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DROPPED OBJECTS - IMPACT PROBABILITIES AND CONSEQUENCES

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ABSTRACT

In the assessment of the safety of offshore structures it is now necessary to determine the risk and consequences of damage and loss of life due to dropped objects. The resistance of the target area is assessed taking into account reserves of strength and energy absorbing capacity up to rupture and penetration by the object under a variety of failure assumptions.

The probability of penetration depends also on the probability that only weak areas of the target are hit. The paper describes methods of determination of ultimate target resistance and a new method for determining the probability of unfavourable impact is presented for irregularly shaped objects enabling significant reductions in the failure probability to be justified.

1 INTRODUCTION

This paper describes the scope and methodology used for the dropped object assessment of a major northern North Sea platform.

The problem is defined and the main definitions and assumptions are listed.

There are a number of excellent published papers on the subject which concentrate on the calculation of energy absorbing capacity of target structures[1,2,3] these aspects are discussed briefly in section 5.

The main development of this paper deals with the calculation of the probability of impact of dropped objects with beams and inter-beam plate. The prototype problem is the impact of a rectangular container with a repeating rectangular pattern of deck beams. The solution to the general problem of the calculation of the probability of impact of an irregular object of general shape with beams and point targets is described.

2 OBJECTIVES

The objectives of a typical dropped object assessment are as follows:

1. To determine the probability of a particular impact scenario.
2. To quantify the capacity of structural components to energy absorption in different regimes.
3. To establish whether a dropped object defeats the capacity of selected target areas on the platform.
4. To provide the maximum height of a dropped object that a target area may withstand without breach of its integrity.

3 PROBLEM DEFINITION

The target areas considered included:

The lift motor room.
The helifuel storage skid.
The roof of the accommodation module.
The external stairwells.

The dropped objects considered were:

A helicopter weighing 14,557 Kg.
Half a rotor blade of 64Kg at in–flight tip speed of 204m/s.
The helicopter engine turbine, weighing 2 tonnes.
The worst case scenario of a dropped object during lifting operations, this was a 9 tonne 20' container.

The SRI empirical formula[4] for determining the kinetic energy required for high velocity missiles with small masses and contact areas to penetrate steel plates was applied

Methods for determining energy absorption by structural components other than deck plating/cladding (e.g. plate girders, universal beams, stringers, etc.) were established.

The probability of impact of these objects with specific target structures was also determined and combined with the probability of the object being dropped to evaluate the risk associated with each of the above scenarios. The following section describes some of the methods used to calculate this impact probability.

4 PROBABILITY OF IMPACT

Consider an irregularly shaped dropped object as shown in figure 1a. The footprint or area which will be impacted is the projection of the object in a plane perpendicular to the direction of motion. In most realistic situations, the target plane is usually horizontal and the relevant projection is the plan view of the object.

The exact orientation of the object about the vertical axis will be unknown and this leads to the concept of the radial probability distribution function calculated as follows.

Choose a reference point in the body which may be the centre of volume or some symmetry axis. For each radial distance from this point calculate the probability that points at this distance are occupied by the body. This is analogous to spinning the body about its vertical axis. The function so generated is the radial mass distribution function '$P_r(r)$' given by:–

$$P_r(r) = \frac{1}{2\pi r}\int_o^{2\pi} r\rho(r,\theta)d\theta \qquad (1)$$

where r is the radial distance from the reference point
θ is the angle measured about the vertical axis
$\rho(r,\theta)$ is the density function for the body in the horizontal plane.

The radial mass distribution function for the body in figure 1a is shown in figure 1b. Here 'R_{min}' is the radius of the inscribed circle and 'R_{max}' is the radius of the superscribed circle, corresponding to maximum extent of the object from the reference point. $P_r(r)$ gives the probability of impact of a point target a distance 'r' from the reference point in the horizontal plane.

Often it is necessary to determine the probability of impact of the dropped object with a line target representing a beam or pipeline. This situation is shown in figure 2.

If the perpendicular distance 'r_p' from the reference point to the line is greater than R_{max} then the probability of impact is zero, if the perpendicular distance r_p is less than R_{min} then the probability of impact is one. For intermediate points the probability of impact with the line is given by the ratio θ_R/π, where θ_R depends on R_{max} and r_p and is as shown in figure 2.

For rows of parallel line targets the probability of impact with one or more beams may be calculated simply by combination of probabilities of non–impact. For a rectangular grid of beams, which is the situation which commonly occurs for deck impact, the probabilities may again be superposed i.e:–

Pr(contact with beams 1 or 2) = Pr(contact with beam 1) + Pr(contact with beam 2)

Pr(no contact with either set of beams) = 1 – Pr(contact with beams 1 or 2)
– Pr(contact with both beams 1 and 2)

and

Pr(contact with both beams 1 and 2) = Pr(contact with beam 1) x Pr(contact with beam 2)

A simple case of a rectangular object dropped onto a rectangular grid of beams will be examined to illustrate the method.

Consider a rectangular dropped object with length L and width W dropped at an arbitrary angle 'θ' about the vertical axis onto a deck composed of beams in a grid with separations A and B as shown in figure 3.

For the object to miss the beams the reference point must lie within a rectangle with sides (A–L') and (B–W'). Where:–

$$L' = L\cos(\theta) + W\sin(\theta) \qquad (2)$$

and

$$W' = W\cos(\theta) + L\sin(\theta) \qquad (3)$$

Hence the probability of the object missing the beams is (A–L')(B–W')/AB giving a probability of beam impact of one minus this value. The overall probability of beam impact at any angle θ is given by integration of the function over θ. Alternatively this final integration may be avoided if the radial mass distribution function '$P_r(r)$' for the rectangle is used.

Having obtained the impact probabilities the consequences of impact have to be assessed.

5 METHODOLOGY AND FORMULATION

A group of structural components put together (the **target**) may resist the energy of an impacting object (the **object**) in one of several ways which depend on the mass of the object, its contact area, velocity and energy absorbing ability.

In this study, each target was examined as a collection of members whose energy absorbing capacities were independent of each other. The failure of members was examined in shear, bending and tension as appropriate.

5.1 Definitions and Modes of Failure

Blunt Objects (termed 'Belly impact')

Energy absorbing modes by the target can include shear, plastic deformation and membrane action.

Sharp objects (termed 'Edge impact')

When a sharp–edged object hits a target, the energy absorbing failure modes in the initial impact are limited to shear. However, the sharp edged object may present a larger area after the initial penetration and allow global plastic deformation and membrane action to be included in the total energy absorption. Thus initial penetration may not be followed by total penetration of a sharp object, such as occurs when a container falls edge on.

Corner Impact

If a sharp edged object is dropped as the result of a rigging failure it may impact the target corner on. As the impact area is small, the target is unable to respond in a global sense as it does with edge or nose impact. The target then has to take the impact energy locally by elastic and plastic deformation and finally tensile rupture. We predicted that all large, sharp edged dropped objects are likely to **puncture** the roof plate if no deck beams are hit.

Total energy absorbing capacity

The analysis leads to the evaluation of the total energy absorption capacity of a target for a given type of impact together with the stated assumptions about which components of the target contribute to energy absorption. There will be no gross failure of any of the target components unless the total energy absorption capacity of the target is exceeded. For example, if a nine tonne container hits 10mm deck plate and two supporting stringers, the energy of the object will exceed the energy absorbing capacity of the plate but not that of the plate plus the stringers. **Complete failure** (see definition below) does not occur as the plate does not fail and the object does not fall through the roof, even though there may be gross local distortion.

This energy absorption capacity was compared with the kinetic energy acquired by the object in dropping from any given height. As a convenient measure of 'pass–fail' the height from which an object would have to be dropped to achieve penetration was calculated.

Failure and Complete failure

Failure of the target is deemed to have occurred when the object deforms the target but does not penetrate it completely. For example an object may penetrate deck plate but hang up on the deck beams, in this case the target has **failed** but not **failed completely**.

Complete failure of the target is where the object completely penetrates through the target. This would mean the dropped object ends up inside the accommodation module or in the case of the stair tower these items are not usable after the impact.

5.2 General Assumptions

Several general assumptions were made for the purposes of this work.

1. The potential energy gained by a dropped object is completely transformed into the kinetic energy of the object just before impact.
2. No energy is absorbed by the missile/dropped object on collision.
3. Energy dissipated in the form of heat or sound is ignored.
4. The kinetic energy is completely transferred to the target.
5. Minimum contact areas of the dropped objects were assumed so as to investigate the most onerous situations.
6. Composite action between connecting components of target areas (mainly deck beams and plating) was ignored. This conservatism is advisable as this composite behaviour cannot be guaranteed in practice.
7. The effective yield stress of steel may be enhanced by 20% to represent the increased strength of the material under high strain rates.
8. A maximum strain limit of 20% for steel before tensile tearing was assumed.
9. A maximum rotational angle of 10°, from the horizontal in the direction of the loading, of beams was assumed in determining the plastic capacity of deck beams and stringers.
10. Ultimate tensile strengths were considered where tension is the dominant local loading.
11. Impact normal to the target area surface was assumed.
12. No energy is absorbed by the adjacent supporting structural displacement.

5.3 Specific Assumptions

This Section lists the additional assumptions which are specific to particular scenarios.

5.3.1 Helicopter Crash

A helicopter rolls over the edge of the helideck onto the roof of the accommodation module; the fall height was taken to be 5m.

No energy is absorbed by the helicopter or goods stored on the roof.

The centre of gravity of the helicopter at impact is at the same elevation above the target area as it was above the helideck initially.

The dimensions were those of an EH101 helicopter.

5.3.2 Engine Turbine Impact

The dropped object is an engine of weight 2 tonnes and with a 900mm effective diameter.

The turbine engine is assumed to drop from a height of 8m after disintegration of the helicopter.

As the engine breaks loose it may have lateral kinetic energy, this is assumed not to contribute to penetration of the roof, and is not included in the penetration calculations.

No energy is absorbed by the engine upon impact.

5.3.3 Nine Tonne Container

The container has dimensions 1.2x2.4x6.1m.
No energy is absorbed by the container itself upon impact.
The centre of gravity of the container remains unchanged at impact.
Nose impact refers to a contact area=1.2x2.4m^2.
Belly impact refers to a contact area=1.2x6.1m^2.

6 RESULTS AND DISCUSSION

The energy absorption capacities of the target areas were obtained. The engineering assessment of the results was based on determining what constituted a lower bound for the energy absorption capacity of the target region. This energy absorption capacity was compared with the dropped object impact energy.

If a sharp edged object was dropped as the result of a rigging failure it was assumed to impact the target corner on from a lower initial height given by the rigging geometry. As the impact area is small, the target was unable to respond in a global sense as it did with edge or belly impact. The target then has to take the impact energy locally by elastic and plastic deformation and finally tensile rupture. We predicted that all corner impacts are likely to puncture the roof plate (of thickness up to 10mm) if no deck beams were hit.

The helicopter half rotor blade was treated separately[4] since its high kinetic energy is associated with a very high velocity and relatively small contact area.

For the helicopter crash onto the roof of the accommodation module. The results showed that, in the event of the helicopter nose-first impact in-between two main deck beams, there may be possible penetration of the deck plate. Other scenarios of helicopter crash on the roof indicated that the helicopter was stopped at the main deck beams. It was therefore concluded that no complete failure develops as a result of helicopter crash on the roof.

The edge on impact of a container on the roof will not cause complete failure if the container hits one or two stiffeners as well as the deck plate. If it hits 8mm deck plate and only one stiffener a container can cause complete failure i.e. go right through the roof.

In the case of the engine turbine dropping onto the roof, after disintegration of the helicopter, similar results are obtained. The dropped engine only completely fails the roof deck in the case of 8mm plate with only a single stringer being struck.

The case of a 9Te container dropping onto the external stair tower did not result in a global collapse of the stair tower. However the stair tower will become unusable. This was classified as a complete failure.

Calculations showed that half a rotor blade, travelling at an average linear velocity of over 150m/s with its small contact area, perforated all plating in its trajectory. The blade was treated as a hard missile which experienced negligible deformation during impact.

7 CONCLUSIONS

The energy absorption capacities of the target areas have been obtained. The engineering assessment of the results was based on determining what constituted a lower bound for the energy capacity, compared with the impact energy.

A method has been presented for the calculation of the impact probabilities of irregularly shaped objects with beams and stringers of a deck or roof structure. This was found to be crucial in reducing the calculated risk associated with complete roof failure to an 'acceptable' level.

This did not, however, prevent us from reducing these risks further to a level which was as low as reasonable practicable.

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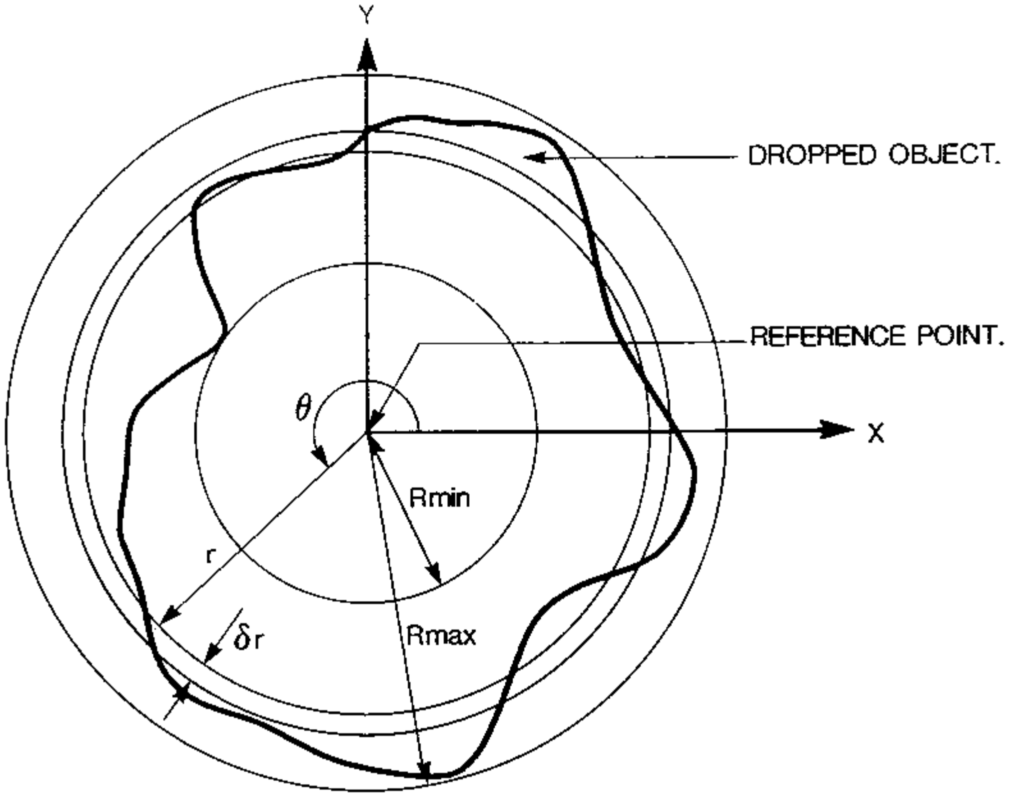


FIGURE 1a

IRREGULARLY SHAPED DROPPED OBJECT

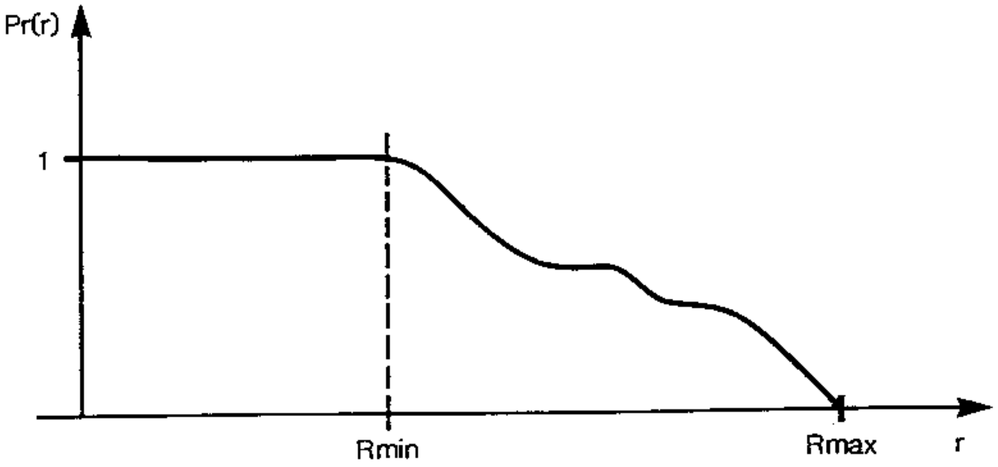
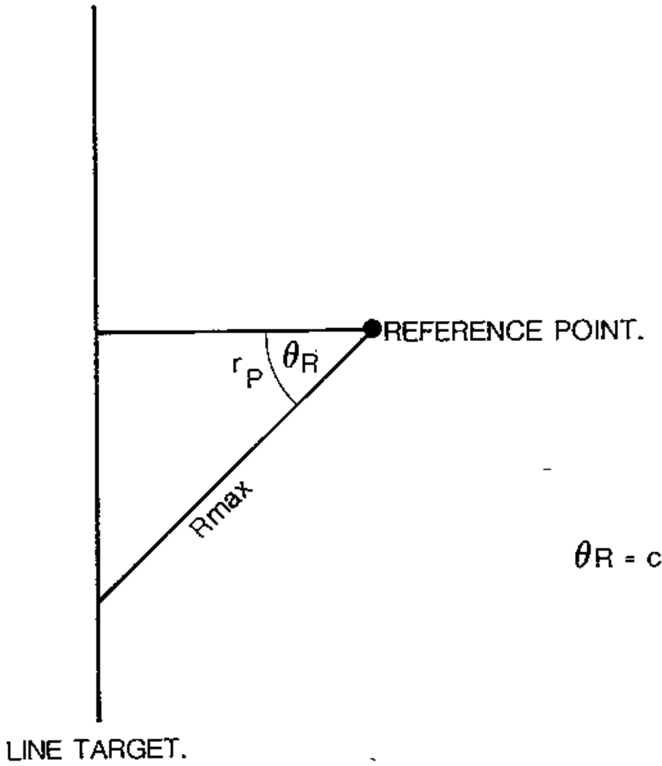


FIGURE 1b

RADIAL MASS DISTRIBUTION FUNCTION



$$\theta_R = \cos^{-1}\left[\frac{r_p}{R_{max}}\right]$$

FIGURE 2

IMPACT WITH LINE TARGET

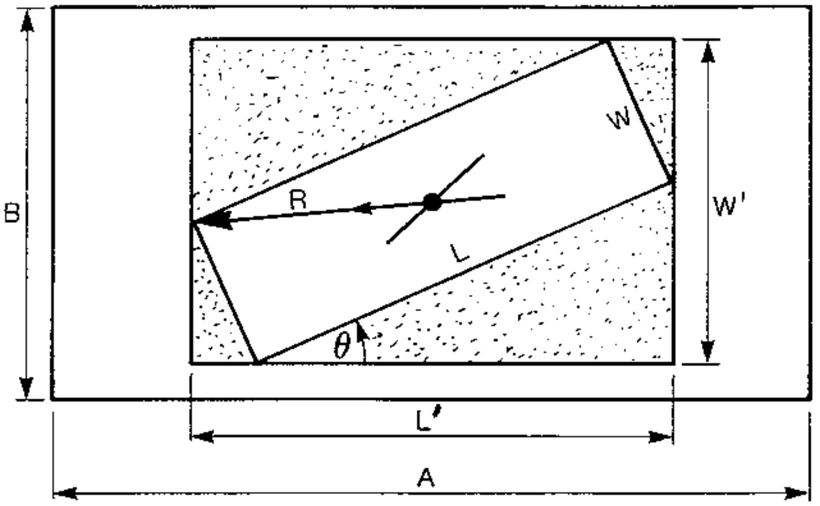


FIGURE 3

RECTANGULAR DROPPED OBJECT ON GRID

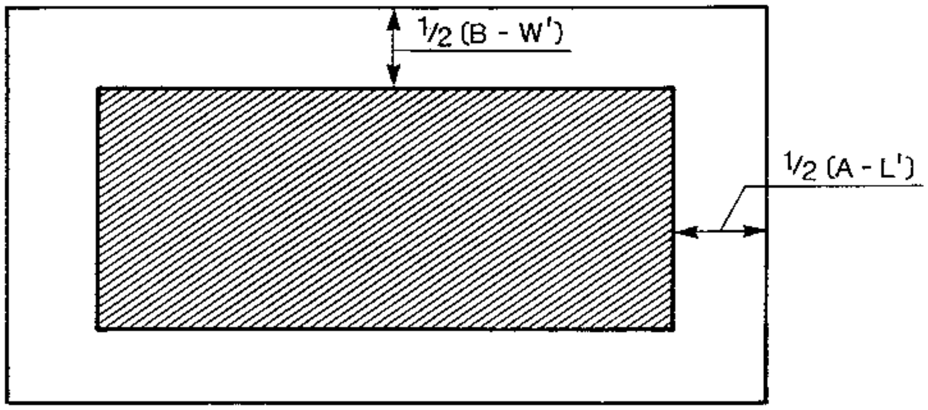


FIGURE 4

ALLOWABLE REGION FOR NO BEAM IMPACT