

## SEISMIC UPGRADES OF THE CLAREMONT TUNNEL

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### ABSTRACT

The East Bay Municipal Utility District is undertaking seismic upgrades of the Claremont Tunnel in the San Francisco Bay area. The tunnel carries treated water across the active Hayward Fault to supply a major metropolitan area. Studies indicate the tunnel could be severed by fault offset during a major seismic event.

A design approach to achieve limited operation of the tunnel following fault displacement has been established and design details are currently being evaluated. This paper describes the project, the design approach, and summarizes significant construction constraints.

### INTRODUCTION

The Claremont Tunnel, built from 1926 to 1929, is a 2.74 m (9 foot) diameter, 5.5 km (18,000 foot) long horseshoe tunnel that carries treated water by gravity flow through the Oakland/Berkeley Hills from the Orinda Water Treatment Plant to the Claremont Center in the East Bay region of the San Francisco Bay (refer to Figure 1). The tunnel is owned and operated by the East Bay Municipal Utility District (EBMUD). It routinely carries between 416,000 to 662,000 cubic meters per day (110 to 175 million gallons per day) to serve about 70 percent of EBMUD's 1.2 million customers. As such, it is a critical link in EBMUD's water supply system.

The active Hayward Fault crosses the tunnel alignment, almost perpendicular to its axis, about 259 m (850 feet) from the west portal at the Claremont Center in Berkeley, California. The fault's movement is characterized as right lateral strike/slip. The Hayward Fault last experienced a major seismic event that resulted in surface rupture in 1863. The Working Group on California Earthquake Probabilities estimates that there is a 17 percent probability of a magnitude 6.7 or greater earthquake occurring on the Hayward Fault Zone from 2000 to 2030. EBMUD has adopted the magnitude 7.0 Maximum Credible Earthquake (MCE) along the Hayward Fault as the design event for the seismic upgrades. Geologists have estimated that the lateral

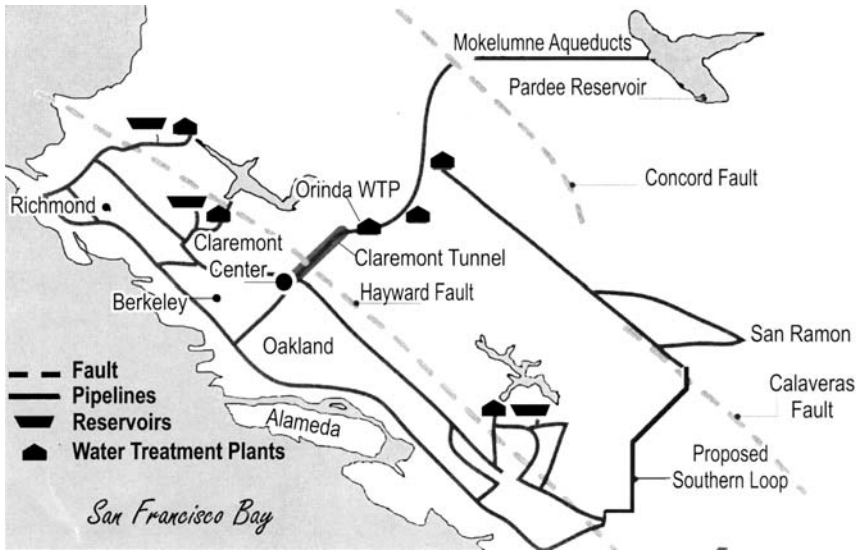


Figure 1. East Bay Municipal Utility District's water supply and distribution system

offset from the MCE could be on the order of 2.3m (7.5 feet). This event would render the existing tunnel unserviceable.

### PROJECT DEFINITION

In 1994, the EBMUD Board of Directors approved a \$189 million, 10 year Seismic Improvement Program (SIP) to protect their water system from catastrophic seismic damage. Seismic upgrade of the Claremont Tunnel was identified as a key element of the program.

Based on an earlier geological assessment that indicated the width of the zone of potential fault displacement was 30.5 m (100 feet), the SIP initially assumed that the upgrades to the Claremont Tunnel would be accomplished by retrofitting the existing facility alignment. Ongoing geologic studies indicate that the width of the zone of potential fault displacement is 280 m (920 feet). Recent EBMUD studies also indicate that, due to the high system demands, outages of the tunnel must be limited to wintertime construction windows of three months between January and March.

As a consequence of this recent information, the extensive improvements required to upgrade the existing tunnel over the 280 m (920 foot) fault zone were judged to be not feasible due to the excessive number of outage windows required to complete construction. In addition, there were significant concerns regarding the risk of exceeding individual outage windows due to construction delays. The estimated costs for upgrading the existing alignment also exceeded EBMUD's allocated budget. EBMUD therefore decided to investigate design alternatives that would permit completion of the upgrades within the limited available outage windows.

Subsequent studies showed the preferred alternative to consist of mining a new 457 m (1500 foot) bypass tunnel through the Hayward Fault Zone, with a 229 m (750 foot) long access tunnel driven parallel to the existing tunnel. The bypass tunnel would tie into the existing Claremont Tunnel on either side of the Hayward Fault Zone (refer to Figure 2). This design allows the majority of the construction to be performed

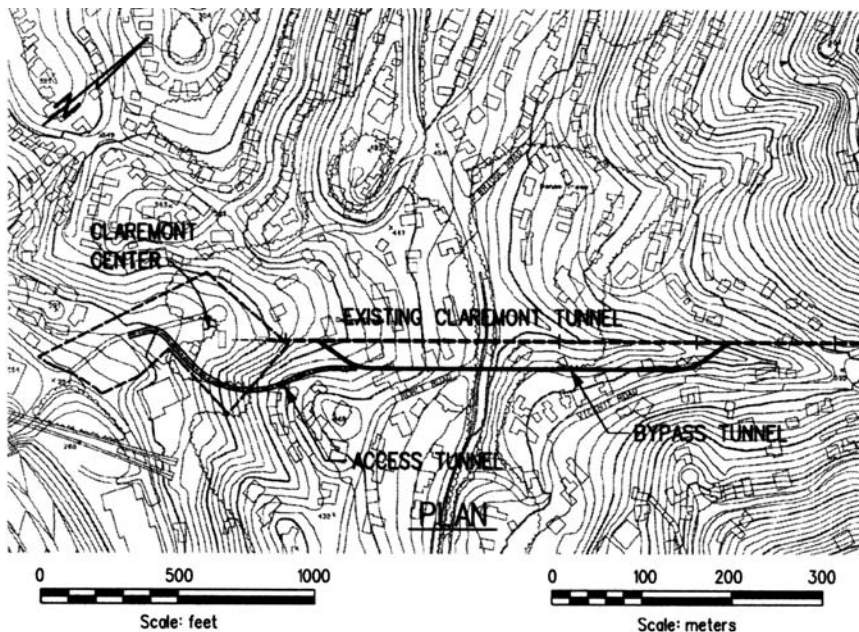


Figure 2. Preliminary layout of proposed bypass and access tunnels

while the existing tunnel remains in service. It also minimizes risks of construction delays during the outage windows.

Following a major seismic event on the Hayward Fault, EBMUD's expects available labor and equipment resources to be fully utilized on emergency repairs of other parts of their distribution system and treatment plants. As a result, EBMUD required that the Claremont Tunnel seismic upgrades be designed to allow reliable operation for a period of 60 to 90 days following the earthquake.

### GEOLOGIC AND SEISMIC CONDITIONS

The geology along the proposed bypass tunnel alignment is characterized by three reaches (refer to Figure 3). The westernmost reach, extending approximately 122 m (400 feet) from the proposed tunnel portal, consists of mélange of the Franciscan Complex. The mélange is a chaotic mixture of sheared shale, sandstone, altered volcanic rocks, serpentinite, and occasional hard blocks of chert and blueschist. The rock quality is expected to vary considerably from crushed, soft and plastic in the shear zones to blocky, hard, and strong. Heavy, squeezing ground could be encountered in the sheared shale, serpentinite and within significant shear zones.

The next 280 m (920 foot) long section along the alignment consists of the Hayward Fault Zone. Detailed geologic logs and instrumentation of the Bay Area Rapid Transit (BART) tunnels, located approximately 800 feet southeast of the Claremont Tunnel, provide valuable information with respect to anticipated ground characteristics. The ground expected within the fault zone is similar to the Franciscan Complex mélange, with the exception that a significant reach of serpentinite is anticipated. The rock quality is expected to consist of soft clay fault gouge with occasional hard blocks

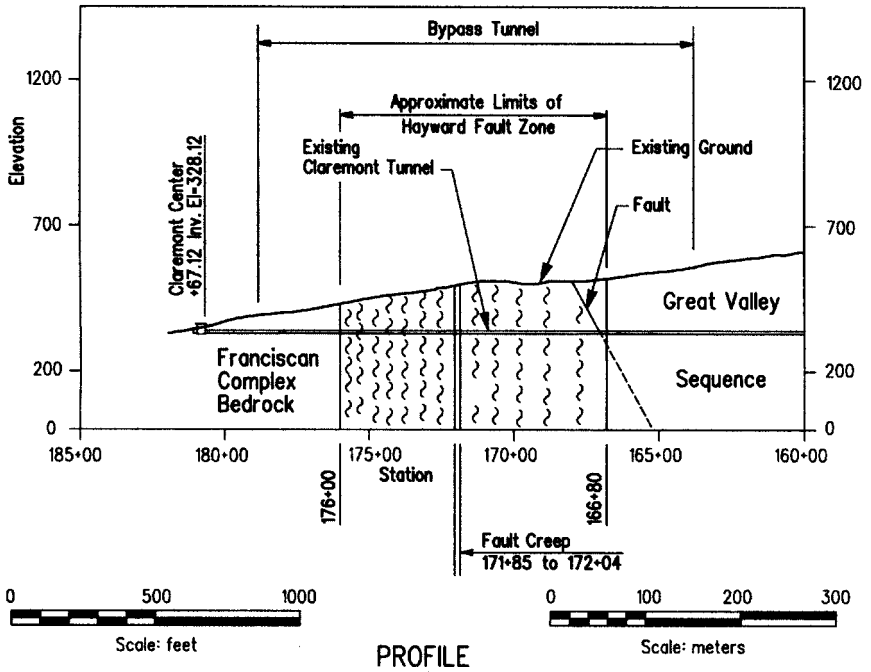


Figure 3. General geology along the proposed bypass tunnel

of sandstone and altered volcanic rocks. A variety of other sheared rock types are also anticipated within the reach. Materials within this reach will be susceptible to heavy squeezing.

Ongoing geologic studies have estimated a primary fault displacement of 2.3 m (7.5 feet), with a 16 percent probability of exceedance, for a the design magnitude 7.0 earthquake on the Hayward Fault. This displacement has been adopted for design, and geologic evidence suggests it could occur within an 18.3 m (60 foot) long section of the tunnel. The tunnel section susceptible to primary fault displacement was established based on past inspections and surveys of fault creep damage to the Claremont Tunnel. Historical rates of active fault creep along the Hayward Fault in this area range from about 4.5mm to 6.4mm/year (0.18 to 0.25 inches per year). For the seismic upgrade of the Claremont Tunnel a design fault creep rate of 6mm per year (0.25 inches per year) and a total creep offset of 300mm (1 foot) over a 50 year period has been adopted.

The 18.3 m (60 foot) wide zone subject to primary fault offset is centered within a 280 m (920 foot) wide zone that is susceptible to secondary fault offsets. The estimate of secondary fault displacement is 0.7 m (2.25 feet). Secondary fault offsets could occur anywhere within the 280 m (920 foot) wide zone.

The geologic unit at the easternmost reach of the bypass alignment consists of interbedded shale and sandstone of the Great Valley Sequence. The sandstone is fine grained and moderately hard. It is thinly bedded, with some thick beds of blocky rock. The shale beds are typically highly sheared and contorted. The bedding generally dips steeply to either the northeast or the southwest.

Naturally occurring methane gas and petroleum were encountered locally during mining of the original tunnel through the Great Valley Sequence, and the future bypass tunnel has been classified as “gassy”.

### GROUNDWATER

Based on information obtained from ongoing geologic investigations and information from past inspections of the existing tunnel, the groundwater levels are expected to range between 1.8 to 12.2 m (6 to 40 feet) above the crown of the proposed bypass tunnel. Historical records from inspections of the Claremont Tunnel in the 1960's indicate cumulative groundwater inflows ranging from 14.5 to 23 liters per second (230 to 360 gallons per minute) over the entire 5,486 m (18,000 foot) long alignment. This is much less than the flows encountered during the original construction in the 1920's, which reached a peak of 247 liters per second (3920 gallons per minute). It is believed that the existing tunnel has acted as a drain for groundwater along the alignment. Inflows of groundwater into the proposed bypass tunnel are not anticipated to be significant.

### PRELIMINARY DESIGN CONCEPTS

The design of the bypass tunnel requires accommodating the primary fault offset of 2.3 m (7.5 feet) as well as 300mm (1 foot) of lateral fault creep for a total of 2.6 m (8.5 feet) of expected movement. The proposed design concept for traversing the Hayward Fault Zone consists of an enlarged tunnel vault section with an internal, isolated carrier pipe. The cross sections of the enlarged vault and carrier pipe are sized to allow up to 2.6 m (8.5 feet) of total fault displacement before the tunnel lining and carrier pipe appreciably interact (refer to Figure 4).

Primary support for the enlarged vault will consist of relatively heavy steel ribs and pattern rock bolts. Presupport measures including grouted pipe spiling and face nails are also anticipated. The steel ribs will be incorporated into the final concrete liner and are expected to provide some ground support following the design earthquake event. The pattern rock bolting will promote favorable ground-lining interaction during the design earthquake.

The steel ribs will be encased in a final lining of cast-in-place reinforced concrete. Longitudinal reinforcing steel within the final cast-in-place concrete liner will be minimized to promote a relatively discrete structural break at the location on fault offset. Circumferential reinforcing steel will help to provide resistance to heavy loads expected to develop in the vicinity of fault offset and may reduce the volume of damaged liner section that could collapse into the vault.

Following the fault rupture, severe cracking of the concrete liner and some fallen debris within the vault section are expected. The potential adverse effects of excessive debris within the vault will be mitigated with the freestanding carrier pipe mounted on skid plates. The pipe will be designed to withstand impact loading induced by failure of the final concrete liner. The carrier pipe is intended to ensure the required passage of 130 million gallons per day, for 60 to 90 days, until inspection and repairs to the vault can be performed. To protect downstream pumps from any debris transported by flowing water, a rock trap will be designed. It is anticipated that water quality prior to the post-earthquake repairs will be somewhat diminished due to an increase in water turbidity.

As shown on Figure 4, the interval of potential secondary fault offsets will have an oversized tunnel section with a nominal 0.7 m (2.25 foot) thick reinforced concrete

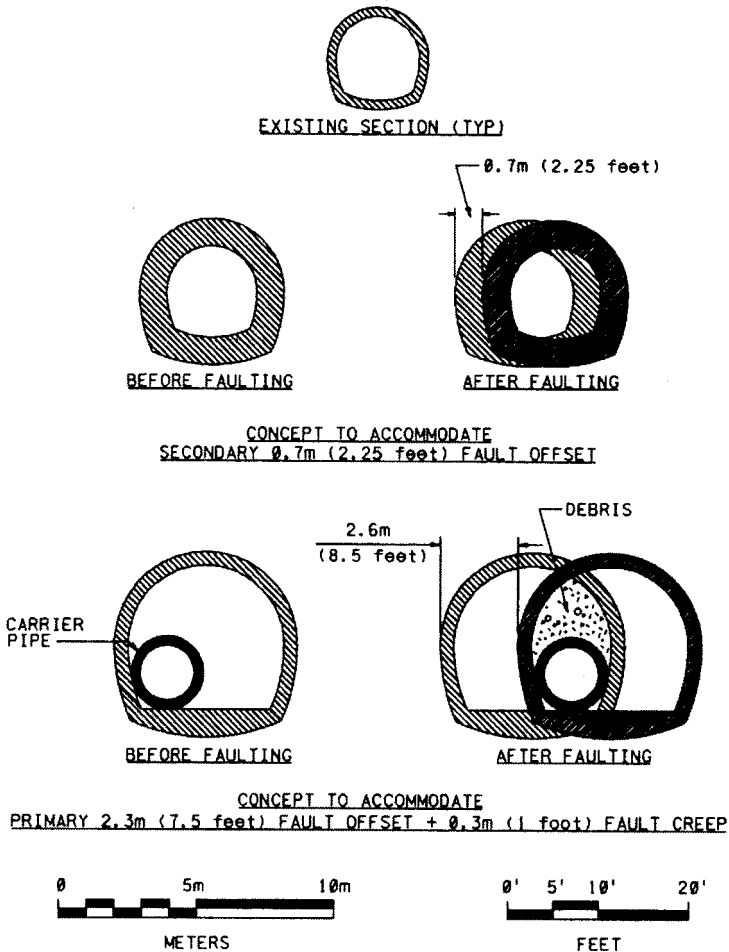


Figure 4. General design approaches to accommodate primary and secondary fault offsets

liner. The flow cross section and liner will accommodate the secondary fault offsets by allowing the required flow to pass through the offset cross section, while minimizing debris that may enter the tunnel from the surrounding ground. Concrete reinforcement for this liner will be similar to reinforcement for the enlarged vault section.

In addition to fault offsets within the Hayward Fault Zone, the new and existing tunnel liners will be subject to strong earthquake shaking. The original tunnel was supported initially with five-piece arch timber sets. The final lining consisted of a combination of reinforced and unreinforced concrete with a thickness of 100 to 150 mm (4 to 6 inches) over the timber sets. Only a small portion of the original lining was contact grouted and it is likely that some of the primary timber support has deteriorated. Gradual erosion of sedimentary formations along the alignment may have also created voids behind the liner. These sections of lining are susceptible to damage from seismic shaking. Systematic contact grouting programs for the most

vulnerable tunnel reaches upstream of the new bypass tunnel are being developed to improve ground/liner interaction during the design seismic event.

### SUMMARY AND CONCLUSIONS

The existing Claremont Tunnel is a critical link in the EBMUD water distribution system. The tunnel crosses the Hayward Fault Zone, an actively creeping fault that is subject to 2.3 m (7.5 feet) of lateral offset under the design earthquake scenario. Such an event would effectively sever the existing Claremont Tunnel. EBMUD is currently engaged in a program to mitigate potential fault-related damage through the design of a parallel bypass tunnel with special seismic provisions through the fault zone. The tunnel design and construction face a number of challenges including heavy squeezing and variable ground conditions, hazardous gases and petroleum, and scheduling constraints.

### ACKNOWLEDGMENTS

The authors wish to thank and acknowledge the support provided by the East Bay Municipal Utility District and Jacobs Associates.

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