplementary Notes

Contract Administered by: U.S. Department of Transportation
Research and Special Programs Administration
Transportation Systems Center
Cambridge MA 02142

16. Abstract

The Workshop on "Tunnel Lining Design" was held at the U.S. Department of Transportation's Transportation Systems Center (TSC) in Cambridge, MA on March 12 and 13, 1979. It was funded by the Urban Mass Transportation Administration's Office of Rail and Construction Technology through a TSC contract. The workshop attempts to provide a forum for the identification and discussion of problems in the design and construction of tunnels centering around six topics:

1) Lining Design
2) Qualifications
3) Geotechnical Investigations
4) Observational Approach
5) Specifications
6) Constructibility and Cost Considerations

A position paper on each topic area is arranged together with appropriate discussions from the working group members. A wealth of recommendations for use in future tunnel work is contained in the proceedings.

17. Key Words	18. Distribution Statement
Tunneling, Underground Construction, Lining Design, Constructibility, Cost Considerations, Geotechnical Investigations, Qualifications	Document is Available to the Public through the National Technical Information Service, Springfield VA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	268	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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
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oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
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		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
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yd^3	cubic yards	0.76	cubic meters	m^3
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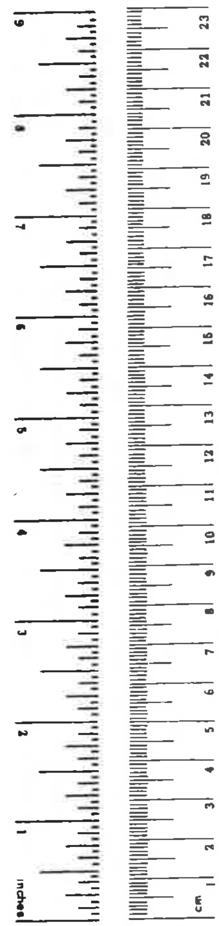

Approximate Conversions from Metric Measures

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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		
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km^2	square kilometers	0.4	square miles	mi^2
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g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
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l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
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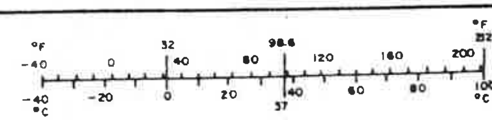

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CHAPTER 1

INTRODUCTION

INTRODUCTION

1.01 GENERAL BACKGROUND

The Underground Technology Research Council (formerly the Underground Construction Research Council) was established in 1969 as a committee of the Construction Division of the American Society of Civil Engineers. In 1970, the committee was expanded to a full council with the joint sponsorship of ASCE and AIME.

The objective of the council is to stimulate research in underground construction and mining. This objective is accomplished primarily by technical committees comprised of knowledgeable and experienced people in a given area. The committees are chaired by full members of UTRC with the balance of membership open to anyone willing and able to contribute.

The Technical Committee on Lining Design was formed in February, 1977 when the Chairman of UTRC, Mr. P.E. Sperry, contacted the editor of these proceedings and asked him to organize a committee to investigate procedures for tunnel lining design. This committee consisted of the following individuals.

Chairman: Dr. Gary Brierley
Haley & Aldrich, Inc.

Advisors: Dr. Ralph Peck
Consultant
Mr. A. A. Mathews
Consultant

Members: Mr. Vinton Garbesi
S & M Constructors, Inc.

Mr. Drupad Desai
Daniel, Mann, Johnson & Mendenhall/Kaiser Engineers

Dr. Stan Paul
University of Illinois

Mr. Thomas Kuesel
Parsons, Brinckerhoff, Quade & Douglas, Inc.

Mr. Terence McCusker
Consultant

Mr. Robert O'Neil
DeLeuw Cather & Company

Mr. Gail Knight
S.A. Healy Co.

The committee met in New York City on 30 June 1977 to establish guidelines for their work and to discuss the topic of tunnel lining design. At that time, the committee was joined by the following individuals who contributed to the discussion:

Mr. George Ziegler and
Mr. Richard Mitchell
New York City Transit Authority

Mr. Victor Feigelman
City of New York Board of Water Supply

Mr. Edward Plotkin
MacLean Grove & Company

Following the 30 June meeting a position paper prepared by Dr. Brierley was critically reviewed by all members of the committee, and published in the July, 1978 edition of CIVIL ENGINEERING Magazine. A copy of that position paper is contained herein in Appendix A of Chapter 1.

On 7 April 1978, the committee met again in Cambridge, Massachusetts to formulate plans for a workshop. The workshop was organized to cover important points raised in the original position paper. At that time a total of seven topics as listed below were selected for discussion by separate subcommittees.

Lining Design
Qualifications
Geotechnical Investigations
Observational Approach
Specifications
Constructibility and Cost Considerations
Risk Distribution

Shortly after the April meeting, it was decided to discontinue the subcommittee on Risk Distribution because a symposium on that topic was being planned in Scottsdale, Arizona in January, 1979.

After selection of the topics, a subcommittee chairman was selected for each topic. The subcommittee chairmen were responsible for preparing a position paper on their respective topic and for selecting the majority of the members of their subcommittee. The people selected for each subcommittee were from diverse backgrounds such as designers, contractors, owners, funders, manufacturers, and academecians in order to provide many different points of view for each topic.

1.02 FORMAT

These proceedings are divided into eight chapters. Chapter 1 is the Introduction including a brief description of background and planning for the workshop, a description of the format of the proceedings, the acknowledgements, and the summary. Chapter 2 is the Keynote Address by A. A. Mathews. Chapters 3 through 8 contain information about the six topics discussed at the workshop. Each chapter from 3 through 8 contains the following items:

- Position paper by the subcommittee chairman.
- Appendix A including the names and addresses of subcommittee members and a photograph taken during the workshop.
- Other appendices, as necessary.
- A verbatim transcript of the discussion about the position papers that occurred during the final session of the workshop.
- Letters to the editor from workshop participants about selected topics.

It is emphasized that although position papers are primarily the work of subcommittee chairmen, each paper was thoroughly discussed and reviewed by the entire subcommittee prior to final printing. Hence, the papers represent a consensus of the subcommittee. Each subcommittee member was repeatedly invited to write letters to the editor expressing minority points of view or emphasizing points of importance. All letters received by the editor are included in the proceedings.

1.03 ACKNOWLEDGEMENTS

Many persons contributed to the successful completion of this workshop. First among these is P.E. (Joe) Sperry who conceived the original idea and assisted with every aspect of planning and implementation. The editor would like to personally thank Mr. Sperry for his continued interest and support.

Dr. Ralph Peck served as an advisor to the committee and was particularly helpful in the early stages of selecting objectives and planning a scope of work. A. A. Mathews also assisted with preliminary planning and continued to work closely with the committee during planning and implementation of the workshop itself.

All committee members mentioned in Section 1.01 and those who actually wrote position papers deserve special thanks for their work. Collectively, they accomplished most of the work associated with this endeavor.

The editor wishes to express his appreciation to Haley and Aldrich, Incorporated for their support during the initial formative stages of the committee. It would, of course, have been impossible to arrange for and hold the workshop without the encouragement and funding of the Urban Mass Transportation Administration of the U.S. Department of Transportation. Mr. Santo J. Gozzo of the Transportation Systems Center served as the federal coordinator and utilized the excellent supporting services of Mr. Roger Dewey and Ms. Ellen Witt of Pacific Consultants to assist in the planning and implementation of the workshop.

Other persons who contributed to success of the workshop include Messrs. Doug Johnson, Gene Waggoner, Harvey Parker, and Bob Conlon of UTRC and Ned Godfrey and Mike Bartos of the American Society of Civil Engineers. Mr. Bartos' editing of the original position paper that appeared in the July, 1978 issue of CIVIL ENGINEERING was particularly helpful.

Lastly, thanks are due to all the participants of the workshop who gave freely of their time and money to attend. Their input provides the breadth of knowledge and experience that makes these proceedings more than just personal opinions.

1.04 SUMMARY

A total of fifty people representing hundreds of years of tunneling experience and hundreds of miles of completed tunnels met in Cambridge, Massachusetts in March, 1979 to discuss tunnel lining design and construction. The discussion was centered around six important topics:

- Lining Design
- Qualifications
- Geotechnical Investigations
- Observational Approach
- Specifications
- Constructibility and Cost Considerations

It is somewhat gratuitous for the editor to attempt to briefly summarize the results of this workshop because the body of these proceedings could be considered a minimal introduction to tunnel design technology. The Keynote Address, the six position papers and the accompanying discussion and letters contain a wealth of useful information and should be read in their entirety by anyone interested in tunneling. Certain important problems with respect to tunneling continue to surface, however, with fervent requests that "something ought to be done" to solve those problems and it is these issues that will be summarized in this section.

Tom Kuesel begins his subcommittee's position paper on Lining Design with the following quotation:

> "The design of tunnel linings is a complex process involving consideration of functional criteria, construction processes, and variable ground conditions. The ranges of both ground conditions and types of linings are great and the process of design is not easily reduced to formulas or to singularly correct procedures."

He goes on to state that:

> "It is widely recognized that many tunnel linings have been overconservatively designed. This discussion

is not intended to provide a cook book for correct design. It is intended to provide insights into a complex subject in which practical experience offers a surer guide than abstract theory."

It is difficult to improve on these statements. Tunnel lining design is a function of several factors such as ground conditions and the degree of lining/ground interaction that simply cannot be known with certainty during design. In addition, as pointed out in the paper, lining behavior depends as much on the timed sequence of installation as it does on the assumed loads or the lining material properties, and it is for all practical purposes not possible for a designer to incorporate time into his design calculations. Very often, the first indication of potential difficulty on a tunneling project is an undue reliance by the designer on his theoretical derivations and computer output. In many cases, a bonfire of numbers is intended primarily to provide a smoke screen for the designer's lack of knowledge and experience in TUNNELING.

Again and again in this workshop it was emphasized that those owners and funders who ultimately pay for and accept the results of design should satisfy themselves that the design is prepared by knowledgeable and experienced persons. While this is true for any civil engineering project, it is particularly true for tunneling. Two factors seem to cause difficulty for tunneling. Firstly, many people do not recognize tunnels as different from other types of projects, and, secondly, tunnels are frequently included as a part of a larger project such as a power plant or sewage treatment facility and the tunnel design is automatically assumed by the overall designer.

Tunneling is different. Tunnels are constructed entirely within the ground and the ground actually becomes part of the tunnel if the design is done in a proper manner. To know how the tunnel will behave, you must know something about how the ground will behave. This is not easy to know and the consequences of being wrong are compounded because the entire project is located within the medium being investigated.

For instance, if a designer is wrong about foundation conditions for a large building, the effect on foundation costs, although great, still represents only a small change relative to the total cost because the majority of the project is above-ground. Tunnel designers do not have this luxury.

In addition, tunnels must be constructed from inside a highly restricted space. Assume for a moment that the designer of the building mentioned above specified that the entire building be constructed from inside. There is no doubt that unanticipated construction problems would arise, that the cost would increase, and that change orders might have serious ramifications on seemingly unrelated time schedules.

Tunnels should be designed by persons familiar with tunneling. In particular, tunnel designers should have on-the-job, field experience with tunnels. On a large project that is only partly tunnels, the owner should satisfy himself that the overall designer is capable of, or willing to employ knowledgeable consultants who are capable of designing tunnels. The owner should go so far as to insist that he meet with and be able to personally interview those persons who will be responsible for the tunnel design. To do less is to risk the possibility of major cost increases for the tunnels either because of grossly "overconservative" designs, or because of "unanticipated" field conditions.

For a structure that is constructed within the ground, it is necessary to have a well-conceived, well-planned and well-conducted subsurface investigation. In his subcommittee's position paper on geotechnical investigations, Jim Gould states the following:

> "Above almost any other type of geotechnical investigation, there is a need for sound geologic input into one made for mined tunnels. Importance of the geologic setting requires extensive and thorough study of background information and local tunneling experiences. It is absolutely essential that a functional engineering interpretation be placed upon a framework of the local geology, otherwise points of engineering significance will be lost."

He goes on to suggest that disclaimers about the subsurface conditions be avoided, but that legitimate qualification statements about subsurface conditions be included. In essence, what is needed is a well-prepared interpretation of the available data indicating what is, in fact, known about the subsurface conditions and what needs to be inferred. A good geotechnical report will also provide insight into the degree of confidence possible for various inferences.

Current thinking on many projects is toward providing a so-called "Geotechnical Report." Ideas about the purpose and scope of a geotechnical report are expressed in Chapter 5.

Comments about the observational approach as it applies to tunneling generally fall into two categories: one category is that observations should be made during tunneling and the second category is that no one is sure what is the best method to accomplish those observations.

It is generally agreed that qualified and experienced personnel should be retained to monitor ground behavior, construction procedures and lining response during tunneling. The observations may or may not be supplemented by instrumentation and the overall scope and magnitude of the program should be tailored to the size of the project, the character of the ground and the consequences of tunnel collapse.

As indicated in the paper, a controversy exists about what is the best method of accomplishing observations during construction. Although the designer has the greatest desire for, and is in the best position to benefit from the observations, a question remains about liability with respect to injury or damage to men and equipment in the tunnel. It appears that additional study is needed to resolve this controversy and provide guidelines for establishing observational programs.

The final two chapters, Specifications, and Constructibility and Cost Considerations, address similar topics of concern in tunneling. Briefly, those concerns are:

Concrete Forming, Placement and Curing Procedures
Joints
Tolerances
Complicated Geometric Patterns
Uniformity of Approach

It should be recognized that concrete curing requirements are much less stringent in the naturally humid environment of a tunnel. It is suggested that performance-type specifications be used in order to give Contractors considerably more discretion for placing concrete. In addition, steel reinforcement should be used only when absolutely necessary and greater consideration should be given to the use of precast segments.

Construction joints in tunnels are generally not necessary and add greatly to cost. Concrete linings crack every 15-20 ft. because of concrete shrinkage whether or not there are construction joints at wider spacing.

Tolerances for horizontal and vertical tunnel alignment are given in Chapter 8. Designers insisting on more stringent tolerances may cause disproportionate increases in cost.

Complicated geometric configurations are very difficult to construct underground. All geometries should consist of simple circular curves or straight lines. In addition, geometric configurations and lining dimensions should be held constant unless it is absolutely necessary to change. It is almost always less expensive to provide slightly larger dimensions with simple and constant geometric patterns. In the long run, the extra volume is usually found useful for some application.

Uniformity of approach also applies on different parts of the same project and from one project to another. The more uniformity, the easier and less costly it is for the Contractor to do his work.

APPENDIX A

CONTROLLING TUNNEL-LINING COSTS -- TIPS FOR OWNERS AND DESIGNERS

This article discusses the special characteristics of tunnel design and suggests how a tunnel design program can be implemented. It gives emphasis to those aspects of design that may lead to significant cost savings and to the avoidance of "unanticipated" extra cost during construction.

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Haley & Aldrich, Inc.
Rochester, New York
Chairman, Tech. Comm. on Lining Design
Underground Const. Research Council

When tunnel planners and designers lack sufficient experience or proper guidance, increased cost and construction difficulty can be "built into" a tunneling project from the earliest stages. Seemingly inconspicuous design details can have a serious adverse impact on project cost and progress. If costs are not brought under control, many worthwhile projects may not be constructed at all.

When a tunneling project is undertaken, the owner must realize that the project will be complex. For an owner to assume that any design team, no matter how competent and thorough, will be able to foresee every problem prior to construction is exceedingly unrealistic. It is reasonable to say that no tunneling project has been undertaken without some controversy, change, and/or requests for extra compensation.

It is the owner's responsibility to become aware of the types of problems peculiar to tunneling. The owner need not be able to solve these problems, but he should be aware of them so that he can work together with his designer toward a successful lining design.

Owner must select experienced designer.

Tunnel-lining design generally falls within the realm of structural engineering. Frequently the lining is designed by an engineer who has considerable experience in the design of above-ground structures, but no tunnel design experience. It is commonly assumed that this engineer will be capable of adapting standard design techniques to lining design. In some cases, the designer has never been in a tunnel during construction.

A tunnel-lining so designed can be grossly unsatisfactory. This is not because the lining will collapse, but because the design is overly conservative and because the tunnel is more difficult and more costly to construct than necessary.

It follows, then, that the owner's most crucial responsibility may be the selection of his design team. As a minimum, the owner should retain a qualified tunnel design engineer and a qualified geotechnical consultant; both with tunneling experience; on-the-job, get-your-hands-dirty experience. If a project is undertaken in an area where very little tunneling has been done, the owner should insist that local firms retain experienced outside consultants. If owners realized how much it costs to train inexperienced tunnel designers, and how much it costs, in addition, to pay for their oversights and shortcomings, owners would demand additional expert assistance from the earliest stages of planning.

Obtain adequate geotechnical investigation.

The importance of adequate geotechnical investigations cannot be overemphasized. To design a tunnel-lining with confidence requires some knowledge about how the ground will behave upon excavation of the opening. In general, a rather extensive field and laboratory testing program by persons familiar with tunneling work is required. To the extent possible, the best available geologic setting should be selected for the proposed tunnel with the intention of avoiding difficult construction problems.

Equally important is the way the information is presented. It is unrealistic to expect that prospective contractors will not make use of available subsurface information. There is simply no other logical way for them to prepare their cost estimates. Current thinking is that all factual information such as test boring logs and laboratory test results should be provided as part of the contract documents and that the engineer's interpretation of the design significance of the data should be made available for the contractor's evaluation. Nearly all decisions about tunnel design and construction are based on the available subsurface information.

Lining design problems.

At this time (1978), there is no universally accepted method of lining design. Considering the large number of variables involving tunnel use, size, loading conditions and methods of construction, it is probable that no single design method will be developed that designers would be willing to acknowledge as superior.

There are two primary causes of difficulty for lining design. The first is that standard design procedures for above-ground structures cannot be easily adapted to tunnel linings. The second is that the tunnel construction environment is much more restricted than that of above-ground work.

The first consideration when designing a lining is whether the final lining can be eliminated. Even with today's almost unlimited liability exposure, there may still be cases where a lining is unnecessary. Many tunnels without linings have been in existence for years and have provided useful service.

Lining behaves as an arch.

Most tunnel linings form curved surfaces, and as such are capable of transmitting applied load by "arch action" (see Fig. 1). The beneficial effect of arch action was recognized by the Chinese as long ago as 3000 BC. Arch design was a well-established practice in Roman times. Many Roman voussoir spans, some up to 110 ft. (33.5 m), are still in existence today.

By 1900, many stone and plain concrete arches had been built. One of the greatest stone arches was built at Plauen, Saxony in 1905 with a span of 292 ft. (89.9 m). Plain concrete arches have been built with spans as great as 187 ft. (57 m) at a time when concrete had an allowable compressive strength of 500 psi (3450 kPa).

Contemporary designers were well aware of the potential for cracking in an arch caused by tensile stress. Since reinforcing steel was not used to great extent to withstand tension, the designers went to great lengths to eliminate moments that resulted in net tensile stress. German engineers used lead plugs in the arch as hinges and completed concrete work only when the arch had been fully erected. Sometimes, load was intentionally added to the arch to induce higher compressive stress.

In many cases, stone or plain concrete arches were not properly designed and cracking ensued. Observation of these arches led to the following conclusions:

> "The rings (plain concrete) may crack entirely through and still be perfectly stable.
>
> "In case the equilibrium polygon passes without the ring at any point, theoretically a free arch ring would fail. In practice this condition often obtains in stone bridges, yet they do not collapse or show serious signs of failure.
>
> "Such a structure may be said to become more and more stable under an increasing uniform loading, until the safe crushing strength of the arch stone is reached." (1)
>
> "The writer knows of no case of failure of a right hingeless arch on good foundations. Apparently, they are, if the foundations hold, among the most reliable of all structures." (2)

Tunnel linings are not free-standing bridges, but the principle of arch action is similar. In many cases, the primary function of the lining is merely to provide continuity to the surrounding soil or rock mass, so that the ground can develop its full strength. Modern design that requires a 10 to 12 in. (25 to 30 cm) thick, high strength, doubly-reinforced concrete arch to span 15 ft. (4.5 m) underground compares unfavorably with design that yields a 24 to 36 in. (61 to 91 cm) thick arch of 500 psi (3450 kPa), plain concrete spanning 150 ft. (46 m) or more above ground. The differences cannot be entirely explained by the "large" loads expected underground, even in poor rock.

To quote Charles W. Comstock:[3]

> "Design consists in the choice of suitable materials and their proper arrangement to accomplish a given purpose. Stress calculation is a necessary step in this procedure, usually the simplest and often relatively unimportant. The other and more difficult problems rarely admit of unique solutions or mathematical determination. Much is left to the discretion and judgment of the engineer based on the experience of himself and others. If it were otherwise, engineers would be rated on the single standard of mathematical accomplishment, and any mathematician would be an engineer."

It may be that modern, complex methods of analysis such as finite element techniques have disguised the inherent stability of arched structures; the solution having become a big part of the problem.

Ground helps support lining.

Lining/ground interaction greatly reduces stresses and deflections for an arched structure. Consider a free-standing, semi-circular arch. After applying a uniform load of approximately 30 ft. (9 m) of rock, analyze the arch as a free-standing structure. Now assume the same arch is constructed within a rock mass of moderate stiffness, such as a highly fractured schist or gneiss and subjected to the same loading. The rock mass supports the arch, restraining it radially (preventing it from bulging excessively at the haunches) and preventing it from slipping along the rock face.

Table 1 shows a comparison between maximum moments, deflections and thrusts for the two cases. Although the thrusts are approximately the same, the reduction in maximum moments and deflections for the restrained case is substantial. The maximum thrust for the restrained case occurs near the crown rather than at the haunch. Higher compressive thrust near the crown is beneficial for a concrete structure since it reduces or eliminates tensile stress caused by higher positive moment in that area.

Lining/ground interaction aids greatly in maintaining favorable stress and deflection conditions for a tunnel lining. Lining/ground interaction also impedes ultimate failure of the lining. It is overly conservative to ignore arch action and lining/ground interaction during lining design.

Load distribution prevents failures.

Localized weakening of the lining does not necessarily mean that complete failure is imminent. Loading conditions can be redistributed within the ground and the lining to stronger portions of the system.

An article written by Hardy Cross for Engineering News-Record, Oct. 17 and 24, 1935 is particularly applicable to lining design. One quote:

> "It is immaterial in some cases to the structural designer that a computed stress exceeds a certain prescribed value if there is no conceivable way in which the failure of the material could actually occur. The interpretation of stress analysis

makes absolutely necessary a clear idea of the action of the structural part up to the stage at which rupture is conceivable."

Modern lining philosophy is to employ methods of "ground-control" construction that preserve the inherent strength of the ground to the greatest possible extent. In many cases, the primary function of the lining is merely to provide continuity to the surrounding ground so that the ground can develop its own full load-carrying capacity. If unstable conditions are encountered, it is best to install the final lining as close to the working face as possible to avoid the cost of two linings; each capable of supporting the ground individually.

If a temporary lining is necessary for a large portion of the tunnel, it could be designed by the tunnel designer and incorporated into the final lining. Or, the construction contract could provide for alternative minimum lining sections for permanent support, with initial support designed and furnished by the contractor.

It is often necessary to design linings for "serviceability" requirements such as minimal cracking, minimal water infiltration, installation or jacking stresses, or corrosion. Such criteria can be included in a rational design procedure.

It is the owner's responsibility to establish reasonable design parameters for the project. For example, requirement for no water infiltration into a subway tunnel should be imposed only with full realization of the cost.

Need standard lining design criteria.

Standardization of tunnel design encompasses two different aspects: 1) standard sizes or configuration that will help minimize equipment proliferation and 2) standard design criteria.

How many tunnelers have seen a project with numerous drop shafts, each with a different diameter? Choosing one or two standard diameters could save money.

Many designers think only in terms of required inside dimensions. In tunneling, it is equally important to think about outside dimensions. Each change in the outside dimensions may require expensive remaining or detail work. If possible, inside dimensions should be varied or the lining thickness changed to provide uniform outside surfaces or outside dimensions which conform to existing tunneling machinery. It may also be possible to give the contractor the option (with engineer approval) to change outside dimensions to conform to his equipment.

The tunneling industry needs standard design criteria for different types of tunnels. These would not be detailed construction criteria, but rather general criteria such as for allowable water infiltration or leakage, ventilation, safety and size. Such criteria need not be fulfilled in every case, but the existence of general standards will allow an evaluation of local practice. The cost of excessively conservative or extravagant local standards may then be identified and steps taken to reduce the added cost imposed by those standards.

Write flexible specs and contracts.

An important cause of difficulty is that the tunnel construction environment is much more restricted than that of above-ground work. Specifications for tunnel geometry, steel reinforcement, concrete placement and form stripping must be carefully tailored to tunneling and not just copied from above-ground projects. Simple, straightforward design concepts and construction techniques are mandatory for underground work.

There is probably no area that aggravates tunneling contractors more than to be presented with an "above-ground" specification for a "below-ground" project. One of the greatest sources of difficulty is the specification for concrete placement. On one project it was specified that a reinforced concrete lining be placed in 12-ft. (3.7 m) lengths, with 40-hr. form stripping time, 5 days of continuous moist curing and construction joints between each panel!

Such specification requirements must be eliminated if costs are to be maintained within reasonable bounds. Concrete linings crack at regular intervals of approximately 20 ft. (6.1 m) because of concrete shrinkage. To insist that a vertical construction joint is somehow preferable to a vertical shrinkage crack or even to a sloping cold joint is unreasonable, especially when the construction joint is many times as expensive as the sloping cold joint.

Specifications for underground work must be flexible. They must take into account the restricted space available, the difficult construction environment, and the naturally humid tunnel atmosphere, which makes the requirements for concrete curing much less stringent than those for above-ground work. Final concrete strengths of 3000 or 3500 psi (20,700 or 24,150 kPa) are more than adequate for most applications. Continuous placement of concrete with rapid form-stripping at concrete strengths of 500 to 1500 psi (3450 to 10,350 kPa) is highly cost-effective.

Of particular importance is the method the owner uses to treat the problem of changed conditions. Since the owner has identified a need for the tunnel, and since he will presumably be the major beneficiary of its completion, it is his responsibility to establish a method for negotiating changed or unanticipated conditions that occur during construction.

The owner cannot delegate this responsibility. If he attempts to force the contractor to assume the risk for all changes and unanticipated conditions, the contractor will provide ample contingency in his bid and still seek compensation in the courts if a case can be made. If the contractor wins, the owner very often pays twice for the changed condition.

If on the other hand the owner attempts to force his design team to accept the risk of changed conditions, it is reasonable to assume that they will imagine the worst conceivable conditions throughout the project. In effect, the owner will trade the possibility of unanticipated extra cost for the certainty of planned extra cost. In the final analysis, it is beneficial for the owner to make allowance for change and to assure the contractor that his requests for extra compensation will be fairly evaluated (such as by arbitration) and, if valid, honored.

References

(1) Howe, Malverd A. (1911), A Treatise on Arches, 2nd Edition, John Wiley & Sons, New York, p. 49-54.

(2) Cross, Hardy (1925), Discussion of a Paper by Charles S. Whitney, "Design of Symmetrical Concrete Arches." ASCE TRANSACTIONS, Vol. 88 Paper No. 1568, p. 1076.

(3) Comstock, Charles W. (1925), Discussion of Whitney Paper, p. 1061.

TABLE 1

EFFECT OF GROUND/LINING INTERACTION ON LINING[1]

	Maximum Thrust (KIPS)	Maximum Moment (In.-KIPS)	Maximum Deflection (In.)
Free-standing lining	785	17,850	7.21
Lining with ground/ lining interaction	740	190	0.16

1. Semicircular arch, 35-ft. radius, subject to uniform load of 30 ft. of rock.

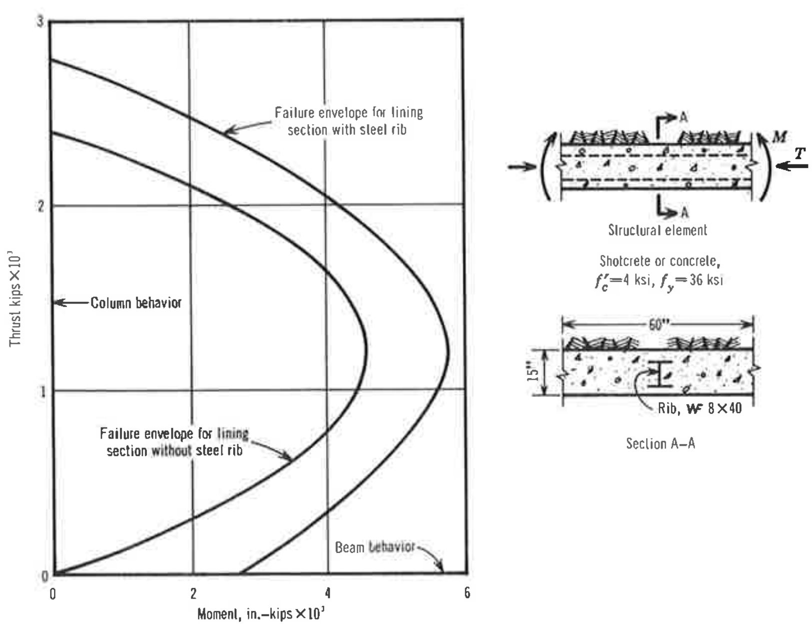

Fig. 1. Arch action. Structural element shown could be used to analyze tunnel-lining behavior. Curves are plots of moment-thrust (M-T) combinations that could cause failure of element. Element can withstand any M-T combination left of appropriate curve. Curves show element subjected to both M and T has broader range of stability than same element subjected to only M or only T. Examples: Element with steel reinforcement could withstand M of about 2700 in.-kips if used as simple beam (i.e., if T=0). Same element subjected to T of 1200 kips could simultaneously withstand M of about 5800 in.-kips; element's moment capacity would double. Without reinforcement or T, element could withstand no M (assuming concrete and shotcrete can withstand no tension). Element could withstand about 4500 in.-kips of M if simultaneously subjected to 1200 kips of T.

When arch action is considered during analysis of lining behavior, it becomes apparent that even unreinforced arch linings can support substantial load (in this case any M-T combination in shaded area) without failure. To ignore arch action in lining design is overly conservative.

CHAPTER 2

KEYNOTE ADDRESS

WORKSHOP

on

TUNNEL LINING DESIGN AND

CONSTRUCTION

Cambridge, Massachusetts

March 12 & 13, 1979

KEYNOTE ADDRESS

by A. A. Mathews

INTRODUCTION

Judging from the title, one might expect this workshop to be rather simple and straightforward. But when you study the agenda and the lists of committee members, you immediately realize that this is not the case. The design and construction of a tunnel lining must involve a lot more than building a simple tube of concrete or steel. And of course, if that were not true, Tom Kuesel would not have published his fable in a recent issue of Civil Engineering.

It is interesting to reflect on the immediate background for this workshop. The last two or three decades have witnessed tremendous advances in the design and construction of underground facilities. But there is one project which stands out as a sort of full-scale laboratory experiment to generate an abundance of technical, legal, and economic data affecting the state of the art. That is the Washington Metro project, with its varied rock and soil conditions, and its activity already covering a span of more than ten years.

The design and construction of the Dupont Circle Station provided a wealth of information concerning the behavior of a large underground structure and its environs. The work of the University of Illinois in instrumenting this and other Metro Projects produced valuable criteria for the design of underground structures in this and many additional settings. In fact, the impetus behind this Workshop, Gary Brierley, used the Dupont Circle Station as the subject for his thesis leading to an advanced degree at the University. And he really produced a classic.

Later, when other underground stations along Connecticut Avenue were in the design stage, the extreme variation in structural design concepts impelled the appointment of a special committee to investigate. That committee was headed by Dr. Peck. And its final report showed that, indeed, there was a lot to be learned from the Dupont Circle experience and from Brierley's thesis.

Introduction (continued)

After the publication of Dr. Peck's committee report, Gary organized, under the Construction Division of ASCE, a Technical Committee on Lining Design. Its central theme was to be, "almost all tunnel linings are grossly over-designed." However, as this committee plunged into its task, it became more and more apparent that the problem extended far deeper than a simple case of over-conservatism.

The subject was complicated by the role of temporary or primary support during construction, by the influence of ground behaviour during and after construction as distinct from static physical factors, by the effect of the builder's methods and workmanship upon the performance of the structure, by the contractual provisions under which the builder worked, and by the economic, esthetic, and operating needs of the owner. It would be impossible for that one committee to do justice to all of these aspects. And that brings us to this workshop.

The subject of Tunnel Lining Design and Construction has been divided into six aspects, each to be addressed by a separate subcommittee. The members of each subcommittee provide input from various disciplines, such as: scientific, technical, practical, economic or operational, and legal. I will now briefly describe these aspects and how I think they should influence the output of this workshop.

LINING DESIGN

The average structural engineer finds it difficult to depart from his standard practice of applying live and dead loads to a structure and then computing its behavior. Sooner or later, however, he begins to accept the concept of soil-structure interaction.

The development of computer programs to mathematically analyze this intricate problem should be a real boon to the tunnel designer. But in some cases, it becomes a bugaboo. Given all of the required physical data about the structure and the surrounding ground, the computer cranks out the thrust, moment, and deflection for any point in the structure. It is easy to accept this as the Word of God, and to design or proportion the structure accordingly.

To do so is to ignore one important question. That is, "What would happen if the structure fails?" An analogy is to imagine a simple beam. With an increasing concentrated load at the center of the span, the beam will eventually collapse. Next, imagine a heavy spring underneath the center of the beam. Now, with the same deflection which marked the original collapse, what will happen? The beam will deflect a little more. The spring will carry more of the load. And although the fibers in the beam may be strained beyond their elastic limit, total collapse will not occur.

Tom Kuesel, the Chairman of the Lining Design Committee appreciates this. He knows that a tunnel ring should not be designed like either a beam or an eccentricly loaded column. He also understands the influence of construction loads and tunneling methods upon the behavior of tunnel linings and supports. His Committee will make a valuable contribution to this workshop.

QUALIFICATIONS

When I read an abstract of Boyd Paulson's position paper, I thought that only God would be qualified to design or build a tunnel. I don't really believe that, and when I read his complete paper, I realized that Boyd doesn't either. He was merely listing all of the desirable attributes of a tunnel builder.

I'm not sure just what aspects of this subject Boyd's Committee will cover. His position paper seems to aim primarily at the qualifications of the various individual professionals associated with the design and construction of a tunnel. While I have no quarrel with that, I would like to see some attention given to the qualifications of the Contractor and of the Engineer's administration and inspection team.

The system of competitive bidding used for public works in this country makes it very difficult to reject, on technical grounds, the proposal of the low bidder. Therefore, it would appear that the only way to be sure that the bidders on a difficult project are technically qualified is to provide a pre-qualification process. Prospective bidders should be required to not only show a satisfactory experience record appropriate for the tunnel to be bid. They should identify the key individuals they propose to put on the job and give their experience records. For an important, difficult job, we must be sure that the Contractor commits his first team, not his second or third.

By the same token, the administration and inspection staff of the Engineer/Owner should be equally well qualified. Only then can we hope to avoid the predicament that Tom Kuesel describes in his fable.

Years ago, Rodney Mims, the project manager on the construction of Oroville Dam, was discussing inspection with California's Construction Chief. If he poured 10,000 buckets of concrete, all being within the 55° maximum temperature requirement, and then the inspector finds one bucket at 56°, should that bucket be wasted? Mr. Dewey replied with a question, "How do you instruct an inspector to ignore the specifications?"

You cannot simply hand the inexperienced inspector a handbook and expect enlightened technical supervision of the work. And you cannot completely ignore the specifications and expect quality construction.

Boyd's committee has a tough job and I'm looking for some interesting conclusions.

GEOTECHNICAL

When the work on the Washington Metro was started, the rock tunnels would have to be excavated by drill and blast methods. Tunnel Boring Machines had not been perfected to the point where they could cope with the rock under Connecticut Avenue.

This simplified the task of the geotechnical engineer. He would be concerned mainly with the question of how much of the tunneling would require temporary support. However, as the work progressed, tunnel boring machines were improved, and most of the tunnel under Connecticut Avenue was actually excavated by TBM.

Geotechnical (continued)

Meanwhile, it was realized that there was one deficiency in the operation of the changed conditions clause. This standard federal differing site conditions clause provides that if subsurface conditions differ from those indicated in the Contract, an appropriate adjustment in the Contract Price can be made. The $64 question is, "What conditions are indicated in the Contract?" With the subsurface exploratory data specifically excluded from the Contract, it was difficult to rationally assess a changed conditions claim.

Therefore, it was decided to include a geotechnical report as part of the Contract Documents for each tunneling contract. Now the geotechnical engineer was really put on the spot. He not only had to provide the designer with subsurface information appropriate for several different construction and support methods. He had to help the designer and specifications writer provide prospective bidders and the Contractor with the answer to that $64 question. He had to help describe the subsurface conditions which are indicated in the Contract.

Jim Gould is chairman of the Geotechnical Committee. He brings to it about 15 years of experience with geotechnical problems in the design and construction of the Washington Metro, as well as many years of experience in other areas. He has a fine committee and we can look for some real results.

OBSERVATIONAL APPROACH

This is a much misunderstood subject and I'm hoping that this committee will provide some clarification. I think the term originated with Rabcewicz, the father of the so-called "New Austrian Tunneling Method." He advocated the installation of initial tunnel support consisting of shotcrete supplemented with rock bolts or grouted dowels. The behavior of this system (principally deflections) would be closely monitored and, if necessary, the primary support would be strengthened. After stability had been achieved, a final lining would be installed, thus providing a positive factor of safety.

This method has met with considerable success in Europe, but has not been seriously tried in the U.S.A. In fact, there is some question as to whether it would be appropriate for the prevailing economic and contractual conditions in this country. Therefore, I dislike the term "Observational Approach" as connoting some special method for designing and constructing tunnels.

Rabcewicz himself stated that in tunnel construction, there is far too much calculation and far too little observation. I agree, but for this workshop I would like to use terms such as "Observing Results" or "Monitoring Behavior."

In the past, we have constructed tunnels and then observed whether they failed or not. And since most tunnels do not fail, we learned only that our designs were not inadequate.

Observational Approach (continued)

I am thoroughly in favor of monitoring the behavior of our tunnel linings. This can have two alternative objectives. During construction, it can identify areas which require additional attention and, outside of these, it can assure us that no problems are likely. Alternatively, it can provide valuable data for the improved design and construction of future tunnels.

This is a very important committee and I hope it will be able to concentrate on some of the prime issues. For instance, the indiscriminate use of instrumentation is not only wasteful, but discredits the use of this technology. I recall one instance, involving the excavation of a large near surface cavity in very competent rock. The Engineer insisted upon an expenditure for tests to measure the in-situ horizontal pressures. I could conceive of no possible results which would impel any changes in the design or construction of the facility. Nor could I conceive of any possible results which might be useful on another project anywhere.

Another problem involves the utilization of the data provided by the instrumentation program. The pilot bore for the Eisenhower Memorial Tunnels, in Colorado was hailed as one of the most highly instrumented tunnel projects up to that time. Nevertheless, the profusion of valuable data collected was not successfully extrapolated into useful criteria for the design and construction of the first full-sized bore.

Another item which deserves attention is the incidence of external hydrostatic pressure on tunnel linings. Countless millions of dollars are expended on tunnel lining designs to resist external hydrostatic pressure or to provide hydrostatic pressure relief. But very little data has been collected concerning the actual pressure buildup on tunnel linings, whether or not they are provided with relief.

The tunneling industry is in dire need of a data bank to store the myriad items of information being generated by instrumentation programs and to make it available to potential users.

Jim Mahar, having worked on the instrumentation program for the Dupont Circle Station in Washington, is highly qualified to chair this committee. I hope it will respond to some of these questions.

SPECIFICATIONS

Paul Tilp has a real handicap with this committee. Being with the U.S. Bureau of Reclamation, he has not been exposed to some of the real contractual fiascos, such as; the Portage Mountain Underground Powerhouse in British Columbia, the First Bore of the Eisenhower Memorial Tunnel in Colorado, or Water Tunnel No.3 in New York City. True, the Bureau has had some contractual problems, such as The Tecolote Tunnel in California and Azotea Tunnel in Colorado-New Mexico. But all-in-all, its Contract Documents are quite well standardized, are time-tested, and are generally accepted by the industry.

Nearly all of the Bureau's tunnels being for water conveyance in rural settings, it has not had to contend with many of the problems confronting our subway builders. Its design configurations are straightforward and it has not

Specifications (continued)

been concerned with trade-offs between esthetics and economy, functionalism and popular demand, or optimum technical siting and customer convenience. Nevertheless, the Bureau has been sensitive to the possibilities for technical innovation and better contracting practices.

The Specifications, or rather, the complete Contract Documents, constitute the medium which brings together all of the other aspects of tunnel design and construction. It culminates in the fruition of the project. To successfully complete a project on time and within budget, a good set of Contract Documents are indispensable. Paul Tilp understands this and all of us on his committee will strive to do justice to our assignment.

CONSTRUCTIBILITY AND COST

Certainly nobody should know more about these items than the Contractors themselves. And Gary has taken a double-barreled shot at this subject by appointing co-chairmen. Both Gail Knight and Vint Garbesi have strong backgrounds in the difficult problem of getting the job built at a reasonable cost.

During the past year or so, I have been intrigued by the vast amount of flak that was created by a letter in the ASCE News deploring the value engineering concept. The author took the position that the very acceptance of this concept was a discredit to the design profession.

I was sorely tempted to respond, but procrastinated. However, there was plenty of response. I just can't understand why anybody could believe that a designer might be so perfect that his design couldn't be improved. That author obviously had had little contact with the contracting profession.

There is no question that our Contractors are the most ingenious people in the world. The real problem is how to convert this talent into better and more economical projects.

There are many designs coming out of our designer's drafting rooms that cannot be built. A good example is the first bore of the Eisenhower Tunnel. The designer classified the ground into 5 categories and prepared a different cross section for each one. Technically, he was absolutely correct. But as a practical matter, there is no way you could change the tunnel cross section whenever the geology changes - especially when you are driving a top heading with the bench to be excavated later.

In Europe, it is common practice to permit bidders responding to the basic specification to offer alternative designs or alternative specifications. In this manner, the Contractor's ability to improve constructability and thus reduce costs is utilized. There is no better way to encourage innovation than to make the Contractor a party to the design and construction details.

This country needs contracting practices which will implement these objectives. I hope this committee will address that subject.

CONCLUSIONS

So, there you have it. From the hundreds of miles of tunnels which have been built just during the careers of the people in this room, there are enough lessons and enough data of all kinds, to answer most of the problems confronting these committees today. The real problem is how to put it all together and to use, all within the accepted manner of contracting in this country.

I hope each Committee will keep that in mind. After you have developed your positions, please devote a little time to making specific recommendations for their implementation.

Thank you.

CHAPTER 3

LINING DESIGN

Note: This position paper was drafted by T.R. Kuesel, and in its final form incorporates comments made at the Workshop session by the members of the Lining Design Committee:

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UNDERGROUND TECHNOLOGY RESEARCH COUNCIL

TUNNEL LINING DESIGN AND CONSTRUCTION WORKSHOP
Cambridge, Massachusetts
March 12-13, 1979

POSITION PAPER

LINING DESIGN

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A. Introduction

The design of tunnel linings is a complex process involving consideration of functional criteria, construction processes and variable ground conditions. The ranges of both ground conditions and types of linings are great, and the process of design is not easily reduced to formulas or to singularly "correct" procedures.

In the following discussion, certain general principles governing the behavior of tunnel linings are set forth. The criteria for selection of a lining system are then discussed, followed by appraisal of various lining types. With this background, structural design concepts and certain non-structural aspects are discussed. The presentation concludes with remarks on the relation between design, analysis and observation.

It is widely recognized that many tunnel linings have been overconservatively designed. This discussion is not intended to provide a cook book for "correct" design. It is intended to provide insights into a complex subject in which practical experience offers a surer guide than abstract theory.

B. <u>Principles</u>

1. In a majority of cases, the material and dimensions of a tunnel lining are determined by functional and construction considerations. The influence of permanent ground loads on lining performance is usually of secondary importance. Linings that have been selected on the basis of other criteria may be <u>analyzed</u> for their behavior under certain assumed ground loads; they are rarely <u>designed</u> for such loads.

2. The most important loads on a lining are construction loads. Proper consideration of these loads requires a realistic appraisal of ground and lining behavior during construction. Variations in construction techniques and equipment may have profound effects on lining behavior.

3. Unsatisfactory tunnel lining performance is usually related to water leakage, rarely to structural failure. Design for watertightness is more important (and generally more difficult) than design for load capacity.

4. The processes of construction greatly disturb pre-existing ground and ground water conditions before the lining is installed. After installation, linings are frequently subjected to large, unpredictable loads by grouting or other sealing systems. Only then does the lining start to interact with the (distorted) ground. Theoretical soil-structure analyses that ignore these processes do not model actual lining behavior.

5. Lining deformation generally mobilizes passive support. Stresses calculated under assumptions of unrestrained elastic ring bending are not proper criteria for design. In most cases, reducing lining thickness (or increasing its flexibility - e.g., by introducing joints) will reduce calculated stresses; increasing thickness produces higher calculated stresses.

6. In most cases controlled deformation of the lining ring is not only acceptable but desirable, in that it transfers load (and more particularly inequality of load) to the surrounding ground.

7. One of the most important variables in tunnel lining behavior is time. Variation in the time that elapses between excavation and installation of initial support frequently has a great influence on the loading and deformation of the lining. For multi-stage linings, the character of loading on primary construction support elements and on permanent lining elements may be quite different.

8. Quality of construction, which is directly related to simplification of details, has a much greater effect on lining performance than sophistication of analysis.

Two exceptional cases require special treatment:

a. When the surrounding ground is exceptionally soft, the deformations of a flexible lining may become so large as to be unacceptable from the viewpoint of water leakage, and secondary strains in the structure and the ground may become significant.

b. When the overburden is exceptionally deep and mobile (squeezing or swelling ground), ground loads may become of controlling importance.

C. Selection of Lining System

The first criterion for selection of a tunnel lining system is its functional use. Water tunnels generally require a smooth lining for hydraulic flow characteristics. Pumping and suction pressures, and infiltration or exfiltration limits, may govern the design. If the water is corrosive, special materials may be required. Highway tunnels require reflective finishes (for lighting considerations), which will resist cleaning with detergent solutions. Water leakage in highway tunnels is objectionable from operation and maintenance viewpoints, especially if the water can freeze. Rail and transit tunnels can accept rough finishes (even, with adequate inspection, unlined rock), and are somewhat more tolerant of minor leakage. Pedestrian tunnels, and public areas of rail and transit stations, require durable, maintainable finishes.

These functional requirements may be met with a double system - a rough structural lining with a furred-out architectural finish. But in many cases, a single lining that can be given an acceptable finish is preferable and economical. Prefabricated metallic or concrete segmental linings provide construction support, permanent structure, and interior finish for rail tunnels in a single stage. In Stockholm subway stations, shotcrete is painted with murals and declared beautiful. As an extreme example, in Atlanta's Peachtree Center Station, the lining has been totally abolished from a large portion of the walls, and the natural rock (excavated by specially controlled procedures) will serve as both structural and architectural finish material.

In considering functional use, maintainability and maintenance cost merit at least as much attention as initial construction cost. The cost of retrofitting an unsatisfactory installation to eliminate a maintenance problem is generally much greater than the extra cost of a design carefully thought out so as to minimize maintenance problems.

The second selection criterion is site conditions--principally ground and ground water. Rock may range from massive granite to ground up fault gouge; soil from cemented sands to Hudson River silt. Some rocks and soils are permanently self-supporting; many have an appreciable "stand-up" time; some are so unstable as to require pretreatment before any excavation is possible. The degree to which the ground requires early temporary support may be the controlling factor in lining selection.

The absence or presence of ground water, and the intensity of its pressure frequently determine the type of lining and its method of construction. By far, the most prevalent complaint about linings that are judged to be unsatisfactory in service is that they leak. Not all tunnels need necessarily be dusty dry. Nonetheless, those that are generally give their owners fewer headaches.

Exposure to earthquake motions places special constraints on tunnel linings. The requirement is ductility, which may be achieved through bolted segments, or in monolithic linings through appropriate jointing at changes in structural section or ground condition.

Lining types are intimately linked with construction methods, which are determined by ground and ground water conditions. Drill-and-blast rock excavation usually is associated with a temporary support system, followed by a permanent second stage lining. Tunnel boring machines lessen the requirement for temporary support; they may make single-stage segmental linings attractive. Soft ground shield-driven tunnels usually call for segmental linings if the ground is wet; if it is dry, ribbed systems may be suitable. The propulsive forces of shields and some TBMs exert major influences on lining designs. Compressed air tunnels imply segmental linings (wet concrete is awkward to handle through air locks, and an early air-tight lining is essential). Slurry-faced moles open new opportunities for alternative linings. Shotcrete has furnished temporary support in a wide range of ground and rock conditions; in some cases it has been found satisfactory as a permanent lining.

The tunnel designer must appraise functional requirements, ground and water conditions, and possible construction methods to make a selection of the most suitable type of lining. Not infrequently, more than one type will be suitable, and alternatives may be offered for selection by the construction contractor.

D. Appraisal of Lining Types

Experience indicates that certain types of linings are peculiarly suited (or unsuited) to certain requirements, conditions and methods. A brief catalogue of major types of linings provides a framework for comments about suitability.

1. Unlined Rock. Suitable only for rock of exceptional quality, this system has been used for many rail tunnels, some water conveyance tunnels, and a few highway tunnels. It has also been used for industrial storage, light manufacturing and office space in Kansas City, document and record storage in New York State, subway stations in Stockholm and Atlanta, and utility tunnels in Minneapolis. Long-term drying and slaking may be a problem; surface sealers may be helpful.

2. Rock Reinforcement Systems. The principle is to encourage the rock to support itself, rather than providing independent structural support. Rock bolts for temporary support may have mechanical anchors; for permanent service grouted bolts are preferred. Cement and resin grouts are used for anchorage and corrosion protection systems. In rock with tight joints, untensioned rock dowels may be suitable; where the rock joint structure is more open, tensioned bolts are preferred. Rock reinforcement has been applied to a wide range of rock conditions. The system lends itself to the observational approach, since the timing and extent of the installation may be varied depending on field observations.

As rock quality deteriorates, there is increasing requirement to supplement the rock reinforcement with a surface skin or lining. This may range from a moisture barrier sealer, through single and multiple layers of shotcrete, to a poured concrete shell. The primary purpose is to contain the loose surface rock layer and prevent spalling of the rock arch.

3. Shotcrete Systems. Shotcrete has been used for early construction support of rock of widely ranging quality, usually in conjunction with rock bolts. It is especially adaptable to drill-and-blast, multiple heading excavation. The maximum thickness of a single layer of shotcrete is controlled by practical application limitations. Thicker shotcrete linings are built up with multiple layers. Shotcrete for construction support is usually unreinforced; if it is to be counted on as a permanent lining a steel mesh is generally added to preclude crazing and fallout under long-term drying conditions. The mesh should be relatively coarse (say 6" x 6") -- close mesh or expanded metal inhibits good shotcrete placement. Composite materials, such as fiber reinforced shotcrete, are under experimental development.

Shotcrete is well adapted to use with roadheader type mechanical rock excavators, which permit ready access to the face but are limited to rocks of medium hardness. Full faced rotating tunnel boring machines are inhospitable to shotcrete, both because the machine occupies the full heading space and because shotcrete rebound clogs the machine. If the ground has sufficient stand-up time with the assistance of rock bolts, shotcrete can be added from the tail of a TBM.

A significant advantage of shotcrete linings is that they are relatively thin, and the reductions in volume of both excavation and lining materials can be important, particularly from the viewpoint of construction logistics.

4. Ribbed Systems. Though in ill repute in academic circles, the traditional steel rib construction support, with timber blocking, is still highly regarded by many practical tunnel constructors. It is adaptable to a wide range of conditions, and is technically superior in broken rock which will not develop reliable anchorage for bolts, and where large blocks bounded by open joints and shear zones are encountered. When provisions are made to adjust the size and spacing of ribs on the basis of field observations, the system can be effective and economical. Rigid designs based on conservative interpretation of geological studies can be wasteful.

Steel ribs can also be encased in shotcrete, but this is usually economical only where the ribs are an occasional supplement to a rock reinforcement system, in bad ground. If substantial thickness of encasement or filling of large voids behind ribs are required, pumped concrete is usually more economical than shotcrete.

Ribs composed of shotcrete encased reinforcing bars have been used in Europe, but are still experimental in the U.S.

5. <u>Segmental Linings</u>. Although usually associated with soft ground, segmental linings have occasionally been used in rock tunnels, especially in conjunction with TBMs, and principally to speed construction. Rough precast segments can furnish construction support to rock with a reasonable stand-up time. Precast segments with embedded steel ribs have been used as a pre-assembled ribs-and-lagging system on a drill-and-blast tunnel. Precast segments are being used as a finished interior lining for the Buckskin Water Tunnel, excavated by TBM. A system proposed for mechanizing hard rock tunneling would use invert segments throughout, but wall and arch segments only where poorer rock is encountered, with bolts and shotcrete used in good rock. (Similar systems with prefabricated invert segments have been used in European tunnels for some years).

Segmental linings have been traditionally associated with shield tunneling in soft ground. Originally developed in cast iron, they have been adapted to fabricated steel (pressed or welded), and to precast concrete. Where hydrostatic pressures are encountered, the segments are bolted together as a means of compressing joint seals. For heavy water pressures, metallic segments offer easier and more reliable sealing alternatives. Nonetheless, concrete segments have largely displaced the metallics outside of North America (for economic reasons), and many sealing systems are promoted.

In dry or impervious ground the purposes of bolting are reduced to maintaining ring circularity. If this can be satisfactorily accomplished by other means, unbolted segmental linings become feasible and economically attractive. Both cast iron and concrete block linings have been successfully used.

A principal control on the design of segmental linings is provision for the longitudinal forces required to propel the shield or TBM, which generally react against the previously placed linings. Cases have been recorded where the lining was jacked out of the tunnel without the shield being moved at all. Segmental linings are also severely loaded by the pressures of grout introduced between the lining and the surrounding ground to attempt to reduce collapse of soil into the annular void left by the shield tail skin plate.

6. Expanded Ring Systems. In dry or cohesive ground, an efficient system utilizes steel ribs erected within the shield tail, and expanded by jacking to the larger excavated tunnel diameter as the shield is moved forward. This system utilizes Couer d'Alene or "barrel stave" timber lagging and a poured-in-place permanent concrete lining. A significant stand-up time is an essential requirement for success of this system.

Expanded segmental ring linings can be used in similar circumstances, where the rings need not be bolted. This reduces, or eliminates the need for grouting.

From this welter of lining systems, construction methods, and site conditions, the designer must select his preferred choice (or alternatives). The number of possible combinations defy setting rules - each case should be considered on its own merits, with all the quirks and peculiarities of the particular site and project. In evaluating and selecting alternative choices, the designer may give special consideration to the following elements.

<u>For soft ground tunnels:</u>

a. The consequences of surface settlements.

b. The importance of water leakage.

c. The variability of the ground.

d. The expected quantity of water inflow during construction; and the designer's confidence in the estimate of this quantity.

e. The balancing of the advantages of providing several designs for varying conditions, against the advantage of a single standardized design.

f. Construction aspects, particularly access and handling of lining materials.

g. The consequences of lining failure.

h. Who will inspect and monitor the construction, and the designer's confidence in the quality of this work.

<u>For rock tunnels:</u>

a. Confidence in geology predictions.

b. The likelihood of side loading

c. The choice of machine or drill-and-blast excavation.

d. The degree of anticipated difficulty of construction; and the hazard of necessity of change in construction method.

e. The depth of cover.

f. The consequences of lining failure.

E. Structural Design of Selected Linings

Generally the gross dimensions of the lining will be determined by practical construction requirements. An analysis may be required to establish component sizes or spacings, but only in exceptional cases will the thickness of a tunnel lining be determined primarily by considerations of ground loadings. An important special case exists for water tunnels, where internal water pressure may exceed the ground water pressure, particularly near the portals.

In order to make a meaningful structural analysis of a tunnel lining, the processes and sequence of construction, both before and after the actual installation of the lining, need to be realistically considered.

For prefabricated lining elements, the first consideration is handling and transportation constraints and loadings. This determines maximum sizes, and frequently minimum thickness.

Usually the critical design condition will occur during construction. This is especially true for segmental linings, which are subject to shoving jack and grout pressures, both of which are likely to be of higher intensity and more unequal distribution than long term ground loads.

The basic concept of all tunnel linings is to form a closed ring, which may consist of natural or contrived ground arches, structural elements, or more generally an interaction between the two. (Note that rings need not necessarily be circular -- horseshoe rings, in which a rock invert provides the ring closure, are common and effective.) Rings are very strong when they are constrained against excessive distortion and subjected primarily to uniform radial loads. Rings are weak if unrestrained and subject to unequally distributed or point loads.

Properly designed and constructed tunnel linings derive great strength from deforming to mobilize passive pressures from the surrounding ground, thereby smoothing non-uniform loadings. The greatest structural danger to a lining is not high pressure, or even non-uniform loading, but absence of support. Cases of crushing of tunnel linings are so exceptional as to be newsworthy. Lining failures due to inadequate support are not uncommon. Fortunately, they almost always occur during construction, and are remedied by restoration of the support, so little permanent harm results.

Multi-stage linings, composed of layers or elements installed at different stages of construction, are loaded in a manner different from single-stage linings. Primary or construction linings are generally flexible, and distort to a stable configuration, conforming to ground movements and mobilizing passive pressures and natural ground arches. Rigid secondary or permanent linings are subject only to the incremental loadings and distortions that are introduced after they are placed. These may include hydrostatic pressure if dewatering or compressed air is used during construction, grouting pressures, effects of long-term ground movements, surcharges, creep and rib-shortening effects, and effects of subsequent excavations (parallel tunnels, future building construction). The sequence of the buildup of loading, and its distribution amongst lining stages, should be carefully considered.

An artificial problem is introduced into multi-stage lining design by the legal/contractual doctrine that primary construction support is provided by the contractor to his design, and permanent support is provided by the owner's secondary lining. Too often this results in double systems, each designed to carry the same loads separately. The theory that steel ribs disintegrate from corrosion and that therefore concrete linings must be designed for large bending moments has caused much mischief and needless expense, principally through the introduction of extrados reinforcing steel, which is difficult and costly to place, and unnecessarily increases the thickness of lining required for concrete placement. In fact, the bending moments are largely eliminated by the ground adjustments accompanying the rib distortion; so that all the permanent lining ever experiences is a portion (that part not carried by the remaining uncorroded ribs) of the largely uniform ground pressure. Where steel ribs are embedded in concrete, the embedded portion should be counted on as permanent material. Even for exposed steel, the extent and rate of corrosion are usually overestimated, because the presence of nearby cement provides a chemical inhibition to corrosion, and non-circulating ground water offers little or no oxygen to feed the corrosion process.

If one accepts the view that rib distortion and ground re-adjustment effectively eliminate bending from the second stage concrete lining, it can then be demonstrated that the minimum practical thickness inside the ribs that will provide clearance for concrete placement will almost invariably be sufficient to support the axial thrust of the full load, and the rib participation with the concrete need not be counted on. The principal problem with steel ribs is not their theoretical participation, but that they provide a preferred site for shrinkage cracking of the lining, with the potential for water leakage.

Except in the most unusual cases of very soft, swelling, or squeezing ground, all tunnel linings are relatively flexible compared to the stiffness of the surrounding ground. Provided that voids are properly filled and the lining is enabled to develop passive support, the lining will conform to the ground distortion without undergoing unrestrained ring bending. The calculation of bending stresses in tunnel linings is largely a waste of time, because the assumptions on which the calculations are based usually bear no relation to the actual conditions that exist in the tunnel.

All linings should have a minimal local bending strength to resist stochastic point loads across a span of several feet between the points of passive support - e.g., to carry the weight of a loosened rock block between the bolts, or to resist a bulb of high grout pressure. Primary linings (or segmental linings) should have sufficient ductility and flexibility to absorb imposed ground distortions without losing their capacity to carry axial load, and without developing objectional cracking. Ground distortions are generally within 1 or 2 percent of the ring radius, and this is usually within the elastic deformation capacity of the primary ring. In any case, calculated bending stress is not a proper criterion for design of primary linings. If the lining is "overstressed," it will yield until sufficient passive pressure is developed to relieve the inequality of loading and bending. The proper criterion is ductility - that the ring be able to absorb (elastically or plastically) the imposed ground distortion without fracture.

Unreinforced concrete linings have given completely satisfactory service in many rock tunnels, where they are subject to generally uniform loads. Where rigid linings may be subjected to distortion from subsequent ground movements or other non-uniform loadings, it is desirable to provide an arbitrary bending capacity equivalent to a small eccentricity of thrust. A semi-rational approach to this matter is contained in Appendix A.

The criteria for design of a tunnel lining for structural strength may therefore be reduced to a simple statement:

> "Tunnel linings should be designed to carry in axial compression the average effective overburden and ground water pressures that are imposed

after the lining is installed. Flexible linings need have no bending capacity except to distribute local inequalities of loading. Bending capacity equivalent to a thrust eccentricity of 1% to 4% of the ring radius may be appropriate for rigid linings, if conditions indicate a likelihood of unequal loadings developing after lining installation. Special attention should be given to loadings and distortions imposed on prefabricated elements during manufacture, transportation, and installation. The elements of multi-stage linings should be designed to share the imposed loadings in consideration of the sequence of construction and the manner in which the loads develop."

F. Non Structural Design Considerations

The most important element in many tunnels is control of water leakage. The first question is whether or not to attempt to limit leakage. Where inflows are slight and permanent lowering of the ground water table is not objectionable, the tunnel may be encouraged to leak and to act as a natural drain, with the leakage intercepted, panned, piped, and if necessary pumped (although natural gravity drainage is preferred if possible). Pumps need to be exercised, so a minor amount of pumping energy is acceptable, but long term pumping is seldom cost effective.

Caution is advisable in applying drainage to situations where significant hydrostatic pressures exist in the preconstruction environment. The quality of the ground water should be investigated. Calcification may clog the drains and result in build-up of unanticipated hydrostatic pressures. Poorly sealed exploratory bore holes, and development of new drainage paths outside the tunnel, may produce unexpected hydrostatic pressures. Some urban tunnels have been driven beneath disused chemical and petroleum storage facilities, from which acid or explosive drainage may percolate into a free-draining tunnel.

Where ground water levels are depressed owing to human activities, the persistence of these activities needs to be considered. Some New York subway tunnels were constructed many years ago with open inverts, and served for years with nominal water infiltration. Recently changes in land use and water management policy have caused ground water levels to rise, resulting in enormous increases in the volume of water flowing in the tunnels.

If the decision is to limit water infiltration (or exfiltration for a pressurized water tunnel), a criterion is needed for what constitutes an acceptably dry tunnel. This will vary according to functional use. It should be recognized that achieving a dusty tunnel invert is usually impractical as well as unnecessary, and pursuit of this asymptotic goal can become very expensive. Good practice usually limits the obligation of the tunnel construction contractor to reducing the amount of infiltration to not more than a certain number of gallons per minute per 100 feet of tunnel. If further sealing of specific leaks or seeps is deemed advisable, this is best accomplished by injection sealing under a separate specialty contract.

One item of construction detail that deserves design attention is joints. In above ground construction, joints are commonly provided to separate concrete pours into convenient size, to minimize complex formwork and to control shrinkage and temperature deformations. Experience has led to the stipulation of relatively close joint spacings, frequently 30 to 50 feet. It should be recognized that in a tunnel the conditions for concrete curing are much more favorable than above ground, both from the high relative humidity generally prevalent and because the surrounding ground readily absorbs excess heat from the relatively thin lining sections. In addition service temperature variations are usually less severe than above ground. Finally tunnel linings are locked into intimate contact with the surrounding ground, and are unable to deform independently of the ground, which is largely immobile. The reasons for adopting construction, contraction, and expansion joints above ground are largely inapplicable to tunnel conditions.

Actual long-term experience with tunnels indicates that monolithic linings generally give superior performance and joints are locations of long-term deterioration. As a general design rule, joints in tunnel linings are to be discouraged.

It is necessary to provide construction joints in tunnel linings, simply to avoid having to provide forms for the full tunnel length. However, lengths of 300 to 500 feet between joints are not uncommon, and generally satisfactory. Vertical formed joints are difficult to form and provide potential leakage planes. Sloping joints, in which the concrete is allowed to assume its natural slump angle in the forms, are preferred. The weight of the next pour effectively seals the joint, if laitance and debris are carefully removed. This may be done by water jetting while the concrete is still green, but may also be accomplished by trowelling the interior edge of the joint and starting the next pour with a cement-sand grout.

Consideration of construction and service conditions in tunnels also indicates less need for longitudinal reinforcing steel than in above ground construction. In some tunnels in good quality rock, all reinforcing steel has been eliminated from the lining, with fully satisfactory performance. More generally, some longitudinal steel is advisable for ribbed support systems, to distribute loads between ribs, but this can generally be accomplished with a single layer.

G. Relation Between Design, Analysis and Observation

Mathematical elaboration is not justified for the design of a specific lining for a specific tunnel project, owing to the inevitable variability of ground conditions and the uncertainty of the effects of the construction processes. An approximate design for a range of assumed conditions is the most that should be attempted.

To increase understanding of lining and tunnel behavior, more elaborate parametric studies may be useful. For such studies, mathematical models of tunnel lining/ground interaction systems are developed. The importance and difficulties of modeling construction systems and sequences, as well as heterogeneous ground conditions, should not be underestimated. Although elaborate 3-D finite element analyses may generate useful insights through parametric studies, all tunnel constructors recognize the overriding importance of the fourth dimension - time. Tunnel construction is a dynamic process, and the properties of the ground and of the tunnel structure change constantly during this process.

It is difficult and costly to develop and implement a 4-D digital mathematical simulation of the actual processes of tunnel construction. It is both practical and instructive to utilize prototype scale, real time 4-D analog computers - i.e., to instrument and monitor the field behavior of actual tunnels during construction and over long periods of operation. Valuable work in the area of rock tunnels has been reported by K.S. Lane (Ref. 1), and for soft ground tunnels by R.B. Peck (Refs. 2 and 3). This subject is covered more fully by the Committee on Observational Approach.

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APPENDIX A

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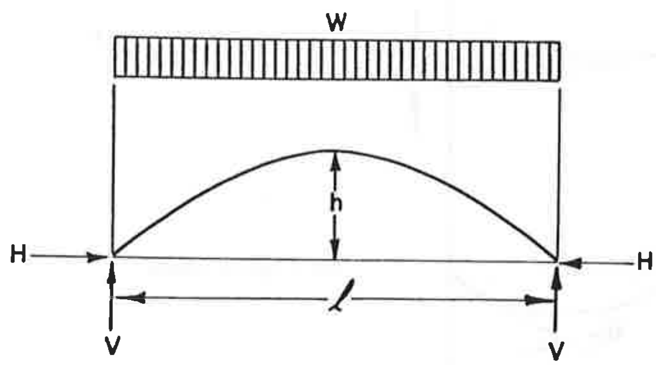
APPENDIX B

APPENDIX B

Thrust Eccentricity in Unequally Loaded Rigid Tunnel Lining Rings

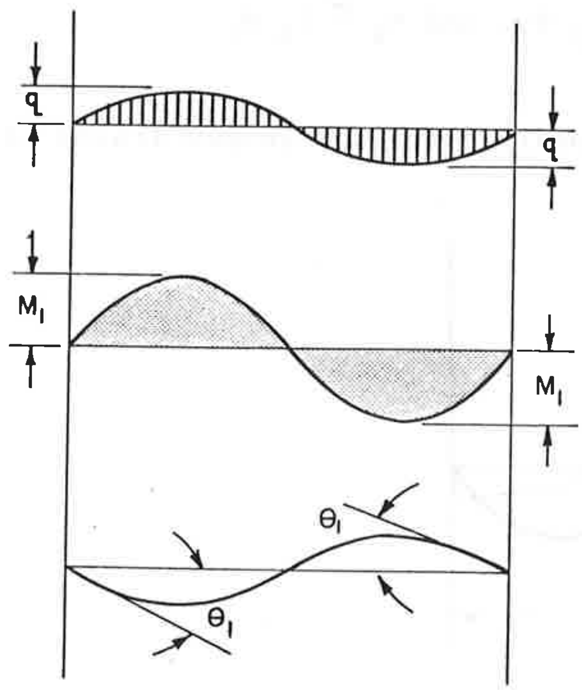
Consider a parabolic arch subjected to uniform vertical load of intensity w:



$$H = \frac{wl^2}{8h}$$

$$M = 0$$

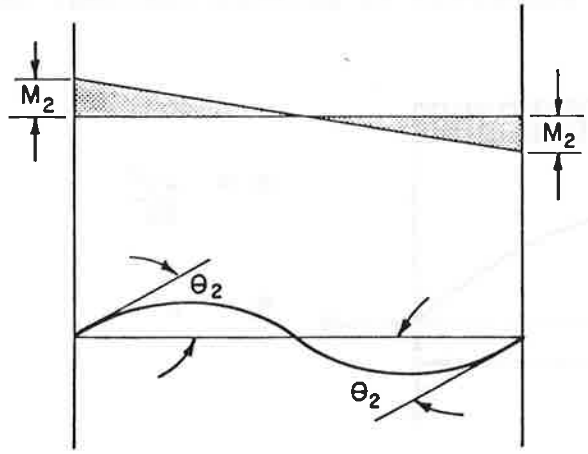
Add to this the effects of an antisymmetrically loaded beam, with a parabolic load distribution, of intensity q:



For hinged ends, $M_1 = \frac{5}{192} ql^2$

$$\Theta = \frac{M_1 l^2}{6EI}$$

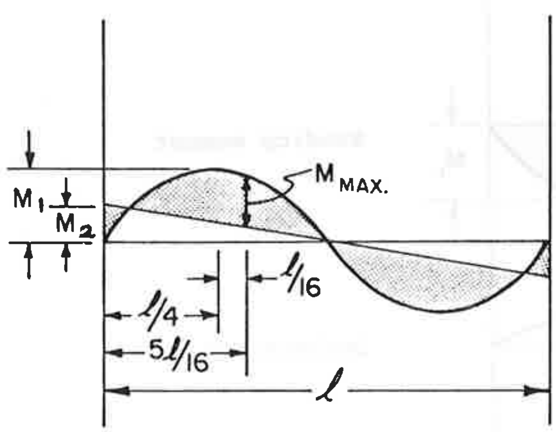
If the ends were fixed, end moments M_2 would be applied to produce $\theta_2 = - \theta_1$



$$\theta_2 = \frac{M_2 l^2}{6\ EI}$$

For a continuous lining, $\theta_2 \cong l_2\ \theta_1$, and $M_2 \cong l_2\ M_1$

The effect of antisymmetrical loading of a continuous lining is then:



$$M_{max} = (15/16\ M_1 - 3_8\ M_2) = 3/_4\ M_1$$

$$M_{max} = \frac{15}{768}\ ql^2$$

The maximum eccentricity (at about $5/_{16}$ of the span length) is then:

$$e = \frac{M_{max}}{H} = \frac{15}{96}\left(\frac{q}{w}\right)h$$

or approximately, $e = \frac{1}{6}\left(\frac{q}{w}\right)h$

For a semicircular arch, with $h = R$

$$\frac{e}{R} \cong \frac{1}{6}\left(\frac{q}{w}\right) \cong 16\%\left(\frac{q}{w}\right)$$

For a circular arch with a rise of one quarter of the span, $h \cong 0.4R$ and

$$\frac{e}{R} \cong \frac{1}{15}\left(\frac{q}{w}\right) \cong 6\%\left(\frac{q}{w}\right)$$

A measure of inequality of distributed loading on a lining ring is the ratio of maximum intensity to minimum intensity, or $\left(\frac{w + q}{w - q}\right)$

From this we may appraise likely thrust eccentricities for unequal loading:

Max/Min	q/w	Semicircular Arch $h=R=\ell/2$ e/R	Circular Segment Arch $h=0.4R=\ell/4$ e/R
1.0	0	0	0
1.2	0.091	1.5%	0.6%
1.4	0.167	2.7%	1.0%
1.5	0.200	3.2%	1.2%
1.6	0.231	3.7%	1.4%
1.8	0.285	4.6%	1.7%
2.0	0.333	5.3%	2.0%

The estimate of the Max/Min pressure ratio must be subjective, but it is believed that the above table covers the range of most practical cases.

An unreinforced rectangular section can accept an eccentricity equal to 1/6 of its thickness (thrust within the kern). For this condition the maximum compressive stress will be twice the average. This supports the practice that the average compressive stress in a tunnel lining should be about half the maximum allowable stress.

With nominal reinforcement, the eccentricity can reach t/5. For a semicircular arch with a Max/Min ratio of 1.5, e/R = 3.2% and the thickness of the lining should be 5 times the maximum eccentricity, or 16% of the radius, or 8% of the span. For a circular segment arch with a rise: span ratio of

1:4 and a Max/Min ratio of 1.5, e/R = 1.2%. The thickness should be 6% of the radius, which works out to 9.5% of the span. These examples may be compared with the old rule of thumb of one inch of lining thickness per foot of span.

The analysis presented here is not intended to be precise, but rather to indicate reasonable bounds for arbitrary thrust eccentricity in unequally loaded rigid linings.

DISCUSSION

MR. KUESEL: We had a very enjoyable afternoon yesterday. I don't think we talked very much about lining design, but Drew Desai, Vern Garrett, Terry McCusker, Jim Murphy, Stan Paul, Ed Smith, Harry Sutcliffe and myself discussed the draft paper and made a number of amendments. We then spent the rest of the afternoon talking about the real problems of lining design which have to do with this terrible virus that has infected the design profession called "defensive" engineering. You could write all the papers you like, but if you get an organization charged with preparing a set of contract documents who would embrace the standard of Chicken Little under the impetus of their E and O insurance, it wouldn't do you any good. However, on technical matters which we feel we can deal on a rational basis, there were a couple of additions.

I think first it would be useful for me to read off the introduction I proposed last night to set the stage.

The design of tunnel linings is a complex process involving consideration of functional criteria, construction processes and variable ground conditions. The ranges of both ground conditions and types of linings are great and the process of design is not easily reduced to formulas or to singularly correct procedures.

In this discussion, certain general principles governing the behavior of tunnel linings are set forth. The criteria for selection of a lining system are discussed followed by an appraisal of various lining types. With this background, structural design concepts and certain non-structural aspects are discussed. The presentation concludes with remarks on the relationship between design, analysis and observation.

It is widely recognized that many tunnel linings have been overconservatively designed. This discussion is not intended to provide a cook book for correct design. It is intended to provide insights into a complex subject in which practical experience offers a surer guide than abstract theory.

We added one important principle: one of the most important variables in tunnel lining behavior is time. Variation in the time that elapses between excavation and installation of initial support frequently has great influence on the loading and deformation of the lining. For multi-stage linings, the character of loading on primary construction support elements and on permanent lining elements may be quite different.

We added a note on the importance of considering the maintenance cost. It's much more costly to retrofit an unsatisfactory installation to reduce your maintenance cost than to take care of it in the initial design.

Courtesy of Harry Sutcliffe, we've added a checklist for evaluating and selecting alternative choices of lining, the items to which a designer will give special consideration. For soft ground tunnels:

a. the significance of surface settlements

b. the importance of water leakage

c. the variability of the ground

d. the expected quantity of water inflow during construction and the designer's confidence in the estimate of this quantity

e. balancing the advantages of providing several designs for varying conditions against the advantage of a single standardized design

f. construction aspects; particularly access and handling of lining materials

g. consequences of lining failure

h. who will inspect and monitor the construction and the designer's confidence in the quality of his work

They all influence the type of system you select. For rock tunnels:

a. confidence in geology prediction

b. the likelihood of side loading in addition to pure gravity

c. the choice of machine or drill-and-blast excavation

d. pecularly for rock tunnels, the degree of anticipated difficulty of construction, and the hazard of necessity of change in construction methods

e. is your system adaptable to making changes in midstream

f. the depth of cover

g. the consequences of lining failure

We added a section on non-structural design considerations. The most important having to do with control of water leakage. First, the decision is to whether or not you want to attempt to limit leakage, under what conditions it's suitable to utilize the tunnel as a drain, and under what conditions it's advisable to try to seal it off and such matters as clogging of drains and long-term changes in ground water conditions such as the flooded subways in New York.

If the decision is to limit water infiltration, you need a criterion for what constitutes an acceptably dry tunnel, and the acceptable nature of this will depend on the functional use of the tunnel.

In general, it's good practice to require the construction contractor to limit the amount of infiltration to a certain measurable number of gallons per minute per hundred feet of tunnel. This will not get everything completely dry, but gives a standard that is reasonably achievable under the conditions of general construction the contractor has to work with.

If there are specific troublesome leaks remaining after that, you'd do better to seal those under a separate speciality contract with a man whose business is injecting hypodermic needles into leaks.

We discussed joints from the standpoint of design criteria and particularly the standpoint of the difference in conditions in a tunnel from what is normally encountered above ground. With a humid environment and a great heat sink surrounding a relatively thin lining, procuring the conditions for concrete curing are generally excellent. The effects of shrinkage and temperature change are much less than above ground. So, the criteria on which your traditional spacing of joints for retaining walls simply don't hold underground.

We cited experience with tunnels that have been constructed with joints three hundred to five hundred feet apart to be perfectly satisfactory. Sloping joints are both easier to construct and are technologically superior because of the weight of the concrete and the second pour closes the joint if you clean it off properly. A vertical joint may look nice on the drawing, but its a great place for a leak because there is nothing to close it.

Brief mention of rebar. As Paul mentioned, many tunnels have been successfully in service with unreinforced concrete linings. The need for reinforcing steel should be appreciated independently and not just thrown in as a matter of habit.

I also reworked the appendix on thrust eccentricity for rigid linings which were subjected to non-uniform loading.

One thing I didn't get to yesterday was the section on relation between design, analysis and observation. I would like to cover that here. Mathematical elaboration is not justified for the design of a specific lining for a specific tunnel project, owing to the inevitable variability of ground conditions and the uncertainty of the effects of construction processes. An approximate design for a range of assumed conditions is the most that should be attempted.

To increase understanding of lining and tunnel behavior, more elaborate parametric studies may be useful. For such studies, mathematical models of tunnel lining/ground interaction systems are developed. The importance and difficulties of modeling construction systems and sequences, as well as inhomogeneous ground conditions, should not be underestimated. Although elaborate 3-D finite element analyses may generate useful insights through parametric studies, all tunnel constructors recognize the overriding importance of the fourth dimension -- time. Tunnel construction is a dynamic process, and the properties of the ground and the tunnel structure change constantly during this process.

It is difficult and costly to develop and implement a 4-D digital mathematical solution of the actual processes of tunnel construction. You do it by sequential steps. It is, however, both practical and instructive to utilize readily available prototype scale, real time 4-D analog computers, that is, to instrument and monitor the field behavior of actual tunnels during construction and over long periods of time.

Ken Lane composed a valuable compendium of rock tunnel tests for UTRC several years ago. I commend that reference. Ralph Peck also has several reports for soft ground tunnels.

Those examples of observations is not in the sense of immediate feedback to the particular project, but in the sense of what has been observed for the behavior of similar tunnels. It's extremely valuable.

That's the end of our report. Any questions?

MR. TRAYLOR: I'd like to address precast final liners, and I believe they are the coming thing and ten years from now or twenty years from now that's all we'll be using. The reason they're not used now is not because of technology but because of cost. There are two areas of most need of development -- refinement to make them more cost effective (that is their assembly process in the tunnel) and their construction process.

There are only two people who are subconsciously motivated to design a lining that is cost effective in those areas and they are contractor and manufacturer on a particular tunnel project. You must allow the contractor and the manufacturer to be involved in the final configuration of those linings.

MR. KUESEL: I would endorse that and comment that we need very badly to work together as a team: contractor, owners, engineers.

MR. TRAYLOR: You're not going to get the cooperation from the manufacturers and the contractors until they have a job to build.

MR. GOZZO: Correct. I just might point out on that contract that we have, the Bureau of Reclamation doing some testing at their Civil Engineering Research Center in Denver. We're very much concerned with the ability to put together sections in the field. One thing we seem to find while going through R and D type projects that we handled here in tunneling is that we seem to work these projects in a sterile laboratory atmosphere which does not duplicate the dirty field conditions under which the tunnel liners have to be assembled. Even at the test facility in Denver, some of the plants were testing the integrated sealant system for use with these tunnel sections -- tunnel liner sections were such that they were going to be tested again in sterile laboratory conditions. We made a point that we wanted to see the work done with dirt, gravel and so on and the sealant material to see how those things would hold up under those conditions. As a result of that, we've gone into a testing program in which we will assemble these things under dirty conditions and see if they'll still hold up.

Another item that the Bureau has discouraged is that as nice as some geometric configurations for joint geometry are, they don't quite work in the field. When we start to push the sections together, there are certain handling difficulties and assembly difficulties which have to be modified in the field. They have some data from Buckskin tunnel, a study which shows a certain modification of joint configuration will facilitate the assembly of joints. And discussions just a few minutes ago indicate that they are having some difficulty too with joints in the field.

Hopefully the studies we have underway will attack all these questions and enable us to obtain a really efficient tunnel liner section that can be handled readily and start to achieve some of the cost that seem to be in the future for us.

MR. MATHEWS: First of all I'd like to thank Mr. Traylor for making his remarks. I second him 100 percent. I'd like to mention this. There's been some comment about liability of an engineer. When an engineer designs a project and prepares contract drawings and specifications and solicits competitive bids, he is constructively warranting a particular design can be built. Now, it's never been done before. There have been cases that have come up in the past where he winds up paying for his indiscretion. In cases like that -- I agree with Mr. Traylor, there's only one way to really innovate in this industry and get something done in the field that's never been done before, and that's to get the contractor to do it. To get the contractor to participate in it and become partly responsible. If it's a contractor design -- if it's humanly possible to make it work, he'll make it work. If it's the engineer's design and that contractor is handed that design and asked to do it, he runs into trouble and says, well, it's your design not mine. I think that we've really got to give that some serious consideration. There's no reason why we can't modify our contracting practices to get that input from the contractor and make him a partner in the design process particularly when you're starting out on something new and once we all learn how to do it, then we can go back to the old system if we want to.

MR. KUESEL: I would like to comment on the Baltimore problem. I designed this concrete segment lining that Glen is trying to build, and there are three organizations between mine and his who effectively separate us so that we have no opportunity to talk about our common problems. I'm sure if we could have communicated eighteen months ago some of these things would have been anticipated and worked out. But, the organizational arrangements are such that no one is allowed to anticipate problems. You have to wait until they arise and then there are committees set up to investigate them. It's entirely the wrong system.

MR. DAVIS: I want to make one comment here. Al is absolutely right as far has his generalizations and the liabilities of the engineers. Take what he says to heart. I think that there are many systems -- one of the most flexible systems we have in the legal system is contracting, and even with a little innovation, I think those systems will stand up. For example, getting the contractor before you design, I think can be accomplished under our legal system without any variations. I think it's just the method you set up. I think if you go to the proper lawyers they'll show you how to do it, and it will stand up under the legal system with no problems whatsoever.

MR. KUESEL: I agree. It's administrative red tape work.

MR. DAVIS: I don't think even with the administrative red tape that you've got a big problem if you set it up right.

MR. LEWIS: Bill Lewis. I'd like to comment a little bit on what Glen said. We've built two concrete section tunnels, and I'm interested in the research that the Bureau is doing. The research has to be aimed at a non-idealized situation. The segments don't go in or remain in a pre-determined location. For several reasons the circumferential joints are offset from transverse tunnel linings, so we have to provide for, and we have to recognize that in a sense we've got a maze of concrete blocks where the dimensions are finite. We have to find some materials to put between the blocks that is going to bolt and distribute the thrust. We tried neoprene as a material to treat both ends and it did not prove out.

Also, I think the contractors have enough problems trying to make it work down there without someone coming every half hour and saying, "we notice you've got another crack, what are you going to do about it?"

I think research projects are beginning without any apparent input from projects in this country that have gone on and have experienced some successes and some problems. The research must somehow be tailored to the practicalities. That's just about it.

MR. ROSSUM: When you put things in perspective -- if you don't have a research and development project, if you have a competitive bid, shouldn't you put in documents that you only show one lining and specifically what you will permit, whether it's steel or chewing gum, and you do not accept anything other than that after the job, on a competitive bid.

MR. KUESEL: On a competitive bid, yes, but this is no way to develop or demonstrate experimental systems, which should not be done by competitive bids.

MR. ROSSUM: But if you have a competitive bid, if you would consider a concrete lining, it should go into the contract documents that you would consider a concrete lining.

MR. TRAYLOR: I don't think concrete linings are experimental. I just don't think they are cost effective yet. The only way to make them that way is to go through an evolutionary process. It doesn't come through change orders and value engineering. It comes through the input coming from where it needs to come from which is the contractor who has the job, and the builder who is going to make the segments.

MR. EINSTEIN: About this competitive bid, I've had an example in Montreal and now one in Munich where the contractor is simply given the alignment and some tolerence, and they do think the contractor, given a little incentive, and dismissing the legislative taboos, somehow or other, the job takes a different shape after the contractor, through some vehicle, changes the linings as established by the agency. But, I think the agencies and the engineers both have to recognize that we're going through an infancy here in this country. The research has to be aimed at a non-idealized situation. The segments don't go in or remain in a predetermined location. For several reasons the circumferential joints are offset from transverse tunnel linings, so we have to provide for, and we have to recognize that in a sense we've got a maze of concrete blocks where the dimensions are finite. We have to now find some materials to put between the blocks that is going to bolt and distribute the thrust from shield and then treat with the sealant. We try neoprene as a material to treat both ends; it doesn't prove out.

Also, I think, at least until we're into it far enough, that we don't have cracks, that part of getting the segment liners off the ground is recognize the cracks that are going to occur, and we need to take the remedial steps. The contractors have enough problems trying to still make it work down there without someone coming each and every half hour and saying, we notice you've got another crack, what are you going to do about it. You're faced with a maze of problems at the time.

In the example Montreal and the one in Munich, bids are let out and the contractor is simply given the alignment and some tolerances, and they do the deciding. Every new tunnel section in Munich comes up with a new innovation. It's a concept we don't know in this country, but there's a great potential going.

MR. BRIERLEY: I've heard this come up over and over, and Ted, if you have some way of getting the contractors to vow, prior to the submission of the documents, please, tell them about it. Generally what happens is the contractors say, look, you're asking me to help you out, but you can't pay me so forget it.

MR. DAVIS: You've got to set it up, but I think you can competitively bid it.

MR. BRIERLEY: Well, if we come up with some kind of a way to get some contractors involved on the design prior to the documents going on the street, and you do nothing else but accomplish that as a result of this conference, I'll be quite happy.

[Whereupon the conference concluded at 12:30 p.m.]

LETTERS

Bechtel Incorporated
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May 22, 1979

Dr. Gary Brierley
Haley & Aldrich, Inc.
50 Chestnut Plaza
Rochester, NY 14604

SUBJECT: Lining Design Position Paper, UTRC

Dear Gary:

Tom's paper is very well done. I have divided my few comments into technical and non-technical.

Technical Comments

Page 4, paragraph C., line 11. Suggest this line read,
"rough finishes (even, with adequate inspection, unlined rock), and are somewhat more tolerant of".
I believe the decision to go with unlined rock in a transit tunnel would depend a lot on the quality of the owner's inspection and maintenance facilities.

Page 6, line 11. Is the inclusion of TBMs appropriate here? There may be some shield type. TBMs which exert axial jacking forces. If so, fine. This occurs again at the top of page 11.

Page 8. At the end of Shotcrete Systems, it might be worth mentioning that logistics for both prefabricated linings and shotcrete become important because the volume of excavated material and the volume of lining material both are being moved around in the tunnel at the same time and this can be controlling.

Page 10, bottom of top paragraph. I think it is worth commenting here that there is considerable room for ingenuity in this area. The Heitersberg Tunnel in either Germany or Switzerland laid a prefabricated invert section immediately behind the cutter head of the machine and the rear wheels of the machine rode on the prefabricated invert. That was some years ago.

Page 12. Soft Ground Tunnels (a). Suggest substitution of the word consequences for significance. The last line in E., the last words on the page, suggest they read "be determined solely by". Some mention should be made of the special but important case where internal water pressure exceeds the ground water pressure, which often occurs near the portal of water tunnels. If it exists in either soft ground or rock tunnels, full, empty and transient loading conditions must be considered.

Page 14, bottom of second paragraph. Believe we should add something like "The sequence and distribution of the buildup of loading on the second lining should be carefully considered in the design".

Page 17, bottom of page. Suggest addition of: "Pumps need to be exercised, so a minor amount of pumping energy is acceptable, but long term pumping is seldom cost effective".

Page 18, at the end of the first paragraph. Suggest adding: "The effect of multiple, poorly sealed, exploratory bore holes should be considered, if appropriate, as well as the transfer of hydrostatic loads along the tunnel, due to development of new drainage paths along the outside of the tunnel".

Page 20, middle paragraph. I am not sure I agree with the first sentence of this paragraph. Quite often longitudinal steel, which is quite easy to place, can help to distribute loads from one set to another and serves a useful function if the concrete lining is merely acting as lagging between sets. I have not felt it to be money worth saving to cut down on it.

Non-Technical Comments

On the committee list, please change my company from Bechtel Corp. to Bechtel Incorporated.

Page 2, paragraph B., line 6, criteria (typo).

Page 9, third line from bottom. Suggest striking "domestically" and adding "in the U.S." after experimental.

Page 12, Soft Ground Tunnels, e. Suggest "The balancing of the advantages...".

Page 13, fourth paragraph down, second line. Substitute "consist" for "to be comprised".

Page 15, top line. Suggest "theory" instead of "theorem".

Page 18, bottom of second paragraph. Suggest "enormous" instead of "disasterous", if appropriate.

Page 21, line 6. Suggest heterogeneous.

Very truly yours,

Harry Sutcliffe
Manager
Boston Office

HS:lm

cc: Tom Kuesel
PBQ&D, New York

CONSULTING
ENGINEERS

INTERNATIONAL ENGINEERING COMPANY, INC.
A MORRISON-KNUDSEN COMPANY

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1 June 1979

Mr. Gary S. Brierly
c/o H & A of New York
50 Chestnut Plaza
Rochester, New York 14604

Dear Mr. Brierly:

By the time we received Tom Kuesel's report, Ed Smith was off on an extended trip, so he asked me to respond as best I could.

The report is an excellent review of tunnel liners and present practice for designing them. We have no major changes to suggest except for Appendix B. The appendix needs some explanation for those persons who are not well initiated into concrete design; perhaps a brief paragraph explaining the approach to the analysis is needed. It is not clear how each load distribution is added to the total picture and why it is added in the way it is.

Except for the above comments, the report is in excellent condition.

Sincerely,

John Cogan, Ph.D.
Principal Geotechnical Engineer

JC:hms

CHAPTER 4

QUALIFICATIONS

Position Paper on QUALIFICATIONS for Tunnel Lining Design

ASCE Underground Technology Research Council

Workshop on Tunnel Lining Design

Cambridge, Massachusetts, March 11-13, 1979

by Boyd C. Paulson, Jr.
Associate Professor
Department of Civil Engineering
Stanford University

Introduction

This paper summarizes the discussion of the "qualifications" committee during the March 1979 Workshop on Tunnel Lining Design. Committee members are listed in Appendix A. The discussion was largely based on a matrix questionnaire with a structured outline of qualifications for the various parties that impact the design of tunnel liners. The four main categories for which qualifications were indicated were owners, funding agencies, design consultants and contractors.

A draft of a second paper is included as an attachment, and provided narrative background for the committee. It was prepared by Nino Pedrelli* on the basis of research he conducted at the Massachusetts Institute of Technology under the direction of Professor Herbert Einstein. Pedrelli's research included a survey of attitudes and feelings of professionals working in this field, and it fit very well into the subject of this workshop. It comments upon such sensitive areas as the degree to which deliberate overdesign is used to counter the various risks and constraints imposed upon the designer, and the extent to which owners, funding agencies and contractors restrict the designer's ability to work towards the most cost effective solutions.

Problems related to the design of liners for tunnels, especially those on large projects in urban areas, have occurred as much or more as a result of institutional, organizational and contractual factors as they have from technical factors. Therefore, qualifications of professionals working in this area must recognize both of these categories.

Qualifications Matrix

In order to provide a more concise format for discussion during the short time available in the workshop, a matrix rather than a

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*Mr. Pedrelli is currently a graduate student and Research Assistant in the Civil Engineering Department's Graduate Program in Construction Engineering and Management at Stanford University.

narrative presentation was chosen for assessing the various qualifications of professionals working for owners, funding agencies, design organizations, and construction contractors. The questionnaire, which is summarized on the following pages, was reviewed by all committee members before coming to the workshop, was completely filled out by most, and formed the main basis for discussion.

The method of ranking used deserves some brief explanation before proceeding: In the spaces at the right-hand-side of the matrix, a dual ranking notation was used to indicate (a) the particular qualification's importance among all the items in the column pertaining to the type of professional (such as designers), and (b) in the horizontal row, degree of responsibility (ranked 1 to 4) of the various types of professionals. The notation is as follows:

a/b

Vertical column ranking of importance of factor to type of professional (→ a) — Degree of responsibility among the professionals (→ b)

The following abstract table illustrates the method:

Qualification Statement	Owner	Funder	Designer	Contractor
Qualification A	2/3	2/1	2/2	5/4
Qualification B	3/1	4/2	4/4	4/3
Qualification C	1/2	1/1	3/4	2/3
Qualification D	5/4	3/3	1/1	3/2
Qualification E	4/3	5/4	5/2	1/1

In row 3, column 4, for example, this is the second (2) most important qualification among the 5 qualifications for the contractor, but the contractor is only third (3) in order of responsibility for doing something about this qualification.

Within each major category, such as "Technical," additional blank lines were provided for listing important qualifications that were omitted. Two items suggested for the "Technical" matrix were (1) career vs. project orientation of the owner's staff, and (2) understanding local labor constraints (for example, how trade jurisdictions might influence economical design decisions). Three items suggested for "Administrative" matrix were (1) authority to manage (real authority, not just fancy titles), (2) understanding impact of the "trilogy" consisting of "community - politicians - media," and (3) knowledge of contractual risk sharing alternatives and consequences. To some extent item (3), the "trilogy," might be included in the third administrative category, and item (3), risk sharing, might be in the eighth category. All of these items were felt to be important, they provoked a good discussion, but time did not permit their inclusion into the formal ranking mechanism.

TABLE 1

Matrix of Technical Qualifications

Qualification Statement	Owner's Technical Staff	Funding Agency's Technical Staff	Consulting Design Firm's Technical Staff	Contractor's Technical Staff
-Educational background, preferably with an advanced degree, with a program of study that emphasizes both structural engineering and geotechnical engineering.	8M/2M	8S/4S	1S/1S	8S/3S
-Experience working under recognized experts in the field with an organization that is both experienced and reputable in tunnel design and/or construction.	9M/3S	9M/4S	2M/1S	5M/2S
-Registration as a Licensed Professional Engineer.	7W/2M	7S/4S	3M/1S	9S/3M
-Working experience either with a contractor or with an owner or A/E organization's resident engineering staff on at least one tunnel project of each type (hard rock or soft ground) which the professional's organization is expected to own, fund, design or construct.	1M/3S	4W/4S	4S/2S	1M/1S
-Knowledge of the other aspects of tunnel driving (excavation, hauling, etc.) with which the lining operation may have to interface.	6M/3S	3W/4S	9M/2S	2M/1S
-Knowledge of availability and capabilities of the various types of methods, equipment and materials, both U.S. and foreign, that are used in modern tunnel driving.	2M/3S	2M/4S	6S/2M	4M/1S
-Ability to estimate the direct and indirect costs of alternative lining designs under various tunnel construction conditions, as well as their impact on the costs of other tunneling operations.	5M/3S	5S/4S	7S/2S	3W/1S
-Knowledge of and access to publications and research activities in the field, working relationships with other professionals in the field, and the ability and willingness to recognize and seek help from such sources when circumstances of a current problem are beyond his knowledge and experience.	3W/2S	6W/4S	5M/1S	7S/3S

(cont'd)

The letter codes attached to the ranking numbers are interpreted as follows:

S = Strong correlation among participants' answers, small deviations from mean.
M = Moderately good correlation among the answers, but some significant disagreements from the mean.
W = Weak correlation, wide range of responses, the number is an average only, and is not necessarily typical of the majority opinions.

Matrix of Technical Qualifications (Cont'd)

Qualification Statement	Owner's Technical Staff	Funding Agency's Technical Staff	Consulting Design Firm's Technical Staff	Contractor's Technical Staff
-Willingness and ability to stay abreast of the latest advances in tunneling technology, and willingness to encourage their adoption where they have proven or potential advantages in safety, economy and performance over traditional systems.	4M/3W	1W/4W	8S/2W	6S/1W

TABLE 2

Matrix of Institutional, Organizational and Contractual Qualifications

Qualification Statement	Owner's Admin. Staff	Funding Agency's Admin. Staff	Consulting Design Firm's Admin. Staff	Contractor's Admin. Staff
-Educational background, preferably with an advanced degree, with a program study that emphasizes the management of capital projects.	9S/1M	9S/2M	9S/4W	9M/3W
-Working experience either with a contractor or with an owner on A/E organization's resident engineering staff or at least one prior tunneling of the type project which the professional's organization is expected to own, fund, design or construct.	8S/1M	8S/4M	3S/3W	1M/2W
-An understanding of the role of all parties involved in the tunnel design and construction process, including owners, contractors, manufacturers, suppliers, regulators, funding agencies and consulting A/E firms, and an appreciation for the capabilities, rights and limitations of each of these parties.	1M/1S	2M/3M	2W/4M	2M/2W
-An open attitude that will enable him to cooperate with the other parties to the planning, design and construction process, rather than isolating himself from or degenerating into an adversary relationship with them. This includes willingness to consider and accept input and constructive criticism of designs, methods or procedures as might occur in a value engineering program.	3M/1M	4M/4S	1M/2M	3W/3M
-Understanding of the objectives, legal requirements, and procedures of funding agencies, and how to comply with requirements and procedures in such a way that will minimize the impact on the project's cost, schedule and functional purpose.	4W/1S	5W/2M	7M/4S	5M/3M
-Understanding of the importance of adequate and timely funding and decision making, not only to the cash flow, but also the schedule, organizational momentum and morale of contractors, designers and others involved in a projects.	2W/1S	1M/2S	4W/3S	7M/4S

(cont'd)

Matrix of Institutional, Organizational and Contractual Qualifications (Cont'd)

Qualification Statement	Owner's Admin. Staff	Funding Agency's Admin. Staff	Consulting Design Firm's Admin. Staff	Contractor's Admin. Staff
-Understanding of the objectives, legal requirements, and procedures of external regulatory agencies, and how to comply with and/or enforce such regulations in a way that will minimize the impact on the project's cost, schedule and functional purpose.	5M/1S	3S/3M	5M/4M	4M/2M
-Knowledge and appreciation of the contractual and administrative recommendations contained in "Better Contracting for Underground Construction," by the U.S. National Committee on Tunnelling Technology, and willingness to include such principles in contract specifications and assist in their fair and equitable administration.	6M/1M	6S/4M	6M/2W	8M/3M
-Knowledge of and interest in the major institutional organizational and contractual problems facing the construction industry, and willingness to help mitigate these problems by his own attitudes and actions.	7M/1S	7M/2W	8M/4M	6M/3W

Comments on Technical Qualifications

The numbers and codes in Table 1 summarize the results of the questionnaire and discussion on technical qualifications. First of all, from the preponderance of 1's and 2's on the right-hand-side of the slashes in columns 3 and 4, it is clear that the key figures for the technical side of accomplishing a project are the design consultants and the contractors. The relative importance of the various qualifications for technical persons working within each of the four organizations differed considerably. For example, for designers heavy emphasis is shown on demonstrated or certified technical competence, such as educational achievements (1), experience working under recognized experts (2), and professional registration (3). In the other three organizational categories, these qualifications were generally ranked lowest relative to others, while items related to practical experience and working knowledge were rated higher. The last two qualifications dealt with knowledge of the state of the art, publications, and research, and here higher priority was assigned for owner and agency personnel than for designer and contractor personnel, recognizing, perhaps, that unless such methods are encouraged at the top, there is little designers or contractors can do to overcome the resistance that will be felt to implementing new ideas.

The committee discussion generally supported the questionnaire results, and also brought out the aforementioned additions of (1) career vs. project orientation, particularly of the owner's staff, and (2) understanding of the relationship of labor constraints to tunnel lining design. It was also interesting to note that in most categories the priorities of the Japanese participants, who in turn had referred copies of the questionnaire to 11 owner, designer and construction people in Japan, were generally in agreement with other members of the committee. A major difference is that in Japan the owner and funding agency are usually the same organization. A major point of disagreement in the discussion, even among contractor members present, was whether or not qualification criteria of this type ought to be used for formal prequalification of construction contractors or design consultants by the owner or funding agency. Finally, it was generally acknowledged that overdesign is more prevalent than it ought to be, but that this is more a consequence of institutional factors such as risk and liability than it is of inadequate technical qualifications among the parties involved in the design and construction process.

Comments on Administrative Qualifications

Although the results in Table 2 are not as clearly defined, there is a general shift of emphasis to the owner and to some extent to the funding agency personnel qualifications as being more important in administrative matters such as institutional, organizational and contractual problems and decisions. The implication here appears to be that if the owner and funding agency can create and maintain the proper administrative setting, the design consultants and contractors have the necessary technical and management skills to bring about the timely and economical completion of the project. It is worth pointing out, however, that since the committee member from the government funding agency was unable to attend the workshop, that viewpoint may be inadequately represented in these results.

In terms of relative priorities on the qualifications of adminstrative personnel, formal education was generally ranked low (some said because they took it as an assumed prerequisite, or a "given"), as did the last two items, which are related in the sense that they also imply at least self-educational and outside professional activities. The remaining items, most of which relate to experience or pragmatic knowledge of the workings of the various organizations and their procedures, had mixed results depending on which organization employs the individual being qualified, but generally they ranked high. Heavy emphasis is also placed on understanding and cooperation, and willingness to keep the project moving towards its defined objectives. These are largely people- and attitude-related criteria, and are difficult to put into specific terms.

Again the committee discussion primarily centered on the criteria that have been outlined, but three additions mentioned earlier deserve further discussion. First, one of the major handicaps on contemporary projects has been the lack of authority to manage. Even if a particular individual has all the necessary qualifications, including experience, education, credentials and attitudes, together with fancy titles and impressive looking "boxes" on the organization chart, the qualifications are of little value unless there is a commensurate amount of authority. This can be ascertained by asking, does the person have the authority to hire, fire, promote, initiate work, approve contracts and changes, stop work, terminate contracts, etc.? Or do all of these decisions disappear into a hollow bureaucracy structured to make sure that no one individual is responsible or accountable for anything?

The second item, the impact of the "trilogy" of community (presumably meaning intervenors and vested interests who try to disrupt the project), the news media, and the politicians, really is not a qualification as such, but persons working in project organizations, particularly the administrative side, must have an understanding of how these three entities interact and respond to each other, how they related to the project and vice versa, and how to manage a project in this urban "fish bowl" environment.

The third item, risk sharing, is one that is receiving a great deal of attention these days, and to some extent it was intended to be addressed in the last two administrative qualifications in Table 2. Given its importance, it is interesting to note that these two qualifications were somehow ranked lower than the others, so the fact that "risk sharing" was introduced as an "additional" item may indicate that the wording in these last two qualifications is poor.

Conclusion

The qualifications committee was chosen to represent a wide range of viewpoints from people who are respected for their experience in urban tunnel construction. Several of the members are prominent in the industry, and a few are notably outspoken.

It is therefore all the more significant that, for a group so diverse, there was an unexpectedly high degree of agreement about the important problems in urban tunnel construction, with emphasis on tunnel linings, and about the qualifications needed for technical and administrative people in this field. This paper, particularly Tables 1 and 2, the comments, and the attached paper by Pedrelli, is therefore worth the reader's attention, not because of the author's writing or opinions, but because a strong and deliberate attempt has been made to reflect the experience and judgement of all the committee members who participated in this workshop.

APPENDIX A

QUALIFICATIONS COMMITTEE

Chairperson: Boyd Paulson
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QUALIFICATIONS COMMITTEE

FROM LEFT TO RIGHT:
TOP ROW: JACK LEMLEY, BOYD PAULSON, HERBERT PRILUCK, SHIGEO KUROSAWA
BOTTOM ROW: LARRY ECKERT, GLEN TRAYLOR, KANAME TONODA, JOSEPH GUERTIN, GEOFFREY KEATING

APPENDIX B

Appendix B

ASSESSING OVERDESIGN IN U. S. SUBWAY TUNNEL SUPPORT

by Nino Pedrelli

The recent spiralling construction costs of our nation's subways has reached the point where proposals for future mass transit systems are being seriously questioned. However, with over one hundred cities in the world having over a million inhabitants and a forecast that within 20 years the number of such cities will grow fourfold, the need for mass transit seems inescapable. Following this postulate then, the determinants of cost of mass transit construction must be re-analysed in order to bring costs under control. This paper deals specifically with the support of subway tunnel sections, the cost of which can range from 40% to 70% of the total cost of a line section.

Assisting in a U.S. Dept. of Transportation tunnel support research project under Prof. Herbert Einstein at M.I.T., I became aware that the concept of overdesign in tunnel support is a subject of widespread discussion by professionals in the industry. I also noticed however, that notwithstanding the major importance of this subject, there is little published information concerning overdesign and especially of its acceptance in practice. Through a grant from the Sigma Xi Engineering Research Society and with the technical advice of Prof. Einstein and Prof. Raymond Levitt, I attempted to survey professionals in the industry to ascertain what they believe concerning the existence and prevalence of overdesign in tunnel support in this country.

I. DEFINITION

Before proceeding it would be best to first define what exactly is meant by the term "overdesign." In short, "overdesign" refers to the "gap" between the support system or quantities an engineer or contractor would specify if his only criterion was the construction of a safe tunnel at lowest cost, and the support systems and quantities actually being specified today. "Safe" here implies an acceptably low risk of failure, equivalent to risks normally encountered in driving, airplane travel, etc.

The attitudes of subway tunnel contractors and design engineers were surveyed through questionnaires sent to professionals across the country. Since designers are involved with the final support system and initial support to some extent, while the majority of contractors only have input with regards to the initial support, separate questionnaires were developed. The questionnaires were designed to yield results to assess overdesign by determining:

1. Current procedures and inputs for designing and selecting the support of a tunnel.
2. The existence of overdesign and, where present, to what degree.

II. SUPPORT DESIGN AND SELECTION

II.A.1 Selection of type of support system - Designers

Literature in the field and informal conversations with engineers have suggested that three factors which enter into the design process are: union attitudes and procedures; current court interpretation of engineers' liability; and the present tunnel contracting practice that designers specify and detail supports before excavation. We attempted, therefore, to ascertain what effect these factors have on the selection of the type of support system and/or the factors of safety utilized.

The results consistently showed that each of the factors had more effect on the selection of a specific structural system than on the selection of the factor of safety to be employed in that system. This ties in somewhat with the results of a study done by M.I.T.'s department of Civil Engineering* in which designers in a work shop discussion stated that the factors of safety for a support system wouldn't vary with the uncertainty of the project. Instead, the decisive factor was the design philosophy, and this is largely determined by the owner.

As far as relative impact is concerned, as expected, the pre-design of supports before starting excavation proved to be the factor that affected design decisions most. Court liability and union agreements followed, in degree of impact, respectively. A typical response for the engineers in relation to how they considered court liability was that "design is not done under fear of liability, but engineers have a great responsibility for the stability and safety, therefore tunnel design has been traditionally very conservative."

A fair number of designers also admitted to taking into account the probable union attitudes towards a support system in their selection of that system. The major problem here seems to be a psychological one since "some people still like to work under lots of steel," as one respondent wrote.

*"Analysis of Risks in Transportation Construction," August 1978.

Another designer cited the example of the Helms Pumped Storage project in California where workers walked out due to their concern over the safety of rock bolts in a 30-ft. diameter access tunnel and the owner had to have steel sets installed. However, after workers gained familiarity with the bolts, they excavated a 70-ft. powerhouse cavern with bolts and no steel sets.

The intent of this portion of the questionnaire was not to imply that engineers would design unsafe support systems if these factors had no effect, but to see if designers incorporate the effects of the factors over and above what they consider a safe design. The results indicate that designers do take the factors into significant account. This highlights the three factors as cost escalating inefficiencies in the present system.

II.A.2 Selection of quantity of support - Designers

In order to obtain a general perspective of design procedures, engineers were given three alternative procedures for deriving a design load for a support and were asked to select the method which most closely resembled the type they utilized.

Answers in this section were split between those engineers who use a factor of safety for the system as a whole (allowing overstressing of individual components) and those who use differing factors of safety for the individual components. No firm conclusions concerning current design methodology can be drawn from such responses, but it is interesting to note the apparent schism that seems to exist among designers.

Some stated that factors of safety are based on codes while others believed that they are not based on assumptions but are more of a matter of judgement under given conditions. One designer had the extreme view that "linings stipulated by the owner's Design and Construction criteria are frequently so grossly conservative that no analysis is warranted."

II.B.1 Selection of support system - Contractors

Just as designers were asked what factors come into the selection and design of a support system, contractors were asked how they choose an initial support system. As it turned out, the matter is effectively out of their hands as 80% of the respondents stated that the type of structural system was usually specified by the owner. This specification comes predominantly in the form of exact sizes of steel sets and spacing or minimum material and spacing requirements. A similar question in the designer questionnaire also yielded approximately 80% of the engineers responding that they usually do specify to the contractor the initial support system to be used. The general attitude of the engineers' responses however, imply that they feel that contractors are in the process of being given more discretion with regards to the system they utilize. Several engineers stated that they specified a support system only when difficult conditions were anticipated, while others stated that they specify only the minimum requirements and allow the contractor the option of choosing a particular system. The contractors, on the other hand, give the impression that for the most part, their hands are tied in this respect.

II.B.2 Selection of quantity of support - Contractors

As with the designers, after reviewing literature in the field and speaking with contractors, five factors were selected which were believed to have an impact on the contractor when he decides the quantity of support to be put in place. The results of this question are shown below:

Workers' attitudes or prejudices	5
Liability for injuries	1
Liability for failure (w/o injury)	2
Inability of the specified system to completely adapt to changed ground conditions, resulting in purposely overdesigning to make sure the changed condition is accomodated	3
Immediate availability of a certain material at the heading	4

(1-greatest, 5-least)

As to be expected, safety and professional concern affected contractors' support placement decisions most. However, the next selection of, "inability of specified support system to adapt, ... etc.," gives credence and supplements the assertion of overdesign in tunnel support.

III. DETERMINATION OF OVERDESIGN

III.A.1 Overdesign existence - Designers

The designers were asked outright if it was "accepted practice to intentionally overdesign tunnel support systems." The answers to this question were almost unanimous with all but three people admitting to the overdesign. All three engineers who denied overdesigning themselves though, stated that it was accepted practice. The designers based the reason for this overdesign on the fact that they seldom have sufficient boring information, that the construction procedure to be used is unknown to them, and that they are forced to follow the design criteria given by the owner. "The assumption of the design load and the lack of confidence in the contractor's performance tend to make the design conservative," asserted an engineer. Some, however, believed that the overdesign is cost effective, stating that, "you overdesign when it is economical to select a reasonably uniform system for the entire tunnel, then some sections will receive excessive support." Of course the cost effectiveness here depends upon the thoroughness of the preliminary subsurface investigation.

III.A.2 Status Quo evaluation - Designers

The last question asked if the respondent felt that "the present procedure of selecting and designing support is the most efficient." Only three designers believed that the current system is the most efficient. Two main themes were prevalent in the reasons given for the inefficiencies in the present system. One was allied to the answers given to the previous question on overdesign and was concerned with the low budgetary importance given to preliminary geological investigation. This leads to the situation where engineers don't consider the interaction between the support system and the surrounding medium in the design.

The other theme centered more around the liability aspect of designing, asserting that owners and engineers are afraid to depart from past precedence since the most direct penalties come from "sticking your neck out." This therefore, provides engineers with no incentive to achieve economy.

III.B.1 Overdesign existence - Contractors

Contractors were then asked to estimate, as a percentage of total support cost, the "amount of initial support utilized which is not needed for optimal structural support, but is used due to having to 'play it overly safe' or any other factor." Although this question is admittedly rather vague, more than 60% of the contractors answered this question and nearly all gave estimates which ranged from 20-30%. Whereas this number cannot be applied to any specific tunnel to compute a cost of overdesign, it does give a sense of the possible magnitude of this overdesign.

III.B.2 Status Quo evaluation - Contractors

Along the same lines, contractors were also asked if the present procedures of choosing initial support systems and quantities are the most efficient. The vast majority said "No," and gave as their main reason the assertion that they were not allowed to choose their own initial support system. Contractors felt that by specifying support systems, designers were interfering with the efficient use of materials, equipment and construction methods which contractors believed they knew best.

Due to what the contractors regarded as insufficient geological investigation, it was also felt that the design criteria specified are excessively conservative. One contractor stated that the "minimums or maximums specified have no realistic relation to the project unless they are based on the worst possible situation which might exist." Designers were not singled out for criticism though, as some contractors point out that designers were often not given enough time or adequate subsurface information.

When asked to try and estimate the cost of the aforementioned inefficiencies as a percentage of total support cost, contractors responded with a consistent range of values falling between 20-30%.

IV. CONCLUSION

This article should not be viewed as an indictment of subway tunnel designers and contractors. If an indictment is to be drawn, it should be against the overall system of tunnel contracting as it now exists in this country.

In this survey, both designers and contractors have not only overwhelmingly expressed dissatisfaction with the present system but have admitted to significant overdesign. Insufficient preliminary geological investigation, inequitable interpretation of engineers' design liability, and contractors' inability of discretion with regards to the selection and usage of initial support were mentioned as the major inefficiencies in the system. It is obvious that any subsequent efforts to reduce subway construction costs should include recommendations to resolve these inefficiencies.

DISCUSSION

MR. PAULSON: Our committee is the one with the rather intimidating title. Our committee met and split into two sections: the first addressing technical qualifications of owners, agencies, designers and contractors, and the second addressing administrative qualifications in the same categories of organizations.

As I mentioned yesterday, the vehicle for provoking some thinking was a four-page questionnaire. Our Japanese participants, Ohbayashi-Gumi circulated this questionnaire to two top owner people as well as several designers and construction engineers, so I think their's represented a total of nine engineering and construction people.

First of all, among high-priority items in the technical area, we had education. The things related to the experience of having worked in engineering and constructural organizations was another, as was general knowledge of various new methods to keep up with new technologies.

One area where education seemed to come out as having rather high priority was first of all only in the technical area; on the administrative side, somebody said this causes more troubles. But, at least in the technical area, education was ranked very high, particularly for the designer of these four parties. Hopefully, in tunneling, emphasis should be on geotechnical, perhaps even more than on structural aspects of the technical education. Our lawyer emphasized that the education should be sufficient as to stand up under the assault of lawyers and court. Essentially, when things fail, what the lawyer will attempt to do is to discredit the person's education and experience and qualifications. That's the one area where education came out; for credential reasons as well as for technical reasons.

In the technical area, as far as ranking importance of contractors versus owners and others, most of the people seemed to say that designers and contractors are where the real emphasis is, and their technical know-how determines how the job is done. Typically the owners and funding agencies would be less essential, although the owner, in particular, should also be technically knowledgeable. For the contractor, the emphasis is not so much on education as it is on his practical field experience in having built several similar projects.

The funding agency for some reason was largely ignored. As long as they shove the money out, that's considered enough.

For the owner, though, it was believed important to have sufficient education and experience to be able to recognize problems when they come up, and to be in a position to take an affirmative role in resolving disputes between designers, contractors and others.

Again, in the technical area the emphasis was especially on the design and construction people.

As if we didn't have enough on our list already, we did add a few other topics or emphasized a few which, perhaps, weren't expressed clearly enough. The designer should also understand labor relations (let's assume the contractor already does) from the point of view of being able to make trade-offs in design in terms of comparing this method versus that method. Say, you are required to have one worker per pump, that might affect dewatering versus the slurry wall method of controlling water. Even the designers should have that understanding of labor constraints.

In looking at the Japanese side, some of this supports what Doug Johnson was saying. Some of you tried to get contractor input at pre-bid meetings; the Japanese actually have a method where the owner takes people from say half a dozen contractors at the design stage; they work with the designer during that time, so you have fewer design/contractor disputes in the construction phase. There's more cooperation all the way through. Contractors actually assign their people over to the owner during the design stage.

Moving over to the administrative side of the questionnaire, emphasis to a large degree shifts to the owner. He needs to be conscious of the roles and the capabilities of all the different parties who will be involved; -- it's the owner, who you have often spoken about, who can create this open and cooperative atmosphere. These signals start coming very early from the owner, so the need for methods to create this in the contract administration procedures was repeatedly emphasized in our group's discussions.

The owner is also the one who ultimately has the responsibility for making the design go, even though it's the designer who makes sure it gets into the construction phase in a technical form. The owner should at least have the administrative ability to insist on cost effectiveness of design and somehow not abdicate that responsibility to the designer, and insist that proper contract administration procedures, such as described by the better underground contracting practices report be put into this system. The owner should understand contractual relations

The one area of controversy that came up between the contractors was both technical and administrative prequalifications of contractors. On one hand, it was argued that not only should there be contractor prequalifications, but also owner and designer prequalifications, which kind of happens anyway with contractors withholding bids from certain owners.

There is a need to instill a sense of urgency, especially in the owner and funding agency, for both keeping the capital funding going and also urgency for making decisions in a timely manner and essentially maintaining the momentum of the job.

With respect to responsibility, I think I asked a facetious question, are these big transit agencies and big organizations being set up deliberately to make it impossible to pin down any single responsible individual to make a decision? There was, I think, some agreement that if not deliberate, at least that's the way it turned out, and one person said, when you look at these people, and you look at these organizations, you see this shell of organization. You see people with the title of manager of this and manager of that, and resident engineer of this and what not, but what you don't see is real authority, if you start asking questions like, does this "executive assistant manager" have the power to hire, fire, promote, decide. Does he have the power himself to say, okay, you go this way or that way on a particular change situation, for example? Do they actually have that power or the administrative authority to do things? In many cases these days, even though they might have fancy titles, the answer often is no, and so what you have in effect looks like an organization in terms of a traditional responsibility going with the authority and so forth, but it really isn't. Literally ask, does that person have authority? Contractors certainly do it with their own people, but do the owner and engineers have this ability?

In general, as I mentioned before, education was less important in the administrative area, and experience was more important. There is need for more emphasis on right of ways, easements and permits. The owners also need more sophisticated scheduling of easements ahead of time. On one project, the owner failed to obtain a permit after eight months of trying and said, I tried very hard and I'm sorry, but now it's the contractor's responsibility to do it. Yet having recognized that they failed to get permits, the owner still is unwilling to compensate the contractor for the additional cost of delay. The trade-offs of costs and compension to the contractor versus the owner/designer/consultant failure to get these permits is difficult.

The term "wild card triumvirate" of "community - elected officials - media" was introduced; somehow it's got to be considered as one entity, and how they affect the project must be better anticipated. How do you allow for this intervention? Contrary to popular impression, this problem was also mentioned by our people from Ohbayashi-Gumi as one they also have. They mentioned one subway job which was delayed two years, essentially just trying to resolve disputes with the neighbors on noise permits and when are you going to work and how much are you going to dirty up the neighborhood and so forth. It was estimated by someone in our group that this so-called "wild card-joker" in the deck, the trilogy of "community - elected officials - media," have added ten or twenty percent to the cost.

Just one final technical question, since we didn't say anything technical, is that if any of you instrumentation people have any advice on instrumenting say, consistency, pressures and concrete tremmil progress at the bottom of a two-hundred-meter slurry trench, we have some people here who need a little input on that. You're talking thirty-five meters, forty meters, but how about two hundred meters?

I would like to now do two things. One is take questions, but also for others in our group -- is there anybody from our group who would like to add to anything I said?

Are there any questions?

MR. GARRETT: I notice from the listing of your committee you have no one from a transit authority here or from a building organization.

MR. PAULSON: We have one -- Herb Priluck.

MR. GARRETT: He had a couple of experiences. You brought up an interesting point about the qualifications not of the staff, but of the authority for the construction agency, and that is going to affect the legislation that enacts this particular body. There are agencies that have no power of eminent domain. They have to go to someone else hat in hand to get the property for them. In our particular case we are an instrumentality of three organizations; the District of Columbia under the U.S. Congress, and the State of Maryland and the State of Virginia. Most state agencies in those two states are not required to get the approval of every city or county to perform work, and yet our agency must get the approval of every city and every county in which we work. It's in our legislation, and therefore, that's the qualification you're talking about. So, you have a problem with getting approval because of noise, hauling over certain streets, and I can just go on and on.

I think we have to recognize that by the time this society or this part of the society gets involved, the die is already cast, and we have to live, unfortunately, with those peculiarities of each of the agencies that have the money to perform the work.

MR. PAULSON: I think you've got two questions there. One, I think, is what you're saying towards organizational constraints, and our committee agrees -- there were actually favorable comments made even about WMATA.

MR. GARRETT: That's unusual.

MR. PAULSON: Next, the people there do try to be practical in many ways, and yet we recognize you have your hands tied very early in the game. These are the institutional problems that keep coming up. Essentially, it's too late for Washington, but how do you get to new organizations now forming, to say, "If you don't delegate enough authority to the people who are qualified to do this work, that's just the thing that's going to happen to you, from case studies in the past."

We talked about qualifications of organizations and qualifications of individuals and even looking at it, say, at the contractor level which is kind of the tailend of the process, or the designer level, we came back to the individuals again. It still boils down to the actual individual people: project manager and the superintendent and so forth. The designer is an individual who is assigned to design a precast concrete tunnel lining. So even in the context of design organizations it comes back to the individuals in charge.

MR. BUTLER: Boyd, you mentioned that because there was not a representative of a funding agency on your committee, it was shoved down to a lower priority. I would hope to God that it would be a high priority.

Also, getting back to what Vern was talking about, the legislation has a great impact on the mode of the program management. Federal Highway has one type of legislation, P.A. another, and UMTA another. If we merge with Federal Highway, we become a surface transportation administration; do we in managing the UMTA projects want two thousand engineers to start peering over our shoulders? I think not. I think, really, what we want to do is develop the in-house expertise to be able to see that proper management is taken by the owner. I would put it priority one on qualifications.

MR. PAULSON: This was kind of my bias as well, and I tried steering that way. Especially, qualifications in terms of understanding the impact of delayed funding on morale on jobs which are shut down. One contractor for example, but not on a transit job, mentioned they had documented not only the period of shut down, which is basically the overhead, but also, the period of knowing the money was running out and during the start-up once the money came back in again, he had really documented the decline of labor productivity, and the decline of the technical people. So this kind of uncertainty very much comes down from the top and did come out in our discussions. Now that technical people are getting into the grants office, things may be looking up. I think that's certainly a plus to have the technological knowledge in there with all of the accountants and lawyers on that side of the organization.

MR. LEMLEY: It really doesn't make any difference what kind of qualifications you've got in a funding agency if you aren't exercising any prerogatives other than writing checks or sniping at the local agencies. First, you have to decide what you're going to need and then staff up to handle those responsibilities, and from what I can see, sitting at the executive-contractor level, there's a lot of cheap sniping going on between the local agencies and the government, not only in transportation, but other areas. I'm not being particularly critical of UMTA, but I'm picking on all of them. It seems to me, these are ill-defined roles at this point, and we need certain types of people to run one organization and other types to run another, so you have to decide on a philosophy before you decide on what kind of staff you need, and it seems that there is no decision on that issue.

MR. PAULSON: One thing I've been attempting to mention is that in addition to the people I introduced yesterday, Jack Lemley joined our group and participated throughout the whole discussion and made many contributions.

MR. PRILUCK: If I can draw from some similar experience in the private market where you're talking about private development, a funding agency is essentially the bank. The lending officer makes a very careful management audit of the developer, and a developer, in order to be loaned by a commercial bank twenty, thirty, forty million dollars, has got to demonstrate some kind of a track record before he gets a mortgage commitment. I think that in this case, the equivalent of the banks is the funding agency, and I think what is needed is to do a management audit and to ask the question, if you don't have the authority to get a piece of land in less than six months, and you have a schedule of someone starting construction in three months, if that's the way you're set up and those are the ground rules, we will just not make the loan. The only people that can really mandate this is UMTA. From my way of looking at it UMTA is certainly entitled to their opinion. When they're investing eighty cents on the dollar.

The other area which I mentioned yesterday was the whole complex of the media and the public officials and so forth; you've just got to stop bemoaning the fact, and I think that we ought to start highlighting in dollar and cents what this is costing rather than hiding it. Again, the funding agency is in the position to say we are not allowed to take project funding in the transit system and use it to build a new city hall. You can't use it to renovate the mayor's office. On the other hand, we won't let you use the same funds to preclude trucking in the highly industrialized cities because somebody, somewhere promised it. You want a dollar tag as to how much these kinds of commitments take, and then say, okay, now we'll put it back into a legitimate political process saying here is X-million dollars on top of this job which is in the front end which is being spent for the following purpose. There are two places where a funding agency can do something, but the owner must have the fortitude to spot these things and to put dollar tags on them, and you can put price tags on most of these commitments and most of these things that go on. I think in those two areas the owner can act as the commercial developer. Again, the loan officer in the big banks would definitely make a check of what's the opposition to this project. If there is no mechanism set up to somehow deal in a rational way or least value what a potential cost may be, the loan won't be made.

MR. LEMLEY: I have one additional comment. It seems to me that one particular qualification that all of us have is credibility. In the engineering profession, the government has destroyed its credibility with the public over the last several years, and we're continuing to do it in a rapid way. Contractors have to put their money where their mouth is most of the time, and generally, I think their credibility has stayed higher than in the engineering profession or government, but we can't continue to attach false budgets just to start a project and then keep moving the dollar targets up just because we got the first hundred million dollars into it, and we know we've got to go from A to B. We're eroding our credibility with the public, and with all of our constituents, and that's the one qualification that we all have to have is some kind of credibility; all of us are guilty in this room and 99 percent of us in the engineering profession of distorting the facts, from time to time, to get support to get something started. In the end, it really is destructive.

MR. LEVITT: First of all, whereas a private sector company decides what they want to do and then steps up to do it, realistically UMTA has to live with the people they have, to some extent, to try the best they can to move them in the direction of maybe getting a better return on their money. I think that relates to the second point that, again realistically they're a bank that's looking for a safe return on investment and redistributing Federal dollars to the political process, and the decisions might not always be the decisions that have the least positive effect on a particular project. I think we should be realistic in what we expect from them, and I would strongly suggest that the trend go in the direction of more review by UMTA of the way the funds are used. Point out what are the costs of things being done in certain ways and then throw that back into the political pot. In other words, if you interrupt it, this is what it will cost, rather than suggesting that they should change their mode of operation.

MR. PAULSON: The bank does not have Congress saying, you will spend so much in this area and that area.

MR. SUTTCLIFFE: We talked a little of qualifications of individuals and how important they are. I think an owner in selecting an engineer should think about the track record of that company, the track record of the engineer, and they should also find out something about what his authority is; will he hire people, fire people and staff with the right sort of quality. The same question should be asked of the owner -- assuming the owner is doing the construction management -- what authorization does that project manager have to extend time, to grant change orders. If a man has several hundred million dollars worth of work, and he's limited to ten thousand dollars of change orders, he's not going to get it done. I submit that one of the reasons on our job that the overrun on the civil structure work was kept so low was that it was a unique situation where the man in charge of construction management had a tremendous amount of leeway in what he could do, and was able to get all the problems solved the day after they arose instead of four years later.

One last item. It seems to me that questions should be asked about the qualifications of people who set up the first organization for the implementation of the project. In other words, the owner's organization, so it's done under the existing organization that the owner had or separate organization with separate authority. That seems to me the very first step where half the projects get off on the wrong foot.

MR. PAULSON: One thing that did come up was the attitudes of the owner and whether or not they really directly want to be informed about what's going on, and so there are two different kinds of owners you will have here. One who insulates the "managers" with ten layers of channels, and maybe they get things filtered through several organizations. The other one is the one who actually wants to be right there on the firing line with carbon copies from contractor problems or whatever. You know, we do get into combinations. Some people sense the difference. Owners who really want to be involved and are willing to take responsibility and willing to be part of the action.

LETTERS

SCHOOL OF ENGINEERING
STANFORD UNIVERSITY
STANFORD, CALIFORNIA 94305

DEPARTMENT OF CIVIL ENGINEERING
FREDERICK EMMONS TERMAN ENGINEERING CENTER

May 2, 1979

RECEIVED MAY 7 1979

To: Dr. Gary S.Brierley
H & A of New York
50 Chestnut Plaza
Rochester, New York 14604

Subject: Comments for Qualifications Committee

Dear Gary:

Since I had responsibility for preparing and revising our Committee's position paper, it would be redundant for me to add anything that I did not express therein. Nevertheless, I would like to take this opportunity for two reasons.

First, I was very grateful for the willing and voluntary contributions of all of our committee members. They are listed in an appendix to our paper, and each of those individuals specifically and constructively participated in our workshop. Our Japanese committee members particularly deserve special mention since they came so far to assist us, but all of our people went to considerable trouble and expense to come serve the needs of our profession and our industry.

Second, many of the people one sees at tunneling conferences sponsored by UTRC, DOT, USNCTT, and others appear to be the same small subset who are really only a small minority of a much larger industry and professional group. While these individuals are to be commended for their continuing voluntary efforts on behalf of better tunnel construction, the industry still very much needs a far broader participation from individuals representing several diverse viewpoints, including owners, contractors, designers, consultants, lawyers, and government people, if we are to make real progress toward solving the problems identified at the workshop. By specifically requesting such broad input, this workshop took a significant step toward dismantling barriers between "insiders" and the "adversaries."

I certainly hope that people who for the first time became involved with UTRC activities will continue to be interested, and that others reading the proceedings will also seek such professional forums to help solve major industry problems. As has been repeatedly emphasized, our problems are largely institutional and administrative rather than technical, so any mechanism that encourages better communication within the industry should be encouraged.

Sincerely,

Boyd C. Paulson, Jr.

Boyd C. Paulson, Jr.
Associate Professor
of Civil Engineering

BCP:fc

CHAPTER 5

GEOTECHNICAL INVESTIGATIONS

LINING DESIGN WORKSHOP OF MARCH 1979
POSITION PAPER ON GEOTECHNICAL INVESTIGATIONS (FINAL DRAFT)

James P. Gould-Partner: Mueser, Rutledge, Johnston & DeSimone, New York, N. Y.

I. INTRODUCTION

This position paper is concerned with geotechnical investigations applied to mined tunnels, not merely those aspects pertaining to tunnel lining design. We should recognize at the outset that available exploration procedures are imperfect and yield approximate results. This truism will not save us from responsibility for being downright misleading if we expect our data to reduce bidders' contingencies. Exploration traditionally has concentrated on servicing planning and design but the elaboration of construction methods, the focus on urban sites and third-party involvement create tasks for the exploration beyond the designer's traditional concerns. Exploration for design can be less significant than the impact of exploration on contractor's choice of equipment and methods wherein substantial economies can be realized from detailed and accurate knowledge. We need to alter our response accordingly. This paper is concerned with three areas of application of the geotechnical data: planning and design; construction procedures and equipment; influence on existing adjacent facilities. After describing special geotechnical problems and appropriate investigation methods, recommendations are given for utilizing the exploration data so as to make a favorable impact on the bidding environment.

II. GEOTECHNICAL SUBJECTS DISTINCTIVE TO TUNNELING

Planning and Design

Geotechnical information is chiefly utilized in the following functions:

1. Overall design choices: the attempt to select the most favorable tunnel position in plan alignment and in profile; choice between mined and cut-and-cover tunnels; selection of tunnel cross section.

2. Decision on support loading: soil-like or rock-like ground loadings; stress-strain properties of supporting medium; influence on loading of secondary structure (slickensides, joints, shears).

3. Selection of lining: influenced by loading, ground water, seismic factors, invert stability; excavation procedure and constructibility; possibility of combining primary and secondary lining; unlined possibility.

4. Requirements for watertightness or permanent drainage: draining water quantity and quality (pH, resistivity, solutes); design of hydrostatic pressure relief (HPR) system, HPR system maintenance.

Construction Equipment and Methods

Subjects that should be enlightened or clarified by geotechnical investigations are as follows:

1. Character of material to be excavated: soil-like or rock-like; presence of anomalies, discontinuities or interfaces, influence on blasting and excavation procedures.

2. Requirements for ground stabilization or temporary support: stand-up time, stability of materials at face, crown or invert, need for compressed air.

3. Ground water conditions: overall permeability, flow quantities and concentrations; influence of inflow on stability of openings and constructability; special recharge requirements.

4. Degree of uniformity or predictability of the ground: obstructions, variations or erratic conditions.

Influence on Existing Adjacent Facilities

Problems which are geotechnical in origin include the following:

1. Immediate or close-in settlement due to ground movements into the tunnel.

2. Possibility of hazardous erratic local movement by runs, chimneys or sink holes extending to the surface.

3. Overall consolidation settlements produced by ground water drawdown.

4. Need for measures to protect adjacent facilities.

5. Temporary or permanent changes in ground water regime: unusual rise or fall of water levels; effects on plantings, water wells, basements.

III. SPECIAL REQUIREMENTS FOR THE GEOTECHNICAL INVESTIGATION

Given the above array of problems, geotechnical investigation for mined tunnels is subject to the following conditions that distinguish it from conventional exploration for surface construction:

1. Above almost any other type of geotechnical investigation, there is a need for sound geologic input into one made for mined tunnels. Importance of the geologic setting requires extensive and thorough study of background information and local tunneling experiences. It is absolutely essential that a functional engineering interpretation be placed upon a framework of the local geology, otherwise points of engineering significance will be lost.

2. There is a need to include sufficient data on soft ground characteristics so that bidders can make a tunneler's interpretation of conditions. He should be able to visualize if materials will be squeezing, ravelling, or running or the like. Similarly in rock, there is need for meaningful descriptions of rock quality, its weathering, the character of the secondary structure, plus whatever interpretation can be made of the continuity of major secondary features. In both of these respects ordinary soil mechanics procedures can be deficient and may have to be amplified.

3. Discontinuities, interfaces or major secondary structural features assume a special character since these will be met in a setting where there is no turning back, they cannot be avoided and there is a limited degree of freedom to alter methods. Of particular importance are recurrent patterns of softness or weakness within rock or erratic distribution of hardness of obstructions within soft ground. Difficulties in construction often attend a departure from the expected average condition and it would be useful to derive a ground classification relating to the mode of occurrance of anomalies, their frequency and degree of predictability that could be factored into some sort of contingent price arrangement or assignment of risk.

4. Ground water conditions to a considerable depth must be studied. This includes the distribution of permeability properties, the presence of artesian or perched water levels, special recharge from utilities, irrigation or building drains.

5. Special tunneling hazards should be identified. These include: buried structures, or man-made obstructions, character of man-made fill; presence of natural gas, whether methane in coal environment or heavier hydrocarbons in petroleum environments; ground impregnation by flammables from former storage sites.

6. A study of the ultimate cost effectiveness of various elements of the exploration suggests that if there is doubt as to the adequacy or coverage of the boring program, the obvious course of action is to add borings. In some circumstances it is desirable to provide extra borings for questions of constructability even at a time when design is complete or even if their results would not influence the design.

IV. SPECIAL PROCEDURES FOR THE GEOTECHNICAL INVESTIGATION

In addition to performing conventional boring and laboratory testing, consideration should be given to employing special procedures whose costs may be justified many times over by the information they produce.

1. The need for characterizing the overall texture of subsurface units gives a particular value to examination of exposure and outcrops. This can help to delineate soft ground stratification or the attitude of rock joints and discontinuities. The pattern of earlier surface topography should be studied to identify original drainage features and stream channels since these can be the focus for deep penetration of weathering and recharge from concentrated infiltration. For major projects a study of gross surface texture and grain through remote sensing techniques (satellite photography, side-looking radar imagery, etc.) can help to delineate geologic structure.

2. Continuous sampling of soft ground directly above and within the planned tunnel opening, though not conventional, may be justified. This permits a detailed examination of the texture and arrangement of materials and more extensive strength or identification testing. Utilization of two-inch Shelby tubes in an ordinary split-spoon sample boring probably is all that is needed for ordinary conditions. These tube samples should be examined in detail for evidence of cementation or potential flowing or running sands.

3. Ground water studies need special attention. On major projects full-scale well pumping tests often are justified. Permeability values obtained from simple borehole tests can be unreliable in quantitative terms but give information on the potential variation in permeability characteristics. Field tests should be supplemented by fairly extensive information on gradation and the plasticity of the fine fraction of soil samples. A suitable array of piezometers should be installed in the test borings, generally meeting the following requirements:

a. There should be a greater number of piezometers for semi-permanent installation than usually employed in foundation exploration.

b. Piezometers should consist of inert plastic materials.

c. It is essential that the borehole containing a piezometer be sealed from surface seepage so that the water level observation is localized at a specific zone and is not subject to extraneous influences from other horizons.

d. A record of observations should be built up before construction on at least a few key piezometers.

e. At least a few check samples should be taken from these piezometers and tested to determine water quality (pH, resistivity and solutes).

4. There is insufficient understanding of and attention to information useful for contractors in selecting soft ground tunneling equipment. Data might be provided from exploration on the following:

a. Jacking forces necessary to advance a soft ground shield and the approximate arrangement of eccentricity of these forces around the perimeter of the shield.

b. Stability of coarse-grained soils in the heading and crown, their potential stand-up time and the need for breasting arrangements.

c. Characteristics of the soils relating to mechanical excavation procedures, the presence of obstructions and the type of muck to be produced.

In this area better communications should be set up between geotechnical engineers and equipment manufacturers and users so that the geotechnical investigation can provide rudimentary soil data for the equipment selection. The time may be ripe for an industry-wide effort to establish a tunnelman's classification system that would relate to the performance of both soil and rock materials in construction. The purpose of such a move would be to determine what geotechnical data is chiefly needed to evaluate performance and how to translate it or catagorize in a fashion most useful for tunnel construction.

5. After problem areas are delineated by the boring program there may be justification for test pits from the surface or possibly pilot tunnels from a test shaft. Test pits made by caisson boring machines or hand-dug in a braced box, can be of value in revealing ground conditions and often can serve as a deep sump for long-term pumping tests. Consideration should be given to the use of innovative exploration methods such as horizontal boring techniques and geophysical procedures.

6. In large tunnel jobs, sections are often designed and built sequentially. This is a chance for information gained in construction of an early section to be passed along to bidders on a later section. At the very least, the "as exposed" geology at the interface should be mapped and the results made available. It may even be appropriate to pass along mapping from a complete tunnel section because of its application to regional jointing trends, etc. The mapping from one small area of tunnel can be more useful than the observations from several isolated test pits or shafts because the former highlights the problems as they are actually seen rather than as projected or interpreted.

7. Ordinarily, the tunnel investigation tends to de-emphasize esoteric soil laboratory testing. For a soft ground investigation comprehensive soil identification testing and undrained strength determinations usually suffice. However, increasing use is made of identification testing of rock core specimens. These include unconfined compression, hardness, drillability or abrasion tests of various sorts, plus determination of the character and frictional resistance of joints and joint filling materials. It should be anticipated that the scope of rock tests both in field and laboratory will increase in the future.

8. In some environments the physio-chemical properties of the surrounding soil and ground water can become important. Consideration should be given to determining pH, resistivity and percentages of sulfates and chlorides for both soil and water samples. The presence of soluble carbonates in soil or as calcite in rock joints or carried in solution in ground water can become important in the design of an HPR system for the tunnel.

V. ORGANIZING THE GEOTECHNICAL INFORMATION

Information obtained in geotechnical investigations is proliferating both in quantity and complexity. As contractual disputes increase, successive investigations tend to become more elaborate, more wordy, and freighted with details. A problem arises merely of distinguishing the essentials that designers and bidders must know from the background data. Investigation data currently being obtained can be grouped as follows:

1. "Factual" field information: boring logs, geologic mapping, existing conditions of buildings and utilities; field tests including trial blast, pumping tests, shotcrete trials, etc.

2. "Factual" office and laboratory information: original laboratory test data, summaries and correlations of laboratory test data; design properties derived from these data.

3. Information interpreted from "factual" data: summary geological profiles; test descriptions of in-situ conditions; computations of potential settlement, design loadings on support systems, quantities of flow and the like.

4. Special information on constructability: hardness or drillability tests; record of construction and in-situ mapping of test shafts, pits or drifts or pilot tunnels and conditions encountered.

5. Ancillary background information: geotechnical data developed by others for adjacent separate projects, background climatic or ground water data; published geological reports and pertinent case history information.

The conventional geotechnical report has been directed toward the immediate interest of the owner and designer with less attention to constructibility except in so far as contractors benefited from the same information that was of interest to designers. The utilization of special methods of excavation and support and the interaction of design and construction make the contractor's use of geotechnical information of increasing importance in economic terms and trends in geotechnical reporting have reflected this shift of emphasis. Ordinarily there is no serious problem of liaison between the geotechnical consultant, the designer and owner and it is rather uncommon for an adversary position to develop between them. But difficulties arise in the quality of the information and its availability to bidders and eventually to contractors and the impact of the geotechnical information on claims revolving around changed or unknown conditions.

VI. PRESENTATION OF GEOTECHNICAL DATA

Some aspects of a potential changed conditions claim can be defused by two steps: first, increasing realism and completeness in the exploration program; and second, dissemination of this information to create an impact on bidders within the limited period in which they have to master it. Considering the fact that the information may actually take years to develop and may appear to be of overwhelming complexity and diffuseness, it is essential that a system be devised to make it useable for designers and bidders. The general guidelines recommended below for presentation of data were evolved in the workshop of March 11 to 13, 1979 and represent to some extent a consensus of the subcommitee. Every project calls for a somewhat different treatment of data developed and while these rules may represent a desirable standard of performance they cannot be applied universally. They cannot be taken as applicable retroactively to investigations of an earlier date. It is suggested that the following procedures be considered:

1. It would be desirable to formulate a summary report on geotechnical factors which influence design and constructibility. Such a report might most appropriately be made by the final tunnel designer, drawing on geotechnical information produced for the owner with the consultant's assistance, but reflecting the final design and specification requirements. It is suggested that such a report contain the following:

a. A description of ground conditions assumed for design, ground loadings, and design criteria relating to loads, deflection and watertightness.

b. A discussion of the considerations that lead to various construction requirements that appear in the specifications and contract drawings.

c. A review of factors that bear on constructibility. Speculations should be avoided as to possible ground conditions or performance that are not based on local experience or specific evidence.

2. The contract package being purchased by bidders should contain that geotechnical report, plus final boring logs made by qualified professionals and presented in a readily understood fashion. The specifications text should contain a complete and detailed listing of all packages of geotechnical information actually produced for the owner on the project. Specification text should contain a reference to any compilation of available background information produced by others for other projects which were utilized or might be of value. Except for items of special importance, such as drawings by others on adjacent buildings and utilities, it is not recommended that these background items be listed by name since a question would then arise as to what limits are placed on the list of those items which originated outside of the project.

3. Some items of information prepared by others, such as the as-built drawings of utilities and buildings, might be reproduced and placed directly in contract documents. Remaining items of importance produced by others should be collected in convenient locations in the owner's office where the information can be viewed by bidders and the more significant items made available for reproduction by bidders. Background data produced for other projects would also be available at this location where they could be examined without being removed by individual bidders.

4. A clear distinction should be made in all references in the specification text between data developed for the owner and data derived from separate projects. It is believed undesirable to insert the traditional exculpatory phrases or disclaimers in describing geotechnical information developed specifically for the project by the owner and under the owner's responsibility since this tends to dull the importance of that information and dilutes the bidder's responsibility for mastering it.

5. Ordinarily an interpreted geologic profile is a key exhibit in the compilation of geotechnical data. This usually contains a plot of the borings in scale with abbreviated information from logs and laboratory testing and an interpretation of overall subsurface conditions. Subsurface strata or zones are usually separated by "strata lines" extending from boring to boring and delineating the major materials. A knowledgeable interpretation should be made available but the character of these interpolated strata lines should be made clear in the geotechnical report. Strata lines may be considered to fall in one of three general groups: (1) they may portray an actual discontinuity in the ground, an "unconformity" in geological terms, which was once an erosion surface; (2) they can represent a transition between zones within a continuum, such as conditions in a profile of weathering which is not actually a line or surface; (3) they may portray broken or irregular lensing of materials within a complex deposit, and thus be an interrupted and discontinuous boundary. The nature of the strata lines should be described in the discussion of the geological section. If a line actually represents a continuous surface in the ground, as in the first category above, the typical degree of irregularity or relief on that surface which might be expected between borings should be stated.

6. It is important that the samples and rock cores taken in the owner's investigations be available for review of designers and bidders in some manner where they can be examined expeditiously. This requires sufficient space and a well organized inventory so that relevant samples and core boxes can be laid out for inspection without a lengthy warehousing activity. If it is practicable to assemble bidders in a pre-award meeting undisturbed soil samples might be displayed in their natural condition for visual and manual examination. It is desirable to have at that site the record of the sample inventory and a set of color photographs of the cores in their boxes so that the review may be expedited and designers and bidders can focus their attention on precisely the sections of core that seem the most significant to their decisions. In any case, it is essential that physical conditions at the storage location be such that the review can be made with reasonable efficiency by designers and bidders and that these cores are available at least to the end of the contract or preferably beyond the time when any reference to them would have a use in settling claims.

7. In exchange for making the owner's geotechnical data available in a manner useful to bidders, it would be appropriate for the apparent successful bidder to submit a memorandum explaining his assumptions of subsurface conditions prior to award. If such a summary were available for review by the owner's team it might resolve some misunderstandings and differences of opinions so as to avoid or minimize future controversy.

APPENDIX A

GEOTECHNICAL COMMITTEE

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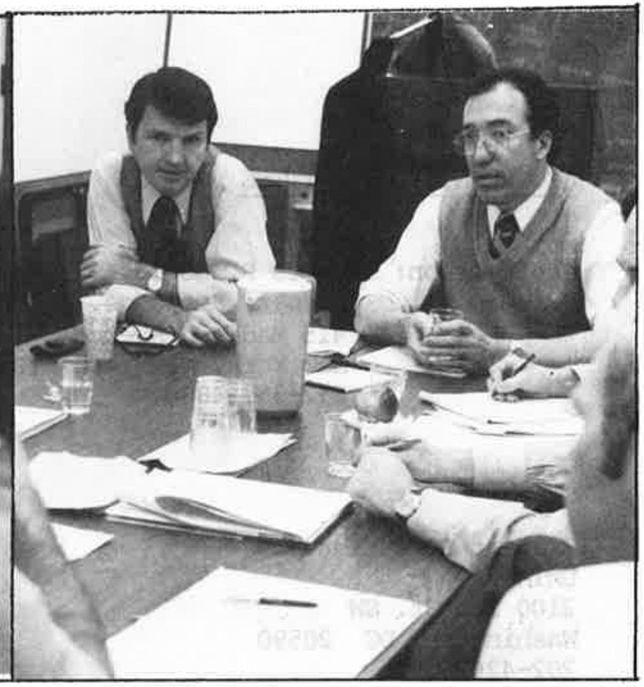
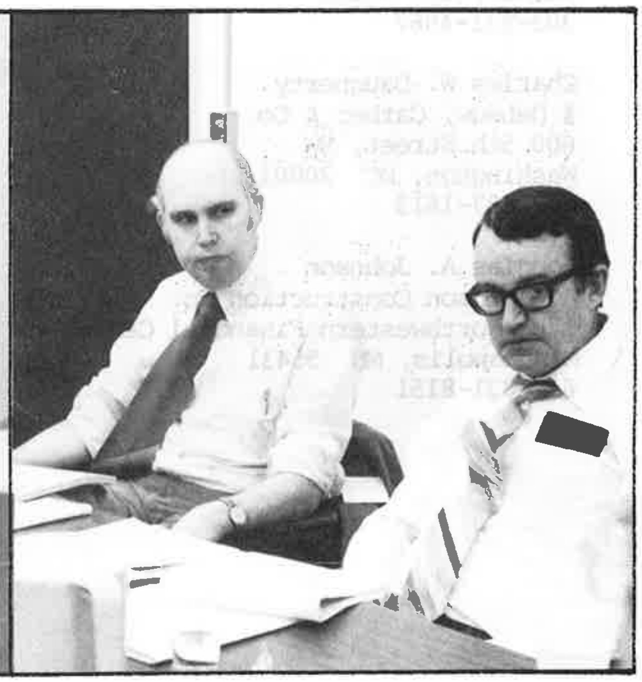


GILBERT BUTLER, RAYMOND LEVITT

NORM NADEL, DOUGLAS JOHNSON



CHARLES DAUGHERTY, HAROLD WHITNEY

GEOTECHNICAL COMMITTEE

DISCUSSION

MR. GOULD: Our committee consisted of a total of nine people including the Chairman, Gil Butler of UMTA, Bob Crookston of Tosco Corporation, Charles Daugherty of WMATA, Doug Johnson of Al Johnson, Ray Levitt of MIT, Dick Murdock of Geotechnical Engineers, Norm Nadel of MacLean Grove and Hal Whitney of Law Engineers. The work of our committee consisted mostly of an interchange on the questions of how to collect, compile, and present geotechnical data.

I was rather disappointed that we didn't have a chance to spend time on any technical specifics, but I don't really think that the technical specifics are judged to be the nub of the current problem and practice. Personnally, I disagree in a couple of rather secondary issues, and I'll mention them later, but with regard to this collection, compiling and presenting, we did, generally, reach a consensus, and in our report we will present the consensus for whatever good it does. It is as I said before not intended to be retroactive. It is perhaps somewhat idealized and a statement of what would be desirable. Each situation, obviously, is different and must be judged on its own merits.

One of the key issues here is that so-called geotechnical report. Now this is what I thought should be included in contract documents, so whether the bidders like it or not, they're going to get it with the package. One key feature of it is while it's called a geotechnical report it probably shouldn't be written by the geotechnical consultant, it should be written by the designer essentially with input from the geotechnical and the owner, and it should deal, not primarily with geotechnical, not primarily with constructability, not primarily with design, but really all those factors together. In brief, perhaps the requirements for it might be stated as follows: it should describe the conditions assumed for design. It should describe the design criteria and design loadings. It should describe the background for choices relating to construction requirements in the specifications. It certainly should avoid speculations on what might happen "if," and speculations as to ground conditions. If that's really the key document, there's a whole raft of background information of various sorts, and we have some suggestions as to the disposition of this information.

Firstly, the key item in the contract documents is the geotechnical report, and presumably the test boring logs.

The package of information, apart from these two that have been made on the owner's part specifically for the project, should be mass-produced. They should be named in detail in the contract documents in the text of the specifications; the names, the dates, and the whole bibliography should be called out in detail, and they should be available for purchase, but probably these shouldn't be forced on the bidders. They should be mass-produced and available for purchase.

Information obtained by others for other projects such as adjacent structures and so on, deemed to be important in various ways can be handled in several ways. As Vern said, some really crucial items can be reproduced and assembled in the contract documents. Perpaps more generally, that background information should be named, described in some way in the specifications, and it should be available for reproduction. The bidders should be told where they can pick up the originals and insofar as they want, to examine it and reproduce it.

Now, the lowest level of information is data made by others for other projects and deemed to be a background of incidental importance. The existence of this compendium of information by others should be made known in the specifications. Its location should be called out, and it should be readily available to bidders and later to the contractor.

Beyond that, it's pretty obvious that the samples and rock cores should be available for review and with regard to the rock cores it was suggested, and I think quite sensibly that color photos be available at the location where the cores are placed and that some soil samples, perhaps contained in their shelby tubes or certainly in their jars, should be as carefully as possible preserved in the original moisture content, and these could be examined by the bidders.

Now, there's a debate as to whether any of this stuff should be carted away by bidders and I think our feeling was that none of this data -- in the interest of the project and other bidders, should be taken and destroyed, but if it were, then you'd have to have a representative of the owner at the scene carefully logging and perhaps delineating what might be taken for the bidders use.

It was our view that the general disclaimer should be removed from the geotechnical information that is prepared specifically for the owner, at the owner's responsibility. However, I think there's some confusion in our discussion over the role of disclaimers. For example, the really very important part of these interpretations is a summary geological section, and personally I put a lot of effort into preparing clear and abbreviated geological sections containing a lot of the essential information for everyone's use. This section, I think, should have your best interpretation but the important thing about the interpretation to me is that you should explain to some extent what this interpretation means. That is, you should really distinguish the strata lines. This sounds like a detail, but when you get into litigation, it may not be. You should distinguish, on the section, strata lines that are actually lines in the ground and that is a profound discontinuity, erosion surface. You should call out lines that are not lines at all, but merely represent sort of a transitional zone, and you should distinguish really a third category and that is a depositional change. Nor a real erosion surface is a continuous line in the ground. The distinction of this from these other categories of strata delineations is really quite important, and that should be made clear. I think it is important to have a good interpretative section, but you should make clear the nature of these changes from zone to zone or stratum to stratum.

Technically, I think there are two areas in which conventional, good practice is different, and by conventional, good practice, I mean you make enough borings, you log them halfway decently, and make the data available. But I think they are two areas in which good practice leaves something to be desired.

On major projects I think this involves the ground water delineation. It really hinges -- and this sounds a little exotic -- it hinges on installing more or less permanent piezometers. They should be inert plastic materials. Above everything else, they should be sealed from surface effects. You really cannot get a reliable delineation of ground water if you're going to let water run into the top of a bore hole and trickle down and stand in a bore hole at some unknown intermediate level. So, for that reason, you need to have an effective seal in the piezometer in order to measure the piezometric level or water level at a specific point in the horizon.

There should be a record of observations, however meager, but there should be some record of observations built up in the period before construction. These things should be noted somewhere in the list of information available.

Last, but maybe not least, you should be able to get quality samples from these holes. Now, that may seem like another exotic wandering into research, but there's certainly some conditions in which the ability to take a good water quality sample in the bore hole can be quite important.

The second area that really strikes me -- is really a better understanding of the equipment manufacturers and designers and the contractor's need for data with regard to soft ground equipment. The factors involved in shield jacking forces and also the eccentricity of forces in the shield. Some sort of delineation or characterization of the stability of the stuff in the heading. You can go back to Terzaghi and so on, but I think we really should come further from that to delineate for the benefit of the bidders and the equipment selectors something about the stability of materials; particularly of uncemented, relatively loose, course-grained soils.

We need to try to delineate something on the efficiency of mechanical excavation, either in terms of obstructions, cementing, stability and so on, because in practice I certainly gain the impression -- it may be a wrong impression -- but very little use is made at the time of bidding or the data we present, and I have a feeling that what we need to do is to get together and really discuss what is desired or what would be useful in the selection of soft ground equipment. We need to have a better understanding before the fact, not when the project goes into litigation. The whole thing becomes fanciful at that stage. Everyone imagines what if. Well, this situation should be avoided, and I think the geotechnical people need some help from the industry on their requirements and the data they need.

That concludes my remarks. I simply would like to say something gratuitous about the observations made in tunneling. I have the feeling that a lot of the problem would go away if the observations were restricted to instruments and procedures and so on that were absolutely essential for control of construction. My objection to many of these programs is that they include so much extraneous stuff obviously aimed at some sort of research or aimed at this nebulous business that we're going to improve the project for a long period of time. That's very difficult to realize. It's only in very special situations, one of which was exemplified by the University of Illinois work in Washington, in which there's really any sort of project, system-wide feedback from this kind of thing. I think if we restrained our urge to get all the possible data we needed to write a paper, there would be one hell of a big difference in the observational programs and the practicality of the observational method. Thank you.

MR. DESAI: On your statement regarding color photographs and the designer's rationale report as we call it in Baltimore, we have learned from the conduct in the fraternity that it's nice to have those pictures and it's nice to have those reports, but that's where they want to stop. They do not really want to recognize that anything more than a bore hole is going to be useful to them until they get down in the tunnel and look at the heading and tell them what they want to know. Everything else in your interpertation versus mine. There's a grey area as to where the actual interpretation stops and the effects take over. Are we telling the contractor everything that went through the designers in mind in the design process. Then, the legal-beagles in the design fraternity take over and say, well, he can't say that. By the time you people get finished writing a rationale report, there's nothing left of meat in it. So, the exculpatory language that we, as a fraternity, have recognized as a necessity. The whole question should be looked at before the reports are produced by the designer before they are going to be of any significant value to anyone, including the designer, when they read their own report, they can't read what they have written.

MR. GOULD: Well, Dru, I certainly agree with a lot you say. I merely said the color photos would be useful as an indexing tool in the core shed. I think there's a terrible gap, really, in the use of this information and no doubt in the quality of the production of the information. The things you say, I don't think should deter us from making an effort to try to improve on certain of these elements, and I agree there are lots of really almost insurmountable obstacles in this exchange of information, contractors are going to have less chance to walk away from it. They're really going to have to assimilate it insofar as we make it better quality, we make it more complete, we make it more available for them to view. There's going to come a time when they're not going to be able to walk away from it, obviously, as they desire to do in many cases.

MR. KUESEL: I won't attempt to speak for contractors, but I would like to comment on the geotechnical reports and the use we made of it in Atlanta at the Peach Tree Center Station in rock. The color photographs were essential. We spent many hours studying them and correlating them with the logs and understanding the logs in looking at the photographs, and I was on the telephone to Harold Whitney and went down there to go over these things. On the basis of this information, we decided the configuration of the station, where you set down the cavern route, what the cross section of the arch should be, where to locate shafts, how big the pillars had to be between the parallel tunnel, and a whole lot of design decisions were made to take advantage of the best rock we could find and to fit this configuration into the places where we thought there would be the least construction problems. I'm pleased to say that in the actual construction the place where we have the worst conglomeration of intersection caverns and shafts and chambers is a place where we have absolutely no joints. It's the best rock in the place. We found that by studying the geotechnical reports.

MR. GOULD: Let me just say that I really think, above everything else, that some of the key decisions by the key people on key points should be made looking at the cores. There's nothing to beat that.

MR. DESAI: I just want to add one thing. In my judgement, one of the things we found in a few places is interpretation of the boring data itself. What you call the material that's seen by the driller at the time of taking and boring samples and analyzing in the jar, versus what a contractor sees sitting in his office in Nebraska or Wyoming. I think it would be beneficial to the fraternity as a whole that during the bidding period or at a pre-bid conference, a designer explains what he means by his description of the sample in the log or in a jar, and it will do much more than providing the color photographs because we have gone through considerable amount of expense and still we have difficulty interpreting what I call a RZ-1 or you call a T-1, and how a contractor sees it. If that's what you call stiff clays, it's different to me. Now, if it was explained how the terminology was derived at, it would benefit both fraternities, designers as well as the contractors, because when you start tunneling that area, what you see in a heading could be interpreted by different persons with a different terminology, and the problems that arise out of changed-conditions, or the claims resulting from it at least would have the same bids before you start.

Certainly that would be a step in the right direction.

MR. CROOKSTON: To comment on these color photographs and relative to what you said about the only person that sees the core is really the driller. The intent of a colored photograph is to show at a much later date the core in the same conditions as was extracted from the ground. I think that the only way you can do that is by color photograph. My greatest concern is the missing interval of core. Usually, I would interpret a missing interval, generally speaking as being the worst part of the ground. That's not always the case. I don't know how we'd photograph that. We talked yesterday about bore hole photography, and it's not as advanced, of course, as color photography on the surface, but it isn't all that bad. I think if you have a succession of missing intervals it might be useful to do some bore hole photography.

MR. GOULD: Well, really, on that point, Bob, this triple tube split barrel coring seems to me to be producing a lot better definition of the missing links.

MR. GARBESI: From a contractor's point of view on the geotechnical reports, we're all in the same fraternity. You people put them so we can understand them, we'll use them. We hire pre-bid consultants to come in to give us a report for the constructability of a project, and you people, if you make your information uniform, easily understood, the contractor has anyplace from twenty to thirty days to prepare a bid on a job. He has to have concise, summarized material that he can draw conclusions from. So, if you give it to us, we'll use it.

MR. GOULD: I think you're quite right, but what you say is not uniformly applicable. I think the producers of the data have a long way to go to put in optimum shape, but I think at the same time lots of bidders have to be convinced that it's of value to them to read it because in the past so much of it has been just tremendous amounts of stuff which is really not of practical value to him.

MR. GARBESI: We don't find that to be the case. We try to study everything that's presented to us and draw what conclusions we can from it.

MR. EINSTEIN: Herb Einstein. How would you document your uncertainty of geotechnical conditions in your geotechnical report?

MR. GOULD: Well, the uncertainty really involves a variation from your generalization, and you should in some way state what you think the possible variation from your generalization should be, whether that's the frequency of major shear zones, whether it's the presence of indentations on an erosion surface or something of that sort. You can present as best you can an interpretation that involves specific lines, but you have to describe the possible irregularities that you haven't depicted and you haven't caught in the borings, and it doesn't suffice to say that you make enough borings to catch it all because you can't. That's impossible to do. You have to speculate on the degree of variability in certain directions, either vertically or horizontally or in quality. I think that a geological section should have some sort of statement as to that variability associated with it, not the geotechnical report, not this key item in the contract document; but in the background information there should be some sort of description of the degree of variability. Now, how exactly you frame that, I'm not sure.

MR. PARKER: Yes, I'd like to comment about that missing core on the Harvard Square project. At Harvard Square we used the integral core which is a concept patented by Rocha from Portugal where you drill a one-inch hole into the rock, say four or five feet, then you grout, and you reinforce a rod or pipe into that hole and you over-core with HX core, and what you get out is everything; 100 percent recovery. You also get an oriented core because you know that orientation of the pipe when it was grouted. We got very good results on that. We had some start-up problems. Dave Thompson was involved in the project, they did the work for us, but once we got going, it was exceptionally good, and we found cases where there were open joints a quarter of an inch or so. We got 100 percent recovery, we got the orientation of the joints, we got the bad stuff, and we actually found joints that were open.

MR. McCREATH: What depth do you think you could take that system?

MR. PARKER: We go down sixty feet at the most.

MR. GOULD: I think effectively it's by people who are fairly skilled and familiar with it. It's something like thirty or thirty-five meters. Beyond that it gets really tough.

MR. PARKER: Actually, you drill this HX hole right down to where you want to begin coring and from there you start your one-inch pilings. So, you just have to control the start of that one-inch piling at the center of the existing hole. You're probably right. It's probably a hundred feet, something like that without getting into difficult problems.

MR. BRIERLEY: I have a question for Vince. In some cases, we've taken the trouble to rent a warehouse and lay out all the core for observation. Is that beneficial or is it a waste of time.

MR. KNIGHT: It certainly is.

MR. GARBESI: It's very helpful. Lay it all out. You might delineate for quick reference the areas that lie within the tunnel, but lay it all out so you can see the whole section. Especially igneous rocks when you can make sort of a statistical analysis or what tunnel to go through by looking at the whole section. We would like to recommend that the core be kept until the end of the project. We find jobs where we might want to go back to the middle of the job and look at cores, and they've thrown them away or lost them. So keep them until the end.

MR. GOULD: Managing an inventory is really not easy. I think there's a real art to it. It should be practiced as effectively as possible.

MR. BRIERLEY: One thing that Bob mentioned, if you take the photograph and keep the core, it represents a very excellent correlation. For instance, if a contractor looks at the boring and it's all the size of poker chips, you can show him in the photograph that it didn't look like that when it came out of the ground. The RDQ in the ground might be 100 percent, and in the box it's something less than zero. These photographs, I think are absolutely essential. Sometimes, too, you might lose a box; it might bump off the truck or the driller drops the box, and the only record you have of that box is the photograph. There's usually a lot more cracking in handling than ever anticipated.

LETTERS

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April 2, 1979

Dr. James P. Gould
Partner
Mueser, Rutledge, Johnston
& DeSimone
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Subject: Position Paper on Geotechnical Investigation
Lining Design Workshop of March 1979

Dear Jim:

Thank you very much for sending me a copy of your draft position paper. You and your committee should be commended for preparing an excellent paper.

As I had stated to you at the meeting, I would like to offer a few suggestions for consideration by you and your committee. I have assigned them the sections as per your paper, but feel free to use them as you see appropriate.

Section II

An item may be added in this Section to recognize the use of compressed air technique in lieu of underpinning. This can save considerable sums of construction money, if the criteria pertaining to underpinning take contribution of compressed air into consideration during the planning stage, and owners and designers work together in approaching the planning phase of the system using compressed air as a necessary tool, rather than unnecessary "evil."

Section III

As stated in the paper, there is an acute need for developing a link between the Geotechnical findings and the tunneller's interpretations.

Many claims primarily result from interpretation of the same data by two qualified experts (of course, they are sitting on opposite sides of the bench!).

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Planning
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Systems
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Maybe the time is ripe for developing, on a nationwide basis, (by zones--say six or eight) the tunnelman's classification system, along with Geotechnical engineers' terms. There are many variations of terms used, depending upon regional terminology, to describe soil-like, rock-like and rock materials. It is a major undertaking, but it should be done if the wealth of information that is being generated by the designers and Geotechnical engineers (at the great expense to the owner) has to have an impact on the bidders within the limited time period during which they have to prepare competitive bids. Most of the contingency costs in the bids are directly proportional to the bidder's ability to understand the abundance of Geotechnical data presented to him, within the bidding period time frame.

General

Having generated all this data and having included it in the body of specification, theoretically requires that the bidder reads and understands the nature of the project.

Designers and Owners have put their thoughts on the paper about the constructibility and tunnelling methods and dewatering considerations. Why not require "the successful bidder" to prepare such a report, putting his thoughts (or questions, if any) at the beginning of a major project, discuss the alternatives prior to his starting the job? I believe this will go a long way in clearing misunderstandings regarding the interpretive vs. factual data. If Owners and bidders cannot successfully resolve the difference of opinion in the beginning, it will be so recorded and greater attention will be paid to the details during the construction, and possibly may help in solving changed condition claims, which may arise at a later date.

Once again, I thank you for including me in your distribution.

With best regards,

DANIEL, MANN, JOHNSON, & MENDENHALL

Drupad B. Desai
Chief Facilities Engineer

DD/pr

cc: Dr. G. Brierly (Haley & Aldrich)

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June 19, 1979

Mr. Gary S. Brierley
Haley and Aldrich of New York
50 Chestnut Plaza
Rochester, NY 14604

Subject: Discussion of Position Paper of the Subcommittee on Geotechnical Investigations, UTRC Tunnel Lining Design and Construction Workshop

Dear Gary:

I have reviewed the position paper which was prepared by Dr. James P. Gould, Chairman of the Subcommittee on Geotechnical Investigations. My comments are subjective except where noted. To facilitate my response, I have listed my comments below under the appropriate subheading of the report:

II. Geotechnical Subjects Distinctive To Tunneling Planning and Design

In addition to the items listed in the report, two additional functions should be considered:

Line Item 5: The geotechnical information can provide an assessment of the probability that adverse geological discontinuities which may be encountered during construction which can have an appreciable effect on the proposed tunnel design and anticipated construction sequence.

Line Item 5: Recent studies indicate geotechnical information should address special topics such as the presence of large stray currents and caustic groundwater associated with underground subway schemes and how these conditions may influence existing and proposed structures planned in the vicinity of the tunnel alignment.

IV. Special Procedures For the Geotechnical Investigation

Consideration should be given for the use of geophysical techniques to locate geological anomalies which require additional subsurface borings to determine the extent and character of these anomalies.

VI. Presentation of Geotechnical Data

Utility information shown on drawings is usually design information since as-built drawings are seldom prepared. The contract package should include a statement indicating that the utility information shown on the plans has not been substantiated as to its correctness.

Arrangements should be made by the awarding agency for bidders to reproduce background information listed in the specifications at his own expense.

Representative soil and rock samples should be made available to prospective bidders to examine and test in their own laboratories.

In summary, I feel the position paper is complete and well organized considering the complexity of the interrelationships between the owner, architect-engineer and the contractor.

Sincerely yours,

GEOTECHNICAL ENGINEERS INC.

Richard F. Murdock
Principal

RFM:ms

CHAPTER 6

OBSERVATIONAL APPROACH

OBSERVATIONAL APPROACH IN LINING DESIGN - BY: JAMES MAHAR

UNIVERSITY OF ILLINOIS

I. INTRODUCTION

The observational approach for tunnel linings has been used primarily to evaluate the performance of initial support elements during construction or in-place linings adjacent to ongoing tunneling operations. With the use of thinner final linings and placement of openings in difficult ground, the observational approach has played a key role in successful lining design and construction. The observations of underground conditions serve the necessary link between design and construction by providing the engineer an opportunity to evaluate the design assumptions and the contractor a means of assessing the stability of the opening. In no case should the observational approach be used as a safeguard against inadequate design or construction methods, but it should be implemented to evaluate and if necessary modify design requirements or construction procedures that are based on the most realistic estimates of ground conditions to be encountered in the opening.

The observational program can range from inspection of ground and support conditions by contractor and resident engineer personnel to extensive observational and instrumentation programs depending on the purpose of the project, the complexity of the tunnel and/or ground conditions, and the consequences of lining failure. For many projects such as small diameter tunnels in high quality rock, the openings can be driven successfully using observations made by contractor and inspection personnel. On the other hand, for large shallow rock chambers in adverse ground extensive observations and instrumentation may be required to assess the stability of the opening and the performance of the lining. One of the key elements in the success of an observational program is the presence of experienced personnel who understand both the design and construction requirements and who have had extensive experience in observing rock and/or soil behavior and performance of support elements.

Four major topics are covered in this paper: the nature and types of observations, typical observational programs, methods of evaluating lining behavior, and the impact of observational programs on changes made during construction. The last topic includes a discussion of some of the contractural and legal aspects of directed changes in construction methods and support by the engineers based on observations of actual ground conditions and estimates of ground behavior ahead of the tunnel face.

2. TYPES OF OBSERVATIONS

The types of observations needed to assess the performance of a tunnel lining are basically: ground behavior, construction conditions, and behavior of the lining in response to ground movements. All of the observations and measurements in a given section of tunnel should be correlated in order to obtain a complete picture of the behavior of the opening. Observations in different sections of the tunnel should then be compared to develop stability criteria and to predict ground conditions and support requirements ahead of the face.

2.1. GROUND BEHAVIOR

The behavior of the rock and/or soil controls the mode of lining deformation and the mechanism of lining failure. In both rock and soil tunnels the forces acting to move the materials toward the opening are gravity, ground stresses, and water. The lining requirements and installation procedures are usually very sensitive to the ground behavior. For example in squeezing ground the permanent lining should be placed after some rock/support deformation has occurred at a time when the combined rock pressures and gravity loads are lowest. In loosening ground, the support should be placed immediately after exposure of the rock in order to maintain rock strength and minimize gravity loads.

At the same time the rock or soil behavior is being studied, the geologic conditions associated with the ground movement should be defined. The geologic factors that are usually most important include the rock or soil strength, ground water and state of stress, and in rock tunnels the geologic structures and weathering. Geologic details such as surface coatings or materials on joints may be very important and should be noted and evaluated in terms of expected lining behavior. In a given tunnel, rock and soil problems including associated geology usually fall into one or a couple of categories such as unstable rock blocks located in the crown and bounded by planar shears in the same joint sets. Study of the ground behavior and associated geologic features will assist in recognizing potential problem areas, predicting ground conditions in advance of construction, and estimating the magnitude and nature of the ground loads on the tunnel lining.

2.2. CONSTRUCTION CONDITIONS

Observations of construction conditions include the method of excavation, geometry of the opening, and the type and placement of the support. Again details are needed in order to properly interpret lining performance. For example, thin linings on an irregular tunnel surface tend to behave as membranes and, in loosening ground, may be subjected to eccentric loads and have capacities that are governed by their tensile and/or bending strength. On the other hand the installation of other support elements such as rock bolts may prevent the short and long term loads from developing on the lining.

Observations should also be made on the characteristics of the materials in the lining and on the chemistry of the ground water and soil or rock units. In some cases cracking and deterioration of a lining may be caused by lining shrinkage, deleterious materials in the aggregate, improper mix design, high dosages of accelerator and/or corrosive chemicals or minerals such as sulfides in the medium surrounding the tunnel.

2.3. LINING BEHAVIOR

Based on the observed geologic and construction conditions the expected behavior of the lining should be visualized along with the anticipated deformations that may result from the applied loads. The conceptual model of lining behavior assists the observer in recognizing and determining the level of significance of measured and observed deformation of the lining related to ground movements. Differences between expected and actual results may be related to unanticipated ground behavior or potential problems with the lining itself.

During construction, observations of cracks and lining deterioration and measurements of lining pressures and strains are made in order to evaluate the performance of the lined opening. The observations and measurements of lining behavior must be correlated with the geology and construction conditions in order to properly interpret the results. A more detailed discussion of field observations of lining behavior is given in Section 4.

3. OBSERVATIONAL PROGRAMS

3.1. REQUIREMENTS

The requirements for implementation of a successful observational program are:

1. Experienced personnel present on a regular basis.
2. Correlations between lining behavior and geologic and construction details.
3. If instruments are used they should be simple and easy to install, read and interpret.
4. Results processed quickly and data summarized in simple form for timely use in making on-the-job decisions.
5. Contingency designs developed prior to construction to handle potentially adverse ground conditions.

The use of instruments extends the observational capability of the observer into the rock or soil and into the lining and provides a means of early detection of potentially serious lining deformation. Not all projects require the use of instruments other than for simple measurements (such as opening of lining cracks) and can be successfully completed by making observations of tunnel conditions during construction. However, implementation of instrumentation into the observational program usually provides a better record of conditions that can be used both on the present project and in future work.

3.2. PRESENT PRACTICE

Formal observational programs that are beyond tunnel inspection usually include some type of instrumentation which is specified as part of the contract documents. In both specified and unspecified programs observations are made in the heading as the tunnel is advanced and behind the working face in areas that may be potentially unstable. The instruments are placed in advance of construction (from the ground surface) or as close as possible to the working face in order to obtain a complete history of ground movements and lining deformations. In all cases, it is essential that conditions be documented on a round by round basis so that potential changes in conditions can be recognized early and so that a full picture of geologic and construction conditions is obtained.

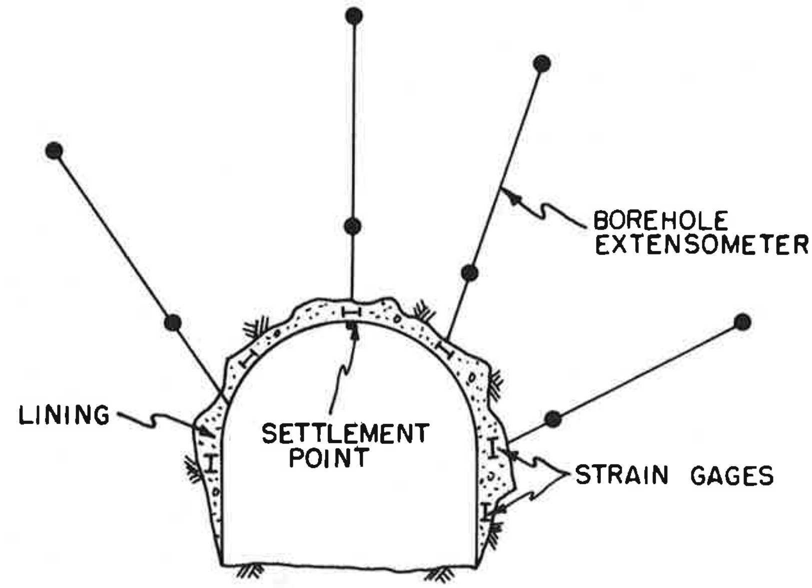
Typical instrumentation programs for linings in both rock and soft ground tunnels are shown in Fig. 1. Extensometers are used to measure rock and soil movements and strain gages and convergence points used to measure lining strains and diameter changes. For soft ground tunnels survey points are placed at the ground surface to measure the settlement profile. Inclinometers may be used to monitor soil movements into the tunnel face.

3.3. EUROPEAN PRACTICE

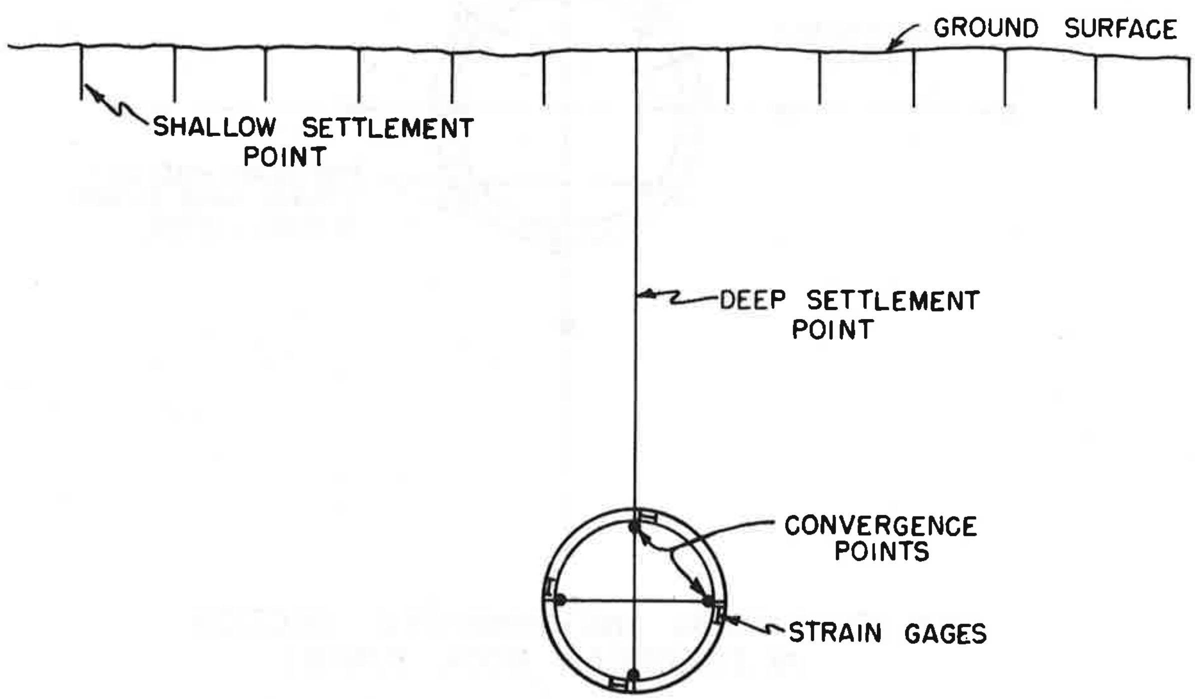
Observational programs in European tunnels are similar to those used in North America except that more instruments with closer spacing of monitoring stations are used in tunnel construction. A typical instrumented cross section is shown in Fig. 2. Main instrumented cross sections are generally spaced 100 to 500 m apart with convergence measurement stations located between the main cross sections and spaced as close at 50 m apart. The results of the instrumentation program are used more frequently than in the United States to modify the excavation procedures and the design and placement requirements of initial and final support systems.

4. EVALUATION OF LINING BEHAVIOR

One of the most important requirements for evaluating lining behavior is the development of criteria for acceptable levels of ground movement and lining deformation. For example, acceptable levels of rock movement in loosening ground are typically less than 5 to 10 times the calculated or measured elastic displacements. Acceptable lining strains are usually established at some fraction (for example 2/3) of strains required to reach yield. Different criteria will be used depending on the nature of the ground movement, the characteristics of the lining, ground/lining interaction, and serviceability requirements for the project.



A. ROCK TUNNEL



B. SOIL TUNNEL

FIG. I TYPICAL LINING INSTRUMENTATION

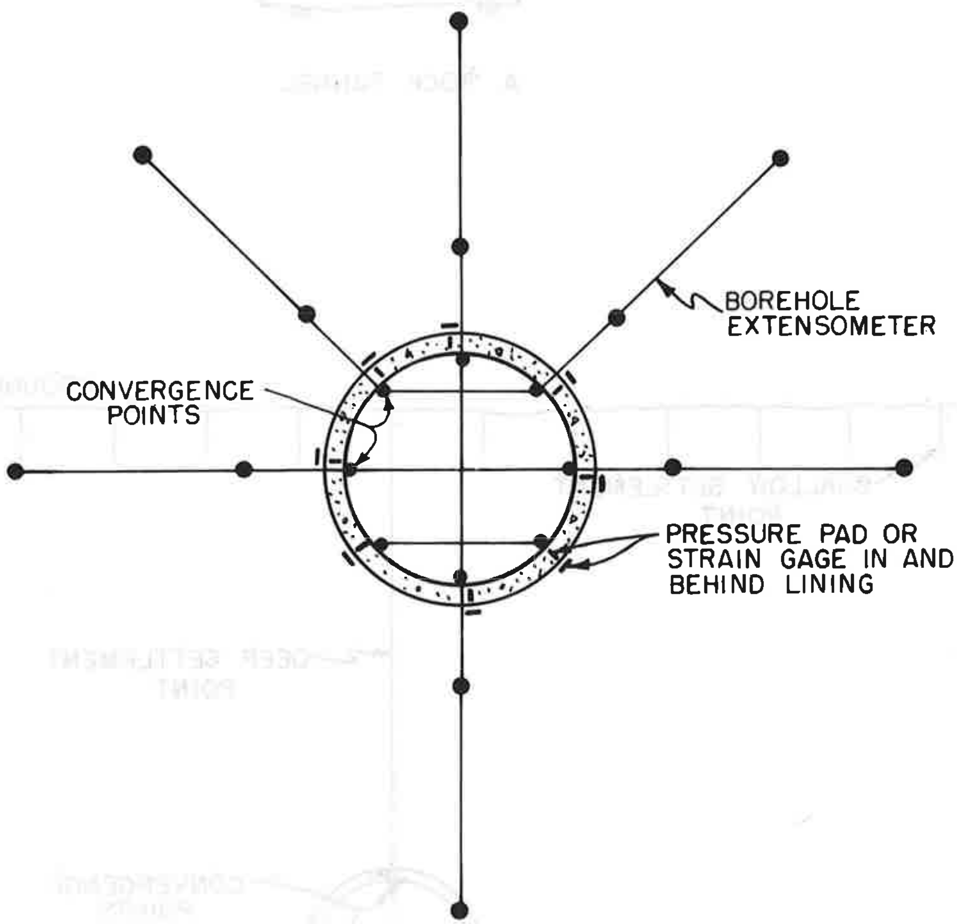


FIG. 2 TYPICAL INSTRUMENTED SECTION IN EUROPEAN ROCK TUNNEL

4.1. GROUND MOVEMENT

Ground movements at depth should be known in order to properly interpret the lining behavior. In most cases, measurements of ground movements are more important than measurements of lining strains or displacements because abnormally high lining strains may develop as a result of temperature changes, malfunction of instruments, or cracking of the lining in response to shrinkage rather than from rock loads. The most complete picture of lining behavior is obtained by measuring both ground movements and lining deformations.

In rock tunnels the measurements of displacements at depth can be used to evaluate the design assumptions and to establish the relative displacement capacities of the rock and the support system. For example, the depth and volume of rock in the zone of movement can be compared with the equivalent height of rock and rock loads assumed in design of the support system. In loosening ground, if all of the movement is taking place at or above the equivalent height of rock assumed in design, remedial measures should be contemplated and perhaps implemented even though the full gravity load in the zone of movement has probably not been mobilized on the support system.

In most lined tunnels in loosening ground the displacement capacity of the rock is usually less than that of the tunnel lining. However, in squeezing ground or loosening ground in which rock blocks are bounded by discontinuous structures, the displacement capacity of the rock may exceed the displacement capacity of the lining.

4.2. DISPLACEMENT CAPACITY

The capacity of the lining to undergo radial deformations is an important parameter used to evaluate opening stability. The displacement capacity can be calculated using the assumed loads and some type of structural analysis, or can be based on field measurements and model test results of lining capacity. The displacement required to reach yield or ultimate strength depends on the nature of the ground movement and on the thickness, ductility, and passive resistance of the lining. For the thin shotcrete linings in the Washington Metro tunnels, the displacement capacity ranged between 0.02 to 2. in. depending on the presence of rock shearing, the geometry of the rock blocks, and the localized mode of deformation of the lining. Rabcewicz and Gosler (1973) show that a tunnel lining in squeezing ground was still functional even after it had undergone a radial closure of more than 1 ft. The difference in the displacement capacity was related to the ground behavior; in the Washington case the lining was acting as a membrane and failure was primarily in tension and bending whereas in the squeezing ground case the lining was acting primarily in compression.

4.3. LINING STRAINS AND PRESSURES

Some of the most difficult measurements to interpret properly are lining strains and pressures. When strains are measured, the results are usually converted to stresses which are then compared with yield and ultimate stress values. Thrusts and moments may be estimated from calculated stresses and compared with moment and thrust values on a failure envelop of an approximate interaction diagram for the lining.

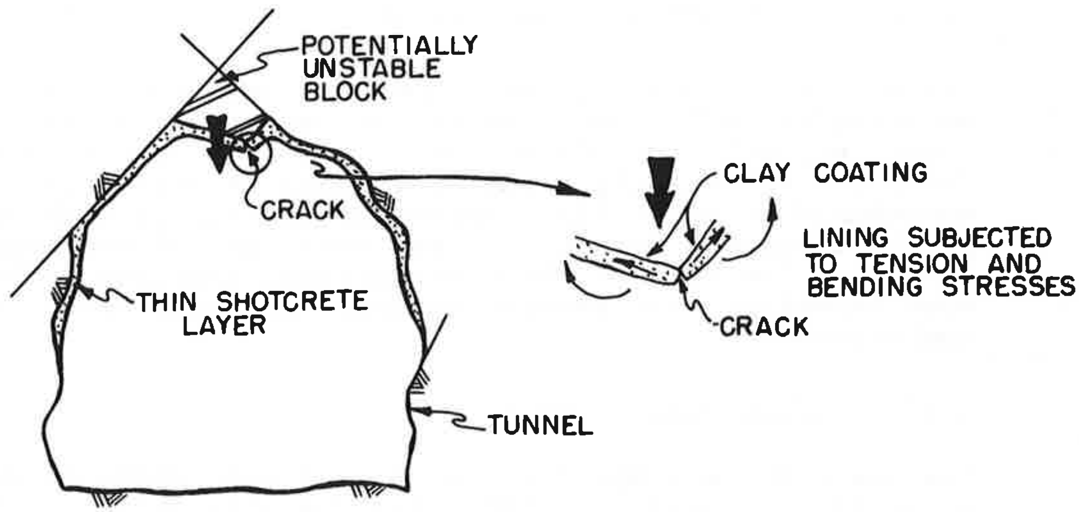
The use of strain gage results in assessing lining stress levels is difficult because of potential problems in selection of modulus, determination of strain (stress) distribution in the cross section of the lining, and corrections for temperature effects in thick linings. Modulus values can vary by a factor of 10 (particularly during initial curing and are usually assumed or are estimated from compression tests. In estimating the stress distribution, a sufficient number of strain gages should be placed without strongly affecting the behavior of the lining at the measurement section. Large temperature changes associated with curing of thick linings can produce substantial stresses that should be estimated and subtracted from total stresses so that pressures related to ground loads can be determined.

The use of stress meters may eliminate some of the problems of estimating modulus, however the stress meters are usually much less reliable and more subject to malfunction than the strain gages.

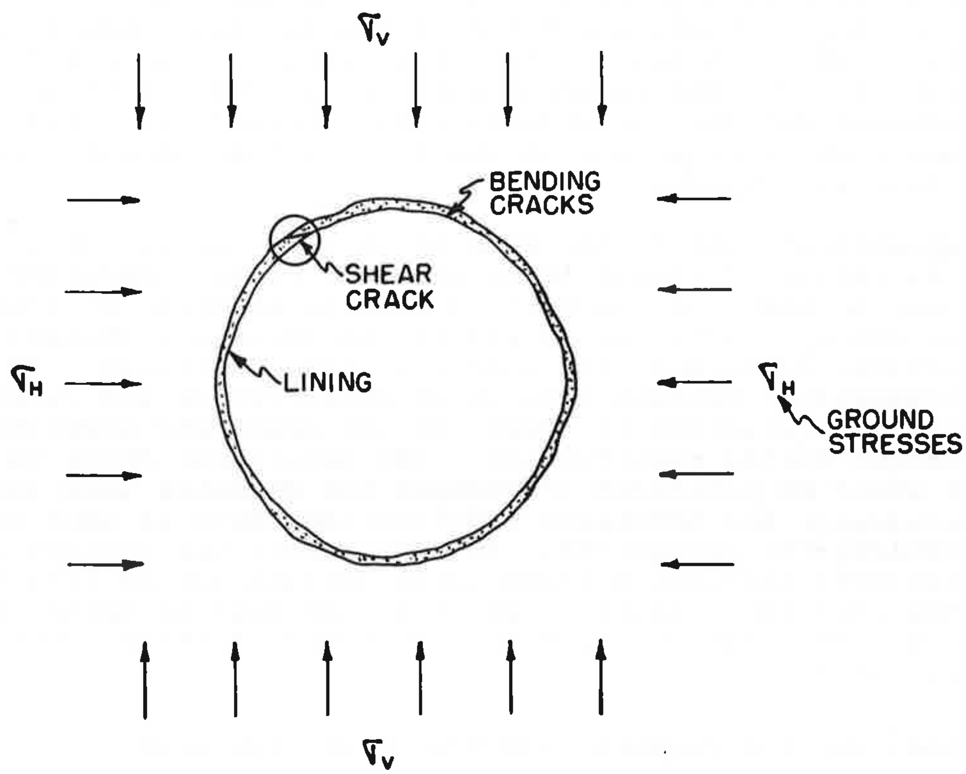
4.4. VISUAL OBSERVATIONS OF LINING BEHAVIOR

Cracks in a lining (particularly linings for initial support) can be sensitive indicators of lining performance and should be used with other observations and measurements in monitoring opening stability. The significance of a lining crack from a stability standpoint depends on the ground behavior and the mechanism of crack formation. For thin linings in loosening ground where failure is by tension and/or bending, the cracks may be very significant and the full load of a potentially unstable wedge with possible collapse may develop after the initial crack has formed (Fig. 3). In squeezing ground, a lining crack may not be as significant provided the lining is in compression and large loosening loads do not develop above the opening.

Cracks can also occur from shrinkage, deterioration, and improper placement of the lining. The effects of shrinkage and lining defects must be considered when using crack surveys to evaluate opening stability. In problem areas, shrinkage will tend to cause additional widening and lengthening of cracks, however the effect is usually small in comparison with crack development caused by additional ground loads.



A. MEMBRANE BEHAVIOR IN LOOSENING GROUND - POTENTIAL ROCKFALL



B. ARCH BEHAVIOR IN SQUEEZING GROUND - LINING ADEQUATE

FIG. 3 SIGNIFICANCE OF OBSERVED CRACKS

5. IMPACT OF OBSERVATIONAL APPROACH ON CONSTRUCTION

The use of the observational approach can have a real impact on construction efficiency, costs, and safety, and its role and scope depend primarily on the design philosophy and contract practices. There are essentially three approaches in design of linings: 1) non-adaptable 2) initial support by contractor with supplemental or final support directed by engineer, and 3) engineer-directed support. The role of the observational approach becomes increasingly more important with greater engineering involvement in construction operations.

5.1. NON-ADAPTABLE DESIGN

The observational approach is used in non-adaptable designs primarily to identify potentially unstable areas of the excavation and provide the necessary data for devising and evaluating remedial measures if needed. In many cases where potentially unstable areas or sections are delineated, both the owner and contractor are reluctant to take action because they do not want to compromise their positions in a possible claim of changed conditions. Oftentimes the work proceeds until the ground movements become critical and action must be taken to prevent possible collapse even though responsibility for the remedial work has not been settled. For non-adaptable designs the observational approach is rarely used to reduce support requirements where conditions encountered are better than anticipated.

Non-adaptable designs do not have to be based on extremely conservative estimates of ground loads and conditions. Moreover, the design can be based on the most reasonable estimate of ground behavior and contracts can be written to include a changes clause for equitable adjustment for unanticipated conditions. In reality, the non-adaptable designs tend to be conservative and owners and engineers are reluctant to recognize and negotiate geotechnical-type changes during construction. The additional costs to the project would be minimized if changes and disputes were resolved as they developed and necessary modifications made as soon as potential problems were recognized. In cases where the geology is known and relatively uniform, non-adaptable designs may be less expensive and allow more rapid rates of advance than designs based on use of the observational approach to direct construction procedures (Einstein 1978).

5.2. CONSTRUCTION CHANGES DIRECTED BY THE ENGINEER

On some projects, designs are being used in which placement of supplemental and final support is directed by the engineer based on results of detailed observations during construction. The contractor is still generally responsible for excavation, initial support, and safety. Prices for engineer-directed support and ground treatment are established as separate pay items in the bid quantities.

Placement of support and implementation of ground treatment measures directed by the engineer generally fall into two categories: 1. execution well behind the tunnel face or 2. execution close to the tunneling operations. The first case is exemplified by projects in which areas for placement of a final lining are decided by the engineer based on observations after the rock is exposed. The work is generally carried out far enough from excavation areas so that little to no interference occurs.

In the second category, supplemental support or ground treatment is directed close to or in the working area and will very likely affect tunnel progress for which the contractor is entitled to compensation for the extra work and any real delays. In addition the engineer must now assume some responsibility for safety during construction. Potential disputes may develop over initial and supplemental support requirements particularly in cases where the initial support is part of the excavation costs and directed support is paid for under a separate item.

The design approach that includes direct engineer participation in placement of construction support has been used successfully and may be a means for overcoming some of the problems of present design and contracting practices which in recent years have dramatically escalated costs for underground construction. Hamel and Nixon (1978) report that engineer direction of supplemental support based on observation and instrumentation results have minimized delays, claims, and cost overruns at one of the powerhouses of the LaGrande River project. In order to be successful, excellent cooperation must exist between the resident engineer and the contractor and the contract should be carefully written to delineate between initial and supplemental support requirements. The most suitable contractual arrangement may be one in which the engineer serves as an objective arbitrator between the owner and the contractor and the bid is awarded to the most qualified contractor who submits the lowest bid.

5.5. ENGINEER-DIRECTED CONSTRUCTION

In engineer-directed projects, the initial design is based on the most reasonable conditions expected and modifications are made during construction. The design maximizes direct use of the observational approach and must contain procedures for treating the full range of ground conditions that could be encountered. The engineer with contractor input directs both the excavation operations and placement of support. This method of design has been used most frequently in some of the European countries, particularly where the owner does both the design and construction work.

The required support must be versatile enough to control the expected range of ground conditions and should be available in sufficient quantity to prevent delays in tunnel progress. In tunneling, the support placement and quantities are changed to meet the specific ground conditions as they are encountered. The engineer must be able to recognize the ground behavior and must be familiar with construction equipment, procedures and capabilities.

Observations are made at the face to assess initial support requirements and instrumentation results are generally used to evaluate performance of the opening and the need for supplemental support or changes in tunneling procedures.

If uniform and good tunnel conditions prevail, progress rates may be lower and costs higher where construction is engineer-directed as compared with construction in which excavation and support is primarily a contractor responsibility. However, in tunnels where significant stability problems develop or changes in ground conditions occur, direct engineer participation in excavation and construction support may produce quicker settlement of real claims and provide for a more rapid and efficient solution of tunneling problems. If conditions are better than anticipated, support requirements can be reduced and possible cost savings realized.

In order to successfully implement engineer-directed designs in North American tunneling practice, changes will have to be made in present contract practices and methods of settling disputes. Contract documents will have to be more specific in setting forth excavation and support procedures yet flexible enough to allow for changes in construction requirements. One method used in Europe is to define sections of tunnel in which specific excavation and support procedures are to be used with provisions for changes based on observations of ground behavior and opening performance. Contingency designs must be available to handle unexpected ground conditions. Decisions on excavation and support procedures must be made rapidly as conditions are exposed and problems develop and procedures for making construction changes and settling disputes should be set forth in the contract. Two of the most important requirements for success of engineer-directed designs are: 1. the designer must be very knowledgeable of construction methods and requirements and 2. excellent cooperation must exist between the owner, engineer, and contractor. If engineer-directed designs are not carefully conceived and administered, then implementation in this country may produce overdesigned or inadequately designed tunnels at costs well above those that would be incurred if present contracting practices were used.

6. SUMMARY AND CONCLUSIONS

The observational approach should be used in all tunnel construction with the level of effort dependent on the purpose of the project, the difficulty of the ground and/or tunneling conditions, and the consequences of tunnel collapse. The observational approach should be used to modify design requirements or construction procedures that are developed assuming the most reasonable conditions and not to compensate for unconservative designs or construction procedures.

To be successful the observational program should be carried out by experienced field personnel who are present on the job and understand the design assumptions and construction practice. Detailed observations of geologic and construction conditions along with support deformation must be made and correlated so that a complete picture of tunnel behavior is obtained. Results should be rapidly summarized and presented in simple form so that timely decisions can be made as problems arise. Contingency designs should be prepared in advance of construction to handle potential problems.

The use of instruments extends the observational capabilities of the observer. The results can be used with other observations to evaluate opening stability. Criteria should be established prior to tunneling and modified during construction to evaluate the performance of the opening and the need for additional support or changes in construction procedures. Displacement measurements provide one of the best means for monitoring opening performance and results should be evaluated in terms of the displacement capacity of the rock and the support elements.

Implementation of the observation and instrumentation results in the project depends on the design approach and contract practice. Three basic design approaches are used: 1. non-adaptable, 2. changes directed by engineer, and 3. engineer-directed construction. The present trend in U.S. design practice is toward greater engineer involvement in directing construction operations with greater emphasis on measurements and observations. If the approach is to be successful, good cooperation must exist between the owner, engineer, and contractor and the engineer has to be knowledgeable of construction equipment, practice and limitations.

7. ACKNOWLEDGEMENTS

The author wishes to acknowledge and thank the members of his committee for their excellent comments, participation, and contributions to the position paper and in the discussions at this conference. The committee consisted of: Mr. John Davis - Monroe County Division of Pure Waters, Mr. Ted Davis - S.J. Groves & Sons Co., Dr. Herbert Einstein - M.I.T., Mr. Dan Goodwin - Atlas Copco Inc., Dr. Chih-Cheng Ku - Mass Transit Administration, Baltimore, and Mr. Dave Thompson - Haley & Aldrich, Inc. Special recognition is given to Dr. Einstein for his discussion on the requirements for implementation of engineer-directed design in U.S. tunneling projects given in the last part of Section 6.

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APPENDIX A

OBSERVATIONAL APPROACH COMMITTEE

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OBSERVATIONAL APPROACH COMMITTEE

FROM LEFT TO RIGHT:
CHIH-CHENG KU, JOHN DAVIS, DAN GOODWIN, JAMES MAHAR, TED DAVIS, HERBERT EINSTEIN, DAVID THOMPSON

DISCUSSION

MR. MAHAR: First of all, I'd like to thank the committee members who participated with me in the discussions yesterday: Mr. Dan Goodwin from Atlas Copco, Mr. Ted Davis from S.J. Groves, Mr. John Davis from Pure Waters in Rochester, Dr. Herb Einstein from M.I.T., Dr. Cheng Ku from Baltimore Metro, and Dave Thompson from Haley & Aldrich.

The discussions were fairly extensively oriented towards the legal and contractual aspects of the observational approach. One of the points that Mr. Davis brought out was that the engineers may be legally liable for not making observations, particularly where the contractors point out a specific problem or conversely a contractor may be legally liable for not performing observations if telltale signs of impending failure are present in the opening.

The rule of the observations and measurements I think really has to be defined, and we must be rather careful in terms of using the observational approach as a cure-all for our problems. When we make observations in a heading and we take a look at the ground conditions, obviously it's going to be very difficult to pinpoint all the problems that exist underground. There are certain instances and certain conditions where deciding whether or not a roof stability problem exists might be very difficult. One can have an opinion, as to whether or not a particular roof fall is going to take place, but certainly the observational approach may or may not predict that fall. One of the problems is that the observational approach really is geared towards individuals down there on a constant basis. There are certain instances where observations can be made, and one can pinpoint potential problems, but yet there might be conflicts or differences of opinion between the construction people who are putting in the support and the resident engineer in terms of what's required in that opening.

Observations themselves add to the evaluation both of the safety and stability and are really an important aspect in terms of heading support and heading problems. Even though the instrumentation may go in the heading or it may go in ahead of the construction, there may not be sufficient time to determine whether or not a heading support problem exists. Back further in the tunnel when we have a sufficient amount of data to make judgement and use the instrumentation effectively, then modifications can be made for additional support. But, the key is having those experienced personnel in the heading making the decisions with regard to safety and stability, and as it is right now that really falls under the contractor's role.

Also in terms of the observational method, there are certain instances where in using the observational approach we can't anticipate every problem that might be encountered. There are certain situations, buried channels, that without probe holes ahead of the tunnel, we may not realize that we're approaching a condition which is entirely different from the problem we're dealing with. So, the observational approach is really a tool to be used for the designer and the contractor in completing the excavation.

A major portion of the discussion was oriented towards identifying the roles and responsibilities of the various groups involved in the construction process, namely, the owner and the engineer and the contractor, and if each one of the individuals operates within their role and cooperates, projects can be handled very successfully both from the standpoint of stability and cost.

There was some discussion as to who should carry out the observational approach. Should we give the observational approach to the contractor and make him entirely responsible for the stability and safety of the opening, or should the engineer carry out the observational approach, and should he be making the observations and measurements.

I think we came to the consensus of opinion that really both groups should be involved in making the observations and measurements, and that they must cooperate in making decisions which are going to have not only an impact on the construction, but also on the economics of the project. It was the general consensus that certainly the designer should have a major role in the observational program. He is the one who established the design parameters. He is the one who knows how he expects that ground to behave.

There are certain instances where, as designers, we try to disassociate ourselves from the initial support portion of the project. We try to disassociate ourselves from construction. One method, of course, is to use disclaimer-type clauses. Another method is to use performance-type specifications. In the legal sense, really, the disclaimer clauses don't hold any weight, and as far as performance-type specifications go, the contractor, in making a bid, has to base that bid on what you represent in the contract drawings and documents and the available geotechnical information. You're responsible for that geotechnical information. Not only for the conclusions that you draw with regard to the permanent support, but also for the implications that are given to the contractor in making a basis for his bid.

There are five topic areas we discussed in terms of how the engineer and contractor fit together in developing the program. One is the program outline and philosophy. I think the general consensus was that this is really an engineer responsibility. He had been following through this project, for three to five years, he's been studying the conditions, he's been taking the samples, he's been making his design considerations even for the permanent support based on what his feeling is for the ground behavior and the conditions that exist. So certainly, he should be involved in what sort of instrumentation and what sort of observations should be made and how they fit into the construction. He should also be involved in the design of the instrumentation. Most contractors, unless they go to an outside specialist sub-contractor in instrumentation, don't have the background to decide what instruments are required. I think that for the most part, unless there's a cost item in the contract, the general feeling is that, well, perhaps we can drive this tunnel without the need for any instrumentation at all. Why bother having people putting in extensometers and making measurements, and telling us how the ground is going to behave, whereas, we've had the experience and we know how the ground is going to behave, and we can take care of the problem.

The physical installation -- there are really two different schools of thought here as far as installation is concerned. The geotechnical people were divided. Some people felt that the contractor should be making the installations either through a subcontract or in paricipation with the design team. My own feeling is that the design engineer should be making the installations in cooperation with the contractor. Too often design firms in specifying an instrumentation program will send people out in the field with insufficient experience to really get the full benefit of the instrumentation program. Some people simply install the instruments, read them and that's it. The guy won't go out and make the critical observations, not only for installing the instrument, but also for reading them and interpreting the ground conditions. There are problems if one uses this approach. One of the problems is that you might interfere with the contractor's operation, and indeed, if the program is set up for the designer to carry out the work, then the contractor should be warned of potential delays. Delays which will undoubtedly be a minimal amount, but delays nonetheless. Also, there was some discussion as to whether or not the contractor should do the interpretation of the instrumentation data. Should the contractor take that information and make adjustments in his operation. Certainly there can be instances where we come to an impasse between the field personnel and the resident engineer and the contractor in terms of what's required for a safe and stable opening. If you've got the data and the observations together, and you know how the ground is behaving, and you feel as though there's a problem; then you probably can convince both the contractor, the resident engineer and the owner that a problem exists and that some sort of remedial action is called for.

The data collection -- it was generally felt that the contractor could obtain the data for unsophisticated instrumentation such as surface survey points, observation wells and so forth, but that perhaps the engineering team should make data collection as far as inclinometer measurements go and some of the more complex instrumentation.

One of the interesting comments was made by Mr. Davis with regard to prequalification type specifications, and also selecting the individual who you thought was most qualified. It's been his experience that in the private sector there's really more problems with contract and contract type problems where the owner is able to select the person that he wants to work on that project than with public works projects. That's his experience.

Professor Einstein commented on the development of the observations and measurements in terms of design or engineer directed construction, and if this is going to become a viable method of design and a viable method of contract practice, he sees some changes that are necessary in order to implement this sort of approach. One of them is that the contract has to be very specific. It has to define those locations in the tunnel where you expect a certain type of ground behavior to exist and define a certain type of support requirements. It has to have an allowance for flexibility. There really has to be a multiplicity of designs that could be used to handle the ground conditions as encountered in the heading. There's really a variation in the amount of a common type of support that's used based on the observations and measurements in the opening. There also must be contingency designs for handling problems that might develop which are totally unanticipated. To use one of Tor Brekke's famous jokes, "We hit a solution cavern even though we didn't even know we were tunneling in a limestone."

Also, we've got to have a technical basis for making the observations and measurements really work. We can't proceed totally on intuition; that we've got a problem here or we don't have a problem. There has to be some sort of criteria that we use based on present observations and measurements and so forth to decide whether or not we've got a potential problem.

There has to be a tremendous amount of cooperation between the owner's representative and the contractor, and decisions have to be made fairly instantaneously. Those decisions I find are made fairly rapidly where you've got an impending problem.

Most contractors, when they see a problem approaching, will go in and take the initiative and try to prevent the problem. I think there's a tremendous amount of cooperation in those types of situations. In other cases where you have time for discussion it takes a little bit longer to make these changes and adjustments.

Another thing that is used in European practice, of course, is binding arbitration, which is an arbitrator on the job making the decision with regard to the contract and this is usually a technical person and that's probably acceptable for technical-type problems, but it may or may not be for contractual-type problems.

There were some comments with regard to over estimation, and Mr. Mathews in his opening presentation, made the comment that there are situations where we really over estimate the cost of openings, and there's no question about it. There's also instances where we've under estimated, and we've missed the boat. There are certain situations where I think that it may have been possible to show a potential problem. I won't mention any projects, but I can think of several that I've worked on that had failures that perhaps some sort of instrumentation and observation might have prevented. On some of the projects that I've been associated with I know that the instrumentation, indeed, did prevent a possible collapse. There was a very good likelihood that a collapse would have occured.

Also, there was some discussion with regard to a data bank, and true, there is a tremendous amount of information available out there. Even published information. I think that this information really needs to be gathered together, just the available information. Even beyond that, there's even more information that is sitting in people's files and records from all the jobs that exist. Good night, if you just think of the total amount of information that we've gathered at Washington Metro and how much is actually disseminated to the people involved, it's a fairly small amount. If you take a look at some of the problems in Washington, they are reoccurring type problems. Some of the collapses that we've had were associated with open excavations and shafts. It's the same sort of instability problem that has developed before. One of the reasons for it, I believe, is that the information really hasn't been carried forth and sent to the contractor. If the contractor, in his design, does not know that they've had heading collapses on other jobs, and if the designer assumes that just because he's a contractor, and he's working in the field, that he should be familiar with these problems, and he should know every detail with regard to opening performances and so forth, he's kidding himself. That information has to be made available and it has to be included and it has to be recognized. I think that's really one of the drawbacks with regard to the summary of the available data. It has to be summarized in a form that people can use it. Thank you.

MR. GUERTIN: Did you in your discussions address the question of the best way contractually to undertake a monitoring program in the ground?

MR. MAHAR: In some respects we did, Joe, in that we tried to decide who would be responsible for certain elements of the observational program with the instrumentation-type program, and there were discussions with regard to making it part of the contract specifications and requiring the contractor to perform the work; hiring an instrumentation specialist, having the instrumentation specialist responsible for making the installations and then also perhaps bringing him back during the interpretation stage. The other alternative is for the authority or the design engineer to set up a contract with a consulting firm to do the work through the authority. It depends upon where you want the information to go. If it's subcontract type of work, the information is going to go through the contractor. You're working for the contractor. You're employed in his services. If it's going to go the other route -- then it goes through the owner engineer.

MR. GUERTIN: I would like to make one short point. There's been monitoring programs under public projects in this country today. There's a move to do it on a bid basis. You'll have the contract documents, and you'll have a lot of instrumentation in the contract documents, and the contractor has to carry that, and sometimes there's a unit pricing schedule for it, and sometimes they just bury it. I would just like to make the point that I don't feel that's the way to do this kind of work. It's really an engineering function. It should be done as an engineering service. It can be set up. John Davis did it in Rochester, setting it up where it was funded and handled through the construction documents and through the contract. By bidding it you kill flexibility. The average contractor, and not putting contractors down, but they are in the business of building tunnels and, in general, they regard some of these monitoring programs as a nuisance for somebody who is in their tunnel and in the way, and it will affect the quality of work. The people who are setting these things up, I feel, should consider doing things like John Davis did in Rochester, some things that are going to be done in Buffalo and some things that are going to be done here in Boston where contractual arrangements are more flexible.

MR. GARBESI: I would like to comment on about working for private owners versus public agencies. Our company and parent company have been in business for fifty years. We've never had a dispute with a private owner, and we've always been able to work out our problems and settle the contracts a few days after the work has been complete. As I say, it's our experience that this confrontation type posture doesn't exist with private owners when you're prequalified to bid.

MR. MAHAR: Ted, would you care to comment on that, please?

MR. DAVIS: Well, let me say, I was in the private sector for sixteen years. I've been in the public sector for about seven years as a lawyer, and I can tell you that the confrontation in the private sector is just as bad as it is in the public sector, and that's where they picked the contractors. You've got to recognize the problems that exist. I agree with everyone in the conference that instrumentation is primarily an engineer's function because he started out and determined what the ground conditions would be, and what he expected, and his designs were built around it, and now he needs to adjust from there. The thing that he's got to recognize, however, is that he may, because of timing and various other things, increase the contractor's cost, and when he does so, he should recognize it and pay for it. That's where we come into cooperation. He needs to recognize what he's doing to the contractor and recognize that when he does this, if he anticipated coming in in July and putting in instrumentation, and now he gets it in in December, the ball game has changed for the contractor. Consequently, the increase in cost should be paid by him or by the owner because the terms and conditions of the contractor changed. That's the thing that we need. As far as I'm concerned, one of the things that we get away from here, both in the private and public sector, and I guess my experience is different than my friend up here, but what you really need is the cooperation. I still say, and I said it in the conference, our goals -- really look at the goals of everybody that's involved in a project; good quality within the time schedule, within the budget. Now, those budgets may be different but the contractor has his budget, and his estimated costs. When you affect those costs, you've got to recognize it and that's true with instrumentation, and that's true with everything else. So, there's where you get the confrontation. Have I addressed it properly?

MR. MAHAR: Well, there are certainly differences of opinion with regard to the private versus the public sector, and the ability to choose the contractor. Certainly, this practice has been used in Europe and fairly successfully where the bids are placed, and you don't necessarily have to take the lowest bidder. At least there have been some indications that people felt that this was a better contracting practice.

MR. BRIERLEY: How do you see that relating to the instrumentation aspect or observational aspect?

MR. MAHAR: Part of it depends upon the cooperation, and also, part of it depends upon the economics. If the economics are bad to begin with, and you end up starting off on a bad foot -- if you've left ten million dollars on the table, and it's a twenty million dollar contract, two things are going to happen. You're going to have some animosity to start off with, and the instrumentation could end up suffering, or it's going to be used as a vehicle for a changed condition. Either a real condition or a fabricated condition. There's no question about it. In many respects it serves as the basic data for deciding whether or not, indeed, the conditions are changed. If the reason for the discrepancy in the bid was because of a changed condition, certainly it should be taken care of. I think the important aspect of it is really cooperation. That cooperation has to be there. It has to be there between the engineer and the contractor as well as the instrumentation team. Without it, it's going to be a big hassle, and nobody is going to gain any information from it.

MR. LEVITT: I worked with Herb Einstein a year or two ago looking at what were some of the legal and institutional barriers in the U.S. to adopting observational practices, and our conclusion was there were no legal restrictions. It's quite feasible to do it under the unit price contract. You have the same problems you have in highways or dams with unit price things like this, but there are ways to deal with that. The owner can set the unit prices in some cases, and you can get around that problem, but I think the other problem of the traditional role of the engineer versus the role of the contractor is something that doesn't suddenly go away because it's an observational project, and especially if the engineer finds himself in a very difficult situation of perhaps having to tell a contractor, "you should use less support." I say, "you should use less support than you say you want to use," and then inherently assuming some liability for the potential failure of the tunnel, and having a European designer/contractor and working in that environment where it's really more of a design-build then a design and then construct kind of arrangement. I'm not sure that's going to go away very easily, so where there is not institutional barriers, there are certain barriers in roles and responsibilities and traditional views of what professions are. I think, if, in fact, there is some evidence that the observational is less expensive in some kinds of ground conditions, then we might have to bite the bullet and say what we need is to reorganize the alignment of the actors in the industry and use some of the flexibility in the Federal procurement and other procurement arrangements to do something like design build or in some way to alter the existing structure so that the parties are not put in the traditional adversary relationship in a situation that really requires a tremendous amount of cooperation.

MR. MAHAR: Those are good comments. I also think that contractors and designers both are willing to try new things and new approaches, and I think both of them realize some of the potential problems with the escalation of costs, and I think that conferences like this really allow you to air certain restraints and develop ideas and concepts that can have a tremendous impact on financial conditions in the contract.

MR. PARKER: I have a point. Joe, one of the problems is funding and where the funds come from and those that determine the roles. If you were to elabroate just briefly on what was done at Rochester, that would be helpful.

MR. GUERTIN: There are two ways to go with instrumentation as we see it. Rochester was one way where a specialist was obtained to provide services for rather extensive monitoring programs, and it was done through the construction contract, and the specialist had a contract with the general contractor on the project. The engineer controlled the program, but it was funded through the contract, and it was done against some allowance item in the contract. There were several allowance items. One for drilling, one for professional services and so on, and it was done that way on more or less a force account basis. It seemed to work quite smoothly. In Buffalo, in the upcoming subway there, and also on some of the work from the Red Line extension here in Boston. It will be done where the specialist will work for the owner, but there will be a section in the construction documents to provide for allowance items to do some of the work that needs to be done. Things that can be easily defined are unit priced. You know, drilling holes and installing extensometers. There's a unit price for NX drilling. If you need some support from the contractor, and you need a couple of laborers, you need an electric power somewhere, he can provide it, and it will be paid for on a force account basis and reimbursed against an allowance item which is in the contract.

As part of the specification, there's a requirement that the contractor assign one of his senior project management personnel to interface on the monitoring program. We talked about cooperation, and I can't agree with you more, Jim.

In an attempt to develop the spirit of cooperation, to compensate the contractor fairly for any inconvenience you may cause him, and hopefully everything will go smoothly. The specialist will be working for the owner, and funded against the allowance.

MR. GARBESI: From one contractor's point of view, we prefer to have the geotechnical people work for us in the tunnel. We think the specifications can be written so the information goes immediately in both directions: to the general and to the engineers. We've done it both ways, and we find it is a much smoother job if we can work directly with the geotechnical people and schedule them in the tunnel, and we think the communications are a lot better.

MR. GUERTIN: Let me ask you a question. Do you have any feeling about bidding the work versus doing it the way we did it in Rochester?

MR. GARBESI: The Rochester arrangements were great. We didn't have a problem. We think that it's easier that way in that we're not that keen on how much something should cost from a geotechnical point of view.

MR. ROSSUM: If you were to accept the team effort or cooperative effort, doesn't that imply that the engineer has now taken over full responsibility?

MR. MAHAR: Certainly the engineer is put in a decision-making role along with the contractor. Ultimately, he may end up being responsible for the supplemental support, in any event. I mean, obviously, if a potential problem develops, no matter who the geotechnical people are working for, the contractor and the engineer are going to get together and decide what's going to be done about that particular problem. There's always the difficulty that the engineer is afraid to tell a contractor, "you go in and put in an additional support," because he's opening himself up for the possibility of a changed condition claim. By the same token, if that support is needed, and it is something outside the main scope of the contract, then the engineer should make that decision, and I believe that for a lot of these instances, you're much better off making the decisions early in the ball game than letting the situation go to where you've got a potential impending collapse.

LETTERS

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17 May 1979

Gary S. Brierley, P.E.
H & A of New York
50 Chestnut Plaza
Rochester, New York 14604

Reference: Observational Approach in Lining Design

Dear Mr. Brierley:

I received Jim Mahar's paper as a member of his committee. I find his paper completely satisfactory but have the following comments.

I think it should be emphasized, as in my comments to the earlier drafts, that failure of the engineer to take the observational approach, regardless of what kind of contracting method is used, might result in suit and/or liability for negligence or malpractice. Of course, litigation always depends on the right set of circumstances or factual situation. For example, under 5.1, Non-adaptable Design, suppose the engineer does not use the observational approach. Actual rock conditions during construction differed substantially from those anticipated by the designer when he formulated his design. The contractor builds to the design and it fails because changes were not instituted. Then, the engineer would probably find himself in litigation and likely would find the judge or jury holding that he was negligent due to his failure to make observations and correct his design assumptions.

The final paper, relates essentially three approaches to the design of linings, classifying them as non-adaptable, changes directed by engineer and engineer-directed construction. While this classification might be valid to the engineer, a contractor who must read and execute the design would not know or recognize that classification. Therefore, at the outset, there probably would be a failure of communications.

The type of contract has nothing to do with good communications or lack of communications. All a contract does, regardless of classification or type, is set forth the parties' understanding and most often in our industry it is written by the engineer in the form of drawings and specifications.

Engineers are notoriously weak in communications skills and, thus, the owner and engineer, and his lawyer, instead of recognizing the weakness and strengthening these skills, devises all kinds of exculpatory clauses to protect the owner and himself from the weakness and/or unanticipated events occurring during the construction phase of the tunneling. (See the standard clause for checking the drawings and specifications and calling mistakes to the engineer's

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attention. Also, see the standard clauses stating that the engineer used the borings to formulate his design, but contractor should not rely on them. They are for information only.) What does "for information only" mean? Everything an engineer provides the contractor is information and the use of such wording is ambiguous.

Moreover, the paper states: "In order to successfully implement engineer-directed designs in North American tunneling practices, changes will have to be made in present contract practices and methods of settling disputes." I submit that present methods of contracting do not need changing. What needs change is, not only the examination of the contract documents for better communication and less hedging, but also the attitudes of the contracting parties when that expression is nonexistent, inexact or ambiguous. For some reason we have an adversary approach to building a project and over the years have built up this adversary approach, particularly under certain type (fixed price) contracts. Why should an engineer believe that if he didn't anticipate the event, the contractor should have? Also, when the engineer knows he anticipated the event, should he not examine the drafted documents to make sure he expressed that expectation in clear unambiguous language? Should a contractor expect to be paid twice for an event he anticipated but about which the contract language is ambiguous?

Many engineers take the approach at the jobsite that their sole function is to keep the contractor from making money on extras instead of deciding that a clarification or revision is necessary and establishing his reasonable price for that clarification or revision. Likewise, the owner takes the same position. Yet, the objective of all three parties is to build the project within (1) a reasonable cost, (2) a reasonable time, and (3) a reasonable quality. There is an axiom which we often forget, and that is most of the time the owner gets exactly that for which he pays.

Contractors or engineers or owners are not universally dishonest, nor do they universally try to beat the other party out of something. I submit to you that <u>any contract</u> procedure will work if the parties take the position that all actions by any one of them must be fair and equitable and that each party must perform his function in a professional manner, and with the utmost integrity and ethics. In other words, the owner should get the facility (tunnel) which the engineer designed. The engineer and contractor should get paid a reasonable amount for their function, including a reasonable profit. Otherwise, they cannot stay in business.

From the contractor's standpoint, it often seems that someone wants to get something for nothing. From the engineer's and owner's position, the contractor is always making a bundle and finding loopholes to collect more money. Yet, more businesses go broke in construction than any other industry. What happened to the old fashioned word, trust? The fault is not that of the type of contract. It is lack of communication and distrust that the parties have built up over the years.

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17 May 1979
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As I stated at the last conference, I am firmly convinced that we have sufficient legal flexibility and contracting procedures. There is a method of contracting which will work and serve all the owner's objectives, including experimental, such as getting a contractor in to perform functions on the job prior to design being completed. All we need use is the correct procedure.

Yours very truly,

S. J. GROVES & SONS COMPANY

Theodore T. Davis

Theodore T. Davis
Corporate Counsel

TTD:vh

cc: Dr. James Mahar

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May 28, 1979

Dr. Gary S. Brierley
H & A of New York
50 Chestnut Plaza
Rochester, New York 14604

Subject: Observational Approach in Lining Design

Dear Dr. Brierley:

Most of us in the business of underground construction are aware that due to its unique nature the most logical approach to the design and construction of tunnels is an observational one. The successful use of New Austrian Tunneling Method in Europe demonstrates amply the merit of this approach. Unfortunately, the current contractual practice in this country doesn't readily permit the use of the observational approach. With ever increasing construction cost, it becomes more urgent that the observational approach to the design and construction of tunnels be introduced into the contractual arrangements.

One of the encouraging developments is the requirement of the designer to prepare a set of technical reports (called geotechnical report, design summary report). These reports should include detailed subsurface information, analysis and interpretation of significant geologic features and material properties and their effects on the design and construction. These reports have been incorporated into the bidding documents, for example, in Baltimore Region Rapid Transit and Washington, D. C. Metro projects. It can be hoped that this is a small step in the direction to the use of the observational approach to the design and construction of tunnels.

Sincerely yours,

C. C. Ku

C. C. Ku

CCK/kmb

cc: Dr. James Mahar
University of Illinois
2207 Civil Engineering Building
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An Administration of

CHAPTER 7

SPECIFICATIONS

UNDERGROUND TECHNOLOGY RESEARCH COUNCIL

TUNNEL LINING DESIGN AND CONSTRUCTION WORKSHOP
Cambridge, Massachusetts
March 12-13, 1979

POSITION PAPER

TUNNEL LINING SPECIFICATIONS

TUNNEL LINING SPECIFICATIONS

I. INTRODUCTION

A. Purpose of the Paper

1. Assist in creating better contractual relationship.
2. Reduce the number of change orders and claims.
3. Encourage contractor innovation.
4. Reduce tunneling costs.
5. Provide a discussion of problem areas concerning tunnel lining construction for those who do not have experience in all of the myriad aspects of this work.
    a. List of technical provisions pertaining to tunnel lining in Appendix B.
    b. List of contractor activities pertaining to tunnel lining in Appendix C.

B. Definition of Terms

1. Contract documents include:
    a. General Conditions and Contract Provisions.
    b. Technical Provisions.
    c. Engineering drawings.
    d. Geotechnical reports.
    e. Supplemental data (available upon request by contractor).
        1. Drawings of adjacent utilities.
        2. Building plans.
        3. Design criteria.

C. Purpose of Contract Documents: to define the type of end product desired by the owner and the constraints under which this product must be furnished.

D. Desirable Characteristics for Tunnel Lining Contract Documents

1. Clear and concise.
2. Minimal use of exculpatory phrases.
3. Performance type specifications are usually more desirable than method-material type.
4. Bid schedule item for mobilization should be included.

E. To obtain a quality tunnel lining, contract documents must be (1) tailored specifically to meet the requirements of each particular job, and (2) properly interpreted and enforced by construction management personnel.

II. PRE-BID DISCUSSIONS

A. Reasons Discussions are Needed

1. To create interest in bidding.
2. To cut down on addenda (supplemental notices).
3. To increase understanding of designs by inspection and contractor personnel.

B. Techniques

1. Inspection of construction site by contractors.
2. Drill core showings for contractors and tunnel boring machine manufacturers.
3. Discussion meetings incorporating specification writers, design engineers, geotechnical, legal and construction personnel.
4. Preparation of document entitled "Construction Considerations" by design engineer.
5. Conference with contractors after contract documents are published.
6. Written or telephone inquiries by contractors.

C. Time Allowances for Preparation of Bids

1. Small contracts (less than $5 million) 5 weeks.
2. Large contracts (greater than $30 million) 9 weeks.

III. GENERAL CONDITIONS & CONTRACT PROVISIONS

A. Informational

1. All data available to the engineer should be made available to the contractor. A geotechnical report (memoranda) should be a mandatory part of the contract documents. All other general data such as old reports, drill core boring data banks, building foundation plans, etc. should be added as supplementary information.
2. The geotechnical report (memoranda) should be detailed sufficiently to form a basis of the overall subsurface conditions that should be expected.
3. A prebid conference (or conferences) should be held on all projects. Further discussion on this point is given in Appendix D.
4. The engineer's estimate of cost should be published as an expected range (say 10 to 15 million) and consideration should be given to stating what the <u>maximum bid</u> could be.

B. Contractual

1. Project delay - The contractor should be reimbursed for his added costs resulting from delays (other than strikes) that are not caused by him. This would include the delays resulting from (1) abnormal time required for issuance of orders to proceed with the work (the start), (2) community actions, and (3) abnormal time required for engineer's approval of contractor's

drawings. The contract should therefore include specific turn-around times for the contractor's submitted drawings, e.g. 30 days for 1st submissions, and 15 days for 2nd submissions.

Similarly the contractor should be required to pay for excessive submissions of drawings, e.g. the engineering costs involved in reviewing drawings after the 3rd submission.

C. Payments

Payments to the contractor should not be based on a minimum dollar value. The contractor should receive a payment each month.

D. Mobilization

All contracts should include a mobilization item, with the amount dependent on the type of project.

E. Estimated Quantities in Bid Schedules

A plus and minus % deviation for estimated quantities should be set - with a revised payment established when quantities do not fall within this deviation. A plus or minus 15% figure has been recommended for consideration.

F. Type

Performance type of specifications are advocated for all work items where applicable.

G. Escalation

Where legally permitted, escalation clauses should be included for all projects where the contract time exceeds 24-30 months. The absorbed cost (by the agency) could fall between 75 and 100% of an escalation criteria. Escalation clauses are suggested to cover hourly labor and materials or be tied in to some escalation index.

H. Exculpatory Statements

The Committee recommends that efforts be made to minimize the use of agency disclaimers - and to reduce usage of the expression "as directed by the engineer."

I. Changed Conditions

All contracts should include a changed condition clause - with the geotechnical memorandum a major element in the determination of the changed condition. We suggest that the changed condition clause have a plus and a minus criteria, with (1) additional payment due the contractor for more severe subsurface conditions, and (2) credits to the owner for better conditions than expected.

Please note that the changed conditions clause tends to reduce the restraint on a contractor - and that closer review of the contractor's procedures are mandatory when such a clause is incorporated in the contract.

J. Non-Binding Arbitration

Favorable consideration should be made given to including provisions for ongoing, non-binding arbitration to resolve disagreements between the contractor and the agency.

K. Methods of Construction

The methods of construction should generally be left to the contractor - within contractual restraints. General field design criteria used by the agency should be part of the supplementary data of the contract.

L. Alternative Bids

All alternatives acceptable to the agency/engineer should be spelled out. All options that will be accepted should also be spelled out.

M. Innovation

The majority of the Committee believes the contractor should have maximum latitude for innovation - the minority believes that contractor innovation should generally be limited to methods of construction so long as all acceptable alternatives and options are spelled out in the contract.

It follows that the majority believes a value engineering clause should be included - the minority does not.

Time was not available for the Committee to address itself to the troublesome subject of calling for temporary support - nor for contract set-up...i.e. lump sum, cost per lin. ft., or unit price contract. These subjects should be studied by a future group.

IV. TECHNICAL PROVISIONS

A. Cast-in-place concrete lining.

1. Preparation for concrete placing.

a. Specifications should not require more extensive invert cleanup than absolutely necessary for adequate functional performance of the tunnel.

b. Wedging and barring of semi-detached rock blocks and "dinner plate" cleanup is generally unnecessary.

c. Cleaning of joints and fractures in rock is not required unless piping is a concern.
d. Removal of traffic compacted muck, ties and rails and timber outside "A" line is often unnecessary. (A minority of the Committee considers the "B" line to be more appropriate.)

2. Forming

To the extent possible, forming techniques should be left to the contractor. Specific examples are given below:

a. Do not specify invert placement first unless a clear design reason exists.
b. Specifying long strip times for tunnel forms increases construction cost and time required for completion of the work. The specification intent should be to minimize stripping time, perhaps by using criteria such as "no sag."
c. Acceptable concrete joints should be shown on the plans.
d. Form windows should be spaced on 8-foot centers (for forms that are supplied in 4-ft. length increments) or 10-foot centers (for forms that are supplied in 5-foot length increments).

3. Tolerances

a. Specified tolerances should not be more stringent than required by the function of the tunnel. The following tolerances are suggested as economical, although they may not be practical considering the size and functional use of the tunnel.

	Fluid Conveyance	Rail Transit
Line	18"	6"
Elevation	±3"	±2"
Corrections	2%	1/2%
Size	-0", +24"	
Offsets	longitudinal 1", circumferential 1/2"	
Chording	to allow unbroken 30' form panels	

b. Fluid conveyance tunnel hydraulic design should be adjusted to allow for the tolerances mentioned above.

4. Placing

a. Many concrete placing techniques for surface structures are not applicable to tunnels.
b. Pneumatic placing and slugging should be allowed, as well as pumping and conveying.
c. Slump loss restrictions must be modified to reflect tunnel haulage and placement requirements.
d. Drop pipes and boots should be allowed whenever practicable.

5. Joints

a. To the extent possible, joint spacing should be left up to the contractor.
b. Sloping construction joints should be allowed in both plain and reinforced concrete lined tunnels.
c. Maximum construction joint cleaning should be that which can be accomplished by an air-water jet.
d. Unreinforced concrete tunnel linings will crack circumferentially every 15' to 20'.

6. Contact or Backfill Grouting

a. Grout holes are generally specified on five-foot centers, with additional holes as required for grouting and venting of high spots or over-break.
b. Maximum grout pressures should be 30 psi. Grout strength is not critical, but enough cement or bentonite must be used to assure pumping the grout into all voids.

B. Although shotcrete and/or precast concrete segments are sometimes used for tunnel lining, time was not available to the Committee to agree upon detailed recommendations to specifically cover these types of lining.

V. PRECAST CONCRETE SEGMENT LINING

In the past 10 years a number of tunnels have been or are being constructed in North America using precast concrete segments for support and final lining. A partial list of these tunnels is given below:

	Tunnel	Type	Bolted or Unbolted	Finished diameter (feet)	Owner	Length (Miles)
1.	Buckskin Mountains* Parker, AZ.	Free flow water conveyance	U	22	U.S. Bureau of Reclamation (USBR)	7.0
2.	Stillwater* Duchesne, UT.	Free flow water conveyance	U	8.25	USBR	7.0
3.	Parker River* Hartford, CT.	Pressure-storm sewer	U	22	U.S. Army Corps of Engineers	1.7
4.	Stevens Creek Culvert under I-205 Cupertino, CA.	Free flow water conveyance	U	22	California Dept. of Transp.	0.11

	Tunnel	Type	Bolted or Unbolted	Finished diameter (feet)	Owner	Length (Miles)
5.	East Portland Freeway Crossing, Portland OR.	Storm drainage tunnel	U	8.0	Oregon Dept. of Transp.	1.14
6.	Toronto Subway	Subway	B	16	Toronto Transit Comm.	6.0
7.	Neebing-McIntyre Sanitary Trunk Sewer	Sewer	U	7.1	City of Thunder Bay, Ont.	2.1
8.	Lexington Market Line* Baltimore, MD.	Subway	B	17.8	State of Maryland, Dept. of Transp., Mass Transit Administration, Baltimore Region Rapid Transit System	Experimental Reach
9.	Mexico City (Tacubaya Tunnel)	Subway	U	27.8	Sistema de Transporte Colectivo (Mass Transit System) of Federal District of Mexico)	0.7

*Under Construction

Although several successful patented precast concrete segment liner systems have been developed in Europe, no one universally accepted system has yet evolved in the United States. It is interesting to note that each of the tunnels listed above has incorporated a different shape of joint and sealant system. The fact that the many different configurations of joints have actually been used successfully in some 25 miles of tunnels is a tribute to the ingenuity of contractors and their consultants. In tunnels 1, 2, 4, and 5 above, segment joint configurations that were shown in the specifications drawings were not used by contractors. Instead the contractors submitted joint configurations prepared by their consultants that were accepted by owners. This was accomplished under Value Engineering on tunnels 4 and 5.

Although the precast concrete segments have been successfully erected and have adequately supported tunnels 1 and 2 listed above, only random watertightness tests have been made to check on the ability of the miles of joints to prevent leakage from the tunnel. Prototype ponding tests are planned for both tunnels but these tests cannot be made until the tunnels are completed several years from now. (A need exists for a compilation of tunnel leakage data and the chairman of this committee hereby solicits information from organizations that have made leakage tests).

When alternate contractor designs for precast concrete segment lining are permitted in the specifications, provisions also should be made for (1) erection of a test section of segments to be fabricated and erected outside the tunnel, and (2) water tightness tests to be made on the test section.

When calked joints are specified, some difficulty has been experienced in obtaining proper insertion and tooling of the calking compound in the grooves. Continual threats to shut-down the work have been necessary in many cases to force contractors to (1) apply calking in a proper manner and (2) set segments within specified tolerance limits.

Experience has shown that as many as 25 to 30 percent of precast segments in a recent tunnel have exceeded the 1/4-inch allowable offset tolerance between segments. In cases of this type designers should (1) obtain frank contractor appraisals why specifications are not reasonable and (2) reevaluate their designs to accommodate more reasonable expectations; e.g. if segment offsets cannot be held to a 1/4-inch tolerance an option might be given to increasing the tunnel diameter very slightly and allowing 1/2-inch offsets on the segments. Other options for segments that should be considered are an alternate bid with a contractor design or performance type specifications rather than a method-material type specifications.

Much experimental work has been accomplished and research is now underway on sealants and sealing systems for joints for segments. Examples are the Bureau of Reclamation's (1) standard specifications entitled "Tentative Specifications for Edge Sealant for Precast Concrete Tunnel Liner Segments," and (2) continuing laboratory research program on Segmented Concrete Tunnel Liner and Sealant Systems Study funded by the Department of Transportation's Transportation Systems Center. Published results of the tests described in item 2 above are anticipated in 1980.

VI. VALUE ENGINEERING

In recent years there has been much discussion concerning the desirability and usefulness of Value Engineering (VE) clauses in tunnel contracts. This Committee recommends that a VE clause be considered for all future tunnel contracts as one method to encourage contractor innovation. Although a VE clause may be most appropriate for use in above ground construction contracts, this clause provides needed encouragement to contractors to inject their vast knowledge and experience into the complex process of obtaining a least costly end product. Special consideration should be given to including a VE clause in the contract documents when (1) designers are not adequately familiar with the construction process, and (2) when conditions require a method type specifications rather than a performance type specifications.

The Committee is aware of several cases where VE proposals were made by contractors and accepted by owners. In 1978, the Baltimore Rapid Transit Authority reported accrued savings of about $500,000 on $250 million worth of work under construction (about 18% complete).3 The use of precast concrete segments, in place of a conventional concrete lined tunnel, was allowed for the Stevens Creek Culvert in California and the I-205 Crossing in Oregon listed in Section V of this report.

The U.S. Bureau of Reclamation has not reported any savings from VE proposals on tunnel contracts although a VE clause has been included in the contract documents for the last 15 years. One proposal, that was submitted on a $14.8 million water conveyance tunnel, received an extensive and expensive in-house review and was approved. The contractor then began implementation of his proposal, and after a trial run, decided his construction technique was not economical. He then did not carry out the terms of his proposal. In this case a considerable expenditure of both contractor and owner time was wasted.

In 1978, the New York Transit Authority (NYTA) examined in detail the pros and cons of including a VE proposal in their construction contracts. This agency decided not to include the VE clause and stated reasons for the decision in an excellent report described in Reference 11. One of the chief reasons that the VE clause was not incorporated was the opinion by NYTA legal department that it would be necessary for the State Legislature to pass new qualifying legislation to enable use of the clause. This problem must, of course, be discussed before the VE clause can be incorporated in a contract.

Reference 3 makes the following points:

1. There are significant costs and administrative problems involved with preparing and approving VE proposals.

2. Minimum savings under VE clause that should be considered is $100,000.

3. A more accurate description of a cost reduction incentive (VE) clause is a "Contractor's cost incentive program whereby savings are effected by the contractor's ingenuity and expertise, or by his improving and correcting less than optimum contract designs.

A reasonable time for approval of a VE proposal should be stated in the contract documents. Owners have taken notoriously long periods for deciding on whether a VE proposal will be accepted. In one case, it has been reported that the contract was substantially complete before the VE proposal under which the work was performed was approved. Because of the anticipated long delay periods for approval contractors often hesitate in submitting a VE proposal.

The Committee concluded that a need exists for a more comprehensive summary of owner experiences with VE clauses.

For reference purposes, a copy of a Value Engineering clause that has been used in water conveyance tunnel contract documents follows.

Cost Reduction Incentive
(Value Engineering)

This paragraph applies to proposals initiated, developed, and submitted in writing, after award of contract, by the contractor for modifying the plans, specifications, or other requirements of this contract for the purpose of reducing the cost of construction. Only those proposals will be considered which would not impair essential functions or operating characteristics of the facility being constructed under this contract. Acceptance will be made by issuance of an order for changes or by other written notice. Proposals based solely on reducing contract delivery or completion periods, changing basic engineering designs, or eliminating requirements necessitated by public law will not be considered.

Cost reduction proposals shall contain a description of the difference between the existing contract requirement and the proposed modification, an itemized and detailed estimate of the anticipated reduction in the contractor's costs, the time within which a decision thereon must be made by the Government and other appropriate information.

The Government shall not be liable for any delays in acting upon, or for failure to act upon, any proposal submitted pursuant to this paragraph, and any such delays shall not serve to extend the time of performance under the contract unless authorized by the contracting officer. The decision of the contracting officer on all questions relating to proposals submitted and/or accepted under this contract shall be final and shall not be subject to the "Disputes" clause of this contract. The contractor shall remain obligated to perform in accordance with existing contract terms unless an order for change is issued accepting the proposal or he is otherwise notified in writing of acceptance of the proposal.

If a contractor's cost reduction proposal is accepted, an equitable price adjustment will be made under the "Changes" clause of this contract. The amount of such adjustment will be established by determining the total estimated decrease in the contractor's cost that would result from acceptance of the proposal and reducing the contract price by 50 percent of such total estimated decrease. (For example, if it is determined that an accepted proposal will reduce the contractor's costs by $100,000, the contract price will be reduced $50,000, thus permitting the contractor to benefit by the remaining $50,000.)

Unless the contractor expressly restricts the Government's right to utilize in whole or in part a cost reduction proposal submitted and accepted under this paragraph by reason of established proprietary rights, e.g., patent or copyright, the Government shall have the right to use all or any part of the proposal for work or procurement under other contracts without payment or royalty or further obligation to the contractor.

VII. RECOMMENDATIONS

1. To obtain a quality tunnel lining, the contract documents covering construction of the lining must be (1) tailored specifically to meet the requirements of the particular job, and (2) properly interpreted and enforced by construction management personnel.

2. To improve future contract documents on tunnel lining, the suggestions presented in this paper should be considered.

3. Quantitative expressions, rather than qualitative expressions, should be used in specifications to reduce the possibility of a misinterpretation of meaning.

4. Design engineers and specifications writers should travel to underground construction sites whenever possible to observe construction activities and discuss improvements in future specifications.

5. Field personnel who administer underground construction contracts and tunnel design engineers should review all contract documents prior to publication.

6. An adequate period of time for bidding should be allowed to contractors between the construction specifications issuance date and the bid opening date. Suggested periods are given in this paper.

7. Requirements for handling tunnel drainage water and invert cleanup should be clearly specified in the contract documents.

8. Contractor suggestions for tunnel lining joint configurations should be allowed by the contract documents. (Differences of opinion between designer and contractor have frequently occurred on the shapes required for the longitudinal joint between an invert and sidewall concrete placement, and longitudinal and/or radial joints for precast concrete segment liners.)

9. A Value Engineering paragraph should be considered for inclusion in contract documents, especially when designers are not adequately familiar with the construction process and/or when conditions require a method-type specifications rather than a performance-type specifications.

10. Additional effort should be devoted to providing information summaries on the following topics.

    A. Contractual methods for handling drainage water in tunnels.

    B. External water loading on tunnel lining.

C. Infiltration and exfiltration rates for water in cast-in-place concrete lined and precast concrete segment lined tunnels.

D. Prototype flow resistance measurements in shotcrete lined and precast concrete segment lined tunnels.

E. State of the art of precast concrete segment tunnel lining in the U.S.

F. Merits of per linear foot bids for tunnel work.

G. Owner and contractor experience with Value Engineering in tunnel work.

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5. Standing Committee No. 4, "Contracting Practices," of the U.S. National Committee on Tunneling Technology; Better Contracting for Underground Construction, National Academy of Sciences. (Copies available as Report No. NSF/RA/S-74/005 from National Technical Information Service, U.S. Dept. of Commerce, Springfield, VA 22151.)

6. Peters, John C.; Pollution Control During Construction of Water Resource Projects, Bureau of Reclamation, Office of Assistant Commissioner and Chief Engineer, Engineering and Research Center, P.O. Box 25007, Denver Federal Center, Denver, CO 80225.

7. New York City Transit Authority; Information and Instructions for Personnel Assigned to Inspection Work in the Construction Division, 370 Jay St., New York, NY 11201.

8. U.S. Dept. of the Interior, Bureau of Reclamation, Tentative Specifications for Edge Sealant for Precast Contact Tunnel Liner Segments; Office of the Assistant Commissioner and Chief Engineer, Engineering and Research Center, Mail Code 1521, Denver, CO 80225.

9. Tuthill, Lewis H.; Tunnel Lining With Pumped Concrete, Journal of the American Concrete Institute, No. 68-27, April 1971, pp. 252-262.

10. Following are papers from the Journal of the Construction Division, Proceedings, American Society of Civil Engineers, that present additional pertinent discussions on responsibilities of the Engineer and Contractor in underground construction work.

    Papers No. 8781, 10607, 13585, 13801, 14001, and 14414.

11. New York City Transit Authority; Policy on Pre-Bid Conferences, Letter from Acting Executive Officer and Chief Engineer, 370 Jay St., New York, NY 10017.

APPENDIX A

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APPENDICES B & C

APPENDIX B

Items concerning tunnel lining that should be covered by contract documents (from owner's standpoint).

Although formats for tunnel specifications have generally been established by many consultants, utility companies and government agencies, a check list of items pertinent to tunnel lining specifications is included below. Copies of typical standard paragraphs pertaining to tunnel specifications and associated construction activities are available upon request from various government agencies. A list of such paragraphs entitled "Contents Guide for Construction Specifications and Supply Solicitations," is available from the Specifications Section, Mail Code 1330, Bureau of Reclamation, Engineering and Research Center, Denver Federal Center, Denver, Colorado 80225.

I. Type of excavation that will be permitted.

A. Drill-blast
B. Machine

If possible, this should be at contractor's option.

1. Full face rotating cutterhead.
2. Road-Header type rotating cutterhead.
3. Claw and bucket type.

C. Provisions for payment if tunneling machine unable to proceed.
D. Hand or machine spading.

II. Shape of Finished Lining.

A. Circular.
B. Horseshoe.

1. Conventional.
2. Flat bottom.
3. Vertical sides.
4. Elliptical.

C. Standardization of shapes.
D. English vs. metric dimensions.
E. Specify minimum size opening in small tunnels.

III. Type of Support System.

A. Structural steel ribs.

1. Spiling.
2. Crown bars.

B. Shotcrete.
C. Rock bolts (tensioned).
D. Rock anchors (untensioned).
E. Split set anchors.
F. Segments.

1. Concrete.
2. Metal.

G. Liner plate.

IV. Lagging and Spreaders

A. Timber.
B. Concrete.
C. Steel.
D. Shotcrete

V. Handling of Groundwater Flows

A. Lump sum bid for handling water?
B. Owner pays for flows above set amount and adjustments in contract price made for delays caused by water problems.
C. Statements in specifications on anticipated waterflows.
D. Bid items for drilling weep holes.
E. Design details on drawings for drains?
F. Water treatment plant (for cleanup of tunnel drainage water before discharge into stream or municipal sewer).

VI. Type of Lining to be Allowed

A. Excavated rock surface only.
B. Shotcrete.
C. Shotcrete and structural metal shapes.
D. Cast-in-place monolithic concrete.

1. Unreinforced.
2. With reinforcing steel.
3. With steel liner.

E. Precast concrete segments.

1. Bolted or unbolted.
2. Expanded or backfilled.
3. Designed for thrust from tunneling machine.

F. Metal segments (liner plate)
G. Post tensioned concrete.

VII. Invert Cleanup

A. Hard rock situation.
B. Soft ground situation.
C. Subinverts.

VIII. Forms for Concrete Lining

1. Submittal of drawings for approval.
2. Location of windows.
3. Form and concrete vibration.
4. Time limitations for stripping.
5. Repairs after stripping.

IX. Concrete Placement

1. Admixtures.
2. Pozzolans.
3. Joint cleanup.
4. Vibration requirements.

X. Construction Tolerances

A. Excavated opening.

1. Overbreak prevention.
2. Payment for overbreak.

B. Inside finished surface

1. Concrete.
2. Shotcrete.
3. Precast segments.
4. Offsets and surface roughness.
5. Horizontal alignment (Line).
6. Vertical alignment (Grade).
7. Owner - Contractor relationships on surveying.

C. Concrete and shotcrete strengths.
D. Concrete laboratory testing (by owner or contractor)
E. Concrete curing requirements.

XI. Joints in Lining

A. Construction joints in monolithic lining.

1. To prevent outflow of water.
2. To prevent inflow of water.
3. Optional locations.
4. Shape and location of joint between sidewall and invert.

B. Construction joints in segment lining.

1. To prevent outflow of water.
2. To prevent inflow of water or grout.
3. Performance or detailed specifications on sealants.
4. Shape.
5. Option for contractor design.

C. Waterstop joints.

XII. Grouting Behind Lining

A. Backfill grouting.
B. Pressure grouting.

XIII. Method of Payment

A. Fixed quantity per foot.

1. "A" and "B" lines.
2. Cement payment outside "B" line.

B. Per linear foot quantity.
C. Measured in-place volume.

1. Batch count for concrete.
2. Surveyed cross sections.

D. Method to allow contractor an option to provide a larger finished opening than specified - (for tunnels 10 feet in diameter and smaller).
E. Changed conditions.

APPENDIX B (continued)

XIV. Value Engineering provisions

XV. Instrumentation of Tunnel Lining

A. New Austrian tunnel support method.
B. Interference with construction progress.

XVI. Geotechnical Data

A. Surface geology.
B. Interpretive cross sections.
C. Construction materials.

APPENDIX C

Contractor activities concerned with cast-in-place concrete tunnel lining.

I. Develop Site and Utilities.

II. Assemble and Erect Plant and Equipment.

III. Excavate and Support Portals, Shaft, and Tunnel.

IV. Primary Cleanup Before Placing Lining.

A. Adjust supports.
B. Invert cleaning.

V. Placement of Concrete Lining.

A. Final cleanup.
B. Subinvert.
C. Set forms.
    1. Invert.
    2. Arch.
    3. Full circle.
D. Place and consolidate concrete.
E. Strip and move forms.
F. Cure and protect concrete.

APPENDIX D

APPENDIX D

PREBID DISCUSSIONS

Once a contract is signed, the contract documents become the "rule book" which governs the performance of all work until the last construction operation is complete. After signing a contract, the contracting officer is not able to change the specifications unless a formal adjustment (change order) is made in the contract. Such contract adjustments can be very costly to the owner because they are not subject to competitive bidding. It is therefore prudent for designers, specifications writers, legal advisors, geotechnical, construction and inspection personnel and contract administrators to spend as much time as practicable anticipating and discussing possible changes in the work before the specifications are issued.

Often it is useful for the owner to invite contractors to review the construction site several months prior to issuance of specifications. During such a site review it is possible to determine contractor interest in the particular job, encourage bidding, and to discuss problems that may be encountered during construction. If a contract is to be awarded in winter in a relatively inaccessible area, the site review should be held in warmer weather when roads are passable.

Showings of rock core drilled from the tunnel alignment have been used to generate contractor interest. For tunnels where machine boring is allowed as an alternative, the Bureau of Reclamation permits contractors and tunnel boring machine manufacturers to select samples of the core to be tested in their own laboratories.

One technique that has been found effective in obtaining a better understanding between involved parties, and is standard operating procedure for most agencies, is to invite field personnel into the design office to review preliminary drafts of the specifications before they are published. Field personnel that should be involved in such a review are the construction engineer, the office engineer, and the chief inspector. This in-house prebid conference should include the all important specifications writer as well as designers, geotechnical personnel and legal counsel. Because of the large amount of narrative material involved, it is wise to allow field personnel several days of review time to assimilate the information and provide meaningful comments.

Another technique, which has proved to be effective, is for owners to invite contractors to their offices for a prebid conference after specifications have been issued to explain the work and ask for comments. After consideration of comments, supplemental notices or addenda to the specifications can be included prior to the bid openings. A useful set of guidelines covering policy on prebid conferences has been published by the New York City Transit Authority. 11

A narrative publication entitled "Construction Considerations" should also be considered. In some agencies this publication is prepared by design engineers as a guide to inspection personnel to bring out "reasons why" for specifications requirements. The publication serves as a permanent communications link between designer and inspector that can be reviewed periodically during the progress of the work. It should be completed prior to the first preconstruction conference between the owner's construction engineer and the contractor. Consideration should be given to furnishing a copy of this document to the contractor.

Discussion during the Workshop indicated that one agency includes (1) a summary of the design assumptions used for the tunnel support system in the Geotechnical Report, and (2) requires that design engineers assist in preparing the Geotechnical Report.

Adequate time should be allowed contractors to prepare bids between the date that specifications are distributed to prospective bidders and the bid opening date. Although each tunnel contract has extenuating circumstances that may cause variations, the following times are considered reasonable:

Estimated cost of contract	Time from specifications issuance to bid opening
Less than $5 million	5 weeks
$5 to $30 million	7 weeks
Greater than $30 million	9 weeks

After receiving copies of specifications, most owners and designers appreciate receiving calls from qualified contractors concerning parts of specifications that are unclear, unfair, in conflict, or, in the potential bidder's opinion, will be uneconomical. Some agencies require that all requests for clarification of specifications be submitted in writing.

If the time periods listed above are allowed, time will be available for most contractor comments to be considered and included in a supplemental notice when the designer and specifications writer consider the comment or design modification to be appropriate.

DISCUSSION

MR. TILP: Yesterday afternoon we had quite a spirited discussion on the original draft of the paper. We had one new member join the group, Dougal McCreath of Acres American International in Buffalo. We appreciate his contribution very much. As expected, we found quite a diversity of opinion on several aspects of the paper, and I think the package that we put together was good considering the time available.

In contract documents we include general conditions and contractual provisions. That's one very important section. The second section is the technical provisions of a specification. We generally agreed that in order to have a good end product these two sections need to interact quite well and you need to tailor the documents to each particular tunnel job. There was some talk about standardization of a tunnel specification, and we all concluded that that would be rather difficult to do. It's a worthy goal, but quite difficult.

Of course, in the contract documents, we include the engineering drawings and the geotechnical reports. Then there's the supplemental data that's usually available upon request by the contractor that includes drawings of adjacent utilities, building plans, etc.

The format of the paper changed somewhat in that we went into more detail in the particular areas of the general provisions, general conditions and the contract provisions. I think I just might read one by one, some of the ideas that were put forth and agreed upon by the committee. Some of the things that we'll cover in the technical provisions were touched on by Mr. Garbesi in the Constructibility Committee.

Under the general conditions and contract provisions we think that all data available to the engineer should also be made available to the contractor. That includes a geotechnical report. The geotechnical report should be a mandatory part of the contract documents. All of the other general data, such as old reports, boring data and building foundation plans should be added as supplementary information.

Number Two, the geotechnical memoranda should be detailed sufficiently to form a basis of the overall subsurface conditions that can be expected. We restated, as we said yesterday, that prebid conferences should be held on all major projects. We recommend that the engineer's estimate of cost be publicized as an expected range, for example, ten to fifteen million dollars, and consideration should be given to stating what the maximum bid should be for a job.

Concerning project delays, the contractor should be reimbursed for his added costs resulting from delays that are not caused by him. This might include delays in order to proceed with the work, delays due to community actions, and delays due to extended response time to the contractor's drawings. The contractor should, therefore, include specific turn-around times for contractors submittal of drawings; say thirty days for the first submission, fifteen days for the second submission, and if a third one is necessary, you might want another time in there.

On the other hand, a contractor should be required to pay for excessive submission of drawings. For example, the engineering costs in a design office and reviewing of drawings after the third submission.

We recommend that contractor progress payments not be based on a minimum dollar value but that the contractors should receive a payment at least each month.

On mobilization, all contracts should include a mobilization item. The amount should be tailored to the type of project.

On a bid schedule of quantities, we recommend a plus or minus percent be set with a revised payment schedule established when the quantities do not fall within the actual percentage. Fifteen percent plus or minus has been recommended for consideration.

We mentioned yesterday that performance-type contracts are advocated for tunneling whenever possible.

Escalation clauses, where legally permitted, are recommended to be included for all projects where the project time exceeds twenty-four to thirty months. The absorbed cost by the agency could fall between seventy-five and one hundred percent as a guide for the escalation criteria. This might include hourly labor, materials, or be tied to some escalation index.

We recommend that exculpatory statements be eliminated. Great efforts should be made to eliminate disclaimers and expressions such as -- as directed by the engineer.

We recommend that all contracts include a changed condition clause with the geotechnical report or memorandum to be the major elements in the determination of a change. A changed condition clause should have a plus or minus criteria with additional payment due the contractor for more severe subsurface conditions and credits to the owner for better conditions than expected.

We would like to qualify that a little bit. It must be understood that this clause tends to reduce restraint on a contractor, and that closer review of the contractors procedures are mandatory in a situation like this.

We recommend that favorable consideration be made with regards to ongoing non-binding arbitration to resolve disagreements between the contractor and the agency.

The methods of construction should generally be left to the contractor within contractual restraints although this is open to controversy. The general field design criteria used by the agency or the engineers should be included in the supplementary data part of the contract. I'm not sure all groups do this today.

All alternative bids acceptable to the agency or the engineers should be spelled out. All options that will be accepted should also be spelled out.

On innovation -- contractor innovation, that gets into value engineering to a degree. Here's where we had a dissenting opinion. The majority of our committee believes that the contractor should have maximum latitude for innovation. That would include a value engineering clause in the contract documents. However, the minority of our committee believes that contractor innovation should generally be limited to the methods of construction so long as all acceptable alternatives and options are spelled out in the contract.

Then, we discussed technical provisions of the specifications. Yesterday we found that we really didn't have time to cover precast linings in much detail so we kept our paper to only cast-in-place concrete lining. Under the technical provisions, we list some areas concerning concrete lining and the preparation for concrete placement. We do not recommend more invert cleanup than absolutely required for the adequate functional performance of the tunnel. Now again, this is a little bit exculpatory, but I think the general idea is there. We don't recommend wedging and barring of rock-blocks, and we do not recommend dinner-plate clean-up. We think that's generally unnecessary. We concluded that the cleaning of joints and fractures is not required unless piping around the outside of the tunnel is possible. We've said it's often unnecessary to remove traffic compacted muck. Say you have rubber-tired vehicles travel the invert. It might be possible to leave that compacted material in place, and it also might be possible to leave ties and rails outside the "A" line in place.

Forming. We concluded as far as possible that forming techniques for concrete lining -- this is cast-in-place -- should be left to the contractor. Specifically, do not specify placement of the invert concrete first unless a clear design reason exists. We noted that long stripping times for forms increases the cost and the time schedule. The intent of the specification should be to minimize the stripping time, and I think that it was a good suggestion to strip the forms with a concrete compressive strength of six hundred psi.

We recommend that acceptable joints be shown on the plans. This is especially true if you place the invert first and then place the arch at a different time. We recommended that form windows be placed on eight foot centers. However, ten foot centers may be acceptable for larger tunnels.

Generally, we agreed with what's been stated by the other committee on tolerances. We did recommend that in a fluid conveyance tunnel the hydraulic design might have to be adjusted a little bit. It should be adjusted to meet the tolerances that the tunneling industry thinks it can obtain on line and grade.

On placing of concrete, we brought out, that many concrete placing techniques for surface structures are not applicable to tunnels. A slump loss must be modified to reflect tunnel haulage and placement requirements. In other words, enough slump must be allowed so that you can get the concrete in to the tunnel and get it placed.

Joints. Joint spacing should be left up to the contractor. Sloping construction joints should be allowed in both plain and reinforced concrete tunnels. This may require, I think, a lot closer inspection than we've obtained in the past. It was noted that plain concrete tunnel lining normally crack circumferentially every fifteen to twenty feet because of shrinkage.

Just one last point here on contact grouting. Back-fill grouting holes behind cast-in-place linings were generally specified on five-foot centers with additional holes as required for grouting and venting of the high spots or overbreak. Normally we recommend thirty psi grout pressure for back-fill grouting. We concluded that grout strength is not critical, but enough cement or bentonite must be used to assure pumping the grout into the voids.

MR. KNIGHT: I would like to comment on your four-foot or eight-foot spacing on your doors and forms. Most forms are made in five-foot increments. So, if you call for an eight-foot spacing, this means you're going to have a door every five feet instead of every eight feet. I think you should be looking at a ten-foot spacing rather than an eight-foot spacing.

MR. TILP: Good comment, thank you.

MR. GARRETT: Vernon Garrett of WMATA. You mentioned a geotechnical report. As a specification group, what did you intend to have in that geotechnical report?

MR. TILP: Well, this is a good question. I think each agency would have to work on this particular problem. We've had, in our agency, quite a debate on whether or not we should show geologic cross sections of the tunnel by our own geologists and geotechnical people. In other words, would the surficial geology project downward to a cross section of the tunnel at a depth of 1000 feet or more? At the present time, we do not do that. But, the content of the geotechnical report, I think, would have to be determined for by each agency.

MR. GARRETT: The reason I raise the question is we do require, in tunneling jobs, soft and hard ground both, a geotechnical report as part of our package, wherein we expect the designer to put into that report how he proposes that the work be done, and how he would envision the construction to be performed. In effect, he's going beyond just specifying end-product, but indicating during the design period what he considered the essential features of that tunnel. I don't believe the designer wants to deviate from what he intended to go into the tunnel, and he should avoid statements about what-if this or what-if that. I think that would give no support to the owner. I think if you stick with the intent, you're better off.

One of the points you raised indicated prebid conferences. I agree with that approach. However, on our program, we found the construction industry just would not participate in prebid conferences. If we held them, they simply sat there as if they were afraid to divulge whatever they were thinking about. They'll write you letters and request information, but they won't sit there with their peers and discuss the job. I don't know how you get past that point. We have the capability to give prebid conferences, but the industry just would not participate in them. If you call them, a few of them would show up just to see what the next guy was going to say, but he wouldn't say anything himself. Another point, you raised -- you mentioned something about supplemental information. Do you mean that to be part of a contract or just referenced information?

MR. TILP: Well, there is a certain amount of referenced information that the contractor can ask for that is not normally distributed with his specifications.

MR. GARRETT: We found that in metropolitan work if you don't specify it, they won't look at it. If you don't call it part of the contract, and it comes to an adversary situation, don't expect to be supported by the fact that you've said it's referenced information. The whole world is referenced as far as the courts are concerned.

MR. TILP: So, you advocate making sure they get the whole bundle?

MR. GARRETT: If we want them to review it for any reason, we insert it in the contract, but just referencing a particular piece of information is of no value to us as a client.

MR. ROSSUM: Excuse me, Vernon. You say you specifically say that those things are part of the contract document, or you actually make it part of the document?

MR. GARRETT: We would actually incorporate it. If we wanted a particular drawing, we put it in there and we say that is to be part of this contract.

MR. DAVIS: You mentioned a controversial item including design criteria. I didn't really understand what you said; field and design criteria. Would you expand on that?

MR. TILP: Leon, would you like to elaborate just exactly what you would interpret the field and design.

MR. ROSSUM: Essentially what we do at the transit authority in New York, we publish what we call field Design Guidelines. Various slopes that you would carry or things like that. It's not specifics, it's guidelines that a contractor would know, the context of what you would be reviewing or looking for.

MR. TILP: This, to a degree, might get into what I believe you're talking about in a geotechnical report. This is an interesting innovation to me to put design ideas in the geotechnical report. Did you actually put loading criteria or the construction methods in your document?

MR. GARRETT: We use a geotechnical report to bridge the gap between the end product and what the designer was performing back in his office to give the contractor a better understanding or thought behind this job.

MR. McCREATH: I'm Dougal McCreath, Acres American. I think you'll all agree that taking exculpatory language out of a contract as much as possible is a very desirable thing. But, if that extends into deleting clauses like as directed by engineer, that's where I cut off because as far as I'm concerned the tunnel design is not finished until after that tunnel is constructed, and short circuiting the flexibilities of the engineer to reasonably modify that design during the process of the construction, to me, is quite wrong. It goes dead against the necessary philosophy of tunnel design as opposed to structural design or something more deterministic. So I think there's a very important line between taking out exculpatory language and taking out as directed by engineer, and I would hate to see this group pushed too far. I won't go with it.

MR. KUESEL: You mentioned that unreinforced rock tunnel linings crack circumferentially every fifteen or twenty feet. Is this a good thing or is this considered objectionable?

MR. TILP: Well, this is a good point. We got into the discussion to a degree last evening about specifying actual leakage rates in tunnels. To my knowledge, there hasn't been too much accomplished as far as proto type tests in unreinforced concrete tunnel lining. There needs to be more done. But as far as whether it's desirable or undesirable, I guess it's how valuable your water is; it's a fact of life, it happens.

MR. KUESEL: Well, I guess what I'm getting at is it sufficiently objectionable to be worth the cost of putting in a whole lot of rebar.

MR. KNIGHT: On the Pennsylvania Turnpike tunnels which were heavily reinforced, we still had shrinkage cracks at a twenty-foot interval. It didn't make any difference whether it was heavily reinforced.

MR. TILP: Now, again, in water conveyance tunnels, we've got several hundred miles of water conveyance tunnels in the West that are unreinforced. So, we've never found the economy necessary yet. Water isn't quite that valuable to reinforce.

MR. JOHNSON: Doug Johnson. I'd like to address the problem of the prebid conference that was mentioned here. We recently made a site investigation on a project where the resident engineer told me that he never read the specifications until after the job was awarded so that he couldn't be pinned into making a comment prior to the bidding. Once the bid documents are published and out for bid, I think that you do run into a very closed-mouth situation, and then it's too late. I think on most major projects, if the contractors were invited in prior to the publishing of the formal bid documents, then you would find openness on both sides of the table to discuss the various parts of specifications. Again, once the document is made public for the bidding it becomes a problem.

MR. KUESEL: I'd like to mention something about the BART Project that confirms both your comment and Vernon's. During the pre-advertising stage, we held regular meetings with the local chapter of the AGC and a lot of dirty linen was aired in those sessions very informally. Now, we were able to find out what was really bothering the contractors and in many cases to make changes before the specifications were published. Once you get the thing on the street in published form, it will take a formal addendum to change it, it gets very sticky. As to the prebid conferences, Vern, you're right. Very few useful questions were asked. The one I remember most clearly was, what is the purpose and contractural significance of all of this instrumentation. It was a hurried, whispered conference, and the answer was given, "for the amusement of the engineers."

LETTERS

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RECEIVED MAY 10 1979

May 7, 1979

Dr. Gary S. Brierley
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Rochester, New York 14604

Subject: Underground Technology Research Council
Lining Design Workshop
Specifications Committee

Dear Gary:

I want to congratulate you and the other members of the Technical Committee on Lining Design for a job well done in organizing and conducting the Workshop on Tunnel Lining Design and Construction. As a general rule, I find that too many such meetings consist of a few high spots and a lot of wasted time. This workshop was a notable exception - I agree with many others who felt it was too short. To keep the interest high, however, it might be productive to consider keeping future workshops just as short and intense but to have more of them.

Our committee found that we had a challenging but impossible task to tackle "Tunnel Lining Specifications" in the time available. I'm sure the other members of the Specifications Committee join me in thanking our chairman, Paul Tilp, for a great job in preparing a draft position paper for us to consider and to take "pot shots" at, in maintaining order during our spirited discussions, and then in collecting the pieces of the position paper and putting it back together again. This position paper was improved by our efforts but still should be considered as a first effort, hopefully to be improved upon at future workshops.

We trust that other members of the underground construction "fraternity" will provide us with comments or observations to consider toward our mutual goal of improving tunnel lining specifications. I would like to suggest the following:

1. The committee states a couple of times in the position paper that contract documents must be tailored specifically to meet the requirements of each particular job. This thought is crucial. Anyone who uses tunnel lining specifications by this or any

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future committee must not accept the committee's work verbatum but must, instead, use them as a point of departure for writing their own documents that address conditions and requirements of that specific project.

2. The committee agreed that the bid preparation time should be longer for larger projects and suggested a nine-week period for projects over $30 million. This seems long. Comments from contractors on this matter would be appreciated (Para. II.c.).

3. Contractors should receive monthly payments for work accomplished during the month (Para. III.c.).

4. Consideration should be given to making mobilization a bid item. Monies to be paid upon delivery to the site of, and presentation of invoices or evidence of fair market value for, major items of equipment or materials. Any balance of monies in the mobilization item paid with final payment (Para. III.D.).

5. The final version of the position paper does not include a request stated by some members of the committee for a gripe or grievance list from contractors. However, such input would be helpful to future committees attempting to make further improvements to tunnel lining specifications.

6. The committee recommends that sloping joints be allowed in both plain and reinforced concrete linings (Para IV.A.5.). It seems however, that additional thought may be required for several items if sloping joints are to be tried in reinforced linings:

   a. Presence of reinforcing reduces space available for working, especially for vibrating.

   b. Joint cleaning and bar cleaning, if required, are more difficult.

   c. A feather edge should be avoided at the invert by placing a low bulkhead.

   d. Treatment of joints by bonding agents or cement-enriched concrete is more difficult.

7. Several suppliers are marketing plasticisers, set-inhibitors, and the like that may prove useful especially when concrete must be transported a long distance before final placement in the forms. Research into the usefulness, reliability, restrictions, and

specification requirements for such products should be conducted so that they can be used with confidence when required by specific job conditions.

8. Precast concrete segments (bolted) have been used for about 12 miles of 20-ft diameter interceptor sewer tunnels in Mexico City (Para. IV.A.C.).

9. Construction management or inspection personnel must have the training and experience required to adequately interpret and enforce the contract documents. They must also have the authority within the constraints of the contract to issue modifications required to obtain the end product required.

I have enjoyed serving on the specifications committee and trust that the position paper and ensuing responses will lead to improvements in tunnel lining specifications. Please call on me if I can provide additional information or assist in any way.

Very truly yours,

STRAAM Engineers, Inc.

James E. Monsees
Senior Vice President

JEM:hh

cc: Mr. P. Tilp

CHAPTER 8

CONSTRUCTIBILITY AND COST CONSIDERATIONS

CONSTRUCTIBILITY AND COST - BY: GAIL KNIGHT
CONSIDERATIONS S.A. HEALY COMPANY

One of the outstanding problems that the tunnel industry faces today is the high cost of tunneling. In many instances, bids are far above the engineer's estimate and appear out of touch with the times. Sometimes the difference is so great that the contracting authority or the funding agency decides that the bid must be rejected. When this happens all parties lose. The taxpayer and consumer, if and when the project is rebid, pays for a bid higher than the rejected one. The owner pays the administrative costs and the contractor loses the use of his own generally limited time plus the time his engineers expended to prepare the estimate plus other bidding costs. However, even when bids are in line with the estimate, improved designs that are easier and cheaper to construct might have reduced costs substantially.

A large portion of the tunnel construction volume today and in the foreseeable future is associated either with subway systems or large sewerage and storm water collection as well as temporary storage facilities. A general state-of-the-art report on underground construction can be covered here only briefly. This report identifies several aspects of tunnel construction, both general and specific where substantial cost savings could be achieved through improved constructibility. Excavation methods for hard-rock tunnels have changed in the last ten years from a stage where TBM's (Tunnel Boring Machines) were used occasionally when the rock formation was not too hard, to the present stage of development where almost any size tunnel in all but the hardest rock can be excavated with a TBM using single disc cutters.

The excavation of soft ground tunnels on the other hand remains more of an art than a science. The subject is too complicated to be covered meaningfully here except that the construction procedures should generally follow the cost-reduction methods of standardization and uniformity. The use of less-costly tunnel liners together with improved ground-water control techniques is also mandatory to allow effective and meaningful cost reductions. One area under study at this time which appears promising in reducing costs for concrete linings is the use of extruded or continuous casting processes for placing it. This process if developed to its ultimate could eliminate a large portion of temporary supports for soft ground tunnels.

The excavation of rock shafts with RBM's (Raise Boring Machines) has become almost standard practice in the last three to four years. The standard procedure at this time is to down drill 6' to 8' diameter holes using a reverse circulation method, then enlarge to the required diameter by one of several reaming methods or by drill and shoot slashing. The Federal government is presently financing a pilot project using a 24' diameter SBM (Shaft Boring Machine) which is very similar to a self contained TBM except for the method of removing the muck. This SBM method probably has the most potential if shaft designers are agreeable to standardized shaft sizes.

The RBM's are presently feasible in sizes from 6' to 20' in diameter. The SBM's effective range will probably be from 15' to 30' in diameter.

The big question today is where do we make changes to reduce project costs. It is believed that a start in this direction would be to get the designers and specification writers to think in terms of constructibility on the same level as they think of structural design.

The best way to accomplish this would be to have a set of constructibility guidelines. We should also discuss the use of the new types of equipment and the best ways that the designer can allow for use of new and existing equipment.

To explore this broad range of methods and equipment, we should start at the surface, investigating open cut structures, earth shafts, and rock shafts in a descending order. At the bottom of the shaft we will discuss working arrangements at the shaft work area, followed by tunnel construction and tunnel concrete. As a separate but equally important subject, we should study the bottom or boot structure in drop shafts and their connections to sewer tunnels. So that we do not forget the importance of this last item, it has been our experience that in general 50% or more of the cost on storm water collection projects is in building of the shafts and related structures.

Our thoughts for the constructibility guidelines would be; first, a set of general rules as follows for specifications that could reduce costs without reduction in the quality of construction. We are sure that a number of useful rules can be added to this list.

GENERAL RULES:

1. Specifications:

   Specifications should clearly define the quality and tolerances of the work so as to limit the amount of on-site discretion allowed the engineer.

2. Methods of Construction:

   The contractor should have as much latitude as possible to choose the construction methods. Each project will have conditions and problems requiring methods, equipment, and personnel, that if matched to each contractor, will result in the most economical cost.

3. An Allowable Range of Sizes Should be Specified:

Allow a range of maximum and minimum sizes of shaft and tunnel diameters that meet the design requirements. If the contractor knows when he bids that he will be able to use available equipment without alteration, he will be able to tender the best price.

4. Construction Joints at Contractor's Option:

Allow construction joints at the contractor's option, consistent with good design practice.

5. Eliminating Reinforcing:

Eliminate reinforcement steel wherever possible.

6. Do Not Change Tunnel Size at Structures:

Do not call for extra concrete thickness or enlargements at shaft connections. This type of enlargement requires specialized excavation and is very expensive due to its thin section and the disruptive effect of stopping the operations that are beyond that point during its excavation.

SPECIFIC GUIDELINES:

A list of guidelines covering specific constructibility problems should be helpful in reducing cost. These are some of the high-cost areas and possible solutions.

1. Connections to Live Sewers:

Connections to live sewers are usually a problem. One solution would be to build the new structure around the existing sewer. After the structure is completed, portions of the sewer could then be quickly removed.

2. Circular Excavation in Earth:

Structures in overburden are always difficult to excavate and difficult to form for concrete. Structures that can be excavated in a circular shape and formed with circular forms would greatly reduce costs. Shafts up to 12' can generally be machine bored. Larger shafts require conventional earth-shaft excavation methods.

3. Projections in Open-Cut Structures:

Changes in shape and projections from the main structure should be eliminated wherever possible. Offsets increase the cost of ground support, the cost of forming and the cost of backfill. Offsets up to 3' from the form to the ground support can be filled with concrete at less cost than it can be formed and backfilled. Walls that go to the surface should follow the excavation line wherever possible.

4. Construction Joints in Open-Cut Structures:

The contractor should be given the option of placing construction joints to match his ground support system to allow removal of walers and struts at the optimum time.

5. Transition to Open-Cut Structures:

The combined elbow transition in diversion structures for sewers can be very difficult to construct and the awkward ground supports for them generally waste considerable concrete. One solution would be to have horizontal transitions. Another method to replace this difficult construction would be to have a circular open chamber built concentrically above the shaft.

6. Shafts in Rock:

In contracts which have shafts in rock, the contractor should be allowed to select the method of construction. Drilling or boring only become practical with deep shafts and with a large total quantity for a particular project. Standardization of sizes will help reduce equipment costs. Shaft drilling with an SBM requires a large array of backup equipment and the use of settling basins in order to control the contaminants in the discharge of the drill water. The larger units require a 250-ton crane to set them in place. Upon completion of drilling, a large quantity of silty water must be disposed. The RBM overcomes most of the water handling problems, but requires development of access to the chamber or tunnel. This sometimes delays the drilling until near the end of the project. All of these factors must be given careful study.

7. Anchor Recesses or Brackets in Shaft Walls:

Anchor recesses or brackets in shaft walls are a very expensive item which should be eliminated if possible. Even in drilled shafts the irregularities caused by the drill on the shaft walls has proven successful in conjunction with pressure grout in anchoring the shaft walls to the rock.

8. Tail Tunnel Construction:

Tail tunnels at construction shafts should be allowed for in the right-of-way for the tunnel design wherever possible with sufficient room for the longest train, a locomotive and a double switch. On smaller tunnels, 200' will generally be sufficient, on medium size 250' will do and on the largest tunnels, 300' should be a minimum length. The specifications should also indicate what treatment and/or support of the excavation will be required.

9. Shafts to Remove TBM's:

Whenever possible, some method should be considered for removing the TBM at the end of a run. Backing a TBM out of a tunnel requires either removal of the tunnel utilities or partial dismantling of the machine. Either will be expensive.

10. Work Shafts:

Work shafts should be the same diameter as the tunnel, or larger, and should be centered on the tunnel if possible.

11. Match Existing Tunnel Sizes:

Try to match tunnel sizes with tunnels that are being built or have been completed. Existing machines and existing designs will save contract time. Repeat operations are generally improved operations. Refurbishing a TBM generally costs about 25% of a new machine cost. Resizing a TBM costs in the 50% or higher range. Neither change increases the value of the machine so that the full cost of the change must be written into the project. Presently there are TBM's working in the following sizes: 35', 32', 30', 26', 22', 19', 18', 16', 14', 12', 10', 8', and 6'.

12. Maintain One Tunnel Size:

Changing tunnel size in the same contract is wasteful unless there is a major difference. Any savings in materials will generally be more than offset by the additional cost for equipment and reduced efficiency.

13. Select Long Tunnel Contracts:

Tunnel sections should be selected in as long a length as possible keeping in mind a reasonable length of contract. Consider that any start up with a TBM will require three or more months. These first three months of operation will have a 30% to 50% efficiency rate because of the learning curve and usual machine alterations. After the start up the efficiency should reach the 60% range. Therefore it can readily be seen that significant savings can develop from the longer sections. In place of two short parallel tunnels in one contract, design for two long parallel tunnel contracts.

14. Wide Space Between Parallel Tunnels:

Parallel tunnels should be as far apart as possible to avoid ground support problems in the adjacent tube.

15. Tunnel Alignment Tolerance:

The state of the art for controlling alignment of bored rock tunnels is such that a contractor with "reasonable" care can carry elevation to ±3" and horizontal alignment to ±12", although on tight-radius curves even more horizontal tolerance would be helpful. The most economical combination of mining diameter and concrete lining thickness will result when the owner allows the tunnel lining tolerances to be similar to "reasonable" mining tolerances. The foregoing will allow the "design" thickness of concrete to be the same as that placed in the field. A tightening of tolerances in alignment will cause contractors to excavate larger diameters and place thicker concrete linings to maintain design diameters, which in today's market, cost about $75.00 to $100.00 per cubic yard.

16. Curves Should Have a Long Radius:

Curve alignments--curves in bored tunnels should be designed with as long a radius as possible for ease of mining and for maximum chord lengths during the placing of the concrete lining. The optimum length of a chord is 40 feet.

17. Location of Pre-Bored TBM Tunnel Through Subway Station Section:

Pre-boring through mined subway stations--when TBM tunnels are pre-bored through drilled and blasted stations, the outside excavation line of the bored tunnel should be at least two to three feet outside the excavation line of the station. Any extra concrete will be offset by the advantage of placing a footer and a lower post with a minimum of excavation.

18. Cost Savings by Avoiding Complicated Shapes:

Avoid exotic shapes if possible. For example: The drop shaft, boot and adit portion on the large collector tunnel projects in the United States could cost up to 65% of the total cost of the project. The boot structure is a new type of construction and we should be able to find better ways to construct them. In all of the projects to date there has been only one basic design; a vented drop shaft with a boot at the bottom. The boot-shaped excavation requires a drill and shoot type of development. The complex shape and limited access combine to make the development and concrete work very expensive.

The committee suggests that the design of these structures be studied by a team comprised of hydraulic, geotechnical, and structural engineers; contractors and owners. The cost implications of the savings that could result from the redesign of these structures warrants an immediate special study.

Another example of designs which are difficult to build are the turn-outs on the running tracks in subways. They are often presently designed as changing cross sections which require costly and special considerations at each section. An economical solution to this problem would be to design a constant horseshoe section from the end of the turnout to its confluence.

19. Communication Between Engineers and Contractors:

Alternate designs would save on almost every project that is constructed. Better communication between designers and contractors would help. One method of reducing costs would be for the owners to retain on their board of consultants eminent construction managers and contractors charged with the responsibility of reviewing all designs for constructibility and recommending possible alternate designs in order to reduce costs.

20. Forming Considerations:

The most economical lining systems are circular and of a size that is self supporting. Warped surfaces should be avoided because they must be fabricated from wood. Tunnel form-stripping time requirement is much too long in most instances. This committee recommends that a concrete strength of approximately 600 psi, cured under normal tunnel conditions, be obtained prior to stripping. The foregoing is based on stable ground conditions; i.e., no ground loadings on the green concrete. It is suggested that the tunnel lining design committee of this workshop, or the ACI committee verify that concrete damage caused by plastic flow will not occur at this stength.

Concrete tunnel linings usually crack due to shrinkage, therefore water stops are not always practical to stop infiltration. Infiltration control is a very costly operation, and designers should determine just how much infiltration can be tolerated and design for this quantity.

21. Concrete Placing:

Sloping cold joints should be allowed in placing tunnel linings. This approach eliminates vertical bulkheads and most waste of concrete.

Pneumatic placing of concrete is no longer prevalent in the industry. However, placing specifications should recognize that selective air-slugging of the slick-line to facilitate cleaning of plugged lines and to help fill voids is usually advantageous.

22. <u>Precast Segmented Concrete Linings</u>:

Precast linings are now being introduced to the United States as a potential cost-saving lining system. However, infiltration control is one area that needs intensive study before widespread industry acceptance will be obtained.

APPENDIX A

CONSTRUCTIBILITY AND COST COMMITTEE

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CONSTRUCTIBILITY AND COST COMMITTEE

FROM LEFT TO RIGHT:
THOMAS WILSON, GAIL KNIGHT, ROBERT JENNY, VINTON GARBESI, HENRY CERUTTI, HARVEY PARKER, R. JAMES IRISH

DISCUSSION

MR. GARBESI: I represent the Constructibility Committee. First of all I would like to thank the committee members for their participation yesterday. It was a good session. We had a lot of give and take, and I think everyone contributed. Mr. Irish was included as an alternate, and his contribution was quite considerable.

I'm going to go through what the Committee thought should be reviewed and reworked from Gail's paper that he presented yesterday.

The first item is under what we consider to be the general rules, and it's a statement of what we feel Specifications should do for us. We think Specifications should clearly define the quality and tolerances of the work so as to limit the amount of discretion allowed the engineer. Now, we define the engineer to mean the resident engineer or the inspecting people on the job site.

We're going to jump ahead here to construction joints. We think that in concrete tunnel construction that the contractors should be allowed to place construction joints at his option consistent with good design practice. We think that most contractors are fairly sophisticated today, and if the designers are willing to work with them and move some construction joints around it might save some money.

Another point is, do not change the tunnel size at structure intersections, such as where a shaft penetrates a tunnel. We find some designs where the designer will show a nice six-inch additional excavation on a twenty-foot or thirty-foot tunnel, and this is very expensive. Not only does it cost a lot to come back and take that excavation out, but most everything that's downstream of that shaft is interrupted or affected by the drill and blast operation at the shaft. So, if there's any way possible for the designers to use uniform sections through shaft bottoms, I think that would be a saving.

Again, on the construction joints, one of the details is that in open-cut structures we find that construction joint options can save money in that it allows the contractor to place his wales and struts at his option and take them out at the most opportune time. You can pour your walls to certain elevation, allow them to set, even if you have to go back in and restrut, and you can then pull the wales and struts. The contractor might have a certain shoring available that would fit better, and you wouldn't have to go out and buy some new steel supports for an open-cut structure.

We find that in bidding the water quality work that the designers are including brackets, anchors and shear keys in shaft walls in order to anchor the reinforced concrete to the rock. We find that this is not practical, not needed from design point of view, and we suggest that even in the drilled shafts the irregularities caused by the rock are enough to key the reinforced concrete lining to the rock and with a good pressure grout job there's no problem in supporting the reinforced concrete walls with the shaft wall rock.

We think that designers should take a look at uniform size ranges for TBM's. Look around, see what machines are available. There's presently being built and available sizes of TBM's from 35 foot down to 6 foot diameter, and we suggest that if the optimum size for a lined tunnel is 32 ft. 6 in., then the designer should look at 32 feet in that there are machines available in that size. A 32-foot-diamater TBM today is in the six to seven million dollar purchase price range, and it could be a significant saving to a project to be able to use a used tunnel boring machine of this size.

We spent a lot of time in the committee yesterday talking about both vertical and horizontal tolerances for tunnel boring machines. We came up with a consensus, and this applies generally to transit tunnels, and I'll read it. "The state of the art for controlling alignment of bored rock tunnels is such that a contractor with reasonable care can control elevation to plus or minus 3 inches at the horizontal alignment to plus or minus 12 inches. Tight radius curves are more difficult to handle this horizontal tolerance, and it should be considered in designing transit tunnels that the tolerance might be relaxed for tight radius curves. The most economical combination of mining diameter and concrete lining thickness will result when the owner allows the tunnel lining tolerances to be similar to reasonable mining tolerances. The foregoing results in the designed thickness of concrete being the same as what is placed in the field. A tightening of tolerances in alignment will cause contractors to place thickened concrete linings, which is today's market, cost about $75.00 to $100.00 per cubic yard."

What we're saying is that if the designer can give us a bigger hole, design his lining to follow the TBM, the tolerances we have, you could place a thinner lining. The contractor does not slow his operation down, he just makes a bigger hole to fit the tolerances so that he can mine it as quickly as possible.

Curves should have as long a radius as possible, and we feel that the optimum length of a chord for placing tunnel lining today is forty feet.

Another area that we think should be worked on is designs that are repeated over and over again for agencies. A case in point are the drop shafts that the EPA now has in several different locations in the country, and our point is to avoid exotic shapes. For example, the drop shaft, boot and adit portion on most of the collector tunnel projects in the United States could cost up to 65 percent of the total cost of the project. The boot structure is a new type of construction, and we should be able to find better ways to construct them. In all of the projects to date there has been only one basic design, and that is a vented drop shaft with a boot at the bottom. The boot-shaped excavation requires a drill and shoot type of development. The complex shape and limited access combine to make the development and concrete work very expensive.

The committee suggests that the design of these structures be revised by a team comprised of representatives of design organizations including hydraulic, geotechnical, and structural engineers, contractors and owners. The cost implications of the savings that could result from the redesign of these structures warrants an immediate special study.

Another example of a design that is difficult to build are the turn-outs on running tracks in subways. As they are presently designed, they must be mined and supported as constantly changing sections which require each operation from mining through concreting to be a continuously changing operation. An economical solution to this problem would be to design a constant horseshoe section from one end of the turnout to its confluence.

We have some forming considerations for tunnel linings. The most economical lining systems are circular and of a size that is self-supporting. Warped surfaces should be avoided in that they must be fabricated from wood. Tunnel form stripping time is much too long in most instances. This committee recommends that a concrete strength of 600 psi be obtained under normal tunnel conditions prior to stripping.

The foregoing is based on stable ground condition, i.e. no ground loadings on green concrete. It is suggested that the Tunnel Lining Design Committee or the ACI Committee verify that plastic flow will not be a factor at this strength.

Concrete tunnel linings are going to crack due to shrinkage. Therefore, water stops are not practical to stop infiltration. Infiltration control is very costly. Therefore, designers should recognize how much infiltration can be tolerated and design for it.

Concrete placing. Sloping joints should be allowed in placing tunnel linings whether reinforced or not. This approach eliminates most vertical bulkheads and eliminates a lot of waste concrete. It allows a contractor underground to know how much concrete is in his pipeline and not have to clean out a whole system when he gets his bulkhead just full. It's a considerable consideration to a contractor.

Pneumatic placing of concrete is no longer prevalent in the industry. Placing specifications should recognize that selective air slugging of the slick line to facilitate cleaning of plugged lines and to help fill voids is advantageous.

Last, we think that there's a real opportunity to save money with precast concrete segmented linings. We just say that we think this is one area where the designers can come up with some good ideas, and we think one of the areas that really needs work in precast linings is the control of ground water infiltration, and we think that's the area that needs the breakthroughs in order to get the cost of precast linings down to where they're practical.

MR. BRIERLEY: We'll take questions now. I would like to make one comment myself. I've talked to Gail, and I've talked to you about sizes for tunnels. It's very difficult for the engineers to find out what equipment is available. Even if you know that a particular size boring machine has been constructed, it might not be available and it might behoove the construction industry to provide an inventory of the various sized machines that are available and make it available for the engineers, and then they can take that into account. If it is beneficial from the contractor's point of view, I think it might behoove the contractors to take the impetus in that regard to provide an inventory of available equipment.

MR. KNIGHT: I think these jobs are planned so far ahead that I don't believe you can assume that any particular machine is going to be available at the time the bid comes out or that the man who has the machine is going to get that bid. I think the advantage of staying with sizes that have been constructed before is that the machine for that size has been designed. There has been equipment used for that particular size.

MR. GARBESI: There's another point to that also. Try to give the contractor some alternate sections. Say, you want a 28 through 32 foot tunnel. That's the range you can build and show him some details of various sections and so on. That will usually get you more bids a lot cheaper.

MR. KNIGHT: I would like to comment on the anchor brackets in the walls where designers keep insisting on reinforced concrete. I think that should just be a concrete shaft, not a reinforced concrete shaft.

MR. OBERLEITNER: I think there should be a table prepared like they do in England and when designers design a tunnel, they have to build to the next foot. So, the majority of tunnels could be graded into certain fixed diameters wherein everything could be accomplished, and I think that the advantage of that is not only tunnel boring machines, but everything in the back-up system. There are certain sizes of locomotives, and cars that all follow a certain size tunnel, and if you could simply have a standardized section and repeatedly use those sections you will save money.

MR. BUTLER: What you're talking about is getting into standardization in a sense, and it would appear that some standardization would lead to lower costs in the long run. Did the committee get much into consideration of standardization, not only on the tunnel size, but other components?

MR. GARBESI: No, we didn't discuss the back-up systems. They are important, but they are more easily changed and fit a broader range of tunnels. A back-up system can be designed that will fit a sixteen-foot tunnel through a twenty-two-foot-diameter tunnel. Our company does that. We size our back-ups to fit ranges of tunnel sizes so that we can move them from tunnel to tunnel and hook them to a different TBM.

MR. BUTLER: I might also mention, you were talking about infiltration of water and precast concrete tunnel linings, through TSC, UMTA is sponsoring a study with the Bureau of Reclamation. It's been about a three-year effort into precast concrete joints and sealant systems, and the work is progressing quite well. I'm sure that there will be a lot of valuable information to come out of that study that would meet some of these requirements. We also had the Bureau do some special testing to help out on the work in Baltimore with some of the problems with joints sealants and that sort of thing. There's another year to go on this, but if anybody is really interested, we'd be happy to update them. Also, the Bureau people themselves, I'm sure, would be happy to discuss the progress of that study.

MR. GOZZO: I just might add that if anyone here is interested, we have a program review on that contract coming up in early April.

MR TILP: My name is Paul Tilp. Did your committee get into the possibility of using the metric system on your standardization?

MR. GARBESI: Not at all.

MR. TILP: One of the things I might mention in the Bureau of Reclamation we did put out a specification in metric units. Rather slowly there was quite a push on it a few years ago, but the pressure seemed to ease a little bit as far as metric units are concerned.

LETTER

BLAW-KNOX

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One of the White Consolidated Industries
WCI

April 4, 1979

Mr. Gail Knight
S. A. Healy Company
1845 Market Street
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Dear Gail:

Following our meeting in Boston with regards to constructability and cost, we discussed some of the comments in your paper and as I remember you plan to re-edit that original copy. I have noted Mr. Parker's comments and between his editing and yours, I am sure it will be a fine presentation.

As a designer and manufacturer of form equipment, I am continually amazed at the lack of aggressiveness of contractors to ask owners for revisions or changes to enhance the constructability of the project. There is hardly a job that comes over my desk on which we prepare subbids, and hardly any job comes through our engineering for final design where we are not able to recommend changes in construction joints, shape of structure, and method of prescribed construction where in our opinion, money can't be saved by the contractor.

In too many instances, the contractor refuses to ask for a change on the premise that the owner will immediately ask for a reduction in contract. No one wants to give back money. In this case, so called value engineering is a detriment rather than a benefit toward constructability.

Since this publication will probably go to owners and engineers alike, I believe that a limit should be established in each contract at which point value engineering would come into play. If the contractor can save a nominal amount (say up to $100,000) and increase his profitability, he should. I believe it should be a one-way street on that project with the benefits accruing to the owners and engineers on future similar projects. This would increase the inventiveness of contractors and provide the construction industry with eventual lower costs for similar work.

Todays value engineering is too cumbersome and really stifles new ideas rather than promoting them. From the ideas on one finished single project serving as a germ, the owners and designers can promote multiple savings on future work and can generate many times the reductions in costs by drawing on an accumulation of hundreds of small ideas.

The one requirement that would be placed on the contractor is that he document the revision and if necessary submit record drawings showing the improved method of construction, but the benefits up to a limit should accrue

Mr. Gail Knight
S. A. Healy Company

April 4, 1979

to the contractor and only to the contractor. There are, I am sure, those who will counter with problems of legality; on the other hand, if the rules are spelled out during bidding there should be no problems with the contract as a legal document.

I, too, enjoyed the workshop and hope to be able to contribute more as the scope is broadened.

Best personal regards,

BLAW-KNOX EQUIPMENT, INC.

H. P. Cerutti
Vice President Engineering

HPC/ck