Limiting Criteria of Dent Damage for Fixed Offshore Platform in Peninsular Malaysia

by

Muhamad Syafiee Bin Mazlan

Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Civil Engineering)

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CERTIFICATION OF APPROVAL

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Civil Engineering Programme
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Approved by,

____
(Assoc. Prof. Ir. Dr. Mohd Shahir Liew)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

September 2012

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible to the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources and person.

MUHAMAD SYAFIEE BIN MAZLAN

ABSTRACT

Offshore industry has set up its based a long time ago. Throughout the years, many offshore platforms have been installed and many damages of installed platforms have been recorded. The damaged offshore platforms must be repaired where a standard reference is needed to determine the level of damages as well as to come out with maintenance program. Researches have been carried out based on Gulf of Mexico's platforms. However there are platforms which have been installed in other fields outside Gulf of Mexico like in Peninsular Malaysia. Therefore a threshold of damages of the offshore platforms must be determined for Peninsular Malaysia as well due to numbers of offshore platforms that have been installed in Peninsular Malaysia. This study is carried out to determine the critical depth of underwater dent damage in braces for Peninsular Malaysia platforms. This study also aims to quantify the effects of dent damage on member integrity (reduction in member strength). Finite element analysis is a significant analysis to determine the maximum strength of the platforms subjected to dent damage which is then used to quantify the reduction in member compressive strength. The analysis is run by using SACS software where a PMO's platform is modeled before the analysis take place. Dimension of the platform is needed to model the structure in SACS software. Modeling of the platform is an important step before the other steps. The modeled platform is subjected to storm condition environmental load as well as ship impact load which later can cause dent formation.

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CHAPTER 1

INTRODUCTION

1.1 Project Background

Offshore industry has started its first step a long time ago. Over 50 years of the age of the offshore industry, there are many kinds of development have been made to suite the current purposes and challenges in offshore industry, especially the performance of installed offshore platforms. Installation of offshore platform was first recorded in 1947 when Kerr-McGee had successfully drilled an offshore well in the Gulf of Mexico in 15 ft. (4.6m) of water off Louisiana (Burleson, 1999). However, the first drilled offshore well was found earlier than the time of the first offshore platform installation, which in the 1890s into the waters of Pacific Ocean, offshore Summerland, California (Chakrabarti, 2005). As the offshore industry move forward more offshore platforms have been built due to increase of oil and natural gas exploration and production all over the world. On December 31, 1997, 5561 number of installed offshore platforms had been recorded in the Gulf of Mexico OCS region (MMS, 2001). It is norm of the life that everything present in this world somehow will be experiencing damages. The structure of installed offshore platforms experienced it as well. The damages are classified by what caused it; accidental damage – due to supply and boat impact to the structure or/and dropped objects during operation, performance damage – due to platform ageing, insufficient design or fabrication, and pre-commissioning damage – due to defect in materials or/and improper transportation (Kallaby & O'Connor, 1994). The most recorded damages of the fixed offshore platforms all over the world is accidental damage. In UK Continental Shelf, between years 1980 to the years 2005, recorded number of accidents of fixed offshore platform unit was 7018 and from the total number of accidents recorded, 6510 accidents came from production unit (Det Norske Veritas, 2007). Typical examples of accidental damages are dents, bows, gouges, and crack. The type of damage that is looked into consideration in this project is dents. Denting is caused by the impact of ship or boat collision to a broadside of jacket component of fixed offshore platform. Fixed jacket structure is a three-dimensional space frame which consists of tubular bracing members – horizontal brace, vertical brace, and diagonal brace – and piles that are driven into the seafloor through tubular jacket legs (Chakrabarti, 2005). Therefore the impact of the boat collision to the jacket structure will be dealing on the tubular members of the jacket. The denting effect on the tubular members leads to a reduction in member strength (Visser Consultancy, 2004). Underwater damages occurred at the jacket that were commonly recorded are joint failures, jackets leg failures, conductor guide frame failures, and brace failures. Brace failures are major contributor to the damages of the fixed jacket structures of the offshore platforms (Energo Engineering, 2006). The assessment on the tubular brace is necessary and the diagonal braces are taken into consideration and highly emphasize as the diagonal members are taking higher load as compared to the horizontal and vertical braces. In the most of cases of damages, the members within the area of splash zone are more critical due to high exposure to accidents. Therefore it is important to assess these members in order to ensure the strength capacity of the members as well as the whole jacket structures are fit to current operational condition. Damage threshold is required to perform the assessment and as in this project the threshold of dent damage will be configured. There are many researches had been done to come out with the damage threshold for the fixed offshore platforms all over the world especially in Gulf of Mexico and UK Continental Shelf. However there is no damage threshold set up for PETRONAS Peninsular Malaysia Operation’s (PMO’s) platforms. Instead of following the value from Gulf of Mexico platforms, damage threshold for PMO’s platforms itself is required for the assessment due to different in environmental conditions from Gulf of Mexico or other places.

1.2 Problem Statement

A standard threshold for typical damages of PMO's offshore platforms is not configured since the first platform was operated. Up to now, Carigali Sdn Bhd has 44 platforms including Floating, Storage and Offloading (FSO) and Floating, Production, Storage and Offloading (FPSO) in Peninsular Malaysia operated by PMO. For the configuration of damage threshold, the most critical member that takes load the most is considered. In this case, the major contribution of underwater damages is bracing failures (Energo Engineering, 2006) and the most critical braces in the jacket structures are diagonal braces because diagonal component always take higher loads as compared to horizontal and vertical components.

Gulf of Mexico and other places platforms are installed in different location as compared to Peninsular Malaysia's platforms. As the locations of the platform installation are different, the environmental condition and metocean criteria used are different. Gulf of Mexico's platforms are based on hurricanes and winter storm condition for the analysis (API, 2000). Different in Peninsular Malaysia, normal operating condition – 1 year return period environmental loads; and extreme storm condition – 100 years return period of environmental loads; are used for the analysis (PTS, 2010). These environmental conditions of Gulf of Mexico and Peninsular Malaysia are totally different each other. Therefore this project proposed to focus on dent damage acceptance criteria of the diagonal brace of fixed jacket platform at depth of splash zone in Peninsular Malaysia.

The dent acceptance limiting criteria could be used for the risk assessment and maintenance planning purposes for the Peninsular Malaysia's platforms later on.

1.3 Objectives

The objectives of the project are:

a) To determine the critical sizes of underwater dent damage of jacket brace for Peninsular Malaysia's platforms.
b) To quantify the effects of dent damage on member integrity (reduction in member strength).

1.4 Scope of Study

There are three main tasks identified in order to achieve the objectives of this study. These are:

a) Collection of data of PMO's platforms to develop a model for the analysis and simulation (MSL Engineering Limited, 1999).
b) Generation of dent depth of the diagonal jacket brace at splash zone region due to ship impact load and storm environmental load.
c) Develop capacity reduction factor due to dent damage to quantify the reduction in member compressive strength.

CHAPTER 2

LITERATURE REVIEW

2.1 Fixed offshore structures

Offshore structures are classified into two major groups; fixed structures and floating structures. The different between the groups of the offshore structures is the water depth where the structures are installed. As going to deeper water depth, fixed offshore structures are no more applicable and economical. However the most commonly installed offshore structures recently are fixed structures. In the Gulf of Mexico OCS, the number of fixed structures had been installed was 5561 as December 31, 1997 and it is increasing over the years (MMS, 2001). Jacket platform, Gravity Based Structures (GBS), Compliant Tower, and Jack-Up are the widely used fixed offshore structures in oil and gas industry. All the fixed structures are attached and fixed onto the sea bed.

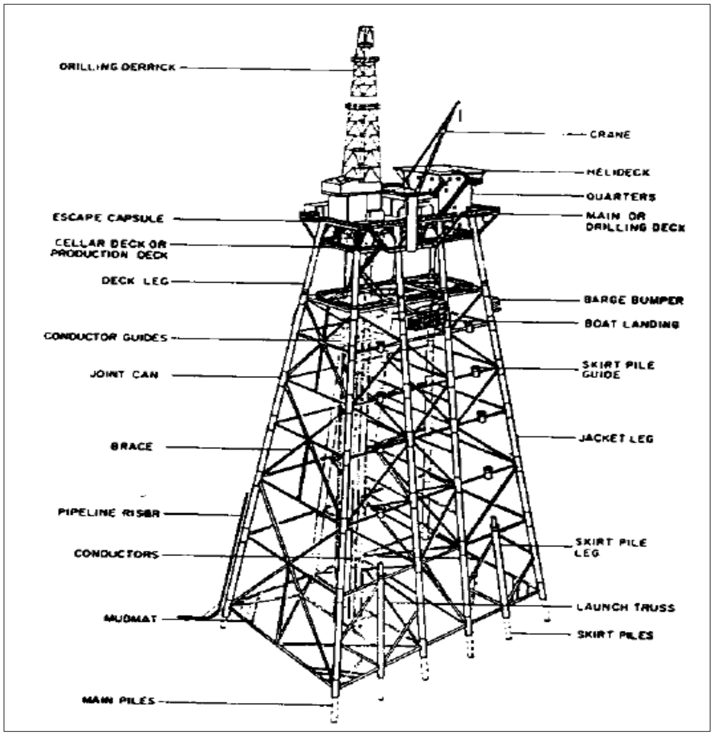

Figure 1 Jacket Platform

Jacket platform is a three-dimensional vertical section space frame formed by interconnection of tubular members (Chakrabarti, 2005). It is called ‘jacket’ due to the concept of providing enclosure for conductors. Jacket platforms are having two parts which are topsides and jacket. The top part of jacket structure is connected to the bottom part of topsides where decks are placed. The jacket structure is fixed on the seafloor by tubular piles driven through the jacket legs (major piles). Some of the tubular piles are driven through skirt piles which are attached to the bottom part of the jacket. The principle behind the jacket platforms is to minimize the natural period of the structures below 4s to avoid resonant behavior with the wave period (Nallayarasu, 2012). Jacket platforms are installed in the shallow water depth up to 500m. At the early era of the operation, it is limited to a water depth of 150m-180m in North Sea. In the Gulf of Mexico, many jackets were installed in deeper water depth as more sources were explored. Jacket platforms are commonly used for drilling and production. Cognac Oil and Gas Drilling Platform (311m) was built in 1978 over the water of Cognac Field in Mississippi Canyon.

Figure 2 Cognac Oil and Gas Drilling Platform

2.2 Underwater damages of offshore platform

Based on extensive work carried by Amoco in the North Sea, underwater damages are classified by what caused the damage (Kallaby & O'Connor, 1994). The most common damage is accidental damage. Accidental damage is caused by impact of workboat to the jacket structures. Dropped objects during the normal operation are also causing it. Bows, dents, gouges, and cracks are the examples of typical accidental damage. Platform ageing and inadequate design or fabrication is causing performance damage. Performance damage is leading to corrosion and overload or fatigue cracks. Pre-commissioning damage is due to fabrication defects in materials or welds. It is also due to transportation damage and installation faults. Examples of typical pre-commissioning damage are lack of fusion and incomplete weld.

Hurricane Ivan that attacked Gulf of Mexico on September 15th, 2004 had destroyed and significantly damaged the platforms. From this event, a few researchers had studied on the effects of Ivan to the structural component of the involved offshore platforms. This study had come with underwater jacket damage classification.

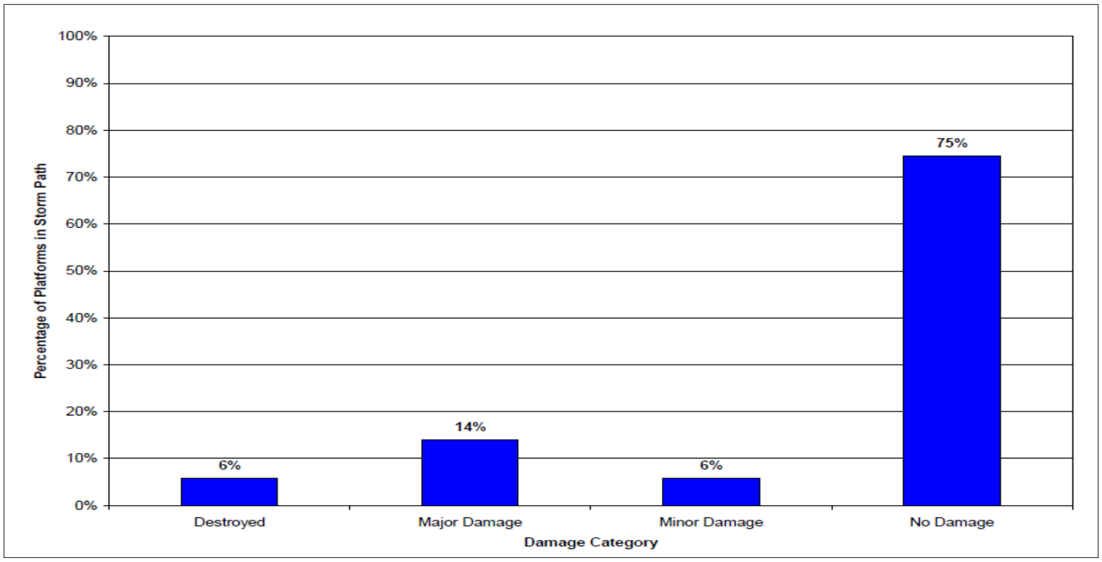

Figure 3 Damaged platform sorted by damage type (Energo Engineering, 2006)

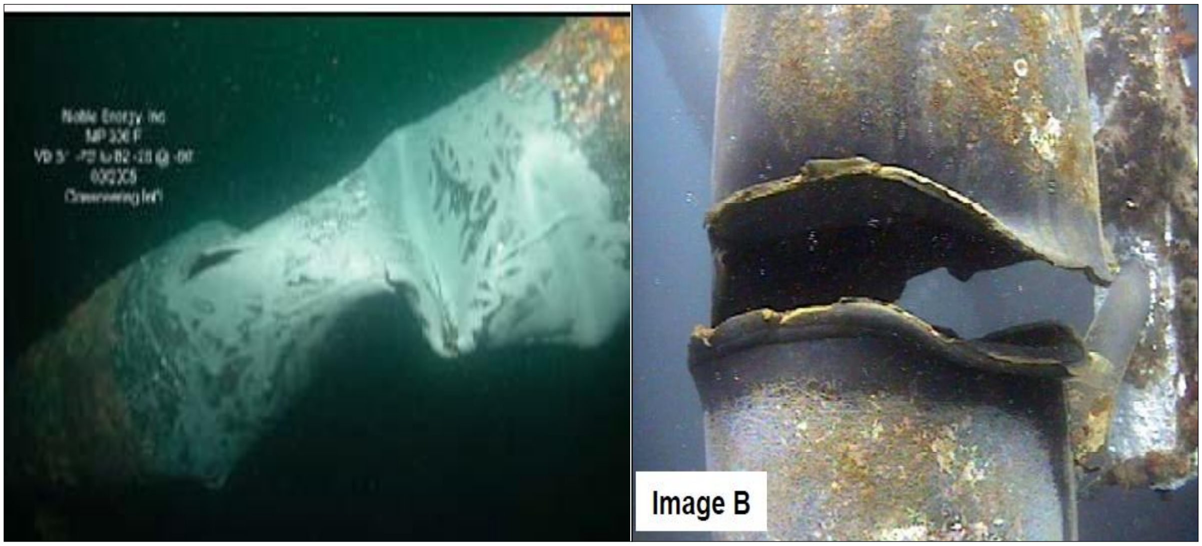

Figure 4 Brace damage (Energo Engineering, 2006)

Most of the damages happened to the platforms at water depth of 200ft to 350ft (≅ 61m to 107m) (Energo Engineering, 2006). Underwater jacket damages are jacket leg failures, joint failures, braces failures, and conductor guide frame failures. Some assessed platforms experienced leg buckling and separation on the diagonally opposed legs. Punching, crashing, and cracks are the joint failures which had been found at the platforms that experienced Ivan. The majority of the platforms that affected from Ivan sustained brace failure. Most of the damages were local buckling of braces (Energo Engineering, 2006). Hurricane Ivan had given the chances to study the performance of fixed platforms in the Gulf of Mexico.

Figure 5 Crashing on X-brace (Energo Engineering, 2006)

2.3 Damage threshold

Since the late 1960's, about 200 fixed platforms had been installed in the UK sector of the North Sea. Most of these platforms are now over 20 years old and approaching their design lives. The possibility of these platforms affected from in-service damage is high. Several studies have been conducted to quantify the strength of the impacted tubular. For example, due to the incidents occurred in 1975 and 1983, Lloyd presented the results of an assessment from the in-house database platforms which had been strike by vessels and had suffered damage to members and joint (Lloyds , 1985). The incidents included dents and bows damages to members and punching shear and weld pull-out failures at joints.

In October 1999, MSL Engineering Limited had prepared a report on detection of damage to underwater tubular and its effect on strength (MSL Engineering Limited, 1999). The objectives of this survey were to determine the critical sizes of bow and dent damage and to examine and establish the reliability of available procedures. Based on 118 numbers of data, the detected dents depth ranges from 4mm to 305mm. The first significant set of dent depth data recorded was 12.5mm. However, the most frequent recorded dent depth was 38mm. Therefore two levels of thresholds are possibly exist; 12.5mm and 38mm. Another survey was on bow damage based on 32 numbers of data. The first set of recorded bows is 9.5mm. However this is associated with dents. The first significant set of bow is in the range between 105 to 155mm followed by the second set between 305 to 410mm. There are two thresholds identified for bow damage which are 130mm and 350mm. These thresholds values are representing average of 105mm to 155m and 305mm to 410mm consequently. The summary of reduction in member compressive strength and the thresholds are shown in Table 1.

Table 1 Reduction in member compressive strength for threshold levels of dents and bows (MSL Engineering Limited, 1999)

Typical Member	Member Geometry			Dent (mm)					
				12.5			38		
	Dia. (mm)	λ	D_o/t	Bow (mm)			Bow (mm)		
				0	130	350	0	130	350
Brace	750	1.01	30	0.04	0.44	0.63	0.11	0.47	0.65
	750	1.01	50	0.06	0.46	0.65	0.17	0.52	0.68
Leg	2500	0.31	30	0.01	0.16	0.33	0.04	0.18	0.34
	2500	0.31	50	0.02	0.17	0.35	0.06	0.20	0.37

Another survey had been carried out and the paper was presented in May 1994 on underwater survey and damage assessment (Kallaby & O'Connor, 1994). The study is made based on 36 ksi steel and 50 ksi steel. The axial capacity due to bowing is calculated for the specific d/D of each yield stress of the steel. The reduction capacity, R is calculated based on ultimate compressive stress for out – of – straightness, $\delta_o/L = 0.001$ for typical brace and leg member. The capacity reduction factors are based on the worst-case slenderness assumption therefore it is conservative. From the study, axial load capacity is affected by less than 10% for bows up to 1.0” – 1.5” for braces and 1.0” for legs; is affected by less than 15% for bows up to 1.5” – 2.0” for braces and 1.5” for legs. Two tubular sizes of a leg and a brace are used in developing capacity reduction factors for dent effect:

a) 39” ∅ × 0.50” w.t. × 50’ – 0 long
D/t = 78, L/r = 43, Fe = 160 ksi.
b) 16” ∅ × 0.375” w.t. × 42’ – 0 long
D/t = 43, L/r = 91, Fe = 36 ksi.

In the case of larger dents, the ultimate axial stress is about the same because the larger tube has minor reductions in stress due to local buckling. While in the case of smaller dents, the strength of the larger diameter members maintain a higher portion of the yield stress, while for smaller diameter members, higher slenderness members are more adversely constrained by the buckling effects of dents. As for the conclusion, the less the slenderness ratio is causing greater reduction in strength.

In establishing a damage threshold guideline, assume that the platforms have been designed for a 50-years storm conditions have the following interaction ratios, I.R. (1.25 represents yield stress):

Table 2 Typical Interaction Ratios (Kallaby & O'Connor, 1994)

Member Type	Typical Max I.R.
1. Horizontal bracing at top of jacket	0.45
2. Legs at top of jacket	0.65
3. Vertical bracing at top of jacket	0.90
4. Vertical bracing at lower bays	0.45 – 1.20

Limiting criteria for bows and dents is derived based on I.R. = 1.0 and 50-years storm condition. The limiting criteria are used to define significant damage.

Table 3 Limiting damage criteria (Kallaby & O'Connor, 1994)

Member Type	**Significant Damage**	
	Bow (inches)	**Dent Depth (inches)**
1	6	3
2	4	2
3	4	2
4	0.5 – 4.0	0.5 – 2.0

2.4 Dent Energy of Bracing Members

An offshore structure will absorb the energy from impact and deformation of the structure. The impact to the structure is mostly coming from the ship. The ship impact scenario involves transfer of ship's kinetic energy into strain energy resulting from:

a) Local deformation of the impacted member due to denting and beam bending.
b) Global deformation of the entire structure.
c) Deformation of the ship structure.

The kinetic energy of vessel can be calculated by using equation (1) (API, 2000):

$$E = 0.5\, a\, m\, v^2 \tag{1}$$

Where:

E = kinetic energy of the vessel
a = added mass factor; 1.4 for broadside collision, 1.1 for stern/bow collision
m = vessel mass
v = velocity of vessel at impact

The coefficient for the added mass is based on ship-shaped or boat-shaped hull. The following minimum requirements should be used for platforms in calm environment and close to the base supply:

Vessel mass = 1000 metric tons

Impact velocity = 1.64 ft/s (0.5 m/s)

The minimum requirements are set up based on typical 180-200-foot-long supply vessel in Gulf of Mexico.

The member must sustain to absorb the energy during impact and withstand the environmental load of 100-year storm after the impact. For individual members where energy absorption can be calculated, further checking is not required. For very stiff members (grouted) which can cause the main energy absorption to be in the vessel, the supporting braces for the member, the joints at each end of the member, and the adjacent framing members should be checked for structural integrity resulting from the impact loads. The energy absorption to cause locally damage tubular bracing member can be calculated by using Furnes formula or Ellinas formula (API, 2000). Relationship between force and dent depth from O.Furnes resulting:

$$P_d = 15\, M_p (D/t)^{\frac{1}{2}} (X/R)^{\frac{1}{2}} \tag{2}$$

Where:

P_d = denting force
M_p = plastic moment capacity
D = Diameter of tube
R = Radius of tube
X = Dent depth

Alternatively, C.P.Ellinas has come out with other force and dent depth relationship:

$$P_d = 40\, F_y t^2 (X/D)^{\frac{1}{2}} \tag{3}$$

The dent energy is calculated from integration of denting force over distance:

$$E_d = \int_0^x P_d \, dx \tag{4}$$

The calculated dent energy is an amount of energy absorbed by a member resulting in a respective dent depth on it and it may reflect the stiffness of the member. The higher the dent energy, more energy is absorbed to cause a dent means the stiffer the member.

2.5 Splash Zone

Splash zone can be defined as the external area of offshore structures that are occasionally in and out of water (Det Norske Veritas, 2011). The splash zone is a part of installation where all members within the splash zone have special requirements in design. Det Norske Veritas (DNV) has come out with standards to calculate the limits of the splash zone. Wave height in determining the limits is taken as 1/3 of wave height that has annual probability of being exceeded of 10^{-2} (Det Norske Veritas, 2011).

The upper limit of splash zone (SZ_U) can be calculated by:

$$SZ_U = U_1 + U_2 + U_3 + U_4 + U_5 \tag{5}$$

Where:

U_1 = 60% of the wave height defined above
U_2 = highest astronomical tide level (HAT)
U_3 = foundation settlement, if applicable
U_4 = range of operation draught, if applicable
U_5 = motion of the structure, if applicable

The lower limit of splash zone (SZ_L) can be calculated by:

$$SZ_L = L_1 + L_2 + L_3 + L_4 \tag{6}$$

Where:

L_1 = 40% of the wave height defined above
L_2 = lower astronomical tide level (LAT)
L_3 = range of operating draught, if applicable
L_4 = motions of the structure, if applicable

Splash zone is different from one location to another. The splash zone determination is mainly affected by environmental condition – tidal and wave height. Splash zone in Malaysian waters has been determined by PETRONAS. In the PTS, it is stated that the region of splash zone is below +5.0m MSL and above -3.0m MSL (PTS, 2010). The region of Malaysian splash zone is illustrated in Figure 6. All designs and studies on Malaysian platforms must be referring to this splash zone otherwise stated.

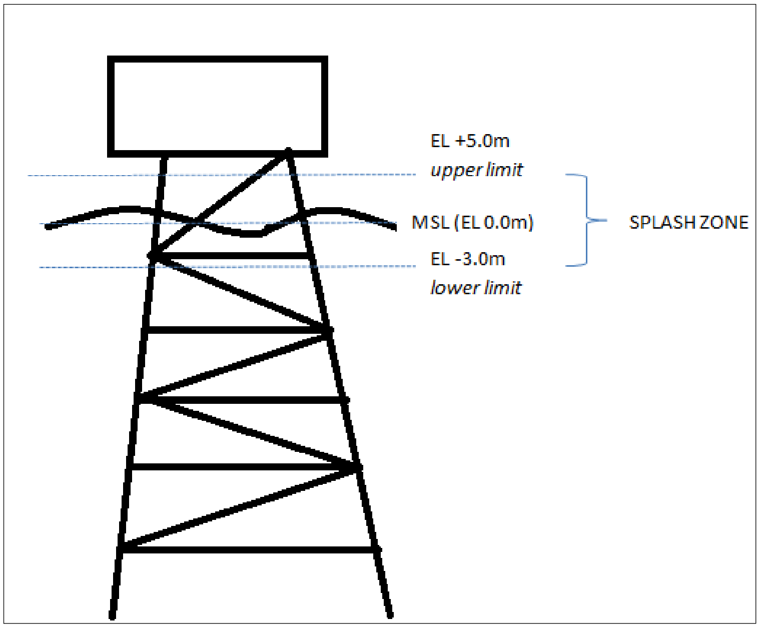

Figure 6 Splash zone for Malaysian water

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

In this study, five phases are involved for the methodology. The flow of the phases along the project is shown in Figure 7.

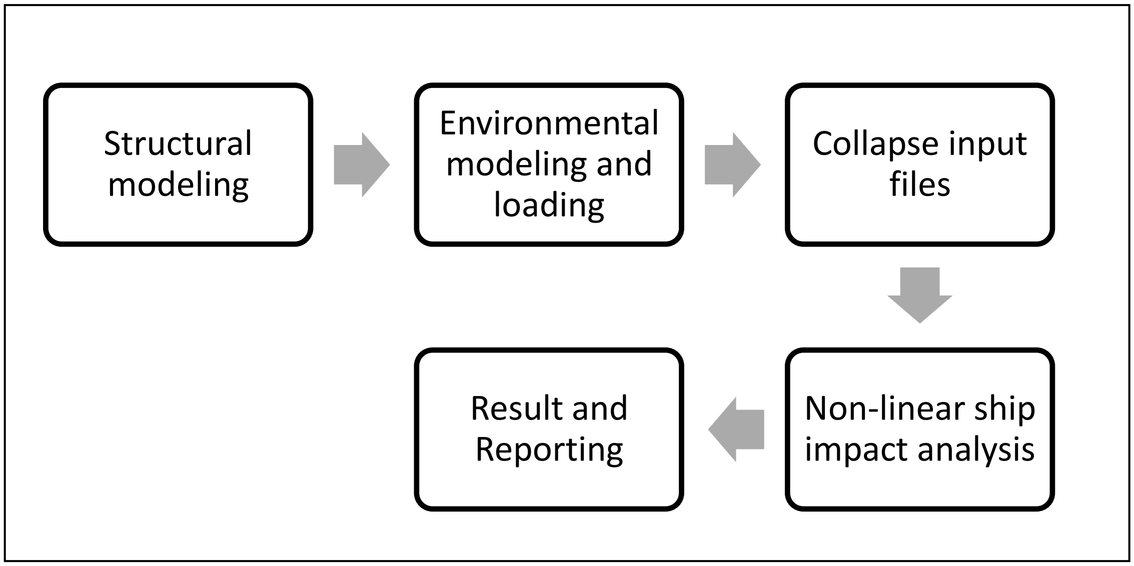

Figure 7 Flowchart of project

3.1.1 Structural modeling

Structural modeling is performed by using software. The input data such as geometrical and material properties are required to perform this task. Data related to this study is gathered from various sources and authorities before the analysis part start. The data that is required in this study are:

i. Dimension of fixed jacket platform which are currently in service within the Peninsular Malaysia region.

ii. SACS input file for a platform model.

Metocean data is required for environmental modeling before the analysis take place. The model is usually in space frame model and is described with three major global axes X, Y and Z consist of local and global coordinate. Once the model of structure is available, the model will be subjected to environmental load and boat impact load. The model used in this study is the ABU jacket platform located in Peninsular Malaysia water. The platform is modeled by using SACS software. The analysis has been carried out using the same structural model *(intact)* developed for In-place analysis with minor modifications / modeling considerations for the purpose of defining the non-linear plastic analysis requirements. The platform is modeled based on joints which are interconnected by members. The members, joints and plates are categorized into groups based on the material properties and location of installation. Therefore, the structural elements will be reported and listed in their respective groups. The material properties of structural elements must be defined in SACS otherwise SACS cannot recognize its existence in the model. A complete structure model is reported in SACS input file (sacinp). Any corrections to be made on the model can be done on the modeler or the input file.

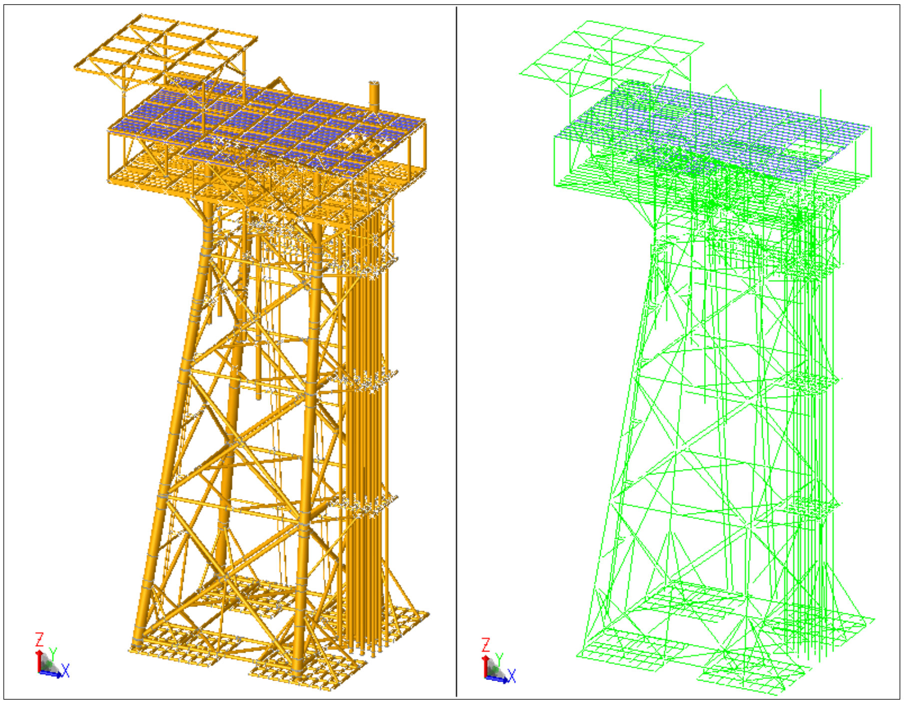

Figure 8 ABU platform model

3.1.2 Environmental modeling and loading

There are two main environmental conditions are assessed for offshore structures. The normal operating conditions and storm condition are the conditions to be considered in design. The comparison of the environmental condition is stated in Table 4. However for the integrity purpose, only storm condition is used for the analysis in this study because the storm condition is more critical as compared to normal operating condition even it occurs rarely during the platform life. The structural model has been initially preloaded with in-place dead loads. The loads are equally distributed and transferred until the mudmat at the bottom part of the structure. The storm environmental load for extreme load condition is directed from eight directions.

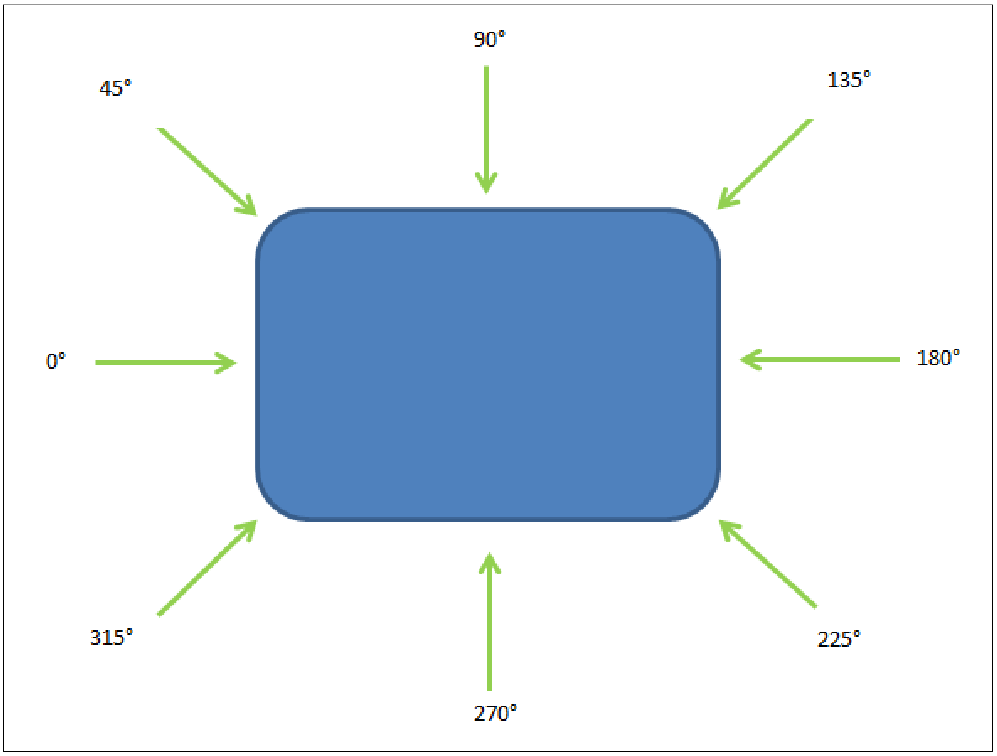

Figure 9 Direction of environmental loading

The load used in the analysis is the combination of storm environmental load and maximum topside dead load. Eight load combinations are used in the analysis where each of them is differed by the wave current properties of each direction. New ship load is defined and selected for the analysis purpose. These loads –

dead loads, environmental loads and ship impact load – are clearly defined in input file.

Table 4 Environmental conditions [extracted from API RP 2A-WSD]

Environmental condition	Normal	Extreme
Description	Expected to occur frequently during the life of the platform.	Occur rarely during the life of the platform.
Importance	Construction and service life of the platform.	Formulating platform design loadings.
Return Period	1-year return period	100-years return period

3.1.3 Input files

In this study, two input files are generated for the purpose of non-linear collapse analysis due to ship impact:

a) SACS model input file (sacinp).
b) Collapse input file (clpinp).

SACS model input file is auto-generated from the modeling of structure in PRECEDE module. Modification has been made on the existing input file for the analysis. New load condition is defined in the input file which is "SHIP" load. The "SHIP" load is defined as a force from the ship which acting on a defined joint on the structure. Therefore new joint named IMP1 is defined along the 7784-7785 member at elevation, Z = 0 m and joint IMP1 is an impacted joint. The impacted joint is selected at such elevation because it is in the region of splash zone where structural elements are exposed to the water in most of the time and high exposure to the ship impact. The force value of the ship that gives the impact on joint IMP1 is defined as 10000 kN (concentrated load) in Y-direction.

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LOADCNSHIP
LOAD   IMP1            1.000+4                              GLOB JOIN   SHIPIMPC
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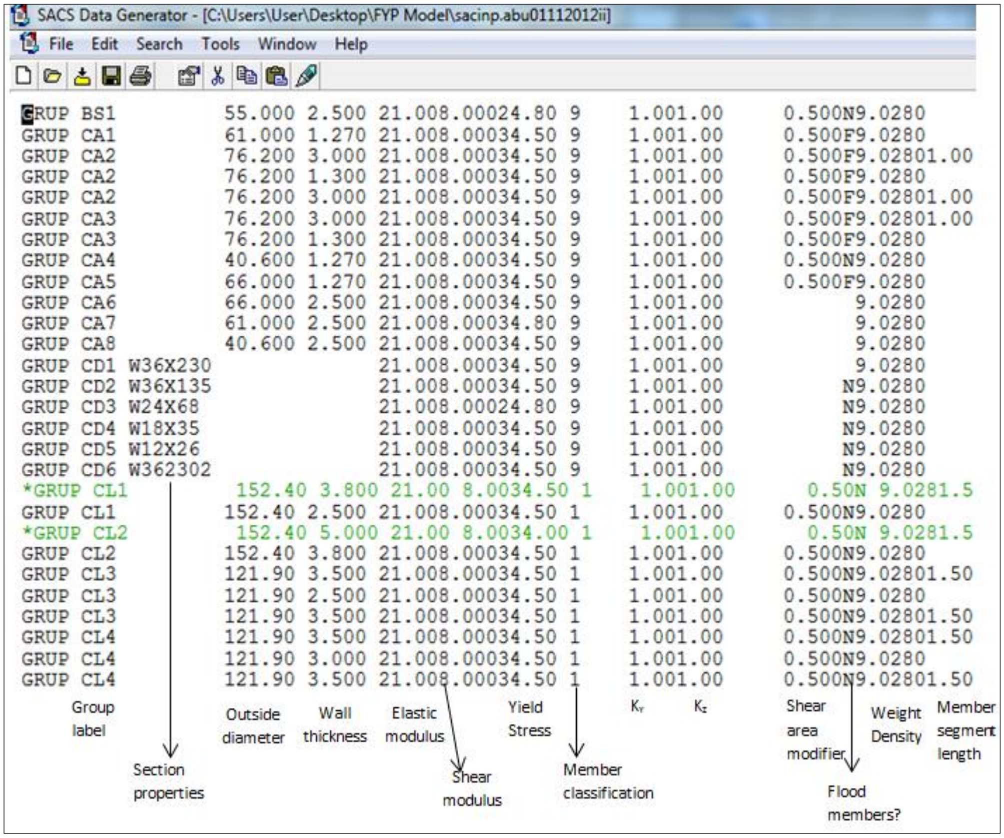
Figure 10 Ship load impact



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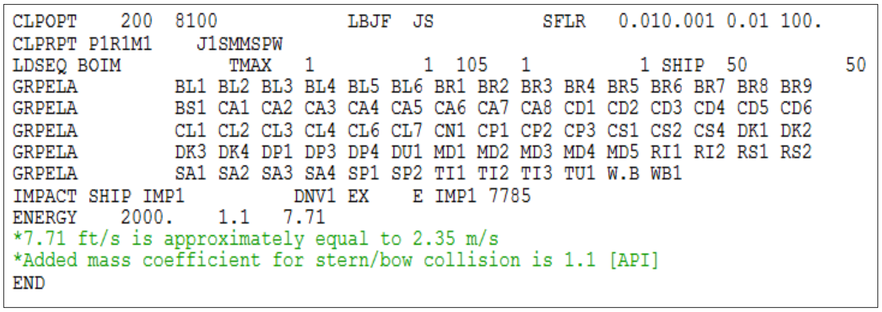
GRUP BS1         55.000 2.500 21.008.00024.80 9    1.001.00     0.500N9.0280
GRUP CA1         61.000 1.270 21.008.00034.50 9    1.001.00     0.500F9.0280
GRUP CA2         76.200 3.000 21.008.00034.50 9    1.001.00     0.500F9.02801.00
GRUP CA2         76.200 1.300 21.008.00034.50 9    1.001.00     0.500F9.0280
GRUP CA2         76.200 3.000 21.008.00034.50 9    1.001.00     0.500F9.02801.00
GRUP CA3         76.200 3.000 21.008.00034.50 9    1.001.00     0.500F9.02801.00
GRUP CA3         76.200 1.300 21.008.00034.50 9    1.001.00     0.500F9.0280
GRUP CA4         40.600 1.270 21.008.00034.50 9    1.001.00     0.500N9.0280
GRUP CA5         66.000 1.270 21.008.00034.50 9    1.001.00     0.500F9.0280
GRUP CA6         66.000 2.500 21.008.00034.50 9    1.001.00           9.0280
GRUP CA7         61.000 2.500 21.008.00034.80 9    1.001.00           9.0280
GRUP CA8         40.600 2.500 21.008.00034.50 9    1.001.00           9.0280
GRUP CD1 W36X230              21.008.00034.50 9    1.001.00           9.0280
GRUP CD2 W36X135              21.008.00034.50 9    1.001.00          N9.0280
GRUP CD3 W24X68               21.008.00024.80 9    1.001.00          N9.0280
GRUP CD4 W18X35               21.008.00034.50 9    1.001.00          N9.0280
GRUP CD5 W12X26               21.008.00034.50 9    1.001.00          N9.0280
GRUP CD6 W362302              21.008.00034.50 9    1.001.00          N9.0280
*GRUP CL1         152.40 3.800 21.00 8.0034.50 1    1.001.00      0.50N 9.0281.5
GRUP CL1         152.40 2.500 21.008.00034.50 1    1.001.00     0.500N9.0280
*GRUP CL2         152.40 5.000 21.00 8.0034.00 1    1.001.00      0.50N 9.0281.5
GRUP CL2         152.40 3.800 21.008.00034.50 1    1.001.00     0.500N9.0280
GRUP CL3         121.90 3.500 21.008.00034.50 1    1.001.00     0.500N9.02801.50
GRUP CL3         121.90 2.500 21.008.00034.50 1    1.001.00     0.500N9.0280
GRUP CL3         121.90 3.500 21.008.00034.50 1    1.001.00     0.500N9.02801.50
GRUP CL4         121.90 3.500 21.008.00034.50 1    1.001.00     0.500N9.02801.50
GRUP CL4         121.90 3.000 21.008.00034.50 1    1.001.00     0.500N9.0280
GRUP CL4         121.90 3.500 21.008.00034.50 1    1.001.00     0.500N9.02801.50
```

Figure 11 SACS input file

Collapse input file is prepared as the requirement of COLLAPSE program. The collapse input file determines the precision of the analysis and the condition to the analysis. The loads to be implemented in the analysis are defined in the collapse input file which is corresponding to the load selection in the SACS input file. The loads are set based on the sequence to be implemented in the analysis which is later explained in section 3.1.4. The increment of the loads condition is entered. This increment is the number of steps from the starting load factor to the end load factor. Some elements are defined as elastic large deflection element with no plastic or buckling effects included. These elements are considered as non-structural elements since the elements have not participated in energy absorption. The defined elastic elements are:

a) All topside elements
b) Caisson/ conductor/ riser



```
CLPOPT    200  8100            LBJF  JS          SFLR   0.010.001 0.01 100.
CLPRPT P1R1M1    J1SMMSPW
LDSEQ BOIM          TMAX   1          1  105   1          1 SHIP  50         50
GRPELA         BL1 BL2 BL3 BL4 BL5 BL6 BR1 BR2 BR3 BR4 BR5 BR6 BR7 BR8 BR9
GRPELA         BS1 CA1 CA2 CA3 CA4 CA5 CA6 CA7 CA8 CD1 CD2 CD3 CD4 CD5 CD6
GRPELA         CL1 CL2 CL3 CL4 CL6 CL7 CN1 CP1 CP2 CP3 CS1 CS2 CS4 DK1 DK2
GRPELA         DK3 DK4 DP1 DP3 DP4 DU1 MD1 MD2 MD3 MD4 MD5 RI1 RI2 RS1 RS2
GRPELA         SA1 SA2 SA3 SA4 SP1 SP2 TI1 TI2 TI3 TU1 W.B WB1
IMPACT SHIP IMP1          DNV1 EX    E IMP1 7785
ENERGY    2000.    1.1   7.71
*7.71 ft/s is approximately equal to 2.35 m/s
*Added mass coefficient for stern/bow collision is 1.1 [API]
END
```

Figure 12 Collapse input file

Properties of ship impact load are specified in the collapse input file. The ship impact load case is entered correspond to the load case defined in SACS input file otherwise SACS cannot correlate the input files. The impacted joint “IMP1” as stated earlier is specified as well. This study has considered bow/ stern impact of the ship therefore ship indentation curve “DNV1” is selected for energy absorption. The calculation of denting force on member is specified as using Ellinas Formula as stated in section 2.4. The ENERGY line in the collapse input file is for calculation of kinetic energy of the ship which is then absorbed and transferred into strain energy. The properties of ship to be used in this study are specified based on the minimum requirement set by API as stated in section 2.4.

Ship mass = *2000 metric-tons*
Velocity at impact = *2.35 m/s ≈ 7.71ft/s*
Added mass coefficient = *1.1 (bow/stern collision)*

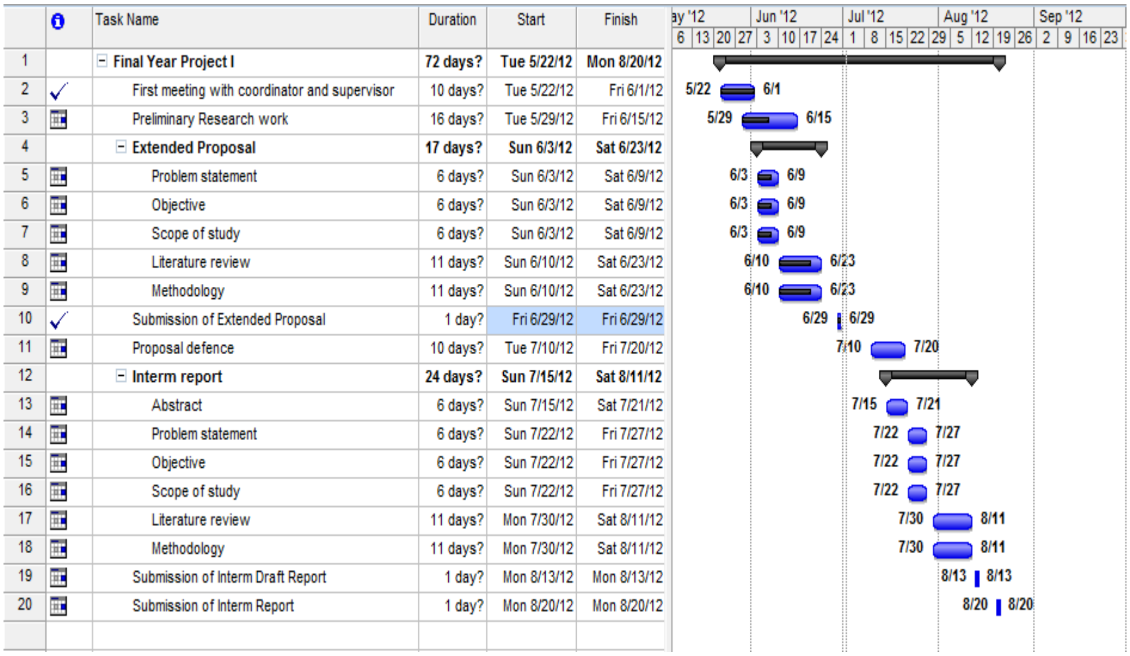
3.1.4 Non-linear ship impact analysis

In order to simulate ship impact scenario and to assess the integrity of the structure due to incident, a non-linear ship impact analysis have been performed using SACS COLLAPSE module. The COLLPASE module is capable of handling structural problems where the plasticity occurs through large deflection including ship impact and progressive collapse. The platform is analyzed non-linearly using a step-by-step procedure. The loads are applied incrementally which initially preloaded with in-place dead load and followed by the eight-direction storm environmental load. Non-linear static collapse analysis has been performed to assess the effect of the platform model to ship impact collision including spread of plasticity and dent formation. The kinetic energy of the ship is primarily absorbed as "work done" due to deformation of structure. The SACS COLLAPSE module updates the stiffness matrix by calculating the nodal displacements and element forces for each load step. Plasticity is introduced when the stress in the member reaches the yield stress. The introduction of plasticity reduces the stiffness of the structure and additional loads due to subsequent load increments will be re-distributed to members adjacent to the members that have gone plastic. Plasticity is not introduced on the groups of structural elements which have been defined as elastic ("GRPELA" in collapse input file). This procedure is continued until the prescribed energy is absorbed by the structure.

3.1.5 Result and reporting

The end results are compiled and tabulated for quantifying reduction of member strength. The reduction of member strength is based on the impact energy, dimensions of the platform and dent formation. The report of the whole findings and result in this study is prepared. The SACS generated result for this study is compiled in the report Appendices.

3.2 Gantt Chart



	ℹ	Task Name	Duration	Start	Finish
1		**Final Year Project I**	**72 days?**	**Tue 5/22/12**	**Mon 8/20/12**
2	✓	First meeting with coordinator and supervisor	10 days?	Tue 5/22/12	Fri 6/1/12
3	▦	Preliminary Research work	16 days?	Tue 5/29/12	Fri 6/15/12
4		**Extended Proposal**	**17 days?**	**Sun 6/3/12**	**Sat 6/23/12**
5	▦	Problem statement	6 days?	Sun 6/3/12	Sat 6/9/12
6	▦	Objective	6 days?	Sun 6/3/12	Sat 6/9/12
7	▦	Scope of study	6 days?	Sun 6/3/12	Sat 6/9/12
8	▦	Literature review	11 days?	Sun 6/10/12	Sat 6/23/12
9	▦	Methodology	11 days?	Sun 6/10/12	Sat 6/23/12
10	✓	Submission of Extended Proposal	1 day?	Fri 6/29/12	Fri 6/29/12
11	▦	Proposal defence	10 days?	Tue 7/10/12	Fri 7/20/12
12		**Interm report**	**24 days?**	**Sun 7/15/12**	**Sat 8/11/12**
13	▦	Abstract	6 days?	Sun 7/15/12	Sat 7/21/12
14	▦	Problem statement	6 days?	Sun 7/22/12	Fri 7/27/12
15	▦	Objective	6 days?	Sun 7/22/12	Fri 7/27/12
16	▦	Scope of study	6 days?	Sun 7/22/12	Fri 7/27/12
17	▦	Literature review	11 days?	Mon 7/30/12	Sat 8/11/12
18	▦	Methodology	11 days?	Mon 7/30/12	Sat 8/11/12
19	▦	Submission of Interm Draft Report	1 day?	Mon 8/13/12	Mon 8/13/12
20	▦	Submission of Interm Report	1 day?	Mon 8/20/12	Mon 8/20/12

3.3 Software for analysis

The structural analyses have been performed using the Engineering Dynamics, Inc.'s SACS (Structural Analysis Computer System) Software. SACS modular programs are industry standard finite element package, which includes modules for the application of wave loads, analysis of pile-soil interaction, subsequent code checking of structural elements, dynamic / static spectral fatigue analysis and push-over analysis. The following SACS modules have been used in non-linear ship impact analysis:

PRECEDE	Advanced Graphic Modeler for modeling
SEA STATE	To generate environmental loads
COLLAPSE	To perform plastic non-linear pushover analysis
COLLVUE	To perform interactive collapse result processor

The SACS COLLAPSE module provides two approaches for the simulation of the ship impact force as follows:

a) Prescribed Displacement Approach
b) Prescribed Force & Energy Approach

A Prescribed Force & Energy approach has been selected for the analysis. In this approach, a joint force together with total kinetic energy or the mass and velocity of the impacting object are used to simulate the impact load condition. This feature makes it possible to stop the impact loading (after maximum prescribed energy has been absorbed) and start unloading of the impact load for further post processing utilizing the residual stresses within the structure due to collision.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Load sequence

Dead loads have been applied first to the model, followed by the environmental load and ship impact load applied incrementally. Each load has initial load factor value, end load factor value and increment numbers. For any load case the magnitude of each increment is constant and is determined by:

$$Load\ Increment = \frac{(End\ load\ factor - Initial\ load\ factor)}{No.of\ increments}$$

Table 5 Load increments applied for each load case

Load Case	**Initial Factor**	**End Factor**	**Number of Increments**	**Load Increment**
TMAX (Dead)	0	1	1	1
101-108 (8-directions Storm)	0	1	1	1
SHIP (Ship Impact)	0	50	50	1

Energy shared by the Structure and Ship is controlled by the IMPACT and ENERGY line (see Figure 12).

4.2 Impact scenario

The total energy absorption and dent energy are calculated thru COLLAPSE run for every direction of storm environmental loads. The ship velocity value used for this analysis is taken as 2.35 m/s (≈7.71 ft/s) while the ship mass is taken as 2000MT. The velocity and ship mass value has passed the minimum requirement set by API therefore higher values are used to give the higher impact on the structural model for conservatism and integrity purpose. The kinetic energy of the ship is calculated from equation (1):

$$E = 0.5\ a\ m\ v^2$$

$$E = 0.5\ (1.1)\ (2000MT)\ (2.35m/s)^2$$

$$E = 2585\text{kJ}$$

Dent energy is calculated for every direction of storm environmental load. The dent energy is an amount of energy required to form dent on member. Non-linear ship impact analysis of eight directions environmental load results the maximum dent depth on bracing member corresponding to the maximum calculated dent energy. The results are summarized in Table 6.

Table 6 Maximum dent depth for eight-direction storm environmental load

Load Condition	Maximum Dent Energy (kJ)	Maximum Dent Depth (cm)	Collision Force (kN)	Energy Absorbed by Member (kJ)
Max. topside load + 0° storm environmental load + Ship impact load	36.0	10.72	1000	71.3

Max. topside load + 45° storm environmental load + Ship impact load	36.0	10.72	1000	71.3
Max. topside load + 90° storm environmental load + Ship impact load	36.0	10.72	1000	71.3
Max. topside load + 135° storm environmental load + Ship impact load	47.5	12.98	1100	94.9
Max. topside load + 180° storm environmental load + Ship impact load	47.5	12.98	1100	94.9
Max. topside load + 225° storm environmental load + Ship impact load	47.5	12.98	1100	94.9
Max. topside load + 270° storm environmental load + Ship impact load	36	10.72	1000	71.3
Max. topside load + 315° storm environmental load + Ship impact load	36	10.72	1000	71.3

Graph of dent energy against dent depth for all directions of storm environmental load is plotted by SACS. From non-linear ship impact analysis, the impact load is also calculated. The graph of collision force against dent depth is plotted by SACS and these graphs are attached in Appendix A1 – A8. From the all directions of storm environmental load, the dent energy in increasing with the dent depth. The Ellinas Formula has shown that dent energy has directly proportional related to the dent depth. Therefore the pattern came out from this analysis has met the relationship of Ellinas. However the dent depth is not increasing with no boundary. The dent depth in increasing until the member has reached its plasticity. This is due to the yield stress that limits the formation of dent on the member. The yield stress is also called as elastic limit.

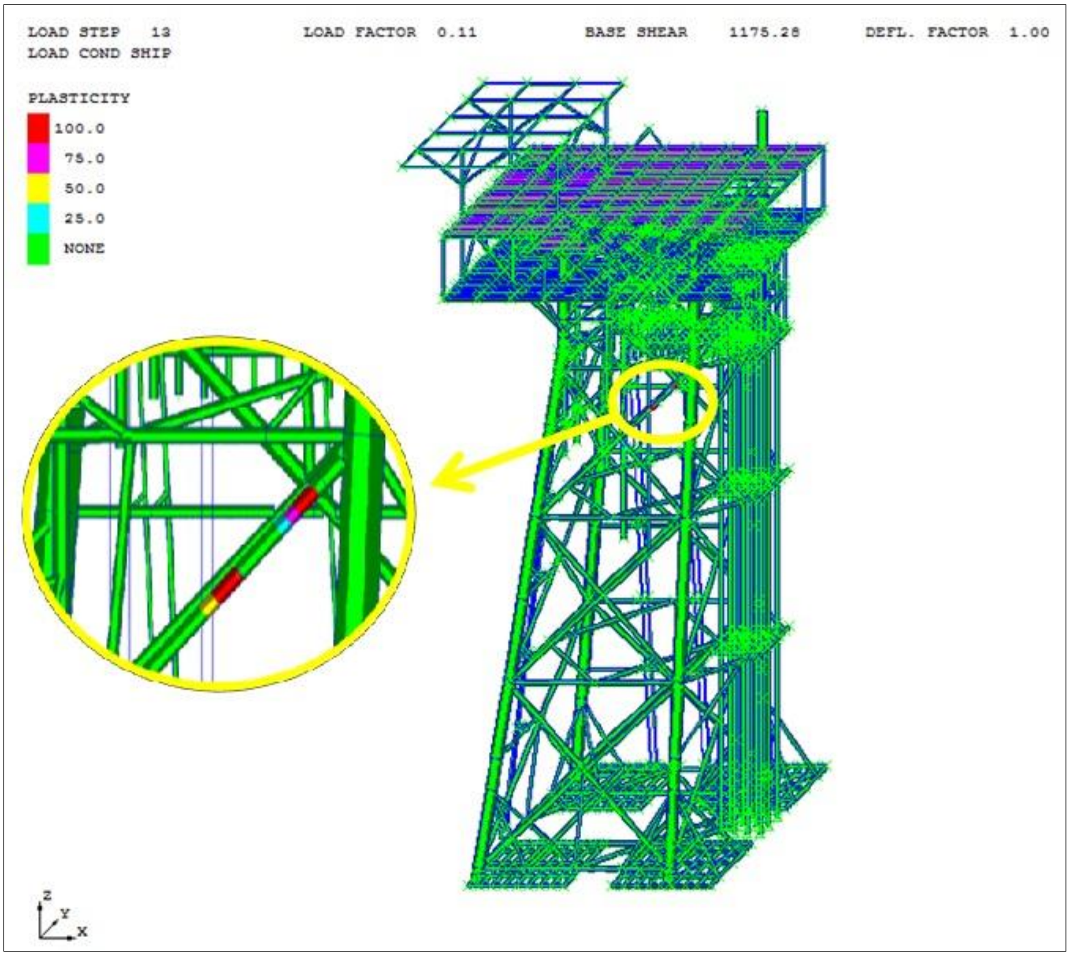


Figure 13 Representative of the plasticity formation

A graphical representation of the spreading of plasticity (% plasticity) in the impacted member, based on the corresponding maximum dent depth. SACS collapse analysis stops the load increment once the plasticity is introduced on the member. Graphs of collision force against dent depth as attached in Appendix A1 – A8 have shown that the dent depth is increasing with collision force. The collision force is increased incrementally by the SACS by increasing the load factor of the ship impact load. The increment of collision force stops when the plasticity is introduced on the member. This is where the maximum dent depth is recorded for each direction of storm environemental condition. However the boundary of the collapse analysis is not only limited by the member plasticity but also due to environmental condition. Peninsular Malaysia's storm environmental condition is not much vigrous as compared to the other offshore region in the world. Due to that, the performance of the member and structure globally is not much affected by the the collision force. Member performance might or might not be affected by those limiting factors. It will be further discuss in section 4.3.

The maximum dent depth due to all storm environmental condition is extracted as shown in Table 6 to determine the acceptable dent depth of jacket brace for Peninsular Malaysia region. Two values of maximum dent depth form the analysis are 10.72cm and 12.98cm. Corresponding to the maximum dent depth, the dent energy is also recorded.

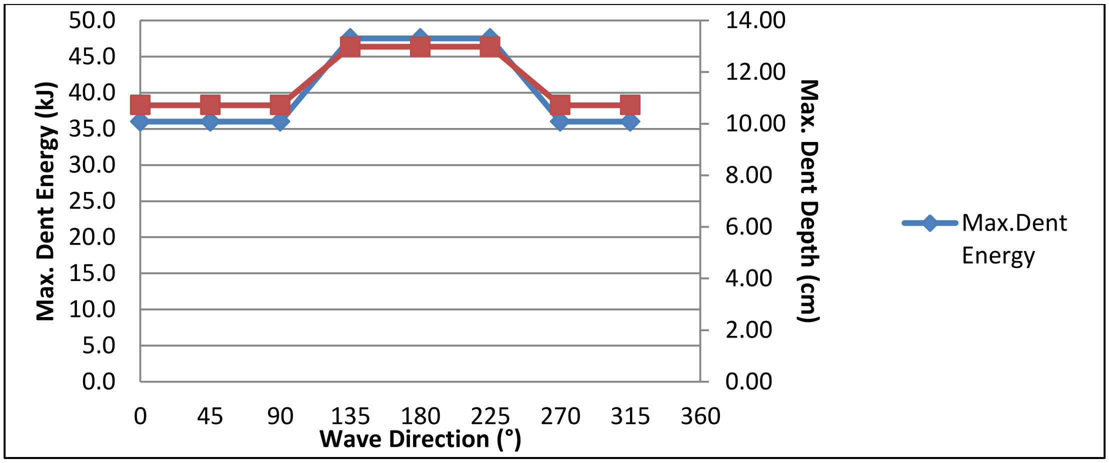


Figure 14 Graph of dent depth & dent energy vs. wave direction

The dent is generated due to gravity load, storm environmental load, and ship impact load. The imposed gravity and ship impact load are the same but the storm environmental load is different for every directions. The maximum and minimum storm environmental loads have been applied in the analysis. The lower value of generated dent depth, 10.72cm, is due to the storm environmental load from wave direction of 0°, 45°, 90°, 270°, and 315° which are the maximum one. The upper value of the dent depth, 12.98cm, is due to the storm environmental load from wave direction of 135°, 180°, and 225° which are the minimum one.

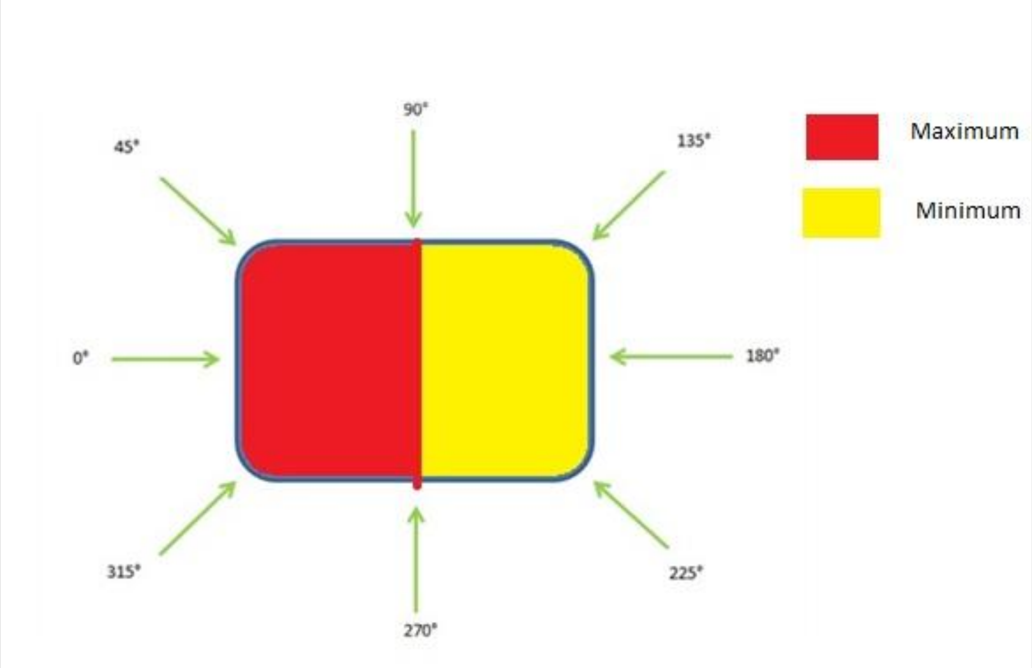


Figure 15 Maximum and Minimum Wave Directions

Figure 15 shows that the maximum storm is coming from the left side while the minimum storm is coming from the right. The storm wave from left is more dominant than right. The higher environmental load that is imposed frequently can cause fatigue to the structure. The fatigue will result in losing of structure strength to withstand incoming load such as boat impact load. Due to the fatigue, the structure only allows small effect from the ship impact load to ensure it still behave as elastic. Therefore for the safety reason the lower value of dent depth is chosen as the limiting criteria or threshold for the dent damage because the lower dent depth is formed due to maximum storm environmental load. A dimensional summary of the dent damage as a result of the ship impact analysis is presented as follow:

Table 7 Limiting criteria of dent damage

Typical Member	**Member Geometry**		**Dent Depth (cm)**
	Outer Diameter, D_o (cm)	**D_o/ t**	
Jacket Brace	58.6	45.08	10.72

4.3 Dent sensitivity

The effect of dent is measured by determining capacity reduction factor of the dented member. The impacted member is used to develop capacity reduction factor on brace. The properties of impacted member are as follows:

Table 8 Member properties

Properties	**Value**
Length, l	555.901 cm
E	21000 kN/cm^2
G	8000 kN/cm^2
F_y	34.5 kN/cm^2
Density, ρ	9.028 t/m^3
Outer Diameter, D_o	58.6 cm
Wall Thickness, t	1.3 cm
K	0.8 (Jacket brace)

Calculation of allowable axial compressive stress will be used in determining capacity reduction. Comparison of the allowable axial compressive stress and the actual axial stress applied on the member is used to determine the capacity of the impacted member after dent formation. The actual axial stress can be extracted from result generated by SACS (refer Figure 16). The capacity of the dented member is calculated by subtraction of the allowable axial compressive stress and the actual axial stress. The following is steps to calculate the allowable axial compressive stress based on the member properties stated in Table 8.

$$F_a = \frac{\left[1 - \frac{(\frac{Kl}{r})^2}{2{C_c}^2}\right]F_y}{\frac{5}{3} + \frac{3(\frac{Kl}{r})}{8C_c} - \frac{(\frac{Kl}{r})^3}{8{C_c}^3}} \tag{7}$$

a) Check: ${}^{D}\!/_{t} = {}^{58.6\ cm}\!/_{1.3\ cm} = 45.08\ (< 60)$

b) Calculate moment of inertia of the member cross section:

$$I = \frac{\pi}{64}\,({D_o}^4 - {D_i}^4) \tag{8}$$

$$I = \frac{\pi}{64}\,(58.6^4 - 56^4) = 96\ 093\ cm^4$$

c) Calculate area of the member cross section:

$$A = \frac{\pi}{4}\,({D_o}^2 - {D_i}^2) \tag{9}$$

$$A = \frac{\pi}{4}\,(58.6^2 - 56^2) = 234\ cm^2$$

d) Compute radius of gyration, r:

$$r = \sqrt{\frac{I}{A}} \tag{10}$$

$$r = \sqrt{\frac{96\ 093\ cm^4}{234\ cm^2}} = 20.26\ cm$$

e) Compute: ${}^{Kl}\!/_{r} = 0.8\ (555.901)/20.26 = 21.95$

f) Compute $\frac{{}^{Kl}\!/_{r}}{C_c}$:

$$C_c = [\frac{2\,\pi^2\,E}{F_y}]^{\frac{1}{2}} \tag{11}$$

$$C_c = [\frac{2\,\pi^2\,21000\,\frac{kN}{cm^2}}{34.5\,\frac{kN}{cm^2}}]^{\frac{1}{2}} = 109.6$$

$$({}^{Kl}/_{r} < C_c)$$

$$\frac{{}^{Kl}/_{r}}{C_c} = \frac{21.95}{109.6} = 0.2$$

g) Calculate the allowable axial compressive stress from equation (7):

$$F_a = \frac{\left[1 - \frac{1}{2}(0.2)^2)\right]\ 34.5\ kN/cm^2}{\frac{5}{3} + \frac{3}{8}(0.2) - \frac{1}{8}(0.2)^3} = 19.42\,\frac{kN}{cm^2} = \mathbf{194.2}\,\frac{\boldsymbol{N}}{\boldsymbol{mm^2}}$$

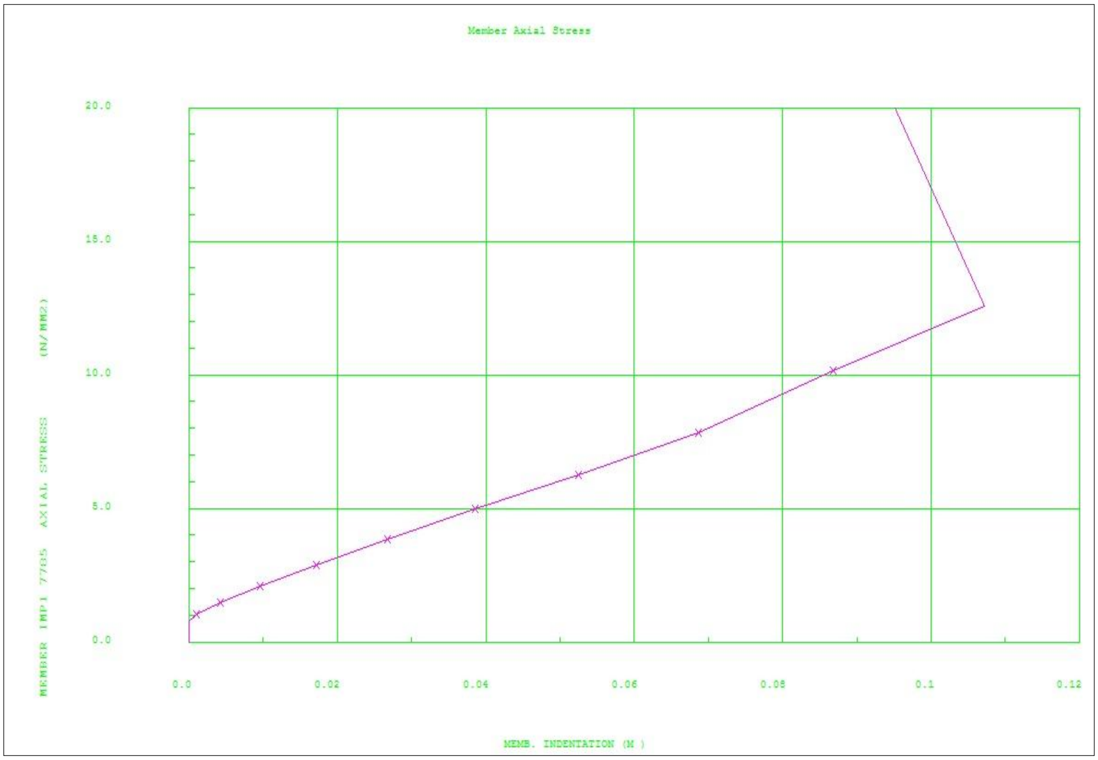


Figure 16 Graph of member axial stress vs. dent depth

The dent depth is increasing with the increase of actual axial stress applied on the member. The increasing of axial stress has exhibited the formation of dent on the member which causes the dent depth increase. However the formation of dent on the member has stopped because the applied actual axial stress is limited. This is happening might be due to plasticity that is governed by the allowable axial compressive stress or might be also due low vigorous of environmental loading as mentioned in section 4.2. To find this, the comparison of allowable axial compressive stress and the maximum actual axial stress recorded is required. From the calculated axial compressive stress, it is noted that the difference to the maximum recorded actual axial stress is too much, between 12.8 N/mm^2 and 194 N/mm^2, which means the member still has a lot of capacity to withstand higher stress. In this case, the environmental load is the limiting factor because the storm environmental load is low and not much impactful to the member. It has the possibility that the member is over designed however it is not yet confirmed.

Table 9 Capacity reduction factor

X/D_o	**Dent Depth, X (cm)**	**F (N/mm^2)**	**F_c (N/mm^2)**	**R**
0	0	0.08	194.12	1
0.002	0.11	1.00	193.2	0.995
0.007	0.43	1.50	192.7	0.992
0.020	0.97	2.00	192.2	0.989
0.030	1.72	2.90	191.3	0.984
0.050	2.68	4.00	190.2	0.978
0.070	3.86	5.00	189.2	0.973
0.090	5.25	6.30	187.9	0.966
0.120	6.86	7.80	186.4	0.958
0.150	8.69	10.20	184.0	0.945
0.180	10.72	12.80	181.4	0.931

Notes: Length = 555.901 cm, E = 21000 kN/cm^2, Fy = 34.5 kN/cm^2, $D_o/t = 45$
Slenderness ratio, $Kl/r \approx 22$
Allowable axial compressive stress, $F_a = 194.2$ N/mm^2

X = dent depth
D_o = member outer diameter
F = actual axial stress
F_c = axial compressive stress capacity
R = capacity reduction factor

The increase of dent depth affects the member strength in term of its capacity to withstand external load and operational load. The capacity reduction factor is developed based on the difference of actual axial stress and allowable axial compressive stress. The capacity reduction factor is stated in Table 9 while Figure 17 shows relationship between dent depth and the member capacity.

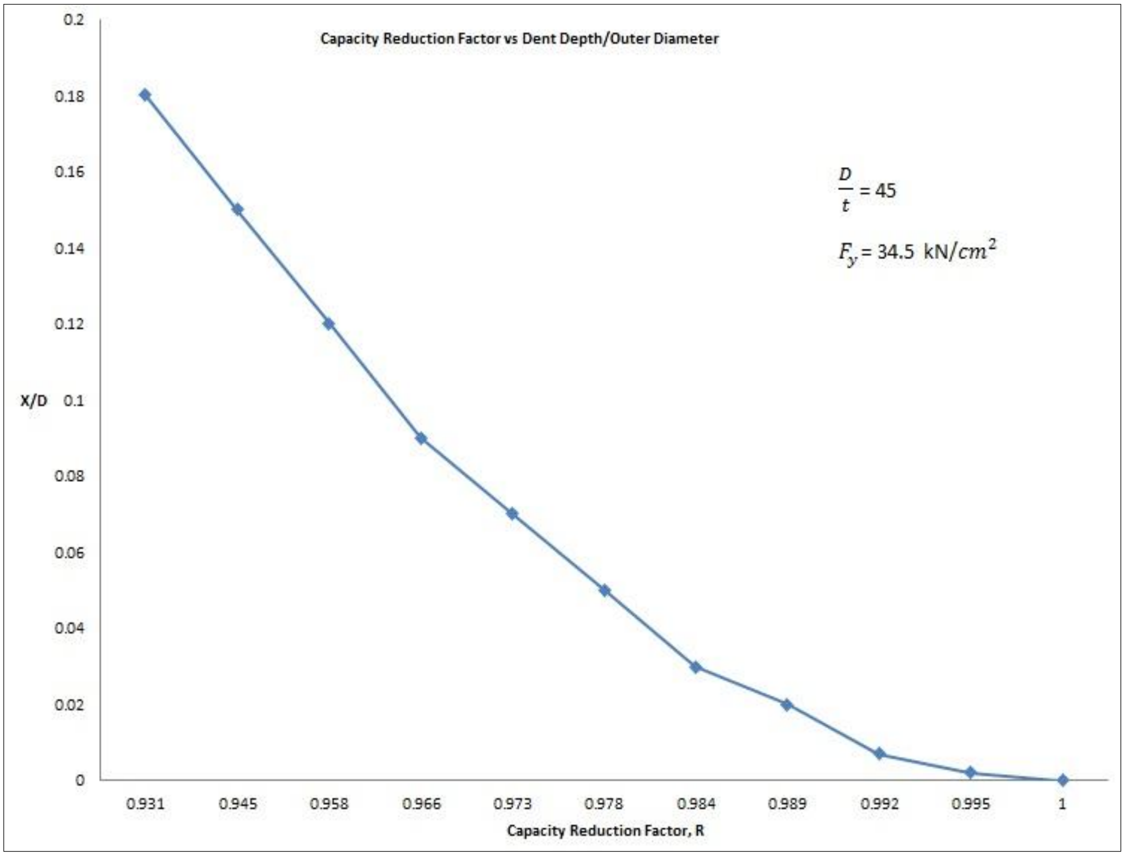


Figure 17 Graph of capacity reduction factor vs. X/D_o

The dent depth increase as the capacity reduction factor is decrease. The capacity of the member to withstand the load is reduced with the formation of dent. The formation of dent on the member causes the reduce in member diameter which reduces its strength. However the effect of dent to the capacity reduction in this analysis is low because of low environmental laod even though storm condition is applied. The maximum recorded dent depth affects the member capacity by the factor of 0.931 only. The another reason of lower effect of capacity reduction is because of high slenderness ratio (Kl/r) of the member (Kallaby & O'Connor, 1994). Therefore some modification should be made to ensure the effect dent damage is more significant to the structural integrity.

CHAPTER 5

CONCLUSION

5.1 Conclusion

From the results, it is concluded that the analysis performed has meet the objectives of the study. The analysis was performed on the model of drilling offshore platform located in Kerteh, Terengganu, Malaysia. Non-linear ship impact analysis was performed by using SACS software. The environmental condition was followed from the real condition at location of the platform which is 100-year storm condition.

The non-linear ship impact analysis has given informative results in this study. The conclusions can be made from this study are as the following.

I. Critical sizes of dent depth of jacket brace for platform in Peninsular Malaysia region is 10.72cm. This dent damage threshold is useful to differentiate either major or minor damage on the platform. The major damage is more complicated and higher cost consumption to fix as compared to the minor damage.

II. The ship with weight of 2000-MT and velocity of 2.35m/s during collision has a kinetic energy of 2585kJ forms the dent on jacket brace. The boat properties used in this analysis can be a reference to define risk level for any future boat impact to the offshore platform in Peninsular Malaysia.

III. From the non-linear ship impact analysis, strength of jacket brace is reduced with the increase of dent depth. The maximum dent of 10.72cm is affected by 0.931 of the jacket brace strength. The jacket brace was over-designed because it has much more reserve capacity to withstand the load and because it has high slenderness ratio. It is advisable to revise the design of structural element to obtain optimum design.

5.2 Recommendations

From this study, some modifications are recommended to enhance the significance of the results towards structural integrity of the offshore platform. The recommendations are as the following.

I. More platforms model from Peninsular Malaysia region should be used for the analysis to have various results. The impacted member of a platform in the analysis should be more with at least 3 members for each platform.
II. Check the survivability of the platform by running the analysis using 10000-years extreme environmental condition. The survivability check will be applying more extreme environmental condition therefore is expected to exert higher impact onto the platform. It is expected to give various damage results up to the most critical damage as possible. This can be used for reference to define risk level in the future. This is more significant study for the structural integrity.
III. Use the heavier and faster ship for the analysis. This will create more critical condition of ship impact therefore it is expected to generate various points of damage for the future reference.

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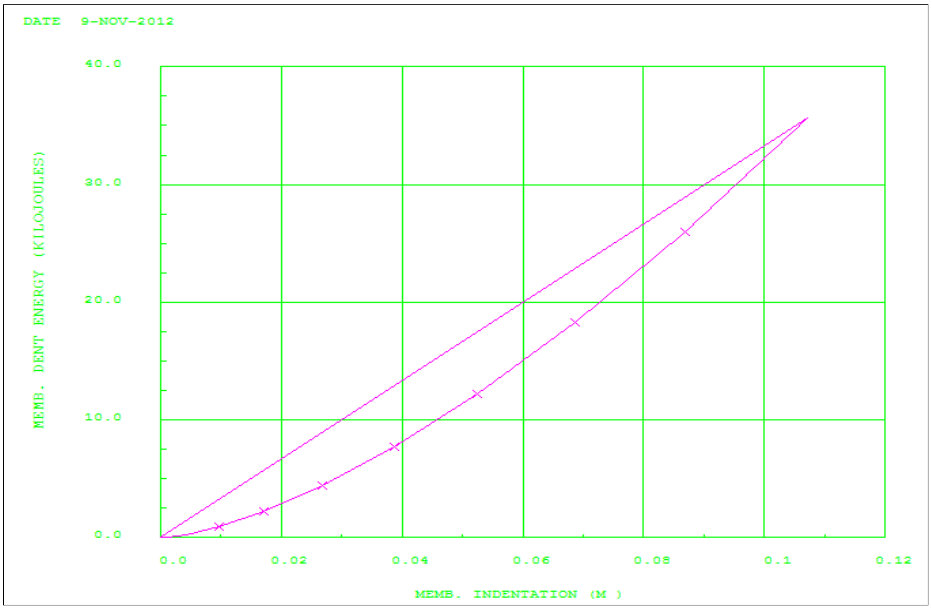
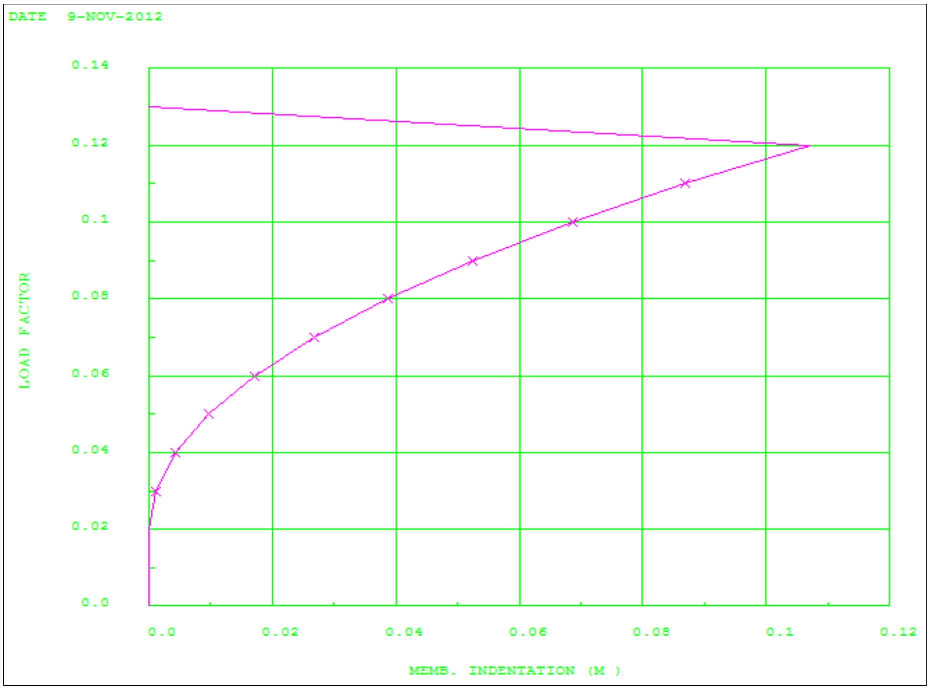
Appendix A1

Appendices

Graphs of Impact Due 0° Storm Environmental Load



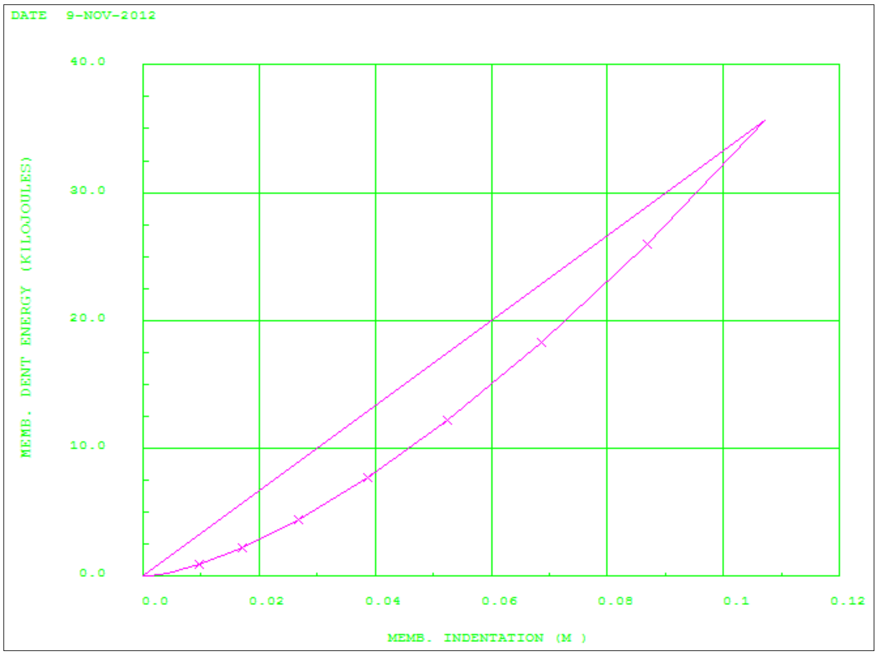
Dent Energy Vs. Member Dent Depth



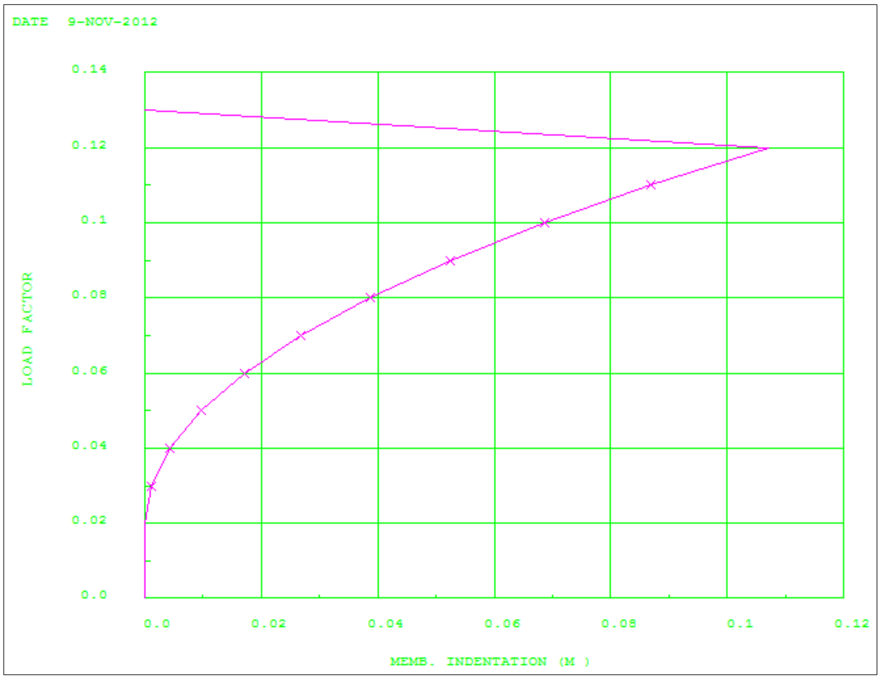
Collision Force Vs. Member Dent Depth

Appendix A2

Graphs of Impact Due 45° Storm Environmental Load

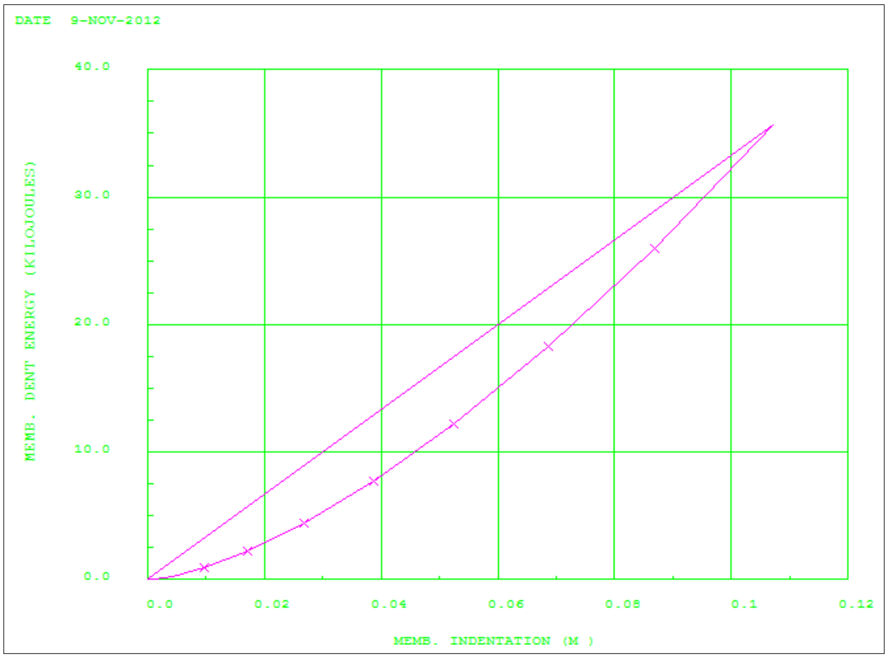


Dent Energy Vs. Member Dent Depth

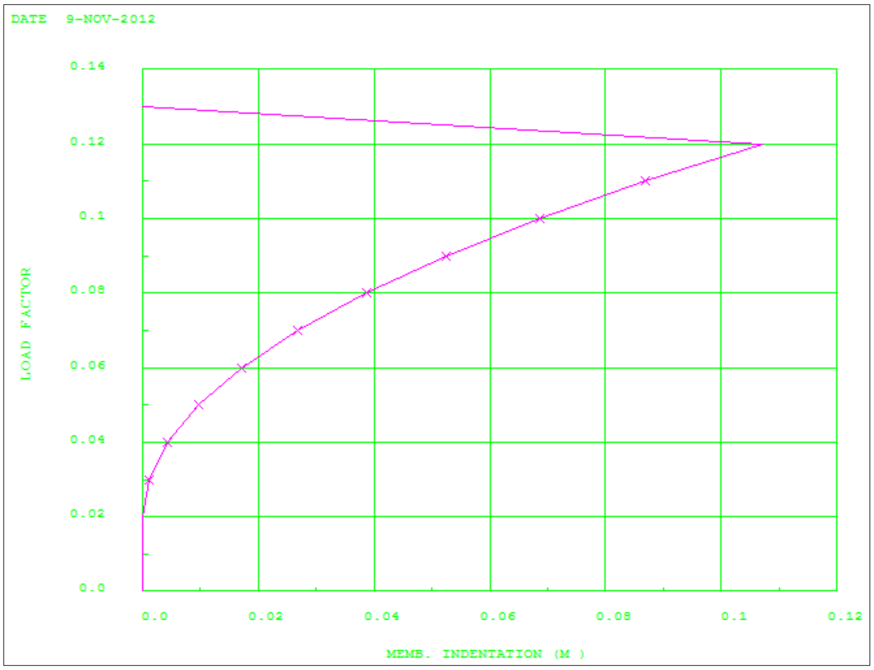


Collision Force Vs. Member Dent Depth

Graphs of Impact Due 90° Storm Environmental Load

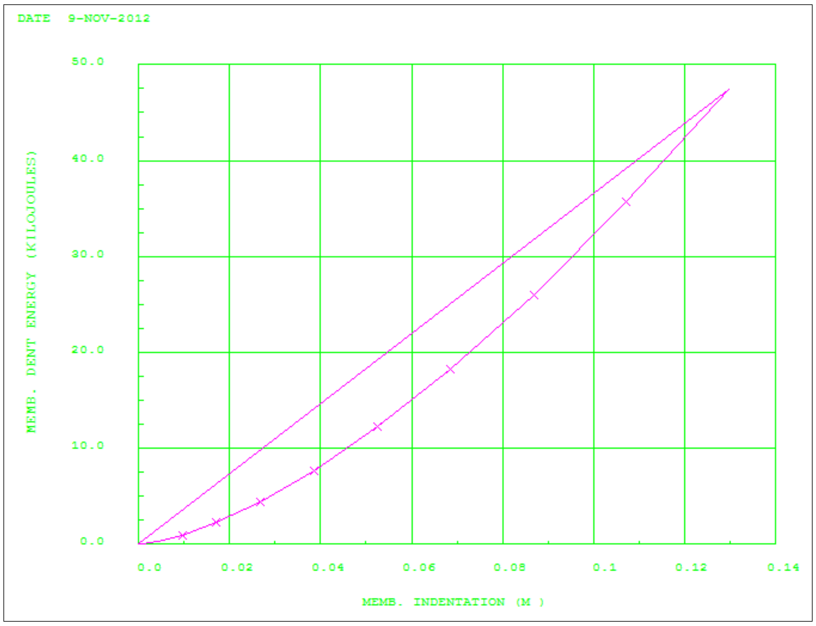


Dent Energy Vs. Member Dent Depth

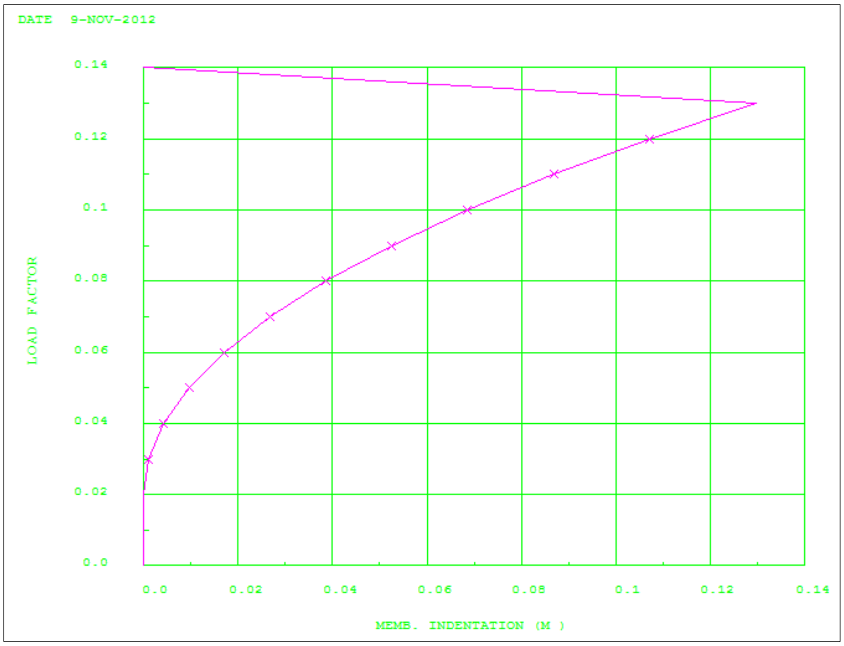


Collision Force Vs. Member Dent Depth

Graphs of Impact Due 135° Storm Environmental Load

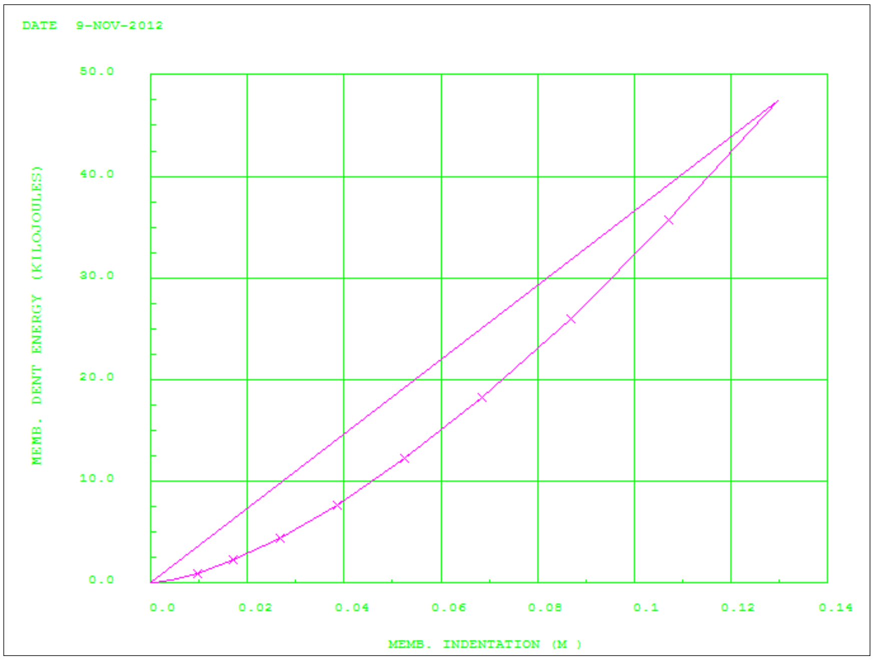


Dent Energy Vs. Member Dent Depth

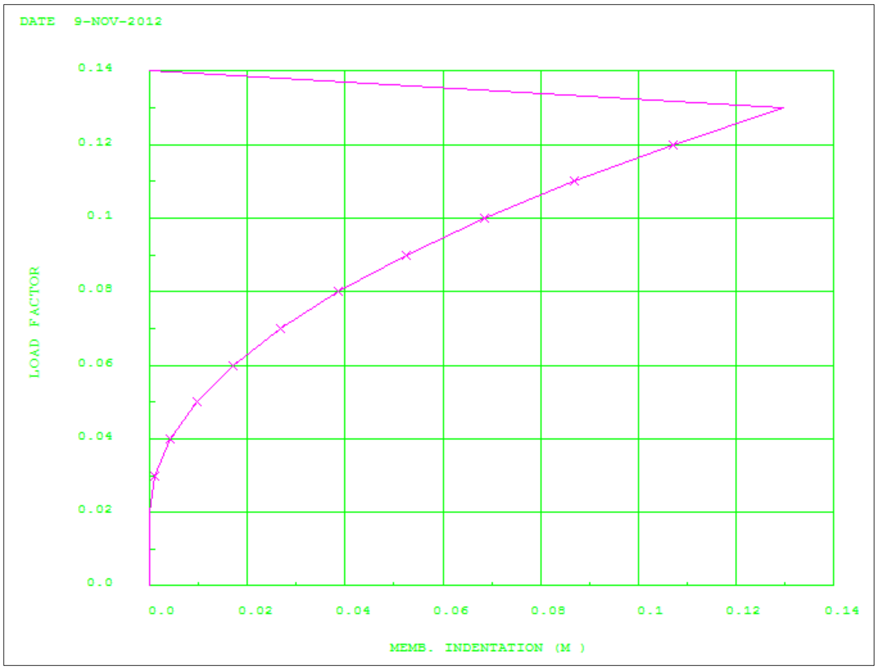


Collision Force Vs. Member Dent Depth

Graphs of Impact Due 180° Storm Environmental Load

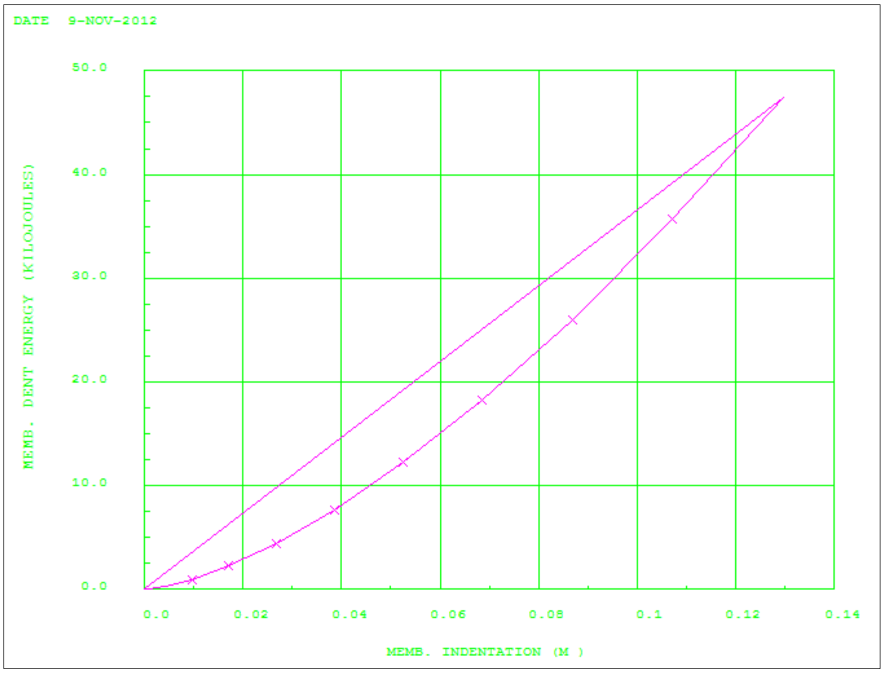


Dent Energy Vs. Member Dent Depth

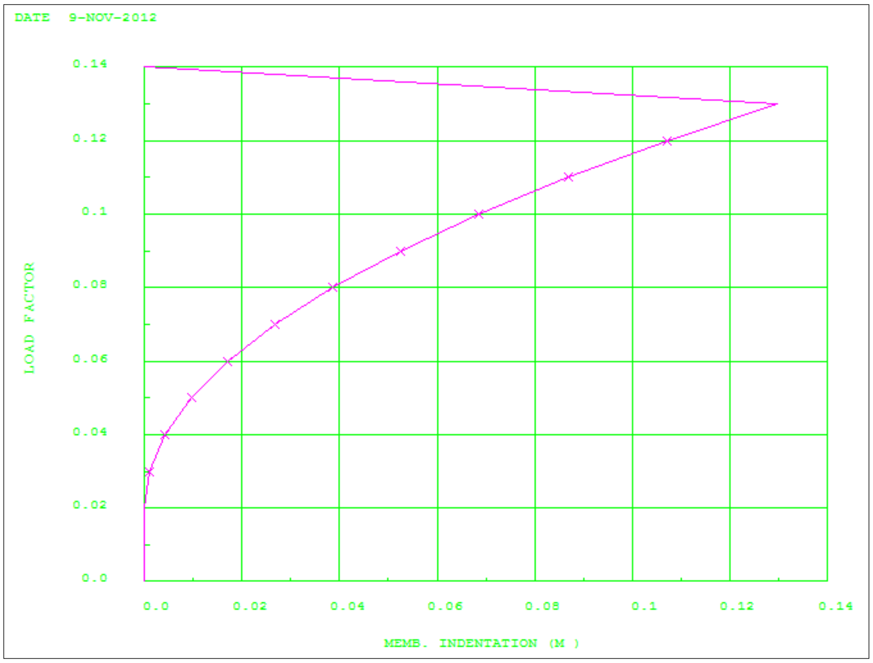


Collision Force Vs. Member Dent Depth

Graphs of Impact Due 225° Storm Environmental Load

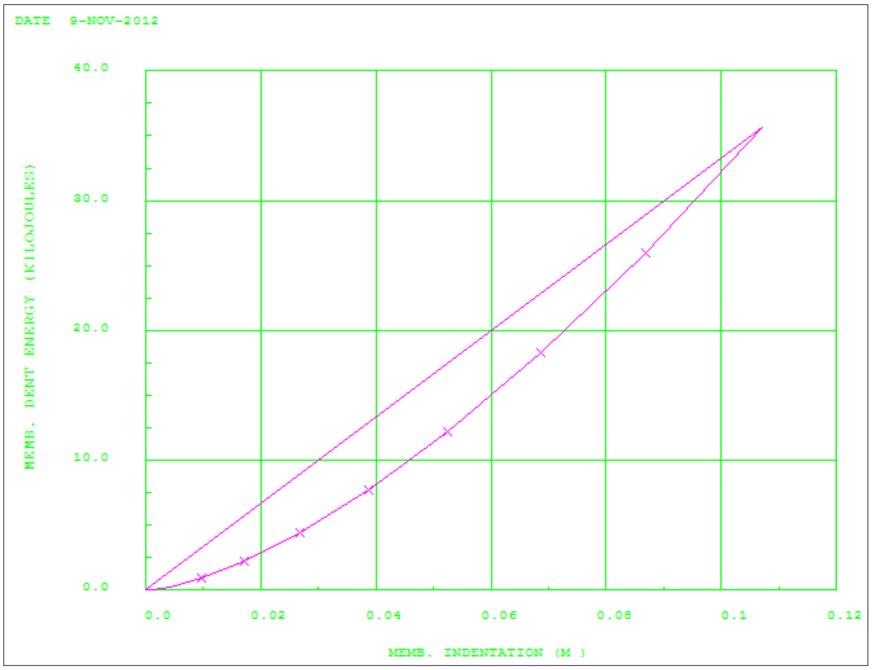


Dent Energy Vs. Member Dent Depth

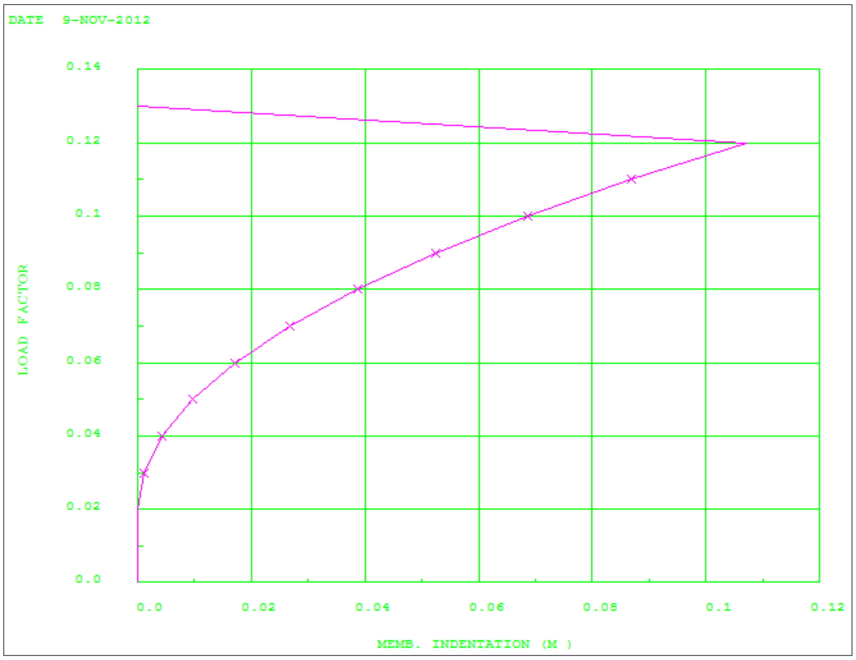


Collision Force Vs. Member Dent Depth

Graphs of Impact Due 270° Storm Environmental Load

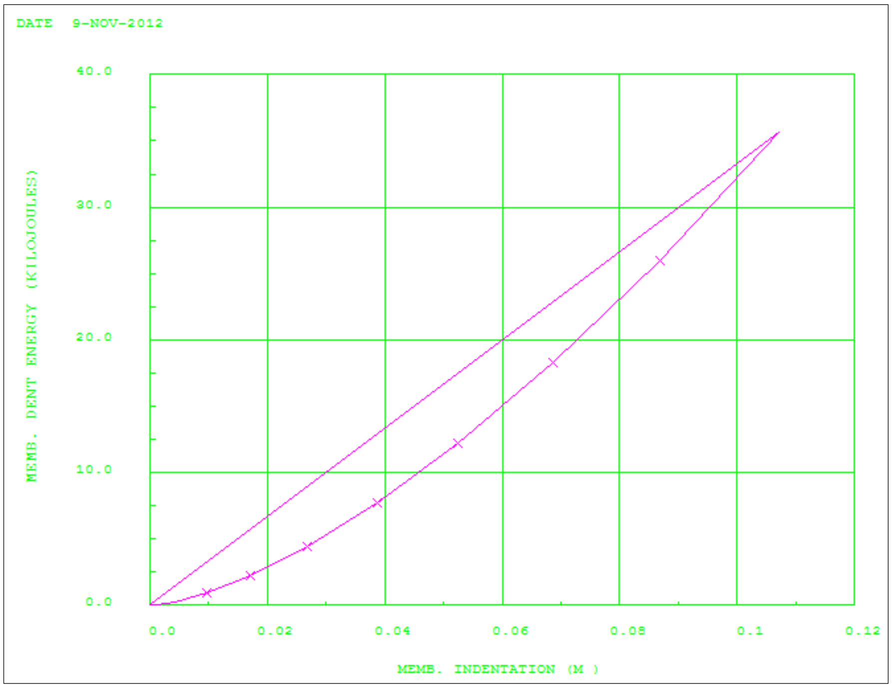


Dent Energy Vs. Member Dent Depth

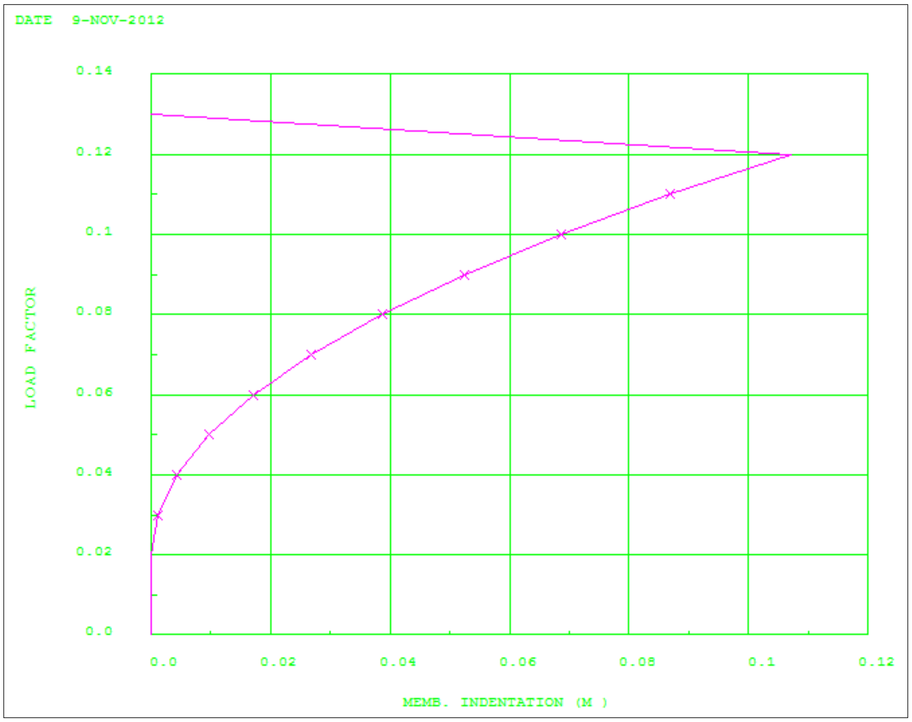


Collision Force Vs. Member Dent Depth

Graphs of Impact Due 315° Storm Environmental Load



Dent Energy Vs. Member Dent Depth



Collision Force Vs. Member Dent Depth