MARY KAY O'CONNOR PROCESS SAFETY CENTER
TEXAS A&M ENGINEERING EXPERIMENT STATION

21st Annual International Symposium
October 23-25, 2018 | College Station, Texas

Dropped Object Risk Assessment for Fixed Offshore Platforms

Ali Sari, Ph.D., P.E.,
[1]*Omega Advanced Engineering and Risk Consulting, "Omega-Risk", 15700 Lexington Blvd #1650, Sugar Land, TX 77478*
Email: asari@omega-risk.com[1]

Abstract

Dropped object risk assessment quantifies the risk caused by accidental dropped objects on potential targets from topsides of a fixed offshore platform to seabed. The risk assessment evaluates both the likelihood of the dropped object accident and its consequence. Often a risk matrix is used in mitigation decision, i.e. high impact frequency and high consequence events require attention. The potential targets from platform deck to seabed pipelines define three types of dropped objects analysis (DOA): Topsides DOA, Appurtenance DOA, and Subsea DOA.

Topsides DOA involves the risk assessment for platform structural components and equipment while Appurtenance DOA includes any potential targets from the sea surface to the seabed, such as jacket legs. Subsea DOA is often of concern because of the high environmental and economic consequences as well as loss of human life, particularly gas release close to an offshore facility. This paper will give an over view of the dropped object risk in offshore lifting/drilling operations and how the risk is assessed in current practice of the oil and gas industry. Next, it will discuss a practical approach in which a two-stage Monte Carlo simulation is used to estimate the impact frequency for potential targets such as upper decks, jacket legs, risers, mooring lines, and pipelines on seabed. The two-stage Monte Carlo approach is an extension to DNV approach which does not take into account the randomness of dropped location on the sea surface. The two-stage Monte Carlo simulation estimates impact probability at different levels along the depth of the platform from sea surface to seabed. In the first stage, a random variable pair based on the drop point distance and angle with respect to the crane position is used. Crane extension is sampled from normal distribution, constrained by crane minimum and maximum radii. Crane rotation is sampled from uniform distribution, constrained by crane lifting arc. In the second stage, a probability distribution on level Z of the sea depth (including seabed) is used that is centered at the drop point on the sea surface. The point of impact is sampled using a normal distribution of the extension based on DNV-RP-F107 approach and a uniform distribution for the rotation angle. For the second stage, the parameters for the normal distribution of the extension radius change based on water depth, weight, and shape of dropped objects. The frequency of impact due to each dropped object is calculated by adding drop frequency and number of lifts per year. The accumulative impact frequency for jacket legs or pipeline is estimated by summing

values along the length (taking integral). The consequence analysis is done by means of advanced nonlinear finite element analysis which is believed to remove the conservatism in simplified approaches.

The paper seeks to discuss the asset risk assessment for dropped objects in offshore drilling operations in the oil and gas industry and proposes recommendations to common practice.

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. 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.

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 subsea pipeline, a protection structure may be required and must be designed to sufficiently absorb the impact energy from the dropped object.

The objective of this paper is to focus on the dropped object assessment, both probabilistically and consequence-wise, of the subsea assets such as pipelines, X-mas tree, etc and discuss pipeline protection systems in cases where the risk due to damage from the dropped objects is intolerable.

METHODOLOGY

A safe design of offshore assets 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 assets, 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.

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 Error**! No text of specified style in document.**-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.

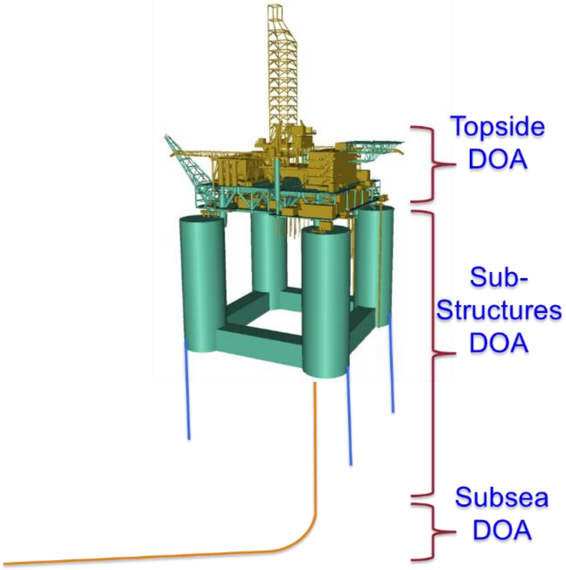
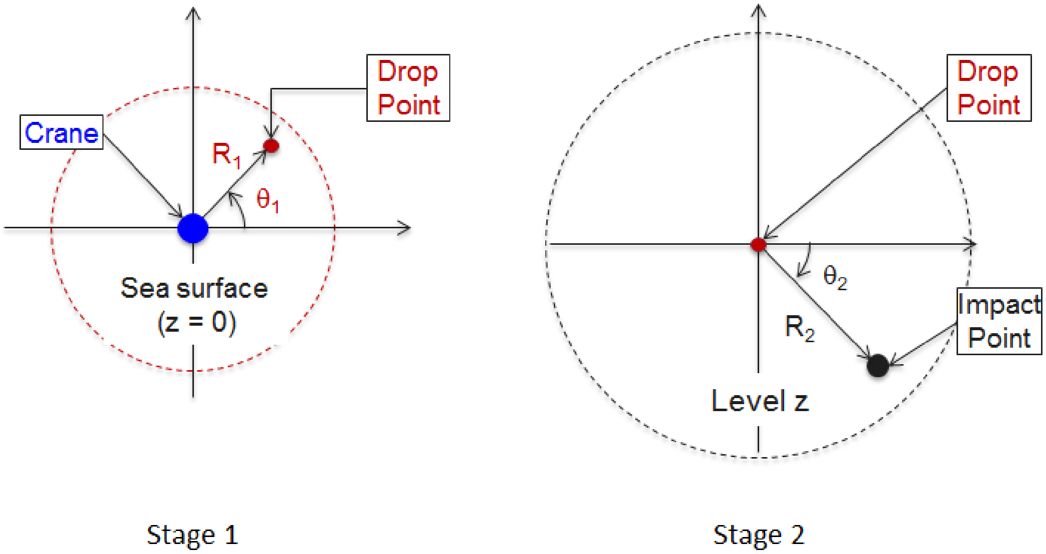


Figure Error! No text of specified style in document.**-1: Three Types of Dropped Object Analysis (DOA).**

In this paper the approach for dropped object frequency analysis is based on the extension of the approach outlined in DNV-RP-F107 (2). This approach uses a two-stage Monte Carlo simulation technique to estimate impact probability at different levels from the offshore structure deck to the seafloor. The frequency of impact due to each dropped object is calculated by multiplying 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 assumption that 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 Error**! No text of specified style in document.**-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 Error**! No text of specified style in document.**-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 used for calculating the dropped object lateral excursion are summarized in Table Error**! No text of specified style in document.**-1. The definition of the angular deviation is shown in Figure Error**! No text of specified style in document.**-4.

Figure Error**! No text of specified style in document.**-5 shows the illustration of discretization of impact area on topsides/seabed (or any level Z) into 1mx1m cells. 1,000,000 or more drops can be simulated for each dropped object at different levels along water depth. Impact probability in each 1mx1m cell is 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 Error**! No text of specified style in document.**-5).



Stage 1

Stage 2

Figure Error! No text of specified style in document.**-2: Two-Stage Monte Carlo Simulations.**

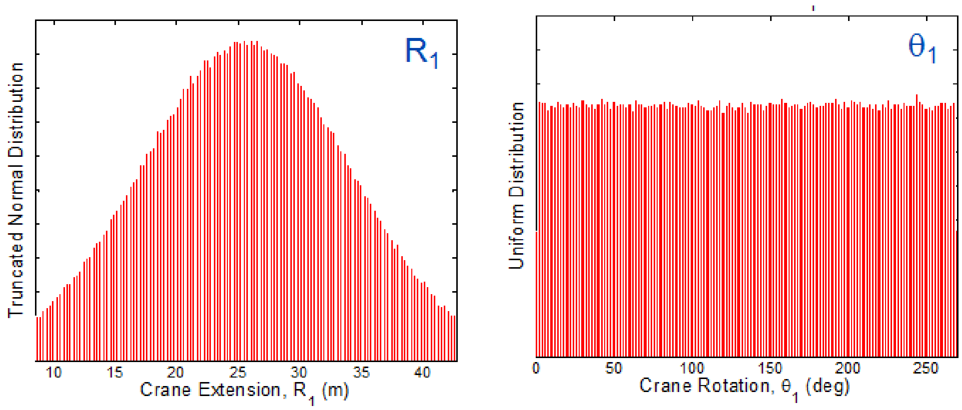


Figure Error! No text of specified style in document.**-3: Normal and Uniform Distributions for R_1 and θ_1.**

Table Error! No text of specified style in document.**-1: Angular Deviation of Dropped Objects (2)**

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

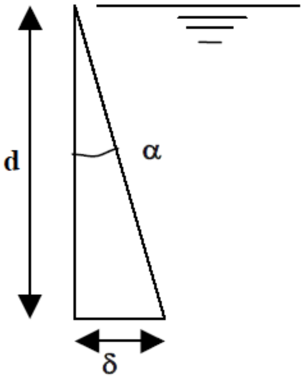


Figure Error! No text of specified style in document.**-4: Angular Deviation Definition (2)**

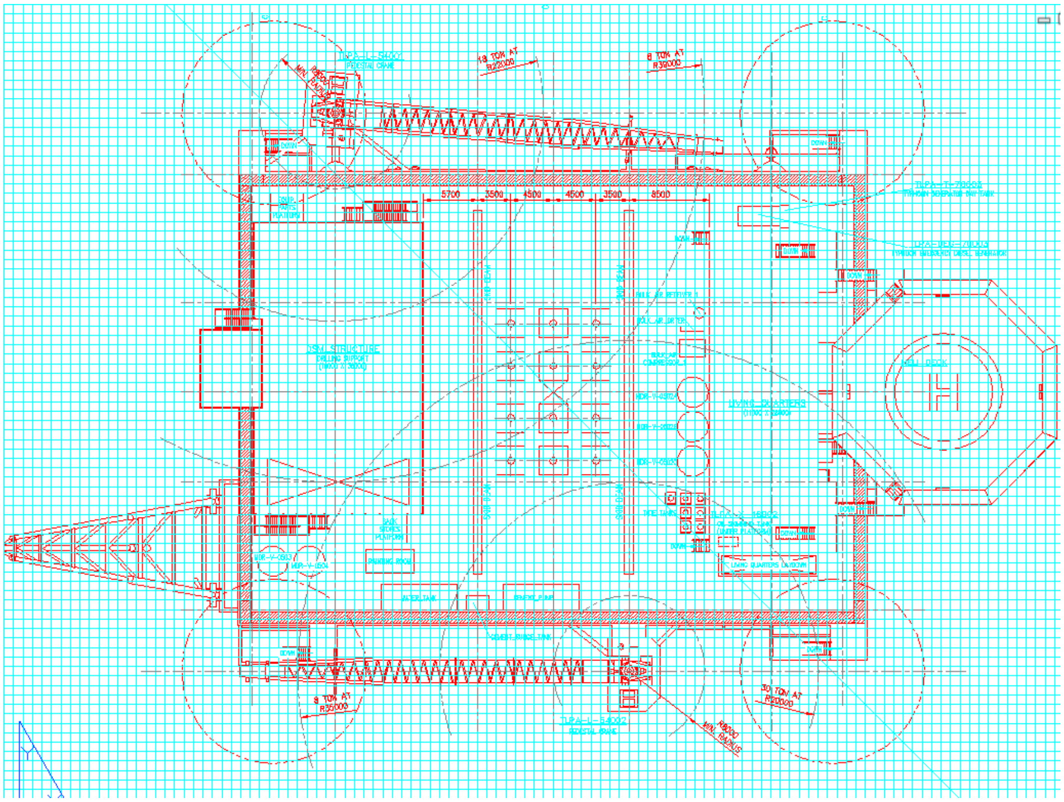


Figure Error! No text of specified style in document.**-5: Illustration of Discretized Impact Area on Topside/Seabed (or any Level Z)**

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

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

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 (3). 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 (2).

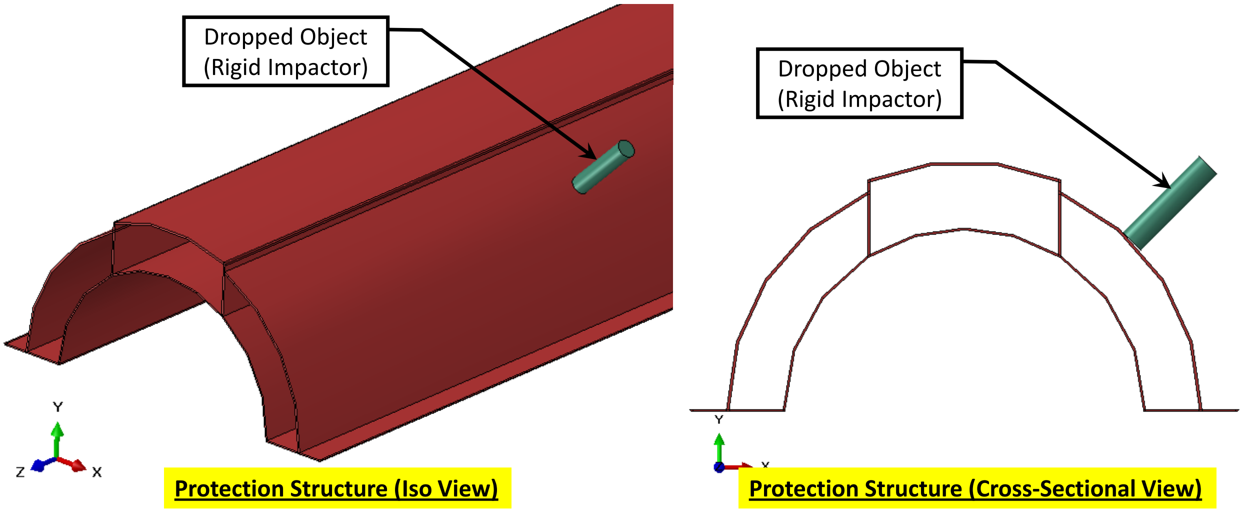
Consequence Analysis

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 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 dropped object loads are accidental loads, structural response of a target 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 FEA is more applicable in the design against collision loadings. A general finite element package such as Abaqus (4) is suitable for this type of analysis and was used for all of the consequence analyses in this paper. If the target can absorb the impact energy and damage caused by the impact is acceptable or tolerable based on performance criteria, no action is required. However, if the performance criteria are not met, either the target has to be re-designed or protection structures need to be provided.

Geometry Modeling

In FEA, impactors, i.e., dropped objects are usually modeled as rigid bodies with the initial impact velocity. The impact energy is calculated by multiplying the impactor's velocity with mass that accounts for the impactor mass and hydrodynamic added mass. 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. An example of an FE model for dropped object is shown in Figure Error**! No text of specified style in document.**-6.



Protection Structure (Iso View)

Protection Structure (Cross-Sectional View)

Figure Error! No text of specified style in document.**-6: Example FE Model: A Rigid DO Impacting a Deformable Structure**

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 Error**! No text of specified style in document.**-7 presents stress-strain relationships up to fracture for low-carbon mild steel at different strain rates (5). 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 Error**! No text of specified style in document.**-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).

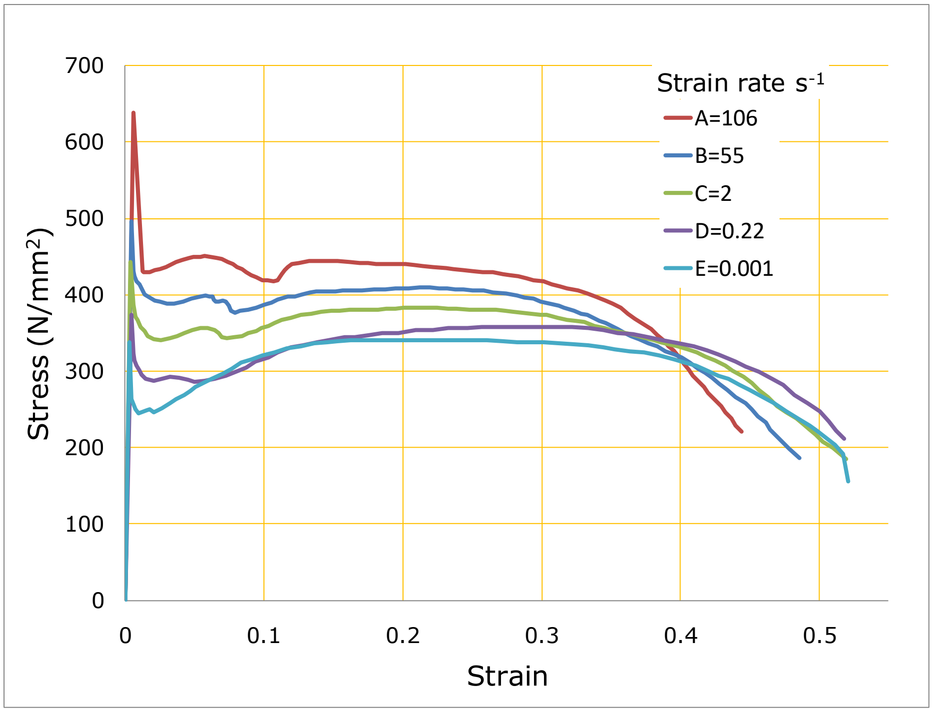


Figure Error! No text of specified style in document.**-7: Effect of Strain Rates on Behavior of Mild Steel (5)**

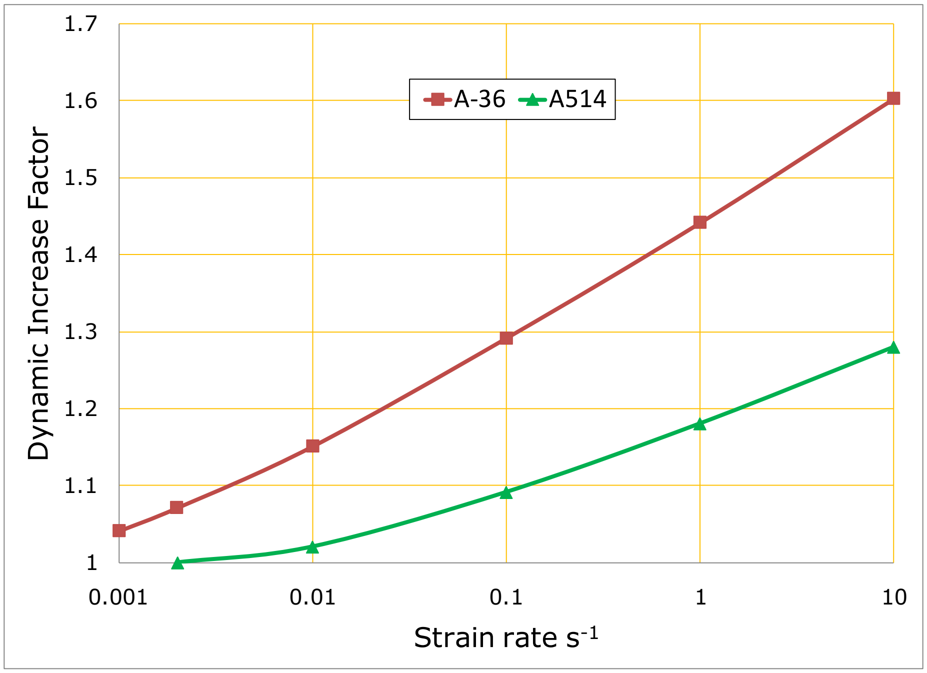


Figure Error! No text of specified style in document.**-8: Dynamic Increase Factor for Yield Strength of Mild and High Strength Steels versus Strain Rates (6)**

CASE STUDY

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 that includes 14 lifted items is shown in Table Error**! No text of specified style in document.**-2.

Table Error! No text of specified style in document.**-2 – Lifting Manifest**

#	**Item**	**Length (m)**	**Width (m)**	**Height (m)**	**Weight (ton)**	**Lifts/ 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 approach 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 Error**! No text of specified style in document.**-9 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 Error**! No text of specified style in document.**-10.

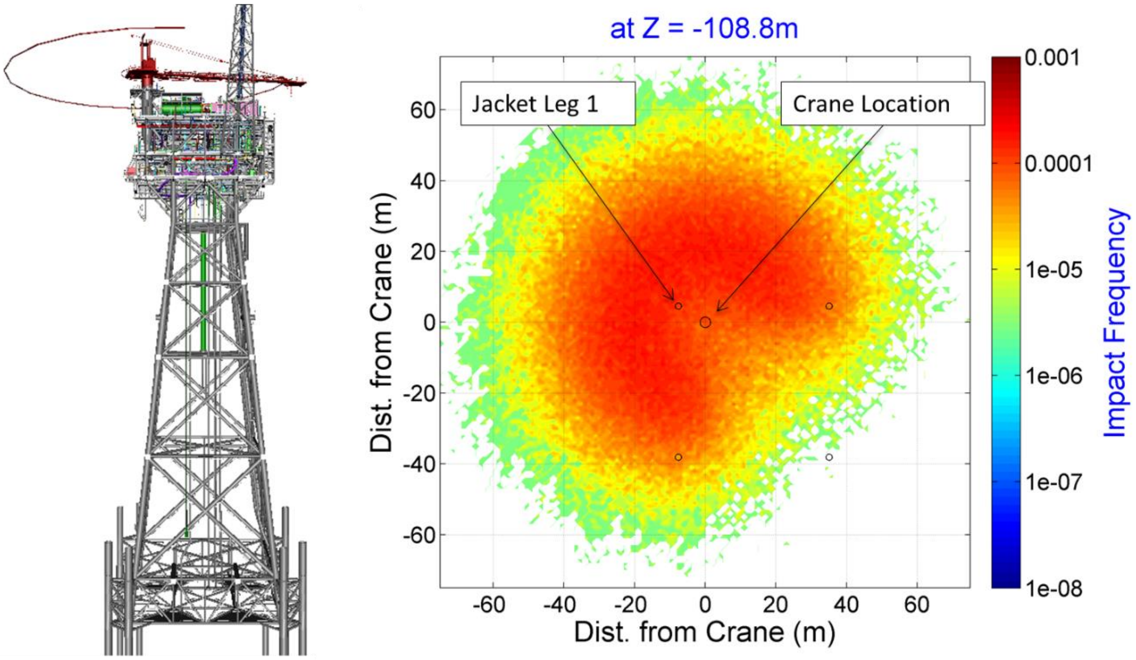


Figure Error! No text of specified style in document.**-9: Impact Frequency Contours on Seabed due to Waste Bins DO**

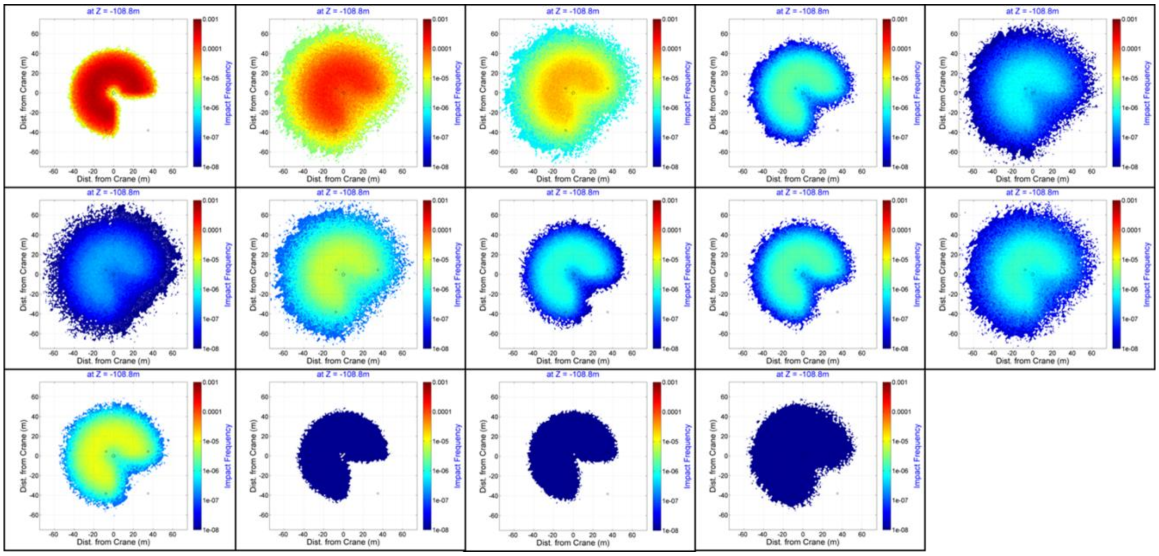


Figure Error! No text of specified style in document.**-10: Contours of Impact Frequencies for Total of 14 DOs**

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 pipelines on the sea bed. The goal of a structural consequence analysis is to estimate the energy absorption capacity of the components within the performance criteria, i.e., acceptable damage level. As an example, Figure Error**! No text of specified style in document.**-11 presents the energy capacity as a function of deformation of a 26” flowline pipe with an elasto-plastic seabed assumption. In this simulation, the energy was dissipated through both pipe and soil plastic deformations. Figure Error**! No text of specified style in document.**-12 shows the comparison of the results between FE analyses with different assumptions and simplified approach outlined in DNV-RP-F107. In the FE sensitivity 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 underestimate energy capacity compared to an FE approach in which the seabed is 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 Error**! No text of specified style in document.**-2, a protection structure may be required if the risk is not acceptable or tolerable.

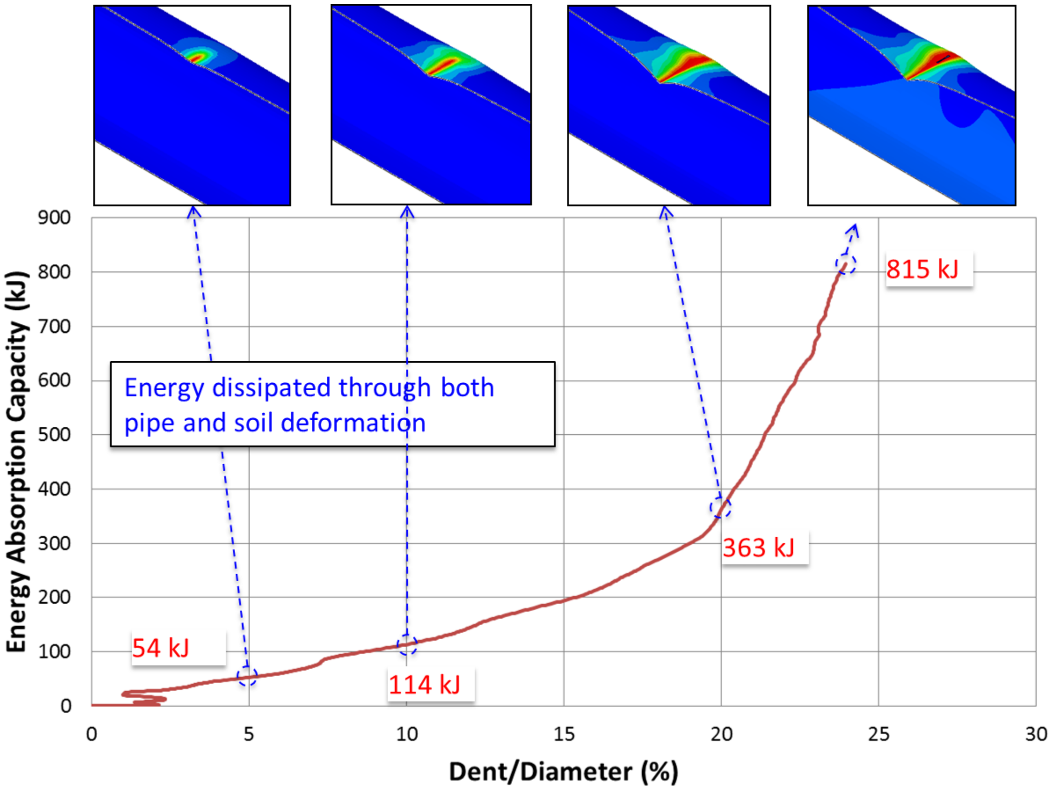


Figure Error! No text of specified style in document.**-11: Energy Capacity vs. Deformation of a 26” Flowline Pipe with Elasto-plastic Seabed Assumption**

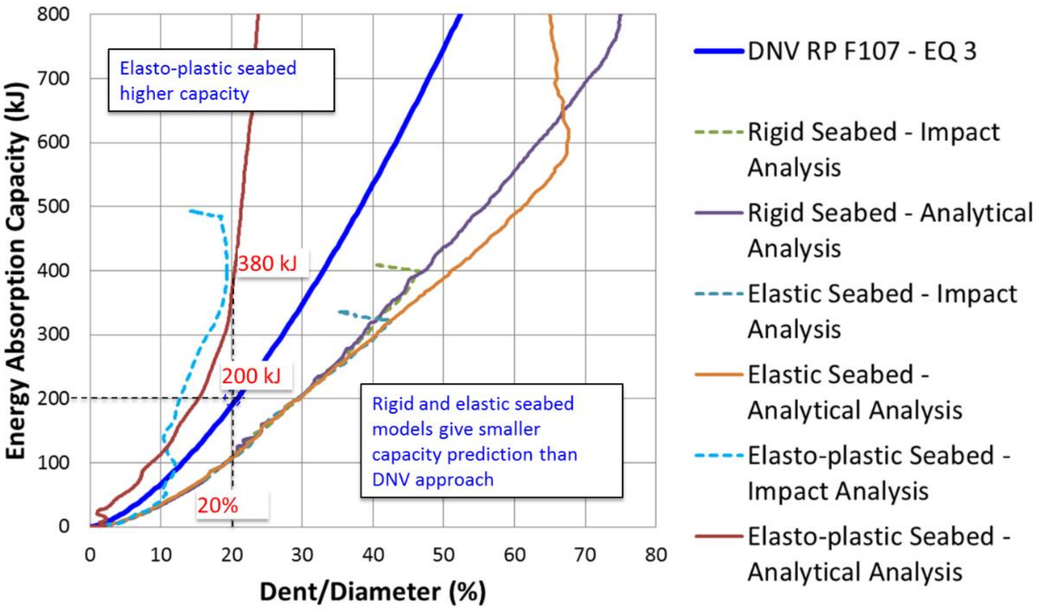


Figure Error! No text of specified style in document.**-12: Energy Capacity vs. Deformation of a 26” Flowline Pipe: FEA vs. Simplified Approach (DNV-RPF107)**

CONCLUSIONS

In offshore drilling operations, accidental loads such as dropped objects 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 an extended version of the approaches outlined in industry guidelines such as DNV-RP-F107. For the consequence analysis, it has been demonstrated that advanced analysis method 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.

REFERENCES

1. **Seward, Simon.** *PREVENTION OF DROPPED OBJECTS, presented at DROPS Forum Asia Singapore 6th Apr 2011.*
2. **Det Norske Veritas.** DVN-RP-F107 - "Risk Assessment of Pipeline Protection". October 2010.
3. **OGP.** *Mechanical Lifting Failure, Report No.434-8, March 2010.*
4. **Abaqus 6.14.** *Abaqus Documentation, Dassault Systèmes, 2015.*
5. **Campbell, J.D. and Cooper, R.H.** *Yield and flow of low-carbon steel at medium strain rates. Proceedings of the Conference on the physical basis of yield and fracture. Institute of Physics and Physical Society, London, 77-87 (1966).*
6. **Smith., P.D., Hetherington, J.G.** Blast and ballistic loading of structures. *Betterworth Heineman.* 1994.