JOINT WATER POLLUTION CONTROL PLANT TUNNEL AND OCEAN OUTFALL PROJECT

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ABSTRACT

The Joint Water Pollution Control Plant (JWPCP), operated by the Sanitation Districts of Los Angeles County (the Districts), treats wastewater generated by over 3 million people and processes wastewater solids generated by over 5 million people. The JWPCP Tunnel and Ocean Outfall Project, if constructed, would be one of the major marine outfall projects in the world. The new tunnel and ocean outfall system would provide relief to the existing outfall and allow inspection, maintenance, and repair of the existing tunnel and outfall system, portions of which were constructed as early as the 1930s.

Geologic conditions are challenging along the alignments within the study area being considered. Conditions include saturated alluvial soils, weak sedimentary rock, mixed face conditions, and squeezing ground conditions. Other significant challenges include the potentials for encountering up to 11 bars of water pressure, crossing seismically active faults, and encountering gassy and contaminated ground conditions. This paper discusses the details of the proposed project and the associated challenges.

INTRODUCTION

The Districts are 24 independent special districts that serve approximately 5.3 million residents in Los Angeles County. Seventeen of the districts that provide sewerage to metropolitan Los Angeles are signatory to a Joint Outfall Agreement that provides for a regional, interconnected system of facilities known as the Joint Outfall System (JOS). The JOS serves an area that encompasses 73 cities, unincorporated territory, and parts of the City of Los Angeles. Figure 1 shows the area served by the JOS. The JOS provides sewage treatment, reuse, and disposal for households, businesses, and industrial customers. It includes seven treatment plants, the largest of which is the JWPCP, located in the City of Carson. Currently, secondary effluent from the JWPCP is conveyed through two parallel tunnels of 2.4 and 3.7 m (8 and 12 ft) in diameter. The tunnels interconnect at a manifold structure at Royal Palms State Beach on the Palos Verdes Peninsula, from which two operational seafloor outfalls extend offshore.

During a storm in January 1995, which was particularly severe in the southern portion of Los Angeles County, discharge through the tunnel and outfall system reached the maximum hydraulic capacity. The new tunnel and ocean outfall system, if constructed, would provide additional capacity and long-term redundancy, and would allow inspection, maintenance, and repair of the existing tunnel and outfall system. The

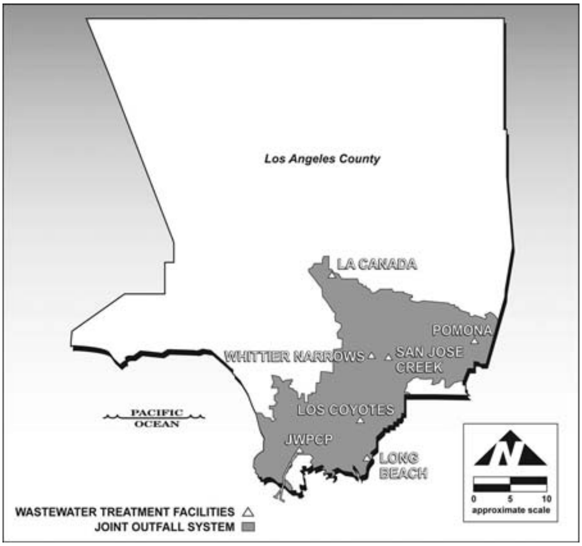

Figure 1. District's service area

peak flow for the new JWPCP Tunnel and Ocean Outfall will be determined as a part of the JOS Master Facilities Plan and may be up to 5.68 million m^3/day (1,500 million gallons per day). The new tunnel and ocean outfall would begin at the JWPCP shaft site. From the JWPCP shaft site, an onshore tunnel will be constructed in a southward direction to either an onshore shaft or if an onshore shaft site cannot be established the tunnel will continue offshore. The offshore alignment will begin with a tunnel which will either continue offshore to a terminal diffuser riser array, or to an offshore riser connected to sea-floor pipelines and conventional pipeline type diffusers.

In June of 2006, feasibility studies and preliminary engineering for the JWPCP Tunnel and Ocean Outfall Project was awarded to the Parsons Corporation in association with Jacobs Associates, who are leading the underground structures design efforts.

EXISTING COMPONENTS

The JWPCP provides treatment for approximately 70% of the wastewater produced in the JOS, and treatment and processing for all of the solids produced. Secondary effluent is conveyed by parallel tunnels of 2.4 and 3.7 m (8 and 12 ft) in diameter (see Figure 2). The tunnels extend from the JWPCP to the manifold structure located at the Royal Palms State Beach. The effluent is discharged to the Pacific Ocean through ocean outfalls of 2.29 m (90 in.) and 3.05 m (120 in.) in diameter that extend 2.4 km (1.5 mi) off the Palos Verdes Peninsula to a depth of approximately 60 m (200 ft). There are also two standby outfalls that are 1.5 m and 1.8 m (60 in. and 72 in.) in diameter that are used only during peak storm flows. The maximum hydraulic capacity of the treatment plant and tunnel and outfall system is 2.5 million m^3/day (670 mgd) with pumping. The average daily flow is approximately 1.25 million m^3/day (330 mgd) with a dry weather peak of 1.63 million m^3/day (430 mgd). The 2.44-m (8-ft) tunnel has been in operation since 1937. The 3.66-m (12-ft) tunnel has been in operation since 1958, respectively. Both tunnels are required to be in service at all times and have not been inspected since 1958.

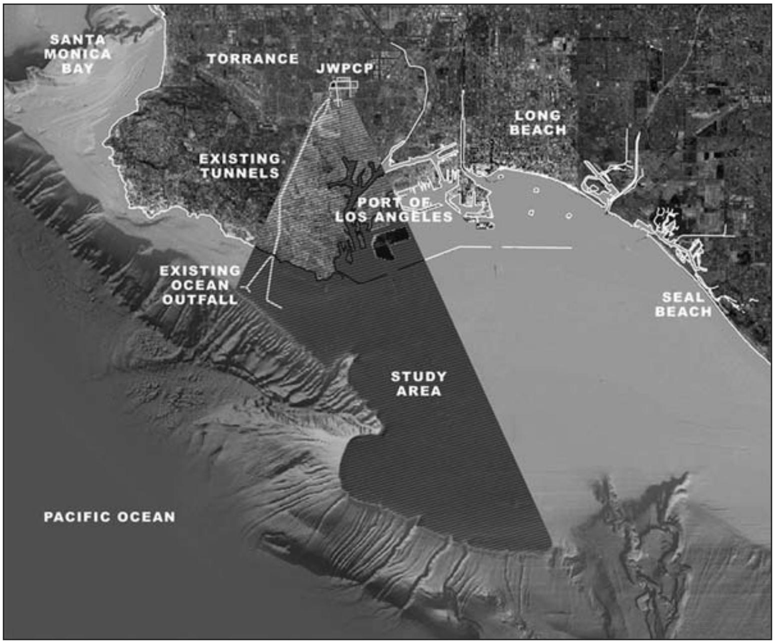

Figure 2. Study area

PROPOSED STUDY AREA

All proposed alignments for the JWPCP Tunnel and Ocean Outfall start at the JWPCP and extend south to a point on the continental shelf. The onshore study area (see Figure 2) includes multiple alignments from the JWPCP to the shoreline—from White Point on the Palos Verdes Peninsula to the far eastern boundary of the Port of Los Angeles. The offshore study area extends from the shoreline, as defined above, southwards to the San Pedro shelf.

SITE CONDITIONS

Geologic Setting

The proposed study area lies along the southwest boundary of the Los Angeles Basin and straddles the paleo-Los Angeles River and two prominent geomorphic features, the Palos Verdes Hills and the Newport-Inglewood Uplift The dominant structural features are the Palos Verdes fault, which forms the northwest-trending Gaffey syncline and anticline. The other pervasive feature of the area is that it is underlain by the Wilmington Oil Field, which consists of a well-developed, northwest-trending anticline structure of oil-bearing rock. The stratigraphy of the Los Angles Basin and the Palos Verdes Hills is summarized as follows.

- Quaternary age: Surficial deposits include recent sediments consisting of fills, alluvium, sand dunes, and terrace deposits. These are underlain by Pleistocene sediments including the Lakewood Formation and the San Pedro Formation, which consists of Palos Verdes sand, San Pedro sand, Timms Point silt, and

Lomita marl. These formations are primarily unconsolidated sediments to very weak rock.

- Tertiary age: Pliocene sediments include the Pico Formation and the oil-bearing Repetto Formation, which are underlain by the Miocene-age Monterey Formation. The Monterey Formation consists of the Malaga Mudstone, Valmonte Diatomite, and Monterey Shale. These formations are primarily weak rock to moderately strong rock.
- Jurassic age: Basement rock is the Catalina Schist. This is a metamorphic hard rock, which varies from moderately strong to very strong.

Seismic Setting

The seismicity of the region is dominated by the intersection of the northwest-trending San Andreas (right-lateral, strike-slip) fault system and the east-west trending Transverse Ranges (vertical, reverse-slip or left-lateral strike-slip) fault system. Both systems are responding to tectonic strain related to the relative motions of the Pacific and North American tectonic plates. The effects of these movements include mountain building, basin development, widespread regional uplift, and earthquakes.

Forrest et al. (1997) note that the recurrence interval for a magnitude M 7+ event is between 400 and 1,000 or more years, based on empirical relations of length and slip rate. M6.5 earthquakes are expected every few hundred years, while M7 earthquakes every thousand years. Forrest et al. also note that small earthquakes in the proposed study area do not appear to be as frequent as on other faults within the Los Angeles Basin. At least two M2+ earthquakes have occurred every year since 1980. In 1988, there were over 25 M2+ events, but activity has decreased since then. There have been fewer than 15 M3–4 events since 1944. Most of the activity is about 8 km (5 mi) deep, with a second horizon of activity about 3.2 km (2 mi) deep. The maximum depth of activity is about 14.5 km (9 mi).

Potential Fault Crossings. A significant feature of the regional tectonic effects is the Palos Verdes fault, which is about 100 km (62 mi) long and extends northwestward into Santa Monica Bay and southeastward off the shore of the Port of Los Angeles harbor. The fault may feed into the Coronado Bank fault (San Diego) and extends as far south as Ensenada, Mexico. The Palos Verdes fault originated as a subduction zone. Then, the tectonic regime changed from a convergent plate margin to a transform or strike-slip margin. It became a right-lateral strike-slip fault somewhere between 3 and 16 million years ago (mya) (in the middle Miocene to early Pliocene age). From 1.5 to 3 mya (the middle to late Pliocene age) the southwest side of the fault was uplifted by reverse motion along it, forming the Palos Verdes Hills. South of San Pedro, strike-slip motion remained dominant during this time.

For its 2020 Expansion between Terminal Island and beyond the middle breakwater, the Port of Los Angeles conducted eExtensive geotechnical and geophysical investigations (Fugro-McClelland, Inc., 1992). These showed that the Palos Verdes fault is a series of several segments with two known prominent left steps of 200 to 250 m (660 to 820 ft) located north of the breakwater, and a second step of 100 to 700 m (325 to 2,300 ft) located south of Terminal Island. The active faulting was shown to be concentrated in a zone 100 to 300 m (325 to 1,000 ft) wide. The fault dips slightly to the east at the surface. The southwestern bock is uplifted consistent with the Palos Verdes peninsula. During the 2020 geotechnical investigations, two ancestral channels of the Los Angeles River were discovered and were offset by the Palos Verdes fault. From these investigations, the average strike slip-rate was determined to be 3 mm/year (0.1 in./year). The horizontal to vertical displacement ratio was determined to be 8:1.

There are several other significant faults and splays that would be of concern in the proposed alignment corridors; these include the Cabrillo fault and possibly the THUMS-Huntington Beach blind thrust fault.

Groundwater Conditions

On shore, toward the JWPCP in the City of Carson, groundwater is about 16 to 20 m (54 to 63 ft) below the ground surface, which is about 7.5 to 9.5 m (–25 to –31 ft) below mean sea level. Perched water may exist in these Quaternary deposits. There are four regionally extensive hydrogeologic units within the Quaternary deposits. These may cross alternative tunnel corridors. From youngest to oldest they are the Gaspur aquifer, Gage aquifer, Lynwood aquifer, and Silverado aquifer. As the corridor moves to the edge of the harbor, the groundwater level is likely to be just 3 to 6 m (10 to 20 ft) below the ground surface or at mean sea level.

Off shore, alignment corridors which are expected to be in flat lying sedimentary deposits, groundwater and hydraulic pressure will be reflective of sea level. Alignment corridors, which are in competent rock, the groundwater inflow would be limited to joints, fractures, or interbedded laminations and would not likely come through the rock matrix. More copious inflows are to be expected with the very block and seamy rock and the fractures associated with major shear zones and/or faults.

Oil and Gas

The study area lies along the southwest boundary of the Los Angeles Basin. This area is underlain by the Wilmington Oil Field, which consists of a well-developed northwest-trending anticlinal structure of oil-bearing Miocene and Pliocene shale and sandstone overlying crystalline bedrock (see Figure 3). In the 1930s, the Wilmington Oil Field produced more than any other field in the Los Angeles Basin. The basin had experienced general subsidence of more than 5.5 m (18 ft) due to oil withdrawal. Consequently, there is strong potential that gaseous tunneling conditions will occur in some alignments.

PROJECT COMPONENTS

The project would convey flows from the JWPCP to a point offshore. The point would be sufficiently far off shore to achieve the desired initial dilution and dispersion characteristics. The terminus of the outfall has not yet been identified. The offshore tunnel would connect to a riser, which would lead to either: (a) pipelines and ocean floor diffusers, or (b) riser/diffusers. A brief description of each major component follows.

Shafts

The project would include a minimum of one shaft to provide access to the tunnels during construction. After construction, the shaft(s) would be completed as permanent structures to allow access to the tunnels and/or house permanent tunnel maintenance and operation facilities. Based on the current understanding of the geotechnical and groundwater conditions, the groundwater control requirements, the anticipated shaft depths, and the construction risk factors, three excavation support systems are considered appropriate for this project: diaphragm (slurry) walls, secant pile walls, and ground freezing. All three methods are essentially watertight systems that effectively control groundwater without the need for dewatering.

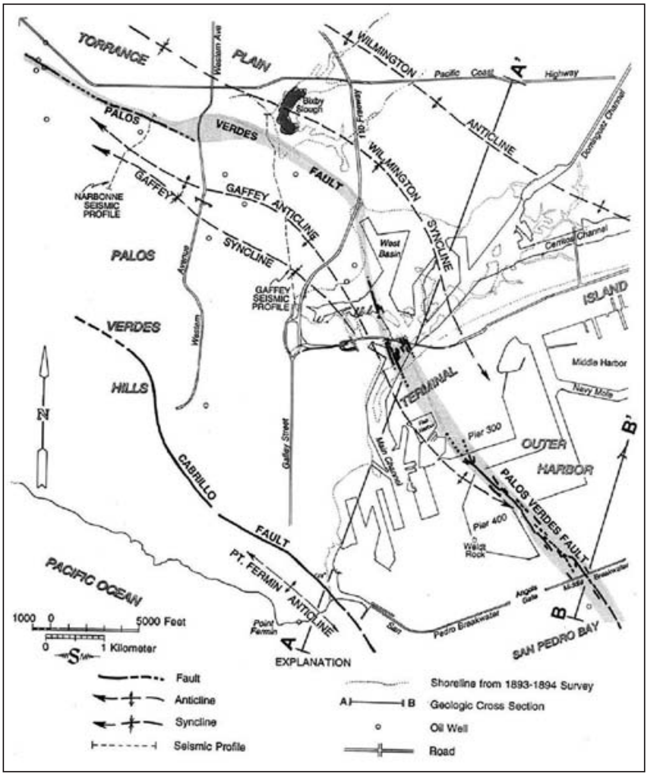

Figure 3. Geologic structures in the Port of Los Angeles harbor area

Other excavation support systems, such as deep soil mixing, interlocking steel sheet piles, or sequential excavation with shotcrete and rock reinforcement (in sedimentary rock only), may be considered appropriate, depending on the depth of the tunnels and the findings of geotechnical investigations conducted at each shaft location.

The internal dimensions of each shaft will be based on an evaluation of construction requirements and the area needed for permanent facilities. Construction requirements will vary based on the shafts use during construction. For example, main construction shafts may range from 15.2 to 18.2 m (50 to 60 ft) in diameter, while receiving shafts may range from 7.6 to 10.7 m (25 to 35 ft) in diameter. If a mining shaft is used to support two tunnel drives it will require an even larger footprint than noted above. Shafts may approach a depth of 200 ft or more in certain alignment corridors. The final depth will be determined based on geologic conditions, engineering analyses, and the need to avoid conflicts with existing underground utilities and surface structures.

Tunnels

The tunnels would be comprised of an onshore tunnel and an offshore tunnel. The onshore tunnel would have a length ranging from approximately 10 to 13 km (6 to 8 mi), depending on the final alignment alternative chosen. The offshore tunnel would have a maximum length of approximately 18 km (11 mi). If a tunnel/seafloor pipeline combination was found to be more advantageous, these lengths would be reduced.

The excavated tunnel diameter would be based on the peak flow, but could be up to 6.7 m (22 ft).

Ground, groundwater, and gaseous tunneling conditions dictate: a precision, precast-concrete, gasketed, segmented tunnel liner; a controlled face; and soft ground TBM methods with rock excavation capabilities. A pressure-face TBM would be of paramount importance to this project due to high groundwater pressures and the varying permeability and strength of the ground units along the alignment corridors. The two methods that will be studied in detail are Slurry TBM and Earth Pressure Balance TBM (EPB TBM). The choice of a Slurry TBM or EPB TBM, or even a hybrid EPB TBM/Slurry TBM will be based on the following factors:

- Soil/rock type
- Ground permeability
- Ability to withstand maximum groundwater pressure up to 11 bars
- Provisions to allow hyperbaric interventions
- Ability to install segmental lining to the required tolerances
- Ability to condition the spoils effectively for transport and disposal
- Ability to operate in gassy ground conditions

The design will ensure that adequate primary components and backup systems are incorporated into the TBM design so that major problems (e.g., delays and cost overruns) are avoided.

Riser

The tunnel is connected to the ocean floor via a vertical connection known as a riser (see Figure 4). Depending on the type of diffusers, the geologic conditions, and ship traffic considerations, the connection can consist of a single riser or multiple smaller risers. A few tunnel outfalls, such as the Boston Harbor outfall, have a diffuser section consisting of a number of vertical risers each connecting the tunnel to a flow distributing head. The head is a rosette that jets out the outflow in a circular pattern through several nozzles. Most other tunnel outfalls discharge the effluent through a traditional diffuser pipe built directly on the ocean floor or protected in an excavated trench ballasted with riprap rock armor. The San Diego outfalls, Singapore Outfall, and San Francisco Southwest Outfall are examples of this type of system.

Construction of a large riser in the ocean is a delicate and risky operation. Generally, the construction of the riser proceeds independently of and prior to tunnel construction. When both the riser and tunnel are completed, the connection between the two is made from the tunnel. This is the riskiest part of the operation, and its success is determined in large part by the accuracy of the planning during the design. The design has to address all that can go wrong with the different methods as applied to the specific site geology, and a procedure that has built-in safety redundancy must be selected.

Diffusers

There are two types of diffusers possible for this project:

- A system consisting of several small risers connected to the tunnel at the bottom and terminating with a flow distribution cap (e.g., Boston Harbor outfall)
- A conventional diffuser pipe built on the ocean bottom (e.g., South Bay Ocean Outfall).

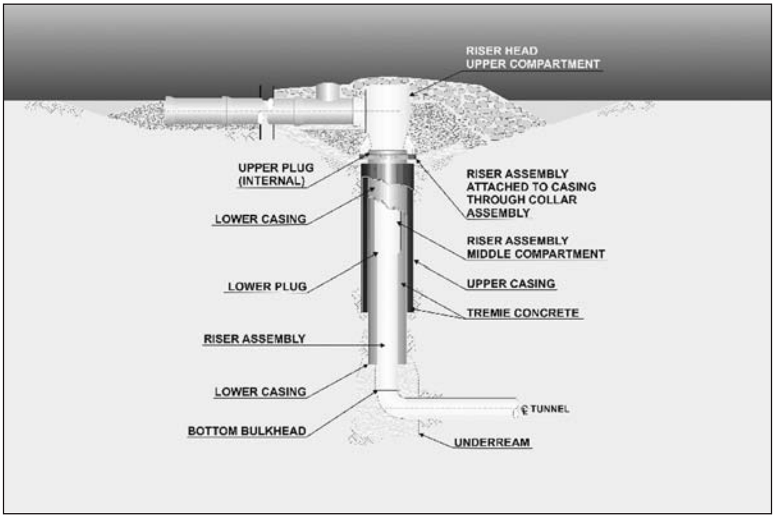

Figure 4. Riser shaft assembly

Conventional diffusers are considered more economical if geologic and ship traffic conditions are favorable. Also, they have better dilution performance characteristics and can be repaired more easily than non-traditional diffusers. However, conventional diffusers still need to be protected from anchors and cables (e.g., by burial and riprap armor protection and by protective structures surrounding the discharge heads). If a conventional diffuser was used, it might consist of a single pipe in line continuing along the tunnel alignment or in a different direction to optimize site conditions and dilution characteristics of the effluent. The diffuser would start either at the top of the tunnel riser or from the seafloor pipeline. If the JWPCP outfall system were designed for the larger spectrum of design flows, sea floor pipelines and conventional diffusers would need to be of very large diameters to accommodate the larger-than-average flows. The diameters that would be required are not standard sizes in the pipe and marine industry. As an alternative to a single large-diameter diffuser, two smaller diffuser sections could be connected to the riser head or a seafloor pipeline, each discharging half of the outfall flow. The total length of the diffuser would be the same in both cases, but there would be some savings in terms of the constructability, because smaller pipe sizes would be used. In addition, operation and maintenance flexibility would be improved with two diffusers, as one section could be closed for maintenance while the second remained in operation.

DESIGN CONSTRUCTION CHALLENGES

The entire study area crosses a complex geologic zone of structural folding and faulting. The alignments will be evaluated based on: the potential for expansive clays, squeezing ground, crossing a potentially active fault, hard rock, hydrocarbons, and high external water pressures.

Figure 5. Abandoned oil wells

Methane and Hydrogen Sulfide Gas

The study area traverses a region known for hydrocarbon deposits. The final alignment may pass through ground that is potentially gassy, gassy, and possibly extra-hazardous. The gassy designation is applied to tunnels with flammable gas accumulations greater than 5% Lower Explosive Limit (LEL). The extra hazardous designation is applied to tunnels with 20% LEL.

In addition to methane gas, hydrogen sulfide gas may also be encountered. Hydrogen sulfide has an odor similar to rotten eggs, and the threshold of smell is less than one part per million.

In these conditions, a Slurry TBM will be advantageous since it operates in a "closed circuit," minimizing workers' exposure to gas underground. An EPB TBM would discharge the muck into muck cars underground and transport it by rail to the surface. During transport, gases could be released and could be dangerous. A number of provisions would need to be in place to mitigate dangers, such as increased ventilation and restrictions on electrical equipment. An EPB TBM could be outfitted with a "closed circuit" muck removal system similar to a slurry system to prevent discharge of gas into the tunnel environment.

In addition to methane and hydrogen sulfide gases, records from the State of California's Department of Conservation Division of Oil, Gas, and Geothermal Resources indicate that numerous active and abandoned oil wells are located along all of the alignment corridors (see Figure 5). These wells were drilled for exploration and production purposes in the Wilmington Oil Field. The active production zone is thousands of feet below the ground surface. However, the well casings would be obstacles for TBMs.

Table 1. Recommended pressure working range for hyperbaric interventions on TBM

Environment	Recommended Working Pressure Range (bars)
Compressed Air	0 to 3.6
Mixed Gas	3 to 8
Saturation	4.5 to >45

TBM Interventions

Groundwater pressure of up to 11 bars could be encountered, depending on the chosen alignment. To access the cutterhead for maintenance, compressed air pressure could be required—if good ground conditions could not be found—to maintain stability and prevent groundwater inflow at the tunnel excavation face. Work performed in a compressed air environment above 3 bars requires the use of mixed gases and/or saturation diving techniques. Typical working ranges as noted by Holzhauser, et al. (2006) for use of compressed air or mixed gases and saturation diving are summarized in Table 1.

It should be noted that Cal/OSHA Tunneling Safety Orders do not cover compressed air work above 3.5 bars. This is to discourage the use of compressed air tunneling and to control the safety of operations by reviewing each job under a variance request. Every attempt would be made to identify favorable geology for cutterhead maintenance so that work could be performed in free air. Alternatively, ground freezing or pre-excavation grouting ahead of the TBM could be used to create a safe haven for tool change interventions.

Mixed Face Conditions

Geotechnical conditions within the study area are very complex and vary significantly. Ground conditions include saturated Quaternary deposits of the Los Angels Basin, folded and faulted Miocene-aged sedimentary rocks, localized intrusions of hard rock lenses, and high points of very hard Catalina Schist.

Due to the potentially long tunnel lengths and the variability in geotechnical conditions within the study area, it is unlikely that mixed face conditions could be avoided. A particularly undesirable condition is a mixed face condition where the face is in both rock and soft ground or several materials of widely-differing density and hardness. When these conditions persist, problems may develop. Problems may include difficulty steering the TBM and maintaining constant face pressure, higher cutter wear, and reduced progress rates. As the feasibility studies are completed, tunnel alignments will be optimized as much as practical to be favorable to TBM excavation methods.

Squeezing Ground Conditions

There is a potential for squeezing ground conditions, particularly in the Palos Verdes fault zone. This phenomenon was confirmed during the construction of the original tunnel, where squeezing ground conditions were encountered in four separate zones along the tunnel (Schultz 1937). This ground condition is problematic not only for tunnel excavation, but for lining design.

Squeezing ground usually occurs when two ground conditions exist: high in situ stresses and clay or weak rock. Squeezing is a serious problem when the magnitude is such that friction on the sides of a TBM is high enough to resist the forward movement of the TBM. Special measures would be necessary to minimize the effects of potential squeezing, such as: increasing the overcut, lubricating the TBM shield skin, reducing the TBM shield length, limiting TBM stops at critical stations, and monitoring tunnel deformation and earth pressure.

CONCLUSIONS

The JWPCP Tunnel and Ocean Outfall Project would involve many engineering and construction challenges. As discussed above, the work would encounter diverse and variable ground conditions, such as saturated alluvial soils, weak sedimentary rock, mixed face conditions, and squeezing ground conditions. High external water pressures, gassy ground conditions, and fault crossing(s) are also anticipated. As the feasibility study and design progresses, some of the design and construction concepts described herein will be modified. Planning, environmental documentation, geotechnical investigation and project design would last approximately six years. The feasibility study is to be completed in September 2008, with preliminary design anticipated to be complete in September 2009 and final design in 2012.

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