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Model Studies for Improving Sewage Pump Sump Operation

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ABSTRACT

This paper describes the experimental programme on model studies of a typical sewage pump sump in Singapore and attempts to identify measures that can be taken to minimise the adverse operating problems. The model sump was constructed to a scale ratio of 1:13.123 and tests were conducted at flowrates determined by Froude scaling law. The test results conclude that with the appropriately designed baffle walls and the water in the sump maintained above certain minimum level, it is possible to avoid falling jet air entrainment and surface vortices at pump intake.

On the surface scum removal, the experimental studies of using horizontal surface jets to promote surface mixing for preventing the scum formation and jet pump to entrain and remove the floating solid suspension were carried out. Both methods were found to be effective.

INTRODUCTION

Typical sewage pump sumps built in Singapore are probably unique in design due to the land scarce problem. The narrow cross-section of the sump leads to a number of adverse operating problems such as falling jet air entrainment at pump intake, surface vortices and scum formation on sump surface. The short distance between the falling jet from the comminutor and the pump intake is the main cause for air entrainment and air entraining vortices. Entrained air can generally lead to vibration, reduction in discharge and loss in pump efficiency as reported by Denny (1956). To minimise these problems, baffle wall of suitable design is normally installed at the middle of the sump to separate the falling jet and the pump intake. The sewage water in the sump is also required to be maintained above a minimum level.

The techniques of using model testing to predict the prototype performance of hydraulic structures were reported by many workers including Zanker (1967), Tullis (1979) and Padmanabhan and Hecker (1984). In the present investigation, model studies were conducted to determine the design and position of baffle wall as well as the minimum water level in the sump.

A more severe problem in sewage pump sump operation in Singapore is the readily agglomeration and formation of scum layer on sump surface probably due to the tropical climate. The scum formation has generated unwelcome odor and other serious pollution problems which are particularly sensitive in Singapore due to the close proximity of sump location and residential area. Existing method of using mechanical mixer to stir the scum layer has proved to be prone to producing surface vortices. The present model studies show that by tapping the high pressure water from the pump discharge, surface jets and jet pump can be devised to prevent the formation of scum layer and to entrain and recirculate the floating solid suspension. Applications of jet pump in pumping slurry with dense solid particles were reported by Fish (1969) and Zandi et al (1970). However, the use of jet pump for pumping floating sewage suspension has not been reported.

MODEL CONSTRUCTION

The geometrically similar pump sump model was constructed based on an existing sump which represented a new generation of sump design in Singapore. The sump consists of two identical compartments divided by a vertical partitioning wall with a 800mm x 800mm square opening which can be closed to allow for maintainance in either compartment without interrupting the sump operation. The line diagram of the pump sump is shown in Figure 1. Only three comminutors C_1, C_2 and C_3, and four pumps P_1, P_3, P_4 and P_6 are in operation. Comminutor C_4 and pumps P_2 and P_5 are provision for future expansion.

The scale ratio of 1:13.123 was selected after consideration of operating flow rates, available sizes of pipes and fittings, cost of construction and Reynolds Number at model pump suction pipe. With the selected scale ratio, Reynolds Number calculated at model pump suction pipe for a nominal prototype flow rate of 440 ℓ/s is 23,500. This value is more than 10 times the critical Reynolds Number for pipe flow and is deemed to be satisfactory for avoiding any scaling effect when employing Froude scaling model testing as reported by Prosser (1977).

The model sump was built with wood and perspex. Perspex was chosen to form three side walls of the rectangular sump to enable the flow conditions in the sump to be observed during the investigation. Flows entering and leaving the sump were modelled as accurately as possible by associated pipes built in the model test rig. The schematic diagram of the test rig is shown in Figure 2.

MODELLING LAW

The surface flow pattern in a sump is mainly influenced by the gravity force and hence Froude scaling is employed for the simulation. If the scale ratio of prototype to model is given as S, the equal Froude Number criteria will lead to

$$V_m = V_p/\sqrt{S} \qquad (1)$$

where V_m and V_p are the velocities in model and prototype respectively. The flow rates in the model and prototype Q_m and Q_p are then given as

$$Q_m = Q_p/S^{2.5} \qquad (2)$$

Equation (2) is used to determine the corresponding flow rate for model testing.

To ensure that the effects of viscosity at the pump intake are modelled correctly, Reynolds Numbers for both prototype and model must be high. Based on the nominal flow rate of 440 ℓ/s for the prototype sump, the Reynolds Numbers based on pump suction pipes for the prototype and model are 1.12×10^6 and 2.35×10^4 respectively. These are high enough to be considered as satisfactory.

Fish, G. "The hydraulic lifting of heavy solid materials by jet pump". BHRA Report RR 1009, England, May 1969.

Padmanabham, M. and Hecker, G.E. "Scale effects in pump sump models". Journal of Hydraulic Engineering, Vol 110, No 11, Nov 1984, pp 1540-1556.

Prosser, M.J. "The hydraulic design of pump sump and intakes". BHRA and CIRIA Report, England, July 1977.

Tullis, J.P. "Modelling in design of pump pits". Journal of the Hydraulics Division, ASCE Vol 105, Sept 1979, pp 1053-1063.

Zanker, K.J. "Some hydraulic modelling techniques". Paper 8, Vol 182 pt 3M, Proceedings of the Institution of Mechanical Engineers 1967, pp 54-63.

Zandi, I and Govatos, G. "Jet pump in slurry transport" First International Conference on the Hydraulic Transport of Solids in Pipes, BHRA, England, Sept 1970.

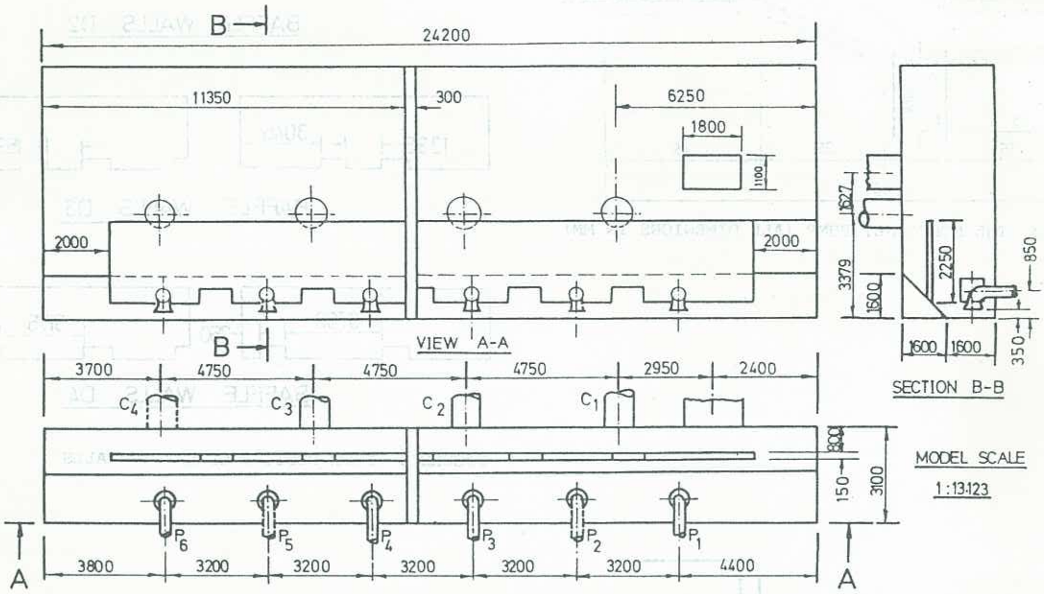


FIG 1 CORPORATION ROAD PUMPING STATION PUMP SUMP

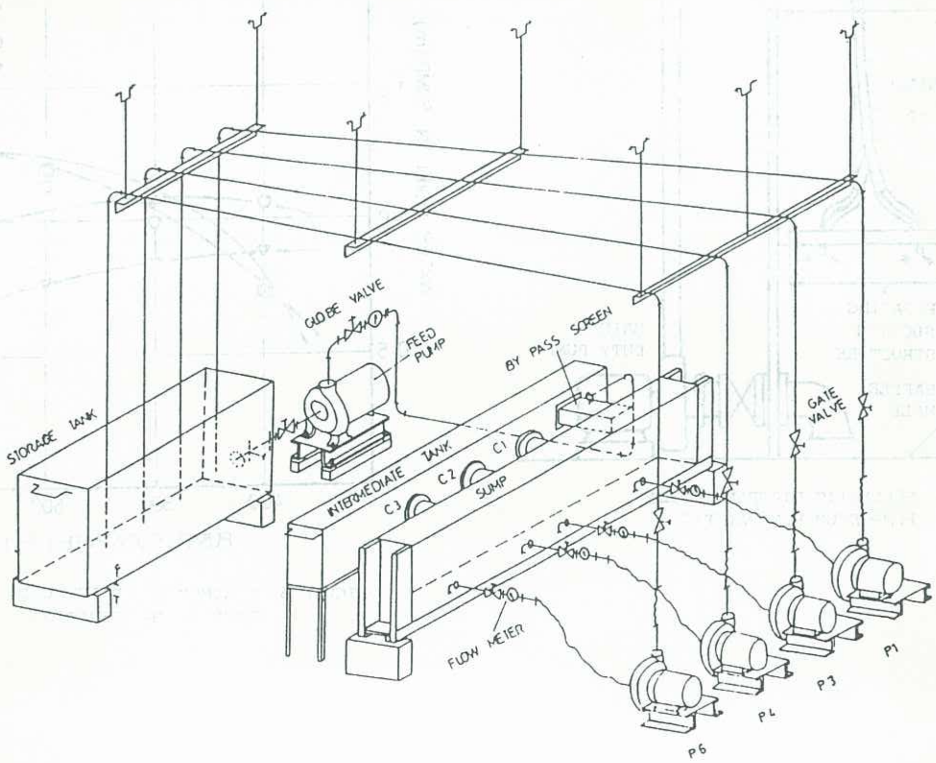


FIGURE 2 THE MODEL TEST RIG

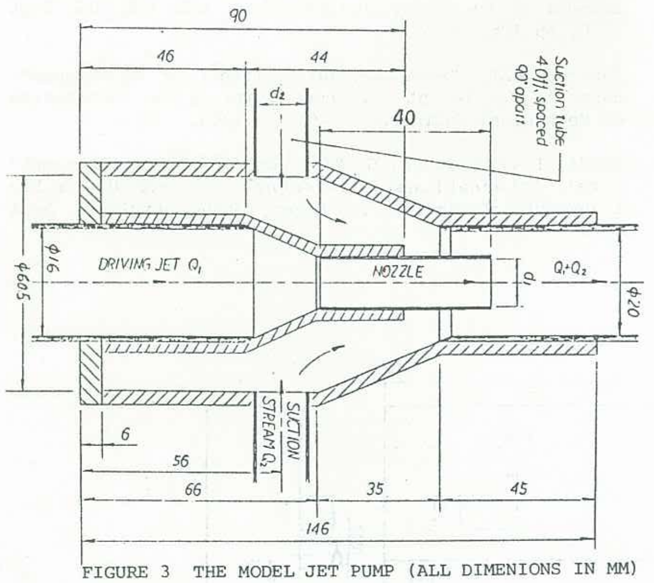


FIGURE 3 THE MODEL JET PUMP (ALL DIMENIONS IN MM)

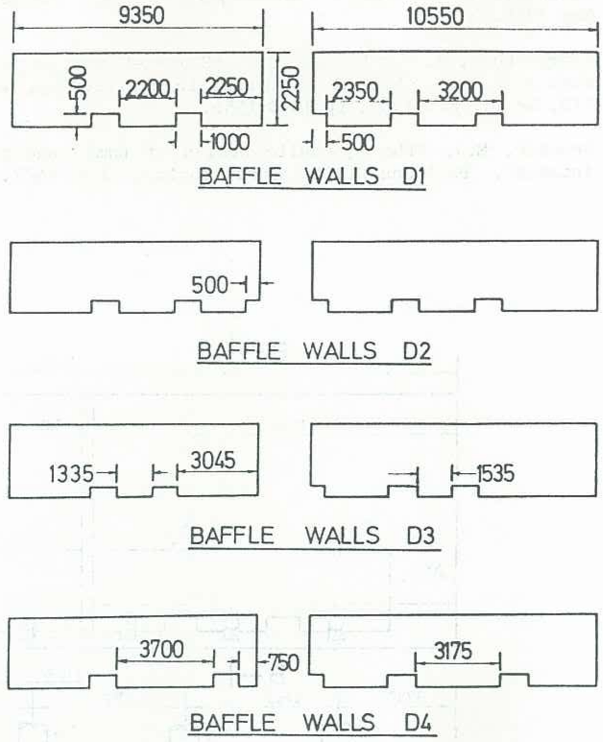


FIGURE 5 FOUR DESIGNS OF BAFFLE WALLS

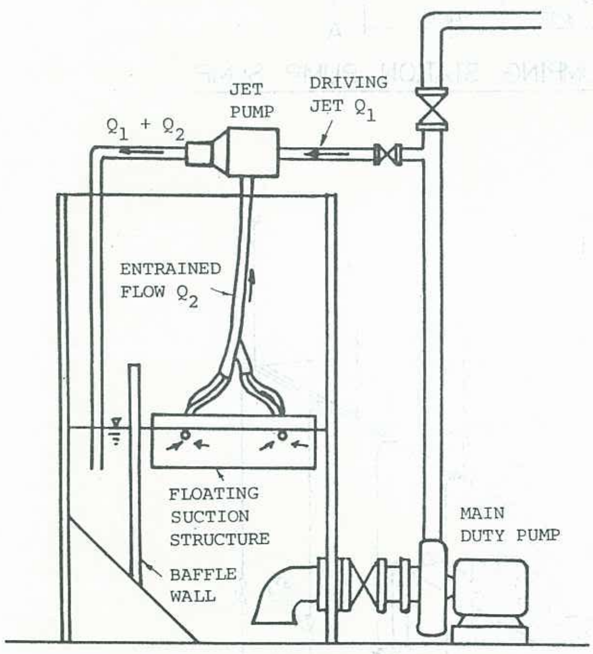


FIGURE 4 SCHEMATIC DIAGRAM OF JET PUMP SCUM REMOVAL RIG

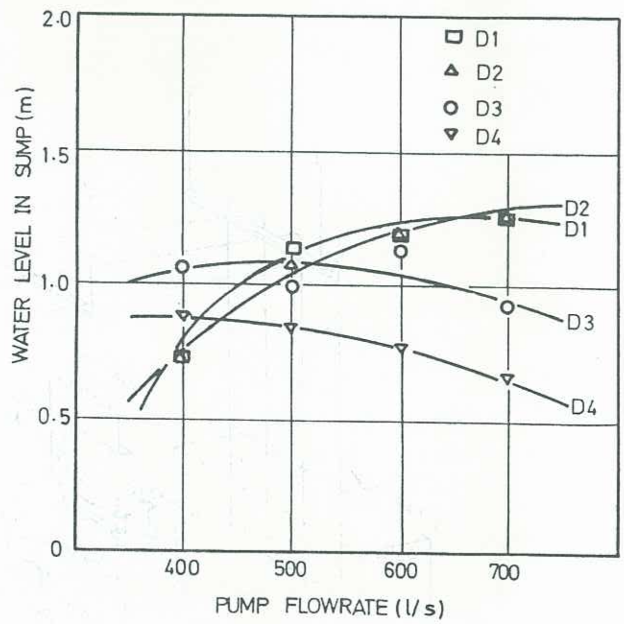


FIGURE 6 MINIMUM WATER LEVEL IN SUMP WITH PUMP P_1 IN OPERATION

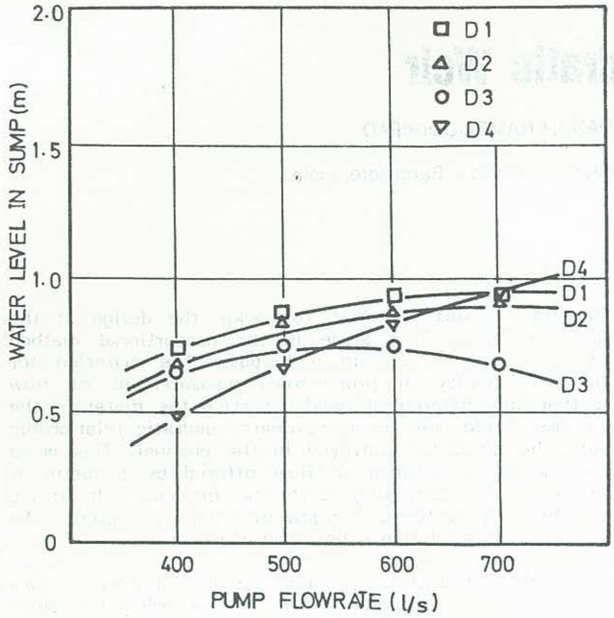


FIGURE 7 MINIMUM WATER LEVEL IN SUMP WITH PUMP P_3 IN OPERATION

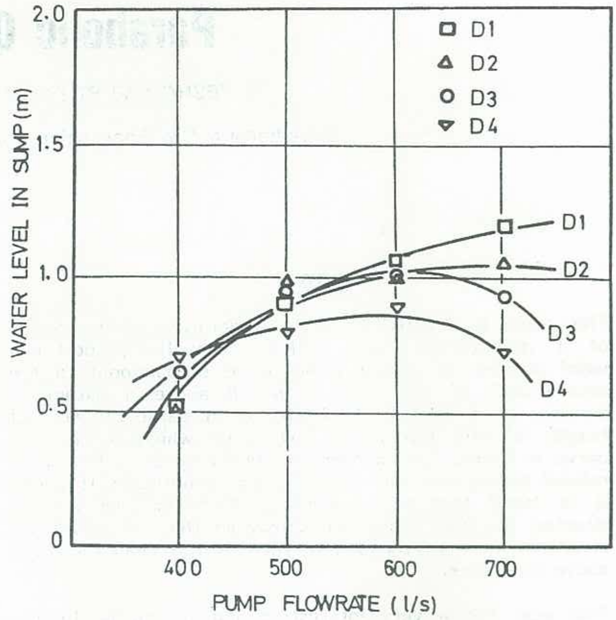


FIGURE 9 MINIMUM WATER LEVEL IN SUMP WITH PUMP P_6 IN OPERATION

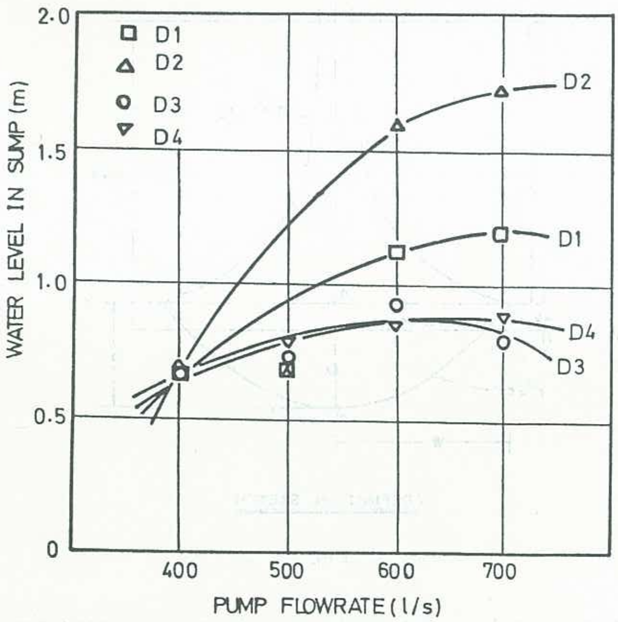
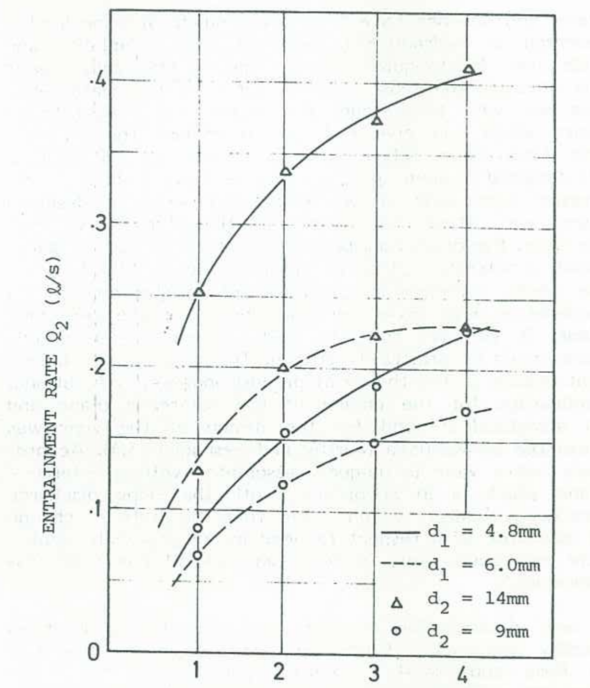


FIGURE 8 MINIMUM WATER LEVEL IN SUMP WITH PUMP P_4 IN OPERATION



NUMBER OF SUCTION TUBES

FIGURE 10 ENTRAINMENT RATE OF JET PUMP FOR A PRIMARY FLOW OF 0.32 ℓ/s