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Dynamics of steel offshore platforms under ship impact

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ABSTRACT

This paper deals with the prediction of the dynamic response of steel offshore platforms to high energy impacts from typical supply vessels. The contribution of the high modes of a cantilever beam type structure with a concentrated top mass subjected to transverse impact from rigid and deformable strikers is analysed. A procedure to develop simplified equivalent systems for efficient structural response analysis is presented and its reliability tested by comparing the results from the explicit non-linear FE simulations. Effects such as the overall rotation of the installation, plastic deformations in the contact area, different impact locations and different hinge mechanisms are taken into account. It is shown that the use of the proposed equivalent systems with a reduced number of DOF's can provide accurate results at significantly less computational efforts as compared to the FE simulations. The derivation of some parameters of the equivalent dynamic elastic–plastic SDOF/2SDOF systems, however, needs to consider the complexity of the analysed steel frames and perform preliminary non-linear static analyses. Therefore, further studies of different impact scenarios on platforms with different configurations are recommended to augment the results presented here.

1. Introduction

The exposure of offshore platforms to ship collision is treated by the current design codes for relatively low amounts of energy that are normally related to accidental berth manoeuvring of supply vessels. Some statistics of reported incidents in Ref. [1] refer the transfer of cargo followed by vessels that approach the installation and unloading operations as the most common type of activities that lead to collisions with the offshore installations. However, incidents involving passing vessels have also been recorded in the same report. The DnV design against accidental loads [2] used to require platforms to be designed for impacts with kinetic energies up to 14 MJ for side impacts or 11 MJ for head-on impacts, and more recently ship collision forces from supply vessels have been estimated for energies of 55–60 MJ, meaning higher impact velocities for a typical vessel with displacement comprised between 2000 and 5000 tonnes. It is also possible to assume that collisions might involve heavier ships surrounding offshore installation areas [3]. The energy of the impacts is the factor normally considered for platform design. While for instance the Health and Safety Executive [4] recommends that the platform shall contribute to energy dissipation with amounts of at least 4 MJ, the DnV code follows the share of energy upon the relative stiffness of the two structures in contact. The mechanisms that contribute to energy dissipation can be divided into local denting, beam bending, frame deformation or ship deformation. Not much from the design codes has been known with regards to beam bending due to axial loading, which represents another way of energy absorption. Some literature related to axial plastic energy of tubes can however be found in [5–8], providing some basis for hand-calculations that could meet the design requirements. The way how the different mechanisms contribute to the energy absorption will also depend on the impact point considered. The platform members that are affected by the impact, for reasons of simplicity and design purposes, are individually treated through hand calculations. While for local denting, bending or ship deformation the response is assumed to be governed by the plastic straining, for the global deformation of the platform the elastic straining might be significant. In order to resist higher energy collisions, platforms can be strengthened by increasing their members stiffness and increase the amount of deformation onto the ship as its energy absorption capacities are by far superior to the platform that the energy is mainly locally absorbed by dented legs or bent bracings, which lead to significant localized damage. For stiffer contacts with platform legs, the dynamic effects are expected to have some contribution to the platform response. The static approaches therefore have their own drawbacks. Amdahl and Eberg [9] compared the dynamic and the static effects for impacts between supply vessels and a four-legged jacket and a jack-up platform. Some conclusions from their study pointed out the importance of the collision point

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as well as the impact duration and the strength of the adjacent members as factors that might differentiate the static from the dynamic approach. The considered collision cases do not include, however, joint impacts for collisions against jackets. The contact was simply modelled through a single point connected to a spring with an attached mass point, which has some limitations in terms of capturing the local deformations in the contact areas.

In this study, through the use of non-linear FE models, the dynamic effects of high energy ship impacts are studied and compared. Based on the intensive simulation results, simplified methodologies that can be used for design purposes are suggested.

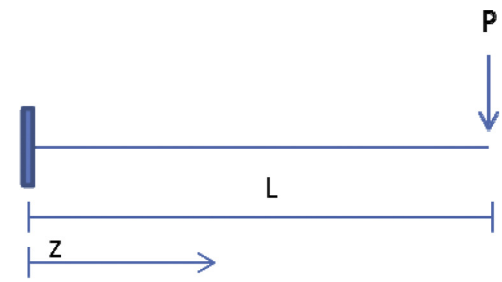

Fig. 1. Cantilever beam subjected to a transverse load at its free end.

2. Development of equivalent system for impact analysis

2.1. Background

It is common that in design structures are simplified to equivalent systems for efficient analysis. Usually some critical response quantities such as deflection of the structure are used as control parameters for deriving the equivalent system, i.e., these response quantities calculated from the simplified equivalent system should be similar to those of the prototype structure obtained from more sophisticated analysis or experimental tests. Finite element codes represent a reliable and popular tool for structural modelling, but are very demanding in terms of computation resources and time. For complex structures subjected to impact loads, simplified models can be developed considering the specifications related to the impact energy, impact velocity or local stiffness. The deformation of the striker can also interfere with the system response in ship impacts against offshore platforms. Simplifications/specifications regarding the material behaviour are equally often assumed in the analyses.

A proper analysis of the global response of a platform subjected to ship impact is easier to be performed if the plastic strains in the contact area are not significant. In other words, the structure responses primarily in global bending should be much straightforward to be analysed than the one with significant local damage from the contact. In Ref. [10] the analysis of beams subjected to transverse impact loads from an external rigid striker is developed through pseudo-dynamic techniques, involving a SDOF system and elastic contact between the striker and the beam. For the scope of the present work, some limitations would however be found concerning the impact speed, where the propagation phenomena must be included for higher velocities since the participation of higher modes might lead to a more complex structure deformation configuration that requires the uses of a higher number of degrees of freedom for reliable analysis. The striker deformation and the possibility of small nonlinearities are some of other factors that are taken into account in the proposed simplified modelling in this study.

2.2. Formulation of equivalent system

The adopted methodology in the current work for deriving the simplified equivalent system for analysis of platform response to ship impact is based on the Rayleigh–Ritz principle [11]. The approach is widely used in assessing the structural response to blast loading [12]. The solution for the loaded structure in question needs an expected deformed shape to be selected which satisfies the specific boundary conditions relating to the displacement. The strain energy per unit volume of material is then evaluated from the deformed shape and curvature, and the total strain energy of the element is calculated by integration.

For structures formed by a significant number and diversity of elements, their somewhat high degree of complexity suggests that the structure could be represented by a reduced number of degrees of freedom in order to reduce the computation time. Fixed steel offshore platforms are among the most representative offshore structures [13,14] and they are usually simplified to a cantilever beam for design analysis to estimate their structural response to transverse loadings.

The contact between the striking ship and the fixed structure does mainly vary due to the ship loading conditions which make it drift at different vertical levels. Nonetheless, and by considering both heights of vessel and platform and the sea level, the impact load is usually taken as applied at the platform top (or very near to the top) which, for a cantilever case, corresponds to the free end. For a given cantilever beam of length L, subjected to a transverse load P at its free end (Fig. 1), the approximate configuration of the elastic deformation, neglecting the transverse shear and the rotary inertia, can be easily obtained by integration of the bending moment equation as

$$EI \cdot u(z) = -\int_0^L \int_0^L (P \cdot z - P \cdot L)\, dz\, dz \tag{1}$$

where EI represents the flexural stiffness of the beam (E – Young Modulus; I – second moment of area of the beam cross section), z is the distance from the cantilever root and the constants resulting from the integration that are related to the boundary conditions of the beam are zero-valued for the illustrated case. The deformation of the beam, thus given as

$$u(z) = \frac{1}{EI} \cdot \left[-\frac{Pz^3}{6} + \frac{PLz^2}{2} \right] \tag{2}$$

can be normalized by its maximum displacement, measured at the free end

$$u(L) = \frac{PL^3}{3EI} \tag{3}$$

as

$$\phi(z) = \frac{u(z)}{u_{\max}} = \frac{u(z)}{u(L)} = -\frac{1}{2}\left(\frac{z}{L}\right)^3 + \frac{3}{2}\left(\frac{z}{L}\right)^2 \tag{4}$$

The equation of the elastic deflection can be re-written in the form:

$$u(z) = \phi(z) \cdot u_0 \tag{5}$$

in which u_0 is the free-end displacement.

The evaluation of the work done, strain and kinetic energy for the beam is then obtained as follows:

$$W = \int_0^L p(z) \cdot u(z)\, dz = \sum_{i=1}^{n} P_i(z_i)\phi(z_i)u_0 = \alpha_1 \cdot Pu_0 \tag{6}$$

$$E_s = \int_0^L \frac{M(z)^2}{2EI}\, dz = \frac{EI}{2} \int_0^L \left[\frac{d^2u(z)}{dz^2} \right]^2 dz = \frac{\alpha_2 EI u_0^2}{L^3} \tag{7}$$

$$E_k = \frac{1}{2} \int_0^L \rho A[\dot{u}(z)]^2\, dz = \alpha_3 L \cdot \rho A \dot{u}_0^2 = \alpha_3 M \dot{u}_0^2 \tag{8}$$