Hydraulic Model Test of the Bottom Outlet of Sivand Dam

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Abstract: - This paper presents the results of hydraulic test of bottom outlet of the Sivand Dam. The aims of the hydraulic model test are, gate discharge characteristics and gate loading. Results for different gate openings are also compared with calculated values obtained by a finite element method.

Key-Words: - Hydraulic model test, Dam, Finite element method, Gate, Gate Discharge

1 Introduction

The *Sivand Dam* is located on the *Sivand River* in *Fars* province near the Shiraz city in Iran. The dam specifications are given in Table 1.

Table 1- Dam Specifications

Type	Earth fill
Height	57 m
Crest Length	600 m
Reservoir Storage	150 MCM

1.1 Bottom Outlet Roller Gates

Two sets of fixed wheel roller gates will be provided in the inlet of bottom outlet to facilitate evacuation of water through the bottom outlet system during flood season. Some technical specifications and design data of the bottom outlet are given in Table 2.

Table 2. Technical Specifications and Design Data of Bottom Outlet

Number of roller gates per set	2
Clear height of opening	4.0 m
Clear width of opening	4.0 m
Max water level	1826.5 m
Gate slot inclination (to horizontal)	60º

The bottom outlet system shall be normally used for evacuation of muddy water during flood period. Furthermore, the system will be used in exceptional cases in order to lower the water level in the reservoir for inspection or some repair work that may be required on the dam or spillway intake structure. The downstream gate shall operate as the service gate to evacuate water through bottom outlet system and operate at fully open position. The upstream gate shall operate as maintenance gate closing normally under no-flow condition and in case of emergency under full-flow condition. It is provided for closing in the case of inspection or repair works at the downstream gate. The upstream gate will also be used for closing in case when the downstream does not close. Operation of the bottom outlet system shall be possible up to a maximum head water level 1826.5 m with guaranteed discharge of 350 m^3/s. In all operating conditions, discharge of water downstream of the roller gate will be free flow inside of the tunnel.

The gates should be designed considering the influences of hydraulic conditions and cavitation and vibration in any part of the gates should be avoided. So, the following aims will be included in the hydraulic model test of the bottom outlet of the Sivand Dam,

- Gate discharge characteristics
- Gate loading and dynamic response
- Absence of detrimental vibrations
- The shape of water passages, which will not include zones of low pressure having high cavitation potential (for stop log slot, if necessary)

The hydraulic model of the bottom outlet including emergency and service gates are built to the geometrical scale 1:20.

In section II the similarity criteria and the model construction are explained. The discharge characteristic results of the hydraulic test are presented in the third section of the paper. The next section contains the hydraulic force on the service and emergency gates evaluated in the hydraulic test. Results of cavitation analysis are explained in the section IV. And finally there is conclusion in the last section of the paper.

2 Similarity Criteria and Experimental Setup

The small-scale hydraulic model will reproduce the

hydraulic phenomena of the prototype accurately, if both geometric and dynamic similarity between the prototype and its model is obtained.
The similarity of hydrodynamics is the similarity of the "dynamic loads". Based on the governing differential equation of Navier Stockes, it is concluded that in order to ensure the similarity of mean and fluctuation quantities, the Froude number "Fr" and Reynolds number "Re", and the roughness, and the boundary conditions of the model and prototype should be similar [1].
However, it is impossible to ensure the similarity of Froude number and Reynolds number simultaneously. In the engineering practice, the models are usually scaled according to Froude similarity. For Froude similarity, the fine scale structures, which are produced by viscous dissipation, are not modeled. For high Reynolds number the energy dissipated by the fine scale of turbulence (which is produced by viscous dissipation) is much less than the total energy production. Therefore, in high Reynolds number a Froudian model may accurately model the hydrodynamic loads, which are produced by large scale of turbulence [2],[3].
In the present hydraulic test procedures, the model for both emergency and service gates are constructed according to Froud similarity.

2.1 Experimental Setup

The hydraulic model of the emergency and service gates are built to the geometrical scale 1:20. The Hydraulic model consists of the upstream and downstream of the gates. The water supply is obtained from a pool with open top, and the model is directly connected to it.
Water discharge is measured using a triangular weir and a rectangular weir at the downstream of the model. By reading the elevation of water, the flow rate can be calculated [4]. The hydraulic model is made of plexi-glass so that it would ensure appropriate flow visualization. The hydraulic model of the test includes the entire water passage in both upstream and downstream of the gates (Fig. 1).

Fig. 1. Hydraulic model

The pressure of water measured in different points using conventional manometers, the plan of manometers location is given in Fig. 2.
The hydraulic tests are done at the openings 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90% and 100% of the service gate and fully open position of the emergency gate at the maximum water level 1826.5m and also at the normal water level 1813m.

3 Discharge characteristics

A sharp-crested triangular weir and a rectangular weir, accompanying with a point gauge (for reading the height of water on the weir) are used to measure the model discharge. The prototype discharge for the service gate opening 10% to 100% and fully open position of the emergency gate is shown in Fig.3.

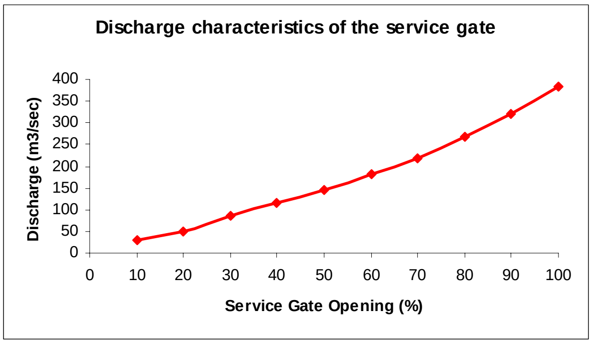


Fig.3 Prototype discharge for service gate openings 10% to 100%

The prototype discharge for the emergency gate opening 10% to 100% and fully open position of the service gate is shown in Fig.4.

4 Hydrodynamic Forces on Gates

Pressure of the water is measured at different locations on the emergency and service gates using manometers at different gate opening (Fig. 5).

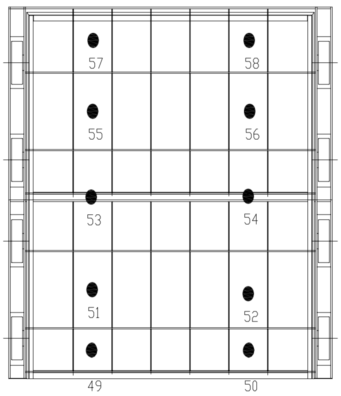


Fig. 5 Manometers location on the service gate (downstream view)

The hydrodynamic forces on service and emergency gates at different gate opening have been calculated with the aim of measured and the results are shown in Figs. 6 and 7.

5 Cavitation

A very useful index against which to correlate the occurrence, and the damage capability of cavitation, is the dimensionless parameter σ_o or cavitation number, namely:

$$\sigma_o = \frac{\left(\frac{P_i}{\gamma} + \frac{P_a}{\gamma}\right) - \frac{P_v}{\gamma}}{\frac{V_i^2}{2g}} \quad (1)$$

Where, the pressure head at reference point, P_i the atmospheric pressure head at reference point, P_v the vapor pressure head of water flow, V_i the average velocity head at reference point.

To estimate cavitation potential, the incipient cavitation numbers σ_i of the critical points can be selected. Hydraulic pressures Pi were measured on the walls and velocities of the flow V_i were measured in the undisturbed flow at centerline of the passage just downstream from the gate (all values are refereed to the prototype). As it is known the likelihood of cavitation, and the amount of damage, both increase as σ_i decreases.

The cavitation risk shall be checked for possible critical points. According to the hydraulic model observations, it seems that the critical points for cavitation for different service gate openings may be near the service gate slot. The prototype pressures at various gate opening for some manometers in the service gate slot is shown in Fig. 8.

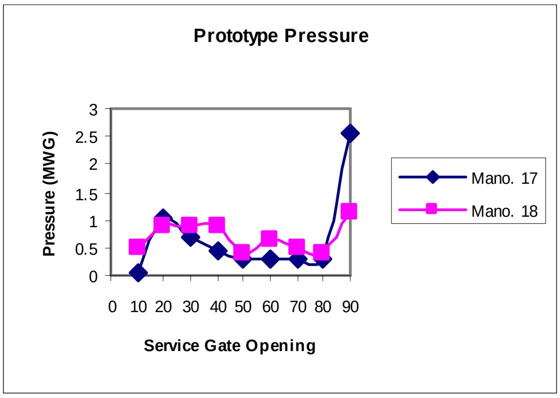


Fig. 8 Prototype pressure for manometers 17 and 18

As it could be seen in Fig. 9 these two manometers are not located in the high velocity flow region up to 60% gate opening, hence the cavitation index must be checked for gate openings higher than 60% (Fig. 10).

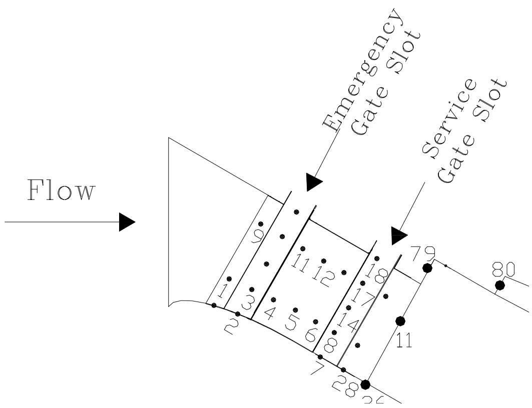


Fig. 9 Manometers locations in the service gate slot

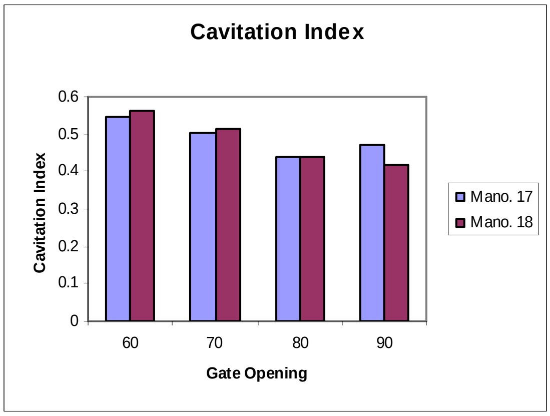
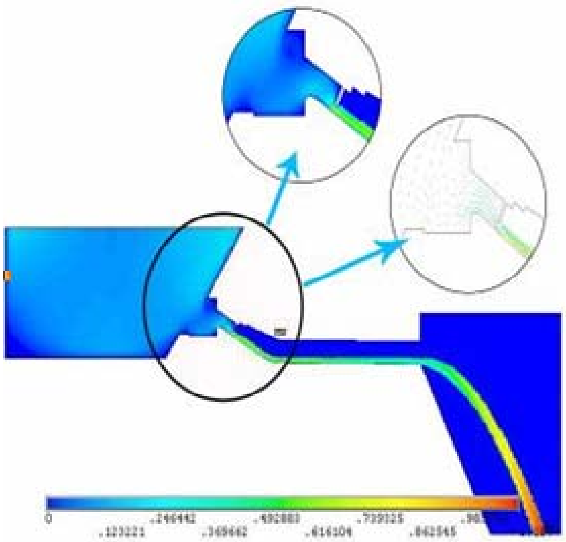


Fig. 10 Cavitation index for manometers 17 and 18 in the service gate slot

Although negative pressure is not appeared in the slot of the service gate, but it can clearly be seen form the model test that some vortices are created in the service gate slot, especially in all service gate openings less than 70%. In fact, gate slots disrupt the boundary lines and create vortices and provide the separation of the flow at the slot boundaries, which causes low-pressure zones in the vicinity of the slot.

6 Finite Element Analysis of the Problem

During the last three decades, the finite element method of analysis (FEM) has rapidly become a very popular technique for the solution of complex problems in engineering. Here the FEM is used to calculate the discharge characteristics of the bottom outlet of the Sivand dam. The finite element model of the problem for 75% and 25% gate openings are shown in Fig. 11 and 12, respectively



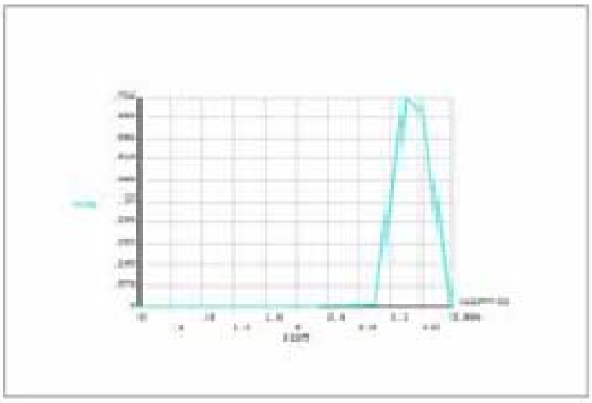


Fig. 11 Finite element model of the problem (75% gate opening)

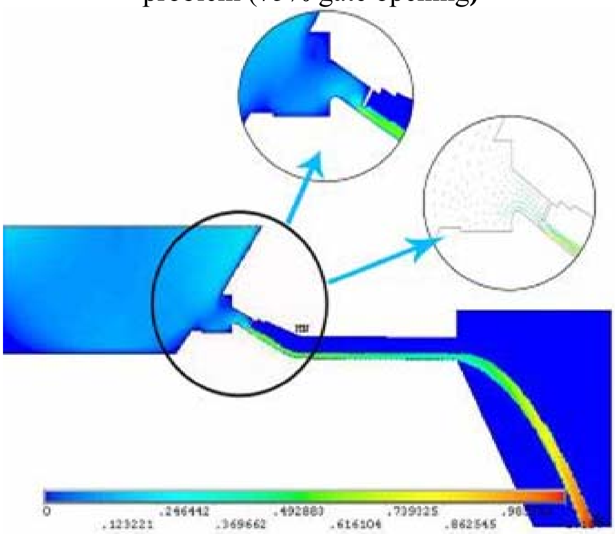


Fig. 12a Finite element model of the problem (25% gate opening)

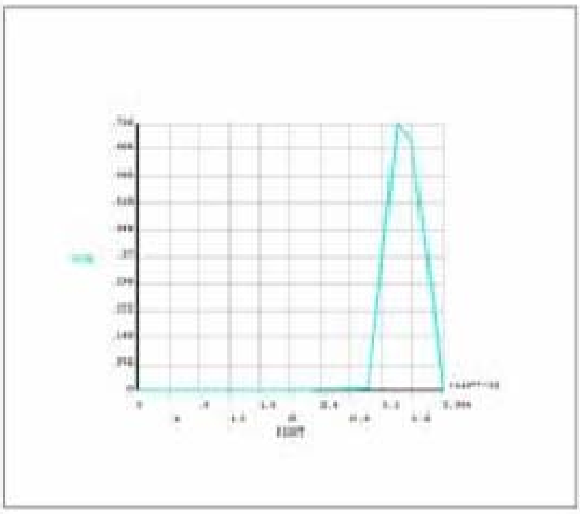
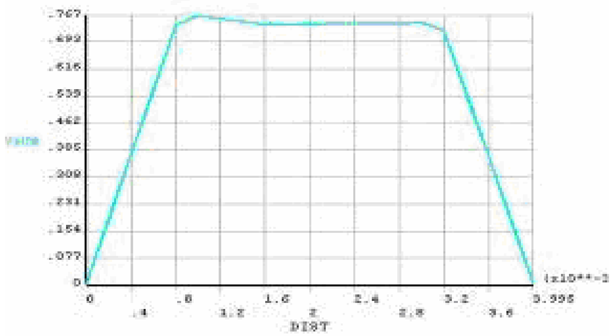
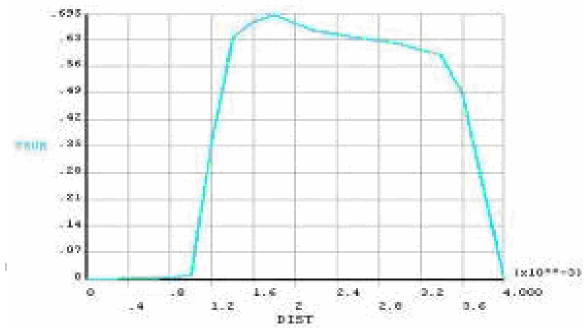


Fig. 12b Finite element model of the problem (25% gate opening)

The velocity distribution of the flowing water in the channel (before the service gate) and for different gate openings is shown in Fig. 13.



100% Opening



75% Opening

Fig. 13a Velocity distribution in different service gate openings

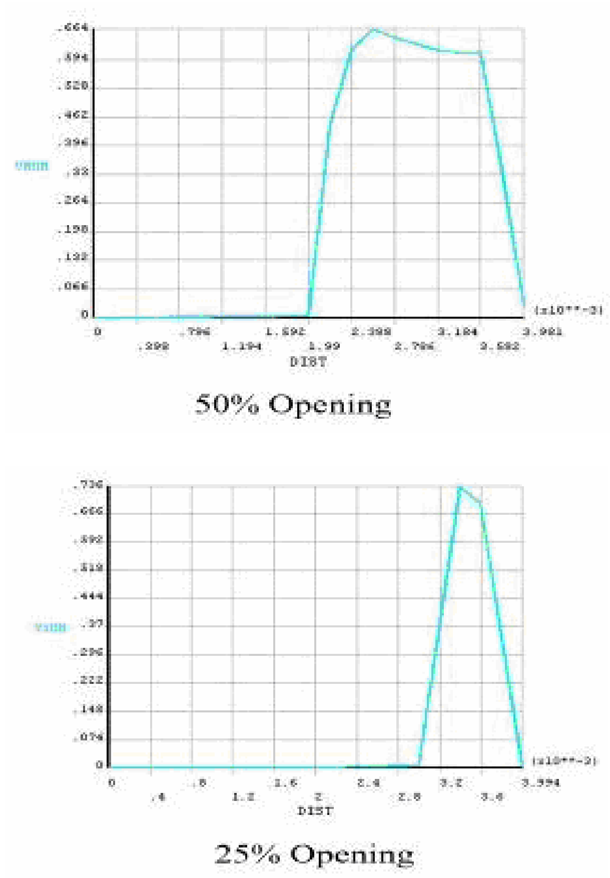


Fig. 13b Velocity distribution in different service gate openings

The values of discharge are 0.030, 0.073, 0.115 and 0.168 m^3/s for 25%, 50%, 75% and 100% service gate openings, respectively. The prototype discharge at fully opening position of the service gate is about 0.195 m^3/s.

7 Conclusion

The results of hydraulic model test of the bottom outlet of the Sivand Dam were presented in this paper. The test was held in the Hydraulic Model Center of Shiraz University. The main results of the hydraulic test which are presented in this paper are the gate discharge characteristics, gate loading the shape of water passages, which will not include zones of low pressure having high cavitation potential.

There are some important observations which are clear from the model test:

a. For the emergency gate in fully opened position and the service gate opening more than 85%-90%, severe disturbances were seen in the emergency gate slot. To overcome this problem, the model was run again after decreasing the emergency gate slot width and the results showed some light improvement in the water flowing through the slot.

b. Although no negative pressure is seen in the slot of the service gate, but it can be seen clearly form the model test that some vortices are created in the service gate slot, especially in all service gate openings less than 60%. In fact, gate slots disrupt the boundary lines and create vortices and provide the separation of the flow at the slot boundaries, which causes low-pressure zones in the vicinity of the slot.

c. To improve the design, it is recommended in some documents that the ratio Length/Span (M/B) for the fixed-wheel gates should be kept between 0.15 and 0.4. As it is shown in Figs. 14 and 15, this requirement is satisfied for the emergency gate slot (1000/4000=0.4) but is taken near the minimum-value (0.15) for the service gate slot (620/4000=0.155).
Considering this observation, increasing the service gate slot may improve the design [7, 8].

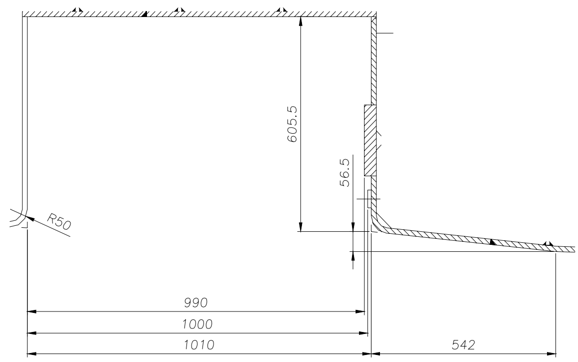


Fig. 14 Emergency gate slot in the present design

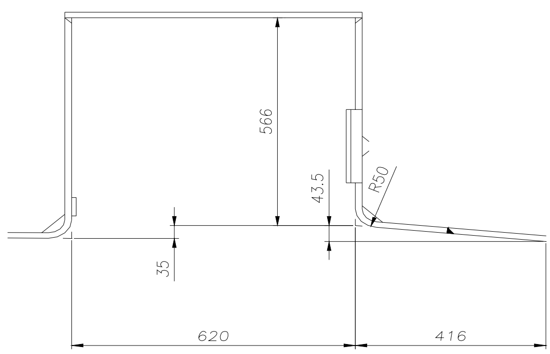


Fig. 15 Service gate slot in the present design

d. Another improvement may be obtained by considering the offset to the downstream end of the slot equivalent to 10 to 20 percent of the slot length as proposed by Sharma. For the present design, this value is 43.5 mm while it should be between (0.1*620=62 mm) to (0.2*620=124 mm) for the service gate slot [9].

e. The uplift and down-pull forces were obtained from the hydraulic model test results.

f. Unsuitable design for the shape of gate and tunnel may cause local negative pressures around the gate, which will induce cavitation damage to the gate and serious gate vibration. It can be seen from the results obtained in the model test that all of the pressures are positive and so there is no low pressure zone having high cavitation potential.

g. Some kinds of bad hydraulic conditions, such as hydraulic jump and submerged bottom seal may induce serious gate vibrations. When the vibration sources formed by bad hydraulic conditions vanish, the vibration of the gate will disappear. So the best way to prevent this type of vibrations is the elimination of the vibration sources. By observing the shape of water passages, both in the liner and under the gate, no undesirable feature is observed. We conclude that the sources of this type of vibration are eliminated well and the vibration can not be induced in the gate by these sources [10].

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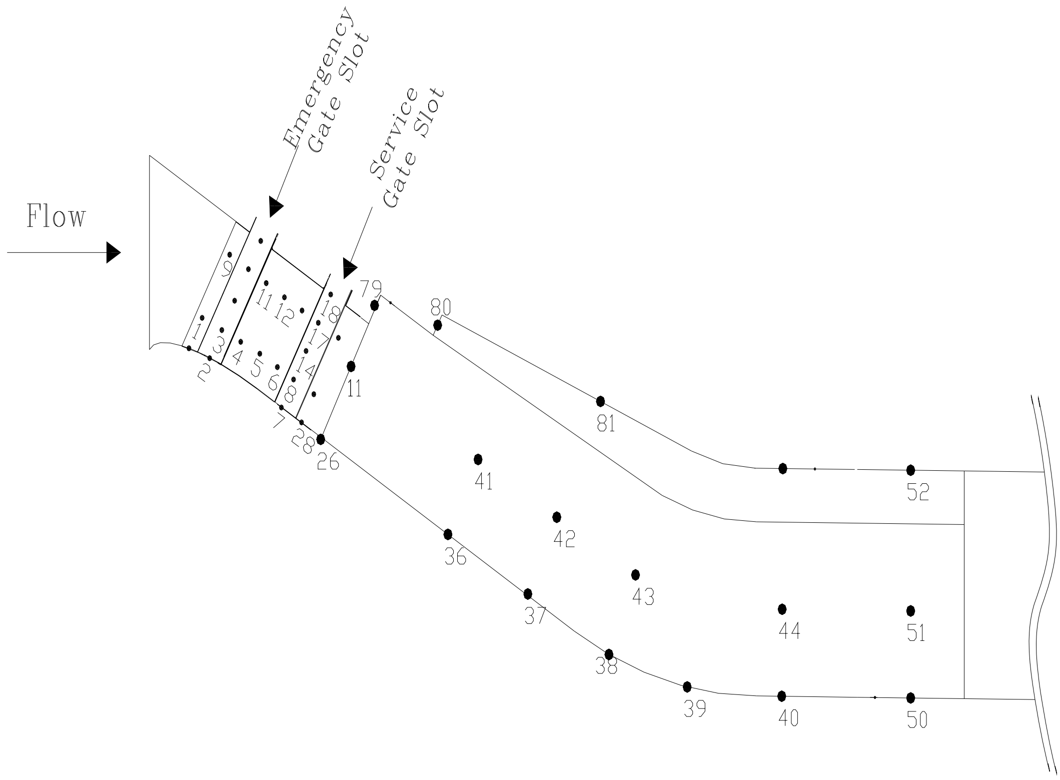

Fig. 2 Arrangement of manometers

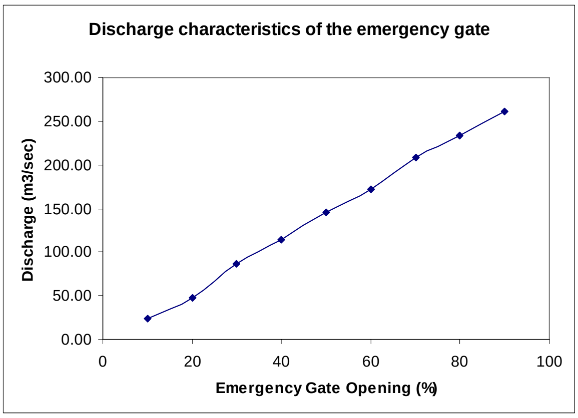

Fig. 4 Prototype discharge for emergency gate openings 10% to 100%

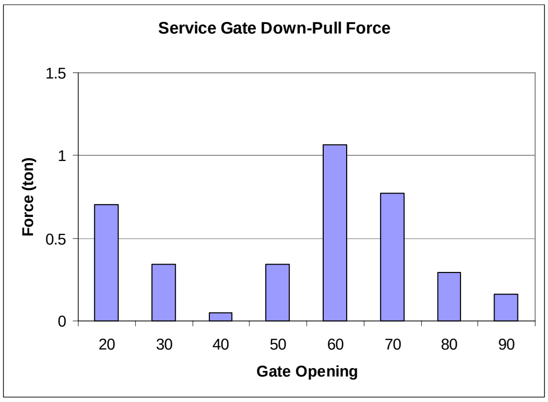

Fig. 6 Service gate down-pull force

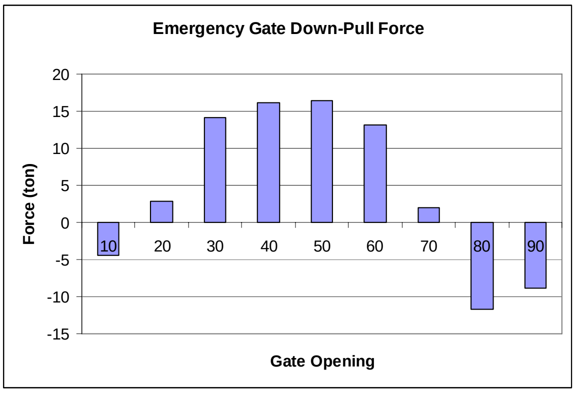

Fig. 7 Emergency gate down-pull force