Covenant Journal of Engineering Technology (CJET)Vol. 2, No. 2, Dec.. 2018

An Open Access Journal Available Online

Finite Element Analysis of Concrete Gravity Based Platform Subjected to Sudden Crash (Impact) Load Using ANSYS

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Abstract: The design, analysis and construction of offshore structures as well as their modeling are one of the most demanding sets of tasks faced by engineering profession due to the complexity of structural designs and the large volume of elements used in the model. Finite element analysis (FEA) technology has become a very important tool for evaluating the structural integrity of massive and gigantic structures of which offshore platforms is an example. Offshore structures when installed are constantly faced with different forces/loads ranging from environmental to accidental loads and the later was the impacting load under consideration. This paper carefully illustrates the design and analysis approaches and requirements for a reinforced concrete based gravity platform, a fixed type of offshore structure which was subjected to a crash load and simulated with a computer based finite element analysis tool-ANSYS EXPLICIT DYNAMICS. The scenario was a collision between an offshore transporting vessel and the said fixed platform. Impacting velocities of 5m/s,10m/s, 16m/s, 50m/s and 100m/s were used and results obtained for deformations and stress induced. The study was done to see at what velocity the structure compromise its load bearing capacity and it was observed that the deformation was proportional to velocities increase.

Key Words: Finite Element Analysis (FEA), Gravity Based Structure (GBS), Collision, ANYSY Simulation, Accidental load.

1. Introduction

As the demand for oil and gas is continually on the increase globally, exploration and production has moved ever more into the offshore environment which has led to the installations of numerous oil and gas platforms for drilling and production operations. Some of these platforms are fixed or floating. The **Fixed** as the name implies is permanently placed in position throughout the offshore operations, while the **Floating** structure floats on the surface of the sea by some devices. These structures are constantly been faced with external forces [1].

The Floating structure has topsides located on a floating hull system which floats with the help of either a *pontoon* (a flotation device with buoyancy that can float itself as well as a heavy load) or a mooring system to hold on station. The pontoon and the mooring systems help the floating platform achieve stability. Examples of such structures are Submersible, Semi-submersible, drill ship, FPSO, Tension leg platforms [2].

The Fixed types has their topside structures attached to the seafloor via a jacket, piles or a reinforced concrete legs and they are categorized into Jacket, Jack Up, Tower, Compliant tower, Gravity Structure. The latter type of *fixed* structure was the focus of this research [2].

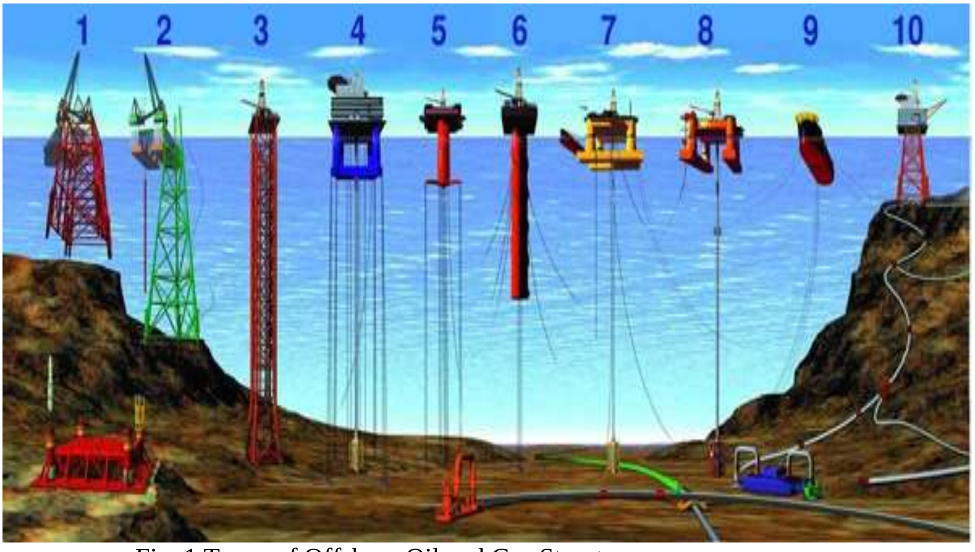


Fig. 1 Types of Offshore Oil and Gas Structures

1 & 2 Conventional fixed platforms (deepest: Shell's Bullwinkle in 1991 at 412 m/1,353 ft)

3 Compliant tower (deepest: ChevronTexaco's Petronius in 1998 at 534 m /1,754 ft)

4 & 5 Vertically moored tension leg and mini-tension leg platform (deepest: ConocoPhillips' Magnolia in 2004 1,425 m/4,674 ft)

6 Spar (deepest: Dominion's Devils Tower in 2004, 1,710 m/5,610 ft)

7 & 8 Semi-submersibles (deepest: Shell's NaKika in 2003, 1920 m/6,300 ft)

9 Floating production, storage, and offloading facility (deepest: 2005, 1,345m/4,429 ft Brazil)

10 Sub-sea completion and tie-back to host facility (deepest: Shell's Coulomb tie to NaKika 2004, 2,307 m/ 7,570 ft)

1.1 Loads on Offshore Structures

Offshore structures are constantly faced with various forces/loads which are categorized into [3]:

- ***Static loads***

- Dead weight (weights of the platform and any permanent equipment and appurtenant structures which do not change with the mode of operation. i.e the structural weight in air, equipment permanently installed on the platform. Example weights of pile, ballast, etc).
- Hydrostatic forces (forces acting on the structure below the waterline including external pressure and buoyancy).

• ***Dynamic Loads***

- **Operational loads** or **Live loads** (loads imposed on the platform during use and which may change either during a mode of operation or from one mode of operation to another.eg the weight of drilling and production equipment which can be added or removed from the platform, the weight of living quarters, heliport etc).
- **Environmental loads** (loads imposed on the platform by natural phenomena including: wave, current, wind, earthquake, snow, ice and earth movement. Environmental loads also include the variation in hydrostatic pressure and buoyancy on members caused by changes in the water level due to waves and tides).
- **Construction loads** (loads arising from fabrication and installation of the platform and components)
- **Accidental loads** (the impact of platform collision with vessel, helicopter crash, objects drop, fire etc)

1.2 Concrete Gravity Base Structure (CGBS)

The term Gravity Based Structures (GBS) implies two main characteristics; firstly, the foundation is not piled but of gravity type and secondly, the main structural elements are of concrete reinforcement. They are fixed structures that are held in place against environmental action solely by their weight (gravity) and that of ballast contained [1].

The Concrete offshore structures are used in the oil and gas industry for drilling, extraction or storage units for crude oil or natural gas in extreme offshore environments were the wave frequency is of high magnitude like the Norwegian North Sea. These structures are massive and house machineries and equipment needed to drill and/or extract oil and gas. Other concrete structures which are not applicable within the oil and gas industry like the wind turbines have being in operation [4].

The early development of gravity platforms was in the 1970s in the North Sea. This was driven by the generic requirement to store large volumes of oil and support heavy topsides in deep waters. The discovery/ development of this structure solved the problem of pipeline infrastructural transportation of crude oil to land which was immature then [5].

Fig. 2 Gravity Based Concrete Structure

CGBS Design Considerations. The design, analysis and construction of offshore structures are one of the most demanding sets of tasks faced by engineering profession.

Three design steps are required in offshore structure design [3] -

- **Foundation Design**

For the fixed structures for example the concrete and jacket platforms, the design consideration is dependent on the weight of the structure, the environmental loads and the soil characteristics. The base for a CGBS or the pile for a jacket should be design to withstand these loads. The choice of location for installation is based on geotechnical report gotten and the soil laboratory test.

- **Naval Architecture Design**

This addresses two issues in the design of offshore structures, the hydrostatics and hydrodynamics requirements. The hydrostatics is the ability of the structure at rest to be afloat. And the hydrodynamics requirement is the resistance the structure has towards the motion due to water flow. It also examines the static stability of the structure, which is its ability to restore itself to the original upright position after being hit/ inclined by wind, wave or other loading conditions.

- **Structural Design**

For validation of the design, structural analysis is conducted. The results gotten from the validation is used for the selection of construction materials.

Structural design validation includes: a *strength check*- to ensure sufficient resistance for material yield strength for all components, a *stability check*- for buckling (propagation of failure on the structure) resistance for all structural components subjected to compression, and a *joint check*- this ensures sufficient connecting capacities between various components. In addition, advanced design validation/ authentications may be required for accidental loads, fatigue and corrosion [6].

Some recommended codes and standards for offshore designs include BS 6235 (1982), API RP 2A-WSD (2000), and DNV-OS-C101 (2011) for steel structures and DNV-OS-C502 (2010) for concrete platforms

Impact Load. Impact load is an accidental load and it's dynamic in nature (i.e. it varies with time). A typical example is the scenario of this work. During this collision, the striking vessel converts its kinetic energy wholly or partially into strain energy in both objects depending on the magnitude of the velocity of impact. Various analysis tools have been developed to analyze the aftermath of this collision (deformation, damage stress etc) like ANSYS finite element analysis tool which was used for this simulation.

2. Methodology

The accidental impact from an offshore transporting vessel to a gravity based platform having a rectangular-based concrete reinforced caisson with a measurement of 126m x 94m x 16m was simulated using ANSYS EXPLICIT DYNAMICS. The structure has four hexagonal shaped shafts each of length 60m, diameter 18m and thickness of 8m, mounted at seabed of water depth 45m. The shafts extend 15m above the water level to provide support for the topside deck. The total weight of the CGS (assumed) is 42,500,000 kg (42,500 tons) with the concrete reinforcement inclusive. The colliding vessel is made of structural steel, with a deadweight/total weight of 4,070 ton (4,070,000kg).

The ANYSY is a general-purpose finite-element analysis/modeling tool for solving numerically problems in the field of sciences and engineering. These problems include but not limited to static/dynamic, structural analysis (both linear and nonlinear), heat transfer, fluid, as well as acoustic and electromagnetic problems [11].

Finite Element Analysis FEA, is a simulation method most often use to predict the physical behavior of structures/systems. In other words, it gives a clue of how a product reacts to real-world forces, vibration, heat, fluid flow and other physical effects. FEM working method is by breaking down (discretizing) a real object into a large number (thousand) of finite elements with nodes, such as little cubes. Mathematical equations then help in predicting the behavior of these elements at those nodes [9, 10].

The geometry model of the structures were done using SolidWorks CAD tool. This tool enables designers to mathematically create solid models of objects that can be stored in a database. It has the advantage of converting 2D drawings immediately to 3D once as desired.

Rock mounts were placed on the seabed to prepare the foundation for CGS installation to accommodate unevenness of the seabed, also mounted at the base edges of the caisson after installation of the CGS for scour protection.

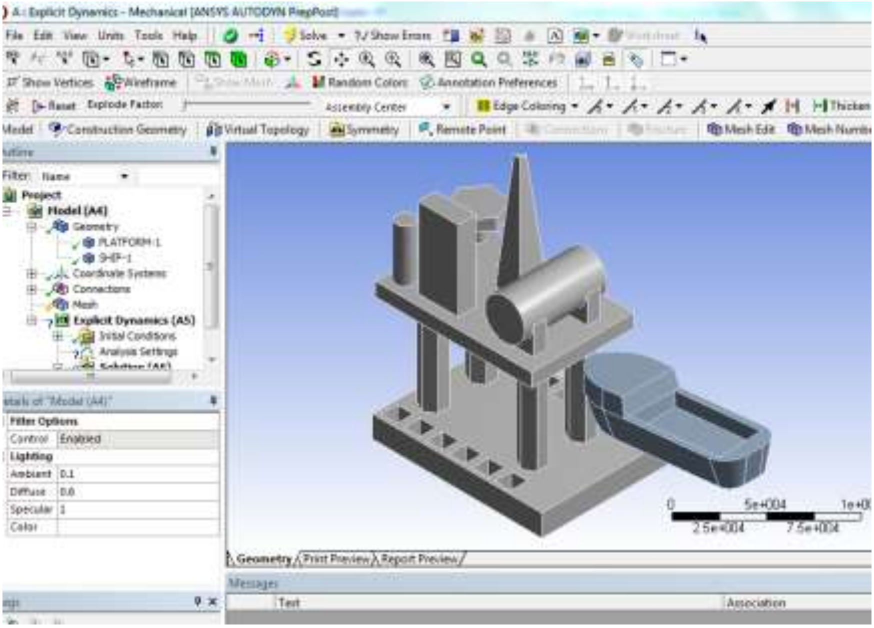


Fig. 3 Imported geometry to ANSYS environment

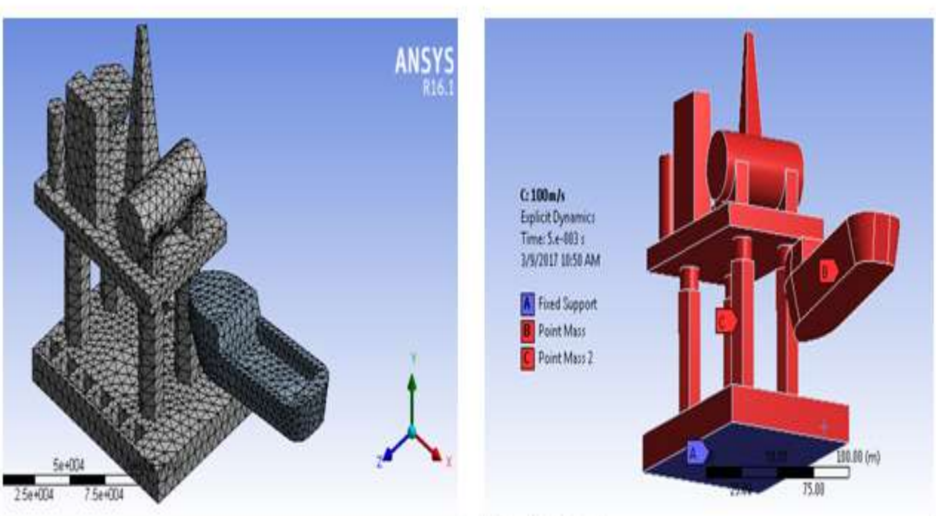


Fig. 4 Meshed Model and model showing fixed support

2.1 Material Data

Table 1 Concrete Structure Constants

Density	2400 kg/m^3
Coefficient of Thermal Expansion	5 C^{-1}
Ultimate Strength	4.8e8Pa
Concrete Material Grade	CONC-35MPA

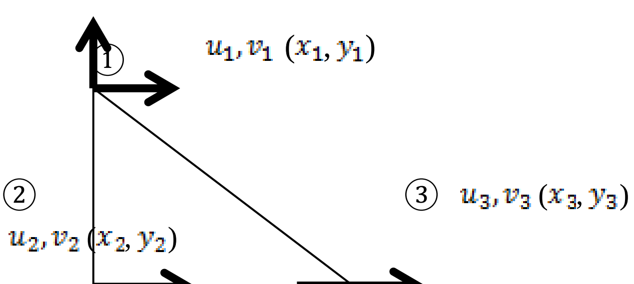
2.2 Assumptions Made

- The modeling of structures is simplified but has the same quality and the dimension.
- The bottom of the platform is treated as rigid (fixed).
- The structure is located at a shallow water of about 45m, hence the effect of wave and sea frequency are neglected.
- The collision is considered at 90 degree.
- The investigation were for a collision of 5m/s, 10m/s 16m/s, 50m/s, and 100m/s vessel velocities.
- End time of 0.005s.

2.3 Governing Equation

The finite element governing equation for displacement and stress of this vessel-platform impact problem scenario is derived from the principle of virtual work, *which states that the external applied load (F) subject on a structure must be in equilibrium with the internal stress (displacement)* [7].
Mathematically,

$$\mathbf{F}=\int_{\Omega}[\mathbf{B}]^{T}\boldsymbol{\sigma}\, d\Omega \qquad (1)$$



$$U(x,y)=H_1(x,y)U_1+H_2(x,y)U_2+H_3(x,y)U_3$$
$$V(x,y)=H_1(x,y)v_1+H_2(x,y)v_2+H_3(x,y)v_3$$

$$\begin{Bmatrix} u \\ v \end{Bmatrix} = \begin{bmatrix} H_1 & 0 & H_2 & 0 & H_3 & 0 \\ 0 & H_1 & 0 & H_2 & 0 & H_3 \end{bmatrix} \begin{Bmatrix} u_1 \\ v_1 \\ u_2 \\ v_2 \\ u_3 \\ v_3 \end{Bmatrix} = [N]\{d\} \qquad (2)$$

$$\{\sigma\} = [D]\{\varepsilon\} \qquad (3)$$

$$[\varepsilon] = \begin{pmatrix} \frac{\partial u}{\partial x} \\ \frac{\partial v}{\partial y} \\ \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \end{pmatrix} \qquad (4)$$

$$\begin{Bmatrix} \frac{\partial u}{\partial x} \\ \frac{\partial v}{\partial y} \\ \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \end{Bmatrix} = \begin{bmatrix} \frac{\partial H_1}{\partial x} & 0 & \frac{\partial H_2}{\partial x} & 0 & \frac{\partial H_3}{\partial x} & 0 \\ 0 & \frac{\partial H_1}{\partial y} & 0 & \frac{\partial H_2}{\partial y} & 0 & \frac{\partial H_3}{\partial y} \\ \frac{\partial H_1}{\partial y} & \frac{\partial H_1}{\partial x} & \frac{\partial H_2}{\partial y} & \frac{\partial H_2}{\partial x} & \frac{\partial H_3}{\partial y} & \frac{\partial H_3}{\partial x} \end{bmatrix} \{d\}$$

$$\{\varepsilon\} = \begin{Bmatrix} \frac{\partial u}{\partial x} \\ \frac{\partial v}{\partial y} \\ \frac{\partial u}{\partial y} + \frac{\partial v}{\partial x} \end{Bmatrix} = [B]\{d\} \qquad (5)$$

$$[B] = \frac{1}{2A} \begin{bmatrix} (y_2 - y_3) & 0 & (y_3 - y_1) & 0 & (y_1 - y_2) & 0 \\ 0 & (x_3 - x_2) & 0 & (x_1 - x_3) & 0 & (x_2 - x_1) \\ (x_3 - x_2) & (y_2 - y_3) & (x_1 - x_3) & (y_3 - y_1) & (x_2 - x_1) & (y_1 - y_2) \end{bmatrix}$$

$$H_1 = 1/2A \begin{vmatrix} (x_2 y_3 - x_3 y_2) \\ +(y_2 - y_3)x \\ +(x_3 - x_2)y \end{vmatrix}, \quad H_2 = 1/2A \begin{vmatrix} (x_3 y_1 - x_1 y_3) \\ +(y_3 - y_1)x \\ +(x_1 - x_3)y \end{vmatrix}, \quad H_3 = 1/2A \begin{vmatrix} (x_1 y_2 - x_2 y_1) \\ +(y_1 - y_2)x \\ +(x_2 - x_1)y \end{vmatrix}$$

From equations (3) & (5) we have;

$$\mathbf{F} = \int_{\Omega} [\mathbf{B}]^T [\mathbf{D}] [\mathbf{B}] \, d\Omega \, [\mathbf{d}] \qquad (6)$$

The element stiffness matrix for the impacting force is expressed as;

$$[\mathbf{F}] = [\mathbf{K}] [\mathbf{d}] \qquad (7)$$

Integrating (6) yields;

$$[\mathbf{F}] = \mathbf{t}[\mathbf{B}]^T [\mathbf{D}] [\mathbf{B}]\mathbf{A} \qquad (8)$$

Equating (6) and (7),

$$[\mathbf{K}] = \mathbf{t}[\mathbf{B}]^T [\mathbf{D}] [\mathbf{B}]\mathbf{A} \qquad (9)$$

Where:

[F] = Impacting force, **[K]**= Stiffness matrix, **[d]**= Displacement/Deformation, ε = Strain, **σ**=Stress, A=Area**, t**=Plat thickness, H= Shape function.
[8, 11]

3. Results and Discussion

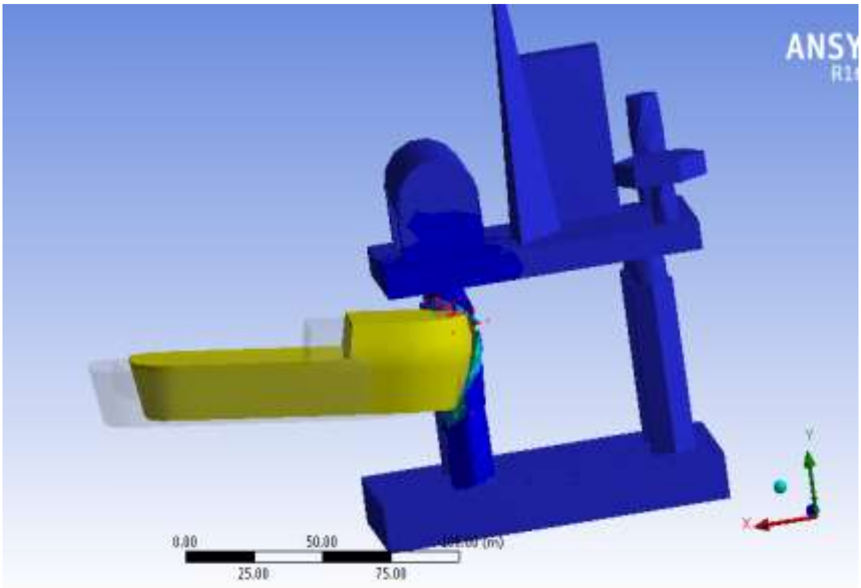


Fig. 5 Simulation model of the collision

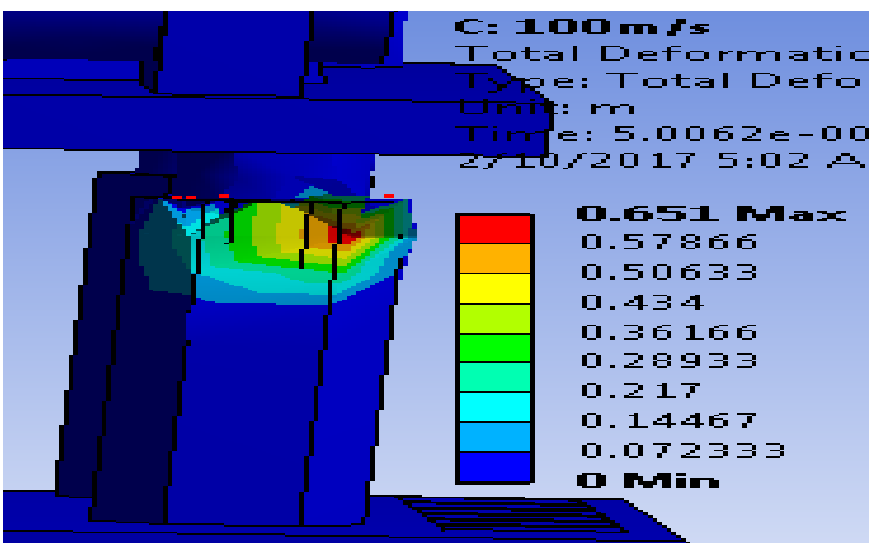


Fig. 6 Deformation contour plot

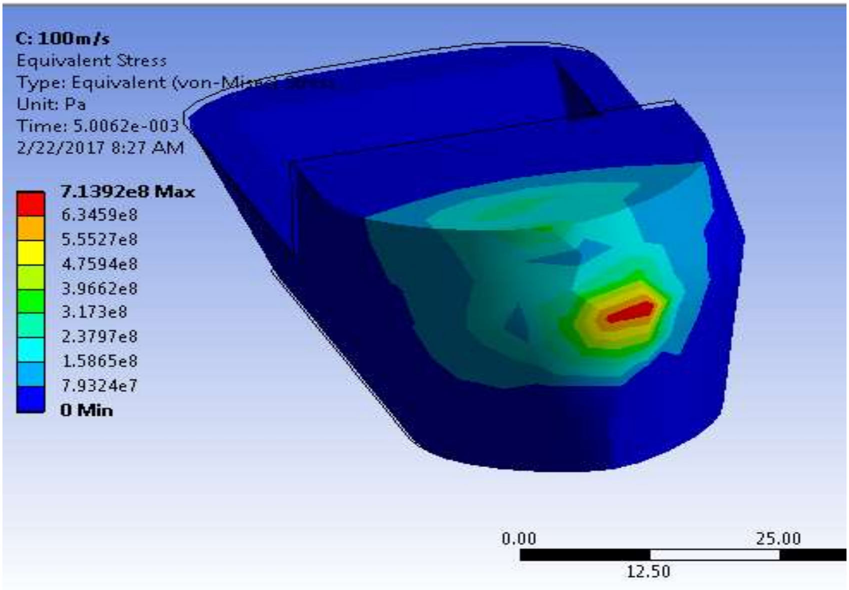


Fig. 7 Stress contour plot

Table 2 Plot of Velocity against Total Deformation

Velocity (m/s)	Total Deformation (m)	Damage Value	Maximum Occurred
5	0.02503100	0.00000	Ship
10	0.05019100	0.05952	Ship
16	0.08067100	0.18284	Ship
50	0.21491000	0.83078	Platform
100	0.65100000	1.00000	Platform

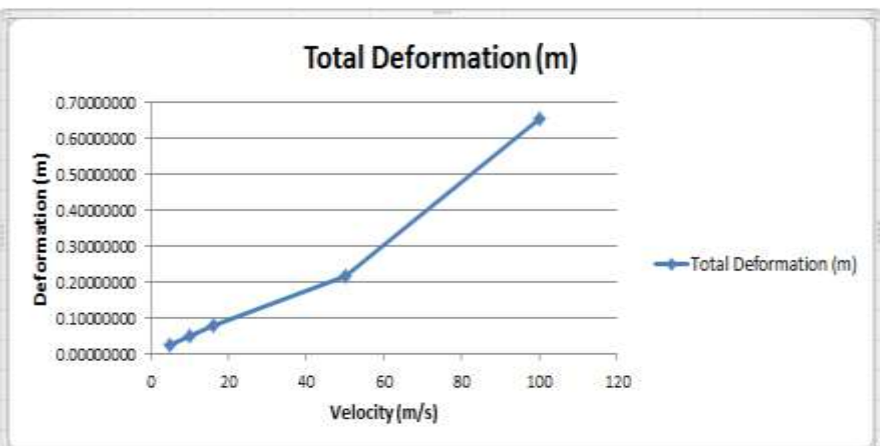


Fig. 8 Graph of total deformation Versus Velocity

Table 3 Plot of Velocity against Stress

Velocity (m/s)	Stress(e7)Pa	Maximum Occurred
5	0.0000000	
10	7.2299	Ship
16	11.695	Ship
50	19.615	Ship
100	71.392	Ship

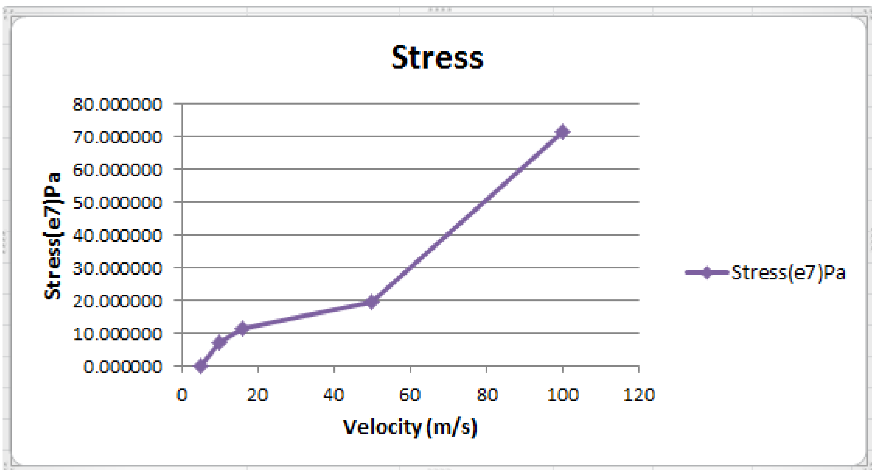


Fig. 9 Graph of Stress versus Velocity

In FEA/ANSYS EXPLICIT DYNAMICS, the contour plot is interpreted using the contour scale which has different colour codes [12]. Simulations were done for the chosen velocities and results gotten for deformation/displacement and stress on both platform and vessel. Damage simulations were carried out also.

Damage in ANSYS simulation shows the load bearing capacity of a structure under consideration. If damage value of 1 is gotten after simulation means the structure has failed [13].

Deformation and Damage

Table 2 and Fig. 8 show results of the total displacement and damage at various velocities. The results revealed that the deformation is proportional to increase in velocity. It also shown that at velocity 50m/s, the platform started compromising its load bearing strength and totally collapsed at velocity 100m/s. From the table it can be seen that the maximum occurred deformation for 50m/s and 100m/s is on the platform depicting that at short impact time of 0.005s the energy generated was transferred to the platform.

Stress

Table 3 is the tabulated results for stresses at the various velocities. This result revealed that the 100m/s velocity exerted a maximum internal force of 7.1392e8Pa, which exceeded the ultimate strength of material in table 1 when compared. This implies that, failure has occurred. The induced stress occurred more on the ship showing that energy was conserved on the impacting structure, see table 3.

4. Conclusion

The study looked into the deformation/ damage rate and stress at the various velocities. And also compared stresses with the material yield strength (the point at which the material starts experiencing deformation) of the structures. It was concluded that:

1. The deformation, stress increases as the velocity increases.
2. At velocity of 50m/s and above the structures started compromising there load bearing capacity.
3. The 100m/s velocity which is equivalent to a velocity of RPG (Rocket Propelled Grenade), both structures experienced high stresses which are greater than their material yield strengths.

It is worthy of note that accident in general does not ring a bell nor been sent by the voodoos but caused as a result of human errors. In order to reduce the rate of accident offshore we therefore recommend that a system like INFRARED MOTION SENSOR OR INDECATOR that will alert and re-awaken the consciousness of the personnel onboard the ship and those on the platform about the presence of an oil facility or an oncoming transporting vessel respectively from a distance.

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