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Selection of Appropriate Instrumentation Based On Physical Hydraulic Model Condition

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Abstract: The typical hydraulic parameters to be measured in physical hydraulic model studies are water levels, flow speed, direction of flow, salinity or turbidity, temperature, turbulence, wave height and discharge. Specialized and appropriate types of sensors are required for the accurate measurements of these parameters based on physical model conditions. Physical models consist of thermal model, dam and spillway model, river model, coastal and offshore model and hydo-mechanical models. The conditionality's of various physical models differ in size, variable discharge levels, quality of water and geophysical layout of models. Careful selection of appropriate sensor is significant for measurement of a particular hydraulic parameter even in diverse and variable conditions of physical models. This research paper highlights the selection of proper sensors and supporting instrumentation as per physical model conditions.

Index Terms: **Hydraulic Parameters, Instrumentation, Model Condition, Sensor.**

I. INTRODUCTION

Physical hydraulic model studies require measurement of various hydraulic parameters. These parameters are water levels, flow speed, direction, salinity, temperature, turbulence, density and discharge. Accurate measurements of these parameters require appropriate instrumentation for applied hydraulic research. Physical model technology is a vital aspect of applied hydraulic research. Physical model technology depends on the geometrical similarity or scale ratio in case of distorted models. Geometrical similar models are constructed for the studies pertaining to waves in Coastal Engineering and sectional or composite models for dams and spillways. Sufficient space requirement is an essential part of physical models. When the horizontal scales differ from vertical scales, these models are termed as distorted models. Generally horizontal scales are larger than vertical scales. Theoretically horizontal to vertical ratio should not be exceeded by five (Heller, V. (2011))[1]. If it exceeds, then scale effects are encountered in the model. Different types of model layout require different flow characteristics. In case of thermal and nuclear power plant model, water is withdrawn from the source for cooling of the plant. Hot water is discharged at a significantly distant location so that the recirculation system of the plant will cool the water to the required temperature as per prescribed guidelines of Environment and Pollution Control Board. All these physical hydraulic models require appropriate and specialized instrumentation for the measurement of various hydraulic parameters as per the requirements of physical hydraulic model studies. This article highlights the selection of proper sensors and supporting instrumentation for the physical hydraulic model studies.

II. ROLE OF SENSORS

The sensors or transducers play a significant role in measuring vital hydraulic parameters for physical hydraulic model studies. Some popular sensors used for the flow characteristics are :

- Water surface follower and Guided wave radar type sensors for the measurement of variation of water level.
- Current meter and Anemometer for measurement of flow velocity.
- Platinum Temperature Resistor (PTR) and Thermistor for measurement of temperature gradient for cooling pond studies of thermal and nuclear power plants.

These hydraulic parameters are used for the sustainable development of ports, coastal structure, approach channel, turning basins, port basins, tranquility studies, alignment of breakwater, and construction of structure in the river reach for Coastal Engineering studies. River training works to improve discharge capability or to reduce the porosity in the river segment; design of gate operating system over a spillway or dam, turbine efficiency on hydroelectric power plant are carried out for River Engineering studies. Schematic Diagram of Sensors is shown in figure 1.

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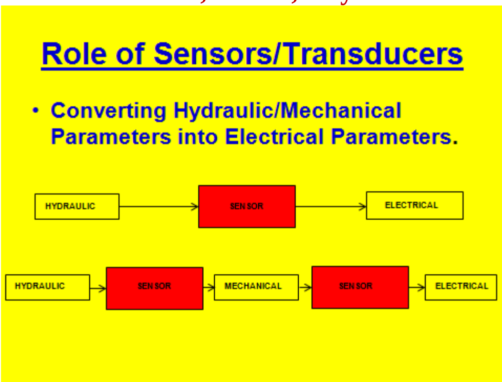

Fig.1: Schematic Diagram of Sensors

III. PHYSICAL MODEL CONDITIONS

Physical models are the miniature of prototypes. The model consists of flow characteristics same as the proto but to the scale. Mechanisms to construct the models are based on following non dimensional numbers. These numbers are :

A) Froude Criterion:

A parameter expresses the relative influence of inertial and gravity forces in hydraulic flow is given by the square root of the inertial to gravity forces.

$$\sqrt{\frac{Inertial\ Force}{Gravity\ force}} = \sqrt{\frac{\rho L^2 V^2}{\rho L^3 g}} = \frac{V}{\sqrt{gL}} \qquad 1.1$$

This is known as the Froude number. A physical interpretation of the Froude number is that it gives a relative importance to inertial forces active on the fluid particles to the weight of particles (Munson, et al. 1990)[2].

The Froude number must be same in the model as it is in the prototype

$$\left(\frac{V}{\sqrt{gL}}\right)_p = \left(\frac{V}{\sqrt{gL}}\right)_m \qquad 1.2$$

Leads to

$$\frac{(V)_p}{(V)_m} = \sqrt{\left(\frac{g_p}{g_m}\right)\left(\frac{L_p}{L_m}\right)} \qquad 1.3$$

Expressing in the terms of scale ratio and rearranging gives

$$\frac{N_u}{\sqrt{N_g N_g}} = 1\ or\ N_{Fr} = 1 \qquad 1.4$$

Equation 1.4 is the Froude Model criteria for modeling flows in which the inertial forces are balanced primarily by the gravitational forces which happens to the most flows with free surface flow. The majority of hydraulic models in the coastal engineering are scaled according to Froude Model Law; consequently it is usually the most important criteria to be considered when designing the coastal model. Other model laws are less relevant to the current study.

B) Reynolds Criterion:

When viscous forces dominates in a hydraulic flow the important parameter is the ratio of inertial to viscous forces given by

$$\frac{Inertial\ force}{Viscous\ force} = \frac{\rho L^2 V^2}{\mu V L} = \frac{\rho L V}{\mu} \qquad 1.5$$

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and is called the Reynolds number.

C) Webber Criterion:

The relative effect of surface tension is given by the ratio of inertia to the surface tension i.e. Inertial force divided by surfaces tension forces

$$\frac{\text{Inertial force}}{\text{Surface tension force}} = \frac{\rho L^2 V^2}{\mu V L} \qquad 1.6$$

This is known as Webber number. Surface tension may become significant if there is an interface between two fluids and the surface tension forces on a fluid particle is most important in the comparison to inertial forces being applied to the particle.

D) Cauchy Criterion:

An index of the relative importance of inertial forces to the compressive forces is given by the ratio of inertial to elastic force is:

$$\frac{\text{Inertial force}}{\text{Elastic force}} = \frac{\rho L^2 V^2}{E L^2} = \frac{\rho V^2}{E} \qquad 1.7$$

Which is known as Cauchy number. The number is important in studies where the inertial forces are large enough to cause changes in the fluid compressibility.

E) Euler Criterion:

Although pressure is usually taken as the dependent force in equation 1.1, it is possible to have situation in which pressure forces are the dominant force acting on the flow. Thus, the Euler number gives an indication of relative importance of pressure and inertia i.e.

$$\frac{\text{Pressure Force}}{\text{Inertial force}} = \frac{PL^2}{\rho L^2 V^2} = \frac{P}{\rho V^2} \qquad 1.8$$

Physical models are based on at least any one of the above cited dimensionless numbers or combinations thereto. In general for free surface hydraulic models Froude number is adopted. Reynolds numbers is accommodated when viscous force is dominated while Webber number in case of surface tension. The Cauchy number dominates when inertial force is in active mode. The Euler number is applicable to the turbines or any pressure body hydraulic models as under:

i) Coastal Engineering Models:

The physical models adopted for Coastal Engineering are wave models and tidal models. The wave models are in general undistorted models except objective specific. Distortion in the scale is observed in the tidal models i.e. horizontal scale differ from vertical scale Valentine Heller[1] (2011). The measurement of velocity profile is shown in figure 2.

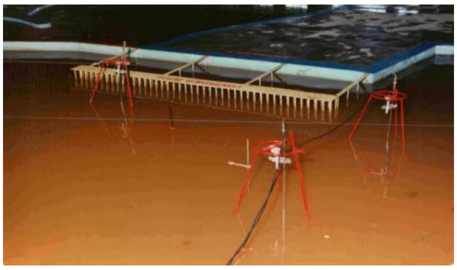

Fig. 2: Measurement of Tidal Velocity Profile on Coastal Model

Figure 3 shows the six channel salinity measurement sensor and display which was used in Bechme dam, Iraq.

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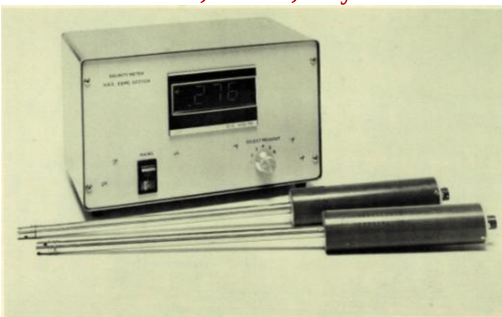

Fig.3: Six Channel Salinity Measurement Sensor with Display

Figure 4 shows the propeller type velocity sensor used for salinity greater than 35 ppt.

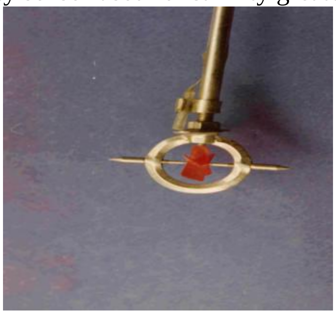

Fig. 4: Propeller Type Velocity Sensor Used For Salinity Greater Than 35 Ppt

ii) River Engineering Models:

River engineering models are generally distorted models. The flow characteristics are simulated similar to prototype by providing scale ratio. River engineering model studies refer to various type of structures, abetments, embankments, spurs and other river training measures. Sediment transport in alluvial channels are also studied which is caused by Coriolosis effect[2]. Measurements of water velocity and discharge on river model is shown in figure 5.

Fig. 5: Measurements of Water Velocity and Discharge on River Model.

The water level measurements can be of two types. Steady water level variation and transient water level variation. If the water level variation is less than 8mm/second, it is steady type and if the water level variation is more than 8mm/second, it is transient type. In case of steady type water level variation, WSF (Water Surface Follower) type telescopic sensors are used and for transient type water level variation, GWR (Guided Wave Rider) type water level sensors are used. WSF type sensor is shown in figure 6 whereas figure 7 shows GWR type sensor used in dams and spillway model.

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Fig. 6: WSF Type Sensor Used In Steady Type Water Level Model

iii) Dams and Spillway Models:

High head structures such as dams and spillway are carried out for two types of studies one is hydraulic and the other is structural. The hydraulic studies cover gradually or rapidly varied flow, energy dissipation, hydraulic jump and effects of eddies or turbulence. The structural health studies cover cracks in dam and peripherals.

Fig. 7: GWR Type Sensor Used In Transient Type Water Level Model

iv) Thermal and Nuclear Models:

Model studies are carried out for the thermal gradients over the vertical for cooling ponds and recirculation of water system with an objective to cool the plant at appropriate desirable temperature. Thermal and nuclear wastes along with temperature gradient are required to be monitored in the water recirculation system so that environment guidelines are strictly followed.

v) Hydro-mechanic Models:

Physical models of hydroelectric power plants are constructed and studied for measuring the parameters of hydro-mechanic equipments like pumps and turbines. The overall efficiency of the hydroelectric power plant depends mainly on the individual efficiencies of the various pumps, turbines and other hydro-mechanical equipments used in the system. Measurement of efficiency of hydro-mechanical equipments require proper and accurate instrumentation.

IV. SELECTION OF SENSORS BASED ON MODEL LAYOUT

Sensors and Instrumentation play a significant role for measurement of various hydraulic parameters for physical hydraulic model studies. The valuable hydraulic parameters to be measured are mainly water level, velocity, current, salinity, temperature and wave height, Measurements of these hydraulic parameters require specialized and accurate sensors and instrumentation. Water level measurements in river engineering models where the variation of water level is less than 8mm/sec, Water surface follower type vicinity sensors are used. In coastal engineering models where the water level is transient in nature due to site conditions, Guided wave radar type sensors are more suitable than telescopic type vicinity sensors. The maximum variation of water depth decides the design of lead screw in Water surface follower. The lead screw design for Water surface follower can be in the range of 15cm to 50 cm. Large water depth measurement (50 cm and above in model) can be achieved with the help of Guided wave radar type sensors. Differential pressure type sensors can also be used for larger depth of water variation with reasonable accuracy.

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The velocity can be measured accurately with the help of proper sensor and instrumentation depending on the various model conditions. The physical hydraulic model of river engineering where only average velocity across the cross section is required for discharge computation, even if number of propeller current meter type sensors are installed at various depths and space, finally average velocity of all the sensors are computed over a period of time. 25mm to 50mm diameter current meter can fulfill our requirement in case of river models where sufficient depth of water is available to fully dip the guide vane of propeller current meter type sensor. In Coastal Engineering models, where tidal flow variations occur, the velocity measurement is an important parameter at various locations. During the flood and ebb phases of the tide the water level varies from lower to higher range of tide. This type of variation of water level, speed and direction require 10mm to 15mm diameter propeller current meters. The guide vanes of these current meters should be fully dipped in shallow water. In the multidirectional flow where the Reynold's number exceeds 3000 (i.e. flow start turbulent phase), Propeller type current meter sensors are not suitable for velocity measurement. Under this situation Anemometers are better options. Two types of anemometer such as Hot Film Anemometer (HFA) and Laser Doppler Anemometer (LDA) are normally used. Laser Doppler Anemometer is applicable to confined (small) models where the flow of water should pass through a 3D laser beam. Hot film anemometers are suitable for larger models where flow of water travels through a hot film and the change of temperature is a function of flow velocity. Where impact of velocity is due to force or pressure (the velocity greater than 3m/sec), under these situations, the above cited propeller type current meters cannot be applied for the measurement of velocity. These conditions can be handled by using "A-OTT" type current meters with magnetic reed switch facility. A-OTT type current meters incorporate bucket type sensors instead of propeller type sensors, which are robust in nature. The normal current meters cannot measure velocity in the saline water exceeding 35 ppt. The current meter sensors should be platinum coated in this case of salinity exceeding 35 ppt to eliminate the noise effect arising due to excess salinity. A Platinum coated dummy electrode is also incorporated in addition to the main electrode in the current meter to avoid the noise effect. The coating of platinum also prevents corrosion of sensors. Figure 8 shows 50 mm diameter propeller type current meter used for flow velocity more than 100cm/sec.

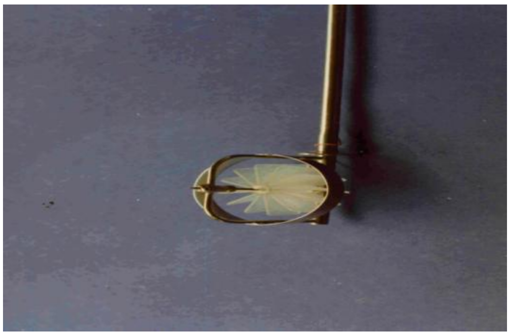

Fig. 8: 50mm Diameter Propeller Type Current Meter Used For U>100cm/Sec

Temperature is a vital parameter to be measured for physical hydraulic model studies of thermal and nuclear power plants. Two vital parameters like temperature gradient and, thermal and nuclear wastes are significant to be monitored while carrying out cooling pond or recirculation studies of these power plants. Two types of temperature sensors such as Thermistors and Platinum Thermometer Resistance (PTR) are normally used in these type of applications. Thermistors are of bimetallic combinations where the temperature coefficient resistance (thermal resistance) of the two metals are significantly different. PTR's are platinum temperature resistance thermometers where the temperature rise is inversely proportional to the resistance (with in operative zone). Equation of the PTR curve.

$$R = Ro(1 + a\Delta T)$$

Where R = The resistance of conductor at temperature T

Ro = The resistance at the reference temperature

Thermistors can cover wide range of temperature measurements. So they are suitable for thermal model studies. PTR's can be used for the nuclear power plant models where nuclear waste is an important factor.

Fig. 9 : PT-100 Temperature Sensor for Thermal Model

V. TYPICAL CASE STUDIES

Mumbai port model can be taken as a typical case study. This model is a coastal engineering model where sea, estuary, river and port are naturally available. This model was constructed with the following objects:

1. Alignment of breakwater
2. Alignment of jetties
3. Alignment of approach channel
4. Alignment of port basins
5. Dredging of channels
6. Reclamation for port development

The alignment of breakwaters, jetties, approach channels and port basins require inshore and offshore wave data and tide characteristics. Wave height and direction are significant parameters to be measured for these studies. Wave height is measured using Capacitance Type Wave Height Recorders (CWHR). Tidal velocity profiles are measured with the help of Propeller Type Current Meters (15 to 20 mm diameter) where the tidal velocity is less than 100cm/sec and salinity is less than 35ppt. in case of salinity being greater than 35ppt, dual electrode type current meters are to be used in place of single electrode type current meter (as used Bechme dam, Iraq). To allow the prescribed size of the ship into the approach channel, optimum level of water must be maintained for the safe navigation of the ship to the port. Therefore seasonal dredging in the navigational channel is required to be carried out. The water level of the approach channel is also to be measured in the Mumbai port physical model studies. The water levels are measured at various locations across the port area with the help of WSF (where water level variation is less than 8mm/ sec) and GWR (where water level variation is more than 8mm/ sec) based water level recorders.

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