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Model Pump Sump Testing

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ABSTRACT

The basic problems associated with intakes of large pumps and the techniques and procedures followed in physical modelling to ensure the specified performance are discussed.

Case histories are presented illustrating the shortcomings of some existing plants and preliminary designs and the corrective measure adopted.

1. PHYSICAL HYDRAULIC MODELS AS DESIGN TOOLS

This paper deals specifically with large pumping stations having a number of low head/high discharge units and complex inflow conditions. The need for hydraulic model tests under these circumstances can not be disputed. The cost savings achieved by minimising concrete dimensions and eliminating costly alterations after construction more than offset the cost of the model study. In addition, no analytical method could take into account the variety of flow conditions, unusual geometries, and operational conditions encountered in practice.

Modern, large hydraulic machines are less robust and less conservatively designed than earlier makes. They are more sensitive to hydraulic and mechanical loading and, because of reduced natural frequencies, they are more ready to respond to cyclic excitation occurring within the system.

Surface vortices may promote air passing through the machine in the form of large slugs, leading to impeller vibration. Subsurface vortices could also cause machine instability because the reduced pressure in the vortex core generates fluctuating load on the impeller. Local pressure, lower than the vapour limit, may also occur along the impeller blade, resulting in cavitation. The associated operational problems are: rough running, performance outside rated values, impeller and casing damage, and early bearing failure.

In our model studies the surface and subsurface vortices were systematically observed using various visualisation techniques. Model boundaries were changed until the tendency for any vortex to occur in a regular, organised form, with a coherent core extending near the pump intake, was eliminated.

Pre-rotation is another detrimental effect on pump performance. Impeller vanes are designed to give optimum performance with axial approach flow, however as is the case with complex entry conditions and multiple units there is always a swirl in the forebay. In the swirl an additional tangential component influences the predominant, axial velocity vector, and the angle of attack of flow on the pump vane is altered from the optimum. 'Pre-rotation' specifically refers to the cross-sectional average swirl on the suction intake of the pump and the 'pre-rotation angle' is the measurement of the strength of the tangential velocity component in relation to the axial component. The consequences of pre-rotation on pump performance are: change in head/discharge relationship, altered impeller speed, varied pressure distribution around the impeller vane, and change in power requirement. If more than one unit is operating in series, periodic reversal of rotation could cause system instability.

In models the pre-rotation is measured with a rotometer which is a freely turning propeller with four blades of zero pitch, mounted axially in 90° symmetry. The number of revolutions (in either direction) in a set time period is recorded together with the average axial flow velocity in the intake pipe. The data is then expressed as the average pre-rotation angle of flow. Since the swirl decays due to energy loss caused by pipe friction, turbulence, and fluid shear, the rotometer should be placed at the cross-section of the impeller, or near to it.

The maximum permissible degree of pre-rotation is dependent on the type of pump and the closeness of the actual operating range to the Design Net Positive Suction Head. Its selection is usually subject to engineering judgement, varying from case to case.

In order to achieve the predicted head, discharge, and efficiency values, with reasonable tolerance, and to avoid vibration, rough running, cavitation, motor overload and system instability, in the cases described in this paper, the pre-rotation at the impeller was restricted to 3°. (In some rare operating modes it was relaxed to 5°). This criterion is supported by past experience and by case histories from the international technical press.

The measurement of approach velocity distribution using miniature current meters, (as recommended by some authors) was found to be tedious and difficult to interpret due to the three dimensional and continuously changing nature of the flow pattern. The corrective measures made to satisfy the pre-rotation criterion, however, automatically led to improved symmetry in velocity distribution. It is not disputed that the ideal condition is to have simple and straight stream flow with constant low velocity in the sump.

2. SCALE EFFECTS

The concept of dynamic similarity proposes that model and prototype systems, built with geometrically similar boundaries have similar flow patterns at corresponding time instants. The conditions for complete similitude however, can rarely be achieved. Gravitational force, inertial force, viscous force, pressure force, surface tension force, Coriolis force, etc. can not be balanced perfectly in the two systems. The generally adopted compromise is to select the predominant force and design the model using the corresponding modelling law.

The flow phenomena in pump intake models are controlled by gravitational and inertial forces, hence Froude similitude is generally used. Vortices on the other hand are generated by differential shear and viscous forces requiring that the tests be based on Reynold's law. A further complication is that air entrainment through vortexing is also influenced by surface tension forces, expressed by the Weber Number.

To overcome these problems our model scale was restricted to not smaller than 1:10 thus a prototype Reynold's No. of 10^6 corresponded to 3×10^4 in a Froude model. Thus operating well inside the fully turbulent zone only negligible distortion due to viscous effects was expected.

Regarding air entrainment, since only the formation of surface dimples was allowed in the model the Weber Number effects were compensated for.

As it is expected that vortices in the prototype will be larger, more vigorous, and more frequent than in the model, scale effects tests were conducted at higher than Froude scale flows, as recommended by a number of researchers. It was found that above a flow rate of 1.5 times the Froude flow, wave formation and gross flow distortion made conditions unrealistic and difficult to interpret.

3. THE USEFULNESS AND COST OF HYDRAULIC MODELS

In the case of large pumping stations, published design guides can only provide the first, rough layout, therefore designers usually welcome model testing because it removes the accountability for the correctness of hydraulic details from their shoulders. Tests are also useful in that pump manufacturers can not blame approach and entry conditions for unsatisfactory performance of the hydro-machinery should it occur.

Figures dissected from the case histories presented in this article indicate that to build and test a 1:10 scale model in the Sydney Water Board's Hydraulic Laboratory costs about $45,000 (or around 3-4% of the design cost) and takes about eight to twelve weeks to complete.

4. CASE STUDIES

4.1 Bondi Outfall Pumping Station - This station to be constructed at Bondi Water Pollution Control Plant (WPCP) is required to drive the proposed submarine ocean outfall. At the ultimate stage the station will house four (one standby) 1200mm dia.vertical mixed flow pumps (Fig. 1). The pumps will be driven by 1100 kW motors and each has a capacity of $4.2 m^3/s$. The suction chamber size for each pair of pumps is 10 m long x 7.5 m wide x 7.5 m deep. Four possible sump inlets meant that 40 inflow/pump combinations had to be considered.

Model tests of the initial design indicated pre-rotation angles averaging 10° - 12°, strong vortex action under certain flow conditions and excessive air entrainment due to the high level entry of the bypass channel. Acceptable performance was achieved with the introduction of back wall and floor splitters (triangular cross section) for each pump, a surface beam in the sump forebay and a drop inlet structure to dissipate energy at the bypass channel entry.

4.2 Malabar Outfall Pumping Station - A station will be necessary to discharge future wet weather flows from Malabar WPCP through the proposed outfall system. Preliminary design provides for two vertical mixed flow pumps each capable of discharging flows between $12 m^3/s$ and $18 m^3/s$. Pumps 2100 mm dia. driven by 2200 kW motors are envisaged. The suction chamber to be constructed as future requirements dictate, has a base 15 m x 15 m and a depth of 9 m (Fig.2).

Model studies investigated the suitability of the proposed station inlet and outlet connections as well as the hydraulic performance of the sump. Air entrainment due to the high level inlet was overcome by raising the minimum operating level and with the introduction of a bubble deflecting beam across the roof at the entrance to the suction chamber. Pre-rotation control was achieved by partitioning each pump unit and providing a full plate flow splitter behind each pump column. A reduction in pre-rotation angles in excess of 10° to less than 5° resulted.

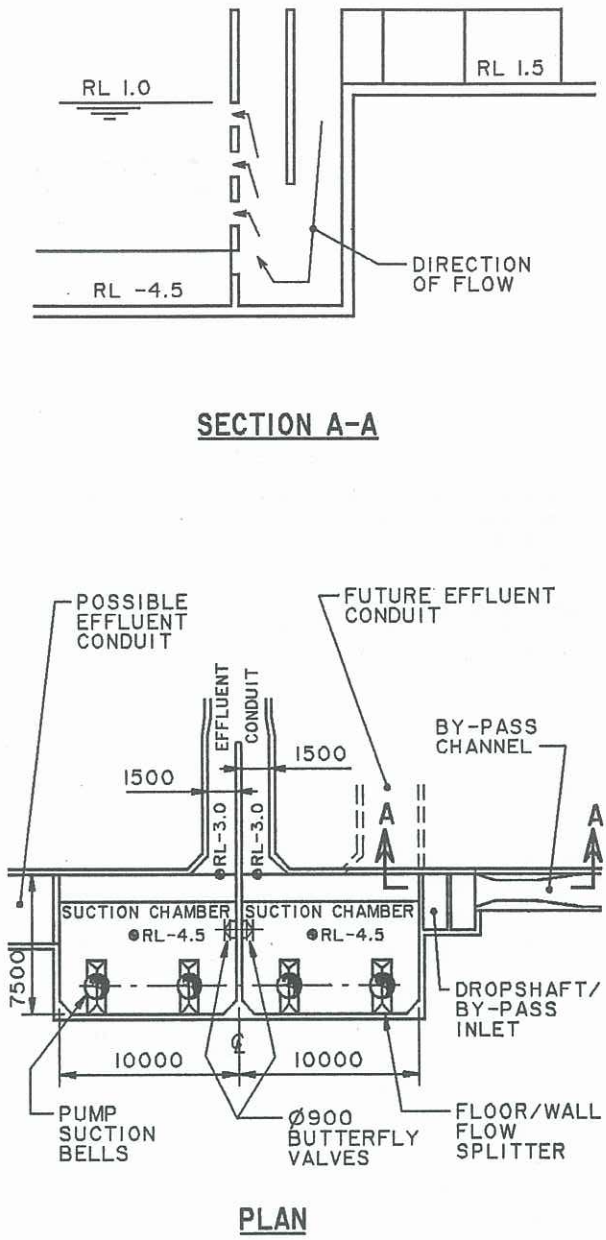

FIG.1 BONDI GENERAL ARRANGEMENT

4.3 North Head WPCP Pumping Station - North Head Pumping Station is required to elevate effluent entering the plant to treatment process equipment located at higher levels prior to transfer to the ocean disposal system. Four (one standby) vertical spindle centrifugal pumps have been installed each with a capacity of $4.2 m^3/s$ and a power rating of 2600 kW. Each pump draws effluent from its own sump 1.8 m x 2.5 m x 8.6 m deep all located off a main inlet channel.

Since commissioning, operational problems have been experienced. During single pump operation, pumps cut out on suction safety due to insufficient flow to the sumps and a wave phenomenon develops in the main channel feeding the sumps during multi-unit operation, causing machine hunting. The Laboratory is currently fabricating a 1:10 scale model in an attempt to overcome these problems. It is anticipated that further project developments will be presented at the conference.

4.4 Liverpool WPCP Pumping Station - This station is to be constructed to enable the transfer of effluent to the Malabar ocean outfall system.

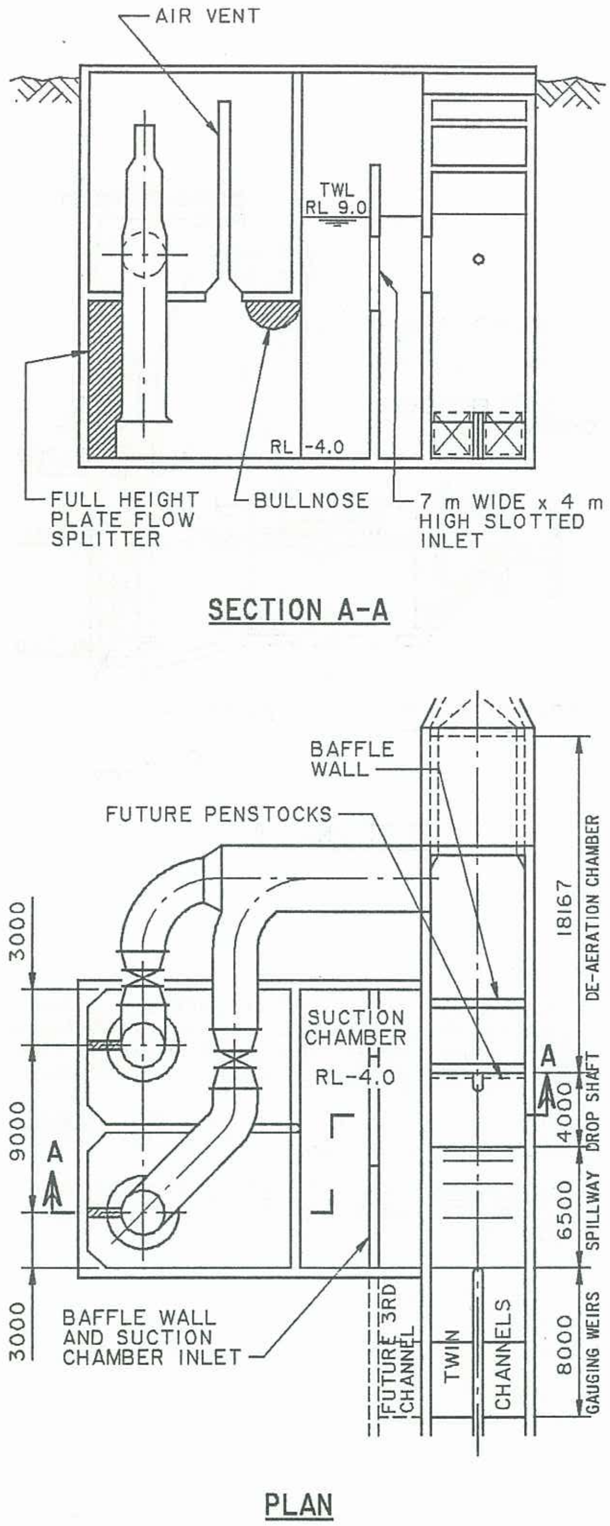

FIG. 2 - MALABAR GENERAL ARRANGEMENT

Four vertical 'squirrel cage' type pumps, each with a power output of 424 kW, will discharge an ultimate flow of 4.3 m³/s operating in parallel. The pumps will be located in a caisson style sump 12 m dia. x 9 m deep (Fig. 3).

Hydraulic assessment of the proposed sump arrangement using a 1:7.5 scale model indicated higher pre-rotation angles than was acceptable. Modifications included: the relocation of each unit into its own rectangular bay, increasing the opening size through the inlet baffle and the location beneath each bell-mouth of a cone and blade type flow splitter. These measures reduced pre-rotation angles to less than 3°, still retaining reasonable construction economy.

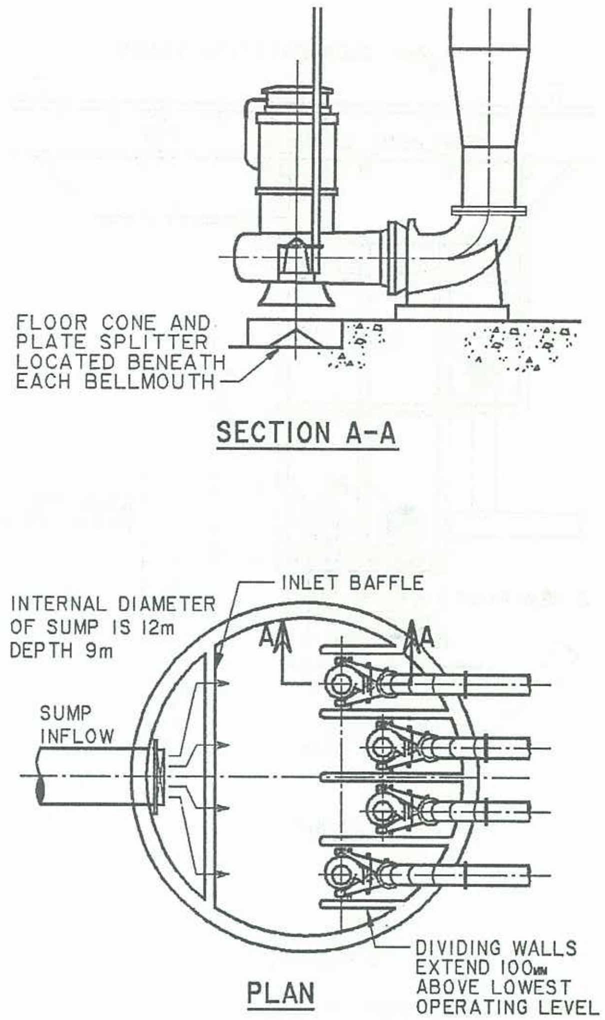

FIG. 3 - LIVERPOOL GENERAL ARRANGEMENT

4.5 Cronulla WPCP Pumping Station Amplification - The amplification will eliminate the incidence of overflow and satisfy future wet weather requirements. Amplification will involve the installation of 2 large variable speed units and the removal of one of the smaller existing units (one to be retained as a standby). The pumps will boost the present gravitational capacity of existing effluent mains from 2.5 m^3/s to 5.5 m^3/s. The new variable speed pumps will each have a maximum discharge of 3.5 m^3/s with a power output of 545 kW. The existing sump facilities are to be retained with some modifications. Each pump will be located within adjoining bays, the bays for the new pumps to be lengthened from 6.7 m to 12 m (Fig. 4).

A 1:8.75 scale model of the proposed design revealed poor hydraulic conditions. At the lower operational levels high pre-rotation, extreme vortex action and air entrainment caused concern. The raising of the pump cut-out levels overcame the latter two problems. Installing an 'L' shaped wall/floor fin with a suitably sized cone beneath the bellmouth of the new units reduced pre-rotation angles to below 3° for most flow configurations.

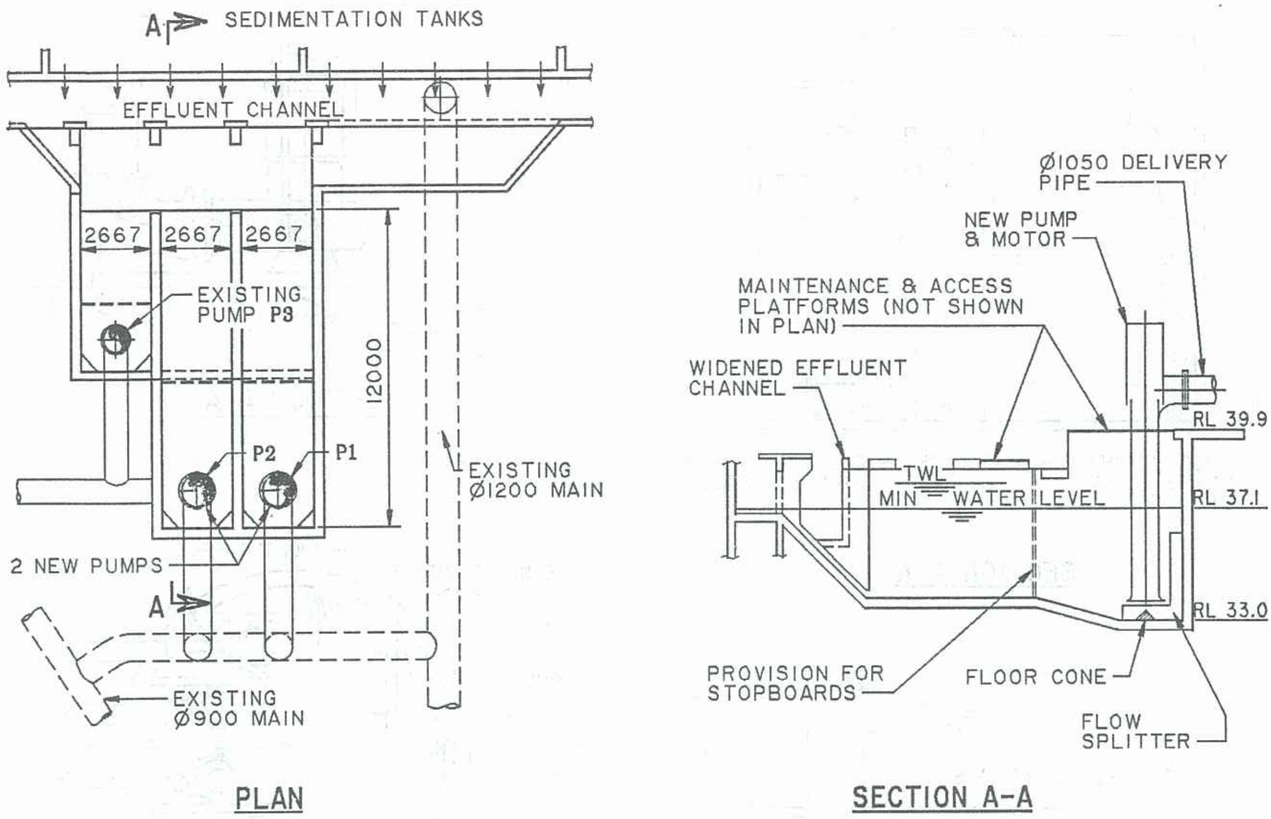

FIG. 4 - CRONULLA GENERAL ARRANGEMENT

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