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Improved Methodology on the Safe Design of Offshore Exploration and Production Facilities for Accidental Collisions

Author(s):
Ali Sari, Ph.D., P.E., Ali.Sari@GenesisOilandGas.com
Hieu Nguyen, Ph.D., Hieu.Nguyen@GenesisOilandGas.com [1]
Watsamon Sahasakkul, Watsamon.Sahasakkul@GenesisOilandGas.com [1]
Umid Azimov, Umid.Azimov@GenesisOilandGas.com [1]
Amir Arablouei, Ph.D., Amir.Arablouei@GenesisOilandGas.com [1]
[1]Genesis, 11740 Katy Freeway, Houston TX 77079

Abstract

Accidental loads constitute the great majority of potential and actual fatalities in offshore drilling operations. An unplanned HSE (Health, Safety, and Environment) event has a great potential to cause permanent disablement or death to onboard personnel. Therefore, it is highly desirable to minimize or prevent the accidental incidents rather than risking an unexpected event. Among all types of accidental collisions, dropped objects can pose the highest risks to the personnel, equipment, and structures on an offshore platform. Other types of accidental collisions, such as ship impact, helicopter collisions etc., can also endanger the safety of offshore platforms, however, these scenarios are often underreported. In order to prevent human loss and for a safe design of an offshore platform, the risks of these accidental collisions should be quantified, in terms of probability/frequency and consequence aspects. The risk assessment quantifies the risk caused by accidental collisions including dropped objects on potential targets from topsides to seabed, helicopter transport risk for inflight crash and for take-off/landing crash on the platform, and a passing vessel collision based on influence factors for severe structural damage and loss of hydrocarbon.

This paper addresses the human and asset risk assessments against accidental collisions including dropped objects, helicopter collision, and ship impact in offshore operations. A new perspective on safe design of offshore structures for accidental collisions is outlined to estimate the associated risk to potential targets such as human personnel as well as platform decks, helidecks, jacket legs, risers, electrical cables, and pipelines. The frequencies and consequences of each modelled event are estimated to measure the overall risk to life in terms of IRPA (Individual Risk Per Annum), PLL (Potential Loss of Life), and WEV (Weighted Expectation Value). A risk matrix is utilized in mitigation decision as high impact frequency and high consequential events require mitigation strategies. The proposed assessment methodology will contribute towards identifying the mitigation measures and safety-critical procedures and equipment.

Nomenclature

DO	Dropped Object
DOA	Dropped Object Analysis
DNV	Det Norske Veritas
FE	Finite Element
FEA	Finite Element Analysis
HSE	Health, Safety, and Environment
IR	Individual Risk
IRPA	Individual Risk Per Annum
OGP	Oil & Gas Producers
PLL	Potential Loss of Life
POB	Personnel On Board
TLP	Tension Leg Platform
TO/L	Take-off & Landing
WEV	Weighted Expectation Value
WOAD	Worldwide Offshore Accident Databank

1. Introduction

In offshore drilling operations, the three main types of accidental collisions include dropped objects, helicopter collision, and ship impact. Among the three, the dropped objects are the highest threat and have constituted the great majority of potential and actual fatalities in offshore drilling operations. According to Ref. (1), overall dropped objects account for approximately 60% of high potential incidents. As an example, a 10 lbs object dropped from 10 ft can potentially cause fatality. Statistics indicate that 50% of dropped object incidents occur above platform deck and wellhead, where the fatality risk is high. Tubular, overhead equipment, and tubular handling equipment items have accounted for the majority of the dropped object categories. The consequences of dropped object may include but not limited to human fatalities / injuries, offshore asset damage / failure, and environment / reputation and business impact. The objective of a dropped object assessment is to minimize the risk associated with the consequences listed above.

Although having less frequency of occurrence, a helicopter collision is directly related to potential loss of life of personnel on the helicopter and on the asset that the helicopter collides with. The associated consequences are always high because of the likelihood of human fatalities. For helicopter transportation, risk is presented in terms of IRPA and PLL using fatal accident rate per flight stage (one take off, one landing and single journey to or from the platform). A good reference for the frequency of fatal helicopter accidents and deaths per fatal accident is the OGP Aviation transport accident statistics Report No. 434-11.1 (2).

Ship collisions may be caused by either passing vessels or field related traffic. According to the OGP Ship/Installation Collisions Report No.434-16 (3), passing vessels are ship traffic which is not related to the installation being considered, including merchant vessels, fishing vessels, naval vessels and also offshore related traffic going to and from other installations than that being considered. For passing vessels, collision risk is highly location dependent due to variation in ship traffic from one location to another. Field related offshore traffic refers to those vessels which are specifically visiting the installation, and is therefore considered to be less dependent of the location of the installation. The frequency of infield vessel impacts will depend on the durations that vessels are alongside, the installation layout, environmental conditions, and procedures.

Risk assessment of accidental collisions involves two aspects: the probability/frequency analysis and consequence analysis. The frequency and consequences of an event are used against a risk matrix to assess the risk level associated with the event. High frequency and high consequence events require mitigation strategies. For example, to mitigate the consequence of dropped object to a topside methanol tank, a protection structure may be required and must be designed to sufficiently absorb the impact energy from the dropped object.

2. Methodology

A safe design of offshore exploration and production facilities for accidental collisions requires the risk assessment of such events. Like any other risk assessments, the accidental collision assessment evaluates both the frequency of the risk (likelihood of the event) and the consequence of the event (human fatalities, structural integrity of the platform, impacts on environment, company reputation, and business). The following sections will discuss our approach for the frequency and consequence analyses for the risk assessment associated with dropped objects, helicopter collision, and ship impact.

2.1 Frequency Analysis

Dropped Objects

There are often three types of dropped object analyses categorized based on the locations and targets of the drop. These include Topsides DOA, Substructure DOA, and Subsea DOA, as illustrated in Figure 2-1. Topsides DOA generally covers the topsides of the platform, i.e., main and production decks of a platform or vessel decks. The targets include deck structural members (primary and secondary steel, deck plates), topsides equipment (e.g., fire water pump, diesel generators, etc.), laydown areas, stair towers, etc. Substructure DOA generally covers the components below topsides to above seafloor. The targets include top of TLP columns, pontoons, tendons, export risers/cables, jacket legs (fixed platforms), etc. Subsea DOA covers the architecture on the seafloor. Its targets include subsea pipelines, subsea cables, subsea architecture, and equipment such as wellheads.

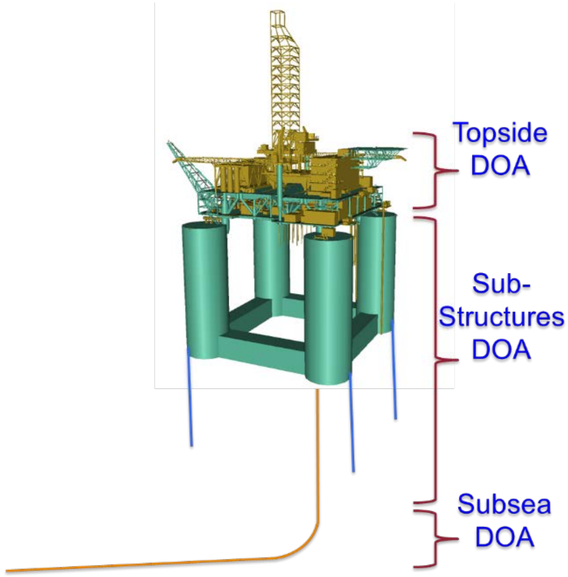

Figure 2-1: Three Types of Dropped Object Analysis (DOA).

In this paper the approach for dropped object frequency analysis is based on an extension of the approach outlined in DNV-RP-F107 (4). This approach uses a two-stage Monte Carlo simulation technique to estimate impact probability at different levels from the main deck to the seafloor. The frequency of impact due to each dropped object is calculated by adding drop frequency and number of lifts per year to the impact probability. The cumulative impact frequency for each target is estimated by summing the values over the areas occupied by the target, i.e., taking integral. Impact energy at any level can be calculated based on the velocity at that level which can be linearly interpolated from the surface impact velocity and terminal velocity. The sea surface impact velocity is equal to square root of 2 times the product of the drop height and the gravitational acceleration. The terminal velocity is the velocity attainable by an object as it falls through the water column. It occurs once the sum of the drag force and buoyancy equals the downward force of gravity acting on the object.

The two-stage Monte Carlo simulation method is illustrated in Figure 2-2. The first stage occurs on the sea surface (or on the main deck if desired). In the first stage, a random variable pair (R_1, θ_1) based on the drop point distance and angle with respect to the crane position are used. Crane extension, R_1, is sampled from normal distribution, constrained by crane minimum and maximum radii. Crane rotation, θ_1, is sampled from uniform distribution, constrained by crane lifting arc as seen in Figure 2-3. The second stage can occur at any level Z from the sea surface to the seabed. Similarly, in the second stage, a normal probability distribution of the impact point on level Z that is centered at the drop point on the sea surface is used. The point of impact at the level Z is sampled using a normal distribution of the extension R_2 based on DNV-RP-F107 approach and a uniform distribution for the rotation angle θ_2 (0-360 degrees). The parameters, for example the angular deviation, for the normal distribution of the extension radius are based on water depth, weight, and shape of dropped objects. Dropped object angular deviations as recommended by DNV-RP-F107 and used for calculating the dropped object lateral excursion are summarized in Table 2-1. The definition of the angular deviation is shown in Figure 2-4.

Figure 2-5 shows the illustration of discretization of impact area on seabed (or any level Z) into 1mx1m cells. 1,000,000 drops were simulated for each dropped object at different levels along water depth. Impact probability in each 1mx1m cell was calculated as the number of hits in the cell divided by the total number of hits (1,000,000). Impact frequency per unit area per year is then equal to the impact probability multiplied with drop frequency and number of lifts per year and adjusted for cell size and dropped object size (see equations below Figure 2-5).

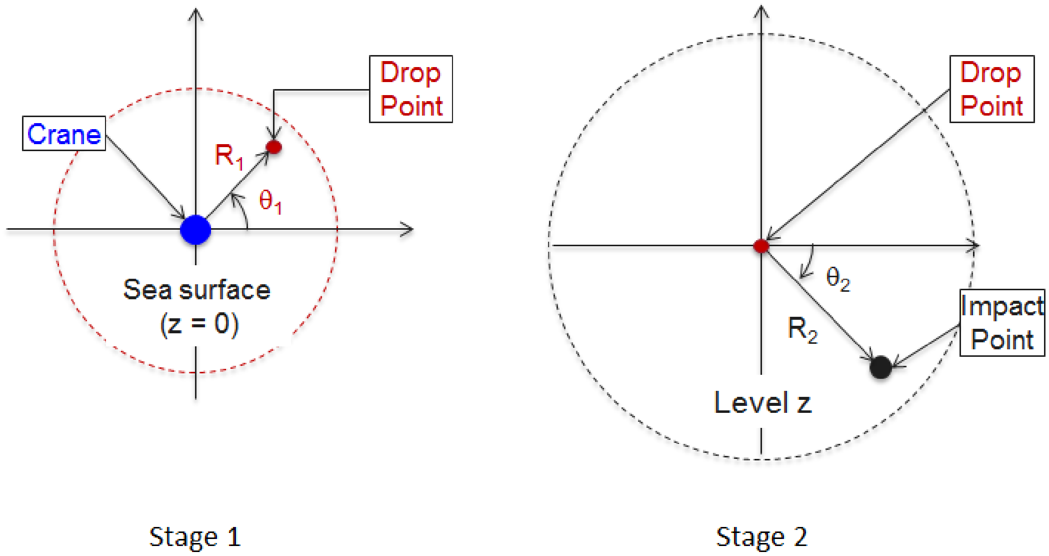

Figure 2-2: Two-Stage Monte Carlo Simulations.

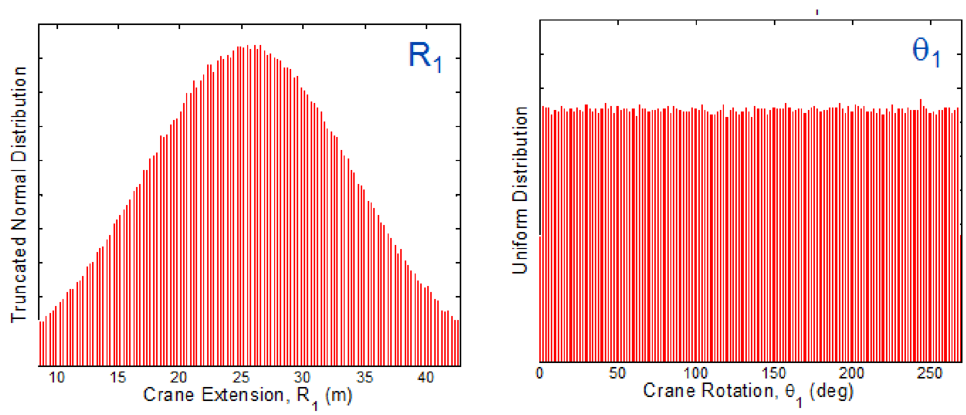

Figure 2-3: Normal and Uniform Distributions for R_1 and θ_1.

Table 2-1: Angular Deviation of Dropped Objects (4)

Object Description	Weight (tonnes)	Angular deviation (α) (Deg.)
Flat/long shaped	< 2	15
	2 – 8	9
	> 8	5
Box/round shaped	< 2	10

	2 – 8	5
	> 8	3
Box/round shaped	>> 8	2

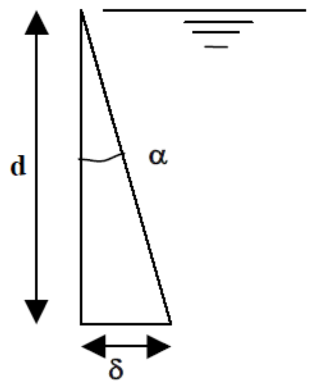

Figure 2-4: Angular Deviation Definition (4)

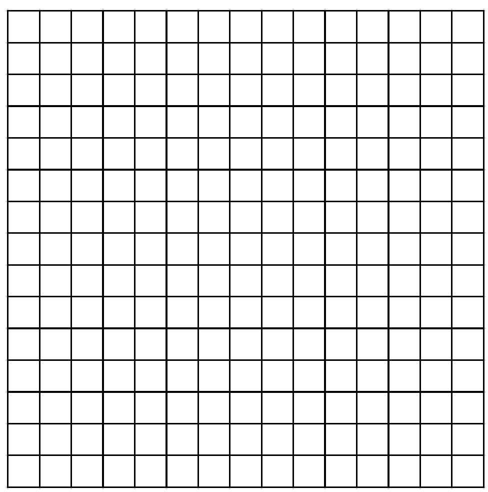

Figure 2-5: Illustration of Discretized Impact Area on Seabed (or any Level Z)

$$\text{ImpProb} = \frac{\text{Num Hits}}{\text{Total Hits}}$$

$$\text{ImpFreq} = \text{ImpProb} \times \text{Drop Freq} \times \text{Num Lifts} \times \frac{A_{DO}}{A_{Cell}}$$

where: A_{DO} = Dropped object impact area; A_{Cell} = Unit cell area

In the equations above, the drop frequency is often based on industry guidelines or standard such as DNV-RP-F107 or OGP Report 434-8 (5). For example, lifts performed using the drilling derrick are assumed to fall only in the sea, and with a dropped loads frequency as for ordinary lifts with the platform cranes, i.e., 2.2E-05 per lift (4).

Helicopter Collision

The frequency analysis of a helicopter collision assessment can be carried out based on the OGP

Aviation transport accident statistics Report No. 434-11.1 (2). The analysis assesses the frequency associated with helicopter crash during transit, take-offs, and landing and helicopter impact on the platform after falling off from the helideck. The analysis is performed deterministically by considering the frequency of fatal helicopter accidents and fatalities, helicopter risk parameters from operation and transportation per trip and probability of impact.

The overall approach for conducting the helicopter crash risk assessment involves the following steps: (1) describe study basis, (2) review operating procedures, (3) determine frequency, (4) assess individual risk, and (5) calculate potential loss of life.

Step 1: Study Basis

In the describing study basis step, the location of the asset is an important parameter. The following information forms the basis for the helicopter crash risk analysis:

- Location of the platform and the shore base with respect to established flight paths, helicopter approaches, and distance
- Number of flights per annum
- Number of stages per flight
- Helicopter passengers per flight
- Number of take-off and landings per annum
- Number of flight hours per annum

Step 2: Operating Procedures Review

In the reviewing operating procedures, information on aircraft flying to and from the asset such as emergency landing speed, number of operational personnel on the platform will be collected.

Step 3: Frequency Determination

The frequency of fatal helicopter accidents and deaths per fatal accident are determined based on the OGP Aviation transport accident statistics Report No. 434-11.1. Risks of helicopter transportation are presented as well in term of in-flight and take-offs/ landing. Relevant accident statistics from OGP are shown in Table 2-2.

Table 2-2 – Helicopter Accident Data based on OGP Report No. 434-11.1 (2)

Flight Accident Data	Value
Risk per hour in flight	8.5×10^{-6} per flight hour
Risk per take-off & landing	2.7×10^{-6} per flight stage
Probability of fatal accident – in flight	0.74
Probability of fatal accident – take-off & landing	0.24
Probability of death in a fatal accident – in flight	0.87
Probability of death in a fatal accident – take-off & landing	0.49

Step 4: Individual Risk Assessment

Individual risk is calculated on the basis of the equations below and the parameters given in

Table 2-2. The individual risk is the chance of an individual becoming a fatality and the potential loss of life is the individual risk for the aggregate platform operations personnel exposed to the collision. The following model is proposed in Ref. (2):

IRPA = In-flight IR + Take-off & landing (TO/L) IR

In-flight IR = Accident frequency in-flight (per hour) ×

Flight time (hours) ×

Probability of fatal accident ×

Probability of death in fatal accident

TO/L IR = Accident frequency in TO/ L (per flight stage) ×

No. of flight stages per journey ×

Probability of fatal accident ×

Probability of death in fatal accident

Step 5: Potential Loss of Life Calculation

Helicopter PLL is calculated to represent the individual risk for the aggregate platform operations personnel exposed to helicopter transportation between the shore base and platform across the project life. PLL can be used to evaluate and compare between options of helicopter risk reduction measures.

PLL = IRPA × Number of crew × flights/crew × passengers/flight

Ship Impact

If the marine traffic information around the platform being considered is not available, the ship traffic data of field related offshore traffic can be taken from the OGP statistical accident data (3).

The overall approach for conducting the ship collision frequency analysis involves the following steps: (1) Overview of historical ship/installation collision information, (2) Field related traffic vessels review, (3) Damage level of ship collision, (4) Collision frequency, (5) Probability of ship collision, (6) Individual risk calculation, and (7) Potential loss of life calculation.

Step 1: Overview of historical ship/installation collision information

Worldwide Offshore Accident Databank (WOAD) provides collision incidents worldwide during 1980-1989 and 1990-2002. Number of collisions and number of exposures from infield vessels colliding the platform have been estimated using WOAD data and are provided in Table 2-3. Ship collision frequency can be calculated from the ratio of number of collisions to the number of exposures. From Table 2-3, it is seen that the number of infield vessel collisions have considerably reduced from the 1980 – 1989 period to the 1990 – 2002.

Table 2-3 – Worldwide Collision Data of Infield Vessels during 1980-1989 and 1990-2002 (3)

Parameter	During 1980-1989	During 1990-2002

Number of collision	103	86
Number of exposure	56243	97627
Collision frequency	1.8×10^{-3}	8.8×10^{-4}

Step 2: Field related traffic vessels review

Offshore related traffic vessels are to visit and serve the installation. Examples of offshore related traffic vessels are standby vessels, supply vessels, and working vessels. Table 2-4 provides examples of the categories of colliding vessels.

Table 2-4 – Categories of Colliding Vessels of Fielded Related Traffic (3)

Traffic Category	Vessel Category	Remarks
Offshore traffic	Standby vessels	Dedicated standby vessels
	Supply vessels	Visiting supply vessels
	Working vessels	Special services/ support such as diving vessels, pipelay, barges, intervention vessels, and crane barges

Step 3: Damage level of ship collision

Damage level of collision due to ship/vessel traffic is one of the factors to define level of individual risk of ship collision in term of impact frequency. These damage levels also help to quantify damage frequency of ship collision due to variations of use of vessels around platform area. Definition of each damage level is provided in Table 2-5.

Table 2-5 – Damage Level of Ship Collision (3)

Damage Level	Definition
Total loss	Total loss of the unit including constructive total loss from an insurance point of view. However, the unit may be repaired and put into operation again.
Severe damage	Severe damage to one or more modules of the unit.
Significant damage	Significant/ serious damage to module and local area of the unit.
Minor damage	Minor damage to single essential equipment; damage to more none-essential equipment.
Insignificant damage	Insignificant or no damage; damage to part(s) or essential equipment.

Step 4: Collision frequency

The frequency of ship collision accidents can be determined by using the WOAD data taken from OGP Risk Assessment Ship/ Installation Collision Report No. 434-16. Example of accident statistics from OGP 434-16 are shown in Table 2-6.

Table 2-6 – Ship Collision Accident Data for Risk Estimation Model (Example) (3)

Ship Collision Accident Data	Value
Risk of collision per installation-year	8.8×10^{-4} per year
Geographical variation of infield vessel collision frequencies	0.17

Step 5: Probability of ship collision

According to Ref. (3), the probability of collision by vessel types is presented in Table 2-7. For a TLP, the fraction of damage levels by vessel types are provided in Table 2-8. Working vessels and supply vessels pose a higher threat to offshore platforms than standby vessels.

Table 2-7 – Probability of Collisions Events given Vessel Type (3)

Vessel Type	Value
Supply vessel	0.34
Standby vessel	0.19
Working vessel	0.34

Table 2-8 – Fraction of Collision Damage Levels by Vessel Type (3)

Vessel Type	Damage Level				
	Total Loss	Severe	Significant	Minor	Insignificant
Supply vessel	0.00	0.00	0.50	0.50	0.00
Standby vessel	0.00	0.00	0.00	0.00	1.00
Working vessel	0.00	0.33	0.00	0.33	0.33

Step 6: Individual risk

IRPA is the chance of an individual becoming a fatality. Ship collision individual risk is calculated as below based on the information given in Table 2-3 to Table 2-8.

$$IRPA = \textit{Collision frequency (per year)} \times \textit{Probability of collision events by vessel type} \times \textit{Probability of damage level by vessel type}$$

Step 7: Potential loss of life

PLL is calculated to represent the individual risk for the aggregate platform operations personnel exposed to ship/marine collision. During normal operations, the number of personnel on board (POB) can be assumed with 100% platform occupancy for conservatism.

$$PLL = IRPA\ x\ POB$$

2.2 Consequence Analysis

The consequence of an accidental collision event can be assessed in terms of human fatalities / injuries, asset damage / failure, or environment / reputation / business impact. For the safe design of offshore exploration and production facilities against accidental collisions, the structural integrity consequence is of interest. This section discusses the use of structural analysis for consequence aspect of accidental collisions.

The structural consequence of an accidental collision to an offshore asset is predicted using either simplified approach (if applicable) or advanced finite element (FE) modeling. The FE approach is often used to remove the conservatism in the simplified approach. Advanced nonlinear dynamic structural analysis is capable of taking into account the effects of dynamic loading, geometric nonlinearity, material nonlinearities (strain rate effects, dynamic increase factor), and contact nonlinearity. Since collision loads are accidental loads, structural response of the targets is not expected to remain in the linear elastic range. Certain damage, i.e., material permanent plastic deformation, is allowed to absorb the impact energy. Hence, advanced finite element analysis (FEA) is more applicable in the design against collision loadings. A general finite element package such as Abaqus (6) is suitable for this type of analysis and was used for all of the consequence analyses in this paper. If the targets can absorb the impact energy and damage caused by the impact is acceptable or tolerable (performance criteria), no action is required. However, if the performance criteria are not met, either the targets have to be re-designed or protection structures need to be provided.

Geometry Modeling

In FEA, impactors, i.e., dropped objects, ships, helicopters, are usually modeled as rigid bodies with the initial impact velocity. The corresponding impact energy is equal to one half of the impactor's mass multiplied by the square of the impactor's velocity. If the impact happens in water, other factors such as added mass have to be accounted for. The targets of the collision are often modeled as a deformable body with shell or solid elements. In this rigid impactor – deformable target set up, the impact energy is dissipated conservatively only through the plastic strains (unrecoverable deformation) of the impacted target.

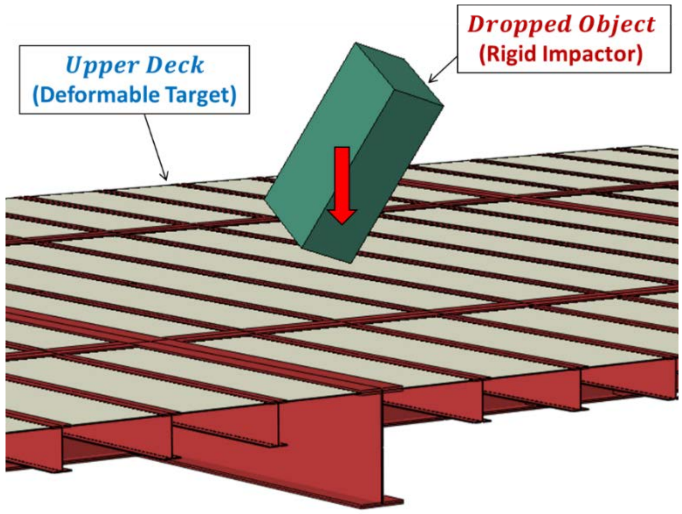

Figure 2-6: Example Abaqus FE Model: A Rigid DO Impacting a Deformable Deck

Material Modeling

Excessive deformation is expected during accidental collision event. It is likely that structural components undergo large plastic deformation, even failure. Hence material plasticity/failure must be modeled to capture these nonlinear effects. Since impact loading happens in very short duration of time, rate-dependent plasticity should be taken into account. Figure 2-7 presents stress-strain relationships up to fracture for low-carbon mild steel at different strain rates (7). Yielding stress is also sensitive to strain rates, especially for high strength steels. Increase in yield strength due to strain rate effects is characterized by a dynamic increase factor. In Figure 2-8, the dynamic increase factor for yield strength versus strain rate is plotted for a mild steel (ASTM A36 steel with static yield stress of 250 MPa) and for a high strength, quenched and tempered steel (ASTM A514 steel with yield stress approximately 760 MPa).

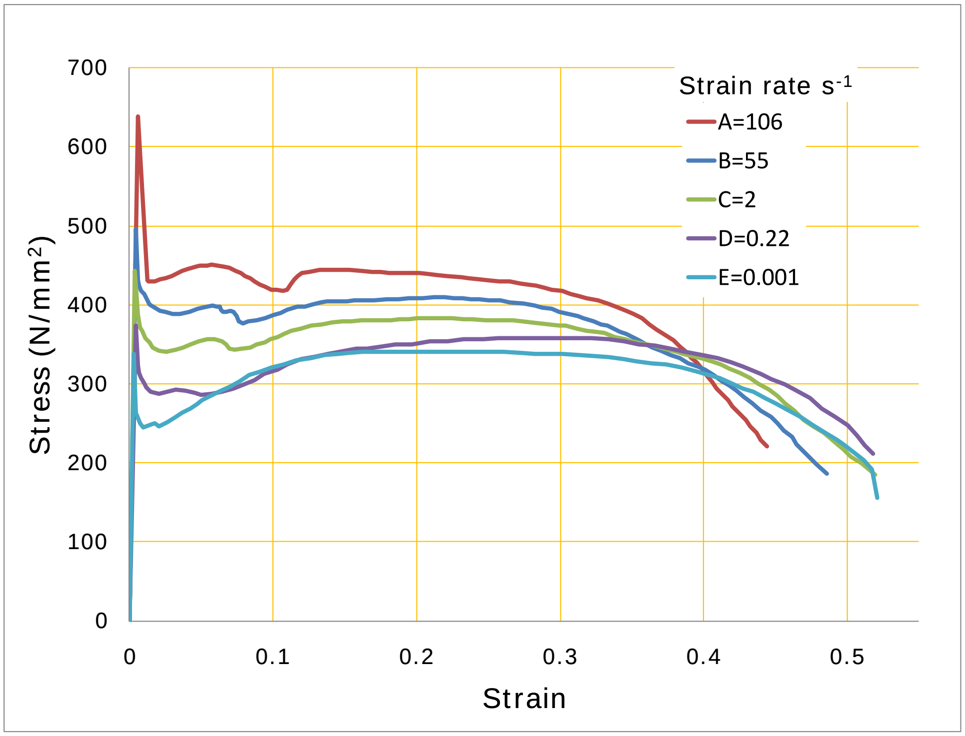

Figure 2-7: Effect of Strain Rates on Behavior of Mild Steel (7)

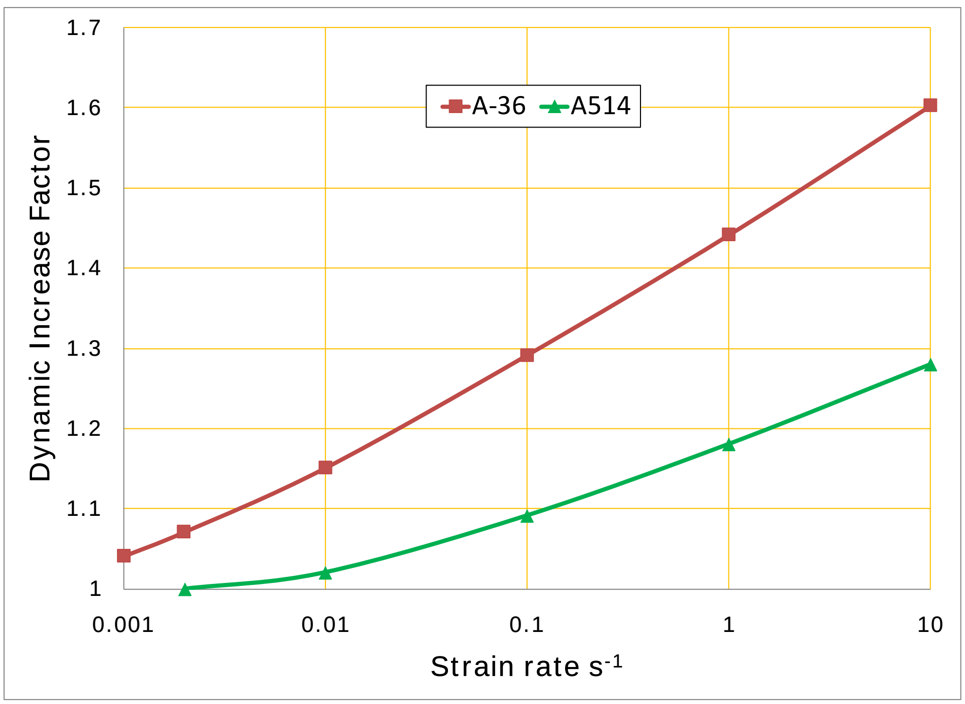

Figure 2-8: Dynamic Increase Factor for Yield Strength of Mild and High Strength Steels versus Strain Rates (8)

Performance Criteria

Under the impact loading, the material will deform into the inelastic plastic range after the first yield point, i.e. unrecoverable damage, and eventually rupture. In the consequence analysis, material failure (i.e. rupture) can be assumed at 15% plastic strain for parent steel and 5% for connections (9).

3. Case Studies

3.1 Dropped Object Analysis

The dropped object case study involved lifting operation during installation of a four-legged fixed jacket platform. The water depth was 108.8 m. The lifting manifest including 14 lifted items is shown in Table 3-1.

Table 3-1 – Lifting Manifest

#	Item	Length (m)	Width (m)	Height (m)	Weight (ton)	Lift/ year	Impact Energy (kJ)
1	Heavy lift	6.1	2.4	1.2	27.22	182	3485
2	Waste bins	6.1	2.4	1.2	1.81	130	103
3	Mini container	1.8	1.8	1.8	1.81	52	36
4	Food box	1.8	1.8	3.1	3.63	12	127
5	Tool box	2.4	1.2	1.2	0.91	12	24
6	Cylinder rack	0.9	0.6	1.8	0.91	12	27
7	MMSL tool box	1.8	1.2	0.6	0.91	52	23
8	Air compressor	3.1	1.5	1.2	3.63	12	153
9	Scaffolding Basket	6.1	2.4	1.2	6.35	12	443
10	Score tool box	1.5	0.9	0.6	0.91	26	24

Frequency Analysis

Based on the method described in the methodology section, we used Monte Carlo simulations to estimate the impact probability due to each dropped object on the seabed. The results of the impact probability analysis for the dropped object “Waste bins” at seabed level are shown in Figure 3-1 as an example. The crane location is shown by a larger circle and the four jacket leg locations are denoted by four smaller circles. The probabilistic assessment was carried out for all 14 dropped objects. The contours of impact frequency at seabed for the 14 different dropped objects are given in Figure 3-2.

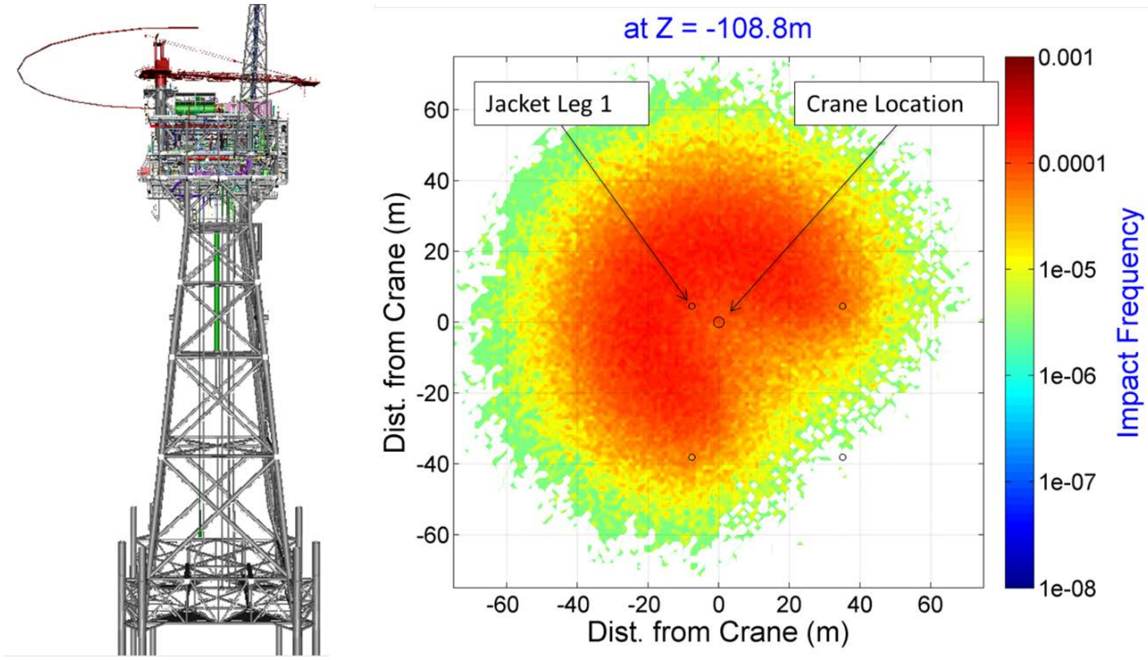

Figure 3-1: Impact Frequency Contours on Seabed due to Waste Bins DO

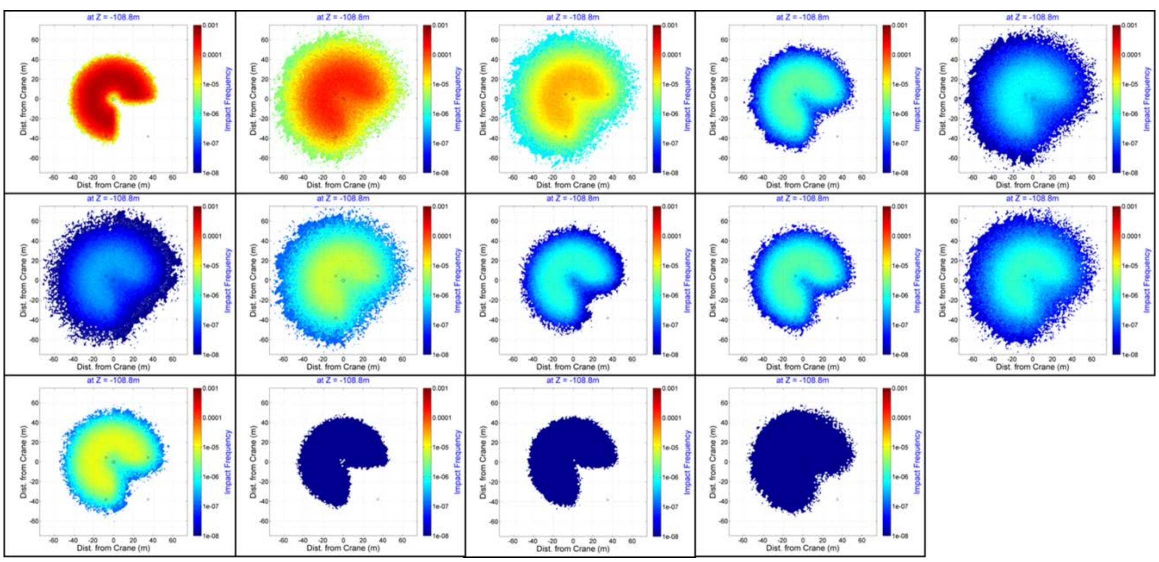

Figure 3-2: Contours of Impact Frequencies for Total of 14 DOs

Consequence Analysis

For an offshore platform, either fixed or floating, different types/scenarios of structural consequence analysis due to dropped objects could be done. These may include dropped objects on topsides upper deck plate members, equipment, on sub-structure components such as jacket legs, risers, mooring lines, or on pipeline on the sea bed. The goal of a structural consequence analysis is to estimate the energy absorption capacity of the components within the acceptance criteria, i.e., acceptable damage level. As an example, Figure 3-3 presents the energy capacity as a function of deformation of a 26" flowline pipe with elasto-plastic seabed assumption. In this simulation, the energy was dissipated through both pipe and soil plastic deformations. Figure 3-4 shows the comparison of the results between FE analyses with different assumptions and simplified approach outlined in DNV-RP-F107. In the FE analyses, the seabed was modelled as rigid, elastic, or elasto-plastic. Two types of FE analyses were done: impact analysis and analytical analysis. The impact analysis simulated an impact event with possible "spring bouncing back" effect in which the deformable pipe acted as a spring. In the analytical analysis, the dropped object was pushed down into the pipe until failure of the pipe occurred. The analysis results indicate that DNV approach could give smaller energy capacity than FE approach in which seabed assumed to be elasto-plastic (realistic assumption). Since the capacity of the flowline is around 363 kJ (before rupturing) which is less than the impact energies of certain dropped objects as shown in Table 3-1, protection structure may be required if the risk is not acceptable or tolerable.

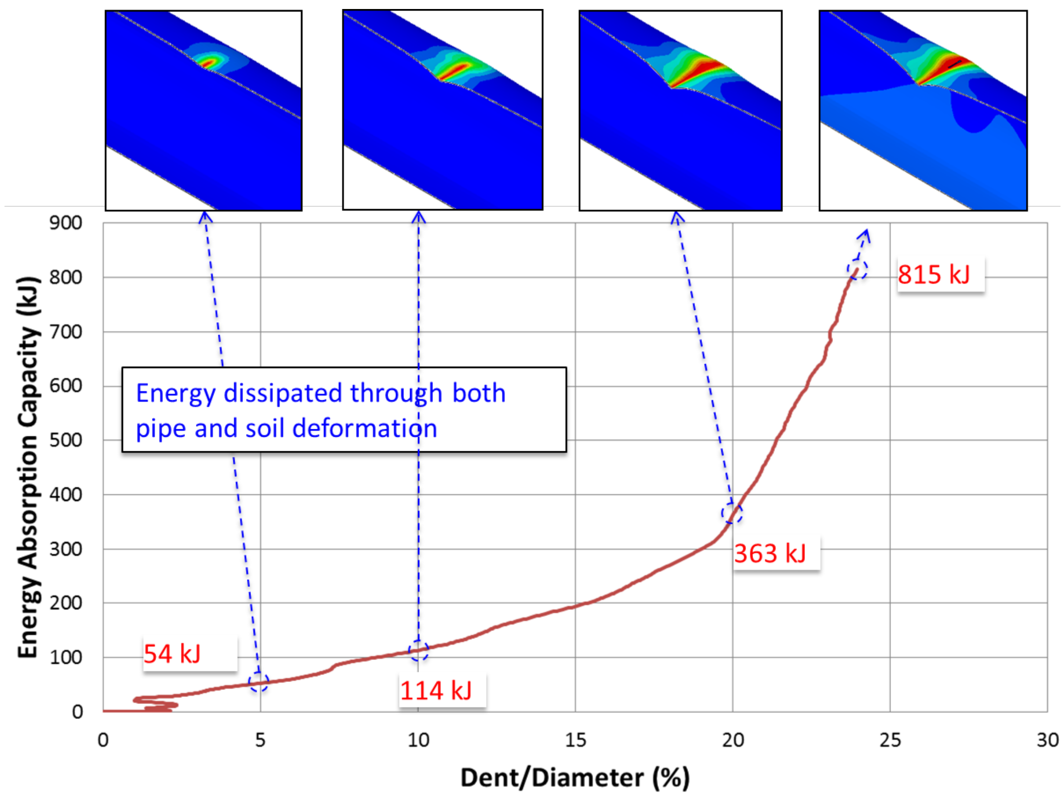

Figure 3-3: Energy Capacity vs. Deformation of a 26" Flowline Pipe with Elasto-plastic Seabed Assumption

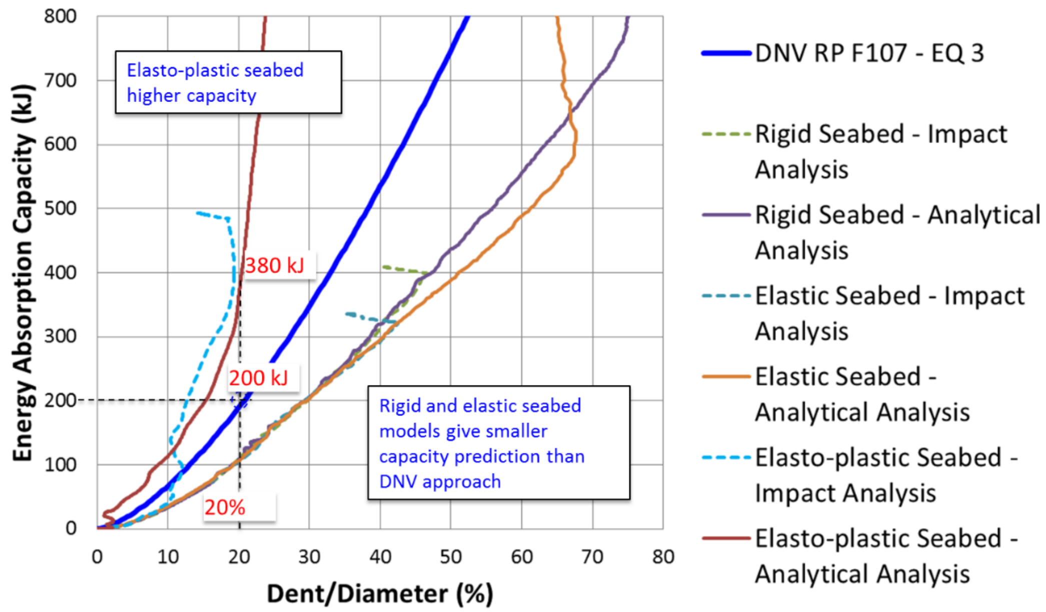

Figure 3-4: Energy Capacity vs. Deformation of a 26" Flowline Pipe: FEA vs. Simplified Approach (DNV-RPF107)

3.2 Helicopter Collision

Following the discussion in the methodology section, this section presents an example of frequency and consequence analyses in the risk assessment of a helicopter collision event. The same four-legged fixed jacket platform considered in the dropped object case study was considered here. For illustration purpose, Figure 3-5 shows a 3D model snapshot in which a helicopter is landing on the helideck of the fixed jacket platform.

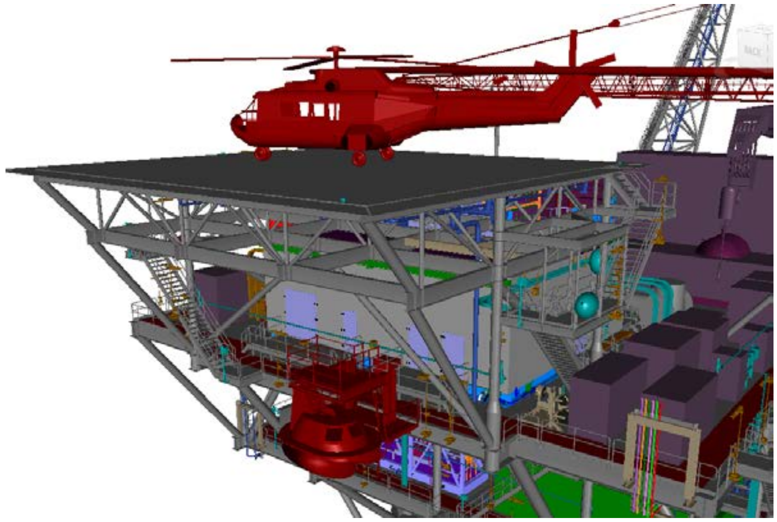

Figure 3-5: 3D Snapshot showing a scenario that a helicopter landing on the helideck of the fixed jacket platform

Frequency Analysis

The frequency analysis was done for two scenarios: (1) Helicopter crash during take-off, transit, and landing and (2) Helicopter impact on platform after falling off from helideck. Table 3-2 summarizes the information used in the analysis.

Table 3-2 – Helicopter Flight Data

Parameter	Value
Duration of round-trip flight between shore base and platform	80 minutes (1.33 hours)
Offshore round trips per annum	104.35 per annum
Number of take-off & landings	4 per round trip
Average number of passengers per flight	14 per flight

Helicopter Crash during Take-off, Transit, and Landing

Statistical accident data were derived from OGP risk assessment data directory (2). The data, based on worldwide accidents in the period 1998 to 2006, was used in this example. The flight time between the shore base and platform was approximately 40 minutes. The number of flights was assumed as approximately 104.35 platform visits per year. From the aforementioned information, the risk contributions were determined as follows:

Total flight time per year =

$$104.35 \textit{ offshore flights/year} \times 1.33 \textit{ hour/flight} = 138.78 \textit{ hours/year}$$

Total flight stages =

$$104.35 \textit{ offshore flights/year} \times 4 \textit{ stages/flight} = 417.4 \textit{ stages/year}$$

In-flight risk =

$$7.60\times10^{-4} \textit{ per year}$$

Take-off/ landing risk =

$$1.32\times10^{-4} \textit{ per year}$$

IRPA =

$$5.62\times10^{-4} \textit{ per year}$$

The annual PLL from helicopter transport for the installation can be calculated with the following additional information. The helicopter model was assumed the AW-139, which has a passenger capacity of 14.

$$PLL = 5.62\times10^{-4} \times 14 = 7.87\times10^{-3} \textit{ per year}$$

The helicopter transport risk contributions are summarized in Table 3-3.

Table 3-3 – Helicopter Transport Risk Contributions

IRPA	5.62×10^{-4}
PLL per year	7.87×10^{-3}

Helicopter Impact at Platform after Falling off from Helideck

The probability of a helicopter impact at the platform has been determined using the event tree shown in Figure 3-6. The conditional probability of helicopter falling off from the helideck and crashing on the platform was estimated to be 0.21× 0.67 × 0.20 = 0.028.

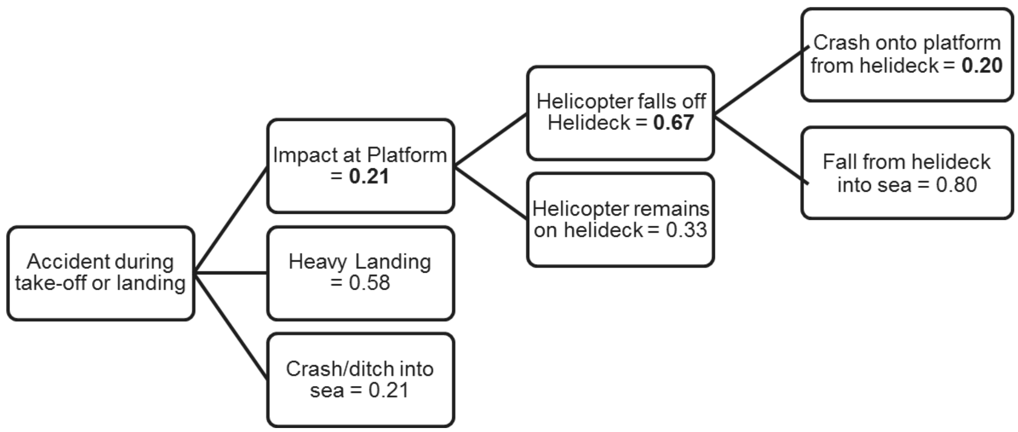

Figure 3-6: Probability of Helicopter Impact at Platform

The total accident rate per take-off/landing operations and the number of helicopter arrivals and passengers are based on data in Table 2-2 and Table 3-2. The risk contributions were therefore determined as follows, assuming a fatality probability of falling off helideck after a crash of 0.1.

$$\textit{IRPA contribution} = 7.89 \times 10^{-7} \textit{ per year}$$

$$\textit{PLL contribution} = 1.10 \times 10^{-5} \textit{ per year}$$

Consequence Analysis

Figure 3-7 shows a scenario that the helicopter impacts the helideck at an angle of 30 degrees. The impact speed was assumed to be 28 m/s. In this example, shell elements were used for the helideck pancake structure, and the helideck support structures were modeled with nonlinear beam elements. The helicopter was modeled as rigid body with shell elements such that the impact energy would be dissipated through the plastic strains of the helideck. The plastic contours in Figure 3-8 indicate that there were damages at the impact location including helideck pancake plank and beams. Rupture and failure in welding and connection regions were observed. However, overall stability of the helideck was maintained after the impact.

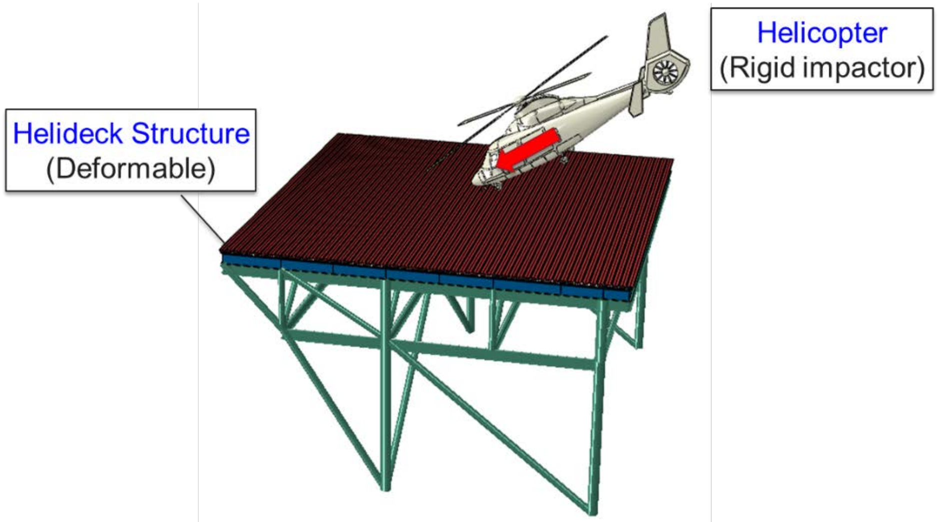

Figure 3-7: FE Model for Helicopter Collision Scenario

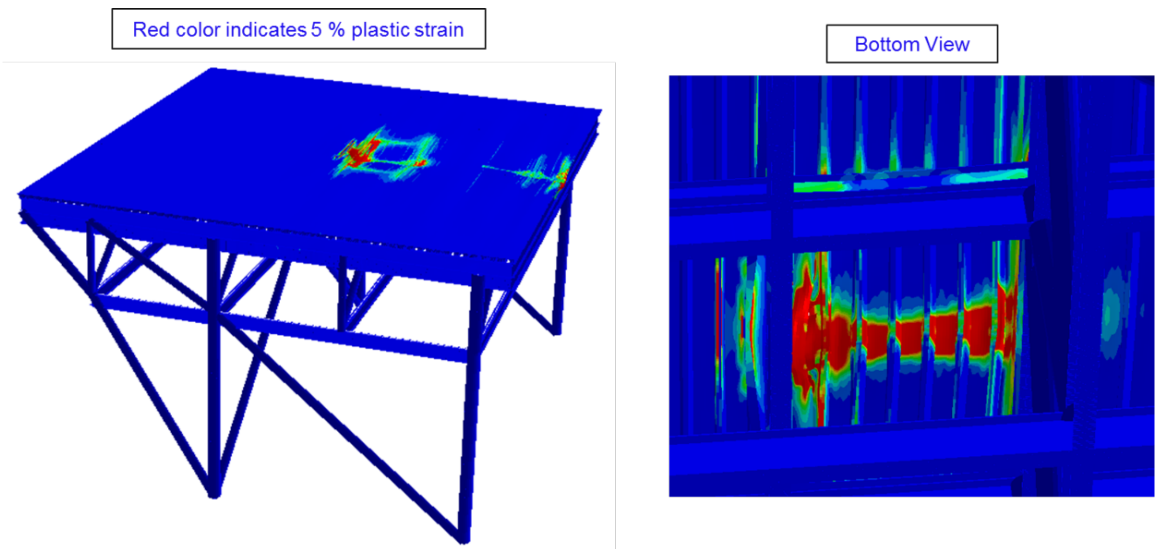

Figure 3-8: Plastic Strain Contours: Red color indicates 5% plastic strain

3.3 Ship Impact

Following the discussion in the methodology section, this section presents an example of frequency and consequence analyses in the risk assessment of a ship impact/collision event. A TLP was considered in this case study. For illustration purpose, Figure 3-5 shows a 3D model snapshot in which a vessel is approaching to impact a column of the TLP.

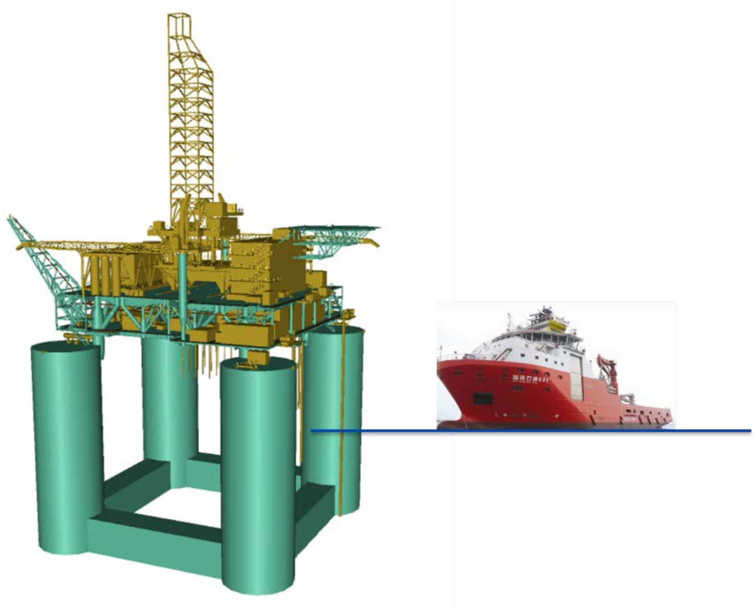

Figure 3-9: 3D Snapshot indicating a ship impacting a column of a TLP

Frequency Analysis

Statistical accident data were obtained from OGP risk assessment data directory (3). The data, based on worldwide accidents in the period 1990-2002, were used in this example. From the aforementioned information, the IRPA values were calculated and are shown in Table 3-4. The ship collision frequency was obtained from the number of collisions and exposures of the infield vessels to the installation. Risk contribution was not only from the collision frequency but also from the fraction of vessel and the fraction of damage level. Total IRPA ship collision frequency due to all related vessels to the floating unit TLP was calculated to be 1.30×10^{-4}. According to the UK HSE's risk criteria (10), the boundary between the tolerable regions and broadly acceptable is $1.00\text{x } 10^{-3} – 1.00 \text{ x } 10^{-6}$. IRPA of $1.30 \text{ x } 10^{-4}$ is lower than the upper limit of the tolerable regions. It can be concluded that this IRPA due to ship collision is tolerable.

Table 3-4 – Individual Risk Per Annum

Vessel Type	Damage Level				
	Total Loss	**Severe**	**Significant**	**Minor**	**Insignificant**
Supply vessel	0.0	0.0	2.54×10^{-5}	$2.\ 54\times10^{-5}$	0.0
Standby vessel	0.0	0.0	0.0	0.0	2.84×10^{-5}
Working vessel	0.0	1.68×10^{-5}	0.0	1.68×10^{-5}	1.68×10^{-5}

The risk to personnel was estimated using PLL values. The PLL values according to ship collision by vessel types are provided in Table 3-5.

Table 3-5 – PLL Ship Collision Risk Contributions per Year

Vessel Type	PLL per year
Supply vessel	5.09×10^{-3}
Standby vessel	2.84×10^{-3}
Working vessel	5.04×10^{-3}
Sum	$\mathbf{1.30 \times 10^{-2}}$

Consequence Analysis

In the following example, detailed nonlinear finite element analysis was used to understand the nature of potential ship impact consequence. The ship/vessel was used with a mass of 6,600 tonnes and an impact velocity of 1.8 m/s for ship impacting TLP column. Figure 3-10 shows the FE model of a column impact scenario. In the FE model, the hull column was modeled using shell elements at impact zone. The column material was AH36 steel. 24mm outer column wall thickness was used. The horizontal and vertical girder sections (assumed welded to the outer column) were T600x16 and HP180x10. 13mm plate and HP180x10 section were used as a part of vertical stiffeners. Vessel including added mass was modeled as a rigid body and assumed with bow shape.

The plastic strain contours are presented in Figure 3-11 which indicates that plastic strain reached 15% (permanent damage) on plating, girders, and stiffeners near the impact area due to the impact from the vessel. It can be concluded from this impact scenario that the vessel caused major damage to the plates, girders, stiffeners, and weld. Girders and stiffeners ruptured. The connections between the plates and the stiffeners failed. The weld connections between the girders, the stiffeners, and the outer column plates failed. This may lead to the leakage at the outer column plates due to the loss of plating material strength at the weld connections. The TLP hull may be flooded. The impact may interrupt the normal operation of the TLP platform.

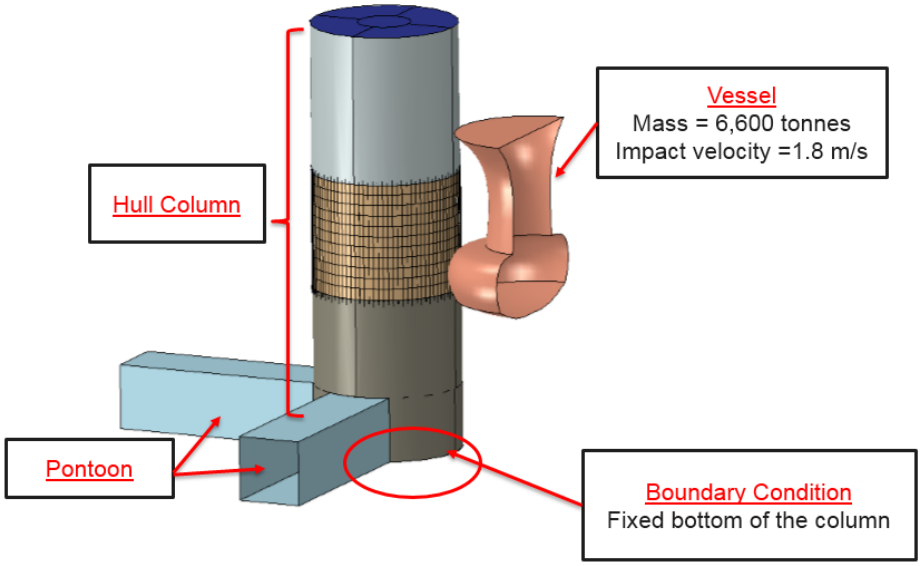

Figure 3-10: FE Model for Impacting TLP Column Scenario

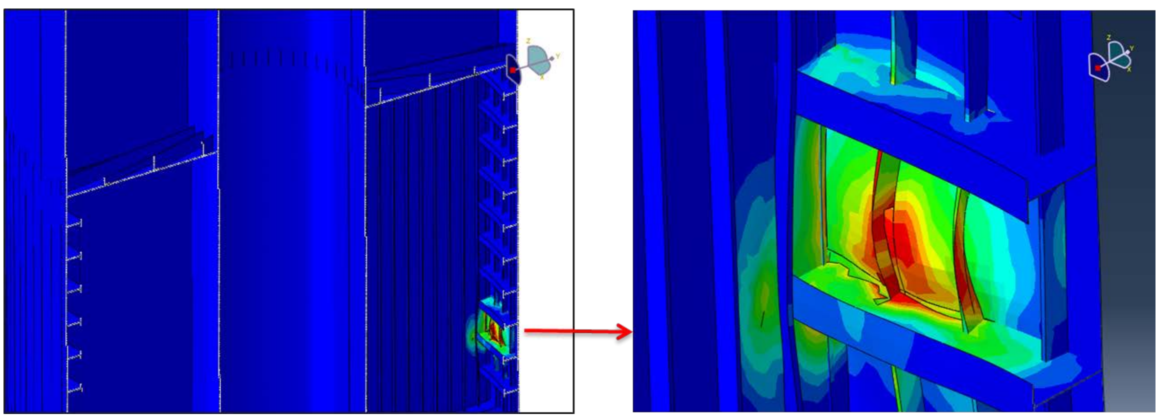

Figure 3-11: Plastic Strain Contours: View from Inside, Red color indicates 15% plastic strain.

4. Conclusions

In offshore drilling operations, accidental loads such as dropped objects, helicopter collision, and ship impact, pose a high potential threat to human safety, asset integrity, environment as well as reputation and business of the operator. A safe design of offshore exploration and production facilities for accidental collisions requires the risk assessment of such accidental events. This paper proposes the methodology to assess such risk. For the frequency assessment part of the risk, the paper proposed extended versions of the approaches outlined in industry guidelines such as DNV-RP-F107. For the consequence analysis, it has been demonstrated that advanced structural analysis is capable and suitable for understanding the response of structures to accidental loadings, not only to remove conservatism inherent in simplified approach but also to assure a safer and economical design.

5. References

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