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Dharan, N. Murali; Mani, J. S.

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FORCES ON A SUSPENDED SEAWATER INTAKE SYSTEM EXPOSED TO WAVES AND CURRENTS

N. Murali Dharan[1] and J. S. Mani[2]

***Abstract**: A comprehensive study has been carried out on the hydrodynamics of the suspended seawater intake system with a vertical suction pipe of 0.16m diameter. The depth of immersion of the suction pipe was varied to 0.395 and 0.305m. For each depth, pressures were measured at three different points of the pipe i.e at seaward side (A) and two beam sides (B and C). The hydrodynamic studies are conducted in a constant water depth of 1m for a wide range of wave periods, wave heights and waves with currents for regular waves in the 2m wave cum current flume at the Department of Ocean Engineering, IIT Madras, Chennai, India. The studies indicated that the pressure distribution around the intake system due to waves and wave with current around the intake system varied due to lateral motions.*

***Keywords**: Suspended seawater intake; suction pipe; seaside; beam side; depth of immersion.*

INTRODUCTION

The phenomenon of global warming, diminishing rainfall, reduction in catchments, siltation in reservoirs, development in arid regions, industrialization and population growth had led to shortage in conventional water resources. In addition, increase in demand for sea water used for many purposes such as thermal power plants, desalination plants, coastal aquaculture, chemical plants, salt production industry, sea water magnesium extraction plants etc. has necessitated engineers to design and construct proper and safe seawater intake structures.

The primary function of an intake structure is to provide continuous and uninterrupted supply of quality seawater. It consists of a suction pipe joining an intake pump house at the seaward end and a sump at the landward end. The maintenance of this system is easy, since the components are exposed to air. It is observed that the installation of suspended seawater intake structure is for a distance of about 3 to 4m in a water depth of about 6 to 8m. Under these circumstances, the projected portion of the sea water intake system will be subjected to wave and current forces depending on the length of projection. Further, if the lip of the intake structure is located close to the sea bed, the intake would be forced to draw sediment laden water which may prove uneconomical.
S. Pradeep (2005) experimentally investigated the effectiveness of the skirt type of vertical

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1 M.Tech Student, Department of Ocean Engineering, Indian Institute of Technology Madras, Chennai 600 036, India, Email: muralidharaniitm@gmail.com
2 Professor, Department of Ocean Engineering, Indian Institute of Technology Madras, Chennai 600036, India, Email: jaysmani@yahoo.com

barrier in reducing the wave forces on a seawater intake structure in the wave flume. Studies were conducted for varying lateral spacing (g_p/d_p) between the adjacent members of the barrier and the longitudinal spacing (G_s/D_s) between the vertical barrier and the intake structure. It was observed that the reduction in force is maximum for a longitudinal spacing of $G_s/D_s = 3.0$ and for a lateral spacing of $g_p/d_p=1.0$ Compared to the structure without protection. R.Sundaravadivelu et al (1997) carried out an experimental study on a sea water intake well model to measure the wave forces and moments on the intake well and the variation of water levels inside and outside the well for two test conditions, one for intake well inlet closed during installation and intake well inlet open. The experimental results on wave forces and moments were compared with the results of the Linear Diffraction Theory. The moment obtained using the experiments is found to be about 8% more than the theoretical results for the test condition when intake well inlets are open. The effect of inlet openings is found to be negligible on the inline wave force on the intake well, while the effect of inlet openings is found to increase the moment on the intake well.

MODELLING PROCEDURE

Froude scaling is adopted for physical modeling, which allows for the correct reproduction of gravitational and fluid inertial forces. For similitude, the Froude number which is a ratio of inertial forces to gravitational forces in the prototype and model must be equal i.e

$$\frac{V_p}{\sqrt{gL_p}} = \frac{V_m}{\sqrt{gL_m}}$$

Where V_P, L_p, *and* V_m, L_m are velocity and wave length of corresponding prototype and model. Defining model scale λ to be the ratio of the prototype characteristic length to model length, then the following relationship results

$$\text{Length scale} = L_r = \frac{L_m}{L_P} = \lambda$$

$$\text{Time scale} = T_r = \frac{T_m}{T_p} = \sqrt{\lambda}$$

$$\text{Force scale} = F_r = \frac{F_p}{F_m} = \lambda^3$$

$$\text{Velocity scale} = V_r = \frac{V_m}{V_p} = \sqrt{\lambda}$$

MODEL DESCRIPTION

A model scale of 1:8 is chosen for experimental investigation and the experimental conditions are given in Table 1. The experimental setup, sectional view is shown in Figs 1(a) and 1(b). The pressure transducer used, the intake model in the wave flume are shown in Figs 2 and 3.

Table 1. ExperimentalConditions

Description	units	Prototype	Model
Water depth (d)	m	8	1
Wave period (T)	sec	2.26, 3.39, 4.52, 5.65, 6.22	0.8, 1.2, 1.6, 2, 2.2
Wave height (H)	m	0.4, 0.8, 1.2, 1.6, 2	0.05, 0.1, 0.15, 0.2, 0.25
Current Speed (C_t)	m/sec	0.229, 0.517, 0.718	0.081, 0.183, 0.254
Diameter of pipe (D)	m	1.28	0.16
Depth of submergence (d_s)	m	2.44 and 3.16	0.305 and 0.395

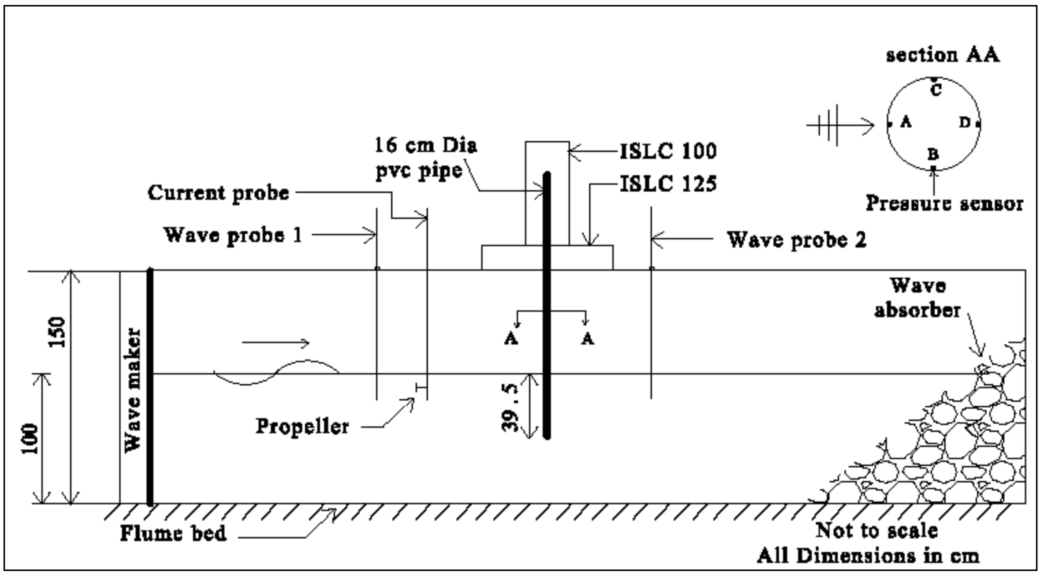

Fig. 1(a). Experimental Setup

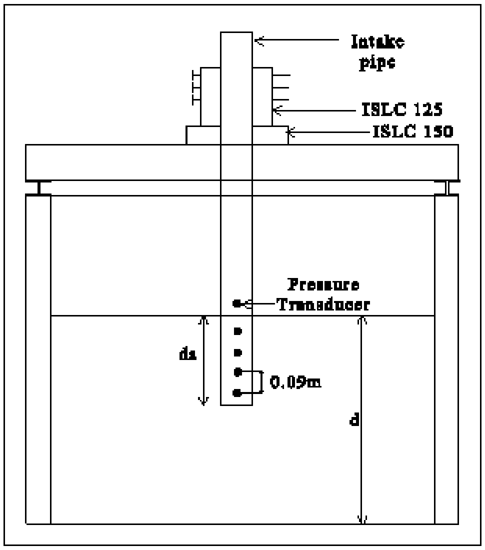

Fig. 1(b). Sectional View

Fig. 2. Intake pipe housed with pressure sensors

Fig. 3. Intake pipe in wave flume

TEST FACILITIES

The experimental investigations were carried out in a 30m long, 2m wide and 1.5m deep wave cum current flume in the Department of Ocean Engineering, Indian Institute of Technology Madras, Chennai. A computer controlled piston type wave maker installed at one end of the flume is capable of generating regular waves of different heights and frequencies as well as random waves of predefined spectral characteristics. The other end of the flume is provided with a rubble mound absorber to effectively absorb the incident waves. In this flume, the water depth can be varied from 0.25 to 1m. The test section was located at a distance of 12m from the wave maker.

EXPERIMENTAL SETUP

For the present investigation two wave probes are used, one to measure the incident wave height, kept at seaward side at a distance of 3.25m and the other to measure the wave height at the lee side of the structure placed at a distance of 1m. A current probe is placed in front of the model which is connected to a current meter through which the current speed generated in the flume is determined. The test section was housed with 5Nos. of strain gauge type pressure transducers along the length of the cylinder at equal spacing. They were numbered for identifying the cables coming out from the fixed end of the pipe to make sure that they are identified during the fixing stage of the model. These pressure transducers are of miniature (strain gauge) type transducers. The strain gauges sense the resulting strain/deflection to give an output voltage proportional to the applied external pressure. A standard bridge amplifier was used to amplify the output to the required level. The range was kept constant for calibration and throughout the experiments. The intake structure was kept at a distance of 12.7m from the wave maker as shown in Fig. 1(a).

CALIBRATION OF INSTRUMENTS

The calibration of pressure sensors, wave probe and current probe is done to convert the output in voltage. The calibration is done for each set of experiments to minimize the errors in the measured values. The calibration procedure is carried out by finding the output of the sensors in terms of voltage for a known value of input physical parameter.
The calibration constant of wave probe is calculated in static condition. The wave probe is immersed inside static water for half of its length and this is taken as initial level. The bridge circuit of wave probe is balanced to zero. From this level wave probe is lowered downward into the water for 0.05m, 0.1m & 0.15m depth and the corresponding reading (change in voltage) are noted. Further wave probe is raised from 0.15m to 0.1m and 0.05m to initial level and corresponding changes in voltage are recorded. Similarly wave probe is raised from the initial level and corresponding voltages are measured. Then a graph is plotted between water depth and voltage and corresponding calibration constant is obtained. A procedure similar to that of the wave probe was adopted for the static calibration of pressure transducers to known depth of submergence and registering the changes in the corresponding voltages. Typical calibration chart for wave gauge and pressure transducer is presented in Fig.4.

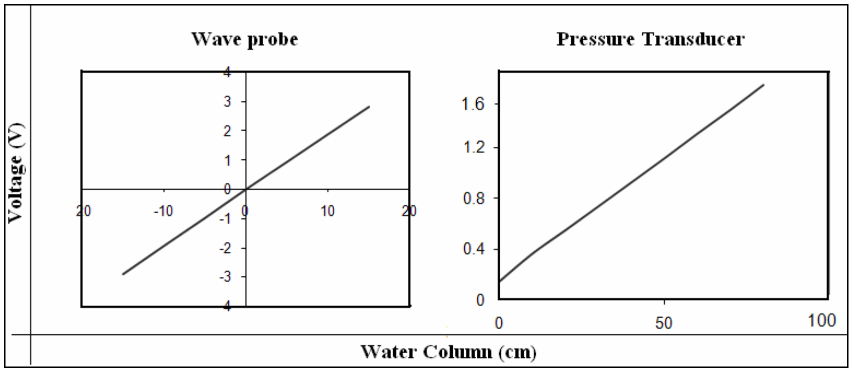

Fig. 4. Calibration chart for wave probe and Pressure transducer

DATA ACQUISITION SYSTEM

The wave gauge signals acquired through corresponding amplifiers were filtered through a 20Hz low pass filter to remove the sample ripple. A dedicated PC was used for the generation of waves and for the simultaneous acquisition of signals from the sensor pickups. The physical quantities viz., water surface elevation; dynamic pressure around the circumference of the cylinder was acquired as electric signals from the corresponding gauges, pressure transducers. The input range was set as +/- 10 V. The electrical signals are acquired using quartz clock controlled sampling converted to digital form using a 12bit A/D (Analogue to Digital). This A/D converter is supported by software, which controls the sampling frequency of the data acquisition, number of signals to be acquired, total time of data collection and data storage in the personal computer The signals from the pressure transducers through a D.C amplifier and the signals from the wave gauges through a wave amplifier via wave meter are acquired simultaneously through the 12 bit A/D card and stored in the personal computer which also used for the driving the wave maker. The details of the data acquisition system are shown in Fig. 5.

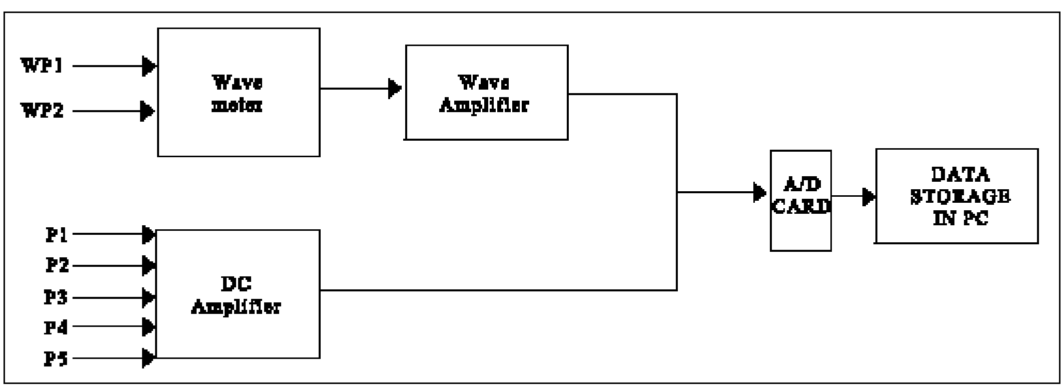

Fig. 5. Schematic sketch of data acquisition system

EXPERIMENTAL PROCEDURE

The test was conducted for a depth of submergence (d_s) of 0.395 and 0.305m and pressures were recorded for seaward side (A) and beam sides (B and C) to study the effect of wave and wave cum current force on the suspended seawater intake model. At each condition of d_s, tests were conducted for minimum of five wave heights, H ranging from 0.05m to 0.25m with an interval of 0.05m and for each wave period ranging from 0.8 to 2.2 seconds with an interval of 0.4 for regular waves and for wave along with current a current speed of 0.081, 0.183 and 0.254 m/sec with wave heights of 5 and 10 cm for wave periods ranging from 1.6 to 2.2 seconds with an interval of 0.4 seconds were recorded. Fig. 6(a). and Fig. 6(b). Shows the intake system subjected to regular waves on seaward side and beam side. Fig. 7. and Fig. 8. Presents the wave and current generated in the flume during the investigation and the intake system subjected to wave and current.

(a)

(b)

Fig. 6. Intake pipe subjected to regular waves on (a) seaward side and (b) beam side

Fig. 8. Intake pipe exposed to wave and current

Fig. 7.Wave & Current generating system

DETERMINATION OF HYDRODYNAMIC PRESSURES

The analysis of regular waves and waves with currents was focused on the determination of peak pressure (P) for all test frequencies and amplitudes. Variation of dynamic pressure for varying wave steepness parameter is presented for the depths of submergence of 0.395 and 0.305m. The theoretical pressure for seaward side A and beam sides (B and C) are expressed as

$$P_{the} = \rho g \frac{H}{2} . \frac{\cosh k(d+z)}{\cosh kd} \tag{1}$$

$$P_{the} = \rho g \frac{H}{2} . \frac{\cosh k(d+z)}{\cosh kd} . \cos(kx - \sigma t) \tag{2}$$

Where ρ = mass density of water = 1000 kg/m^3
g = gravitational force = 9.81 m/sec^2
H_i = incident wave height
k = wave number $= \frac{2\pi}{L}$
d = water depth = 1m
z = positional depth
x = D/2

DETERMINATION OF WAVE FORCES

The wave and wave cum current induced forces were calculated by integrating the measured pressures along the length of the intake pipe and multiplying with the diameter of the pipe. The forces per unit length are represented as F. The results have been presented in a non dimensional form for various depth ratio (d_s/d) and at different points along the circumference of the cylinder i.e at seaward side A, beam sides B and C, for all the test conditions. The theoretical force was calculated using the following formula

$$F = dF_d + dF_i \tag{3}$$

$$dF_d = \frac{1}{2} . C_D . \rho . D . \left| U \right| U . dz \tag{4}$$

$$dF_i = C_m . \rho . \frac{\pi}{4} . D^2 . \dot{U} . dz \tag{5}$$

Where dF_d : Elemental drag force
dF_i : Elemental inertia force
C_d : Drag coefficient
C_m : Inertia coefficient
ρ : Mass density of water
D : Diameter of the cylinder
U : Water particle velocity in flow direction
$\dot{U}$: Water particle acceleration in flow direction.

The studies indicated that the pressure distribution around the intake system due to waves and waves with current around the intake system varied due to lateral motions. Forces on the intake system were estimated with the observed pressure variations. Fig. 9.Shows the percentage variation in forces due to waves and waves with current w.r.t wave steepness for a current speed of 0.081 /sec and the corresponding force values are incorporated in Table 2.

Table 2. Force due to wave and wave-current with respect to wave steepness for depth of submergence of 0.395 and 0.305

Hi/gT^2	Current speed	d_s/d	Wave and Current Force	Wave Force	% diff w.r.t waves
0.001	0.081	0.395	2.975	4.159	-39.8344
0.002			1.743	1.538	11.76834
0.003			1.336	0.859	35.7167
0.001	0.081	0.305	1.832	2.467	-34.6877
0.002			1.022	0.965	5.576592
0.003			0.737	0.557	24.46916

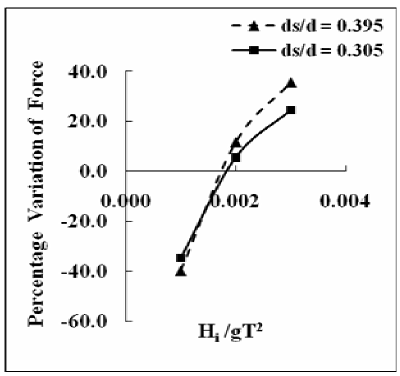

Fig. 9. Percentage Variation in force due to wave and wave-current with respect to wave steepness for depth of submergence of 0.395 and 0.305

CONCLUSIONS:

Based on the present experimental investigation the following conclusions were drawn

- When wave and current interacts, the force on the intake structure decreases when compared with waves alone for $H_i/gT^2 < 0.00173$. However the force due to wave and current increases compared to the force due to wave alone for $H_i/gT^2 > 0.00173$.

- Further when depth of submergence is decreased no appreciable change in the force reduction is noticed for $H_i/gT^2 < 0.00183$, whereas for $H_i/gT^2 > 0.00183$ decrease in d_s/d causes a reduction in increase in force.

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