OWNER RESPONSIBILITIES IN THE SELECTION OF TUNNEL BORING MACHINES, WITH REFERENCE TO CONTRACTUAL REQUIREMENTS AND CONSTRUCTION CONDITIONS

Die Verantwortung des Bauherrn bei der Wahl von Schildmaschinen, mit Bezug auf Vertragsforderungen und bautechnische Verhältnisse

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ABSTRACT: This paper examines responsibilities of owners in the definition and procurement of tunnel boring machines (TBMs), including the degree to which their configuration and operating characteristics should be specified. Use of prescriptive versus performance specifications for TBMs are discussed, with reference to North American transportation projects and the Los Angeles Metro Red Line East Extension.

KURZFASSUNG: Die Verantwortund des Bauherrn in der Spezifizierung von Schildmaschinen is das Thema dieses Beitrages. Das Für und Wider von generellen, leistungsbedingten (performance specifications) gegenüber streng vorgeschriebenen (prescriptive specifications) Baumassnahmen in der Ausschreibung von nordamerikanischen Tunnelprojekten und Los Angeles Red Line East Extension wird diskutiert.

INTRODUCTION

The degree to which the configuration and operating characteristics of tunnel boring machines should be directly specified by the owner, before bids are called, is the subject of some debate and controversy in North America. The owner is ultimately responsible for the conception, planning, financing, design, construction and commissioning of underground works. However, others including the design engineer, geotechnical and tunneling specialists, boards of consultants, construction managers, contract staff, environmental advocates and the community - represented by elected officials and Board members, substantially influence critical decisions which can directly affect the ultimate success of the tunneling work.

Previous papers[1] and, Track II of the North American Tunneling/International Tunneling Association Conference in Washington D.C., April 1996, dealt with the role of the owner, the media, political representatives and examined public policy, management, contracts and resolution of disputes in relationship to underground works.

First, this paper will review procurement alternatives, related to the responsibility of the owner, affecting detailed definition of the tunnel boring machine. Second, we will look at current practice in North America and relate this to the level of detail specified. A categorization of recent procurements will be presented.

For the purposes of this paper, the issue is "framed" between the following (opposite) procurement approaches.

1. The Prescriptive approach

The prescriptive approach fully defines the type and characteristics of the tunnel boring machine, and the sequence of tunneling and ground support operations.

The basis for the prescriptive approach is that the owner, advised by tunneling, geotechnical and other experts, has the time, knowledge and ability to determine the best machine type, machine characteristics, methods and sequence of operations project requirements.

2. The Performance approach.

The performance approach requires only that the contractor meet key project performance requirements and leaves substantial freedom of choice to the contractor, regarding machine types, methods and sequence of operations - so long as he meets his contractual requirements.

The basis for the performance approach is that the contractor, with his experience, is best able to determine the most appropriate methods and techniques, using practices that best suit his equipment and experience. This should result in a bid that represents the best price for the underground work. As will be seen later, this approach is flawed in its application in North America and consequently is falling out of favor, except for design-build and turnkey programs.

Owner involvement and responsibilities, in contracting for tunneling machines

All agencies, through the environmental and design process, define the tunneling machine type and characteristics which they believe are best for their projects. In North America, they are required to do so in such a way to achieve the "best price", through binding public bids which are structured according to prescribed regulations which limit flexibility after bids are taken.

In doing so, they attempt to define or "bound" those machine types and characteristics which they believe will be successful for their project, with its specific geotechnical and logistical considerations while allowing competition and flexibility to the bidders.

Decisions contractors must face in this situation include questions of technology, means and methods, schedule constraints, unknown and difficult ground conditions, public laws, regulations and risk. These questions must be decided, in an intensely competitive environment which requires answers in days, not months.

Owners are aware of this and also know that, in a "low-bid" environment, contractors will never select a more sophisticated tunneling machine - which might be necessary for the work. They will select the cheapest machine that they believe is capable of constructing the facility. The final result is, frequently, a machine that is barely adequate, sometimes inadequate, for the work to be accomplished.

Additionally, the skill of the contractor and, in particular the training of machine operators for the increasingly more sophisticated tunneling machines [2] is often lacking. This introduces another reason for the owner to attempt to direct and specify the machine and its characteristics.

The challenge is to define the appropriate level of machine type and its necessary characteristics, with associated tunneling procedures which are essential to proper ground control and tunneling productivity. The environment that owners seek includes the following:

1. Maximize contractor competitiveness
2. Provide the necessary face control
3. Avoid unnecessary settlements and damage to adjacent buildings
4. Achieve productivity and cost goals
5. Require contractor performance and ground control measures, which can be measured accurately and paid for reasonably
6. Allow all essential design and geotechnical engineering requirements to be fully incorporated in the construction process
7. Assure the owner and the adjacent communities, with their political representatives that their interests are well represented

Procurement and contracting alternatives, for tunnel and underground projects

A range of procurement and contracting alternatives are in use world-wide. For this paper, and to address tunneling machine options for a current project in Los Angeles, a limited survey of North American transit and transportation projects was made. In keeping with a theme of this paper, that more rather then less detail should be defined by the owner, with the input of an experienced, well-balanced team *including construction contractors*, the following alternatives are presented ranging from most to least prescriptive.

1. DIRECT PROCUREMENT OF TUNNEL BORING MACHINES BY OWNER

The most direct and specific alternative is the direct procurement of the tunnel boring machine(s) and tunnel liners by the owner. It is attractive for the design team to develop a very detailed tunnel boring machine specification, provided that they are adequately skilled and knowledgeable in tunnel construction applications and capable of defining procurement documents for the tunnel boring machine and linings. Practically, this is not an easy matter and requires substantial industry and expert input, to the design team, by contractors and specialized consultants.

This situation presumes that the owner, with the associated design and geotechnical engineers, is sufficiently knowledgeable about all relevant ground and construction requirements and that it is possible to adequately and sufficiently pre-determine necessary tunneling requirements and correctly specify tunnel boring machine characteristics. The successful bidder must be capable of operating the resulting machine productively and effectively, and must be given incentives to operate and maintain the tunnel boring machine while performing all ground support and tunneling services required.

This is not an easy task, and should not be attempted lightly. In particular, a high level of tunnel boring machine design and construction expertise is required - whether supplied by owner or consultant personnel. A dedicated, knowledgeable tunnel boring machine and project proponent is absolutely necessary, and must be continuously supported by the owner's management and Board of Directors, especially when controversial issues and public decisions are necessary.

Therefore, requirements for direct procurement of the tunnel boring machine are:

1. Design and geotechnical engineers who are knowledgeable about, and can clearly and cogently evaluate the ground conditions, necessary machine types and characteristics, construction requirements and risk assessment
2. Design and geotechnical engineers who are knowledgeable about construction contractor requirements, profit and other financial motives and, performance limits.

3. A principal proponent that will be dedicated to making this procurement work
4. An owner that is capable of assessing the risks and trade-offs required in decisions during the design phase and will defend them during procurement, bidding and construction.
5. An owner that will fairly recognize changed ground conditions when necessary
6. A Board or Commission that understands and fully supports the procurement approach, understands the trade-offs involved and will defend the initial decision during the construction, particularly when ground conditions are different and contractual changes are required.
7. Contractors who will "buy-in" to the procurement approach - albeit with reservations, which must be expressed, addressed and resolved fairly and reasonably.

Example of direct machine procurement - Toronto Transit Commission (TTC) Rapid Transit Expansion Program (RTEP)

The most directly applicable case[3] of a transit agency directly procuring tunnel boring machines is TTC's Rapid Transit Expansion program. TTC procured, under a sole source arrangement, two 5.9 meter diameter Lovat earth pressure balanced machines for use on three tunneling projects, the Sheppard, Eglinton and Spadina rapid transit tunnels totaling 8.9 km. TBM characteristics were determined by the owner, design engineer, geotechnical engineer and a specially-convened TBM Peer Group of industry experts.

Anticipated benefits included:

1. Assured early availability compared to contractor procured - schedule compression.
2. Agency estimated reduction of each project bid by almost $5 million
3. Direct owner procurement allowed optimization of machine characteristics, with the most appropriate technology and features, as determined by the owner, with the design engineer and associated Peer Group of industry experts.
4. Expected reduction of contractor contingency in bids.
5. Early stimulus to the local economy - a goal of the "Jobs Ontario" program

Potential disadvantages

1. Owner assumes risk of machine performing in the ground conditions identified
2. Definition of operational requirements, maintenance procedures, wear versus performance trade-offs need to be clearly and carefully defined and are influenced by (possibly unanticipated) ground conditions
3. If ground conditions are not as anticipated, the owner has full responsibility for machine performance
4. Contractor will blame owner for problems which (are claimed to be) related to machine issues
5. Potential for disputes is raised

2. NEGOTIATED COMPRESSED PROCESS - OWNER PROCURED TBM

A variation on direct procurement, the negotiated compressed procurement is an approach that involves all parties, the owner, the design and geotechnical engineers and pre-qualified potential contractors. It has been applied to the St. Clair US-Canada[4] and Aguas Argentinas, Buenos Aires[5] projects. It is a method to achieve full tunnel machine design detailing and procurement by the owner, with formally structured owner, engineer and contractor involvement.

The owner at St. Clair, the Canadian Northern Railroad, with its design and geotechnical consultants, decided to save 6 to 9, perhaps 12 months of project schedule with corresponding direct and indirect cost savings by adopting the negotiated compressed process, which was an innovative formalized approach to risk sharing for the project. In making this decision, they considered four different contractual processes including traditional competitive bidding, design-build, accelerated bid process and the adopted negotiated compressed process.

The negotiated compressed process involves the owner, engineer, technical specialists and pre-qualified contractors in the selection and design of all essential aspects of the project, including pre-purchasing critical elements including the tunnel boring machine and tunnel liners. Key elements of the compressed process are:

1. Definition of long lead-time elements
2. Preliminary project advertisements
3. Letters of interest from contractors
4. Pre-qualification of contractors
5. Pre-qualification of suppliers for tunnel boring machine and liners
6. Buy-in and consensus building
7. Risk evaluation and management
8. Bids for tunnel boring machine, liners and construction
9. Fabrication, delivery, construction and management

At St. Clair, the machine encountered a problem with the main bearing seal, just prior to tunneling under the river necessitating a cut and cover shaft to remove the cutterhead and replace the seal. The contract lost some 212 calendar days because of this problem. This problem was independent of the negotiated compressed process which did compress the overall project schedule, saving time lost through the machine seal problem.

It might be argued that the seal problem was "locked-in" by the process itself and would perhaps not have occurred if the project had been open to other machine manufacturers. It is of note that the owner foresaw this problem, having ordered a spare main seal and bearing before the machine started tunneling operations.

Observations - direct procurement

Limited survey of project experience and tunneling literature shows that direct procurement of tunnel boring machines is not common, has not been accepted generally by the industry, nor has this approach been proven to be applicable to any but a few projects, with special circumstances.

Only two North American examples have been attempted, the above referenced TTC Rapid Transit Expansion Project and the St. Clair rail tunnel between Sarnia, Ontario and Port Huron Michigan for Canadian Northern.

The benefits for the St. Clair tunnel are a major schedule gain offsetting serious construction delays and a tunnel machine that performed well with the exception of a significant and expensive seal and bearing failure.

For the Toronto case, the benefits are not proven, since that program is currently restricted due to lack of funding, Due to project cash-flow problems, the tunnel machine procurement schedule gain has been offset and has not been realized. The suitability of the machine for the tunneling conditions, another argument for owner detailing and direct procurement has not been tested, but there is no reason, at this time, to believe that the machines will not perform as anticipated.

3. HIGH LEVEL DETAIL BY OWNER, TBM PROCURED BY CONTRACTOR

Most of the North American owners surveyed (Washington Metro, San Diego ocean outfall, Tri-Met Portland, Oregon) have required the contractor to procure, supply, own and operate the tunnel boring machine but have specified a relatively high level of detail in the bid documents. It should be noted that the level of detail has tended to increase in recent years, both for individual owners and for the North American industry in general.

With this approach, the design team of owner, engineers and geotechnical engineers, using sometimes extensive industry surveys, meetings and reviews[6], with tunnel machine manufacturers and contractors, determine the types of machines which are judged suitable for the soil characteristics[7] , the specific project application and the specific level of detail necessary for machine operating characteristics. This is reflected in the bid documents.

The level of specificity limits flexibility for the contractor with respect to selection and operation of the tunnel boring machine and also frames and defines the level of responsibility, for the owner and engineer, in the subsequent construction. This is a very significant and important consideration in a low-bid environment and has been the subject of continued discussion in the industry[8], [9], [10]. Related is the Geotechnical Design Summary Report[11].

If the owner specifies the type of tunnel boring machine in detail, and ground conditions are encountered under which the machine has difficulty in performing according to the owner's and engineer's expectations, the contractor will, of course, blame the issue on the type of tunnel boring machine and the specific details required by the specification.

However, even if the specification is not restrictive or detailed, the owner is still directly and substantially involved through the soil data and conditions, the Geotechnical Design Summary Report, and through the process of review and approval of the contractor's proposed machine and his methods and construction procedures.

A reaction to this problem is for some owners to consider moving towards a more performance based specification for future work, specifying only the tunneling performance required of the contractor, as described below.

4. PERFORMANCE SPECIFICATION

It is tempting to avoid all the detail and decisions involving tunnel boring machine type, configuration and details and to shift risk to the contractor by simply requiring bidders to meet basic performance.

This however, presumes that the bidders are capable of anticipating all project tunneling requirements, ground conditions, machine characteristics and project needs in the compressed bid time-frame, submitting a low bid that is sufficient to enable them to be financially and operationally successful and, at the same time, meet all of the owner's defined requirements.

While this would seem attractive, it discounts the reality of the "low-bid" competitive environment, puts full faith in the abilities of the bidders and, assumes that they will put first priority on meeting the owner's goals (as opposed to meeting their own economic realities). In effect, this relinquishes control of the construction to the contractor - who must operate in a time and resource-restrictive environment under strong financial pressures. Clearly this is an optimistic presumption and, as such, is not likely to fulfill the expectations of the owner or agency for underground work.

This approach also does not make full use of the expertise and knowledge of the design team who are in the best position to review, study, evaluate and recommend the approach, or range of approaches that is judged best to meet local and owner-specific tunneling requirements.

5. DESIGN-BUILD / TURNKEY

The opposite alternative to direct procurement, beyond a pure performance specification, is design-build. This approach to rapid transit tunnel projects is currently being implemented for two FTA demonstration projects - the Tren Urbano project in Puerto Rico and for the BART San Francisco Airport Extension project. Tren Urbano is in final contract document preparation, with a construction start expected in 1997. The BART San Francisco Airport Extension project has just passed design-build contractor pre-qualification and expects to call for design-build proposals in early 1997.

There are several driving forces influencing the owner's decision to use design-build or turnkey. These include:

1. Overall schedule compression, for transit projects amounting to more than a year
2. Savings of direct and indirect cost due to the schedule compression

3. Contractor provides external financial support and bridge financing
4. Moves performance risk more to the contractor
5. Moves details of design and construction to the contractor

Of these only items 4 and 5 are relevant to this discussion. It therefore follows that the above mentioned problems with the performance approach, and the trend in the industry to move to a more prescriptive approach, argue that the turnkey or design-build approach is essentially a trade-off, improving schedule and financial options but potentially increasing risk for underground and tunneling construction.

Comment on design-build

There is a middle alternative, preserving the schedule and financial benefits of turnkey/design-build, but structuring the contract documents to reflect a higher specificity of tunnel machine and procedural requirements, similar to the prescriptive approach. This is reasonable, if the prescription is limited to fundamental elements and does not introduce details that are best left to a knowledgeable contractor.

Alternatively, the review and approval process could be left flexible, so that critical issues could be discussed after the bid is entered. This however, would tend to negate the fundamental concept of design-build. See also papers on design-build in the North American Tunneling/International Tunneling Association conference, Washington D.C. April 1996[12]

6. LIMITED SURVEY, NORTH AMERICAN TRANSIT PROJECTS

As part of the background for this paper, and to resolve procurement questions for the Los Angeles transit program, several North American transit and related owners, with recent experience in the procurement, contracting and construction management of underground tunnels in urban areas, were contacted. The goal was to determine their policies and experience with regard to tunnel machine procurement, to assess the level of detail in the contract documents and construction packages for their tunnel contracts.

Responses to the survey were categorized in terms of the degree of specificity for the tunnel machine and its operating characteristics. This was done by having the responsible manager or engineer estimate this factor knowing the basic characteristics of the projects involved.

The agencies surveyed, with a summary of the projects and tunnel machine types, were:

6.1. Toronto Transit Commission, Rapid Transit Expansion Program,

Sheppard, Eglinton and Spadina rapid transit tunnel projects. Two owner procured Earth Pressure Balanced Machines (EPBM) TBMs. Contractor bids on installation and operation of TBMs and installation of pre-purchased pre-cast tunnel liner. Design by consultants with involvement of industry experts, owner performs construction management

6.2 Washington Metropolitan Transit Authority (WMATA) Washington DC

Fast-track completion of the 101 mile transit system. Conventional design-bid-construct, contractor procured EPBM TBMs, Slurry Shield TBMs and New Austrian Tunneling Method (NATM), Design by consultants with substantial owner involvement and direction. Owner performs all construction management

6.3 Tren Urbano Transit project, Puerto Rico

Turnkey design-build rapid transit underground line and station program. Project is in tender and contractor selection stage.

6.4 Tri-County Metropolitan Transportation District, Portland, Oregon

Westside-Hillsboro Light Rail Project. Conventional design-bid-construct, hard/soft rock tunnel boring machine. Design by consultants, owner performs construction management services, assisted by consultants

6.5 International Boundary / Water Commission, San Diego, South Bay Ocean Outfall

Conventional design-bid-construct, contractor procured fully shielded Earth Pressure Balanced Machine (EPBM) with slurry and foam injection capability. Initial design by consultants with extensive industry and manufacturer input, final design by contractor, construction management by consultant

6.6 Saint Clair River tunnel between Sarnia, Ontario and Port Huron, Michigan.

Negotiated compressed procurement process, design by consultants, owner procurement of tunnel boring machine and tunnel liners, contractor bids on installation and operation of TBMs and installation of pre-purchased pre-cast tunnel liner, construction management services by design consultants

6.7 Los Angeles Metropolitan Transportation Authority (LACMTA)

Metro segments 1, 2 and 3 involve tunneling in alluvial sands, silts and gravels, as well as soft and medium strength rock in a highly seismic area with significant hydrocarbon presence. Conventional design-bid-construct. Design by consultants and industry experts, construction management by consultants. Significant political and media interest and involvement.

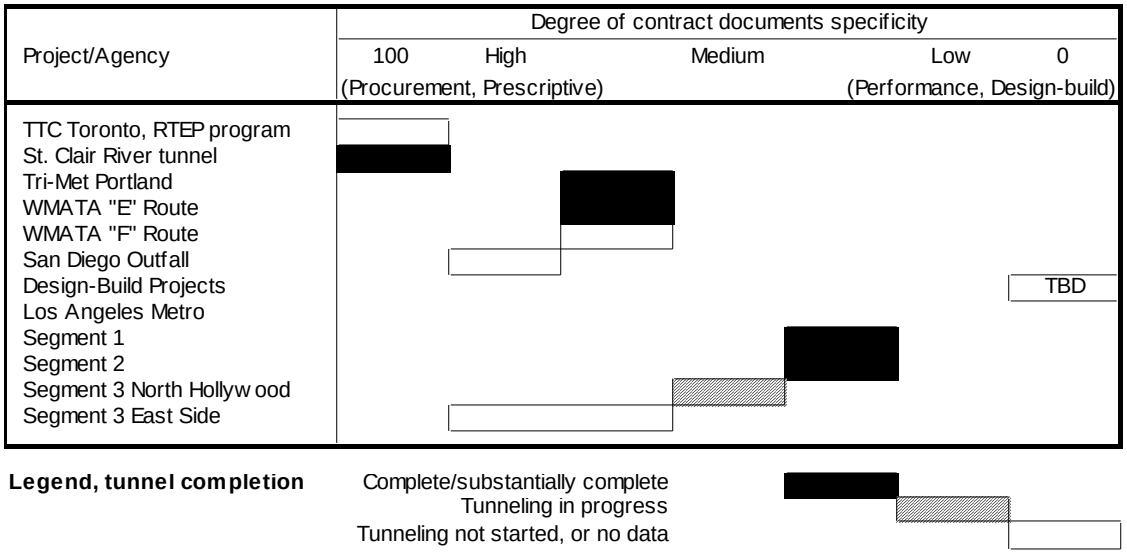
The following chart shows this characterization. Points of note are:

1. Tunnel machine requirements are moving in the direction of more specificity and complexity, in general for the industry and for projects in particular.

   That is, more specific, more sophisticated machines are being used now and are also being required by owners for multiple long-term project programs such as Washington and Los Angeles.

2. As programs mature, more local experience is gained, and the public, media and politicians become aware of the issues, more requirements are placed on the owner, engineer and contractor to perform at higher levels.

TUNNEL MACHINE SURVEY - PROJECT vs. LEVEL OF SPECIFICITY



7. COMMENT - LOS ANGELES TRANSIT TUNNEL PROGRAM

As has been reported in the press over the past 2 years, the Los Angeles Metropolitan Transportation Authority (LACMTA) has had a mixed and difficult history with several of the more recent Segment 2 tunnels. This follows a significantly low level of publicity for the first underground segment from Union Station to Downtown LA. In fact, the absence of publicity for Segment 1 was of note and highlighted the contrast, for the local and national press, when problems were encountered in Segment 2.

Subsequently, after the problems were encountered in Segment 2, a study by Drs. Eisenstein, Parker and Martin[13] demonstrated that the MTA tunnels performance is, in general, "...equal to or slightly better than worldwide performance."

Significantly, this performance was achieved, under "low-bid" competitive conditions, at a cost which is low relative to prices world-wide.

While low cost is an important goal, the ground and settlement problems were attributed, in part, to the cost factor as well as to ground conditions and the lower level of face control by the shields employed. Accordingly, the study recommended that tunneling machines must be considered that have significantly better face control, specifically positive face control in the alluvial soils.

This recommendation, which is in the process of being implemented, under careful scrutiny from the local owner (LACMTA) and the co-funding Federal agency (United States Federal Transit Administration) will result in more specific contract document requirements, will require a higher standard of tunnel machine and tunneling practice and will also result in higher bid prices - but with better tunneling performance expected and correspondingly lower disturbance to adjacent communities and infrastructure.

8. ADVANTAGES AND DISADVANTAGES

Advantages, owner procured machines

- Potential schedule gain, about 9 - 12 months
- Cost saving for multiple reuse of tunnel boring machines, owner controlled
- Cost savings from reduced contractor bid contingency - more risks assumed by owner
- Agency is sure of the type and characteristics of the tunnel boring machine
- Machine reflects best project characteristics as determined by owner/design and geotechnical engineers plus expert advisors
- Agency/design and geotechnical engineers requirements satisfied
- Owner fully responsible for tunnel boring machine capabilities
- Owner fully specifies ground stabilization and mitigation requirements
- No uncertainty about ground stabilization and mitigation requirements
- Responsibility for changed ground conditions are clearer

Cons, owner procured machines

- Contractor claims difficulty in operating owner's machine
- Contractor claims different ground conditions mean owner's machine is unsuitable
- Contractor claims machine problems / maintenance requirement are owner's fault
- Agency clearly most directly responsible to community for problems - settlement, delay, costs overruns
- Agency more directly liable for claims, disputes, litigation
- Contract specifications must deal with expected production rates, maintenance requirements, down-time and methodologies to deal with unexpected conditions
- Construction management requirements are more demanding

Advantages, machine procured by contractor

- Agency has less responsibility for machine problems
- Agency is not responsible for separate procurement
- Agency /design consultant expertise in tunnel boring machine design and fabrication reduced
- Project cash flow reduced
- Number of machines determined by contractor if documents allow
- Agency not concerned about disposal of tunnel boring machine at end of work
- Tunnel boring machine maintenance is contractor's responsibility
- Tunnel boring machine access and removal is contractor's responsibility

Cons, machine procured by contractor

- Owner has reduced input into tunnel boring machine characteristics
- Owner has reduced involvement in machine design
- Tunnel boring machine will be "low-bid" - a basic and limited machine may result
- Unsuitable machine for ground conditions possible
- Unsuitable machine for ground conditions causes extra cost to contractor and owner
- Unsuitable machine for ground conditions causes extra schedule time for contractor and owner
- Longer construction schedule

9. BACKGROUND ARTICLE - THE PRESCRIPTIVE APPROACH, RELATIVE TO CURRENT TUNNELING PRACTICE,

Extracted from a position paper by Wolfgang Roth, Dames & Moore, Los Angeles, California

Successful tunneling requires a careful balance between the cost and effort spent on excavation equipment and techniques versus the cost of ground modification. For example, "the price to pay" for employing an open-face digger shield in coarse alluvium is extensive ground modification including dewatering and/or grouting. Investing in a full-face Tunnel Boring Machine (TBM), on the other hand, reduces grouting costs; and employing Earth Pressure Balance (EPB) or Slurry Shields could even eliminate the need for dewatering. Hence, the choice of tunneling approach strongly depends on economic and investment decisions. Unfortunately, performance specifications allow such decisions to be made by low-bid contractors willing to take the risk of "getting by" with less on tunneling equipment and techniques, without having to pay the price for ground modification.

Based on recent experience in Los Angeles, many multi-million dollar construction claims are traceable to undue reliance on contractors' engineering judgment in the choice of tunneling methods and equipment. More often than not, these claims are successful. That is, owners end up paying for the downside risks which contractors are willing to take in order to produce the lowest bids. With a better than even chance of recovering ground modification or dewatering costs by way of changed-conditions claims, there is little incentive for contractors to invest in refined tunneling methods and/or sophisticated equipment. The results are frequent construction mishaps, delays, cost overruns, and loss of political and public support on highly visible projects. Improving this situation in the low-bidder environment of public works, which lacks the possibility of meaningful contractor pre-qualification, is not an easy task.

One solution to the above dilemma is to shift from performance- to prescription-based specifications. Instead of simply requiring a contractor to "tunnel from A to B". Some owners recently have gone so far as to provide pre-purchased tunneling equipment of their choice. Some may regard this approach to be in utter violation of conventional wisdom (i.e. "never tell a contractor how to do his work"). However, with today's rapidly advancing technologies, this traditional piece of advice may have outlived its usefulness.

Particularly in the U.S., where contractors seem to be reluctant to apply new technologies on their own, the impetus for progress may well have to come from the owner's side. Prescription specifications may be the only viable means of achieving this goal in the short term.

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