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HYDRAULIC LABORATORY REPORT NO. 170

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HYDRAULIC MODEL STUDIES OF THE FLAPGATES AT GILA PUMPING PLANT NO. 1 - GILA PROJECT

By

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Denver, Colorado
May 2, 1945

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Under Direction of

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- - -

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UNITED STATES
DEPARTMENT OF THE INTERIOR
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Branch of Design and Construction
Engineering and Geological Control
and Research Division
Denver, Colorado
May 2, 1945

Laboratory Report No. 170
Hydraulic Laboratory

Compiled by: Fred Locher
Reviewed by: J. E. Warnock

Subject: Hydraulic model studies of the flap gates at Gila pumping plant No. 1 - Gila project.

1. General. The Gila pumping plant No. 1 is a six-unit structure located at station 1101+00 on the Gravity Main Canal of the Gila project east of Yuma, Arizona. The six units will deliver 2,200 second-feet at maximum capacity through a lift of approximately 50 feet.

The plant was designed with the pump runners above the forebay water surface making it necessary that provisions be made for maintaining the prime on the pumps after the initial priming. To accomplish this it was necessary to have quick-acting and tight-sealing gates on the ends of the discharge conduits. Flap gates were selected as being the most satisfactory type of gate for the purpose.

After the plant was placed in operation it was found that the shock to the structure caused by the closure of the gates was sufficient to endanger its safety. The wide diversity of opinion as to the real cause of the shock, the numerous suggestions for reducing it to a safe value and the desirability of obtaining a simple and effective remedy lead to the instigation of hydraulic model tests.

2. The model. The model consisted of an eight-inch horizontal propeller pump powered by a three-horsepower motor. The pump was set

above the water level and was primed with an air-jet pump. The connection to the flap-gate seat was effected by an expander and a 10-inch line approximately 22 feet long, inclined 22 degrees 30 seconds with the horizontal, figure 1. The gate seat was an aluminum casting machined to give a flat seating area for the gate. The original model gate was also an aluminum casting but it was changed later to a fabricated gate made of light sheet metal.

The prototype installation consisted of six units, however, in the model it was only necessary to represent one unit. It was not possible to obtain exact similarity in the 1:9.6 scale model due to the difficulty in obtaining the proper inertia relationships at the pump. This was considered of no consequence as tests showed that the pump contributed very little to either reducing or increasing the shock resulting from the gate closing.

3. Instrumentation. To properly study the problem it was necessary to know the chronological order of events during a gate closure. These occurred quite rapidly, some being almost instantaneous. It was necessary, therefore, to obtain a recording instrument and accessories that would define the chronological order and magnitude of the various occurrences.

A seismographic oscillograph was obtained for the purpose and equipped in the laboratory with the proper electrical bridges, pressure cell, accelerometer, and gate timing device. The pressure cell was placed in the gate to record the transient pressure during a closing cycle. The accelerometer was attached to the gate seat to record the magnitude of the shock and the instant it occurred. The

gate timing device indicated the position of the gate at any instant, the time required for closure, and also made it possible to determine the angular velocity of the gate.

4. Initial tests. The initial tests on the flap gate were made to obtain general information concerning the behavior of the gate and to separate and analyze the factors contributing to the shock. The model was equipped with an accelerometer, a pressure cell in the gate, a pressure cell in the discharge pipe immediately upstream from the gate, and an indicator to show when the gate was seated. All of these instruments were connected to an oscillograph where the record for each unit was recorded simultaneously and continuously during a closing cycle of the gate. The records of the first two tests are shown on figure 2. The upper group of oscillograms show the sequence of events with the gate hinged at the bottom. The lower group of curves shows the normal prototype operation with hinges at the top of the gate.

It was apparent from the records that the negative pressure on the gate did not develop until the gate seated and that the shock was imparted to the structure within 0.01 second after complete closure of the gate. At first it was believed that the inertia forces due to the weight of the gate might be sufficient to cause the shock. To check this, the velocity of the gate was determined for free closure in air and for closing under the hydraulic forces, figure 3. The maximum angular velocity for free fall in air was 8.53 radians per second which did not produce shock, as compared to 3.45 radians per second for closure under hydraulic forces. When it was realized that the inertia force of the gate due to free fall in air was not sufficiently large

to cause an appreciable amount of shock in the model, it became apparent that this force, due to the lower angular velocity, would be of minor importance when the gate closed in normal operation.

Of the three forces acting to produce the shock, inertia, the water in the afterbay, and the vacuum load on the upstream side of the gate, it appeared that the vacuum load was the only one of sufficient magnitude that could produce the severe shock recorded in the 1:9.6 scale model.

5. Tests with air vents open to the atmosphere. To reduce the shock, two types of vents were tested. The first, design 1 of figure 4, was an automatic thruster air control mounted on the top of the conduit. Across the opening into the conduit, there was a spring-loaded flap which remained closed when the pump was in operation and opened when a vacuum formed in the conduit after the pump was stopped. The thruster closed the air vents, after a short lapse of time, thus maintaining the prime on the pumps. The other type of vent was a standpipe open to the atmosphere without provisions for shutting off the air supply and keeping the pump primed.

Neither of these schemes was satisfactory because the shock had already occurred before the vents supplied any air to the conduit. Air had to be in the conduit and near the gate before it seated to be of any benefit, and as the vacuum did not form until the gate seated, it was obvious that air under atmospheric pressure would not enter the pipe until after the shock occurred.

6. Tests with compressed air supplied to vents. The first tests with compressed air consisted of capping the three-inch (model)

atmospheric vent and applying sufficient air to lower the water surface in the vent to the top of the conduit. This reduced the magnitude of the shock considerably below that obtained with either the initial installation or that with the vent open to the atmosphere, figures 5E, 6A, and 6C. However, the severity of the slam varied considerably throughout a number of closures and increasing the size of the air chamber did not improve the performance. Other tests with the chamber partially filled with air gave results similar to the initial installation, figure 6B.

The next group of tests consisted of connecting the laboratory air supply to a 1/4-inch standard pipe fitting attached at various points along the discharge conduit and admitting air to the conduit at 125-lb. pressure a short time before the gate seated. The first connection was made midway between the pump and the gate. Admitting air at this point reduced the vibrations, figure 6D, but not sufficiently. The air port was moved to a point 20 inches upstream from the gate seat. When tested under these conditions a still farther reduction in intensity of vibration was observed, figure 6E. In both this and the previous port locations, it was difficult to determine the correct instant for the admission of the air. If the air entered the conduit too soon much of it escaped from the discharge line, and if the admission of the air was late the shock at closure was noticeably worse.

As the severity of the shock was reduced with the location of the air port nearer the gate seat, it was moved to a new location six inches upstream from the gate. The shock was not materially

changed with this arrangement, figure 5A, but the instant at which air was admitted to the conduit became less critical.

The air port was again changed to a point on the lower part of the gate itself. When tested with this arrangement the shock was less than with any of the previous designs and the quantity of air required was reduced considerably. As a further improvement admission of air by a manifold was tested. Two locations for the manifolds were chosen. The first was on the gate seat and the second was on the lower part of the gate. The former location gave satisfactory results and the latter was a further improvement, figures 5C and D.

7. The design for Gila pumping plant No. 1. Since the model tests indicated that the shock to the structure was minimized more by the use of compressed air to a manifold on the lower part of the gate additional tests were made to determine the size of the manifold, the proper location and size of the ports and the probable quantity of air required. The arrangement of figure 1 gave the most satisfactory results. This scheme would require an air receiver for each gate at least 30 inches in diameter, 65 inches long, and a pressure of 50 pounds per square inch or more. The receiver would be connected to the gate by a flexible coupling and controlled by an automatic valve which will release the air to the manifold at the proper time. In the model, the proper instant for releasing the air was when the gate reached an angle of 45 degrees with the horizontal. In the prototype, provisions should be made such that the gate angle at which the air valve is opened can be varied between 40 and 50 degrees and remain open until the gate is closed. When the gate is closed the valve

should automatically close and the compressor started to replenish the air that escaped from the receiver.

8. Spring loading of the gate. A proposal for spring loading the gate to cause it to close before the flow reversed in the conduit (the principle of the Smolenski check valve) and thus eliminate the shock was tested in the model. The arrangement consisted of a lever arm on the gate attached to a spring which exerted a closing effort on the gates. Although this principle works well in the Smolenski check valve, it was not possible to supply a sufficiently large closing force to cause the gate to close ahead of the reversal of flow and therefore had little effect in reducing the shock. In addition any great amount of force applied to the gate increased the pumping head and reduced the efficiency of the plant, figure 9.

9. The combination dash pot and air vent. A dash pot would eliminate completely the shock in flap-gate structures, but the dash pots would be large and expensive especially for the larger plants. However, a dash-pot design appeared practical for future installations after tests revealed that a retardation of the gate during closing provided sufficient time for an air vent open to the atmosphere to supply an adequate amount of air to the conduit and reduce the shock to a safe value. A small dash pot of insufficient size to support the forces on the gate but sufficient to retard the speed with which the gate closed was designed and installed in the model, figure 4, design 3, with a 3-inch (model) air vent open to the atmosphere. When tested under these conditions, the shock to the model structure

was almost eliminated. Other sizes of air vents ranging in size from 3/4 to 2 inches in diameter were tested in the model. It was found that the 1.5-inch diameter vent was adequate. The results of tests with the 1.5-inch vent are shown on figure 8 compared to a run without the vent and dash pot. The oscillograms of figure 8 cannot be compared with the previous records of figures 5 and 6 as different and better equipment was developed for the former records.

The arrangement was suitable for the installations where it was not necessary to hold a prime on the pump with a vacuum in the discharge conduit. To make the design general and applicable to any flap-gate installation an air flap valve, shown diagrammatically in figure 4, design 3, was developed. The valve is actually a miniature flap-gate spring loaded to keep it open when the pumps are in operation. When the pumps are stopped and a vacuum forms in the pipe, air rushes through the opening under the air flap valve, reducing the pressure on the under side of the flap causing it to close. The quantity of air passing through the vent before it closes is sufficient to reduce the shock but insufficient to cause the pump to lose its prime.

For prototype installations the ratio of the diameter of the air vent to the conduit diameter should be 0.15. The ratio of the dash pot diameter to the conduit diameter in the model was 0.173 with 0.008 of an inch (model) difference in diameters between the plunger and the case. The amount of clearance and the diameter of the dash pot will have to be determined for each prototype installation. The type of dash pot design proposed for the prototype installations is similar to that shown on figure 4, design 3.

10. Conclusions. The arrangement of figure 4, design 3, is satisfactory for reducing shock to the gate structures resulting from closure of the gates. The air flap valve is not necessary when the pump runners are below the forebay water surface.

Compressed air supplied to the gate at the proper time and in sufficient quantity before the gate closes will reduce the shock to a safe value.

Air vents open to the atmosphere are inadequate unless used in conjunction with a retarding dash pot.

Preloading of the gate to cause it to close ahead of the reversal of flow requires a load of such a large magnitude that it is impractical.

The use of closed vents under low air pressure to keep them free of water was not satisfactory.

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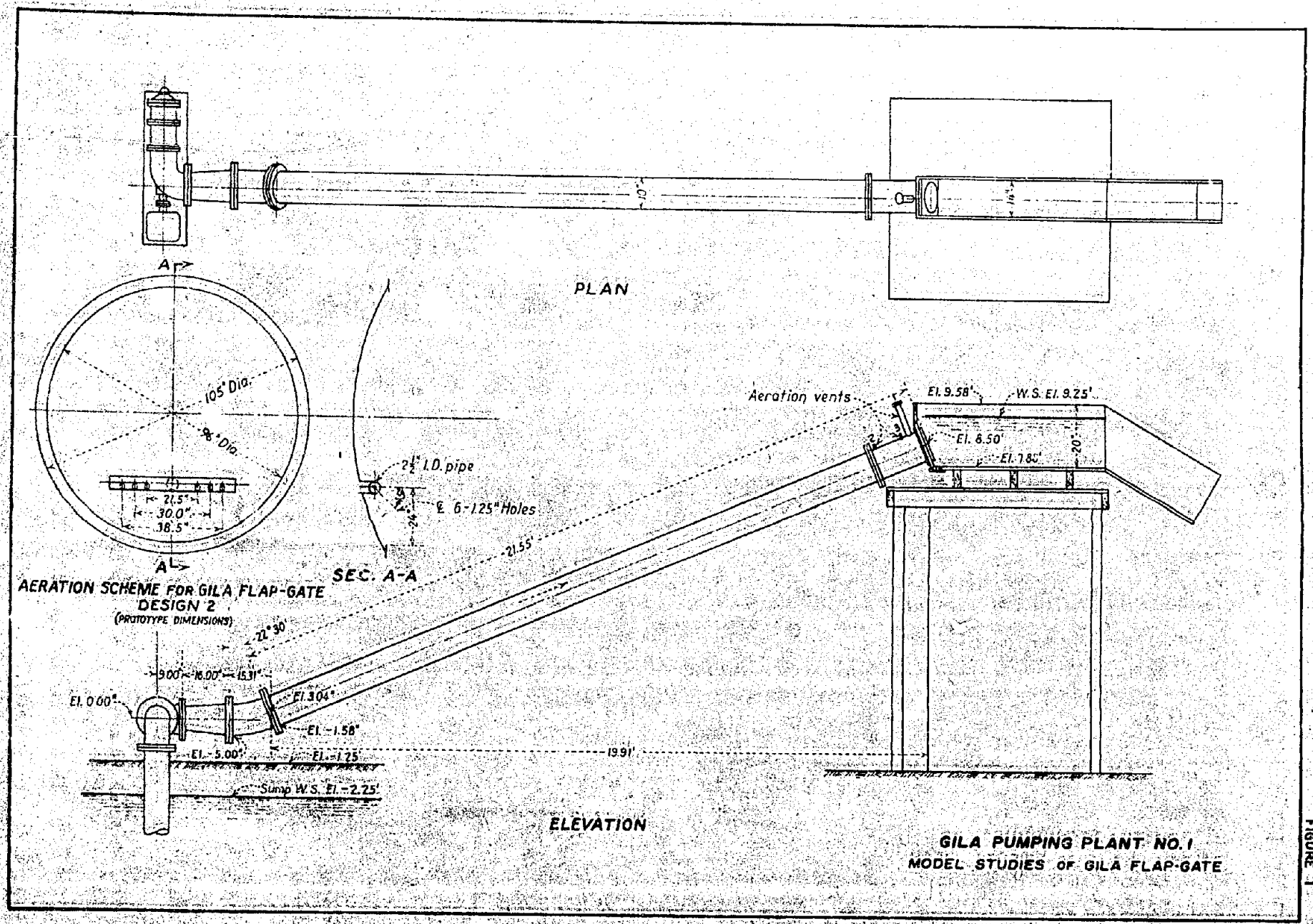


GILA PUMPING PLANT NO. 1
MODEL STUDIES OF GILA FLAP-GATE

FIGURE 1

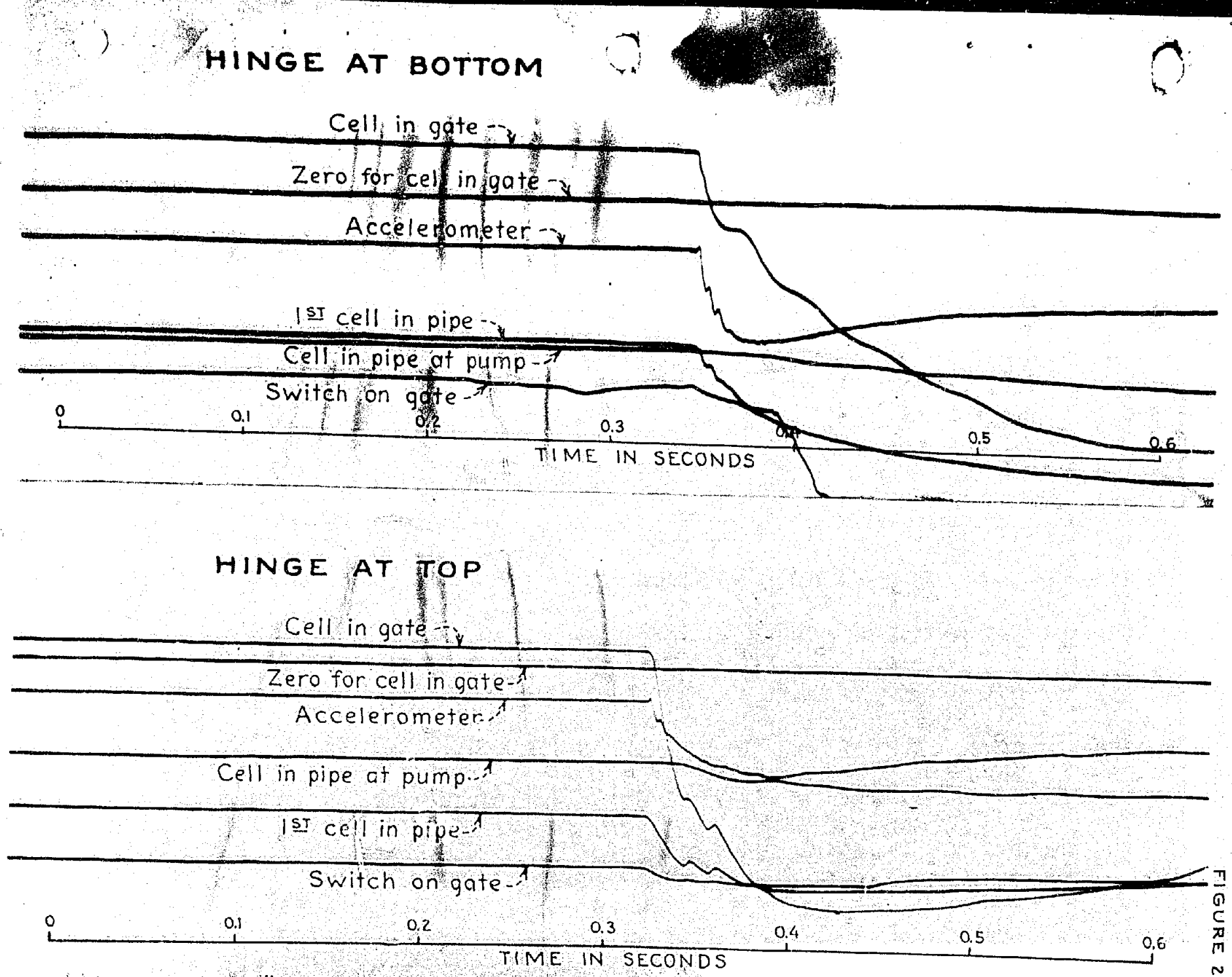
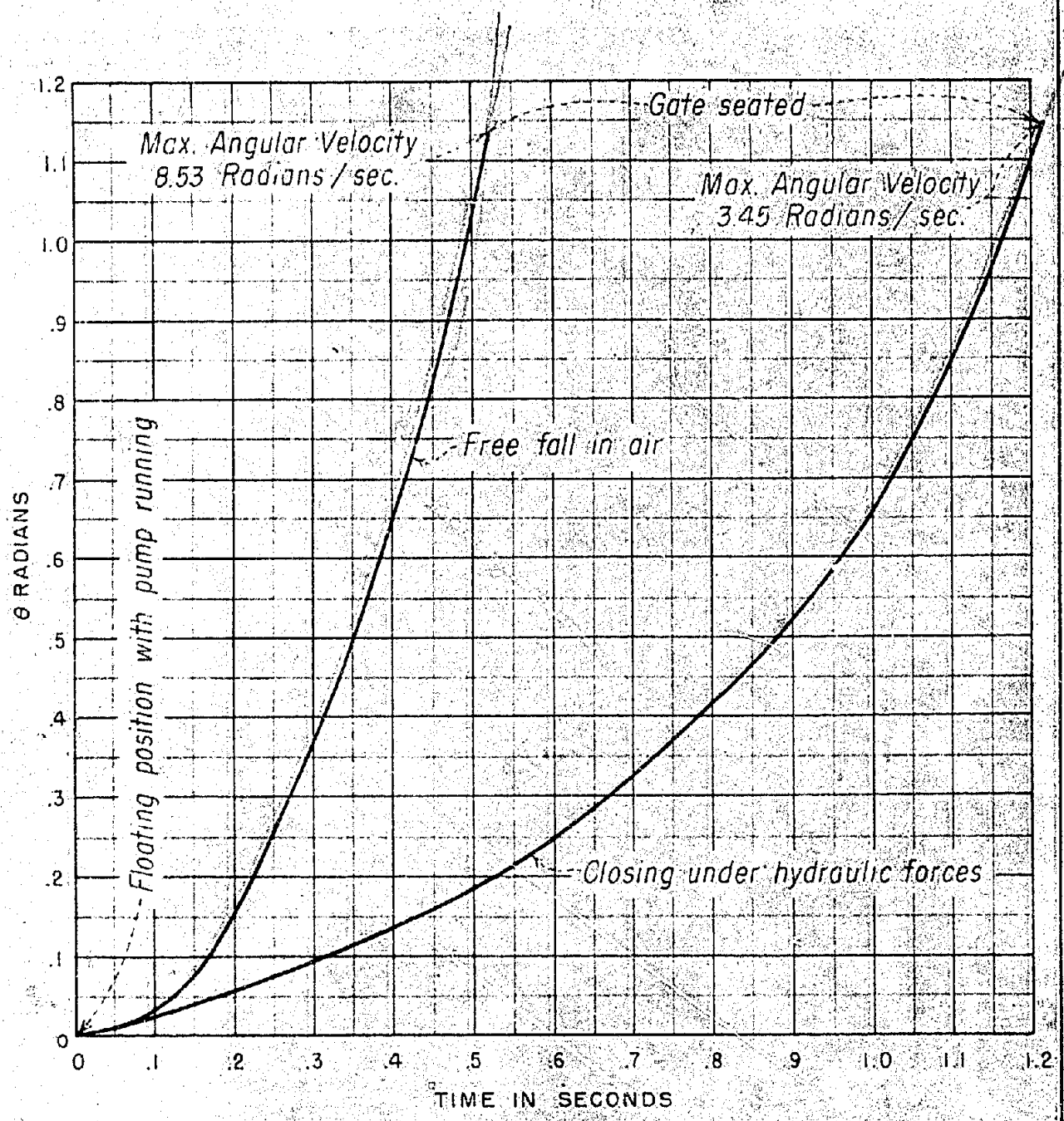

HINGE AT BOTTOM
Cell in gate
Zero for cell in gate
Accelerometer
1ST cell in pipe
Cell in pipe at pump
Switch on gate
0
0.1
0.2
0.3
0.4
0.5
0.6
TIME IN SECONDS
HINGE AT TOP
Cell in gate
Zero for cell in gate
Accelerometer
Cell in pipe at pump
1ST cell in pipe
Switch on gate
0
0.1
0.2
0.3
0.4
0.5
0.6
TIME IN SECONDS

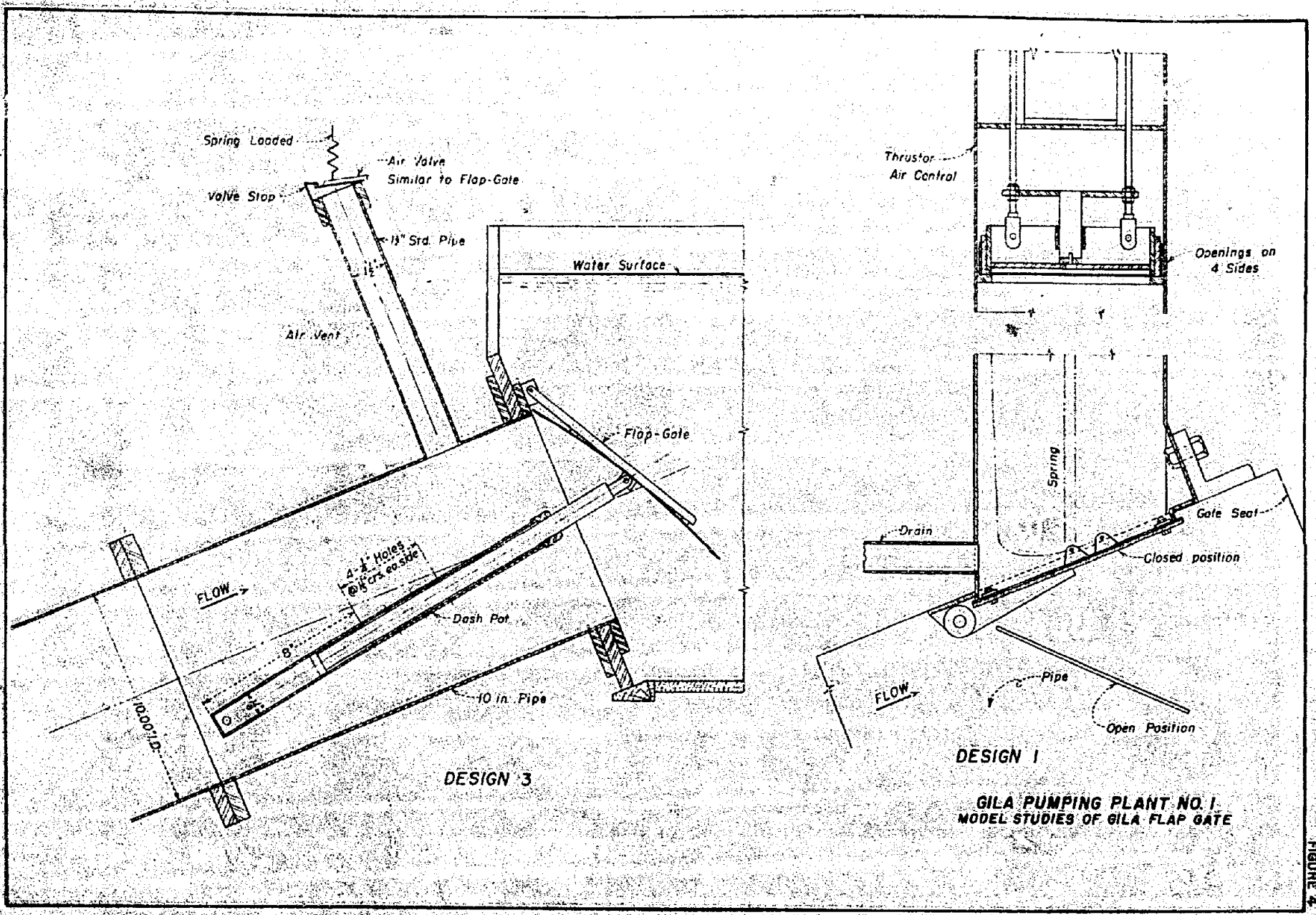
FIGURE 2

FIGURE 3



INITIAL INSTALLATION
GILA FLAP GATE

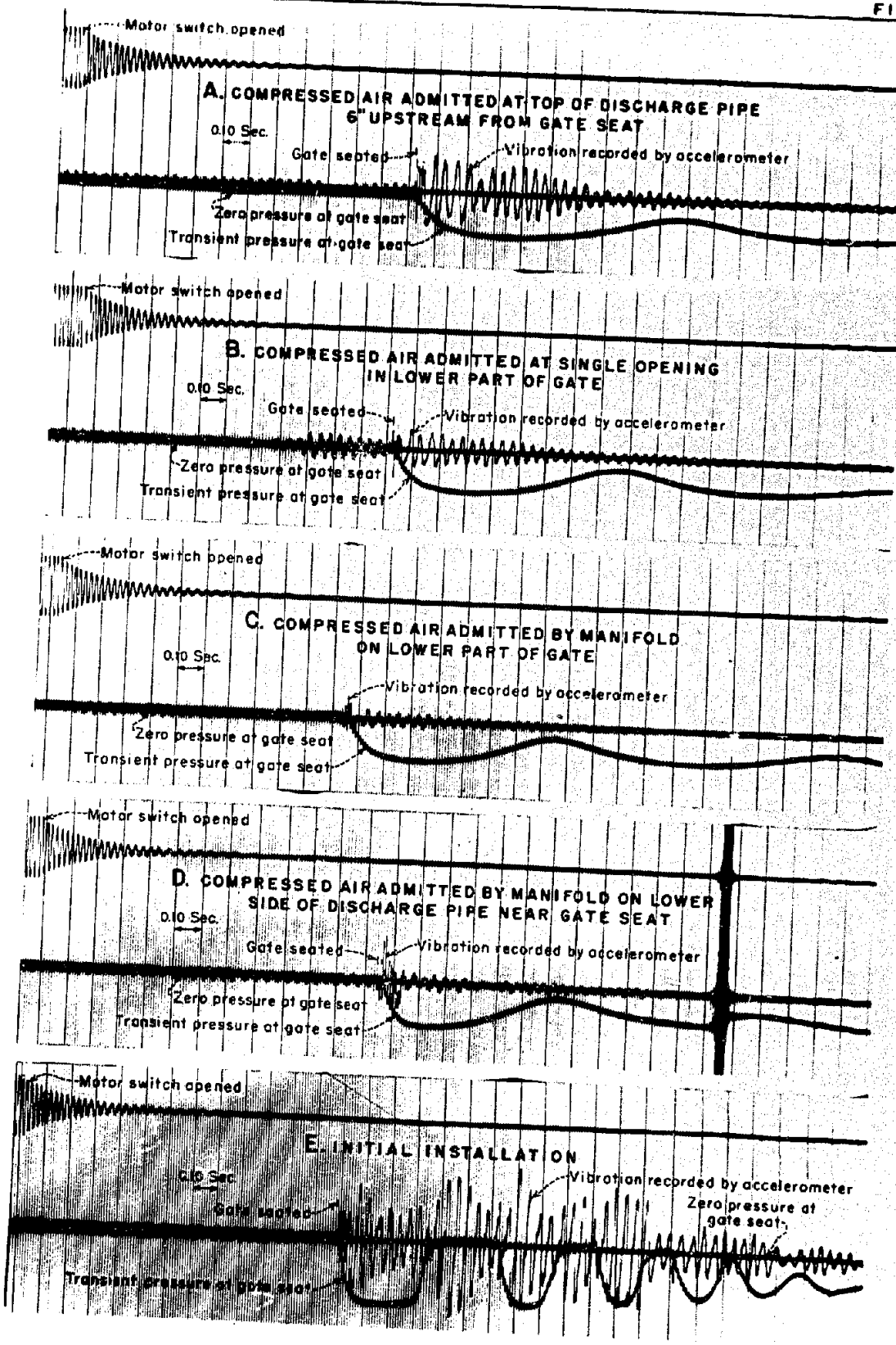
CLOSING – TIME CURVES



GILA PUMPING PLANT NO. 1.
MODEL STUDIES OF GILA FLAP GATE

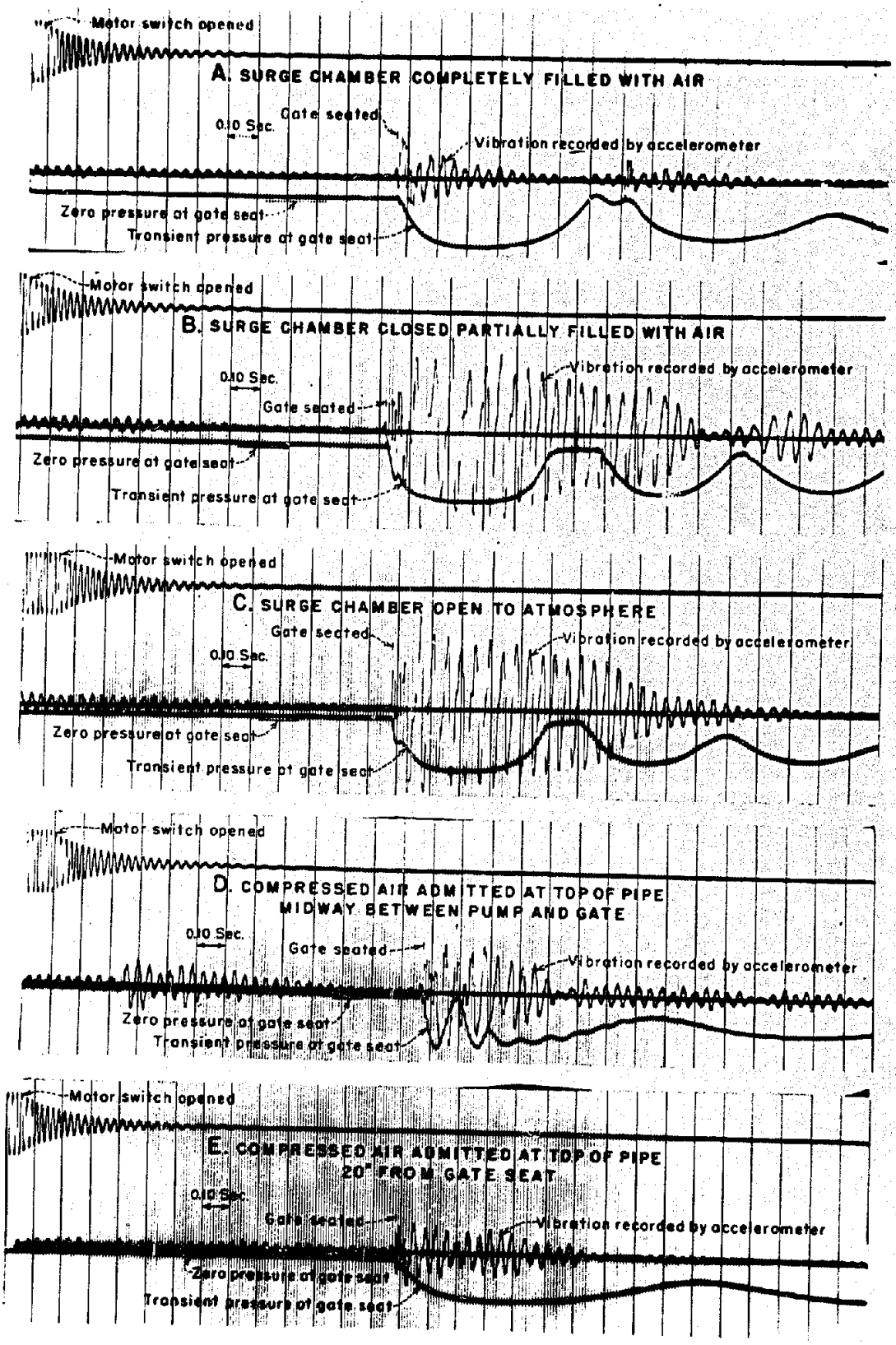
FIGURE 4

FIGURE 5



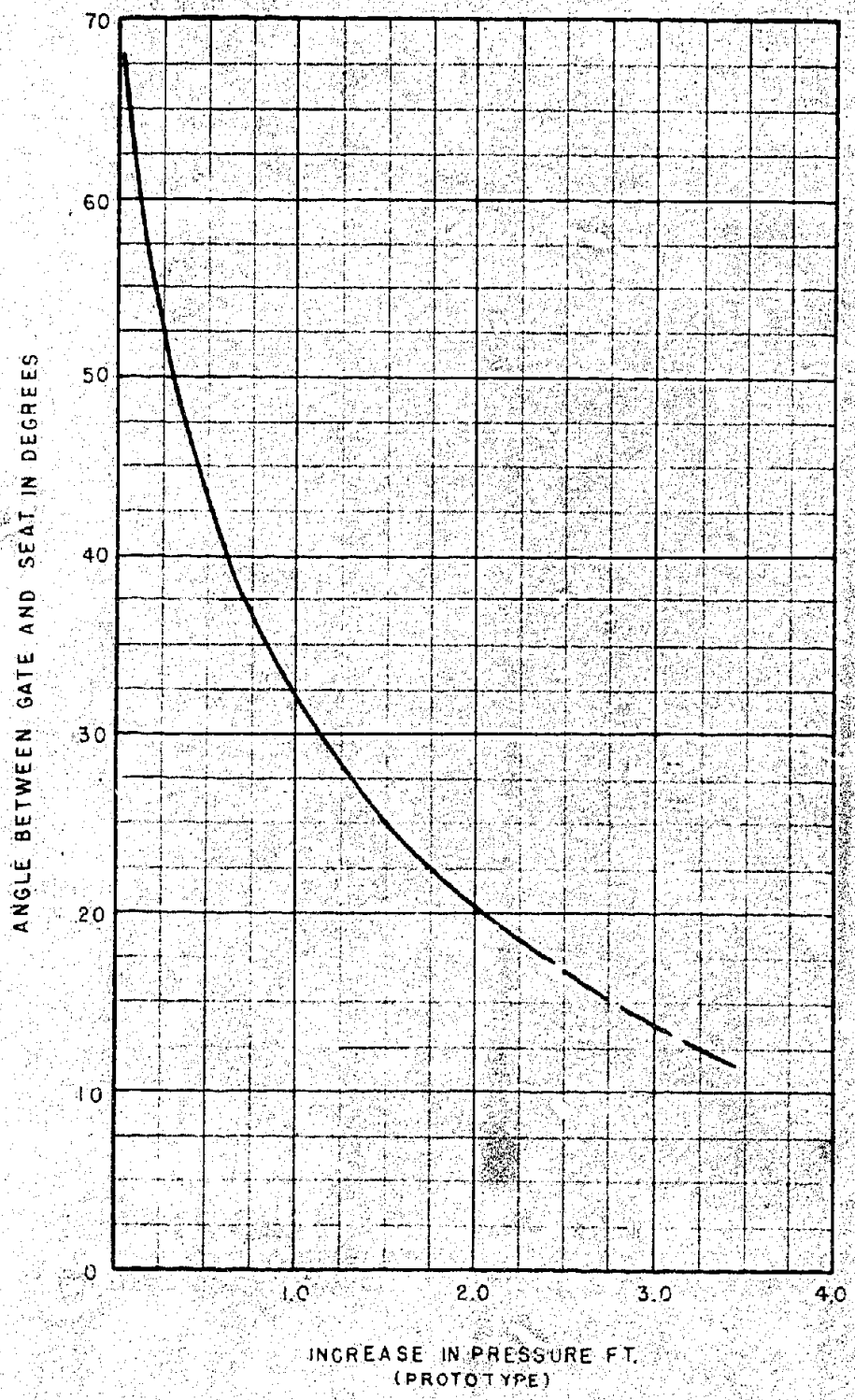
VIBRATION STUDIES OF GILA FLAP-GATE

FIGURE 6

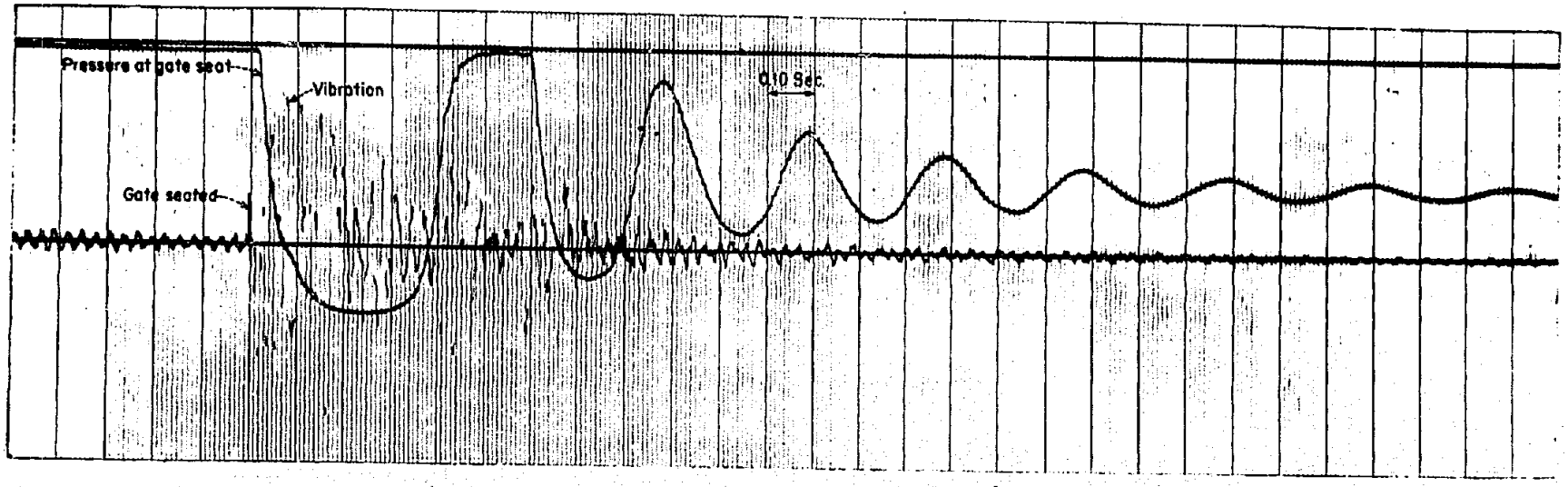


VIBRATION STUDIES OF GILA FLAP-GATE

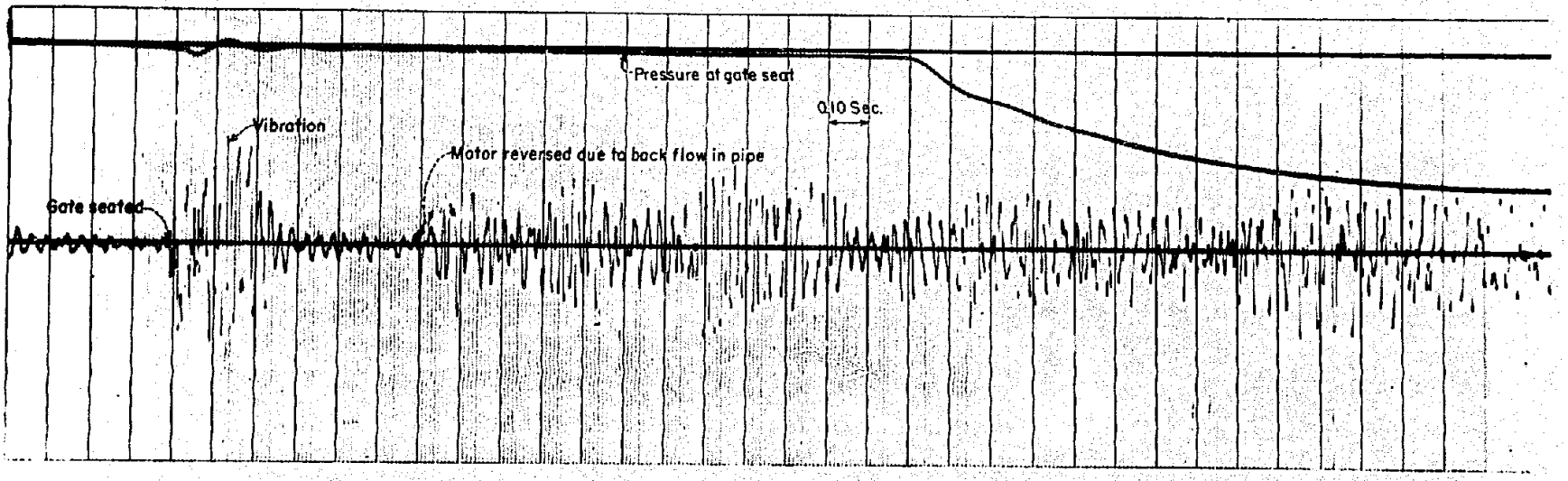
FIGURE 7



GILA PUMPING PLANT
FLAP-GATE OPENING
V.S.
CHANGE IN PUMPING HEAD



DASHPOT REMOVED AND AIR VENT CLOSED



DASHPOT AND 1.5" AIR VENT OF DESIGN 3

VIBRATION STUDIES OF GILA FLAP-GATE

FIGURE 8