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SYNOPSIS: Kirkwood Penstock, located in a deep, steep-sided canyon near Yosemite National Park, California, is an integral part of the Hetch Hetchy system, which conveys water from the Sierra Nevada mountains to the city of San Francisco, California. A heavy rainfall approximately 17 years following construction of the facility triggered settlement of the foundation. Measures undertaken to arrest this settlement included consolidation grouting, construction of facilities to divert surface runoff away from the penstock, and installation of a geomembrane to prevent infiltration of rainfall and snow melt in the vicinity of the penstock. No evidence of further settlement has been detected since completion of the remedial work.

INTRODUCTION

Kirkwood Penstock is a 1955-foot-long, 8-foot-diameter facility located in a deep, steep-sided canyon near Yosemite National Park, California. It is an integral part of the Hetch Hetchy system, which conveys water from the Sierra Nevada mountains to the city of San Francisco, California. Construction in 1966 was preceded by geologic and geophysical investigations that were interpreted to indicate that the penstock would be located on weathered or decomposed in-place granitic bedrock beneath the surface talus (Woodward-Clyde-Sherard and Associates, 1964). The penstock was protected from rockfalls by concrete walls and was secured in place by use of anchor blocks and 60-foot-long anchor cables.

The penstock performed satisfactorily until January 1984, when a Dresser coupling at the top of the penstock and immediately downslope from an anchor block founded on rock was found to have undergone an extension of 1 3/4 inches. Settlement of the concrete foundation slab and walls was also found to have occurred. It was inferred that the settlement had been triggered by heavy rainfall that occurred during December 1983. However, the underlying cause of the settlement was not evident. Therefore, geologic studies to ascertain the cause were undertaken. These studies included geologic mapping, drilling exploratory borings, and installing and monitoring slope indicator casings (Woodward-Clyde Consultants, 1985). Additionally, extensometers were installed on the penstock and a program of frequent surveys was instituted so as to detect any further displacement.

Extremely difficult drilling conditions were encountered in the exploratory holes, delaying accumulation of sufficient data to confidently assess the cause of the settlement. Due to the importance of the Kirkwood Penstock to the Hetch Hetchy Water and Power System, a decision was made to leave the penstock in service and to institute stabilization measures prior to completion of the exploratory work. The measures undertaken were based upon an assumption that loose talus was present beneath the penstock; they included consolidation grouting, diversion of surface flow originating upslope, and covering the affected portion of the slope with an impervious membrane. Stairs and a foot bridge were constructed to facilitate access for long-term measurements in the slope indicator casings.

INFERRED GEOLOGIC CONDITIONS

Preliminary Working Hypothesis

A crude stair-step morphology, in which roughly parallel steep bluffs of granitic rock are separated by intervening areas of talus and deeply weathered rock, exists in the site area. It was inferred at the outset of the studies leading to the design of remedial treatment that the "stair-steps" were related to regional jointing. Because the observed settlement of the concrete support system for the Kirkwood penstock took place in one of the talus-filled areas between bedrock bluffs, it was hypothesized that the settlement was the result of water-induced migration of fine particles into the interstices of coarser talus deposits and into open joints and fractures. The fact that continuous intact rock was not encountered in the core borings that subsequently were made was ascribed to weathering along joints. The initial minor movements shown in the inclinometer readings were inferred to be the result of shifting of casing backfill material and possibly also related to movement in the water-eroded talus materials contained in a subsurface bedrock trough.

Block Sliding Hypothesis

Consideration was given, both during the initial field reconnaissance and the subsequent subsurface studies, to the possibility that the settlement of the penstock was related to landslide movement. One important purpose of the core borings, as well as of the inclinometers, was to examine this possibility. The borings appeared to show the existence of a relatively deep bedrock trough that might conceivably represent a pull-apart feature between in-place bedrock and the main mass of a block slide. However, neither the inclinometer data nor the results of frequent surveys disclosed any conclusive evidence of slide movement.

Ridge-Spreading Hypothesis

It ultimately was concluded that the morphology and apparent subsurface physical characteristics of the site are the result of large-scale gravitational spreading and fracturing processes. These processes, which we will refer to here as ridge-spreading, entail dilation of a ridge along fractures, joints, foliation, or other structural weaknesses as a result of gravity-induced tensional stresses. Such structural weaknesses may become opened to considerable depth. According to Radbruch-Hall and others (1976), the usual topographic expression of this type of gravitational movement, which occurs in many different types of rock, consists of horizontal linear trenches and uphill-facing (anti-slope) scarps on steep slopes and ridge crests.

One implication that can be drawn from this hypothesis is that the penstock may cross an extremely deep crevasse-like opening that is choked with blocks and masses of granitic rock. This condition would account for the large "takes" of thick, mortar-like grout that were experienced during the remedial treatment program. If this condition actually exists, one would expect infiltrating rainfall to tend to flush fine-grained materials into adjacent open zones, leading to readjustment and settling of the larger blocks and masses of material.

SUBSURFACE TREATMENT

Design Approach

The possible need for subsurface drainage measures was assessed. However, on the basis of habitual loss of circulation in all of the exploratory holes, and a finding that the water table depths were in the range of 100 to 150 feet or more, it was decided that no benefits would be derived from a drainage tunnel or drainage borings. As the available data indicated that readjustment of loose talus was the most probable cause of settlement of the penstock, it was concluded that some type of consolidation grouting should be done. It was evident that a conventional slurry grout would travel too far beyond the penstock foundation, so a compaction grouting approach was selected. It was inferred that the grout alone would not be able to bind the presumed talus mass together to the optimum extent, so Dywidag reinforcing bars were placed in each grout hole. In order to provide optimum distribution of grout, one row of holes was drilled and grouted on each side of the penstock. The maximum hole spacing was 10 feet.

Grout Hole Drilling

The drilling and grouting operations were performed with the aid of a steel platform that was mounted on the penstock wing walls, and moved up and down the slope by means of manually-operated grip-hoists. The holes were drilled with a ROC-601 rotary percussion drill that could be shifted along slots in the deck of the platform. NW casing, with an outside diameter of 3 1/2 inches, was advanced above a 4-inch-diameter bit until the planned depth of 60 feet was reached or until there was reason to believe that bedrock had been reached. The drill string was then extracted, the bit removed, and the casing driven back into place. The casing was then cleaned out preparatory to grouting. The rates of penetration ranged from nearly instantaneous where the drill "string" dropped through voids to a few hundredths of a foot per minute in fresh, hard rock.

Grouting Procedures

The grout was batched in a horizontally-mounted paddle-type mixer. The typical content of a 5-cubic-foot batch was 25 shovels full of silty sand, 2 bags of cement, one gallon of prehydrated bentonite, and sufficient water to produce a six-inch slump at the pump. Depending upon the pumping pressure, loss of water at the delivery line couplings dropped the slump to 3 1/2 to 5 inches at the injection point. It did not prove feasible to pump at a pressure sufficient to deliver and inject a thicker grout. As the grout was more fluid than anticipated, the injection quantity was arbitrarily limited to 4 cubic feet per foot of stage length after reaching an injection pressure of 100 psi. Injection of grout was stopped when the pressure exceeded 10 psi per foot of stage depth if the volume criterion was not met. In general, injection was performed in one-foot increments, with the casing being raised following completion of each increment.

Summary of Results

Twenty eight holes were drilled an aggregate depth of 1700 feet, and 4000 cubic feet of grout were injected into the 60-foot-deep zone being treated. An additional 250 cubic feet of grout were injected into an inclinometer hole that extended 85 feet below that zone. In general, relatively large grout takes occurred in the lowest injection stages, where a relatively thin grout was used. Grout takes exceeded 20 cubic feet at intermediate depths in 10 holes. The largest volume injected in a single stage was 59.5 cubic feet; the injection pressure in this stage didn't exceed 140 psi.

The injection pressure commonly would build up to two or more peaks during the grouting of an interval, and then would drop off before building back up again. This behavior, an example of which is presented on Figure 1, is ascribed to the grout pushing loose talus blocks aside and exposing additional voids. These pressure peaks were not necessarily high as compared to the refusal pressure for the stage; as is shown on Figure 2, injection of intervals deeper than about 20 feet was more commonly halted on the basis of grout take than of excessive pressure.

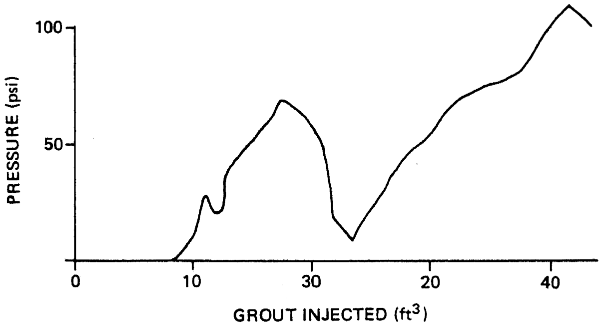

Figure 1. Pressure Behavior at Constant Injection Rate

There was no noteworthy reduction in take between primary holes and secondary holes. Therefore, supplementary holes were drilled and grouted beneath the Dresser coupling that had exhibited evidence of settlement.

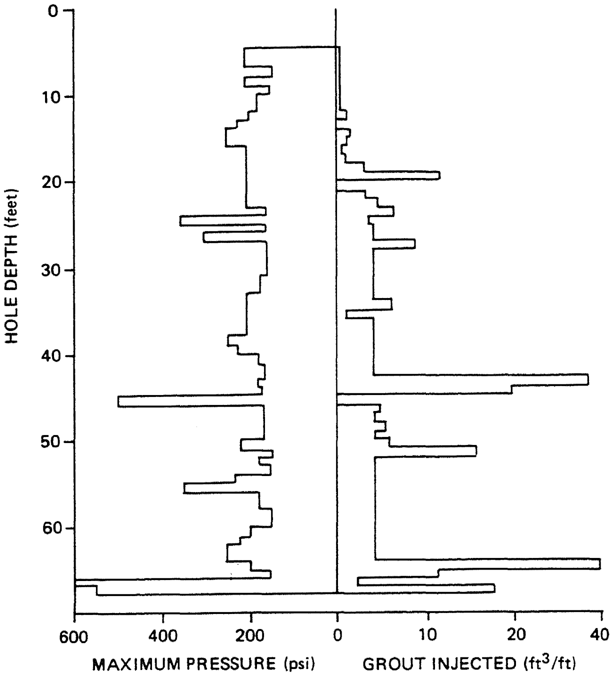

Figure 2. Injection Pressure - Volume Relationship for Typical Hole

These holes, which extended beneath an anchor block immediately upslope from the coupling, took relatively little grout. Contact grout holes drilled through the concrete slab on which the penstock is located also took very little grout. However, the mobile platform was left in place as a precautionary measure in case further grouting is decided to be needed.

SURFACE TREATMENT MEASURES

Surface Drainage

The existing surface drainage facilities were improved and supplemented to divert surface runoff around and away from the vicinity of the penstock. Due to the steep, irregular, brush-covered topography, much of this work had to be accomplished by hand labor. The work performed included the following:

1. An existing interceptor trench was extended and lined, and was provided with outfall pipes to divert the runoff 200 to 300 feet to the sides of the problem area.

2. The access road to the top of the penstock was regraded and paved to divert surface runoff to a new drop inlet and outfall pipe leading away from the penstock.

3. Additional outfall facilities were constructed at the downslope end of the slope area that was covered with a geomembrane.

Geomembrane Cover

The ground surface area extending about 200 feet downslope from the valve house at the top of the penstock and about 150 feet to each side of the penstock was covered with a geomembrane for the purpose of preventing direct infiltration of rainfall and snow melt water into the problem area. Preparation of the ground surface for placement of the geomembrane consisted of clearing of brush and trees, trimming of numerous large protruding rocks, laying and pinning wire mesh to "smooth out" a few irregular areas, and hand-excavating ditches in which to tuck-in and secure the outside edges of the membrane. The area was then covered with a layer of 18-ounce Trevira geotextile. This geotextile is a continuous-spun polyester fabric, and is approximately 235 mils thick. Its function is to provide a tear-resistant foundation for the geomembrane, protecting it from direct exposure to puncturing by sharp protruding rocks.

The geotextile was covered with Shelter-Rite XR-5, style 8130, which is a 30-mil-thick polymer-coated membrane that is extensively used as a pond lining. This material was installed in panels ranging up to 50 feet by 160 feet in size. These panels were heat-welded together to form a continuous waterproof membrane. The membrane was fastened to the concrete foundation of the penstock, to a newly-constructed concrete stairway at the top edge of the western panel, and to a rock outcrop cliff along the eastern side, using galvanized battens and expansion bolts. The outside and downslope edges were tucked into hand-excavated ditches that were then backfilled to tie down the membrane. Finally, sandbags were placed at numerous locations on the membrane to provide resistance to uplifting wind forces.

Small concrete dams were constructed at the lower end of the groins formed by the penstock wingwalls and the geomembrane-covered surfaces that slope toward the penstock. These dams divert concentrated flows into CMP pipes that convey these flows to a pre-existing outfall that collects water from an underdrain system beneath the penstock foundation slab.

POST-TREATMENT MONITORING

Slope indicator readings have been performed weekly during the rainy season and monthly during the dry season since completion of the slope stabilization measures. The data obtained have indicated no continuing or renewed movement.

CONCLUSIONS

The absence of evidence of further settlement following completion of the slope stabilization measures is inferred to indicate that the grouting operations produced a coherent wedge that bridges the underlying opening that is believed to be present. It is further concluded that influent moisture is unlikely to trigger further settlement. However, the geologic mechanism involved in ridge-spreading at the site is too poorly understood to allow a confident conclusion to be reached concerning the long-term stability of the penstock. Therefore, consideration is being given to alternatives for replacing it.

REFERENCES

Radbruch-Hall, D. H., D. J. Varnes, and W. Z. Savage (1976), "Gravitational spreading of steep-sided ridges ("Sackung") in western United States", Bulletin of the International Association of Engineering Geology, No. 14, 23-35.

Woodward-Clyde Consultants (1985), "Geologic report on special treatment area, Kirkwood Penstock, Early Intake, California", Consultant's report prepared for Utilities Engineering Bureau, City and County of San Francisco.

Woodward-Clyde-Sherard & Associates (1964) "Investigations for the proposed Canyon Penstock, Tuolumne County, California", Consultant's report prepared for the Power and Utilities Engineering Bureau, City and County of San Francisco.