High-Energy Ship Collision with Jacket Legs

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ABSTRACT

Risk analysis of planned jacket installations has shown that collision with passing vessels, with a kinetic energy in the range of 40-50 MJ, is a potential hazard. This implies a vessel of 2-3000 tons displacement at a speed of 6-7 m/s. Bow collisions with passing vessels are normally not designed for, and no relevant information of bow strength for leg impacts is available. The objective of the present work is to establish similar design curves for bow impacts against jacket legs by means of non-linear finite element analysis. The penetration of a bow structure by a rigid cylinder representing a jacket leg is simulated. The curves, which are proposed being implemented in the NORSOK N-004 code, can be used for strength design of the platform. The use of the proposed design curves is illustrated in a case study of an actual platform subjected to ship collision on legs.

KEY WORDS: Jackets, high-energy collisions, design curves

INTRODUCTION

A major hazard to offshore structures is ship collision. The largest damage potential is associated with collision with large merchant vessels. Their kinetic energy is, however, so large that it is virtually impossible to design jackets for this event. The risk should instead be controlled by keeping the probability of occurrence acceptably low. Encounters with attendant vessels, on the other hand, have a rather high probability of occurrence, approximately 0.15 per platform year (Wicks et. al. 1992). To this end there has been no catastrophic failures, but rather severe accidents have taken place.

The concern for ship collision is reflected in various design codes. Since 1980 the Norwegian Petroleum Directorate (NPD 1984) requires that platforms normally be designed for impacts from supply vessels of 5000 tons displacement with a speed of 2 m/s, yielding a kinetic energy of 14 MJ for beam impact and 11 MJ for bow or stern impact, when specified values for hydrodynamic added mass (NPD 1984) are taken into account. The design is carried out in the Limit State of progressive collapse (PLS), i.e. local failures in the form of denting, plasticity, buckling etc. are allowed but the total integrity should not be put in jeopardy. In damaged condition the platform shall also be able to resist the design environmental forces, however, with all partial safety factors equal to unity.

Risk analysis of planned North Sea jacket installations, located close to lanes with heavy ship traffic, has identified collisions with passing vessels, with a kinetic energy in the range of 40-50 MJ, a potential hazard. This implies a vessel of 2-3000 tons displacement travelling with a speed of 5.5 - 6 m/s.

The number of collision scenarios with a passing vessel is infinite. The ship may hit the platform on the legs, on braces or both. In the present case a central leg impact is studied. This event has a relatively low likelihood of occurrence, but represents a potential worst case with respect to platform integrity; if the load carrying in a leg is lost, the topside may collapse entirely.

DESIGN PRINCIPLES

The ship collision action is characterised by a kinetic energy, governed by the mass of the ship, including hydrodynamic added mass and the speed of the ship at the instant of impact. If the collision is non-central, i.e. the contact force does not go through the centre of gravity of the platform and the ship a part of the kinetic energy may remain as kinetic energy after the impact. The remainder of the kinetic energy has to be dissipated as strain energy in the installation and, possibly, in the vessel. Generally this involves large plastic strains and significant structural damage to either the installation or the ship or both.

With respect to the distribution of strain energy dissipation there may be distinguished between

- strength design
- ductility design
- shared-energy design

As shown in Figure 1 the distribution depends upon the relative strength of the two structures (NORSOK (1998)).

Strength design implies that the installation is strong enough to resist the collision force with minor deformation, so that the ship is forced to deform and dissipate the major part of the energy.

Ductility design implies that the installation undergoes large, plastic deformations and dissipates the major part of the collision energy.
Shared energy design implies that both the installation and ship contribute significantly to the energy dissipation.

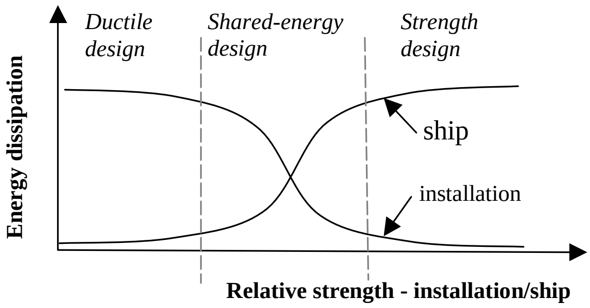


Figure 1 Energy dissipation for strength, ductile and shared-energy design

From calculation point of view strength design or ductility design is favourable. In this case the response of the «soft» structure can be calculated on the basis of simple considerations of the geometry of the «rigid» structure. In shared energy design the magnitude and distribution of the collision force depend upon the deformation of both structures. This interaction makes the analysis more complex.

As shown later, in the case of high-energy collisions against jacket legs, it is favourable to aim at strength design, i.e. the leg is made strong enough to crush the bow. Otherwise, the leg may be subjected to very large deformations.

FINITE ELEMENT ANALYSIS OF BOW-LEG IMPACT

It has not been customary to design against bow collisions with passing vessel. Little relevant information is therefore available on the deformation characteristics of bows colliding with legs. Appendix A in NORSOK N-004 (which in this respect is based upon DnV technical note TN 202 from 1981) gives force-deformation relationship for bow impact against large diameter columns (D > ~8 m). Use of this curve for analysis of impacts against typical jacket legs, with diameter in the range of 1.5 -2 m, is expected to be overly conservative, because the entire bow is not subjected to uniform, or approximately uniform, deformation. Furthermore, the curve from TN 202 is based upon simplified plastic analysis. Today, non-linear finite element codes provide tools, which are capable of producing force-deformation curves with significantly higher credibility

Consequently, energy dispassion in a ship bow is analysed with the computer code LS-DYNA (Hallquist, 1998). The finite element model of the bow, which is shown in Figure 2, is considered representative for vessels in the range of 2-5000 tons displacement. It is a generic model, in the sense that it is not a real structure. The bow superstructure is mainly taken from a real supply vessel, while the bulb is constructed on the basis of similar bulbs. The bulb is cylindrical with an almost elliptical cross-section, and represents a rather strong bulb. The rest of the foreship is also considered to represent a strong bow. Emphasis is placed on modelling all stringers and decks. Cutouts and manholes are excluded to some extent. This is conservative as concerns deformation and forces. The thickness of the shell plating and the deck plating is typically 11 mm and 8 - 9 mm, respectively.

A piece-wise linear, isotropic hardening material model is adopted. The stress-strain curve is shown in Figure 3. Mild steel is assumed, but the strength is slightly augmented to account for expected bias relative to characteristic value. Fracture is modelled as a decrease of the stress to a small, residual value. The strain rate effect is not included. On the other

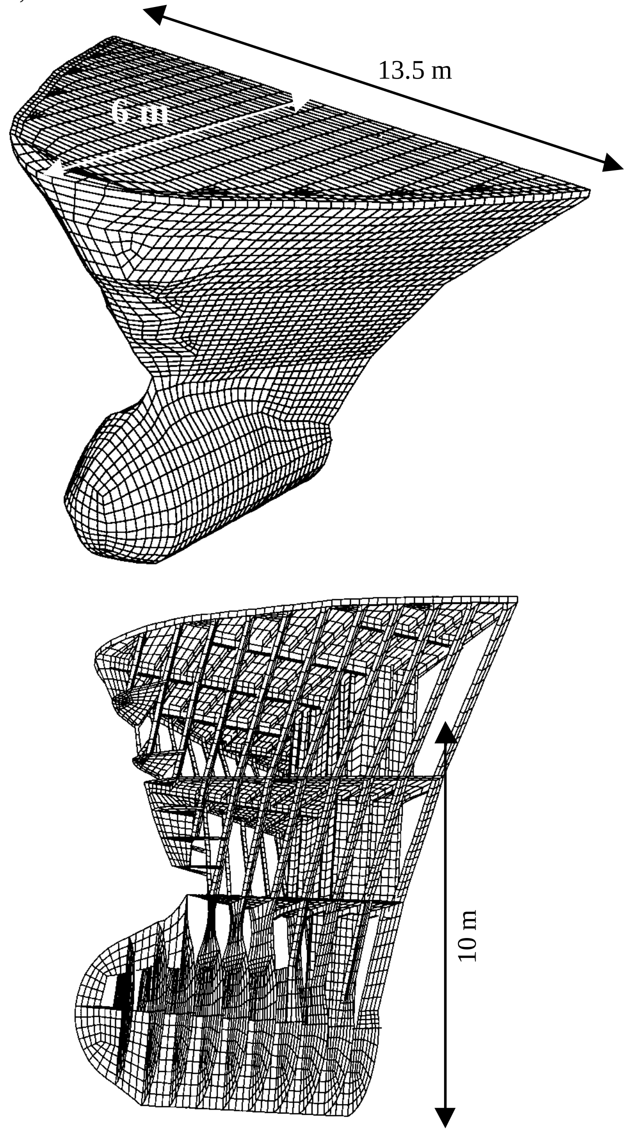


Figure 2 Bow model

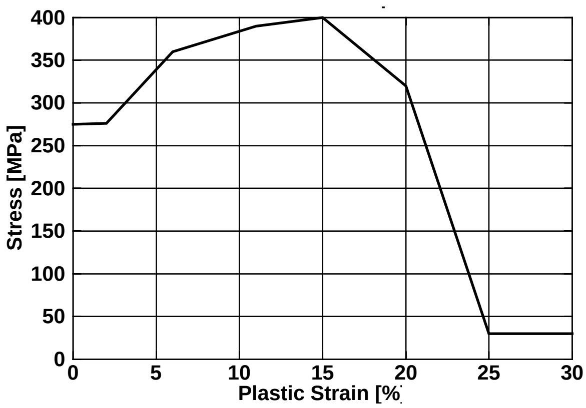


Figure 3 Stress-strain curve for ship material

hand, the finite element mesh is relatively crude, so that some overestimation of the crushing force is to be expected.

The bow of the structure is subjected to penetration by a rigid cylinder with a diameter of 2 m, representing the jacket leg. The column is given a relative speed of 2 m/s with respect to the bow. This is slower than in a real, high-energy collision, but inertia effects are small. This is particularly the case at the end of impact, when the maximum force occurs.

Load-penetration relationships for the bow with and without bulb are displayed in Figure 4, while Figure 5 shows the deformation in the bulbous bow at various stages of deformation.
In the case of no bulb, the force experiences a local maximum, ~12 MN, after 2 m penetration. Subsequently, the force level drops, and is not regained before ~ 4.2 m penetration. At this stage the bow has dissipated 25 MJ. It is intresting to observe that the force-deformation curve given in NORSOK for bow impact against large diameter columns lies above the present results. The curves are not directly comparable, because the bows are not identical. The trend is desirable, because the bow is subjected to uneven deformation over the width in jacket leg impacts.

With bulb the maximum crushing force is higher, ~20 MN, and occurs after 2.5 m penetratrion. Afterwards the force level drops and does not attain the same level for the deformation range analysed.

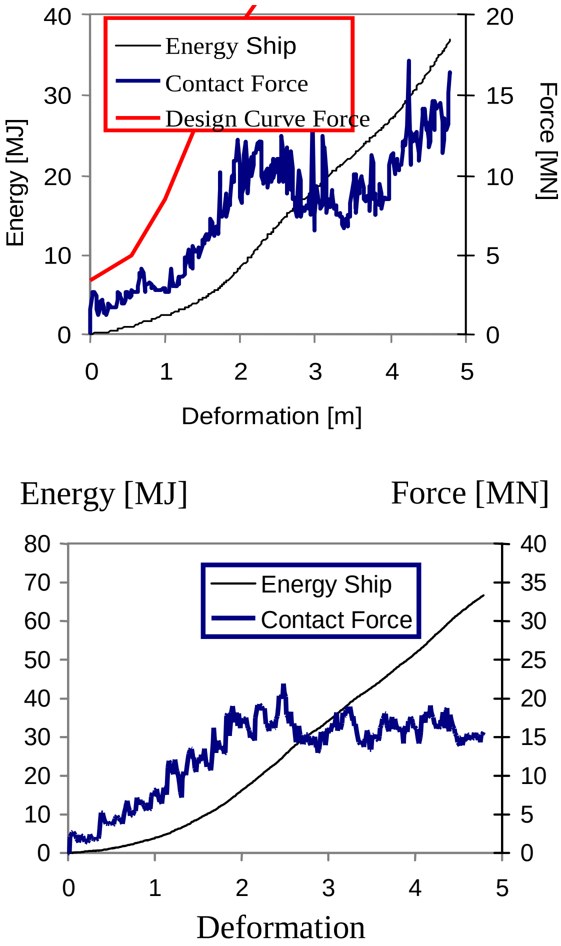


Figure 4 Load-deformation curve for bow without bulb (top) and with bulb (bottom)

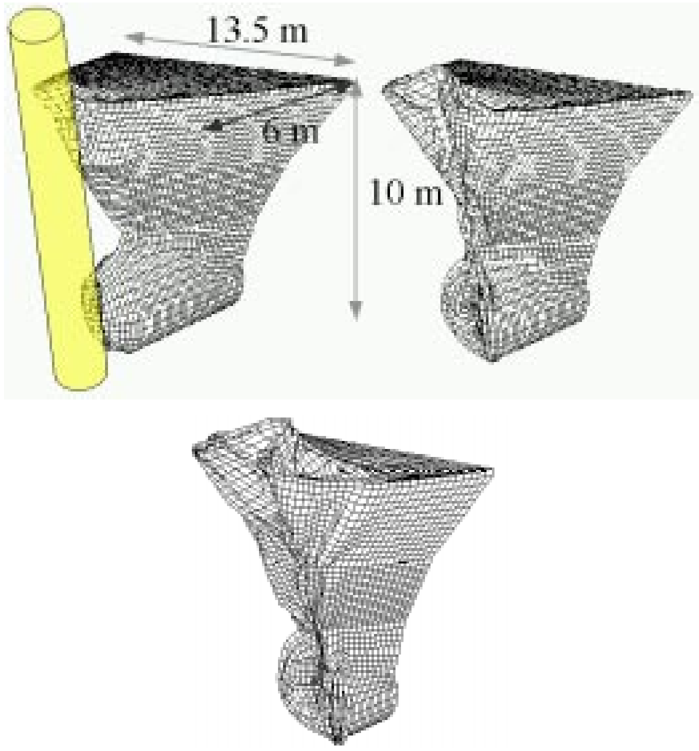


Figure 5 Bow model with bulb - deformations after 1.2 m, 2.4 m and 4.8 m penetration

CASE STUDY: JACKET LEG IMPACT

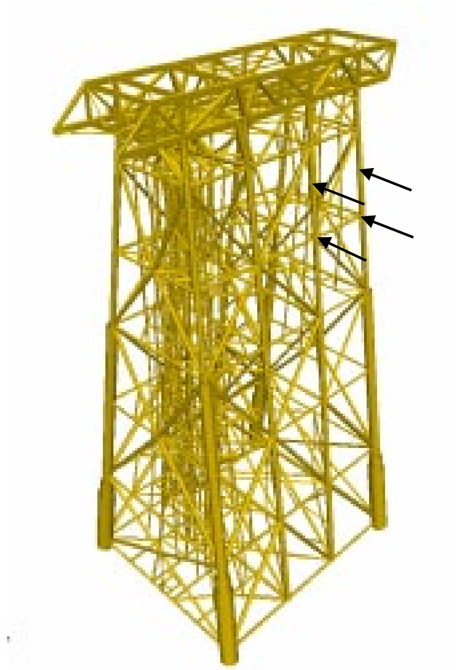
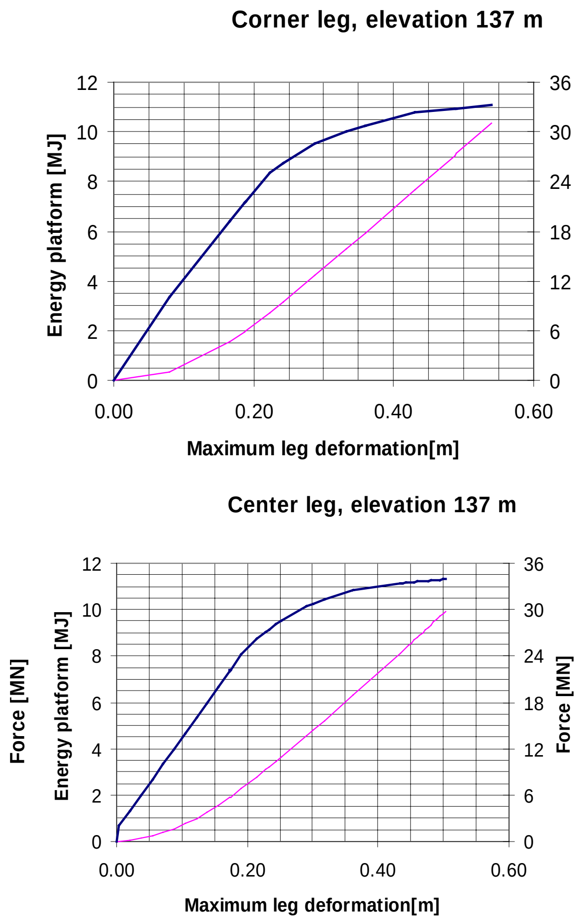


Figure 6 Impact on jacket legs

The structure shown in Figure 6 is representative for North Sea jackets in approximately 140 m water depth. Impact is considered on a corner leg and a centre leg. On both legs contact is assumed to take place on a joint (level 122 m) and midway between joints (level 137 m). Strictly, the joint is below the level normally considered being exposed to ship impact. It is investigated because it represents a hard point of the structure. The mid-span location should represent a weak point. The leg dimensions are 1800 x 70 mm. The force deformation relationship and energy dissipation for the four impact locations are shown in Figure 7. The response is linear up to 24-25 MN for impact mid-way between joints. A three hinge mechanism forms when the force is approximately 32 MN. For continuing plastic deformations, the strain in the plastic hinges grows fast. According to design formulas given in NORSOK the critical deformation with respect to fracture in the leg is 0.5 m for fracture strain of 0.15.The corresponding energy dissipation in the leg is limited to ~10 MJ, which is significantly smaller than the demand in high-energy collision.

For impact on joint the behaviour is linear up to 33 -35 MN. The maximum force level is slightly higher, 35-37 MN. Failure is triggered by collapse of braces supporting the joint as indicated for the centre leg in Figure 8. Because the mechanisms now extends over two storeys, the strains in the leg do not become critical (max. ~ 0.06 after 1 m deformation). The leg is therefore capable of absorbing at least 35-40 MJ.



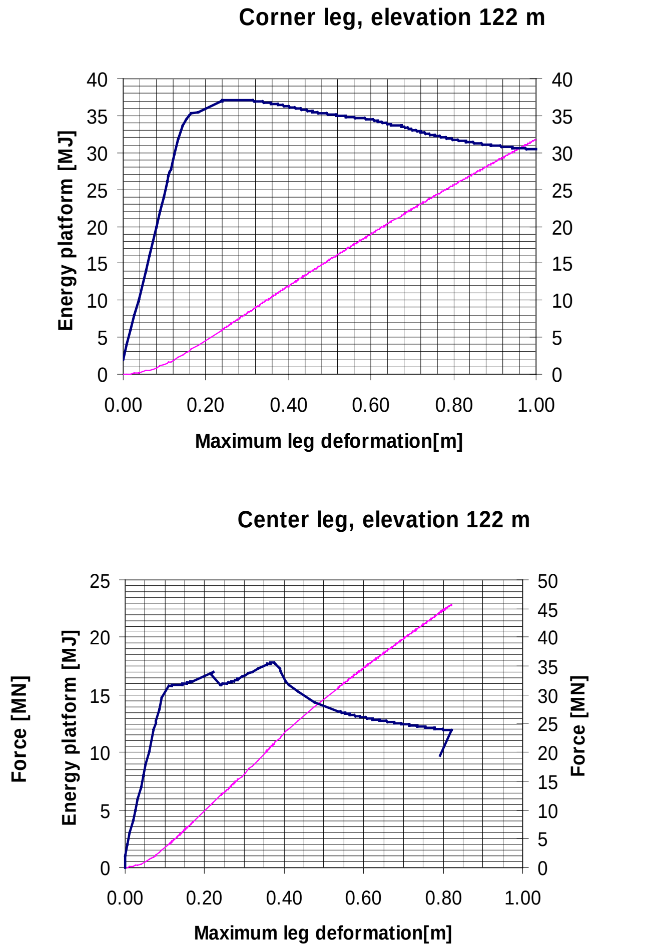


Figure 7 Force-deformation and energy dissipation curves in jacket.

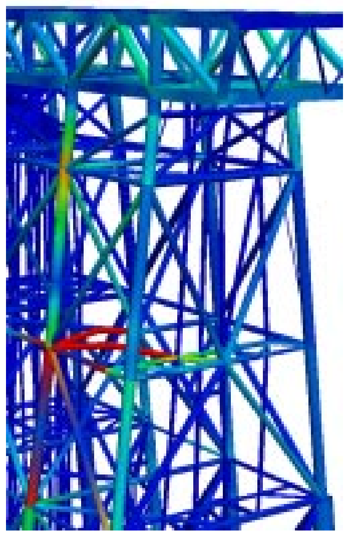


Figure 8 Collapse mode for joint impact on centre leg

Figure 9 shows results from pushover analysis of the platform in intact and damaged condition. The wave load is incremented up to global collapse in cases. It appears that the present structure experiences a very small drop in the capacity when a centre leg is removed, but almost

30 % when a corner leg is removed. This is still sufficient to resist the design environmental load with partial safety factors equal to unity. The actual structure satisfies therefore the NPD requirement to residual strength. The collapse mode for corner leg removed is illustrated in Figure 10.

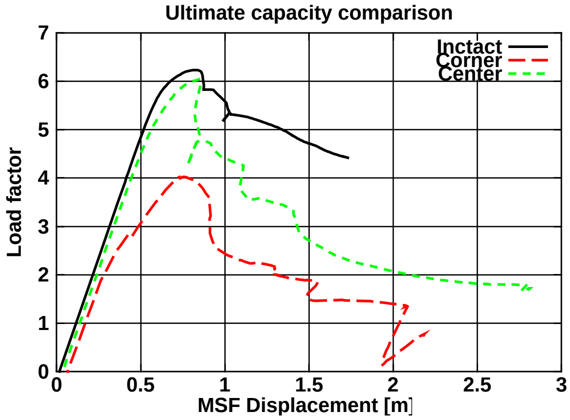


Figure 9 Pushover analysis - load factor versus deck displacement

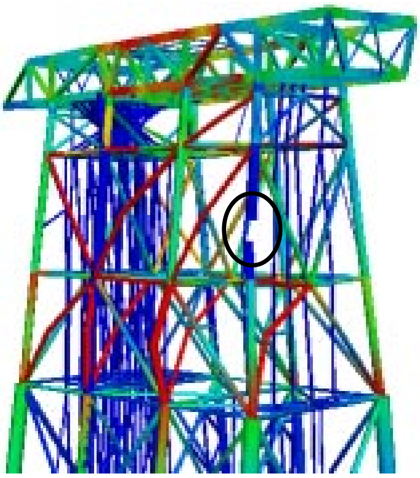


Figure 10 Pushover analysis - collapse mode for corner leg removed

DISCUSSION

The analysis of the actual platform shows that the ultimate strength of the leg is larger than 33 MN, with linear behaviour up to 24 MN or higher. Taking into consideration that the maximum force in the ship is less than 20 MN for a bulbous bow and less than 15 MN in the case of no bulb (for the deformation range analysed), it is likely that the platform will crush the bow. The energy dissipation is then governed by ship deformation and is at least 66 MJ for the bulbous bow and 37 MJ without bulb.

It is important that the leg is strong enough to crush the bow substantially, because the leg may dissipate as little as 10 MJ prior to fracture.

In addition to resisting the force globally, the leg should also resist the contact force without local denting. If denting occurs, the rigid cylinder assumption in the bow indentation analysis is no longer valid. The contact area becomes larger, and the resistance to penetration of the bow increases substantially.

The maximum concentration of the collision force in the bow indentation analysis is less than 1 MN distributed over an area of 0.16 x 0.30 m and less than 4 MN distributed over an area of 0.8 x 1.2 m. Simulating contact with a leg with diameter of 2 m and thickness 80 mm, no denting is observed. If the leg is subjected to a concentrated load, the capacity against denting is found to be 8.5 MN. Hence, it is concluded that a significant margin against local denting exists.

No attempt has been made to calculate the required leg thickness to ensure no denting. In lieu of more accurate information it is proposed to use ultimate strength formulas for tubular T-joints subjected to axial compression with $\beta = d/D = 0$. The NORSOK code gives a capacity of 5.1 MN compared to a calculated capacity of 8.5 MN, i.e. on the conservative side.

Residual strength analyses have been performed where the leg in the collision area is completely removed. This is conservative. For centre leg impact the reduction in capacity is very small, but for corner leg impact a substantial reduction, 30 %, is obtained. This may still be sufficient to survive the accident. The reason for the large damage tolerance is of course that most of the wave loads are taken up by the structure below the collision point.

CONCLUSIONS

The force deformation relationships established may be used for strength design of jacket legs against bow collisions of vessels with displacement in the range of 2000- 5000 tons and kinetic energy up to approximately 50 MJ. The curves should be fairly representative for a leg diameter in the range of 1.5 - 2.2 m. In addition to resisting the collision force, the leg should not be subjected to significant denting. In lieu of more accurate information a simplified criterion is proposed.

A case study of a jacket, representative of new North Sea structures, shows that high-energy collision design requirements may be complied with.

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