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RESPONSE OF SLENDER VERTICAL CYLINDER UNDER BREAKING WAVES

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Abstract

Coastal and offshore structures consist of slender cylindrical member as the fundamental component. Breaking wave loads are significantly important now a days due to calamities and disasters occurring in ocean environment. Structural damages and failures are catastrophic due to wave impact and it is necessary to understand the influence of breaking wave impact on the structural members. The standard codal provisions of breaking wave impact on structural members is scarce, it is essential to understand the physics of the interaction of breaking waves on structural members. In the present study, an experimental investigation has been carried out to measure the response of the slender vertical cylinder under breaking waves due to constant amplitude spectrum. The structural response of the vertical cylinder under constant amplitude spectrum was found from the measured acceleration. The deflection of the vertical cylinder due to breaking wave impact from acceleration measurements were found out by using omega arithmetic method. The acceleration and deflection are found to be maximum for both severe and moderate plunging events. The maximum deflection observed for severe plunging event is nearly 0.1m for the present study.

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Keywords: Breaking wave impact, constant amplitude spectrum, plunging, spilling

1. Introduction

The breaking wave impact on coastal and offshore structures is impressive and natural phenomenon. Now a days, coastal and offshore disasters such as cyclones, storm surges, Tsunami, Flood, hurricanes induce high pressures on structures due to breaking wave action. Coastal areas are always at higher risk since the breaking wave may induce extreme magnitudes of pressure on jetties, piers, light houses, sea walls and other coastal structures. For coastal and offshore engineers, in addition to regular wave action, the wave action also consists of irregular, asymmetric and

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extreme waves including breaking waves. Due to non linearity and unsteady type of wave impact on structures, it is one of the most challenging task for the design engineers. Dynamic response of a structure can be caused by different loading conditions such as earthquake ground motion, wind pressure, wave action, blast and machine vibration Out of these, the inelastic response is caused by earthquake motions and accidental blasts. Also pile group-supported structures are widely used in marine transportation systems, for instance, in the construction of sea bridges, piers and jetties. Many of the offshore and coastal structures consist of cylindrical elements. Now, it has become a significant issue to study the response of offshore and coastal structural members due to such impact, the failure of which results in heavy financial loss. Considering land-based structures with ocean structures, the additional complication of being placed in a dynamic ocean environment where hydrodynamic interaction effects and dynamic response become major considerations in the design of ocean structures. In the past few decades, many experimental explorations were reported in the area of dynamic response of members made up of reinforced cement concrete, steel and composites under monotonically increasing loading. Both elastic and plastic responses were observed for structural members from the experiments and numerical methods. But the studies on structural response of offshore and coastal structures under wave impact load are rather limited.

The pioneering works of Bagnold (1939) and Minikin (1963) proposed a prediction equation for wave breaking caused local impact pressures. The learning experiences from the past failures of vertical breakwaters in United Kingdom, Japan and Italy (Oumeraci, 1994) indicate that the design methods may not be reliable for the impact type loading situations. In the past decades, the qualitative and quantitative determination of wave loads on vertical structures has already been examined (e.g. Oumeraci et al., 2001).Further, the laboratory studies have shown that impact pressure plays a dominant role in the overall wave loading (Witte, 1988). Wienke and Oumeraci (2005) examined the breaking wave impact on vertical and inclined slender cylinders by a series of large scale model experiments using Gaussian wave packets. It was observed that the impact force was shown to strongly depend on the distance between breaking location and cylinder, leading to five different loading cases. The maximum impact force on the cylinder occurs when the wave breaks immediately in front of the cylinder and the velocity of the water mass hitting the cylinder reaches the value of the wave celerity during the breaking. Wienke and Oumeraci (2005) examined the breaking wave impact on vertical and inclined slender cylinders by a series of large scale model experiments using Gaussian wave packets. It was observed that the impact force was shown to strongly depend on the distance between breaking location and cylinder, leading to five different loading cases. Chan *et al.*, (1995) presented the results similar to those obtained in studies of wave impacts on vertical walls (Chan and Melville, 1988) and cylinders of other relative dimensions (Zhou *et al.,* 1991). Manjula et al. (2013) discussed the hydrodynamic response of vertical cylinder due to breaking wave impact. There were huge number of past investigations on the study of hydrodynamic response of vertical and sloping wall due to breaking wave impact. However, only few studies focused the attention to discuss the hydrodynamic impact on cylinders. The present focus of the study is understanding the incident wave kinematics and its structural responses due to breaking wave impact.

2. Experimental Investigations

The experiments were conducted in a well-controlled programmable wave generation facility, 30m long, 2m wide and 1.8m deep wave flume, at Department of Ocean Engineering, Indian Institute of Technology Madras, India. The wave flume has piston type wave maker at one end and rubble mound wave absorber at the other end. The laboratory investigation was carried out in a constant water depth of 0.8m.

The simulation of breaking waves was accomplished by constructive interference of wave components (Chan and Melville, 1988). Following the simulation procedure, the desired signal to the wave maker was computed by combining 28 sinusoidal wave components within the frequency range from 0.42 Hz to 1.10 Hz. The salient parameters that determined the simulated wave packet are given in Table 1. The wave components have been derived from the constant-amplitude (CA) spectrum. The wave breaking was induced at 8.7m (x_b) from the mean position of the wave paddle and the time of breaking (t_b) was 11.7s. The intensity of breaking from spilling to plunging was achieved by increasing the overall wave amplitude so that, the amplitude of the individual wave components within the wave packet was kept constant. The increase in the amplitudes enhances the overall energy level in the simulated wave packet. Simulation of plunging waves of five different intensities, spilling with two different intensities and a non-breaking incipient wave has been achieved by the systematic variation of the wave amplitude. Table 2 presents the wave steepness for the simulated breaking events.

Table 1. Parameters Value.

Lowest frequency, f_L(Hz)	0.42
Highest frequency, f_H(Hz)	1.1
Centre frequency, f_c(Hz)	0.76
Frequency bandwidth, $\Delta f/f_c$	0.895
Number of wave components, N	28
Amplitude of centre frequency component, a_c(m)	0.0061
Characteristic wave period, T_c(sec)	1.32
Characteristic wave length, L_c(m)	2.701
Wave number corresponding to centre frequency, k_c(m^{-1})	2.327
Characteristic wave speed, C (m/s)	2.053

Table 2. Wave steepness for different intensities of breaking waves.

Types of Breaking	H_b/ L_c
Plunging type 1 (P1)	0.1020
Plunging type 2 (P2)	0.0995
Plunging type 3 (P3)	0.0961
Plunging type 4 (P4)	0.0900
Plunging type 5 (P5)	0.0839
Spilling type 1 (S1)	0.0808
Spilling type 2 (S2)	0.0776
Incipient (NB)	0.0738

2.1 Details of Vertical cylinder Model

The cylinder model was made of PVC pipe of 160mm diameter and 5.5mm thickness. The Cylinder was of 1.2m length and it was fixed at the top with the rigid box frame made of four angle sections. On the top surface of the flume, the frame was rigidly supported. The cylinder model was fixed rigidly in the centre of four angles using a metal cover for about 10cm length to provide a rigid fixity. The cylinder was fixed like a cantilever beam. The top side movement was completely eliminated and the bottom end of the model was kept free. The maximum deflection and acceleration was observed only in the impact zone i.e., above SWL (z/H_b =0.5 to 0.94) (Manjula et al., 2014) under breaking wave incidence. Hence the fixity at top would not influence the nature of the impact response of the cylinder. The water was not allowed to enter inside the cylinder through bottom surface. The cylinder was placed at the centre of 2m wide flume. The sectional view of the experimental setup is shown in Fig.1.

2.3 Acceleration Measurements

Accelerometers are mainly used for two specific types of acceleration measurement: impact (shock) and vibration. Impact develops a large acceleration over a short period of time, while vibration is a relatively small and repeatable acceleration. The acceleration (*a*) measurements were made on the front side of the cylinder facing the wave direction. In the present study, acceleration is measured using miniature type accelerometers. The acceleration is expressed in terms of m/s^2. The structural response of the cylinder due to breaking wave action by CA spectrum is measured by using Accelerometers. Accelerometers were fixed on the inner face of the hollow cylinder towards the wave paddle for avoiding the water contact. Sampling rate of accelerometers were 2 kHZ. There were 11 accelerometers which were fixed in the vertical cylinder along the elevation and is shown in Fig. 2. Out of eleven accelerometers, the accelerometer located at a distance of 15cm above still water level (SWL) was found to be inoperative and hence measurements from this accelerometer was ignored. The elevation, z is measured positive above SWL and normalised with breaking wave height, H_b. The incidences of plunging and spilling (P1 to S2) impacts are shown in Fig.3.

The impact pressure characteristics described Manjula et al. (2013) revealed the importance of impact zone above SWL for plunging and spilling events. Hence the structural response of the sections of the cylinder above SWL is only analyzed.

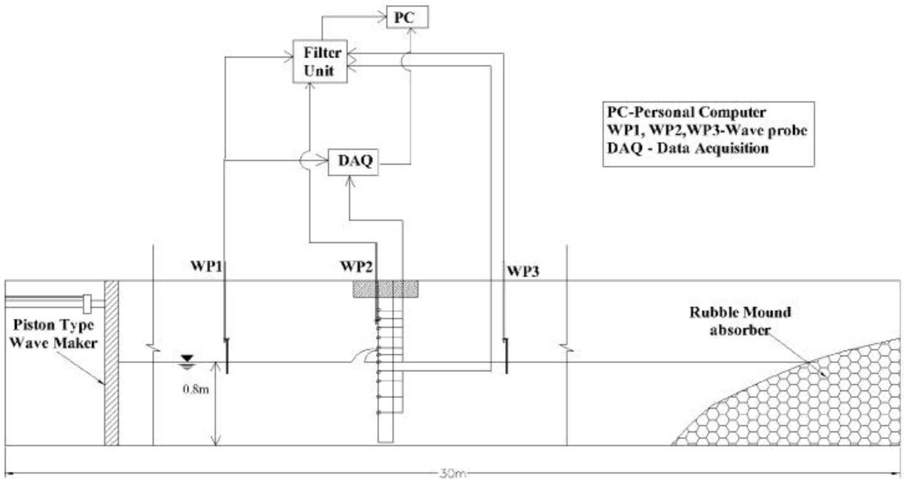

Fig.1. Sectional view of the experimental setup.

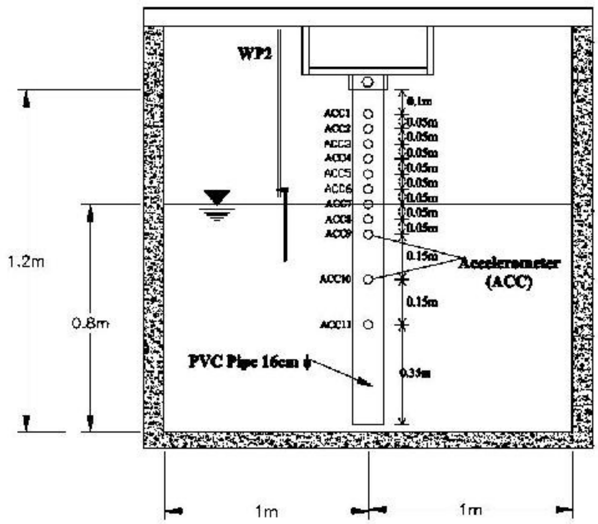

Fig. 2. Front view of the cylinder showing the positions of acceleration measurements along the length of cylinder with 5cm spacing for the first nine accelerometers and 15cm spacing for the last two accelerometers.

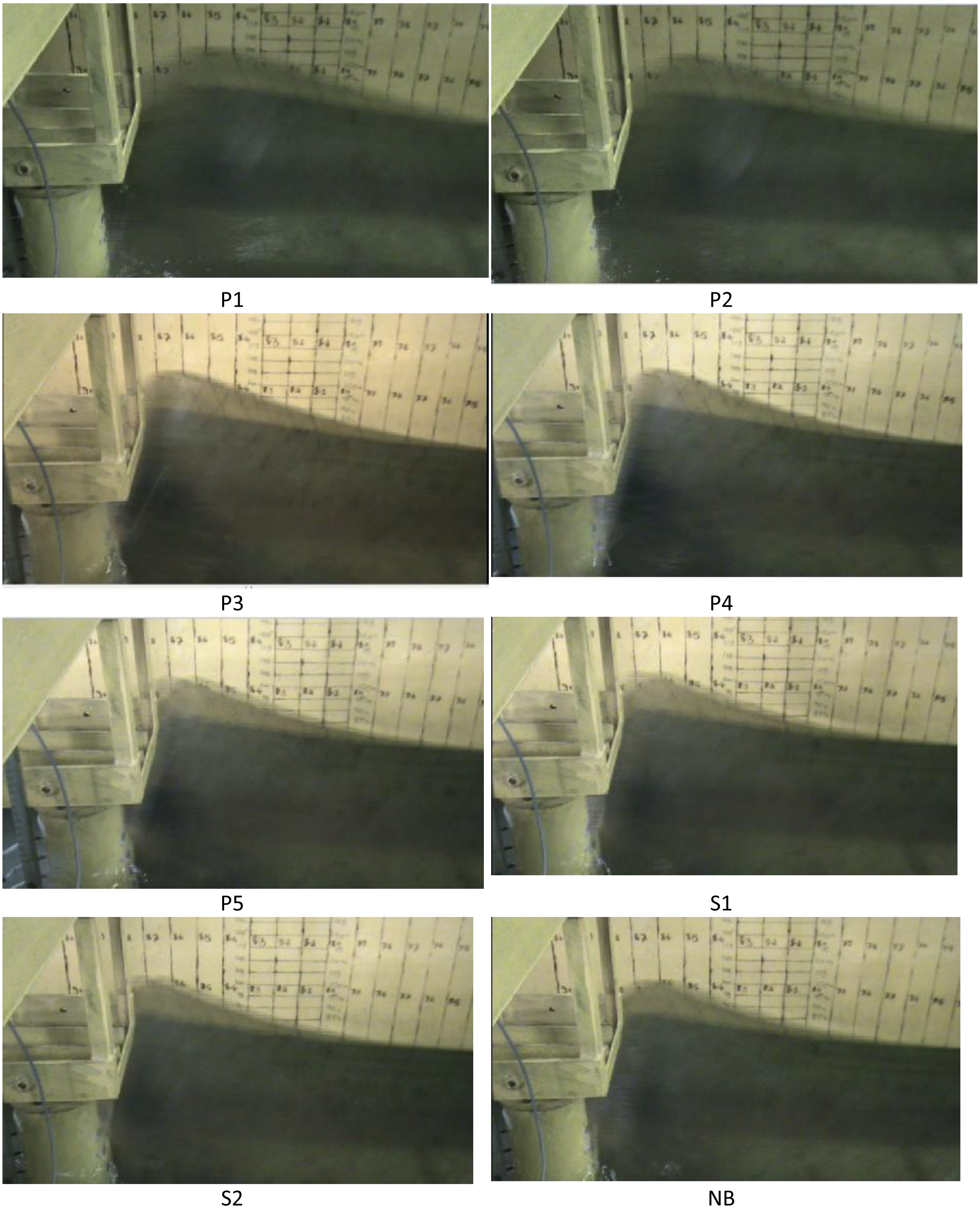

Fig. 3. Hitting scenes of cylindrical member due to breaking waves for P1,P2,P3,P4,P5,S1,S2 and non breaking

3.0 Analysis

3.1 Acceleration

The acceleration time series for P1 event is shown in Fig.4. P1 event induces highest acceleration of the order of 60m/s^2 at an elevation of z/H_b = 0.72. At all other elevations, the acceleration is two order less than the maximum acceleration.

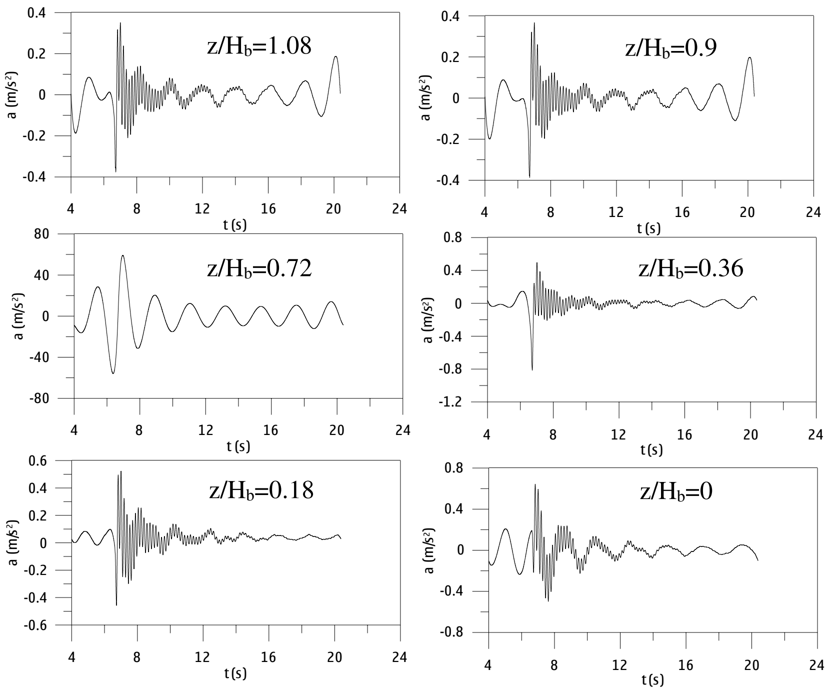

Fig. 4. Acceleration time series for strong plunging event(P1)

The variation of absolute maximum acceleration for various plunging and spilling events is shown in Fig.5. The maximum measured acceleration is 60m/s^2 due to P1 event while for P2, P3, P4 events it lies between 20m/s^2 to 50 m/s$^{2.}$ The max acceleration for strong plunging (P1 event) varies from 0.4 to 60m/s^2. It is observed that maximum acceleration is found to be important only above SWL and not below SWL since the cylinder is reacting only for breaking wave impact load.

The maximum acceleration is observed only in the impact zone(Manjula et al.While the moderate plunging induces in the range of 8 to 20m/s^2. The ratio of max acceleration for P1 to non breaking event is 60. For spilling event, the maximum acceleration lies less than 1m/s^2. The maximum acceleration for P1 to P3 events lie in the range of 15 to 60m/s^2 similar to pressure($p/\rho C^2$) measured due to P1,P2 and P3 which is in the range of 7 to 8 (Manjula et al. 2015) while for P4,P5,S1,S2 and NB, the measured maximum acceleration is found to be less than 10m/s^2. There are two clusters of acceleration i.e less than 10m/s^2 and more than 10m/s^{2}two clusters such as P1,P2 and P3 as one cluster and P4,P5, S1, S2 and NB as another cluster, since only first cluster shows prominence in response than other cluster.

3.2 Deflection

The deflection response of the cylinder under the wave breaking impact has been analyzed by deriving deflection from acceleration. Deflection is derived from the acceleration time history using omega arithmetic method. The acceleration signals are converted to the frequency domain using FFT (Fast Fourier Transform) and then integrated.

An inverse FFT converts the integrated frequency response to the time domain. The variation of measured maximum deflection for plunging and spilling events is shown in Fig.6. The deflection observed under P1 and P3 events are almost in the range of 0.02 to 0.09m while for other plunging events induces deflection less than 0.02m to 0.09m. P4, S1,S2 and NB events induce deflection less than 0.01m. The deflection produced by P5 event is in the range of 0.007m – 0.02m.

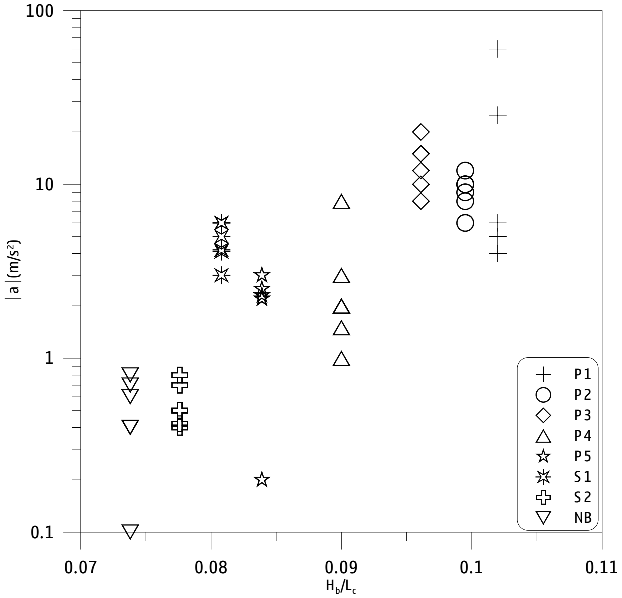

Fig.5. Variation of absolute max acceleration along the elevation of the cylinder under the action of breaking waves with different intensities.

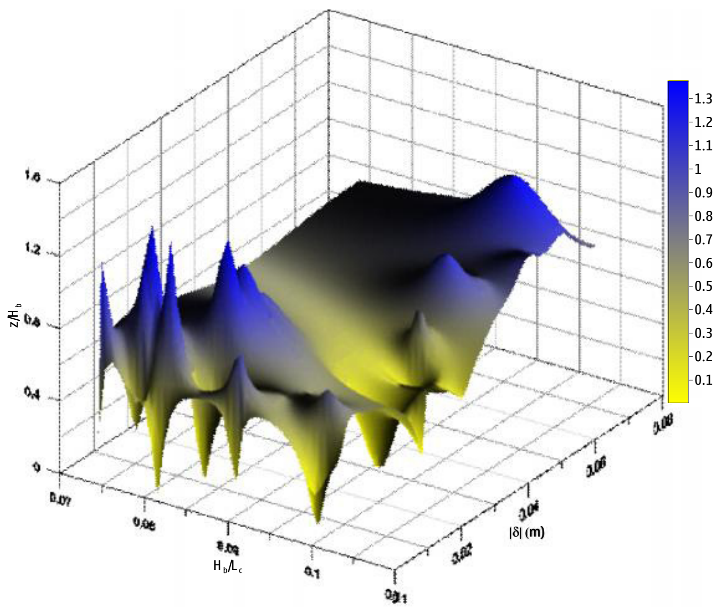

Fig.6. Variation of absolute max deflection pressure along the elevation of the cylinder under the action of breaking waves with different intensities.

The reason for the higher deflection of P1 and P3 events is due to higher rise time(Manjula etal. 2015) observed in the pressure measurements. When the impulsive loading persists to act longer on the structure, i.e., a higher rise time, then the structure is under higher deformation which is observed from the Fig.4. The deflection pattern is following the acceleration pattern almost in a similar trend. Under CA spectrum of breaking waves both P1 and P3 types of plunging must be given importance while under CS spectrum of breaking waves (Manjula et al., 2013) only P3 event induces maximum deflection than all other plunging events.

4. Conclusion

An experimental investigation on wave impact on a slender vertical cylinder has been carried out under different intensities of breaking waves ranging from plunging to spilling under CA spectrum. Based on the measurements the following conclusions were drawn. The max acceleration in the impact zone for plunging events P1,P2 and P3 is higher than other cluster of events(P2,P3, P4, P5, S1 and S2), while for CS spectrum of breaking waves, only moderate plunging event is significantly important. The maximum deflection induced by P1 event is 0.09m. Also the deflection observed by P1 and P3 events is higher than other plunging and spilling events. Hence for the design of offshore and coastal structural members, both severe and moderate plunging events must be given higher importance.

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