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SYNOPSIS The Los Angeles Metro Rail Subway project is initially planned for 30 km (18 mi) of twin, 6-m (20-ft) diameter bored tunnels under city streets and a total of 16 stations. This paper describes briefly the history of the project, the geologic setting, and the challenges encountered during design or anticipated during construction. It also introduces, as part of Contract documentation, an interpretive geotechnical baseline report which establishes the basis for identification and recognition of site condition "baselines". In so doing, this report (known as a "GDSR") has proven to be an effective tool for ameliorating contractual problems and facilitating conflict resolution.

INTRODUCTION

The Los Angeles Metro Rail subway project is part of a larger rapid transit system serving the Greater Los Angeles Metropolitan area. After decades of ever-increasing automobile traffic congestion and air pollution, the voting public recognized the need for an improved public transportation system which would include buses, highway management and a 480-km (300-mi) rail network consisting of subways, light rail and commuter rail (Figure 1). The subway system comprises three segments, with an initial total length of 30 km.

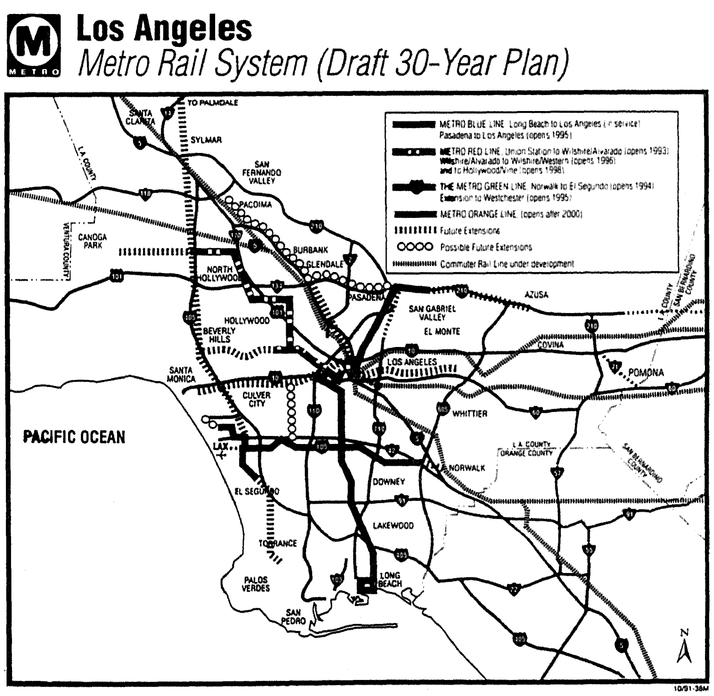


FIGURE 1

This paper outlines the history of the project, the geotechnical data, the challenges encountered or anticipated during design and construction, and the use of comprehensive geotechnical design summary reports (GDSRs) for reducing the cost of potential contingencies or conflicts arising during construction. The GDSR is a document which sets forth the designer's geotechnical interpretations of anticipated conditions for design and construction. Made part of the construction contract documents, the GDSR establishes a baseline from which differing site conditions encountered during construction can be identified. Such a baseline provides a geotechnical basis for bidders, thereby minimizing the cost of contingencies and subsequently resulting in a lower bid price. Thus, the owner does not pay for potential contingencies unless they occur. The GDSR benefits both the contractor and the owner, and reduces chances of prolonged litigation in case of a conflict.

BACKGROUND

Los Angeles is one of the world's largest cities and possesses one of the busiest and most extensive urban freeway systems. The population of Los Angeles and its surrounding areas incorporated into Los Angeles County is over 12 million, with about as many automobiles on its freeways. After two decades of planning and debating, a public transit measure was placed before the Los Angeles County voters in 1980. The voters recognized the need for improved public transportation and passed the measure for a half-percent sales tax increase. Thirty-five percent of the fund was allotted for the design, construction and operation of a 480-km (300 mi) rail transit network. Again, in 1990, the County voters approved another half-percent sales tax increase to speed the construction of rail and highway projects. Forty percent of these funds are being used for improving the transit system. The Los Angeles County Transportation Commission (LACTC) administers these transportation funds for the County. The one-percent tax currently generates $800 million per year, from which about $300 million is allotted to rail transit network. The remainder is to be spent on buses and highway management.

The 480 km of total rail network consists of at-grade light and commuter rails, including over 40 km (25 mi) of underground heavy rail subway system. The completed Metro Rail network is expected to transport 500,000 people daily by the year 2010. The subway projects are being built to handle the heavily populated areas of the County and will provide linkage with light rail and bus lines. The subway is electrically powered by a third rail running parallel to the track. Allowing for travel of up to 110 km (70 mi) per hour beneath the congested roadways, the subway will carry 250,000 passengers each day in safety and convenience.

The subway network is planned in three segments initially (Figure 2). Segment 1, identified as Minimum Operable Segment (MOS-1), is 7.1 km (4.4 mi) long, and extends from Union Station in the center of downtown Los Angeles westward to MacArthur Park. Revenue operation is scheduled to begin in March of 1993.

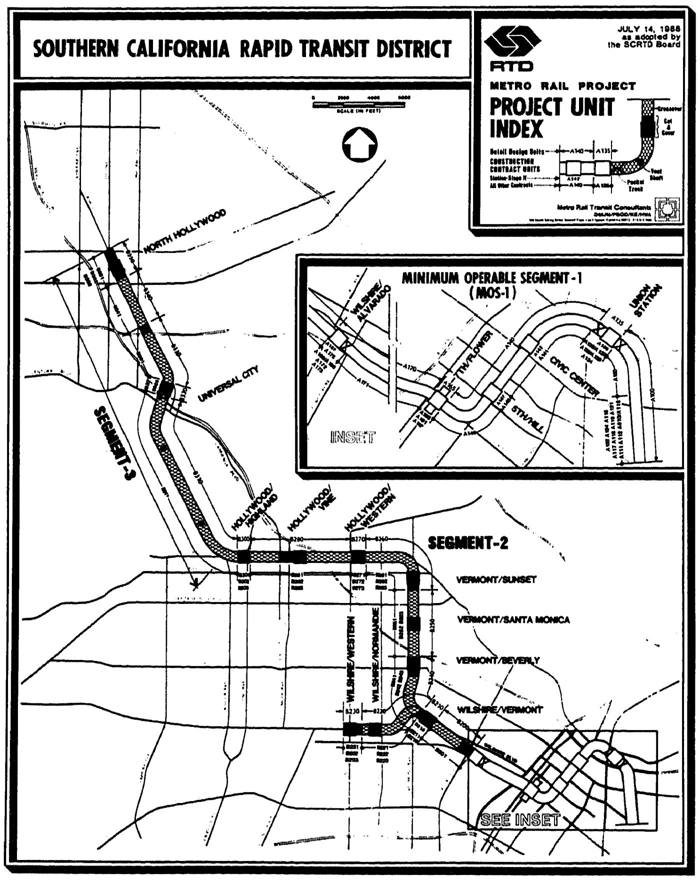


FIGURE 2

Segment 2 is to constitute the main artery of the Los Angeles Metro system. It extends from the western end of the MOS-1 alignment, and proceeds west along Wilshire Boulevard as far as Vermont Avenue. Here it proceeds in two legs. One turns north on Vermont, and then curves west to and along Hollywood Boulevard, terminating at the junction of Hollywood Boulevard and Vine Street. The other continues west on Wilshire Boulevard and terminates at Western Avenue. The length of Wilshire Boulevard leg of Segment 2 is 3.7 km (2.3 mi); that of the northwesterly leg is 7.7 km (4.8 mi). Segment 2 is presently under construction and is expected to be ready for revenue operation in 1996.

Segment 3 extends from the Hollywood end of Segment 2 and proceeds north and west, with its tunnels passing through the Santa Monica Mountains, in rock to depths between 60 m (200 feet) and 250 m (820 feet) below the surface. Segment 3 is 10 km (6.2 mi) in length and ends at the North Hollywood Station.

Segment 4, in the planning stage, will build upon the work performed in previous Red Line segments. One portion of Segment 4 will move westward to extend the Wilshire corridor; another will proceed beyond the North Hollywood Station to the northwest, and a third leg will extend the Red Line eastern limit to the south and east of Union Station.

The entire subway alignment is located in heavily populated and well-developed areas of Los Angeles, amidst some of the most seismically active zones in the United States. The invert depths of planned facilities - except for the Santa Monica Mountains excavation - range from 15 to 30 meters (50 to 100 feet) below the ground surface.

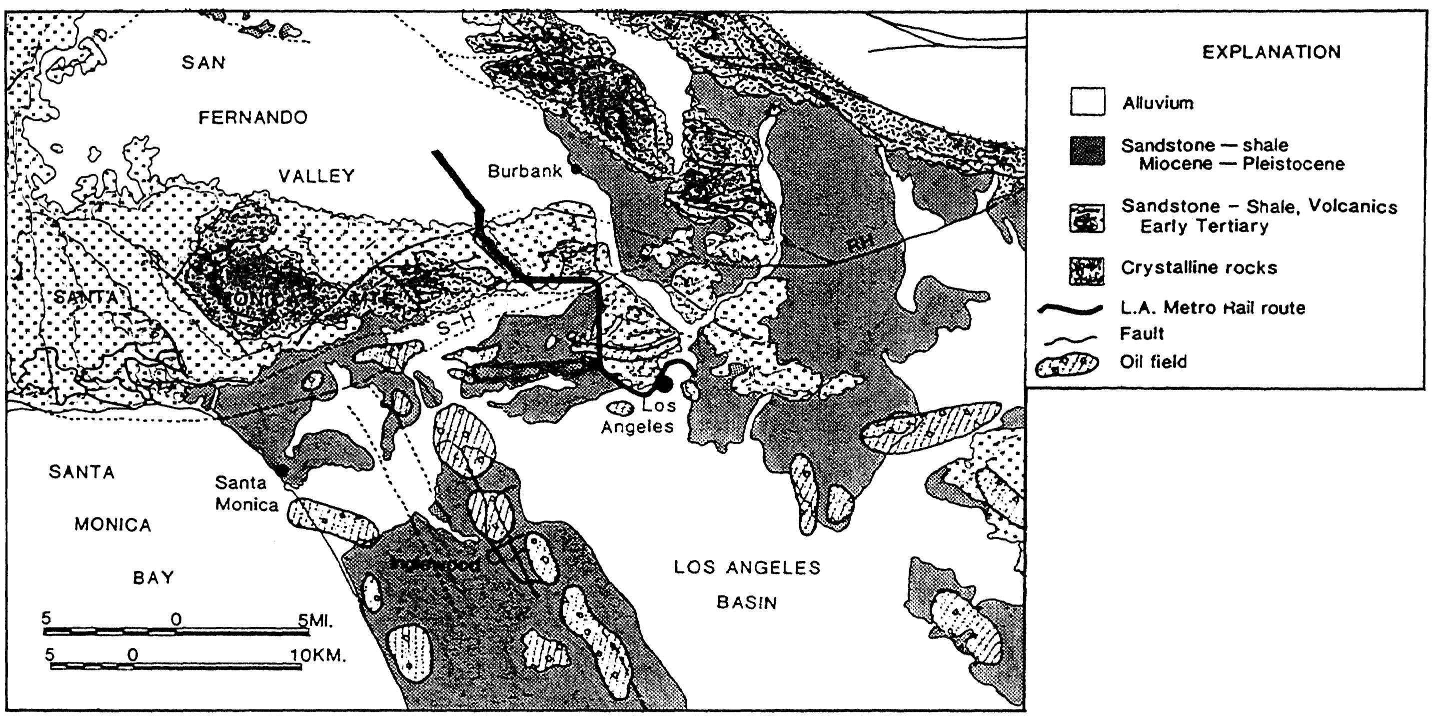
GEOLOGIC SETTING

The subway is located within the Los Angeles Basin, which is defined by Yerkes et al. (1965) as encompassing tectonic or structural blocks. The Basin is subdivided into four such structural blocks: the Northwestern, the Northeastern, the Central and the Southwestern. The subway is located mainly within the Central Block, which is bounded on the north by the Hollywood and Santa Monica Fault zones, on the northeast and east by the Whittier-Elsinore Fault zones, and on the west-southwest by the Newport-Inglewood Fault zones. The Central Block is underlain by a deep structured depression in-filled with various geologic units consisting of Holocene-aged Young Alluvium and Pleistocene-aged Old Alluvium overlying upper Miocene-Pliocene-aged Puente and Fernando Formations. The upper Young and Old Alluvium materials are very heterogeneous, consisting of dense to very dense granular soils with gravel and boulders, and stiff to hard fine-grained soils. Pockets and strata of uniformly-graded sands are also present. The presence of these sands, also called "sugar" sands or running sands, requires special tunneling techniques and grouting during tunnel construction. The Puente Formation consists predominantly of stratified and weakly interbedded claystone, siltstone and sandstone. The Fernando formation is similar to Puente Formation bedrock and consists mostly of sandstone and siltstone.

The margin of the Los Angeles Basin and its four blocks is formed by zones of folding and uplifting along basin/block-bonding faults. Within the Central Block, major geologic features include the fault zones and the Los Angeles Anticline. The Los Angeles Anticline is a gentle upfold in the Puente Formation and trends about N 70° W, which influences the dip of bedrock strata in the area. This anticline acts as a trap for oil and gas within the Puente Formation. The Los Angeles City Oil Field is within this anticline. Part of the subway traverses the oil field, as evidenced by the presence of tar and oil in excavated materials in the area of abandoned oil wells.

Even though most of the subway is excavated in the competent Puente type of soft bedrock, there are significant lengths of tunnels bored in alluvial soils with large boulders, in running sands, and in mixed-face conditions with high groundwater table. Even in the Puente Formation there is significant presence of hard sandstone which slows down the progress of tunneling (Figure 3).

- Dewatering options
- Underpinning and protection of adjacent structures
- Control of construction-induced settlements and movements
- Instrumentation and monitoring
- Logistics of transporting and placing excavated materials
- Separation of contaminated or toxic materials from excavated soils at tunnel headings



Geologic map of the Los Angeles area showing Metro Rail route, major faults and oil fields. Identified faults are MC, Malibu Coast; RH, Raymond Hill; SF, San Fernando; S-H, Santa Monica-Hollywood; SM, Sierra Madre. West end of subway route shown crossing Salt Lake oil field.

FIGURE 3

ITEMS OF SIGNIFICANT CONCERN

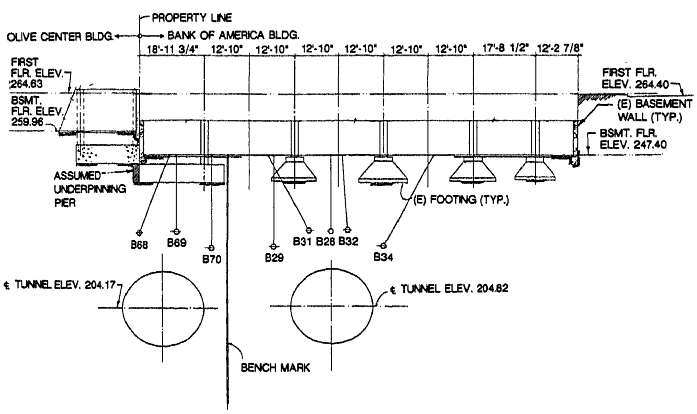
On any project of this size, and passing as it does through different geological terrains and under busy city streets, there are bound to be numerous challenges. Such has been the case for the Los Angeles Metro Rail subway, with its share of problems and controversies, as well as innovations, good managerial decisions and successful efforts at cost savings. Following are some of the items that require continuous attention during design and construction of tunnels and stations.

- Prevention of methane gas intrusion
- Sequence and staging of excavation
- Excavation difficulties, e.g.,presence of boulders or running sands
- Lateral earth pressures and preload requirements for braced excavation

By way of illustration, two of these items are discussed in some detail.

On the MOS-1 segment, the alignment at Yards and Leads was to be constructed by the cut-and-cover method. The location of borings taken during preconstruction geotechnical investigations was such that a large area of highly toxic materials in the ground from a turn-of-the-century coal gasification plant was not detected, only to be discovered during construction of a footing for busway construction. The subway alignment was subsequently revised, thereby causing project delays. Design revision included adoption of slurry walls, to avoid expensive water treatment during dewatering for excavations. However, the cost incurred due to delays was small compared to estimated costs for removal and remediation of highly toxic materials.

Another portion of the MOS-1 alignment passed beneath numerous high-rise structures, which would normally dictate underpinning of the foundations. The cost of conventional underpinning of various spread or combined footings would be over $50 million. Tunneling was done in granular alluvial soils with cobbles, boulders, and uniformly graded "sugar" sands. Settlement estimates for footings varied from 3 to 8 centimeters, depending on tunnel depths. Detailed analyses were undertaken for each structure to arrive at estimates of differential settlements between adjacent columns, and worst-case scenarios were developed. Conventional underpinning would have required right-of-ways from inside the buildings, and resulted in disturbance over a long period to occupants of the lower floors and to sidewalk traffic. Therefore, to protect the buildings, compaction and chemical grouting were employed instead of conventional underpinning, at less than half the original cost estimate. Grouting was performed from inside the buildings using thin steel pipes and also from the tunnel face. A typical grout injection configuration is shown in Figure 4. Cement grout of stiff consistency was injected in the subsoil to reduce settlement.



TYPICAL SECTION SHOWING GROUT PROBES

FIGURE 4

DISCUSSION

On the Los Angeles Metro Rail subway project, extensive and in-depth investigations and analyses were carried out for geotechnical and environmental studies, as part of the preliminary design. Borings and samplings were taken at station locations and along the tunnel alignments at 160-m (500-ft) intervals or less. Depths of borings extended to at least 10 m below invert levels. In most instances, at least one groundwater monitoring well was installed to measure the water level within each contract unit. Laboratory tests were performed to classify soil and rock types, and static as well as dynamic design parameters were developed. Chemical tests were performed on both the soil and groundwater samples to identify levels of contamination and, when encountered, anticipated quantities of contaminated or toxic materials were developed. Remediation studies were carried out for treatment and safe disposal of contaminated materials to meet strict local and federal environmental regulations.

Even with such elaborate and sophisticated explorations and studies, it remains difficult to foresee all conditions that could be encountered during construction of subway projects. It is also not possible to anticipate the actions and positions that will be taken by various parties involved, when some unforeseen conditions develop on the job. Therefore, to improve contracting practices, establishing equitable risk sharing between the contractor and the owner becomes a necessity. Under this arrangement the owner is responsible for payment of increased costs of encountering unforeseen conditions and subsequent delays which are beyond a bidder's ability to anticipate. Successful employment of equitable risk sharing leads to lower bids and a reduced incidence of claims or litigation.

The need for such risk sharing became evident on MOS-1 contracts, where the entire risk was placed on the contractors, in the absence of contractual provision to include a GDSR as part of contract specifications and in spite of all pertinent geotechnical data made available on contract documents.

A GDSR sets forth the designer's geotechnical interpretation regarding anticipated conditions for design and construction. It is a separate document and is made part of contract specifications. The specifications state that in the event of apparent discrepancies or inconsistencies with other geotechnical data made available to the contractor, the GDSR will govern in the reconciliation of a conflict. A GDSR sets a baseline and, if the conditions encountered are different from the baseline and contractor can demonstrate a financial impact, he is then entitled to additional compensation. It is good business to pre-establish an interpretive baseline, resulting in lower bids and elimination of major cost contingencies.

On Segment 2, GDSRs are being incorporated into construction contract documents for each station and tunnel contract and are binding upon contractual parties. Based on experience gained so far on those Segment 2 contracts under construction, the claims for differing site conditions are a fraction of claims either paid or being litigated on MOS-1 contracts.

On the Metro Rail subway project, the significant items resulting in changed conditions and delay have been the size of boulders, the presence of gasoline-soaked or other contaminated soil, lateral soil parameters for temporary support of deep excavations for cut-and-cover station construction, the lack of defined hardness of rock, and the presence of running sands in alluvium or mixed-face conditions, necessitating either compaction or chemical grouting to minimize movement of adjacent structures.

A GDSR must contain a precise description of anticipated subsurface conditions and a delineation of ground behavior during excavation of stations and tunnels, consistent with one or more construction methods likely to be considered by the contractor. Where dewatering is a viable option, estimated pumping quantities, well design and well spacing must be included. It must also contain the designer's estimates of toxic or contaminated materials, if anticipated on a contract unit. The GDSR must also provide reference to sources of information for factual data contained in geotechnical and environmental reports, and to construction experiences on previous projects under similar conditions including grout takes and mixes, measured settlements, structural types and settlement tolerances.

It is the designer's responsibility to respond to the owner's concern as to the correctness of the interpretation in the development of the geotechnical baseline. If the interpretation is too conservative, the GDSR will raise the bid price and may restrict the contractor's initiative for innovation. If such an interpretation is too optimistic, the GDSR may increase the potential for future claims during construction. To arrive at the best possible interpretation, therefore, each GDSR for the Los Angeles Metro Rail project is reviewed by experienced geotechnical, tunnel and civil/structural engineers from the owner's, construction manager's and designer's staff.

A design engineer takes several months to analyze and develop interpretations and, therefore, is in the best position to assess the reliability and representativeness of available data. On the other hand, a bidder has a limited number of weeks during the bid period in which to assimilate all available documents and develop his interpretation. The GDSR thus protects the ultimate bidder by providing a well-defined basis for preparing the bid and a clear definition of the limits of his exposure.

The concept of using GDSRs on large underground projects has received wide acceptance in the United States. Experience indicates that GDSRs provide a more realistic portrayal of actual conditions likely to be encountered than does the raw data reporting with little or overly conservative interpretation. Use of GDSRs is beneficial to both the owner and the contractor.

SUMMARY

The Metro Rail subway is part of a multi-decade mass transportation project for the Greater Los Angeles area. The project deals with many of the problems common to the world's major underground projects, such as coping with methane gas intrusion and tunneling through complex geological formations. It also faces a number of challenges unique to the Los Angeles Basin and the conurbation lying therein. As a means of problem alleviation, the development of a baseline for tunnel and station construction, spelled out for all bidders in the GDSR, provides a common basis for bid. During construction, the GDSR affords a means of assessing the merit of and equitable adjustment to contract price. The use of GDSRs, together with the adoption of a committed attitude by the owner for equitable and timely resolution of claims, has created for the Los Angeles Metro a win-win approach to construction.

The GDSR is one of the innovative management tools employed to deal with the complexities of the Metro Rail project and cut construction costs, by allowing risk to be shared between the contractor and the owner. Thus far, the results obtained through employment of GDSRs have been quite encouraging.