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FRIANT POWER PROJECT

NON-FEDERAL POWER ON A RECLAMATION FACILITY

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ABSTRACT

Designs for powerplants at Friant Dam were produced through the challenging cooperative efforts of Tudor Engineering Company and the Bureau of Reclamation. Complex problems successfully resolved included penstock tie-in, valve submergence, energy dissipation, time constraints, and lining limitation. Several of the problems were solved by the use of a physical model.

INTRODUCTION

Friant Dam is the principal feature of a large, complex irrigation water supply regulation and delivery system, the Friant Division of the U.S. Bureau of Reclamation's Central Valley Project. Because this system is in operation practically the year round and is often very delicately balanced, any major change needs great care and scrutiny. Therefore, the development of the designs for powerplants on the three outlet works at Friant Dam required an extensive cooperative effort by the consulting firm, Tudor Engineering Company, and the project operator, the Bureau of Reclamation.

The most important problems resolved were: location of the tie-in to the existing outlet pipes, submergence of the remaining hollow-jet valves at certain tailwater conditions, the energy dissipators of proposed fixed-cone valves, the restricted periods of time for certain elements of construction, and limitations of the existing canal linings. The key to the resolution of several of the problems was a model study of the Friant-Kern Powerplant, the modified outlet works and stilling basin, and upper end of the canal.

SETTING

Friant Division provides for transport of surplus water through the southern part of California's semiarid Central Valley. The division's main features are Friant Dam, the Friant-Kern Canal, and

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Madera Canal, all constructed and operated by the Bureau of Reclamation. Friant Dam (fig. 1) is located on the San Joaquin River 25 miles northeast of Fresno. Completed in 1942, the dam is a concrete gravity structure 319 feet high with a crest length of 3,488 feet. The resulting reservoir, Millerton Lake, has a capacity of 520,500 acre-feet. The dam and reservoir control the San Joaquin River flows, meet downstream release requirements, and provide flood control, conservation storage, and diversion into Friant-Kern and Madera Canals. Annual full natural flow of San Joaquin River below Friant Dam varies from a maximum of 4,367,000 to a minimum of 361,500 acre-feet. Average discharge is about 1,800,000 acre-feet.

Friant-Kern Canal carries water from Millerton Lake southerly for supplemental and full irrigation supplies. The canal, which is 151 miles long and has an initial capacity of 5,300 c.f.s., delivers an average of 1,400,000 acre-feet annually.

The 36-mile-long Madera Canal carries water northerly from Millerton Lake. The canal, with an initial capacity of 1,250 c.f.s., makes water deliveries which average 350,000 acre-feet annually.

Although an early plan for Friant Dam included a powerplant on the river outlet works, the final design made no provision for power or for future addition of a powerplant. Water releases through the river outlet works average 50,000 acre-feet annually.

Normal maximum reservoir elevation at Friant is 578 feet; the minimum, 468 feet. Elevation and head data in feet for the dam's outlet works are:

	Friant-Kern	Madera	River
Outlet valves			
centerline elevation	464	446	332
Static head			
Normal maximum	114	132	246
Minimum	4	22	136

In the mid-1970's Reclamation evaluated the addition of powerplants at several existing dams, including Friant. A December 1979 report (1) concluded that for Friant Dam, three plants--a 15,000-kW unit on the Friant-Kern Canal outlet, a 5,000-kW unit on the Madera Canal outlet, and a 2,700-kW unit on the river outlet--were economically justified. However, non-Federal interest precluded congressional authorization for construction.

NON-FEDERAL PROPOSAL

In 1978, eight irrigation, municipal utility, and water districts 1/ joined together to form Friant Power Authority. These districts, all purchasers of Friant-supplied water, foresaw that potential revenue from sale of hydroelectric power was a partial solution to their energy costs. The Authority retained legal, financial, bond, and engineering consultants 2/ and proceeded to determine feasibility of a Friant Power Project. The initial study showed a feasible project; a water rights permit and a FERC license were subsequently obtained.

The Authority proposal calls for construction of powerplants on the three outlet works. Friant-Kern Powerplant No. 1 will have a 15,000-kW horizontal Kaplan turbine and synchronous generator; Madera Powerplant, an 8,000-kW horizontal Kaplan turbine and synchronous generator; and the River Outlet Plant, a 2,000-kW horizontal Francis turbine and induction generator. Ultimate development calls for construction of a second unit at Friant-Kern.

OPERATIONAL CONSTRAINTS

The Authority's approach to development of the Friant Power Project has been to work closely with the Reclamation staff. Because of the Authority members' role in the Friant Division, they fully understand and respect the priority of irrigation releases.

Project feasibility was of necessity based on the requirement that hydroelectric power generation is not to dictate when or how much water is released. Those releases are determined by irrigation and flood control demands. Further, in marketing the power, this operational constraint had to be acceptable to a power purchaser. In addition, both Reclamation and the Authority were very concerned about making any modifications to the existing facilities which could possibly jeopardize future operations. Finally, only limited periods of canal shutdown would be allowed during construction.

DESIGN CONSIDERATIONS

Working within constraints imposed by design features of the existing Friant Dam, the design objective for the three powerplants was to provide the most economical project. The five most important problems investigated in the cooperative design of this project are:

1. Location of the tie-in to the existing outlet pipes was a critical requirement. Branch-offs and bends were required to both minimize excavation within the existing dam, and be located a minimum of 5 pipe diameters from the discharge valves. Surge relief at load rejection was also required. As a result, several changes were made.

To avoid excavation near the toe of the dam and to reduce overall excavation for Friant-Kern and Madera Powerplants, horizontal Kaplan turbines were substituted for the original vertical Kaplan turbines.

At the Friant-Kern and Madera outlets, discharge valves on the pipes to be used for the proposed powerplants are to be moved significantly downstream of their present locations. Also, the discharge valves--two hollow-jet valves on Friant-Kern and one needle valve on Madera--are to be replaced with fixed-cone valves complete with energy dissipators. The reduction in construction costs served to offset somewhat the cost of the replacement valves.

2. Submergence of the remaining two hollow-jet valves adjacent to Friant-Kern Powerplant at certain tailwater conditions was a second

design problem. During prepower project conditions, a high tailwater occurs only when all valves are at a high rate of flow. This high rate of flow "sweeps out" the portion of tailwater in the stilling basin immediately downstream from the valves, eliminating any submergence problems. As the proposed powerplant utilizes up to 66 percent of maximum flow to the canal, the flow rate through the remaining two hollow-jet valves will, therefore, be too low to prevent partial submergence of the valves under future normal operation. The valve submergence was eliminated by channeling the discharge jet through a narrow passage, thus preventing the high tailwater from entering the valve chamber. Designs were successfully developed by Tudor and tested by Reclamation, using a physical model.

3. The energy dissipators for Friant-Kern Powerplant's fixed-cone valves were another design area that required model testing and redesign. Again, during operation of the model, the valves were submerged which could cause vibration and cavitation. The solution was to raise the valves by 5-1/2 feet.

4. That certain elements of the construction had to be completed during restricted periods of time was an important design consideration. The Friant-Kern Canal can usually be shut down only during December and January for major maintenance work in the outlet and canal structures, while Madera Canal can be shut down from mid-October through mid-February. The design layouts were developed to minimize construction required within the existing canal stilling basins. Both the Madera and Friant-Kern Powerplants were designed so that they can be constructed while irrigation releases are being made. Portions of the energy dissipators and tailrace passageways also can be constructed without affecting the existing stilling basins. In the Friant-Kern stilling basin, provisions for stoplogs will be made in the initial December-January construction period so that, during the second season, half of the basin can be dewatered in October. This affords additional time for construction while irrigation discharges can continue. During these two short "windows" of construction, the existing valves will be removed, water passageways connected, energy dissipators completed, and fixed-cone valves installed.

5. Canal linings at both Friant-Kern and Madera Canals consist of thin shotcrete which cannot be subjected on a daily basis to any but very minor fluctuations in water level. To prevent canal-lining failure, the canal's allowable drawdown is 1 foot per day. If load rejection occurs, the turbine flow must immediately be transferred to the fixed-cone valves to prevent a negative wave from traveling down the canal. A hydraulic transfer system designed to be fail-safe and to make the transfer in 6 seconds would result in a canal water level drop of not more than 1/2 foot.

MODEL STUDY

A model of the Friant-Kern Canal outlet and powerplant was needed to verify the design. This 1/16 scale model, constructed in the Denver Hydraulic Laboratory of Reclamation, confirmed the viability of much of the proposed design and, as explained earlier, identified problems which required redesign. The redesign was then verified by the model. Three elements of, or resulting from, the design were evaluated in the model. They were the hollow-jet valves and basin, the fixed-cone valves and chambers, and the wave measurements.

Hollow-Jet Valves and Basin

The original configuration of the hollow-jet valve basin was deemed inadequate because, with the operating criteria for the proposed powerplant, the valves would be submerged. Hollow-jet valves are designed to discharge freely to atmospheric pressure. Air vents supplying the inner hollow portion of the jet are located at the downstream face of the valve in line with four splitter vanes dividing the jet into quarter segments. The splitter vanes contain the airflow passages to the inner needle seal-ring, aerating the entire inner surface of the jet. With tailwater filling the air vents, vibration or cavitation would occur in the valve.

A number of modifications were tested in the model before the final configuration was developed. That configuration consisted of short wedge-shaped piers which angled in a downstream direction toward the projected valve centerline (fig. 2). As a result, the opening at the piers' downstream end was reduced to 9 feet 8 inches. The portion of the jet impinging on the wedges is deflected toward the projected centerline, concentrating the jet. The concentration aids in sweep-out and eliminates the possibility of tailwater submerging the valve. Fins which formed at the impingement point, and spread laterally outside of the basin were eliminated through the use of a deflector hood (fig. 2).

With the final configuration, the range of releases which could safely be made through the two hollow-jet valves was increased significantly. Both balanced and unbalanced releases were tested in the model. The higher the turbine flow and resultant tailwater, the greater the releases required through the hollow-jet valves to prevent submergence of the valves. At some operating heads, unbalanced flow through the hollow-jet valves is beneficial. At higher heads, balanced releases are preferable from a standpoint of dissipation of basin energy.

Fixed-Cone Valves and Chambers

The fixed-cone valves, with centerline elevation of 464 feet, were subjected to the same tailwater submergence problem as the hollow-jet valves. The problem is more severe with the fixed-cone valves because of the wide dispersion angle which directs the discharge radially outward at 45 degrees and reduces the sweep-out force in the downstream direction.

The proposed arrangement of the fixed-cone valve energy dissipation chambers provided excellent flow distribution into the tailrace section. However, the valves' lower portions were submerged at maximum reservoir head, and submergence progressively worsened as the head decreased. Elimination of the submergence problem was important as a number of instances of vibration-related failures have been reported on fixed-cone valves, and the use of those valves for submerged releases is not recommended (2 and 3).

The proposed structure was modified to reduce the tailwater at the valves. Included were installation of a 25-degree impact cone and a false floor, a ceiling, and walls tangent to the downstream end of the impact cone. No benefit was realized from the 25-degree impact cone by itself, but with the flow area reduced by the false floor, ceiling, and walls, some improvement was noted. The improvement was most noticeable in the decreased water level in the chamber upstream of the valve. With a high reservoir head and 1,842 c.f.s. discharge through the fixed-cone valves, the water surface upstream of the valves was near the pipe invert. Reducing the discharge to 1,330 c.f.s., the water surface raised to the centerline. As the reservoir head was reduced, the water level increased to near the top of the valve. Because this was considered unsatisfactory, a major change was essential.

Tudor developed an operational scheme which would permit raising the valves 5.5 feet to elevation 469.5 (fig. 3). A series of model tests with tailwater reduced to simulate this change showed a significant improvement. Simulation runs were made with the 25-degree cone, the false ceiling, floor, and side walls installed. From measurements made on the model, water upstream of the valve for most flow conditions would be below the level of the upstream end of the impact cone. This allowed for aeration of the outer boundary of the jet except during low reservoir releases where velocities are low and cavitation would not be anticipated.

Raising the valve in the model would require considerable additional cost and time. As the time schedule was extremely short, the simulation was continued by tailwater adjustments. The simulation provided conservative data when considering velocities at the downstream end of the chamber.

Raising the fixed-cone valves 5.5 feet, in order to prevent increasing the structure's ceiling height, required a 20-degree cone. Tests indicated that the outer boundary of the jet would be adequately aerated and that flow distribution at the end of the chamber would be satisfactory.

Wave Measurements

Utilizing capacitance wave probes, a series of wave measurements were made in the model. These tests indicated waves are within the limits of the requirement for canal lining stability.

CONCLUSIONS

Operational constraints for the existing facilities at Friant Dam--particularly the Friant-Kern outlet works, stilling basin, and canal--resulted in major design and schedule challenges when powerplants were proposed.

Changing the design of the turbines in the canal powerplants from vertical to horizontal axes minimized the excavation at the dam. Substituting fixed-cone valves for the hollow-jet and needle valves on the outlet pipes used for the powerplants and relocating the valves downstream solved the surge and some of the cavitation and vibration problems.

A physical model was necessary to confirm other valve cavitation and vibration problems of Friant-Kern Powerplant's original design. The model was also needed to test various alternative designs for the outlet works and stilling basin, and measure wave height. Through redesign most problems were solved, although some limited reduction in flow through the turbine will be necessary under certain head and flow conditions.

By minimizing construction within the stilling basins of the canals, all irrigation releases can be made. Construction in the basins, canals, and dam will be accomplished in the restricted time normally available when releases are not being made.

Design problems were ultimately resolved through the cooperative working arrangement of the Authority and Reclamation. The model study, in particular, confirmed the problems, and verified design changes needed and powerplant operational constraints. As a result, irrigation deliveries and optimal powerplant generation are assured.

ACKNOWLEDGMENTS

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(1) U.S. Department of the Interior, Bureau of Reclamation, "Friant Powerplants, Central Valley Project, California," December 1979.
(2) Mercer, Albert G., "Vane Failures of Hollow-Cone Valves", IAHR Symposium, Stockholm, Sweden, 1970.
(3) Parmakian, John, "Structural Failures in Hydraulic Equipment," Proceedings, Water and Power Symposium, April 8-9, 1968.

FOOTNOTES

1/ Chowchilla WD, Delano-Earlimart WD, Lindsay-Strathmore ID, Lindmore ID, Madera ID, Orange Cove ID, Southern San Joaquin MUD, and Terra Bella ID.
2/ Consultants include: (a) Legal--Minasian, Minasian, Minasian, Spruance, and Baber; (b) Financial--Blyth, Eastman, Paine, and Weber; (c) Bond--Orrick, Harrington, and Suthcliffe; and (d) Engineering--Tudor Engineering Company.

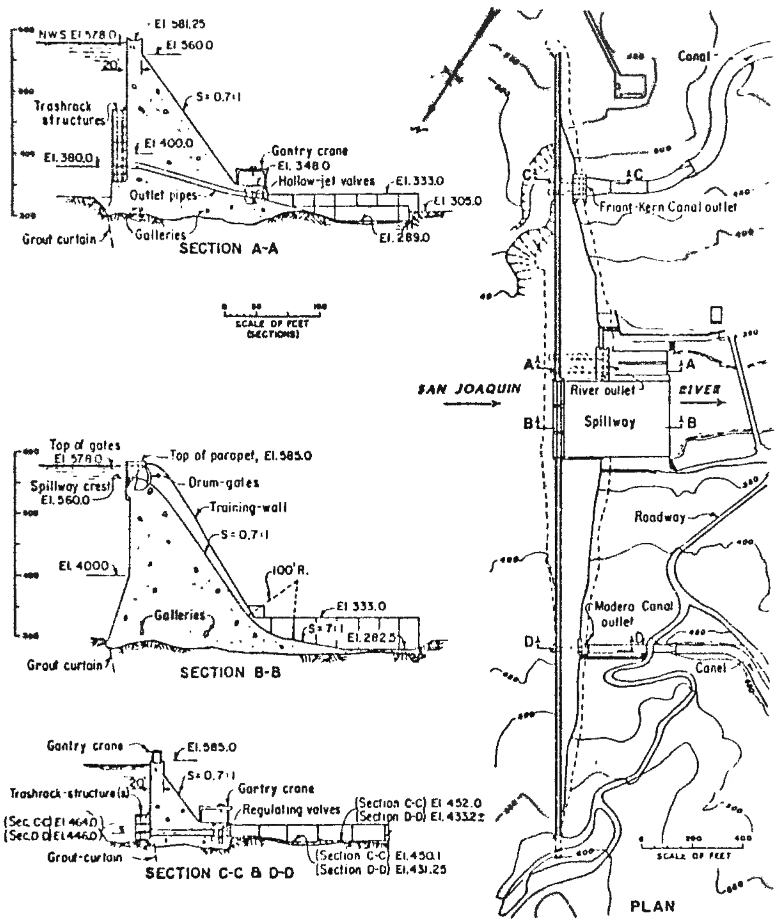

Figure 1 - Friant Dam

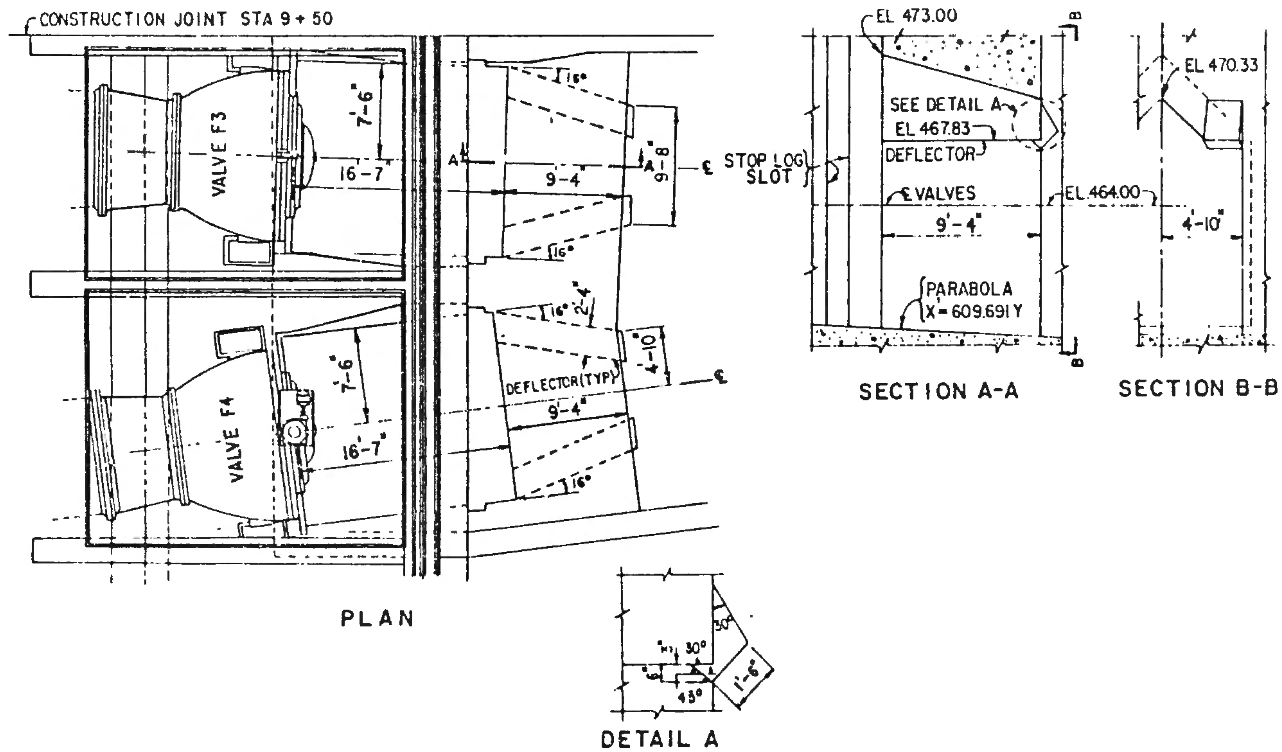

Figure 2 - Hollow-jet valve pier and hood arrangement

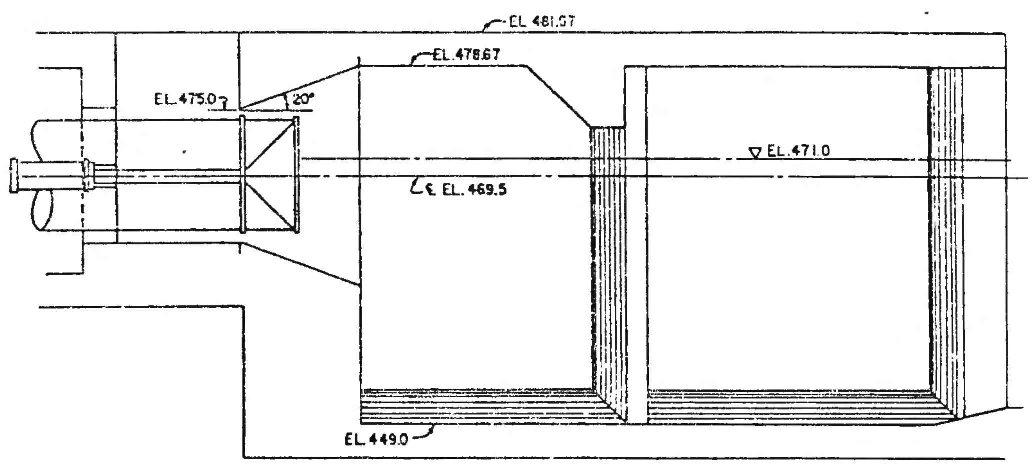

Figure 3 - Fixed-cone valve chamber