Slam Forces and Pressures on A Flat Plate Due To Impact on A Wave Crest

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The uncertain statistics of extreme waves mean that, according to reliability theorists, a severe deck impact is the most likely way in which an offshore platform may suffer a total loss. Oceanographers can now demonstrate that the statistically highest waves in the North Sea have increased in height by more than 5% in the past 10 years, resulting in production platforms suffering heavy-weather damage on a number of occasions. The total load on the deck is thus of great interest in the oil industry. In addition there are many situations when a moving body hits water, suffering loss of momentum, vibration, structural deformation and noise generation. This is particularly marked for bodies in free flight ranging from lifeboat launching to various ditching scenarios, e.g. aircraft, helicopters. There are similar experiences when high-speed marine vessels, such as hydrofoils, hovercraft and catamarans, hit surface waves.

Theories have been developed to predict slam forces assuming incompressible, inviscid flow ignoring gravity. Von Karman (1929) represented the immersion of a circular cylinder as an expanding flat plate with the water surface remaining flat. Wagner (1932) extended this approach for the wedge-entry problem by incorporating some local jet analysis. Self-similar solutions for wedge entry have been produced by Dobrovol'skaya (1969). Greenhow and Yanbao (1987) have applied these theories to the cylinder-slamming problem showing reasonable agreement with experiment. The approach ignoring free-surface distortion has been generalised by Cooker and Peregrine (1995) using the pressure impulse function and has been applied to wet-deck slamming by Wood and Peregrine (1996).

Previous experimental work has mainly considered the impact between a flat plate, wedge shape or circular cylinder on a flat water surface. Chuang (1966) and Verhagen (1967) both performed drop tests in still basins of water, with the cushioning effect of the trapped layer of air between the model and the water surface noted from the lower than expected pressure measurements of both experiments. In a more recent study Lin and Shieh (1997) examined the water impact of a cylinder by using a high-speed digital imaging system. The influence of waves is important in many problems and this has received little attention.

With this background results are reported from an experimental programme initiated to study the forces and pressures generated on a flat plate in free flight due to impact by a wave crest. Experiments were carried out in a wave flume that was 20 m long, 1.2 m wide with a maximum water depth of about 1 m and glass side panels along its length. Waves were generated by hinge-type paddle at one end and dissipated on a beach of 1:20 slope at the other. In order to launch a flat plate into the waves an aluminium frame structure consisting of four 6 m long parallel channels was constructed half way along the flume. The parallel channels act as guide rails for the wheels of a carriage to which the flat plate is mounted, ensuring that the plate is horizontal when it hits the wave surface. Results will be presented with the channel inclined at a steep angle of 80° to the horizontal so that the trolley is dropped almost vertically. Experiments have also been conducted with the track at an angle of 40° to the horizontal.

The elevation of the starting position can be varied to control the velocity of the body in free flight. The carriage is released by a pull rod activated by a pneumatic cylinder with an air supply controlled by a solenoid valve. The stainless steel flat plate has dimensions of 1.0 m by 0.5 m and is 12 mm thick. Steel ribs are bolted along its length to provide extra stiffness and reduce vibrations upon impact. Side plates are fitted to maintain nominally two-dimensional flow. A Kistler 8704B100 type Piezotron accelerometer is fixed centrally on the plate, allowing the slam force exerted by a wave on the plate to be calculated. Three Endevco 8530B-500 piezoresistive pressure transducers are mounted on the plate, with the tip of each transducer flush with the base of the plate. One transducer is always positioned at the centre of the plate while the others can be moved to other positions where mounting holes have been machined. Care was taken to ensure that the transducer response was sufficient to capture the transient nature of the impact. Water surface elevations at four locations ahead of the impact zone are measured using resistance type wave probes. The wave height, celerity and wavelength are thus obtained directly and information on the advancing wave profiles determines, through a computer program, the release time of the plate enabling the body to impact the surface at the desired point in the profile, the wave crest in this study. The velocity of the plate at the bottom of the track just before free flight was measured directly by photocell proximity sensors mounted on the rig. Output from the instrumentation is recorded at a rate of 20 kHz by a Data Translation DT304 data acquisition card mounted inside a Pentium PC. The sampling is triggered to begin by the plate breaking the beam of one of the photocell sensors.

A large number of parameter combinations were tested. For each case the runs were repeated 5 to 10 times to assess repeatability. As well as the velocity of the plate and the profile of the waves the effective mass of the plate was varied by bolting 10lb weights at four points on top of the carriage. Aerated water tests have also been performed to assess the effect of aeration on the impact forces and pressures. The air is supplied through a series of 18 porous plastic tubes attached to a 1.0 m × 0.8 m aluminium plate positioned on the bed of the flume underneath the impact zone. The tubes run the length of the plate and are spaced at intervals of 5 cm in the cross-stream direction. The rate of the air supply is controlled using a valve and the flow rate is measured with a direct reading flowmeter. The bubble diameter produced in the water column is approximately 3 mm.

Results from these tests suggest that the slam force is primarily dependent on the shape of the wave profile at impact (steeper waves providing less loading), the relative velocity between the plate and the wave and the mass of the plate. Analysis relating to the effect of aeration is ongoing and results will be presented for the first time.

A Kodak high-speed digital video camera was used to visualise the flow at impact. Recordings of 4500 frames per second were triggered by a photocell sensor. The jets produced at impact were found to have a fine droplet structure and a high velocity.

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