Proceedings of OMAE04
23rd International Conference on Offshore Mechanics and Arctic Engineering
June 20-25, 2004, Vancouver, British Columbia, Canada

OMAE2004-51074

WAVE SLAMMING FORCES ON HORIZONTAL CIRCULAR CYLINDERS IN INTERTIDAL ZONE

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ABSTRACT
Wave forces on slender horizontal and vertical cylinders are normally estimated using Morison equation (1950). When a cylinder is near the free surface, it experiences the slamming force. Wave slamming on horizontal cylinders of any ocean structure is crucial to its design. API Recommended Practice 2A-WSD(2000) recommends slamming coefficient C_S equal to π for circular cross sectional cylinders near the still water level. The shape of the member (circular, rectangular or square) is also expected to alter the values of C_S. The horizontal cylinders in the inter tidal zone for Port craft jetties are subjected not only to slamming force in the vertical direction but also to berthing force in the horizontal direction. If two cylinders are kept in close spacing, then the load on both cylinders will differ compared to force on a single cylinder. The effect of tidal variation on slamming forces needs thorough investigation. The comparison of single circular cylinder and twin circular cylinder with a clear spacing equal to diameter of cylinder in regular waves is discussed in this paper.

INTRODUCTION
Experiments are conducted for single and twin cylinders of circular cross sectional shapes. The horizontal and vertical forces on different cylinders are measured by keeping the distance between the flume bed and centre of the cylinders constant and by varying the water depth (d) for various tidal conditions.

The main purpose of this investigation is to study the effect of wave height, wave frequency, the distance between the free water surface and the centre of the cylinders, shape of the cylinders, the spacing between the cylinders etc. on the vertical slamming coefficient (C_{SV}) and the horizontal slamming coefficient (C_{SH}). The results of this investigation can be used for the hydrodynamic design of horizontal cylinders in the intertidal zone for any ocean structure. This paper includes the wave slamming forces on single circular cylinder and twin circular cylinder models due to regular waves.

For experimental investigations on the cylinders regular waves are generated in a wave flume of 30m length, 2m wide and 1.7m depth in the Department of Ocean Engineering Indian Institute of Technology, Madras, India. The detailed experimental procedure, analysis and discussion on the results on wave slamming force on the cylinders are reported in this paper.

NOMENCLATURE

H–Incident wave height (m)
T- Wave period (s)
D–Diameter of the cylinder (m)
d- Depth of water (m)
h- Distance between bed to the centre of the cylinders (m)
z- Distance between the centre of the cylinder and mean water surface (m)
S- centre to centre spacing between the cylinders in twin cylinder (m)
L- Wave length of the wave (m)
H/L – Incident wave steepness
d/L – Relative water depth

S/D-spacing parameter for double circle
z/D- relative submergence parameter
KC – Keulegan Carpenter number
η – Incident wave elevation (m)
u- Horizontal water particle velocity
v-Vertical water particle velocity
l- Length of the horizontal cylinders (m)
Csh-Horizontal component of slamming coefficient on the single circular cylinder
Csv-Vertical component of slamming coefficient on the single circular cylinder
Csh1-Horizontal component of slamming coefficient on the upstream cylinder of the twin circular cylinder
Csv1-Vertical component of slamming coefficient on the the upstream cylinder of the twin circular cylinder
Csh2-Horizontal component of slamming coefficient on the downstream cylinder of the twin circular cylinder
Csv2-Vertical component of slamming coefficient on the the downstream cylinder of the double cylinder case
ρ - Mass density of water (kg/m^3)
g - Acceleration due to gravity (m/s^2)
Fh–Measured horizontal component of the slamming force(N)
Fv–Measured vertical component of the slamming force(N)

EXPERIMENTAL FACILITY, PROCEDURE, MODEL DESCRIPTION AND INSTRUMENTATION

Fig.1 is the definition sketch of the present problem. For experimental investigations on the single and twin circular cylinders, regular waves are generated in a wave flume in the Department of Ocean Engineering, IIT Madras, Chennai, India. The experimental investigations were carried out using a 0.063m diameter circular cylinder model with two load cells fixed at the two ends in a varying water depth as 0.4m, 0.45m, 0.50m, 0.55m, and 0.6m. The experimental investigation was carried out first for single circular cylinder, which is taken as a reference for the force variation in the twin circular cylinder. The dimensions of the flume and the characteristics of the waves used for the study are shown in Table 1. The different ranges of the normalised hydrodynamic parameters obtained are shown in Table 2.

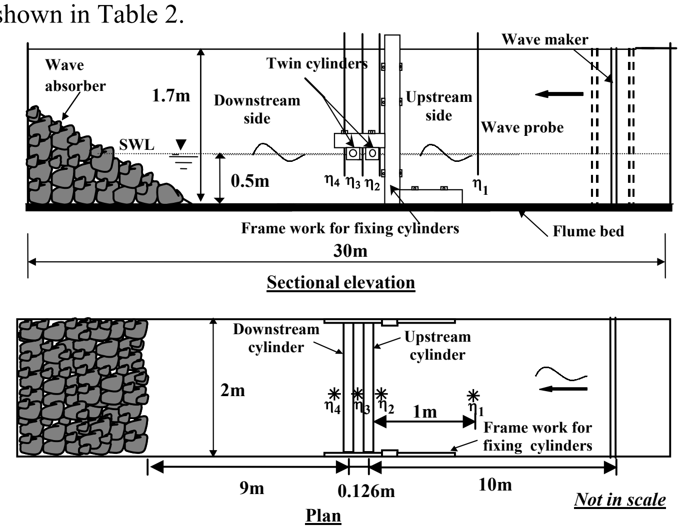

Fig.1 Definition Sketch of the problem

Table: 1. *The characteristics of the waves used in the flume*

Flume length	30m
Flume Width	2m
Flume depth	1.7m
Water depth	0.4, 0.45, 0.50, 0.55&0.60m
Type of Wave generator	Piston type
Waves used in this study	Regular
Incident Wave Height, H_i	10, 15 & 20 cm
Wave Periods, T	1.0 - 3.0 s
Diameter of cylinder, D	0.063 m
Thickness of the cylinder, t	0.003m
Length of the cylinder, l	1.89m
Effective spacing (c/c) between the cylinders for twin circular cylinder	0.126m (S/D=2)

Table: 2.*Ranges of the normalised hydrodynamic parameters*

Regular Waves:

Parameter	circular cylinder (Dia=0.063m)
Incident wave steepness, H_i/L	0.013 - 0.102
Relative water depth, d/L	0.069 - 0.283
Normalised wave height, H/D	1.39 – 3.17
Relative level of submergence, z/D	-1.59 – +1.59
Scattering parameter, D/L	0.009-0.033
Keulegan- Carpenter number (KC)	5-21

The circular cylinder model is fabricated using aluminium with outer diameter of 0.063m and thickness of 3mm. Length of the cylinders is kept as 1.89m. The distance between the cylinder centre and the flume bed is kept constant height as 0.5m. The model was located at a distance of 11m from the wave generator and 19m from the rubble beach which is located at the tail end of the flume.

To measure the wave forces on the cylinders, two-component strain gauge type loadcells of two numbers of capacity 300N each were fixed at the two ends of the cylinders. This loadcell is capable of measuring forces in the horizontal (X) and vertical (Z) directions. Maximum force of the order of about 90N was measured. These loadcells were fixed to the ends the cylinders by providing proper seals made of very thin rubber sheets to prevent the entry of water into the cylinder. Final alignment of the loadcell was based on the elimination of vertical force channel output when the loadcell was loaded in the horizontal direction, and vice-versa. Calibration was done by applying weights to the model fixed with loadcell which is mounted in the framework in the expected principal wave force component directions.

A wave probe is fixed 9m away from the wave maker at the upstream side to measure the incident wave history (η_1).Three more wave probes are used in the study. One to measure the inline water surface fluctuation on the first cylinder (η_2) at its leading edge and one to measure the water fluctuation in between the two cylinders (η_3) and third one to measure the inline water surface fluctuation on the rear cylinder (η_4) at its trailing edge. Standard Conductance type (two parallel stainless steel electrodes with 2-cm distance between them) wave gauges were used for the measurements of incident and inline wave fields.

The natural frequency of the model cylinder with setup is found experimentally to be 44Hz. Regular waves were generated for 60s and the data were collected for 60s at a sampling rate of 40 Hz. The time series corresponding to the clear repetition of the regular occurrences only are collected. A personal computer records the time histories of wave heights and wave forces. A total of 300 runs with different combinations of wave periods, wave heights and water depths were conducted for regular waves.

RESULTS AND DISCUSSIONS

The present experimental investigations on wave loads on the horizontal circular cylinders were carried out mostly in the drag-dominated region. Fig.2 depicts approximately the regions of influence of the various component forces namely drag, inertia and diffraction (Garrison, 1978). Figure.2 shows the applicability of Morison approach to the present study in evaluating the hydrodynamic forces on the cylinders, in which the data points corresponding to all wave parameters are superimposed. It is hence known that the assessment of the slamming coefficient from the experimental investigation is reliable which is defined in the same manner as the conventional drag coefficient

$$Fs = Cs\rho ApU^2/2$$

Where Fs is the slamming force, Cs is the slamming coefficient, ρ is the water density, Ap is the projected area of the cylinders normal to the plane of impact and U is the local particle velocity.

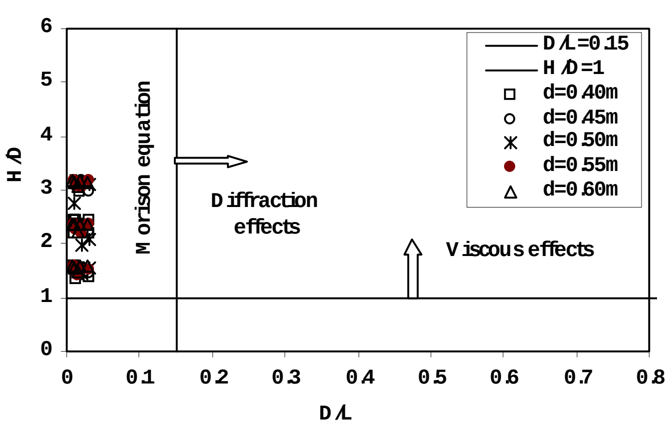

Fig. 2: H/D vs D/L for validity of wave-structure interaction problem

At the instant of contact of fluid with the structure, the water particle in the vicinity of the structure undergoes large accelerations, which give rise to large forces. When the body becomes more immersed, buoyant force will be more predominant. Here in still water condition itself it is reduced so that the obtained vertical force will be buoyant force excluded.

Wave force time series of the cylinder

A typical plot of the in–line force time series on the horizontal cylinder for single and twin circular cylinders for T = 2.0s and H= 0.15m for a water depth of d=0.50m is given in fig.3. plots are shown for vertical as well as for horizontal forces over the cylinders. It is clear that the in-line force is more compared to the vertical force for single circular cylinder.

For the twin circular cylinder, it is clear that horizontal force is more than vertical force for the front cylinder from wave maker and for its rear cylinder vertical force is more than the horizontal force. In all the below plots, wave crest force is higher since the cylinder is in emerged condition. This reduction in forces in the rear cylinder is due to the dissipation of the waves in front cylinder. The variation of these parameters are plotted and discussed below.

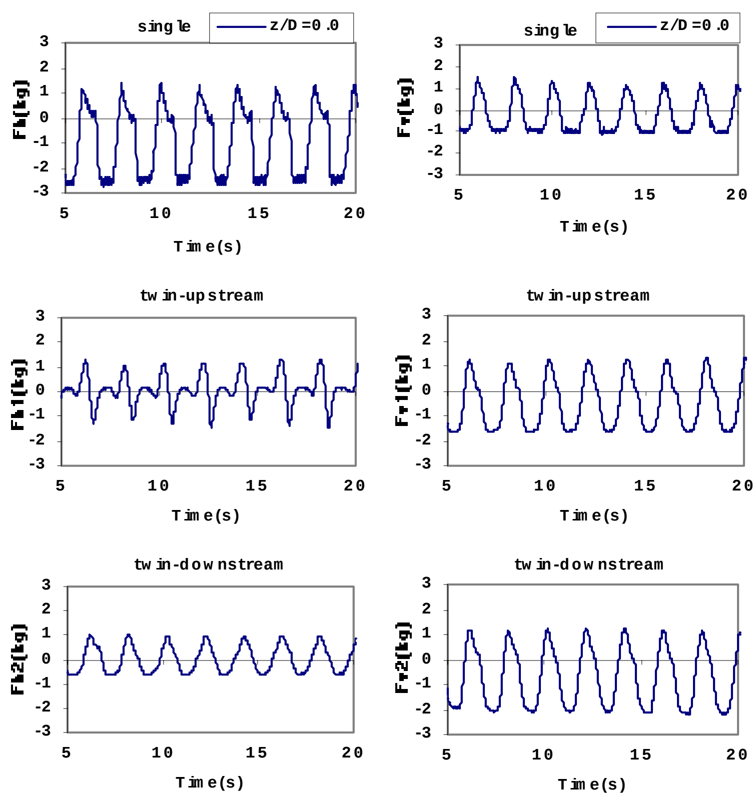

Fig. 3 Time series of the in-line forces (horizontal and vertical) on the horizontal cylinder for d=0.50m, T=2.0s and H=0.15m for single and double cylinder cases.

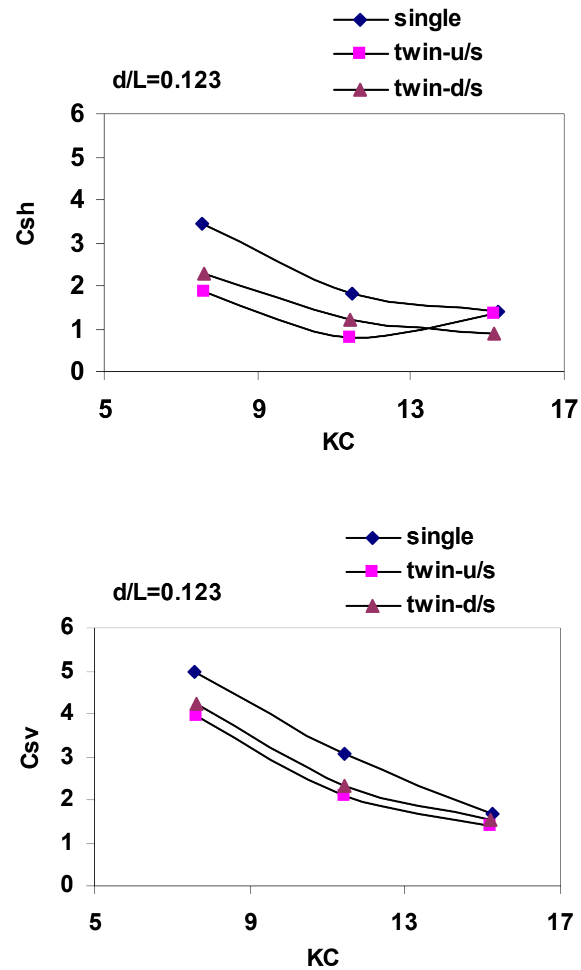

Fig. 4 - Effect of KC on Cs for d/L=0.123 for single and twin circular cylinders (upstream (u/s) & downstream (d/s)) for z/D=0.0

In this investigation it is shown that as the KC value increases, Cs value reduces for d/L=0.123. In Fig. 4, the curves are plotted for z/D=0.0. Slamming force is obtained in two components each for horizontal and vertical. For horizontal slamming force, slamming in the shoreward and seaward directions are measured. Similarly for vertical slamming force, slamming in the upward and downward directions are measured. Here only slamming in the shoreward and upward are given for horizontal and vertical trends.

As the wave height increases, since more waves are overtopping, the effect of impact causing slamming is less for horizontal component compared to its vertical component. It is clear from all the curves for single and twin cylinders.

In the twin circular cylinder, since the same effect of overtopping occurs, the effect of wave height over the slamming coefficient decreases for d/L= 0.123. Since the spacing between the two cylinders are less (S/D=2), the overtopped waves from the upstream cylinder impacts over the downstream cylinder to cause more slamming in the horizontal direction in the downstream cylinder than compared to the upstream cylinder. This hindrance effect is shown in the vertical direction also. i.e, compared to single circular cylinder twin circular cylinder is experiencing less force.

This variation is observed for z/D=0.0, i.e, when the water level is at the centre line of the cylinders. This variation is observed for all the water depths. From lower water depths this variation increases upto the mean level and then decreases. i.e, at the mean water level only it has been observed more Cs values in the shoreward and upward components of the slamming force.

In the present study of all the wave periods and depth of submergence, there is no effect of wave steepness in the slamming force in the lower level and higher levels of submergence. This is clearly shown in the fig. 5.

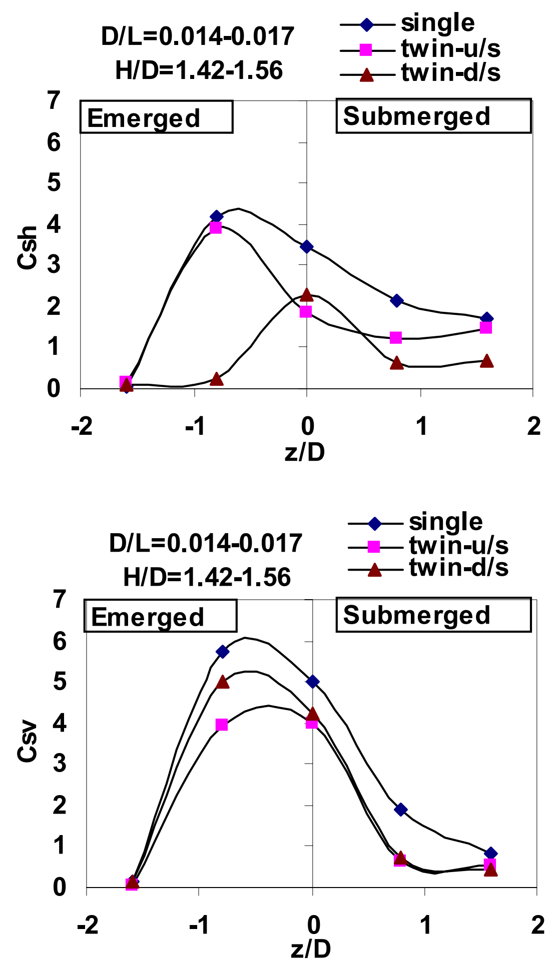

Fig. 5 shows the effect of z/D on Cs for H/D=1.42-1.57 for D/L = 0.014-0.017 for single and twin circular cylinders.

In the single cylinder case, it is observed that there is an increase in horizontal component of Cs upto z/D= -0.794 for H/D= 1.42-1.56 then it decreases as the z/D increases. For the same D/L=0.014-0.017, its vertical component also shows the same trend. For H/D=1.42-1.56, vertical component of Cs is more than the horizontal component of Cs for z/D= -0.794 and 0.0. As the cylinder becomes submerged, there is no much difference between horizontal and vertical components of Cs.

In the twin circular cylinder, the same trend as discussed in the previous section is obtained. In the horizontal component of Cs for upstream cylinder in twin circular cylinder, obtained more Cs than the downstream cylinder except for z/D= 0.0.Because of the hindrance effect, horizontal slamming is less in the downstream cylinder compared to its effect in the upstream cylinder. But in z/D= 0.0, more waves overtops the upstream cylinder and imparts more force over the downstream cylinder. For increased z/D ratios, overtopping occurs in both the cylinders. In the downstream cylinder vertical component of slamming also obtained the same trend as in the upstream cylinder but more in magnitude.

By knowing the depth of submergence and wave height, the value of Cs can be obtained. From the literatures, it is observed that Cs values are provided only for z/D>0.0. In the present paper, the effect of z/D ranging from –1.59 to +1.59 and the effect of twin circular cylinders over single cylinder for different hydrodynamic parameters are presented. From Dalton, C., and James Nash, M., [2], the trend of variation of Cs with KC is well matching with the present experimental results. The present results are also matching with the results presented for Cs with z/R from Faltinsen,et al.[3], Garrison, C, J., [4], and Sarpkaya, T.,[9].

CONCLUSIONS

From the present experimental investigations, influence of the normalized input parameters like relative level of submergence (z/D), and Keulegan Carpenter number (KC) on the wave slamming forces in shoreward and upward components due to regular waves were analyzed and presented. The salient important conclusions of this study are discussed below:

Wave slamming forces on the single and double circular cylinder:

1. The wave slamming force coefficient on the single circular cylinder decreases significantly from 70 to 60% for its vertical and horizontal components when KC value is increased from 5.33 to 19.12 for z/D= 0.0 for d/L= 0.123.

2. For the twin circular cylinder, as the KC value increases, the components of Cs in horizontal and vertical directions decrease but lesser in magnitude than single circular cylinder.

3. In the twin cylinder for d/L=0.123, the horizontal component of Cs is less than its vertical component.

4. In single circular cylinder, as the depth of submergence increases from z/D= -1.587 to -0.794, there is considerable increase in the Cs values for both horizontal and vertical components. As the depth of submergence increases from z/D= -0.794 to +1.587, Cs values reduces.

5. For H/D= 1.51-1.57, as the area of contact for particles having horizontal particle velocity is less, the Cs in horizontal component also less for lower z/D ratios. But the vertical force is imparting over the full diameter area of the cylinder. So in lower z/D, vertical component of Cs observed more than the horizontal component.

ACKNOWLEDGMENTS

The present work is carried out at the Department of Ocean Engineering, IITMadras, Chennai, India. The support of the appropriate authorities for the experimental investigations is highly appreciated.

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