Pardee Reservoir
Calaveras County, California

Tunnel Leakage Report

July 2013

EAST BAY MUNICIPAL UTILITY DISTRICT

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1 Introduction

Jacobs Associates and AMEC were retained by East Bay Municipal Utility District (EBMUD) to review the available information for the Pardee Tunnel and evaluate the ongoing seepage issues at the west portal near the Campo Seco Center. The Pardee Tunnel feeds raw water from the Pardee Reservoir in Calaveras County through the Mokelumne Aqueducts to water treatment plants in Contra Costa and Alameda Counties. The tunnel forms a critical link in the EBMUD supply network from its main source of water. EBMUD can at present only accommodate short outages of the tunnel, and any prolonged outage could have serious repercussions on EBMUD’s ability to provide adequate water supply to its customers.

The seepage is likely caused by leakage from the tunnel. To develop an understanding of the existing conditions, available plans for the tunnel, previous evaluations of the seepage conditions, and local geologic information were reviewed. A site reconnaissance was performed to observe the existing conditions.

This report summarizes the available data regarding the Pardee Tunnel, discusses the most likely cause of the tunnel leakage, and provides recommendations for future monitoring of the seepage, inspection of the tunnel, and options for future repairs if needed.

2 Background

Pardee Dam and Pardee Reservoir are located on the Mokelumne River in the foothills of the Sierra Nevada, near the town of Valley Springs in Calaveras County, California. Pardee Tunnel is an 11,615-foot-long (Sta. 0+00 to Sta. 116+15), concrete-lined tunnel with an 8-foot-diameter horseshoe cross-section over most of its length. The western 915 feet (Sta. 107+00 to Sta. 116+15) of the tunnel has a circular cross section, 8 feet 2 inches in diameter. The tunnel begins at the eastern portal inlet structure, approximately 840 feet upstream of the Pardee intake tower located in Pardee Reservoir, and continues through the hills to the west of Pardee Reservoir to end at Campo Seco Center (west portal area), where the tunnel branches into the three Mokelumne Aqueducts.

The tunnel is straight in plan and has a 0.025 percent slope to the west. The tunnel operates under gravity flow, with an elevation change of 3 feet between the eastern portal and Campo Seco. The head on the tunnel at Pardee Reservoir is 175 feet when the reservoir level is at spillway elevation. Under normal operating conditions the tunnel transfers between 180 and 230 million gallons of raw water per day to the EBMUD water treatment plants.

The majority of the tunnel concrete lining is unreinforced except for the reach at the west portal, as indicated in Figure 1. Between Sta. 94+00 and Sta. 107+00, the horseshoe section is reinforced with a single layer of reinforcing, while from Sta. 107+00 to Sta. 116+15 the circular tunnel cross section is reinforced with a double layer of reinforcing. The westernmost 156 feet of the tunnel (from Sta. 114+59 to Sta. 116+15) is lined with a 0.5-inch-thick steel liner. In 1950 additional concrete lining was installed between Sta. 23+64 and Sta. 23+96.

The tunnel was constructed between 1926 and 1929. The tunnel excavation was initially supported by timber sets with timber lagging. No construction records have been found that provide any specific details regarding ground conditions encountered or tunnel support used during tunnel excavation.

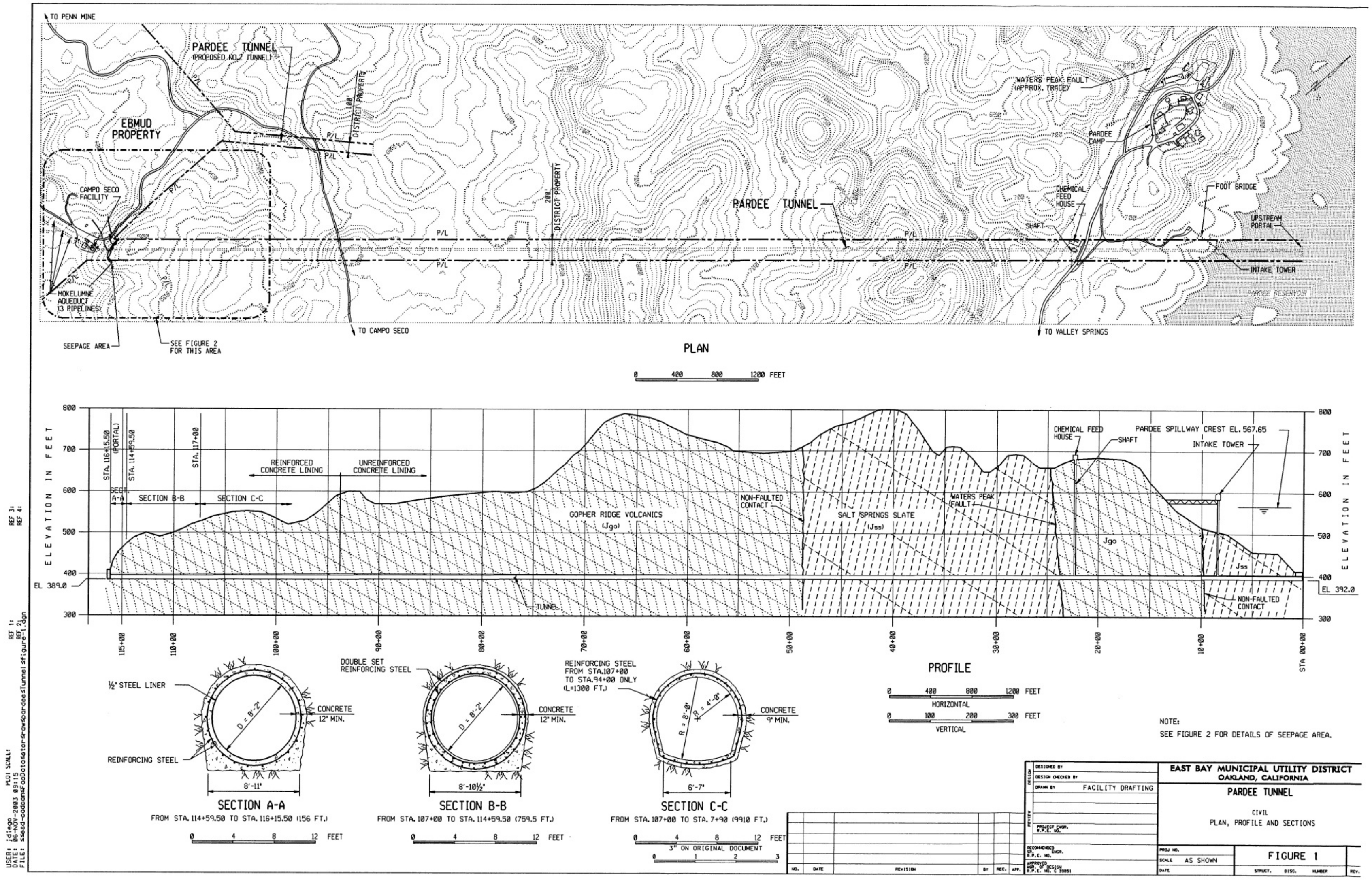


Figure 1. Pardee Tunnel: Existing Outlet Works Plan, Profile, and Sections

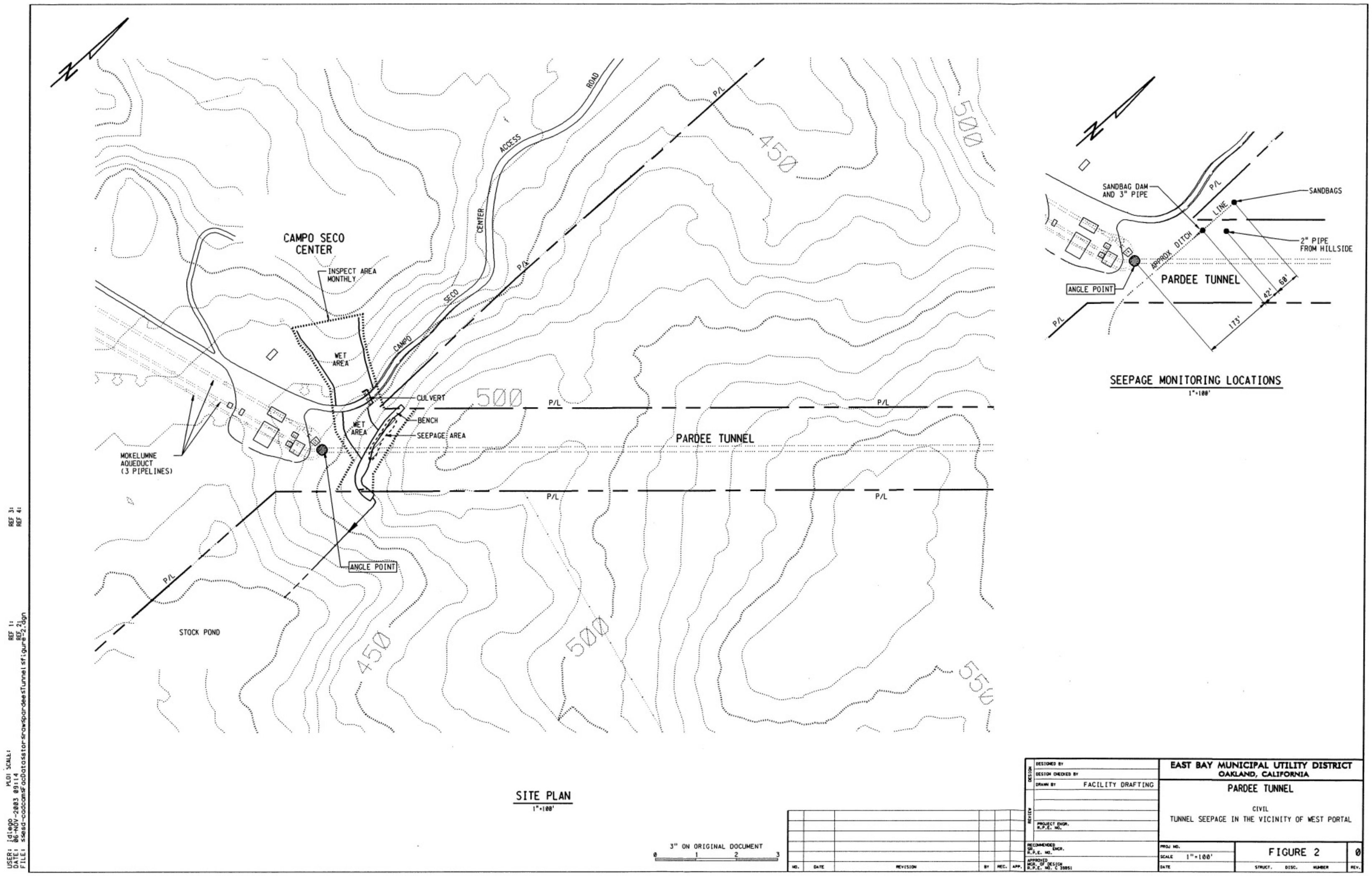


Figure 2. Pardee Tunnel: Plan at Campo Seco Center showing Seepage Areas

3 Regional Geology

The Campo Seco facility is located in the western foothills of the Sierra Nevada, within the watershed of the Mokelumne River, near the boundary between the Sierra Nevada range on the east and the Central Valley on the west. The topography of the area is characterized by low, rounded hills that are vegetated with a mixture of woods (oaks and pines), grasses, and chaparral. The rolling hills in the Campo Seco area are formed in Tertiary volcanic and sedimentary rocks and in older Mesozoic metamorphic rocks, all of which are heavily dissected by westward-flowing creeks and streams.

Available geologic maps indicate the Campo Seco facility is underlain by metamorphic rocks of the Jurassic-age Gopher Ridge Volcanics. In the west portal area of Pardee Tunnel, these rocks consist primarily of metamorphosed tuff, with local interbeds of metamorphosed agglomerate (Earth Sciences Associates and Geo/Resource Consultants [ESA-GC], 1992). Based on mapping by ESA-GC (1992), the metavolcanic rock has a pervasive foliation that strikes about N32°W and dips about 79° to the northeast (into the hillside). The foliation is nearly perpendicular to Pardee Tunnel, which is oriented along a bearing of about N40°W. Weathering of the metavolcanic rock is highly variable, and outcrops of more resistant beds near the western end of the tunnel form short, discontinuous linear scarps and “fins” of protruding rock that, in places, resemble leaning tombstones. Joints cross cutting the foliation are common, and one prominent joint set in the area has an average orientation of N30°W, 19° southwest (ESA-GC, 1992).

A topographic map provided by EBMUD (Figure 1) indicates the west portal of Pardee Tunnel is on the southwest flank of a narrow, approximately north-south–trending spur ridge with an elevation of just over 500 feet.[1] The ground surface elevation at the west portal is about 430 feet, and the invert of the 8-foot-diameter tunnel is at 389 feet, as indicated on the tunnel profile in Figure 1. Based on these data, the cover along the centerline of the tunnel varies from about 30 feet to slightly more than 100 feet over a length of 1,200 feet near the west portal.

Mapping by EBMUD (2003) indicates the seepage area occurs on the west side of the spur ridge, north of the tunnel/portal area, at an elevation of about 470 feet as shown in Figure 2. The seepage area extends for about 100 feet, from approximately the centerline of the tunnel to the north, roughly along the same elevation. The seepage emanates from, or directly above, a topographic bench, which appears to be an old access or construction road above the portal. Much of the seepage flows down the slope to the west, where it enters a culvert and discharges on the west side of Campo Seco Center Access Road, creating a lush, green wetland area. Some of the seepage also flows to the south along the bench and is channeled into a stock pond on the south side of the Campo Seco facility. Based on field and office studies and laboratory testing, EBMUD (2003) concluded that the source of the seepage at the west portal is water from Pardee Tunnel.

Three test pits excavated by ESA-GC (1992) in the vicinity of the seepage area encountered metatuff that varied between blocky to moderately foliated, highly foliated, and highly sheared. The blocky to moderately foliated rock was closely to intensely fractured and moderately to deeply weathered, with low to moderate hardness and moderate strength. The highly foliated and sheared rock had similar physical properties, but generally was deeply weathered and weaker. Thin quartz veins along the

[1] The datum is not specified.

foliation were encountered in two of the pits, and one pit had a quartz vein cutting across the foliation. A thin clay seam, oriented about N47°W, 22° northeast also was encountered in one pit.

Based on our review of available information and observations in the field, we concur that the likely source of the seepage at Campo Seco is leakage from Pardee Tunnel. Leakage from the tunnel is finding its way to the surface in this very low cover area along the foliation, fractures, and shears in the weathered, interbedded metavolcanic bedrock. The seepage does not appear to present any serious geologic issues, as the slopes in this vicinity are gentle and the threat of landslides and erosion is minimal because of the quality of the underlying rock formation.

4 Tunnel Inspections and Evaluation of Seepage

4.1 Previous Tunnel Inspections

The Pardee tunnel was inspected in 1934, 1951, 1962, and 1982, but only the report of the 1962 inspection has been found. Records or reports of the 1934 and 1951 inspections are not available, but are referred to in the 1962 report. The 1982 inspection (no records available) is discussed in some detail in the 2003 Seepage Report (EBMUD, 2003). The available information is discussed below.

4.1.1 Tunnel Inspection, 1962

In December 1962, the District performed an inspection of the entire tunnel, and the location of lining cracks and groundwater inflows were recorded. The memorandum on the 1962 inspection—written by Pardee maintenance personnel and dated December 13, 1962—is attached as Appendix B. A record of the amount and location of seepage into the tunnel forms part of the memorandum. The condition of the tunnel observed in 1962 was compared to the available records of the 1934 and 1951 inspections, and it was concluded that the condition of the tunnel had not changed. The memorandum concluded that the condition of Pardee tunnel was "very satisfactory."

4.1.2 Tunnel Inspection, 1982 (from the EBMUD 2003 Seepage Report)

The last tunnel inspection was performed in 1982, but no records are available and no seepage measurements were recorded. The following information was reported in the EBMUD 2003 report, obtained from Joe Dedic and Mike Young, who entered the tunnel a number of times during the 1982 outage.

- The tower gates leaked badly.
- The tower gates could not be operated unless the water levels in the reservoir and inside the tower were nearly equal. This required closure of the Campo Seco valves prior to tower gate operation.
- The tunnel completely drained once the tower gates were closed and the Campo Seco valves were opened.
- The access ladders inside the tower were in poor condition.
- Access from the ladder to the tunnel was provided by rubber rafts with plywood tied to the top of the rafts. No handrails or safety lines were provided.
- There were a number of areas between the tower and the chemical feed shaft where seepage into the tunnel was extreme. It was described as water spraying into the tunnel from 360 degrees and that the water curtain was sufficient to prevent the forced air ventilation from passing through. Only during the last day of the tunnel outage did the seepage decrease to the point that ventilation airflow was established throughout the tunnel. The seepage inflow was large enough that rain gear and rubber boots offered no protection from getting soaked. The contractor working in the tunnel to install new chemical feed lines resorted to wearing wet suits.

4.2 Previous Tunnel Seepage Evaluations

The seepage from the tunnel at the western portal was investigated and evaluated by District staff in 1962, 1988, and 2003, but only the report of the 1962 inspection has been found. The available information is discussed below.

4.2.1 Seepage Evaluation, 1962

The earliest recorded discussion of surface seepage from the tunnel is a June 6, 1962 memorandum by D. G. Larkin, Manager of Water Production and Distribution Division (see Appendix B). The memorandum indicates that seepage from the west portal area was collected in a concrete structure and conveyed by a pipe, which discharged onto District property to the south of the #2 Control Building. The flow was monitored daily and was reported as 8.6 gallons per minute. The memorandum also noted there were a few springs originating near the top of the tunnel. No specific location of the measurement point or the springs was provided. No records of the daily seepage flow measurements appear to exist.

4.2.2 Seepage Evaluation, 1988 (from the EBMUD 2003 Seepage Report)

The seepage was investigated again in 1988 in response to Engineering Support Request (ESR) 88-641-098. The ESR noted that measured seepage flow was 4 to 6 gallons per minute, but no records of the seepage flows exist. An October 13, 1988 memorandum by B. McCloud, Assistant Civil Engineer, recommended that the seepage be monitored and that the tunnel be inspected to determine the possible sources of the seepage.

4.2.3 Seepage Evaluation, 2003

The seepage was investigated again in 2003 in response to Engineering Support Request (ESR) 02-767-073 (EBMUD, 2003). During the 2003 evaluation, the surface seepage was measured at two locations. The seepage flowing to the north was measured at the culvert under the Campo Seco Center Access Road. This flow was approximately 5.5 gallons per minute. The seepage flowing to the south along the bench was estimated to be 7 gallons per minute.

4.2.4 Water Tests

As part of the 2003 evaluation (EBMUD, 2003) water samples were obtained on February 20, 2003, from one of the seepage areas and from the aqueducts at Campo Seco Center. Each sample was tested for a number of items. Results of the laboratory tests are contained in Appendix A, and a summary of the field test results are shown in Table 1.

Table 1. Pardee Tunnel West Portal Seepage Chemical Analysis

Test	Aqueduct West Portal	Tunnel Seepage
Chlorine	0.42 mg/L	0
pH	8.0	6.8
Turbidity	0.45 ntu	2.00 ntu
Alkalinity	16 mg/L	19 mg/L
Chloride	2.7 mg/L	3.2 mg/L
THMs	4.1 µg/L	0.23 µg/L

The field and laboratory testing of water collected from the seepage areas indicates that the water was similar to that in the Pardee Tunnel. In addition, the Campo Seco area is considered an extremely dry region, based on its hydrology. Wells drilled in the region generally produce very low flows and dry wells are not uncommon.

Based on the field and laboratory testing of water collected from the seepage areas and knowledge of the region's hydrology, EBMUD (2003) concluded that the source of the surface seepage was leakage from the Pardee Tunnel.

4.3 Site Visit, June 2012

As part of this study, a site visit took place on June 19, 2012 to observe current conditions and assess the extent of the leakage. Although the seepage was not measured, it appeared that there was no discernible change in the conditions from those that had been reported during the 2003 inspection or described in previous reports. As described in previous reports, part of the seepage flows to the north down the slope and through a culvert under the access road to Campo Seco Center. Additionally, there is some seepage flowing to the south along the bench and into an existing stock pond.

4.4 Evaluation of Seepage Impact

A review of historical records indicates the seepage flows have not significantly changed over the past 50 years. The seepage probably varies depending on the water elevation in the reservoir, which determines the water pressure in the tunnel, and that could account for the difference in the flows reported. From the information documented in previous reports and observed during the June 2012 site visit, the maximum seepage appears to be on the order of 13 gal/min (0.019 MGD). This amounts to approximately 0.01% of the minimum flow in the tunnel of 180 MGD (or, 125,000 gal/min), and the loss of water is therefore negligible compared to the daily flow in the tunnel.

As noted above in Section 3, the seepage also does not appear to present any slope stability issues, as the slopes in this vicinity are gentle and the likelihood of landslides and erosion is minimal because of the low flows and the quality of the underlying rock formation.

5 Cause of Tunnel Leakage

Leakage from pressure tunnels generally occurs when the ground cover is inadequate, or the surrounding rock mass is permeable in combination with a pervious tunnel lining. Determining the adequacy of the ground cover to provide confinement and prevent leakage is described in the sections below. The permeability of the rock mass depends on its hydraulic conductivity, which provides an indication of whether the rock has permeable pathways that could lead to exfiltration of water. Leakage paths are commonly associated with open joints and crushed rock in shear zones or adjacent to faults. Less common but equally important leakage paths include solution channels, and the excavation-disturbed zone of rock parallel to the waterway. If the rock has permeable pathways, an impermeable final lining, such as a steel lining, is generally considered to provide a barrier between the pressurized water within the tunnel and the surrounding rock mass and to prevent water from leaking into the pathways within the rock mass. A reinforced concrete lining, even though adequately reinforced to accommodate the internal pressure, is considered permeable because of cracking of the concrete, and leakage would be controlled by the permeability of the rock mass. An alternative method of reducing leakage through the surrounding rock mass consists of grouting the rock mass to reduce its permeability to an acceptable level.

5.1 Confinement Criteria

Confinement is the ability of the rock mass to resist internal hydraulic pressures from an unlined waterway. Where there is not enough confinement in a pressure tunnel, hydraulic jacking can occur, which would allow joints to open up and water pressure to progress further into the rock mass. Hydraulic jacking develops when the hydraulic pressure within a jacking surface, such as a joint or bedding plane, exceeds the total normal stress acting across the jacking surface. This progressive failure can cause an increase in hydraulic conductivity and unacceptable leakage in a pressure tunnel and lead to spreading of the hydraulic pressures away from the tunnel. Vertical confinement should be assessed to determine the impact on horizontal features, and lateral confinement should be assessed to determine the impact on vertical features, as demonstrated in Figures 3 and 4, respectively.

5.1.1 Vertical Confinement Criterion

One approach to determine the likelihood of hydraulic jacking is to assess the amount of vertical cover (overburden) that will provide vertical confinement to the pressure tunnel. This approach is presented by Brekke and Ripley (1987). The criterion assumes that the vertical stress is equal to the weight of the overburden, and therefore, hydraulic jacking can be prevented if the depth of cover is greater than the internal tunnel head. Using this concept, a factor of safety against hydraulic jacking of horizontal features can be developed (as shown in Figure 3).

$$FS_v = \frac{Z * \gamma_r}{h * \gamma_w} \qquad (1)$$

where:

FS_v = Factor of safety for vertical confinement

Z = Depth of cover

γ_r = Unit weight of rock
h = Internal head
γ_w = Unit weight of water

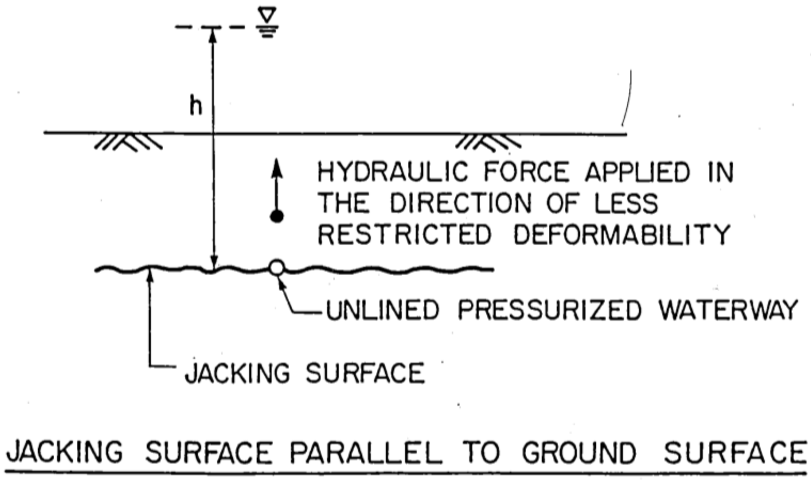


Figure 3. Vertical Confinement Condition

5.1.2 Lateral Confinement Criterion

In addition to vertical confinement, lateral confinement must also be assessed to determine the potential for hydraulic jacking. To determine the potential for hydraulic jacking of vertical features (as shown in Figure 4), two parameters must be considered: lateral rock cover and in situ horizontal stresses. Lateral rock cover can be an issue when steep topography exists adjacent to a tunnel. A procedure similar to the one used to determine the minimum overburden criteria (discussed in Section 5.1.1) can be used to determine the minimum lateral cover. In situ horizontal stresses must also be considered for lateral confinement, particularly when the ratio of horizontal stresses to vertical stresses is less than one. The horizontal stress state at a point depends on the type of ground; in soils it is generally lower than the vertical stress ($k_0 < 1$), while in rock the presence of residual stresses locked into the rock can cause it to be higher than the vertical stress ($k_0 > 1$). The factor of safety against hydraulic jacking of vertical features can be developed by adapting equation (1) to account for this ratio:

$$FS_h = \frac{k_0 * Z * \gamma_r}{h * \gamma_w} \tag{2}$$

where:

FS_h = Factor of safety for lateral confinement
Z = Depth of cover
γ_r = Unit weight of rock
h = Internal head
γ_w = Unit weight of water,
k_0 = Ratio of the minimum horizontal stress to the vertical stress

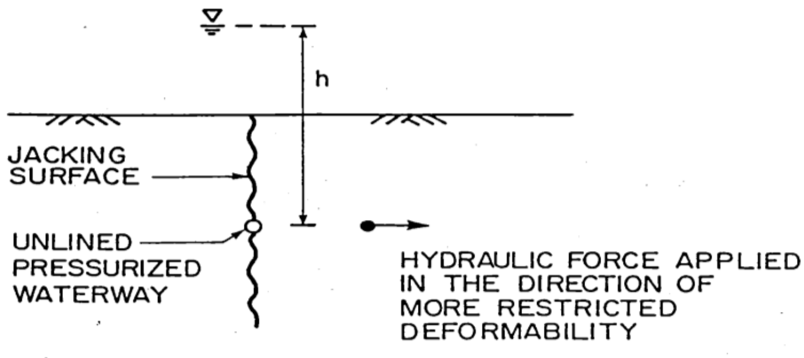


Figure 4. Horizontal Confinement Condition

5.2 Discussion of Tunnel Leakage

Because construction records are not available, it is not possible to evaluate ground conditions along the alignment and identify a reach of the tunnel where leakage could be occurring. Even if full inspection records were available, it is very difficult to identify cracks that could be leaking from such data. However, based on our experience with similar pressure tunnels we believe that the source of the leakage originates in a reach of the tunnel with the reinforced concrete lining upstream of the steel-lined section of tunnel. The reinforced concrete lining,[2] even though it could be adequately reinforced to accommodate the internal pressure, is likely cracked and relatively permeable. An additional source of water could be longitudinal flow from upstream along voids at the crown of the tunnel because tunnels dating from this era were not contact grouted and usually have voids above the crown. The vertical ground cover at the point of leakage is evaluated in the calculations presented below.

Considering the vertical confinement criterion and applying equation (1) to the Pardee Tunnel at the end of the steel-lined section of the tunnel at approximately Sta. 114+60, the factor of safety against vertical confinement can be calculated. The cover over the tunnel is approximately 73 feet, with a rock density of 140 lb/ft^3. The tunnel internal water pressure is approximately 170 feet at the tunnel crown. Based on these values, the factor of safety against vertical confinement is 0.96. This confirms that at this station, where there is a combination of lack of cover (which cannot provide the confinement), and potentially permeable ground (which could allow seepage channels to develop), leakage is possible without considering horizontal confinement. Pressurized tunnel water could be present here caused by exfiltration through the cracked reinforced concrete lining or flow along crown voids. To satisfy the vertical confinement criterion with a minimum factor of safety of 1.3 for permanent static conditions, the steel lining would have to be extended about 460 feet to approximately Sta. 110+00. To satisfy the vertical confinement criterion with a recommended factor of safety of 1.5 for permanent static conditions, the steel lining would have to be extended about 600 feet to approximately Sta. 108+60.

The topography appears to be such that adequate lateral cover to the tunnel is present upstream of Sta. 110+00. However, if the lateral stress ratio is less than 1, then the lateral confinement criterion represented by equation (2) may control and a longer length of steel lining would be required.

[2] Reinforcing details are not available.

6 Recommendations

6.1 Monitor Tunnel Seepage

6.1.1 Measure Seepage Flows

The surface seepage flows should be monitored by measuring the flow on a regular basis (at least annually) to determine any changes in the seepage flows. A minimum of two measurement stations should be maintained: one to measure the flow to the north, and one to measure the flow to the south. The seepage flow to the north can be measured at the existing culvert under the access road to Campo Seco Center. The seepage flow to the south should be measured along the bench within the Pardee Tunnel property. Measurement could be made by installing a shallow weir or small berm and pipe to allow timed collection of the seepage. The basic limitation of developing a measurement point on the bench is to not create excessive ponding of water or to divert the flow off the bench. Measurements of leakage should also be correlated with the reservoir water elevation.

6.1.2 Action Criteria

If the measured tunnel seepage remains unchanged and no new seepage areas are observed, no immediate action needs to be taken. At a convenient time the tunnel should be taken out of service and inspected as described below. Based on the findings of the inspection it can be determined if repairs are warranted.

If the measured tunnel seepage increases slowly over a period of time or new seepage areas appear, the conditions should be monitored more closely. EBMUD staff should assess the need to take the tunnel out of service and perform a tunnel inspection.

If the measured tunnel seepage increases substantially (nonlinear increase), or the seepage increases to the point that substantial erosion is occurring or stability of the ground above or adjacent to the tunnel is compromised, it is recommended that the tunnel be immediately taken out of service and inspected.

6.2 Tunnel Inspection

The tunnel should be inspected to determine its condition and to gather information needed to design and locate repairs to reliably reduce the seepage. Based on current information, which indicates that seepage flows have not changed significantly for the past 50 years, there is no need to take the tunnel out of service specifically for an inspection, nor does the tunnel need an immediate inspection. The last inspection was performed in 1982, more than 30 years ago, so it is recommended that an inspection be scheduled for a time in the near future when other operational issues require the tunnel to be taken out of service. The two main methods of performing an inspection are either by remotely operated vehicle (ROV) or in the dry. Our experience is that ROV inspections for this length of tunnel can only be performed by a limited number of operators and are therefore costly. In addition, the information obtained from an ROV inspection is incomplete and hard to interpret. This makes it difficult to obtain detailed data that can serve as the basis for design. Therefore, it is our recommendation that the inspection be performed in the dry.

Observations during an inspection should include:

1. A detailed examination of the leakage and change in rate of leakage into the tunnel at various points along its length. These serve as an indication of the pressure and volume of water trapped in voids behind the lining or in the rock mass.
2. A comprehensive survey of the cracking and spalling of the concrete lining. Because longitudinal cracks close when the tunnel is depressurized, it is difficult to determine where leakage is occurring. However, the survey serves to document the condition of the lining.
3. Close monitoring and recording of the change in leakage during the tunnel shutdown and rewatering. When the tunnel is out of service, the leakage flow at Campo Seco should stop completely since the tunnel is depressurized.
4. A thorough check of the steel lining’s condition and thickness at the west portal for any loss of thickness. Because of the corrosion of the ladders in the outlet tower, this is necessary to ensure the steel lining’s integrity and continued functionality

6.3 Repair Options

If the seepage increases to a level where repairs or remedial measures are deemed necessary, repair options such as grouting the rock mass, contact grouting behind the concrete lining, extending the steel lining, or a bypass tunnel may be considered.

6.3.1 Grouting from the Ground Surface

A program of systematic grouting from the ground surface could be performed as shown in Figure 5. Access to the surface area above the tunnel may require a temporary road or the use of all-terrain vehicles. Starting from approximately 40 feet downstream of the end of the steel lining, to create an overlap of 40 feet with the steel lining, for a reach of approximately 500 feet in length and about 30 feet wide, a pattern of grout holes would be drilled. The grout holes would be spaced at about 6 feet perpendicularly and 8 feet longitudinally to the tunnel and would be drilled to a depth close to the tunnel crown directly above the tunnel, and on either side of the tunnel to a depth of 12 feet below the invert. If the seepage is not cut off after the first series of holes, intermediate holes should be drilled and grouted and the area of grouting extended until a satisfactory reduction of seepage is obtained. The advantages of grouting from the surface are that it would not affect operation of the tunnel, the ease of access to perform the grouting, and the effectiveness of the grouting can be verified during application. The disadvantage of this approach is the uncertainty in achieving a complete grout envelope below the tunnel invert and cutting off the leakage fully.

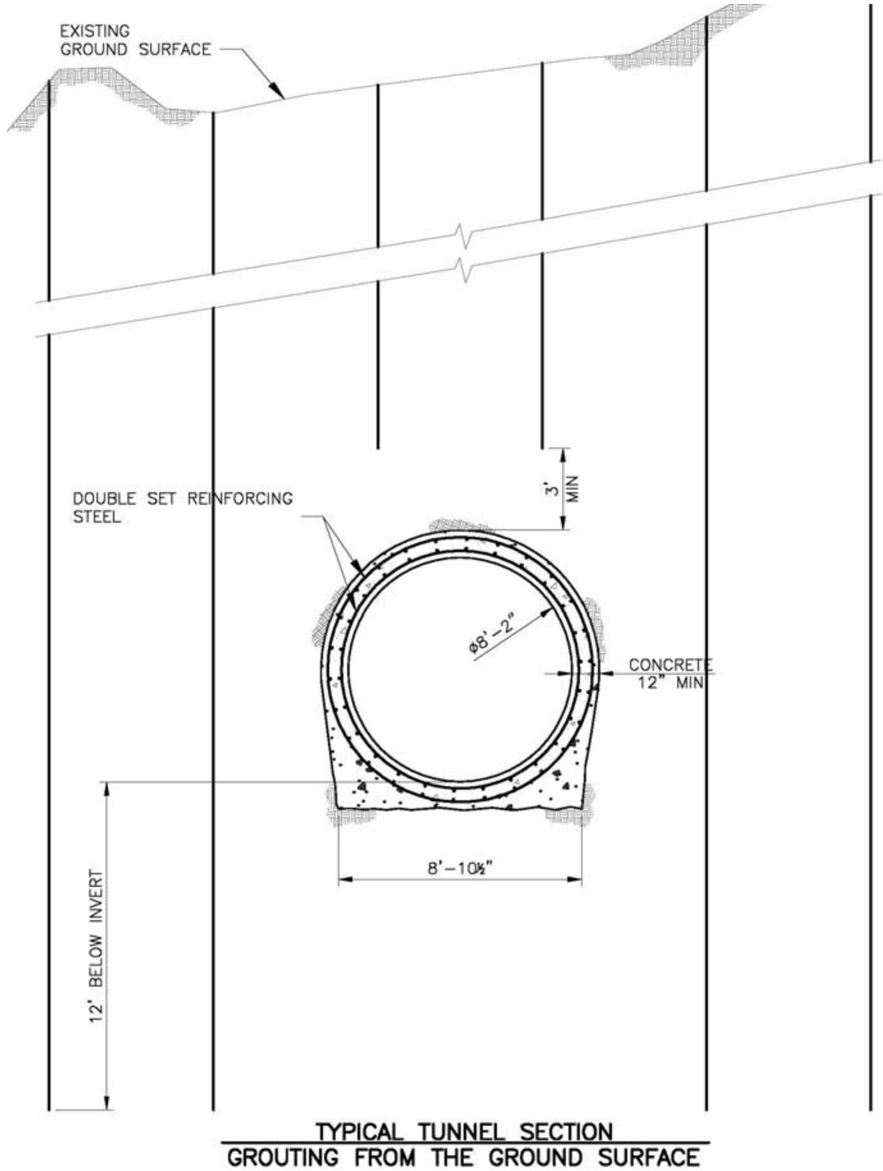


Figure 5. Tunnel Cross Section Showing Grout Holes from the Surface

6.3.2 Grouting from the Tunnel

Grouting from within the tunnel would have to be performed during an extended outage. Fans of grout holes 12 feet in length would be drilled with a jack leg and inclined 15 to 45 degrees from the tunnel trend to account for the orientation of the rock mass foliation and dip, as shown in Figure 6. Grout holes at a spacing of 8 feet longitudinally and about 4 feet 3 inches circumferentially would be used for treatment of an approximately 460 feet length of the tunnel. If grout take is relatively high, intermediate holes will be used to ensure the required tightness. The advantage of this approach is the greater likelihood of achieving a complete grout envelope below the tunnel invert and cutting off the leakage. The disadvantages of grouting from inside the tunnel is the need for an extended outage, the removal of existing valves and piping at the west portal to provide construction access,, working in confined conditions in a small tunnel, and difficulty in verifying the effectiveness of the grouting.

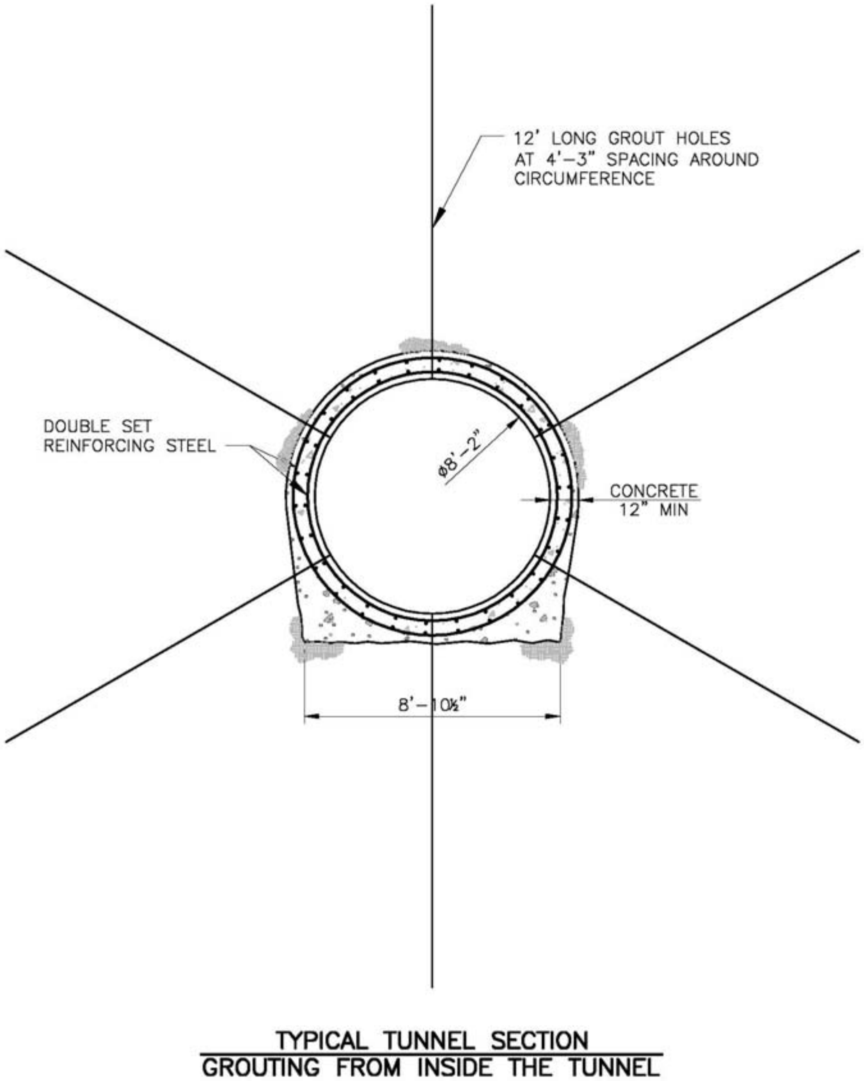


Figure 6. Tunnel Cross Section Showing Grout Holes from within the Tunnel

6.3.3 Extend the Steel Lining

The impervious steel lining could be extended for an additional 460-foot-long reach of tunnel to achieve a minimum factor of safety, or 600 feet long to achieve the recommended factor of safety as discussed in Section 5.2. Note that these lengths are based on the vertical confinement criterion only, and the ratio of the minimum horizontal stress to the vertical stress must be evaluated through a geotechnical exploration program during design. This construction work would also require an extended outage and staging from the Campo Seco portal. The steel pipes would have an internal diameter of 7 feet 8 inches to allow a 3-inch annulus around the pipe that would be backfilled with a cellular grout. The installation of the steel lining should include grouting of any voids at the tunnel crown to cut off this potential source of water. The advantage of this approach is the installation of an impervious lining throughout the vulnerable reach, which would serve to prevent any leakage. The disadvantages of this option is the extended outage required to perform the work, the removal of existing valves and piping at the west portal to provide construction access, and a reduction in the tunnel hydraulic conveyance area.

6.3.4 Bypass Tunnel

Constructing a short length of steel-lined bypass tunnel from a new west portal to the north of the existing alignment could also be considered. The bypass tunnel would connect to the existing tunnel upstream of approximately Sta. 108+00, resulting in a minimum length of approximately 800 feet. The advantage of a bypass tunnel is that only a relatively short outage would be required to make the tie-ins and all other work can be performed while the tunnel remains in operation. The disadvantage of this option is its likely higher cost.

7 Conclusions

The present leakage is minor, appears not to have changed significantly over the lifetime of the tunnel, and poses no immediate problem. The analysis presented above confirms that the existing impervious steel lining does not extend far enough to provide an adequate factor of safety for overburden confinement. The reinforced concrete lining, although possibly designed for the internal pressure, will crack longitudinally under hoop pressure, have circumferential shrinkage cracks, and is therefore considered pervious. The above mentioned cracks would allow leakage, but do not compromise the structural integrity of the concrete lining. Additionally, water could flow along voids above the tunnel crown from upstream of the steel lined reach. Because of the lack of cover, the pressured water from the tunnel has found a seepage path to the surface; this is expressed as the observed leakage. It is recommended that the leakage be monitored on a regular basis because any significant changes in leakage serve as an early warning of changed conditions in the tunnel lining or leakage channels through the overburden.

Based on records of previous inspections, the tunnel lining appears to be in good condition. However, the last inspection was performed in 1982, more than 30 years ago. It is therefore recommended that an inspection in the dry be scheduled within the next five to ten years. Based on the results of the inspection, implementation of remedial measures can be considered. These consist of repair options such as grouting the rock mass from the surface, contact grouting behind the concrete lining, extending the steel lining, or constructing a bypass tunnel, as discussed above.

8 References

Brekke, T.L., and B.D. Ripley. 1987. *Design Guidelines for Pressure Tunnels and Shafts*. Electric Power Research Institute, Report EPRI AP-5273, Berkeley.

Earth Sciences Associates and Geo/Resource Consultants (ESA-GC). 1992. *Raised Pardee Dam, Additional Storage Alternative, Geotechnical Investigation*, Volumes 1–4. Submitted to East Bay Municipal Water District, June 1992.

East Bay Municipal Water District (EBMUD). October 2003. *Pardee Tunnel Seepage Report*, Calaveras County, California.

9 Revision Log

Revision No.	Date	Revision Description
0	May 16, 2013	Draft Issued for Review and Comment
1	July 18, 2013	Final Report

Appendix A. Water Test Results

Table A1. Water Test Results

Sample	Collect Date	Matrix	Analyte	Qualifier	Result	Units	MDL	RL/ML	Method
Comparison Sample of Aqueduct Water at West Portal									
L103184-2	2/20/03 9:15	DrinkH2O	4-Bromofluorobenzene		102	% recovery			EPA 524.2
L103184-2	2/20/03 9:15	DrinkH2O	Alkalinity: Total as $CaCO_3$		16	mg/L	5		SM(18)2320B
L103184-2	2/20/03 9:15	DrinkH2O	Bromodichloromethane		0.34	µg/L	0.08		EPA 524.2
L103184-2	2/20/03 9:15	DrinkH2O	Bromoform	U	0.03	µg/L	0.03		EPA 524.2
L103184-2	2/20/03 9:15	DrinkH2O	Chloride		2.7	mg/L	0.015		EPA 300.0
L103184-2	2/20/03 9:15	DrinkH2O	Chloroform		3.8	µg/L	0.07		EPA 524.2
L103184-2	2/20/03 9:15	DrinkH2O	D4-1,2-Dichlorobenzene		100	% recovery			EPA 524.2
L103184-2	2/20/03 9:15	DrinkH2O	Dibromochloromethane	U	0.08	µg/L	0.08		EPA 524.2
L103184-2	2/20/03 9:15	DrinkH2O	Hardness: Total		16	mg/L	2		SM(18)2340C
L103184-2	2/20/03 9:15	DrinkH2O	Trihalomethanes		4.1	µg/L	0.26		EPA 524.2
Seepage at West Portal, East of the Pipeline									
L103184-1	2/20/03 9:40	GroundH2O	4-Bromofluorobenzene		104	% recovery			EPA 524.2
L103184-1	2/20/03 9:40	GroundH2O	Alkalinity: Total as $CaCO_3$		19	mg/L	5		SM(18)2320B
L103184-1	2/20/03 9:40	GroundH2O	Bromodichloromethane	U	0.08	µg/L	0.08		EPA 524.2
L103184-1	2/20/03 9:40	GroundH2O	Bromoform	U	0.03	µg/L	0.03		EPA 524.2
L103184-1	2/20/03 9:40	GroundH2O	Chloride		3.2	mg/L	0.015		EPA 300.0
L103184-1	2/20/03 9:40	GroundH2O	Chloroform		0.23	µg/L	0.07		EPA 524.2
L103184-1	2/20/03 9:40	GroundH2O	D4-1,2-Dichlorobenzene		104	% recovery			EPA 524.2
L103184-1	2/20/03 9:40	GroundH2O	Dibromochloromethane	U	0.08	µg/L	0.08		EPA 524.2
L103184-1	2/20/03 9:40	GroundH2O	Hardness: Total		16	mg/L	2		EPA 130.2
L103184-1	2/20/03 9:40	GroundH2O	Trihalomethanes		0.23	µg/L	0.26		EPA 524.2
Seepage Approx. 20 Yards North of Seepage Collected on 2/20/03									
L103226-1	2/26/03 15:15	GroundH2O	4-Bromofluorobenzene		102	% recovery			
L103226-1	2/26/03 15:15	GroundH2O	Alkalinity: Total as $CaCO_3$		18	mg/L	5		
L103226-1	2/26/03 15:15	GroundH2O	Bromodichloromethane		0.6	µg/L	0.08		
L103226-1	2/26/03 15:15	GroundH2O	Bromoform	U	0.03	µg/L	0.03		
L103226-1	2/26/03 15:15	GroundH2O	Chloride		2.9	µg/L	0.015		
L103226-1	2/26/03 15:15	GroundH2O	Chloroform		12	µg/L	0.07		
L103226-1	2/26/03 15:15	GroundH2O	D4-1,2-Dichlorobenzene		102	% recovery			
L103226-1	2/26/03 15:15	GroundH2O	Dibromochloromethane	U	0.08	µg/L	0.08		
L103226-1	2/26/03 15:15	GroundH2O	Hardness: Total		19	mg/L	2		
L103226-1	2/26/03 15:15	GroundH2O	Trihalomethanes		12	µg/L	0.26		

Appendix B. Memoranda from D.G. Larkin regarding Pardee Tunnel Leakage, dated June 6 and December 13, 1962

~~H.J.~~ ~~X File~~ Prop # 66-42

JUN 7 1962

June 6, 1962

MEMO TO: J. D. DeCosta, Chief Engineer

F R O M: D. G. Larkin, Manager, Water Prod. & Dist. Division

SUBJECT: Pardee Tunnel Leakage

The leakage from Pardee Tunnel West Portal is collected in a concrete structure at the portal. From this box the water flows in a 10" tile pipe westerly toward #2 control building and then southerly where it is discharged on our property. The water flows in a ditch from our property to the Fisher property to the south.

The leakage is measured daily at the point of discharge, and it amounts to 8.6 gpm. This water is impounded on Fisher's property in a pond of about one acre surface area. The water is pumped to higher elevations and is one of the sources of water for the 700 acre cattle ranch.

In addition to the above leakage, there are a few "springs" originating near the top of the tunnel which flow on to Fisher's property.

The Fisher property was originally owned by N. Frazier during construction of Pardee dam and tunnel and Fisher is the third owner.

D. G. LARKIN

DGL:c
cc: H. J. Wickman
U. J. Hussey
J. W. Kimball
D. G. Larkin
Eng Files
Gen Files

FILE: 360 Tunnel, Pardee #1

Engineering Files

Camp Pardee, Calif.,
December 13, 1962.

MEMO TO: D. G. LARKIN, Manager, Water Production & Distribution

FROM : U. J. HUSSEY, Regional Supt. Assistant, Camp Pardee

SUBJECT: PARDEE TUNNEL

Enclosed please find field note sheets covering the inspection trip through Pardee Tunnel on December 12th, 1962. Shown are the stationing of and condition of leaks observed during the trip. In comparison with uncomplete notes of the 1934 inspection and the 1951 observations, the condition of the tunnel has not changed. Some small leaks and several 1 inch drains from ground springs have dried up, and again, several more leaks have been observed, but these small leaks could have been passed over during the previous inspections. Some water is running out from the tower itself, coming from mostly the 520 foot elevation gates leaking as they do not have too much pressure against them now. In the bottom of the tower the 6 inch influent pipe set-up for the previous camp water supply was observed to be in very good condition and at this time would not be necessary to be removed. The wall ladder from the last landing in the tower down to the sump level is very much corroded and appears to be unsafe at this time. (This broke when the Cons. Western crew went down to install new Camp Water Supply pipe. AH)

At the bottom of the raise in the tunnel at Station 22 + 63 there is a pile of lime residual and sand containing approximately three cubic yards but it is very soft and will dissolve very easily as soon as the flow from the tower reaches it. This residual has sluffed off the walls of the raise as the tower and tunnel water was drained, but does not create any problem in the flow of water through the tunnel.

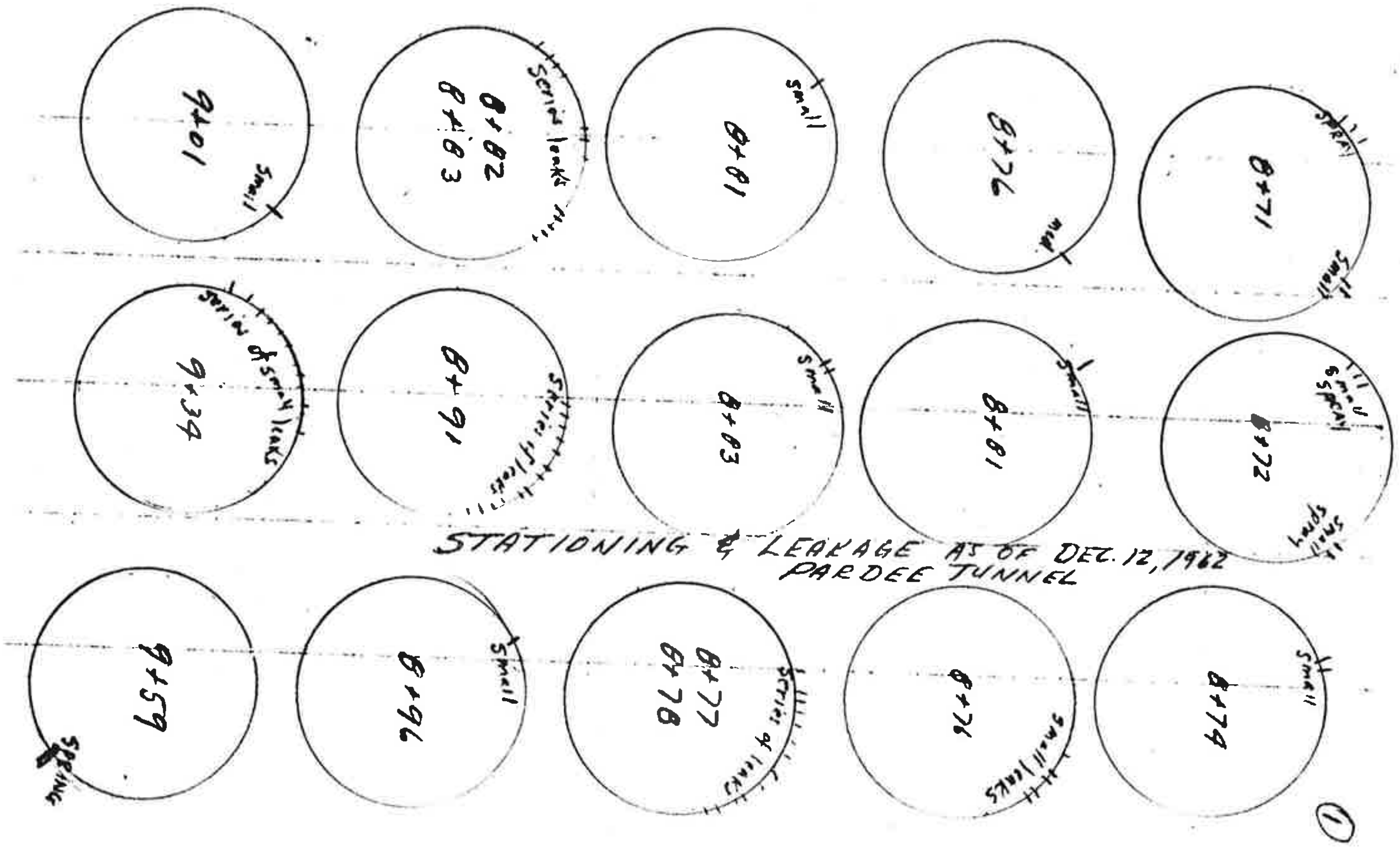
At the transition section in the tunnel at Station 23 + 64² to Station 23 + 96² drains put in the upper part of the section were observed. Two of the drains have dried out, but several others are flowing free and taking care of the ground water previously found to be a contention during the building of the tunnel. The gunite surface is in good condition and no crack were found in it. A small amount of sand residual from the lime used at the Chemical Plant is being held at the beginning of the transition section but does not create a problem.

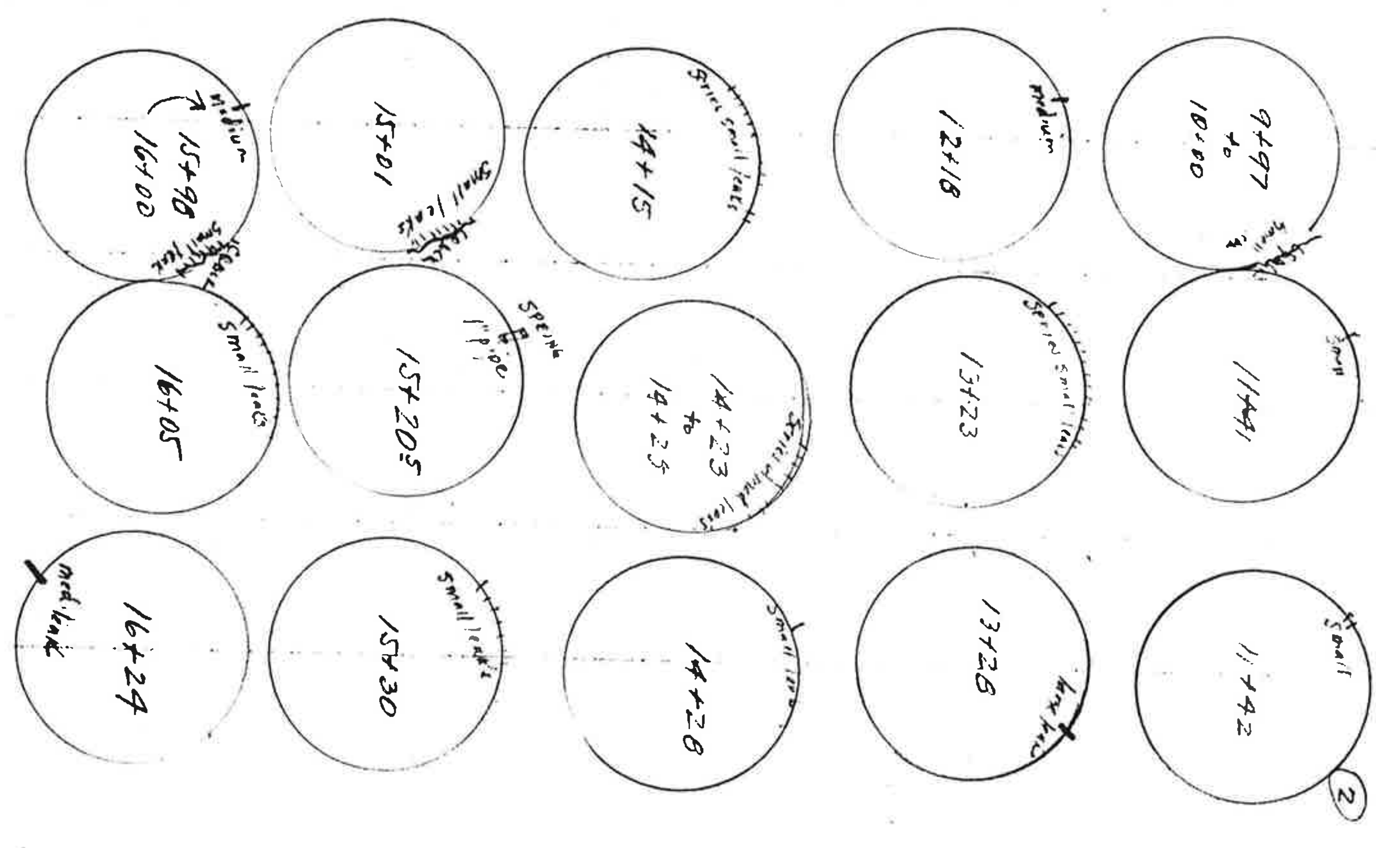
In summary, the condition of Pardee Tunnel is very satisfactory at this time.

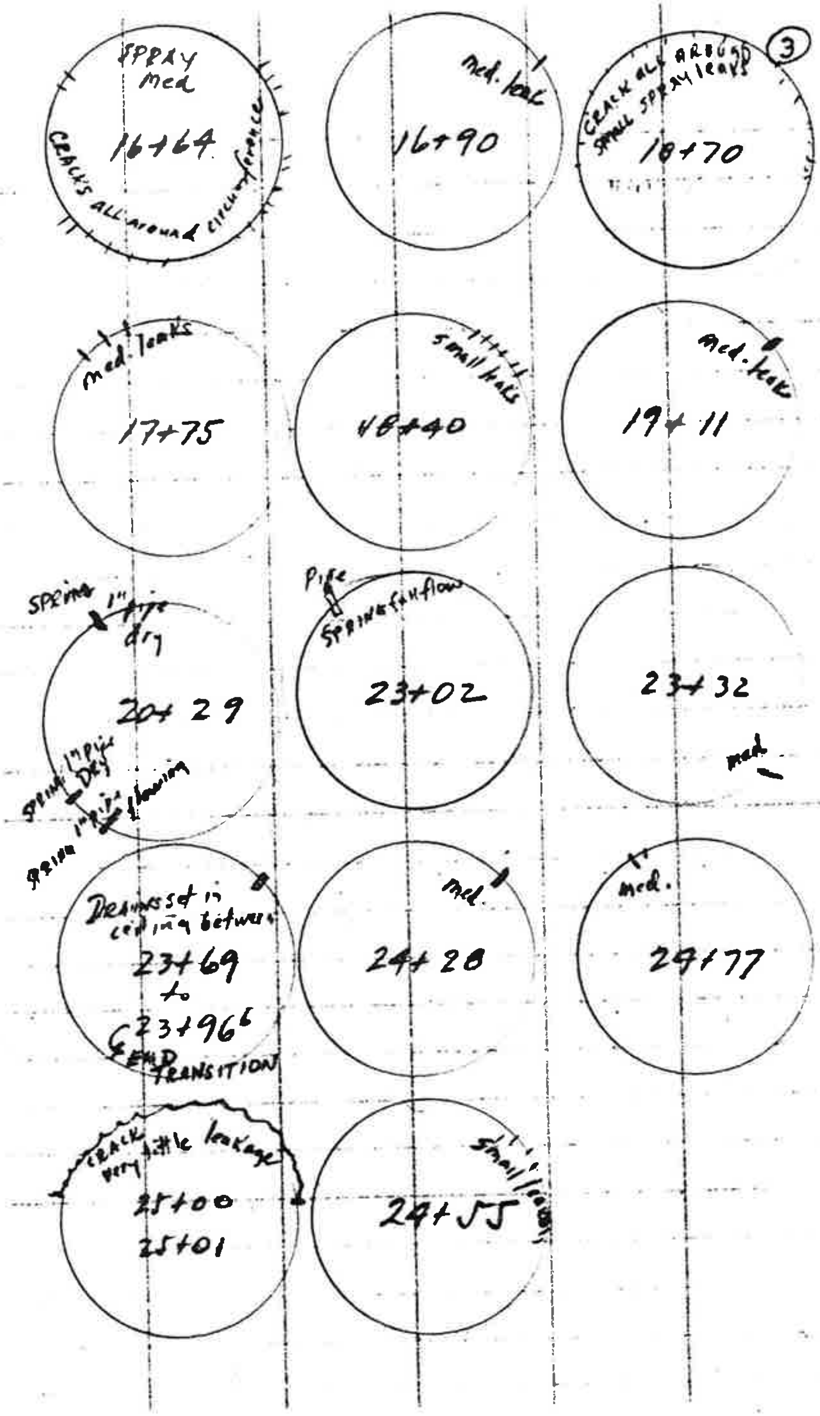
U. J. HUSSEY

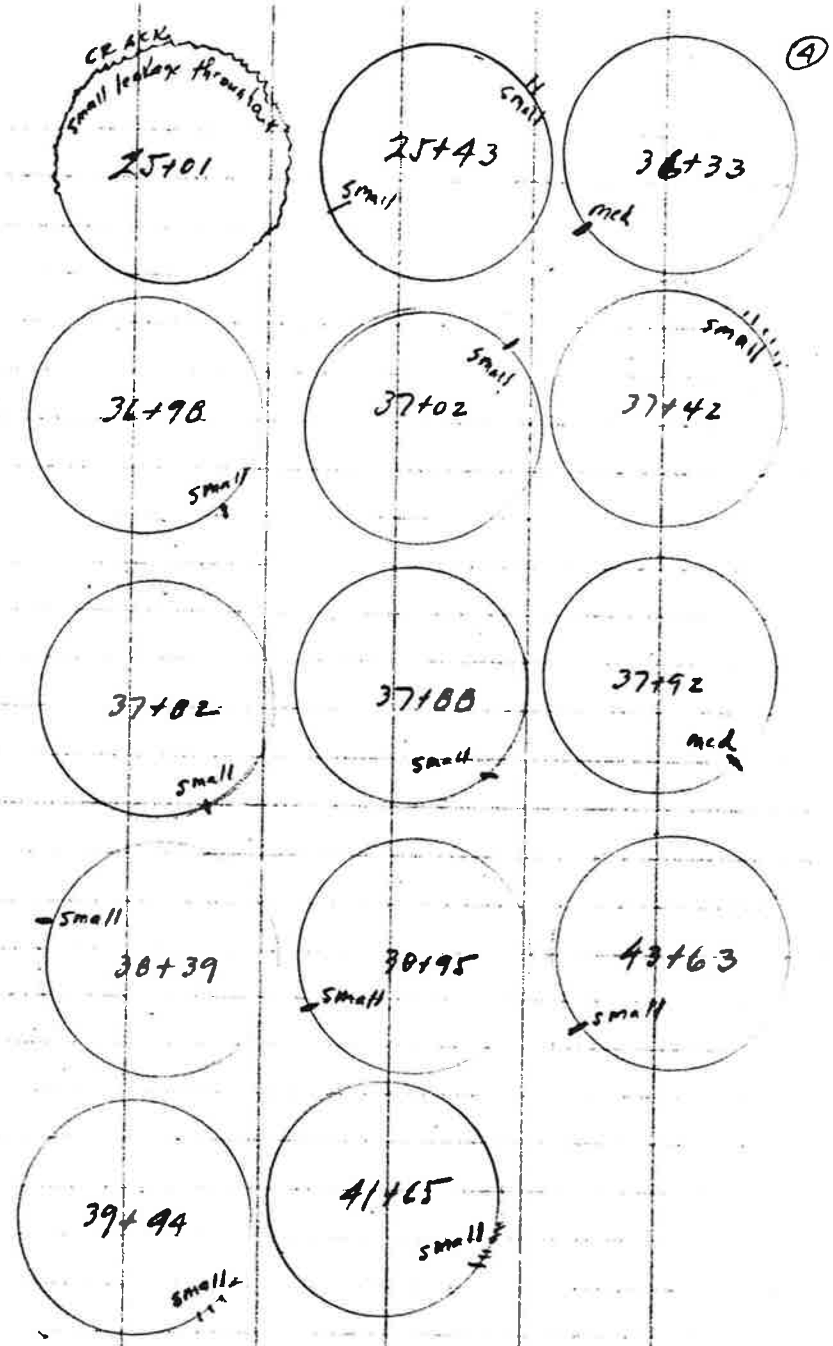
REC'D WATER PROD. & DIST. DIV.
DEC 14

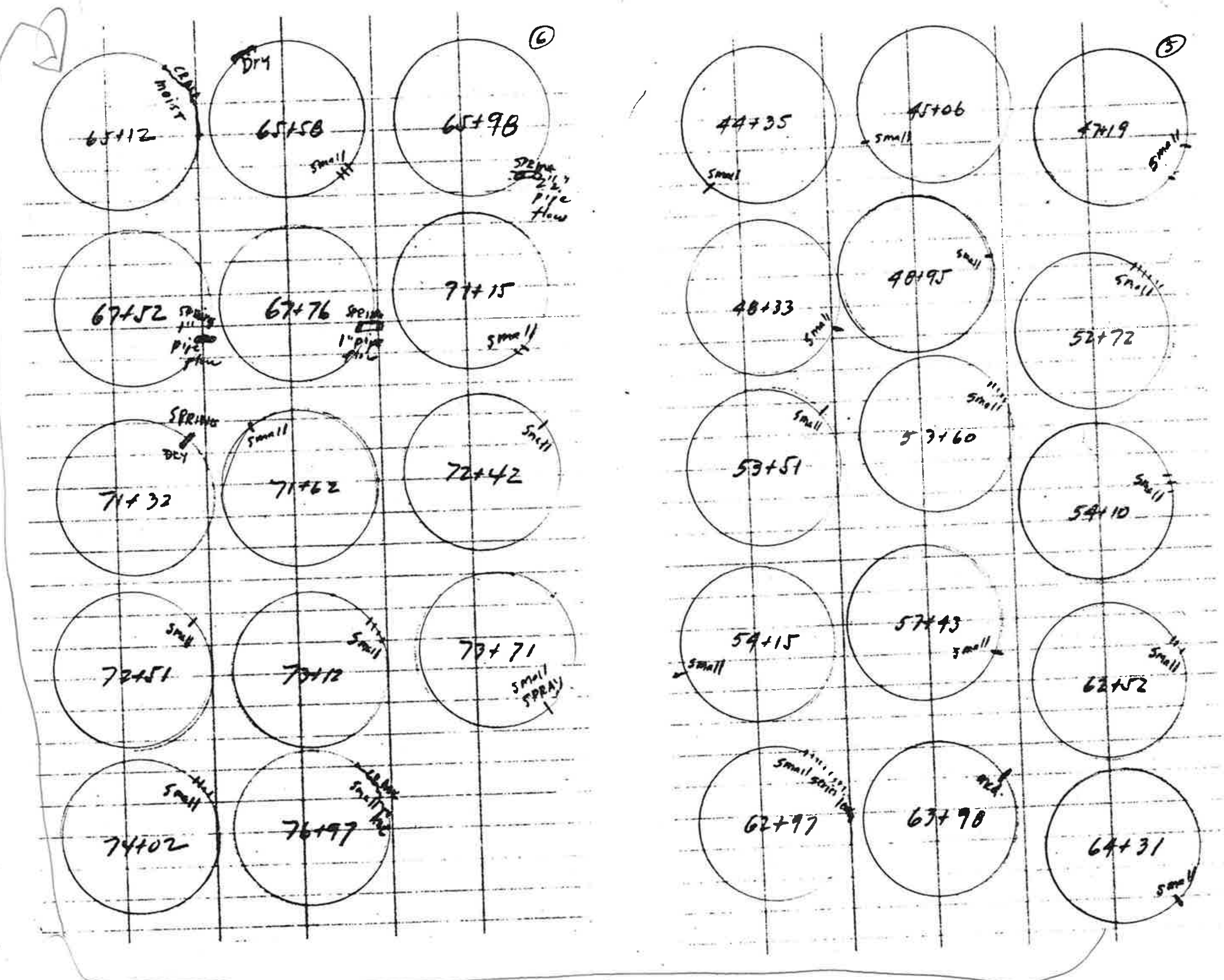
STATIONING & LEAKAGE AS OF DEC. 12, 1962
PARDEE TUNNEL



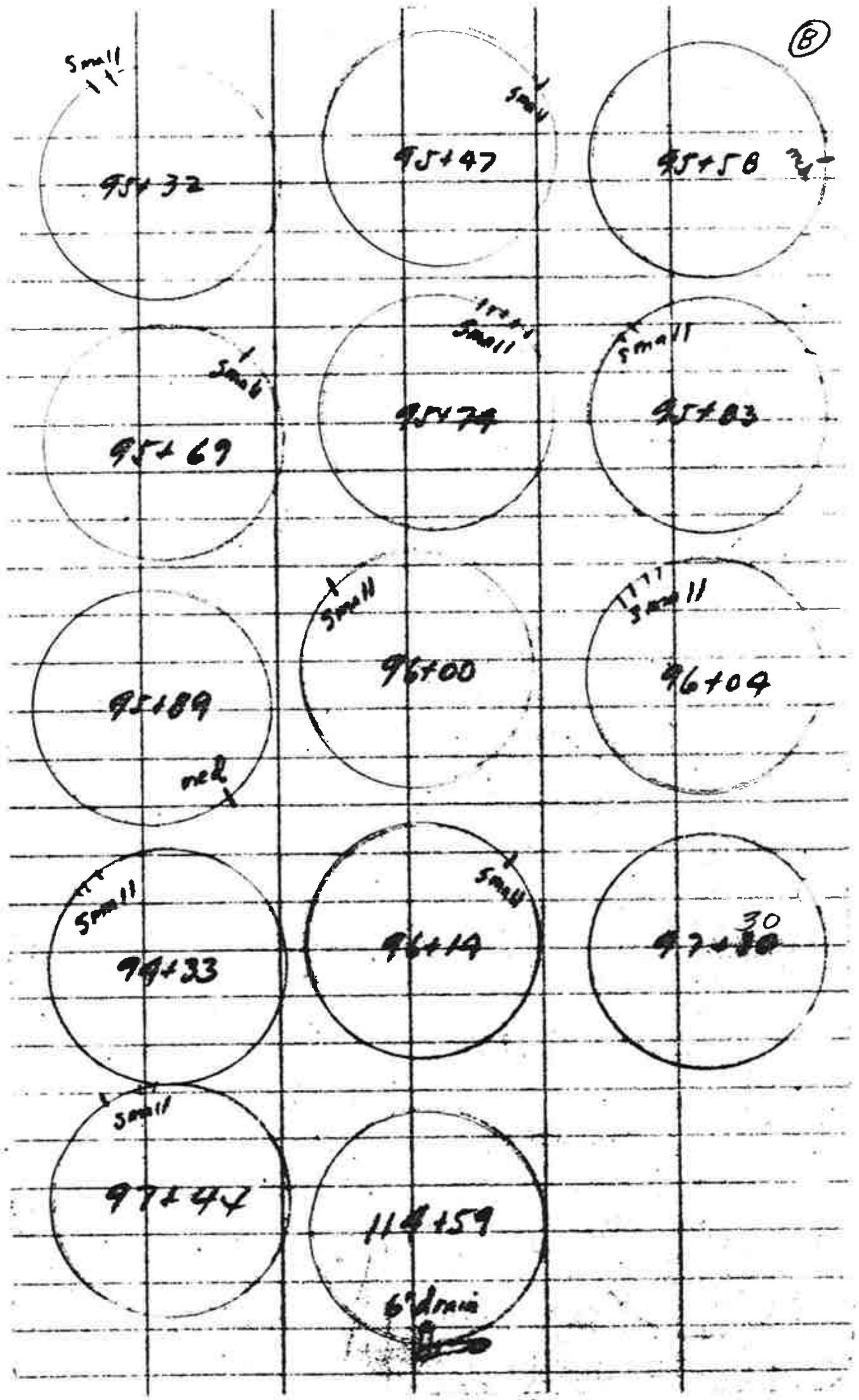


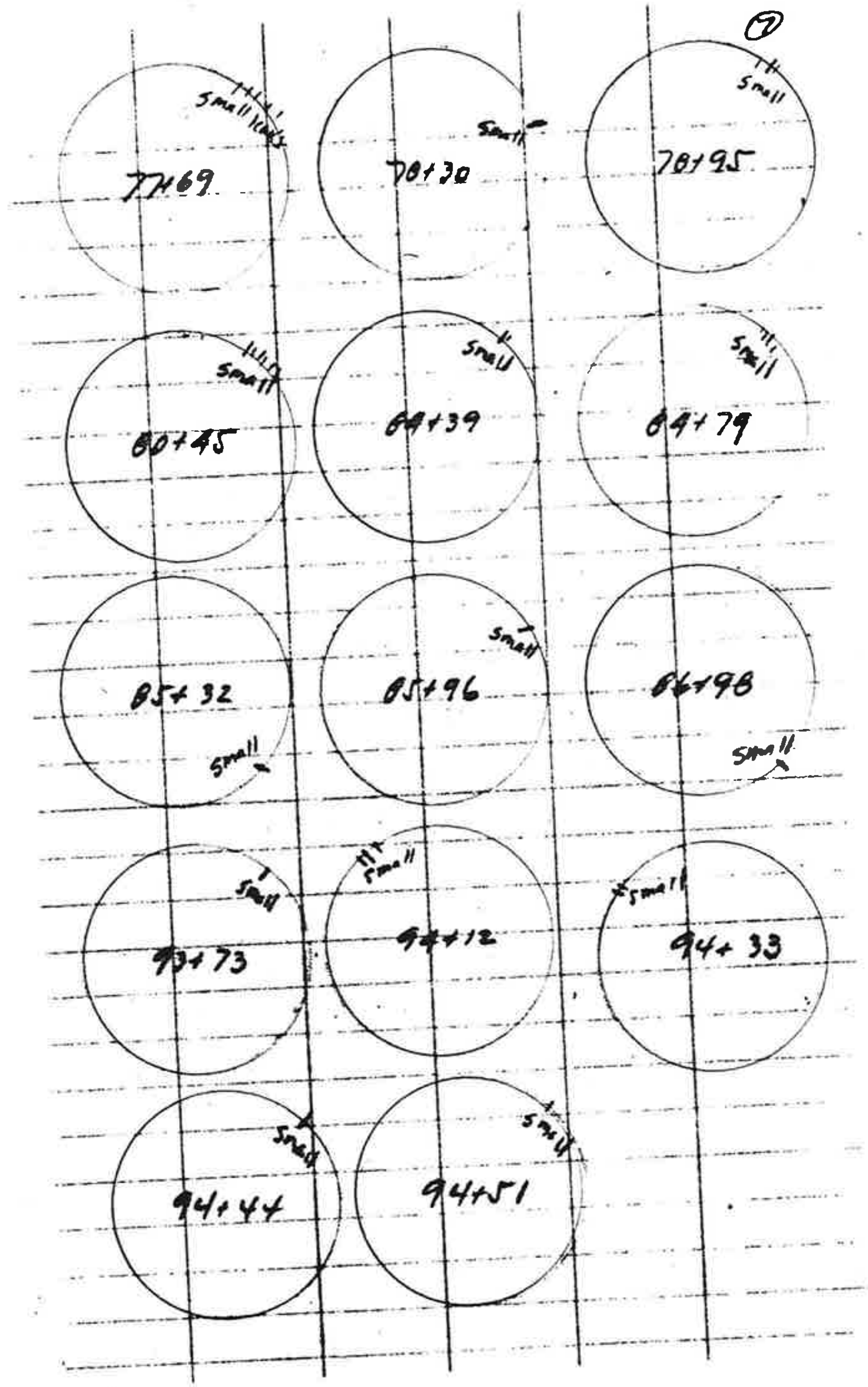

③
SPRAY med
16+64
CRACKS ALL around circumference
med. leak
16+90
CRACK ALL AROUND
SMALL SPRAY LEAKS
18+70
med. leaks
17+75
small leaks
18+40
med. leak
19+11
SPRING
1" Pipe dry
20+29
1" pipe DRY
1" pipe flowing
Pipe
SPRING full flow
23+02
23+32
med
Drainage set in ceiling between
23+69
to
23+96
END TRANSITION
med.
24+28
med.
24+77
CRACK
very little leakage
25+00
25+01
small leaks
24+55


④
CRACK
small leakage throughout
25+01
small
small
25+43
36+33
med
36+98
small
small
37+02
small
37+42
37+82
small
37+88
small
37+92
med
small
38+39
38+95
small
43+63
small
39+94
small
41+65
small



⑥
65+12
CRACK
moist
65+58
Dry
small
65+98
SPRING
2" pipe
flow
67+52
SPRING
pipe
flow
67+76
SPRING
1" pipe
flow
71+15
small
71+32
SPRING
DRY
71+62
small
72+42
Small
72+51
Small
73+12
Small
73+71
small
SPRAY
74+02
Small
76+97
Small
⑤
44+35
Small
45+06
small
47+19
small
48+33
small
48+95
small
52+72
Small
53+51
Small
53+60
Small
54+10
Small
54+15
Small
57+43
small
62+52
Small
62+97
Small
63+98
64+31
small


8
Small
95+32
95+47
95+58
95+69
95+74
95+83
95+89
96+00
96+04
94+33
96+14
97+30
97+44
114+59
6" drain


7
Small
77+69
78+30
78+95
80+45
84+39
84+79
85+32
85+96
86+98
93+73
94+12
94+33
94+44
94+51

Pardee Tunnel
1962
Tunnel Inspection
Observations

station	location	seepage	crack	comments	
8+71	11 and 1 o'cloc	spray and small			
8+72	11 and 2 o'cloc	small sprays			
8+74	11 o'clock	small			
8+76	1 to 2 o'clock	medium			
8+81	11 o'clock	small			
8+83	11 o'clock	small			
8+77 to 8+78	12 to 3 o'clock	series of leaks			
8+82 to 8+83	10 to 2 o'clock	series of leaks			
8+91	12 to 3 o'clock	series of leaks			
8+96	11 o'clock	small			
9+01	2 o'clock	small			
9+34	9 to 1 o'clock	series of leaks			
9+59	5 oclock	spring			
9+97 to 10+00	2 o'clock	small			
11+41	11 o'clock	small			
11+42	11 o'clock	small			
12+18	11 o'clock	medium			
13+23	10 to 1 o'clock	series of leaks			
13+28	1 o'clock	large leak			
14+15	10 to 1 o'clock	series of leaks			
14+23 to 14+25	1 to 2 o'clock	series of medium leaks			
14+28	11 o'clock	small leak			
15+01	2 to 3 o'clock	small leaks	crack		
15+20.5	11 o'clock	spring 1" pipe			
15+30	11 to 12 o'clock	small leaks			
15+98	2 to 3 o'clock	small leak	crack		
16+00	11 o'clock	medium leak			
16+05	10 to 12 o'clock	small leaks			
16+24	7 o'clock	medium leak			
16+64	all around	medium spray	cracks all around		
16+90	2 o'clock	spray leaks			
18+70?	9 to 3 o'clock	small spray leaks	cracks all around		
17+75	11 to 12 o'clock	medium leaks			
18+40	1 to 2 o'clock	small leaks			
19+11	2 o'clock	medium leak			
20+29	11,7,8 o'clock	spring 1" pipe dry, spring 1" pipe dry, spring 1" pipe flowing			
23+02	10 o'clock	spring 1" pipe, full flow			
23+32	5 oclock	medium leak			
23+69 to 23+96	2 o'clock	drains in crown		end transition at 23+96	
24+28	2 o'clock	medium leak			
24+77	11 o'clock	medium leak			
25+00 to 25+01	9 to 3 o'clock	very little leakage	crack		
24+55?	2 to 4 o'clock	small leaks			
25+01	8 to 4 o'clock	small leakage throughout	crack		
25+43	2 and 8 o'clock	small leakage			
36+33	8 o'clock	medium leakage			
36+98	5 oclock	small leakage			

Pardee Tunnel
1962
Tunnel Inspection
Observations

station	location	seepage	crack	comments	
37+02	2 o'clock	small leakage			
37+42	1 to 2 o'clock	small leakage			
37+82	5 oclock	small leakage			
37+88	5 oclock	small leakage			
37+92	5 oclock	medium leak			
38+39	10 o'clock	small leak			
38+95	8 o'clock	small leak			
39+94	4 to 5 o'clock	small leaks			
41+65	3 to 4 o'clock	small leaks			
43+63	8 o'clock	small leak			
44+35	7o'clock	small leak			
45+06	8 o'clock	small leak			
47+19	3 to 4 o'clock	small leaks			
48+33	4 o'clock	small leak			
48+95	3 o'clock	small leak			
52+72	1 to 2 o'clock	small leaks			
53+51	2 o'clock	small leak			
53+60	2 to 3 o'clock	small leaks			
54+10	2 to 3 o'clock	smal leaks			
54+15	8 o'clock	small leak			
57+43	4 o'clock	small leak			
62+52	2 to 3 o'clock	small leaks			
62+97	1 to 3 o'clock	small series of leaks			
63+98	2 o'clock	medium leak			
64+31	4 o'clock	small leak			
65+12	1 to 3 o'clock	moist	crack		
65+58	11 and 5 o'clocl	small leaks			
65+98	5 oclock	spring 21/2" pipe, flow			
67+52	4 o'clock	spring 1" pipe, flow			
67+76	4 o'clock	spring 1" pipe, flow			
71+15	5 oclock	small leak			
71+32	1 o'clock	spring, dry			
71+62	11 o'clock	small leak			
72+42	2 o'clock	small leak			
72+51	2 o'clock	small leak			
73+12	2 o'clock	small leaks			
73+71	4 o'clock	small spray			
74+02	2 o'clock	small leaks			
76+97	2 o'clock	small leak	crack		
77+69	1 to 2 o'clock	small leaks			
78+30	2 o'clock	small leak			
78+95	1 o'clock	small leaks			
80+45	1 to 2 o'clock	small leaks			
84+39	1 o'clock	small leaks			
84+79	1 o'clock	small leaks			
85+32	5 oclock	small leak			
85+96	2 o'clock	small leak			
86+98	5 oclock	small leak			
93+73	1 o'clock	small leak			

24 480
1.25" = 4.63 mi.
1" = 3.7 mi.

Pardee Tunnel
1962
Tunnel Inspection
Observations

station	location	seepage	crack	comments	
94+12	11 o'clock	small leaks			
94+33	10 o'clock	small leaks			
94+44	2 o'clock	small leak			
94+51	2 o'clock	small leak			
95+32	11 o'clock	small leaks			
95+47	2 o'clock	small leak			
95+58	3 o'clock	medium leak			
95+69	2 o'clock	small leak			
95+74	1 to 2 o'clock	small leaks			
95+83	11 o'clock	small leaks			
95+89	4 o'clock	medium leak			
96+00	10 o'clock	small leak			
96+04	11 to 12 o'clock	small leaks			
94+33?	10 o'clock	small leaks			
96+14	2 o'clock	small leak			
97+30		none			
97+44	11 o'clock	small leak			
114+59	6 o'clock	6" drain		end of inspection	

107+00 TO 114+59 8'-2'' CIRCULAR REINFORCED CONCRETE
114+59 TO 116+15.5 8'-2'' STEEL LINER