FINAL PROJECT

RISK ASSESSMENT FOR SUBSEA GAS PIPELINE TO MITIGATE THE POTENTIAL HAZARDS DUE TO THE IMPACT OF THE SINKING VESSELS USING DNV RP F107 STANDARD

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ABSTRACT

Risk Assessment is a systematic approach in assessing hazards which provides an objective to measure the hazard and allows hazards to be prioritized and compared. Risk assessment is undertaken to determine the likelihood of injury or damage to be caused by the hazard. Physical unwanted hazards that cost millions of money and lives are likely to occur in any assets if the level of risk is not analyzed and assessed. Before safety can be implemented, the level of risk involved must be determined.

This final project has been carried out on the untrenched subsea gas pipeline owned by Amerada Hess Export Limited (Indonesia -Pangkah) at zone III.

The risk assessment was carried out for the impact of the sinking vessel on the pipeline under loose control conditions using DNV RP F 107. Event Tree Analysis (ETA) and DNV RP F107 were used as tools to determine the risk level. After the risk level has been known, three technical mitigation methods were designed and their material and installation costs were analyzed. The three technical methods include Submat Flexiform Concrete Mattress, U Type Pre-Cast and Massive Mess Pre-Cast Methods were analyzed based on material and installation costing as the U Type Pre-Cast Method was preferred best alternative forgone and applicable.

Keywords: Risk Assessment, Frequency, Consequence, Mitigation. DNV

CHAPTER TWO
LITERATURE REVIEW

2.1 The Philosophical Nature of Risk

A risk is the chances of negativity of some loss or harm. It is easy to think of risks as mere facts about the world. The philosophical nature of risk is basically how the factual information about risk can be used as a guide in decision-making processes. Understanding the risks incorporate normative evaluation both in the production of data and, even in identifying what risk is all about, is crucial to the ability to make use of risk assessment.

The concept of risk isn't a new concept but has evolved for centuries. The basic concept of risk can be pictured as the dangers involved when one crosses the street, try something new, or choose to go left instead of right there is risk involved. Risks are found in every aspect of our living and are an integral part of nearly every choice we make. In each case we understand risk to be the chance that something unwanted, or possibly harmful, will arise from any given situation. To state possibility that something awkward may occur, while leaving us unable to foretell any specific outcome with categorical assurance. The decision in choosing to avoid all risks would be impossible and in many cases, risks are not foreseeable.

Risks can be made by the natural forces of nature or can be the results of our own actions. According to (Frederick J, Barnard, 2005) has defined three elements of risk-taking, which must be considered when attempting to characterize risk as follows.

a. Choice of action- is choosing to act in a deliberate way to either produce or avoid certain results
b. Negativity of outcome - refers to the fact that taking a risk involves an event that is highly unlikely but

there is still some chance it may occur in some point in time.

c. And chance of realization- relying on an account of the probability of an event's occurrence to determine how much of a risk it might be or the chance of a risk being realized.

2.2 Technical Terms used in Risk Assessment

With the ideology of assessing risk, certain technical terms used throughout in this final project as defined by Fuller & Vassie, (2004), are as follows.

- **Risk** – risk is the chance of a particular situation or event which will have an impact upon an individual, organization or industry's objectives , occurring within a stated period of time
- **Probability** – quantified measure of the likelihood of frequency of a specified event or outcome occurring. It is the ratio of the number of specific event or outcomes occurring to the total number of possible events or outcomes. It is expressed as a number between 0 and 1: the value 0 represents where the situation is impossible and 1 represents the situation is certain.
- **Consequences-** an event having direct influence on society, people, environment and assets.
- **Frequency** – is the measure of the rate of occurrence of event expressed as the number of occurrences of an event.
- **Likelihood** – the quantitative measure of the probability and frequency.
- **Event-** is an incident and situation that occurs in a particular place during a certain period of time.
- **Hazard** – disposition, condition or situation that may be source of potential harm where potential harm refers to injury which requires repair or cure.
- **Mitigation -** the complexity aspect of managing risk through moving risk through risk retention and risk

control avoidance measures such as technical mitigation processes.

2.3 Managing Risk

According to Hiromitsu & Ernest (1996), has stated that risk management is a culture, process and its structures are directed towards realizing potential opportunities whilst managing adverse effects of risk. Risk assessment is conducted to help determine whether to reduce risk and to establish the appropriate level of risk management regulations. A wide set of standards derived from statutes, regulations, and law guide regulatory agencies in making risk management decisions. In such situations, the risk management standard is known as a priority based on "*acceptable risk*" considerations.

Risk assessments may be used to look at risk reduction under various policy alternatives to determine if these alternatives are effective in reducing risks. In some agency programs, the results of risk assessments are an important technical input to benefit-cost analysis, which are then used by managements in decision making processes.

2.3.1 Risk Management Process

The systematic application of management policies, procedures and practices to the task of communicating, establishing the context, identifying, analysing, evaluating, treating, monitoring and reviewing risk is what risk management process is all concerned about (AS/NZS 4360:2004). The AS/NZS standard clarifies what risk assessment is all about in its risk management process. The quoted figure 2.1 below is an illustration of the risk management process used by the Australia and New Zealand standards.

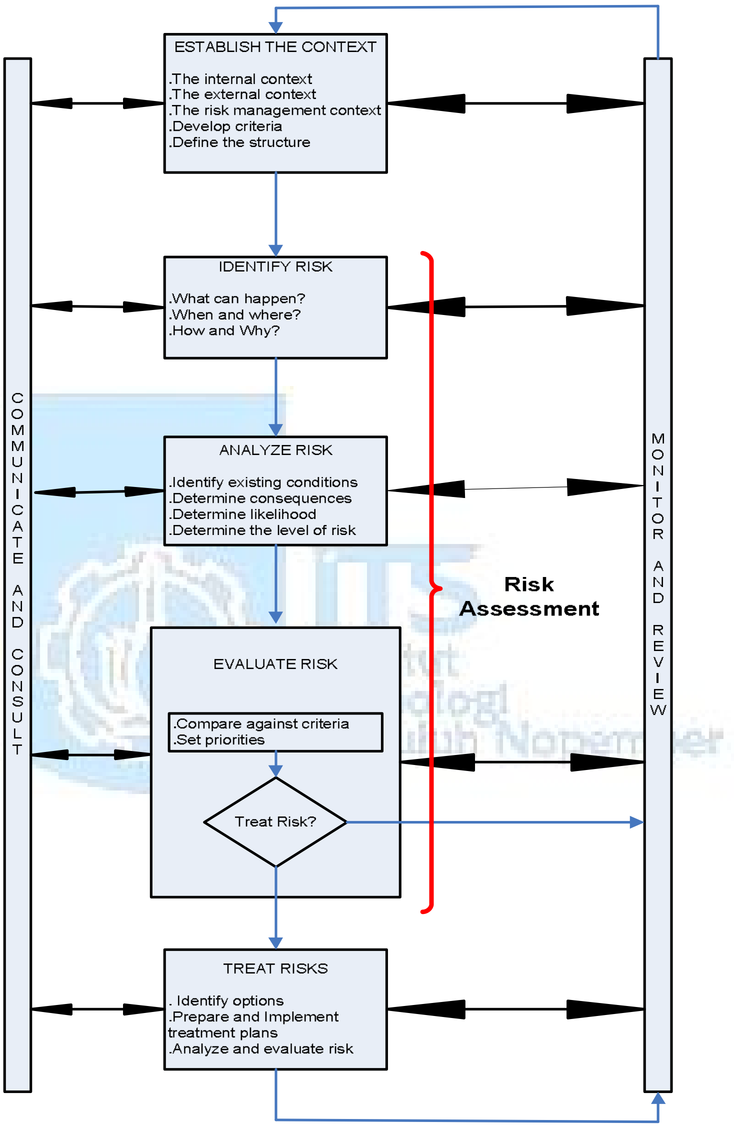

Figure 2.1Risk management process

2.4 Risk Assessment

According to David L.G (2005), OSD Energy Services (2004), S.F. (Steve) Biagiotti, and S.F. (Stephen) Gosse (2000), defined risk assessment as the process of quantifying or measuring the level of risk associated with the operation of an asset. The process of risk assessment involves identifying:

a) The severity potential of injuries
b) The frequent employees, machines and tools that are exposed to hazards
c) Possibilities of avoidance measures involved if such hazards occur and
d) The like hood of an injury should a safety control system fails

Risk assessment is a broad term that encompasses a variety of analytic techniques that are used in different situations, depending upon the nature of the hazard, the available data, and needs of decision makers (Ian Hawkins, 1998 and Frederick J, Barnard, 2005). Different techniques developed by specialists from many disciplines, including toxicology, epidemiology, medicine, chemistry, biology, engineering, physics, statistics, management science, economics and the social sciences for risk assessment.

Most risk assessments are performed by teams of specialists representing multiple disciplines. They are often prepared by government scientists or contractors to the government. Many organizations have supported the use of risk assessment and recommended improvements such as the following

- In 1993 the Carnegie Commission on Science, Technology, and Government issued "Risk and the Environment: Improving Regulatory Decision-making."

- In 1994, the NAS issued "Science and Judgment in Risk Assessment" to review and evaluate the risk assessment methods.
- In 1995, the Harvard Center for Risk Analysis issued "Reform of Risk Regulation: Achieving More Protection at Less Cost."
- In 1997, the Presidential/Congressional Commission on Risk Assessment and Risk Management issued "Risk Assessment and Risk Management in Regulatory Decision-Making

2.4.1 Uses of Risk Assessments

The application of risk assessment are applied in many areas such as manufacturing industries, government departments, mining industries such as oil and gas industries and many more. At a broad level, risk assessments can be used in many settings such as the following.

2.4.1.1 Priority setting

Frederick J. Barnard (2005), Risk assessment is sometimes used as a tool to compare risks for priority-setting purposes. For example, the Department of Transportation in Surabaya City may prepare a comparative assessment of traffic safety hazards related to highway and vehicle design as well as driver behavior. Wide ranges of counter measure are compared to determine which measures would be most effective in saving lives and reducing injuries. Similarly, risk assessment models relating to food safety and agricultural health concerns may be used to rank relative risks from different hazards, diseases, or pests.

Again Frederick J. Barnard (2005), stated that screening-level risk assessments are sometimes used as a first step in priority setting. The purpose of the screening is to determine, using conservative assumptions, whether a risk could exist, and whether the risk is sufficiently serious to justify agency action. If the screening-level assessment indicates that a potential hazard is not of concern, the agency may decide not to undertake a more comprehensive assessment. If the screening-level assessment indicates that the potential hazard may be of concern, then the agency may proceed to undertake a more comprehensive assessment to estimate the risk more accurately.

2.4.1.2 Informing the Public and Other Audiences

The purpose of risk assessment may influence the scope of the analytic work, the type of data collected, the choice of analytic methods, and the approach taken to reporting the findings. Accordingly, the purpose of an assessment should be made clear before the analytical work begins. The best known types of risk assessments addresses low-probability, high-consequence events associated with the failure of physical structures as these events are exceedingly rare. For example, a bridge failure or a major core meltdown at a nuclear reactor may not be feasible to compute risks based on historic data alone. Engineers have developed alternative techniques such as fault-tree analysis, even tree analysis and many more techniques to estimate both the probability of catastrophic events and the magnitude of the resulting damages to people, property and the environment. Such probabilistic risk assessments are now widely used in the development of safety systems for dams, nuclear and chemical plants, liquefied natural gas terminals, space shuttles and other physical structures

2.4.2 Identifying Risk

Risk identification seeks to find hazards that need to be managed. The Australian and the New Zealand standards (AS/NZS 4360:2004), explains risk identification can be through a well-structured systematic process. The aim is to generate comprehensive sources of risks that might have impact on certain assets, the cause of the risk, its occurrences, and the possible consequences in detail. Risk identification can be identified through checking against standard checklists, judgment based on experience, flow charts, brainstorming, system analysis, scenario analysis and system engineering.

2.4.3 Analyzing Risk

Again AS/NZS has stated that risk analysis is developing an understanding about risk. It tries to identify the existing controls and to determine the possible consequences and likelihood of such controls when exposed to hazards. Then it tries to determine the level of risk that are likely to be caused and the possible consequences that are liable to occur. It tries to evaluate the existing controls and the consequences and the likelihood. Risk analysis is performed on the threats identified in the location and on threats generally associated with the asset. The standard prescribes a risk analysis process that assesses the frequency of occurrence of threats to the pipeline and the probability that each threat will result in a loss of integrity or containment of the asset. The consequence of the asset failing is then required to be assessed for the impact on the locality around the possible incident. Impact on the surrounding area is assessed with regard to safety, the environment and economic cost.

The aim of the risk analysis is to reduce the residual risk of an incident to a low ranking or ALARP, by applying physical design controls. In an operating pipeline situation, the risk assessment process may require additional procedural factors of protection to be applied if the pipeline does not fall into a safe enough operating regime through the design process.

There are many types of analysis that can be used to analyze risk. These include the following.

2.4.3.1 Qualitative analysis

The use of technical terms or words to describe the magnitude of the potential consequences, and the likelihood that the consequence will occur. These technique is mostly carried about by risk analysis expects.

2.4.3.2 Quantitative Analysis

Using numerical values to describe scales used for both consequences and likelihood using data from a variety of sources such as experimental data, or past data.

2.4.4 Risk Evaluation

The process of risk evaluation is to make decisions, based on the outcomes of risk analysis about which risks need treatment and treatment priorities. Risk evaluation involves comparing the level of risk found during the analysis process with the risk criteria when the context was established.

2.4.5 Risk Estimation

According to Fuller and Vassie, (2004), risk estimation is the identification of the outcomes of an event and an estimation of the magnitude and probability of these outcomes. In other words to estimate the risk level occurrence because of a hazard being exposed, a precise approximation should be estimated exactly to determine the probability of the risk involved. Most risk experts connote that risk estimations based on qualitative based on experts judgments and opinions and quantitative predictions through numerical evaluations (American Society of Mechanical Engineers (AMSE), American Petroleum Institute, and (API)).

2.4.6 Risk Mitigation

The process of defining and implementing the measures to reduce or control the exposure of risks can be through many ways. Before mitigating risk, the need to evaluate the risk and the possible effects on the surrounding must be considered. If the level of risk is too high, any industries need to insure its properties that are vulnerable to the risky hazards to insurance companies apply a risk control mitigation process. Risk management plays a significant role in identifying and predicting the risk level and implementing a control measure to maintain these risks at an acceptable level. It is the role of risk management experts to determine the level in which stakeholders are vulnerable to the risk available and the possibility of making loses due to the risk associated with the activity in any industries and make decisions whether to accept or reject the risk being identified.

2.4.7 Risk Assessment Techniques and Tools

There are many tools and software used in risk assessment. However, in this research, even tree analysis (ETA) is prioritized.

2.4.7.1 Event Tree Analysis (ETA)

One of the widely used methods in risk assessment technique, used to evaluate the frequency of an event through event tree analysis, coded with codes that try to define the level of risk. ETA is a tool used to find the probability of risk posed by any hazard. This is illustrated by figure 2.2. Beginning with the initiating event that occurs from the far left hand centre. Moving inward, where the decision nodes that will be used to decide the decision factors. Further moving towards the right hand following each individual track to find the outcome of the decision nodes. Finally, cross-multiplying the probability of each individual decision nodes to find the failure probability such as P1, P2, P3, P4 and P5 can be stated as the incidental probability of the decision nodes.

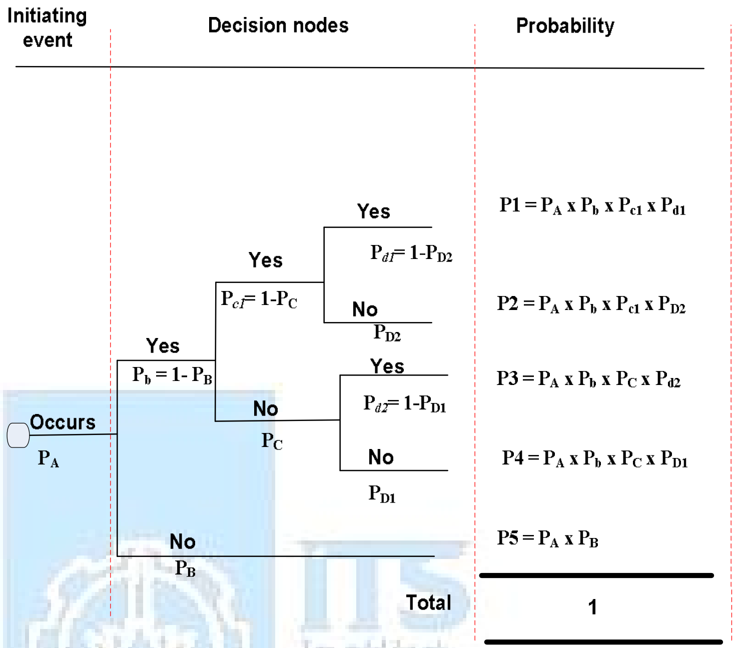

Figure 2.2 Even-tree analysis (ETA) used to calculate the probability.

The frequency or probability calculated using the even tree analysis (ETA) can then be used find out the frequency of occurrence using the table 2.1 below. Table 2.1 is the standard for DNV RP F107, used to rank the incidental probability based on the annual frequency of occurrences. The rank values determine how severe the event is to occur.

Based on the DNV RP F107 standard table 2.1, the results of the incidental probability of ETA can be ranked accordingly using table 2.1.

Table 2.1 Standard DNV RP F107 ranking of the frequency and its categorical impact

No	Rank	Description	Category	Annual Frequency
1	**1**	So low frequency that event considered negligible	Improbable	**<10^{-5}**
2	**2**	Event rarely expected to occur	Remote	**10^{-4}>10^{-5}**
3	**3**	Event individually not expected to happen but when summarized over a larger number of pipelines have the credibility to happen once a year	Occasional	**10^{-3}>10^{-4}**
4	**4**	Event individually may be expected to occur during the lifetime of the pipeline (Typically a 100 year storm)	Probable	**10^{-2}>10^{-3}**
5	**5**	Event Individually may be expected to occur more than once during life time	Frequent	**>10^{-2}**

2.4.7.2 Consequence

This recommended practice focuses on providing a methodology for assessing the risks and required protection from sinking vessels over subsea pipelines and the impact to risers and pipeline systems within the safety zone of installations. Where applicable information exists, specific values or calculation procedures are recommended. If no such information is available, then a qualitative approach is given.

An initial, accidental event such as vessel sinking can develop into an end-event (e.g. hit of pipeline). In general, risk assessments consist of an estimation of the frequency of the end-events and an evaluation of the consequence of the end-events.

2.4.8 Risk Assessment Standard

After the evaluation of the frequency and the consequence as elaborated above, the result of the frequency and consequency can plotted risk matrix table as stated in the Det Norske Veritas, (DNV RP F107) standard.

2.4.8.1 Det Norske Veritas (DNV) RP F107 Standard

DNV comprises of many standards that are used to assess risk level. One of the standards is the DNV RP F107. DNV RP F107 is a risk-based approach for assessing pipeline protection against accidental external loads. Recommendations are given for the damage capacity of pipelines and alternative protection measures and for assessment of damage frequency and consequence. Alternative pipeline protection measures are also presented. As to measure the risk level, the need to determine the frequency and the energy impact on the pipeline using the DNV RP F107 Standard.

In assessing the risk for any pipeline, the acceptance of the risk criteria will follow the methodologies outline in the DNV RP 107 as an international recognized standard. Upon the identification of the risks involved, the acceptance criteria are based on the as low as reasonably possible region (ALARP) region.

In such circumstances, to evaluate the consequence of an event, the impact energy on the subsea pipeline must be evaluated. As stated in the DNV RP F107, the recommended formulas for evaluating the energy impact on the pipeline are as follows. To formulate the scenarios of the sinking vessel impacting the subsea pipeline, figure 2.3 illustrates the likely impact energy on the pipeline due to sinking vessels impact on the subsea pipeline.

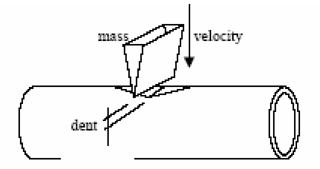

Figure 2.3 Illustration of the sinking vessels impact on the pipeline

To determine impact on the subsea pipeline, the level of energy impact on the pipeline must be determined using the following formula as standardized by DNV RP F107.

$$E = 16 . \left(\frac{2\pi}{9} \right)^{1/2} . m_P . \left(\frac{D}{T} \right)^{1/2} . D . \left(\frac{\delta}{D} \right)^{3/2}$$

(1)

Where:

E = Impact energy on the pipeline in joules (J)
m_P = Plastic moment capacity of the wall (= $\frac{1}{4} . \sigma_y . r^2$)
δ = Pipe deformation, dent depth
t = Wall thickness (normal)
σ_y =Yield strength
D = Steel outer diameter

To evaluate the crushing strength of the pipe, again DNV RP F107 as standardized the following formula for evaluating the crushing strength of the pipe.

Crushing strength of the pipe

$$E_k = y.b.h.X_0 \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Where:

E_k = Kinetic energy
y = Pressure of the pipe in N/m^2
$.b$ = With of the object that fractures the pipe coating
h = Length of the object that fractures the pipe
X_0 = Thickness of the pipe

To calculate the impact energy of the sinking vessel on the pipeline, the need to evaluate the sinking velocity of the vessel in the water needs to be evaluated using equation 3.

$$((m - V).\rho_{water}).g = \frac{1}{2}\rho_{water}.C_D.A.V_t^2 \ldots \quad (3)$$

Where:

m = Mass of the object (kg)
g = Gravitational acceleration, (9, 81 m/s^2)
V = Volume of the object (volume of the water displaced) (m^3)
ρ_{water} = Density of water (i.e. 1025 kg/m^3)
C_D = Drag coefficient of the object
A = Projected area of the object in the flow direction (m^2)
V_t^2 = Terminal velocity through the water (m/s)

The kinetic energy of the vessel can be found using equation 4 after the terminal velocity if found using equation 3.

$$E_t = \frac{1}{2} . m . v_t^2 \quad \text{..............................} (4)$$

The combination of equation 3 and 4 gives the following expression for the terminal energy (Et).

$$Et = \left(\frac{m . g}{C_D . A} \right) . \left(\frac{m}{\rho_{water}} - v \right) \quad ...$$

(5)

In addition to the terminal energy, the kinetic energy that is effective as an impact, E_E, includes the energy of added hydrodynamic mass, E_A. The added mass may become significant for large volume objects such as containers.
The effective impact energy becomes:

$$E_E = E_T + E_A = \frac{1}{2}(m + m_a)V_t^2$$

(6)

Where:

m_a = Is the added mass (kg) found by:

$m_a = \rho_{water} + C_a + V$

m = Weight of ship

g = Gravitational force (9.81m/s^2)

v = Volume of ship (m2),

ρ_{water} = Density of the sea water, 1025 kg/m^3

C_D = Coefficient of the area (m^3)

A = Projection of the area, m^2

V_t = Velocity of the vessel sinking, m/s^2

Table 2.2 Showing the Standard DNV RP F107 used in evaluating the impact capacity and damage classification of steel pipelines and riser.

Table 2.2 DNV RP F 107 categorical ranking standard for impact energy capacity for pipelines and risers

No	Ranking	Category	Dent Diameter (%)	Impact Energy	Description
1	1	Very Low	<5	E_E	Minor Damage
2	2	Low	5-10	E_E	Major Damage Leak Anticipated
3	3	Moderate	10-15	E_E	Major Damage Leakage Rupture Anticipated
4	4	High	15-20	E_E	Major Damage Leakage Rupture Anticipated
5	5	Major	>20	E_E	Rupture

Upon evaluating the impact energy on the subsea pipeline, we can categorize the impact energy as shown in table 2.3 below. The impact capacity on the risers and pipelines are as classified according to the possible damage are shown as follows.

Table 2.3 Impact capacity and damage classification of the flexible pipelines and risers as stated by DNV RP F107.

Impact Capacity and damage classification of the flexible pipelines and risers							
Impact energy[2]	Description	Conditional Probability[1]					
		D1	D2	D3	R0	R1	R2
<2.5KJ	Minor Damage not leading to ingress of sea water	1	0	0	1	0	0
2.5 - 10Kj	Damage needing repair Possible leakage	0	0.5	0.5	0.5	0.5	0
10 - 20 KJ	Damage needing repair Leakage or rupture	0	0.25	0.75	0.25	0.25	0.5
>20 KJ	Rupture	0	0	1	0.1	0.2	0.7

Damage classification

- **Minor damage (D1)**:

Damage neither requiring repair, nor resulting in any release of hydrocarbons. Smaller dents in the steel pipe wall, e.g. up to 5% of the diameter, will not normally have any immediate influence of the operation of the lines. This limit will vary and must be evaluated for each pipe. Note however, if damage occurs then inspections and technical evaluations should be performed in order to confirm the structural integrity. Minor damage to flexible and umbilical that do not require repair action. Any local damage to protective coatings or anodes will not normally require repair action.

- **Moderate damage (D2)**:

Damage requiring repair, but not leading to release of hydrocarbons. Dent sizes restricting internal inspection (e.g. over 5% of the diameter for steel pipelines) will usually require repair. Ingress of seawater into flexible and umbilical can lead to corrosion failures. However, the repair may be deferred for some time and the pipeline or umbilical may be operated provided that the structural integrity is confirmed. Special consideration should be given to pipelines where frequent pigging is an operational requirement. For such pipelines, large dents will restrict pigging and lead to stop in production, and this damage should then be considered as being major

(D3) rather than moderate (D2) even though no release is expected.

- **Major damage (D3)**

Damage leading to release of hydrocarbons or water, etc. If the pipe wall is punctured or the pipeline ruptures, pipeline operation must be stopped immediately and the line repaired. The damaged section must be removed and replaced.

In case of a damage leading to release (D3), the following classifications of releases are used:

- **No release (R0)**

No release.

- **Small release (R1)**

Release from small to medium holes in the pipe wall (<80 mm diameter). The pipeline may release small amounts of content until detected either by a pressure drop or visually.

- **Major release (R2)**

Release from ruptured pipelines.

Full rupture will lead to a total release of the volume of the pipeline and will continue until the pipeline is isolated.

2.4.8.2 Risk Matrix Table

The risk matrix table is a table that levels the level of risk. The calculated results are compared against the DNV RP F107 standard and the plotted risk level becomes the point of concern. The plotting determines the categorical acceptance criteria of the risk level to be high, medium or low as illustrated in the risk matrix table 2.4 below.

Table 2.4 Risk matrix table

RANKING FREQUENCY	RANKING CONSEQUENCE				
	1	2	3	4	5
1	L	L	L	L	M
2	L	L	L	M	H
3	L	L	M	H	H
4	L	M	H	H	H
5	M	H	H	H	H

Key

High

Medium

Low

Where:
L = Low Risk Area
M = Medium Risk Area
H = High Risk Area

Figure 2.4 below shows the risk acceptance criteria. In the *As Low As Reasonably Possible* (ALARP) region, the risk shall be reduced as far as technically and economically possible. The acceptance metrics is valid only for single hazards. With the risk assessment for the gas pipeline, the single hazard shall be defined on an overall level such as the anchor damage, sinking ships, internal corrosions, instability caused by earthquakes and sea currents etc.

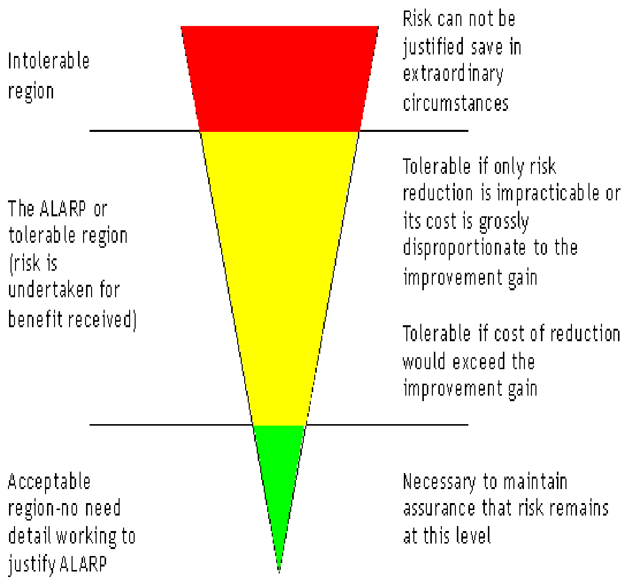

Figure 2.3 ALARP regions of the risk criteria.

2.4.9 Risk Assessment for Pipeline Integrity Prioritization and Planning

Risk Based Assessment is a systematic approach which aims to reduce the overall risk exposure by focusing on the areas of higher risk. This approach reduces the total scope of work and inspection costs in a structured and justified way. In applying risk based assessment for oil and gas pipelines, risk based assessment ensures that it integrates pipeline system while maintaining risk at *as low as reasonably practicable* (ALARP principle). Risk is generally described as the product of the likelihood of a given failure multiplied by the consequence of that event:

Risk = Likelihood or Probability of Failure x Consequence of Failure

Accordingly, risk assessment strategies can be applied to pipelines at all stages of their life, from design through to decommissioning (C. Clausard). The application of risk based assessment methodologies enables the operator to:

- Identify the primary threats to pipeline
- Rank pipelines in terms of risk (probability of failure and consequences)
- Optimize Inspection, Maintenance, Repair (IMR) activities, i.e. defining the appropriate maintenance need and maintenance activities, and
- Define an appropriate frequency for conducting the maintenance activity

Combined with a detailed understanding of pipeline degradation mechanisms the primary steps in conducting a risk assessment include:

- Data collection and storage in a central database
- Segmentation of pipeline into sections (e.g. High Consequence Areas).
- Consideration of threats, consequences
- And mitigation to pipeline sections

This information obtained can be used to optimize plans, inspection and carry out maintenance activities and identify the need for further detailed quantitative risk assessments.

2.5 Pipeline Safety Regulations

All pipeline facilities must be designed, constructed, tested, and operated in accordance with all applicable requirements as stated by internationally recognizes bodies. These include the transportation of hazardous liquids and gases by Pipeline (ASME, API). Other Federal and State Regulations & Industry Standards Regulations and standards ensure protection of the public and prevent pipeline failures.).

2.6 Risk Reduction Modelling

Performing a thorough risk analysis on the various pipelines in a company's system now provides the risk engineer with the necessary tools to accurately select projects that will yield the greatest impact. This includes increasing system integrity, maximized risk reduction, and enhancing project return on investments through accurate cost benefit analysis. Risk modelling has also offered some engineers the tools needed to propose alternate maintenance and inspection strategies in line with traditional pipe replacement requirements,*(http://www.cycla.com/opsiswc/wc.dll?primis~toppage).*

The risk analysis process is not complete unless it has the capability to model potential risk reduction activities and generate the risk reduction benefit achieved by a proposed project. An optimized risk reduction project should consider:

a. Reducing the level of risk below the company defined threshold (i.e., below the risk tolerance)
b. The new risk reduction target should insure that additional major initiatives, (i.e., in-line inspection, pressure testing, pressure reduction, etc.) will not be necessary for a minimum of 3-5years
c. The lowest achievable level of risk (i.e., pipe replacement) may not always be necessary nor the best option

Each alternative should be evaluated using a cost-benefit ratio. The greatest challenge to the risk engineer is changing the corporate culture to one in which new options are accepted in place of the traditional solutions of sleeve installation, pipe replacement, and hydro testing. During the development of the risk algorithm, items such as increased right of way clearing and improved signage are generally.

CHAPTER THREE

RESEARCH METHODOLOGY

This chapter focuses on the research methodology taken to carry out risk assessment in this final project is shown in figure 3.1

3.1 Flow Chart

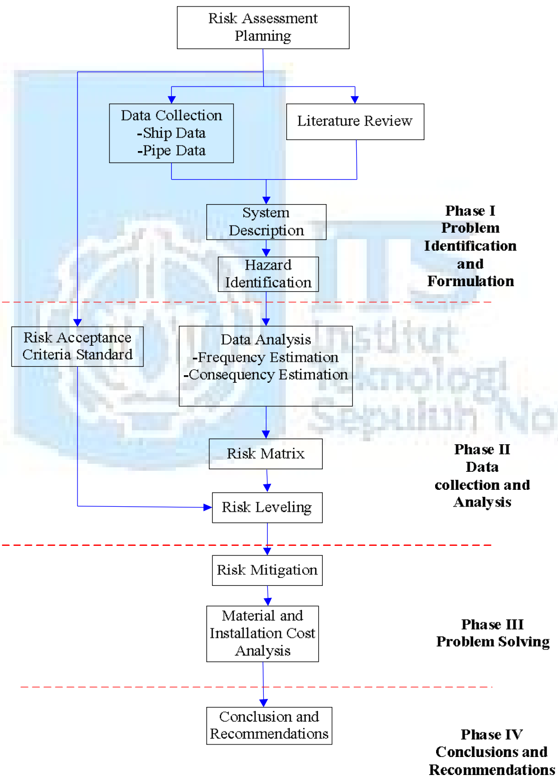

Figure 3.1 Risk Assessment Research Methodology Flow Diagram

Description of the methodology:

3.2 Phase I: Problem Identification and Formulation

- **Risk Assessment Planning** – Topic selection and brainstorming
- **Data Collection -** Collecting the data of the vessels that cross-over the gas pipeline, the weight of the vessels data, and the pipe specifications data.
- **Literature Review** – Reviewing a supportive documented literature that gives the background view of what risk assessment is all about.
- **System Description** – describing what the overall view of the risk assessment system of the pipeline will be like.
- **Hazard Identification** – Identifying the hazards that are vulnerable to cause disaster over the gas pipeline like sinking vessels.

3.3 Phase II: Data Collection and Analysis

Data Analysis can be done through frequency and consequency estimation as follows.

- **Frequency Estimation** – Estimate the frequency of the vessels using event tree analysis to analyze the incidental probability of the vessels crossing over the pipeline.
- **Consequences Estimate** – Estimate how big the impact energy of the sinking vessels consequence if the sinking vessel sinks over the pipeline at zone III and the energy that is vulnerable to dent the subsea pipeline at various dent percentages as stated in DNV RP F107 standard.
- **Risk Matrix** – Plotting the consequence and the frequency on the risk matrix.
- **Risk Acceptance Criteria Standard**– Selecting the risk acceptance criteria standard i.e. DNV standard.

- **Risk Leveling** – Determine the risk acceptance criteria either high, medium or low using DNV standard.

3.4 Phase III: Problem Solving

- **Risk Mitigation** – deciding the technical aspect of protecting the pipeline depending on the risk level.
- **Material and Installation Cost Analysis** - Determine material costs and the installation costs involved in mitigating the pipeline at zone III.

3.5 Phase IV: Conclusion and Suggestions

Make final conclusions based on the research and recommend critics about the analysis being made and what have to be further done on the risks assessment on the gas pipelines.

CHAPTER FOUR

DATA COLLECTION AND ANALYSIS

4. Data Collection

This chapter contains all the data collection and the analysis for this final project. The data collected includes vessel data and the pipe specification data. The vessel data consists of the yearly frequency of vessels that cross over the subsea pipeline, the vessel types, and the death weight tone (DWT) and the light weight tone (LWT) of the vessel. The pipe specification data includes the pipe dimensions, its yield strength, its diameter and its coating and non coating thickness.

4.1 Hazard Identification

The untrenched pipeline lies in front of the busiest sea port in East Java, in Indonesia. Many types of vessels cross over the subsea pipeline at zone III. If such vessels under loose control conditions happen to sink within zone III, the pipeline is vulnerable to potential disaster of the impact of the sinking vessel. The potential impact of the sinking vessel can dent the pipeline resulting in leakages or completely rupturing the pipeline. The liability of the pipeline being ruptured is because the pipeline is not buried under the sea bed as the sea bed is rocky and trenching was impossible at a Kilo Post (KP) of 6.7-9.3 km at zone III. As such potential hazards are liable to occur, and can result in damaging the pipeline causing leakages and complete rupturing of the untrenched pipeline at zone III. As such hazards exist, requires risk assessment to determine the risk level and implement technical risk mitigation process to reduce the risk level.

4.2 Types of data

With the identification of the hazard elaborated above, requires the calculating the risk level. To calculate the risk level, two types of data collected include the vessel data and the pipe specification data.

4.2.1 Vessel Data

The vessel data shown in table 4.1 below, includes the types of vessels and their descriptions, the routes taken, total weight of the vessel which includes the dead weight ton (DWT) and the light weight tone (LWT) of the vessel. The types of vessels cross over the subsea pipeline at an annual frequency shown in table 4.1 below. These types of vessels enter and exit Tanjung Perak, the busiest Sea Port in East Java.

Table 4.1 Vessel Data

TOTAL WEIGHT OF THE SHIP								
No	Vessel Type	Description	Yearly Frequency	Route	Range DWT	Range LWT	Total Vessel Weight (Ton)	Draft (m)
1	PFS	Passenger Ferry (Small)	2190	Madura - Surabaya	2000	500	2500	0 - 5
2	PFM	Passenger Ferry,(Medium)	730	Madura - Surabaya - Gresik	6000	1500	7500	0 - 5
3	PFL	Passenger Ferry (Large)	730	International - Antar Pulau	15000	3750	18750	0 - 5
4	SVS	Supply Vessel (Small)	3650	Laut Jawa - Gresik - Surabaya	1000	250	1250	0 - 5
5	SVM	Supply Vessel (Medium)	1825	Laut Jawa - Gresik - Surabaya	15000	3750	18750	5--10
6	SVL	Supply Vessel (Large)	1825	Laut Jawa - Gresik - Surabaya	35000	8750	43750	> 10
7	TVM	Oil Tanker Vessel (Medium)	1095	Laut Jawa - PT Petrokimia - Surabaya	10000	2500	12500	5--10
8	TVL	Oil Tanker Vessel (Large)	365	Laut Jawa - PT Petrokimia - Surabaya	30000	7500	37500	> 10
9	CTL	Container (Large)	2920	Laut Jawa - Surabaya	35000	8750	43750	> 10
10	CTX	Container (Extra Large)	730	Laut Jawa - Surabaya	70000	17500	87500	> 10
11	NVM	Navy Vessel (Medium)	2920	Laut Jawa - Selat Madura - Surabaya	20000	5000	25000	> 10
12	NVL	Navy Vessel (Large)	730	Laut Jawa - Surabaya	30000	7500	37500	0 - 5
13	FVS	Fishing Vessel (Small)	3650	Madura - Gresik	<50	13	63	0 - 5
14	FVM	Fishing Vessel (Medium)	10950	Madura - Gresik - Surabaya	100	25	125	0 - 5
15	FVL	Fishing Vessel (Large)	7300	Madura - Gresik - Surabaya	200	50	250	0 - 5
16	TUG	Tug Boats	-	Madura - Gresik	100	25	125	0 - 5
17	TNKP	Tanker Primary	24	Laut Jawa - Maspion - Surabaya	90000	22500	112500	> 10
18	TNKT	Tanker Tug (3 per tanker)	72	Laut Jawa - Maspion - Surabaya	1000	250	1250	0 - 5

4.2.2 Vessel Dimensions

The type of vessels given in table 4.1 has the following dimensions in accordance with the standard specifications of international ship construction, where the ratio of the ship dimensions is 1:8 until 1:12. The numerical value 1 is the breadth of the vessel and 8 and 12 are the length of the vessels all in meters. This ratio is applied in the construction of all vessels. Watson (1998), have specified the standard dimensions of some of the vessels given in table 4.1 as shown in table 4.2 below

Table 4.2 Vessel Dimensions

No	Ship Type	Weight (ton)	L(m)	B(m)	H(m)
1	PFS	2000	108.80	19.20	4.70
2	PFM	6000	170.00	27.80	6.27
3	PFL	15000	157.20	26.30	7.20
4	SVS	1000	108.00	17.50	7.07
5	SVM	15000	134.00	23.50	8.30
6	SVL	35000	190.00	30.50	10.00
7	TVM	10000	234.00	42.50	12.25
8	TVL	30000	314.00	58.00	22.20
9	CTL	35000	206.16	32.20	11.00
10	CTX	70000	262.00	40.00	12.00
11	NVM	20000	122.20	24.48	9.20
12	NVL	30000	135.60	28.00	10.44
13	FVS	<50	4.40	1.00	0.50
14	FVM	100	33.00	4.13	-
15	FVL	200	56.60	7.07	-
16	TUG	100	22.00	3.30	-
17	TNKP	90000	234.00	41.20	13.10
18	TNKT	1000	72.80	12.95	4.10

According to Watson (1998), all vessels dimensions must be in accordance to the tonnage weight that has to balance the load on floatation on water. The dimensions of the different types of vessels are constructed in such a way that the vessel can balance the load on its floatation on water.

4.2.3 Pipe Specification Data

The pipe specification data shown in table 4.3 includes the kilo post (KP), which is the distance of each segmented zone I-Vb of the subsea. The pipe's cross-sectional diameter, its thickness and the coating thickness of the pipe are shown in table 4.3 are all given in millimetres. The coating density is given in kilogram per m^3 as shown in table 4.3. The type of pipe used is in accordance with the American Petroleum Institute (API) 5L X65 Standard. This standard is specifically used for pipelines to be used under the subsea pipeline.

Table 4.3 Pipe Specification Data

Zone	KP	Diameter (mm)	Thickness (mm)	Density of the Coating (Kg/m3)
I	0 - 3.5	457	16.8	2400
II	3.5 - 6.7	457	16.8	2400
III	6.7 - 9.2	457	16.8	2400
Iva	9.3 - 15	457	14.8	2400
Ivb	15 - 24.2	457	14.8	3040
Ivc	24.2 - 27.6	457	14.8	3040
Va	27.6 - 35	457	14.8	3040
Vb	35 - 38.4	457	14.8	3040

At zone I to I-Vb, the pipeline is buried 2 meters under the seabed (see figure 4.1 below), except zone III, where trenching was impossible and therefore, the pipeline was laid on the sea bed. It is at this zone III at a distance of 2600 meters the potential risk exists due to the impact of the sinking vessels.

4.3 Pipeline Description

The subsea gas pipeline owned by Amerada Hess (Indonesian-Pangkah) Limited, one of the company's that specializes in oil and gas industries in Indonesia. This company specializes in extracting crude oil and gas for exporting as well as for Onshore Processing. The location of the subsea gas pipeline owned by Amerada Hess Limited lies in between the Wellhead Platform in Block Pangkah, about 3-5 kilometres from the Java Sea and about 35 km West of Surabaya City. The pipeline was installed in the Java Sea, starting from Ujung Pangkah to the Onshore Processing plant located in the Maspion Industrial area, just outside the Surabaya City. The Onshore Processing plant is situated in the Manyar village with an approximation area of 8 hectares (see figure 4.1).

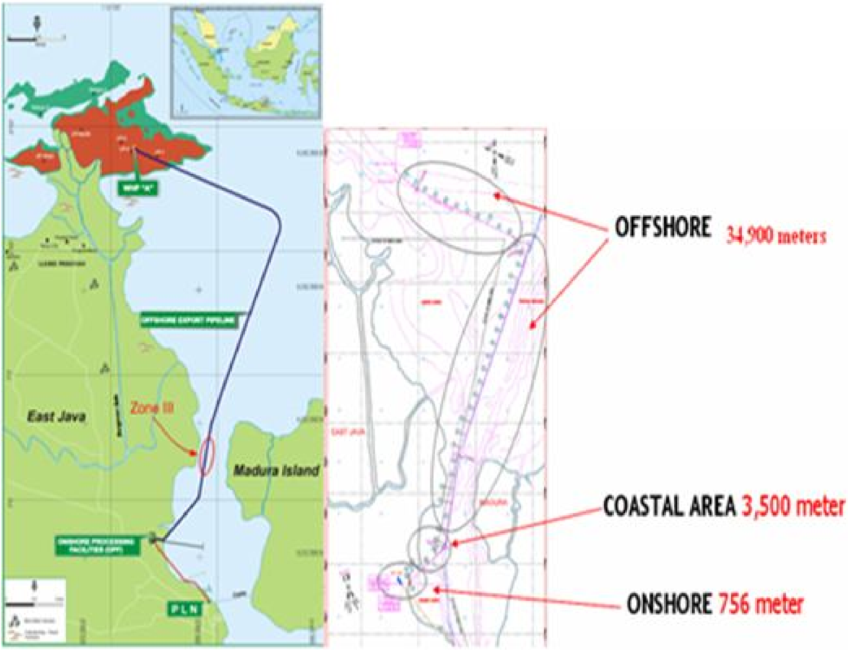

Figure 4.1 Subsea pipeline routing of Amerada Hess (Indonesia –Pangkah) Limited in Java Sea.

The untrenched zone III is located between the Island of Madura and the main Island of Java. It is in between these two Islands that most vessels pass through annually. The untrenched pipeline is located just at the front of the busiest sea port of Tanjung Perak. Zone III is the most danger point where potential danger can occur due to sinking vessels. Figure 4.1 below shows the location of the pipeline. The thick blue line shows the subsea pipeline route. Zone III is the area that is circled red on the map.

4.3.1 Sea Bed Profile

Zone III (circled red) in figure 4.1, has kilo post (KP) distance of about 3.5-6.7 km (2600meters). The depth of the sea is in between 7-13 meters deep as shown in figure 4.2. The pipeline in this zone III was untrenched and the pipeline could not be buried 2 meters under the sea bed in accordance with subsea pipeline safety regulations. Due to rocky sea bed and the pipeline could not be laid under the sea bed as trenching was impossible.

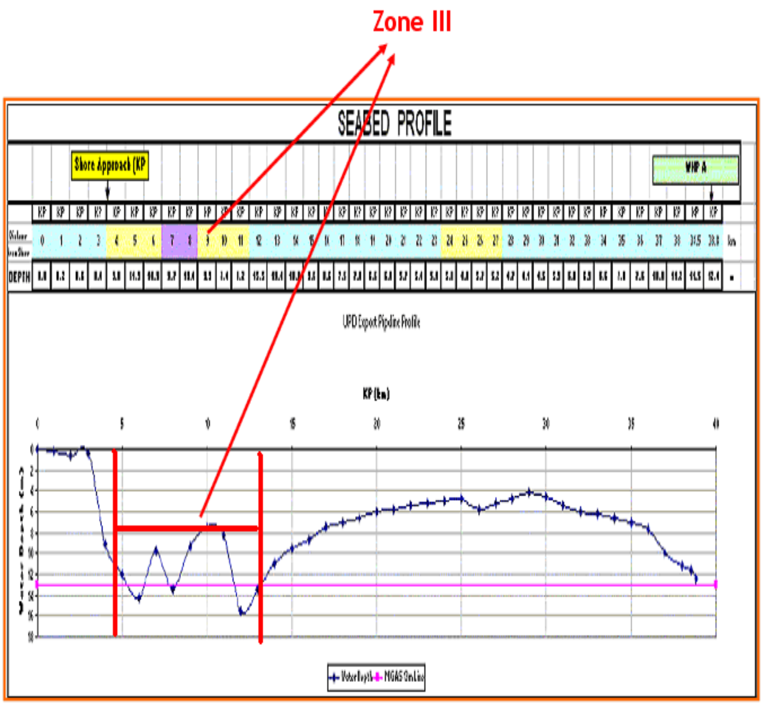

Figure 4.2 Sea bed profile at zone III.

Figure 4.2 shows the sea bed profile. The purple line shows the pipeline. The blue line shows level of the sea from the sea bed. The red line indicates zone III where trenching of the subsea pipeline was impossible. As such untrenched subsea pipeline exists, requires risk assessment to determine the risk level.

4.4 Data Analysis

Data analysis consists of two sections. And that is the Probability Estimation and the Consequency Estimation.

4.4.1 Probability Estimation

To estimate the incidental probability that will impact the pipeline, Even Tree Analysis (ETA) is used. ETA is used as a tool to estimate the incidental probability by combining the probability of three incidental conditions.

a. The probability of the vessel arriving at the untrenched Critical Accidental Damage Zone (CADZ) zone III, at loose control conditions.
b. The likeliness probability of the vessel sinking at the untrenched zone III, (CADZ zone) at loose control conditions.
c. The probability of each individual group vessels and sub group vessels will have on the pipeline during loose control conditions.

Loose control conditions are the conditions to be caused by the mechanical failure of the vessel, bad weather conditions, human error and so forth.

The combination of the probability estimation of the above three conditions can be combined to estimate the incidental probability. To estimate the incidental probability that the sinking vessel will rupture the subsea pipeline, the three conditions above are considered thoroughly.

To estimate the incidental probability, transforming the three conditional statements into questions is as follows for individual conditions.

1. Will the vessel arrive at zone III (CADZ) zone at loose control conditions?
2. Will the vessel sink under loose control conditions?
3. Which vessel group will have the highest probability impact?

In answering the three questions, three factors are taken into account. The first factor is the velocity in which the vessel is travelling, the probability that the vessel arrives at the CADZ at zone III and the likeliness of the vessel sinking. The cross multiplication combination of the three factors will give the result of the incidental probability. The incidental probability is the probability of the pipeline at zone III vulnerable of being impacted by the sinking vessel causing leakage or rupturing.

4.4.2 Segmentation of Zone III

Zone III with a kilo post (KP) of 9.3-6.7 kilometer, about 2600 meters in length has been segmented as shown in table 4.4 below. The KP given in kilometers has been segmented into a distance of 200 meters. Each 200 meters is classified as the Critical Accidental damage Zone (CADZ). The CADZ zone shown in figure 4.3, is the portion of the of the 2600 meter length of zone III. The segmentation of CADZ zone is based on the average assumption dimension of the vessel length. The CADZ area (200m pipeline x (2x the average length of the vessels +0.03m concrete thickness +0.457m diameter of pipe) is sown in figure 3.

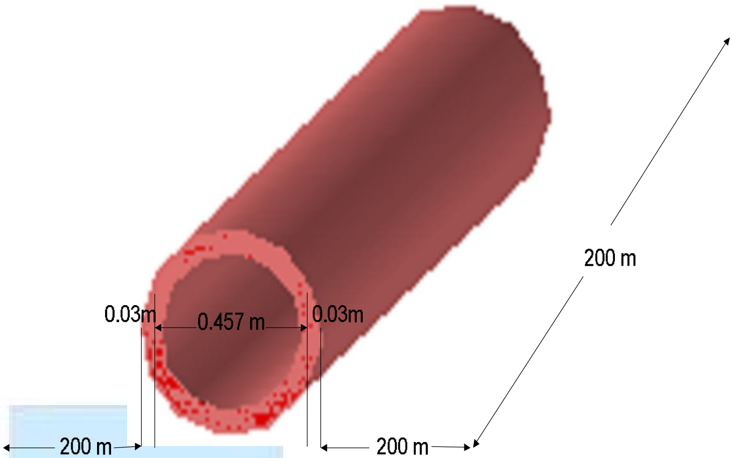

Figure 4.3 CADZ area of the pipeline

Table 4.4 Segmentation of zone III

No	Segment Range (KP)	Meters(m)
1	9300-9100	200
2	9100-8900	200
3	8900-8700	200
4	8700-8500	200
5	8500-8300	200
6	8300-8100	200
7	8100-7900	200
8	7900-7700	200
9	7700-7500	200
10	7500-7300	200
11	7300-7100	200
12	7100-6900	200
13	6900-6700	200

The segmentation of zone III into 200 meters is in accordance with the average length of the vessel, where the average vessels length is just around 200 meters. The 200 meters is estimated average length of the vessel that will impact the pipeline.

4.4.3 Grouping the Vessel Based on Weights Range

To calculate the incidental probability of the vessel arriving at CADZ zone, the vessels given in table 4.1 have been grouped based on the similarities of weight range as shown in table 4.5. In table 4.5, the vessels weight that falls in the range of 0-10000 tons have been grouped into group A. Again group A has been re-grouped into sub groups. The sub group vessel is the vessel with the highest weight. To determine the probability of individual group, the sum total of the annual frequency of the vessel has been taken for individual group of vessels.

Table 4.5 Vessel group range and the probability of each vessel

No	Ship Type	Group Vessel	Sub Group Vessel	Grouping Range of Ship(Ton)	Total Weight of Vessel	Annual Frequency	Total Number of Ships	Total % of Ship
1	FVS	A	A1	0-10 000	62.500	3650.000	28542	0.684
	FVM		A2		125.000	10950.000		
	TUG		A3		125.000	-		
	FVL		A4		250.000	7300.000		
	TKKT		A5		1250.000	72.000		
	SVS		A6		1250.000	3650.000		
	PFS		A7		2500.000	2190.000		
	PFM		A8		7500.000	730.000		
2	TVM	B	B1	10 000 - 20 000	12500.000	1095.000	3650	0.088
	PFL		B2		18700.000	730.000		
	SVM		B3		18700.000	1825.000		
3	NVM	C	C	20 000 - 30 000	25000.000	2920.000	2920	0.070
4	TVL	D	D1	30 000 - 40 000	37500.000	365.000	1095	0.026
	NVL		D2		37500.000	730.000		
5	SVL	E	E1	40 000 - 50 000	43750.000	1825.000	4745	0.114
	CTL		E2		43750.000	2920.000		
6	CTX	F	F	70 000- 80 000	87500.000	730.000	730	0.018
7	TNKP	G	G	>80 0000	112500.000	24.000	24	0.001
					TOTAL	41706	41706	1

From the 18 vessels given in table 4.1, the vessels have been grouped into 7 groups based on their tonnage weight range as shown in table 4.5. The probability percentage of each group vessel is the sum total of the annual frequency of vessel total weight divided by the total annual frequency of the entire vessel group.

4.4.4 Probability of the vessel groups and the sub vessel groups

To estimate the probability of the vessel groups that will arrive at untrenched pipeline at zone III can be evaluated as shown in table 4.6. From table 4.6, the sub vessel group with the highest weight for each group has been selected. These vessel groups include sub group A8, B3, C, D2, E2, F and G. The sub vessel group A8, B3, C, D2, E2, F and G, has the highest weight. The weight of the sinking vessel with the highest weight will have the highest denting percentage on the pipeline. Based on this concept, the vessels have been grouped.

Table 4.6 Probability of sub vessel group and the vessel group

KP 6.7-9.3 at 200m interval			KP 6.7-9.3 at 200m interval		
Group	Total Number of Vessels	Probability	Group	Total Number of Vessels	Probability
A8	730	0.074	A	28542	0.684
B3	1825	0.185	B	3650	0.088
C	2920	0.296	C	2920	0.070
D2	730	0.074	D	1095	0.026
E2	2920	0.296	E	4745	0.114
F	730	0.074	F	730	0.018
G	24	0.002	G	24	0.001
TOTAL	**9879**	**1**	**Total**	**41706**	**1**

The probability of group vessel has also been evaluated for group vessels A-G as shown in table 4.6. The probability of individual sub vessel group is the sum total of individual frequency divided by the total frequency. Likewise for the group vessel, the sum of the annual frequency of individual vessel divided by the total annual frequency for group vessel. This results in giving the individual probability of the sub vessel group and the vessel group as shown in table 4.6 above.

4.4.5 Probability of Vessel Arriving in Critical Accidental Damage Zone (CADZ).

To calculate the probability of vessel arriving at CADZ, three scenarios have been taken into consideration. The first scenario is the consideration of the velocity in which the vessels is travelling equivalent to 5 knots, 7.5 knots and 10 knots. The second scenario to be considered is the loose control condition and the vessel arriving at the CADZ in loose control conditions as assumed to be 2.5%, 5% and 7.5%. And the third scenario is the probability of the vessel sinking considered to be 2.5%, 5% and 7.5%. This is in accordance with the Lloyd's Register for ship dimensions.

Lloyds register (Business / Insurance) is an association of London underwriters, set up in the late 17th century. Originally concerned exclusively with marine insurance and a shipping information service, it now subscribes a variety of insurance policies and publishes a daily list *(Lloyd's List)* of shipping data and news. Lloyds Registry number indicates that 5 to 10 percentage of vessel sinking has been related to cases in overloading, bad weather and mechanical failure of the vessel. Most sinking occurs because there is an imbalance of the vessel dimension and the load it carries. Based on this, Watson, 1998 has stated that in order to balance the load the vessel carries, the dimensions of the ship must be constructed in accordance with the load carries. The vessel dimension ratio of every ship constructed has to be between 1:8 until 1:12 ratios, where 1 represents the width of the vessel and any number 8 and 12 represents the length of the vessel. This is the dimension best suitable for making a vessel float on water.

According to the maritime safety regulations states that the light weight ton (LWT) that the vessel must carry in order to reduce overloading. The light weight ton (LWT) the vessel can carry must be between 20% to 30% of the Death Weight Tonne (DWT) of the vessel of the vessel itself in order to balance in the water.

To calculate the incidental probability, the combination of the three Lloyds Registry percentages for sinking vessels has been considered for sinking. The percentages considered include 2.5% as the lowest, 5% as the medium and 7.5% as the highest. The velocity of the vessel considered to be 5 knots, 7.5 knots and 10 knots. The percentage of loose control is considered to be 2.5%, 5% and 7.5%.The combination of the three scenarios results in 27 scenarios to estimate the incidental probability of sinking vessels. The combination of the three scenarios above can be calculated as follows.

4.4.5.1 Probability calculation for first scenario

The probability that the vessel will arrive at the CADZ zone III can be calculated as shown in table 4.7. The scene in this scenario is that the vessel is travelling at a velocity of 5 knots, the vessel will arrive at CADZ zone is 2.5% and the likeliness of the vessel sinking is assumed to be 2.5% as well.

Table 4.7 Probability of vessels arriving at CADZ zone

1st Scenario						
No	Description	Variables	Equation	Units	KP 6.7-9.3 at 200m interval	KP 6.7-9.3 at 200m interval
1	Length of the pipe	a		meter	200.00	200
2	Sea Depth			meter	<10	>10
3	Vessel Velocity	b		knot	5.00	5
				m/s	2.57	2.57
4	Time required by vessel to cross over the pipeline area	c	a/b	s	77.82	77.82
5	Vessel group that crosses the pipeline				A8,B3,C,D2,E2,F,G	A-G
6	Total number of vessels	d			9879.00	41706
7	Total time for vessel to cross over pipeline	e	c*d	s	768793.77	3245603.11
8	Pipe diameter	f		mm	457.00	457.00
				m	0.457	0.457
9	Length of the largest Ship	g		m	122.20	122.2000
10	Pipe coating thickness	h		mm	30.00	30.00
				m	0.03	0.03
11	Length of the CADZ Zone	i	f+2g+2h	m	244.92	244.92
12	Width of the Strait	j		m	1000.00	1000.00
13	Probability of vessel in CADZ Zone	k	i/j		0.24	0.244917
14	Total time vessel in CADZ per year	l	e*k		188290.66	794903.38
15	Time in one year	m		s	31536000.00	31536000
16	Probability that Vessel arrives in the CADZ every year	n	l/m		0.01	0.0252062
17	Probability that the vessel loose control from shipping channel	o			0.025	0.025
18	Probability of vessel losing control and arrive in CADZ	p	n*o		0.000149266	0.000630156

From the probability of vessel arriving at CADZ zone, the incidental probability can be calculated as shown in table 4.7(a) and table 4.7(b) as follows. Table 4.7(a) shows the incidental probability sub group vessels and the table 4.7 (b) shows the probability for group vessels.

Table 4.7 (a) Incidental probability of the 1st scenario of the sub group vessels

Probability calculation based on 1st scenario of sub group vessel						
Vessel loosing control and arriving at CADZ		**Will the vessel sink**		**From which Group**		**Incidental Probability**
Yes	0.000149266	Yes	0.025	A8	0.074	0.000000276
				B3	0.185	0.000000690
				C	0.296	0.000001105
				D2	0.074	0.000000276
				E2	0.296	0.000001105
				F	0.074	0.000000276
				G	0.002	0.000000007
		No	0.975			0.000145535
No	0.999850734					0.999850734
					Total	**1**

Table 4.7 (b) Incidental probability of the 1st scenario of the vessel group

Probability calculation based on 1st scenario of group vessel						
Vessel loosing control and arriving at CADZ		**Will the vessel sink**		**From which group vessel**		**Probability**
Yes	0.0006302	Yes	0.025	A	0.6844	0.00001078
				B	0.0875	0.00000138
				C	0.0700	0.00000110
				D	0.0263	0.00000041
				E	0.1138	0.00000179
				F	0.0175	0.00000028
				G	0.0006	0.00000001
		No	0.975			0.00061440
No	0.9993698					0.99936984
					Total	**1**

The above result of table 4.7 (a) and (b) can also be represented on an Even Tree Analysis (ETA) as shown in figure 4.4 (a) and (b) below.

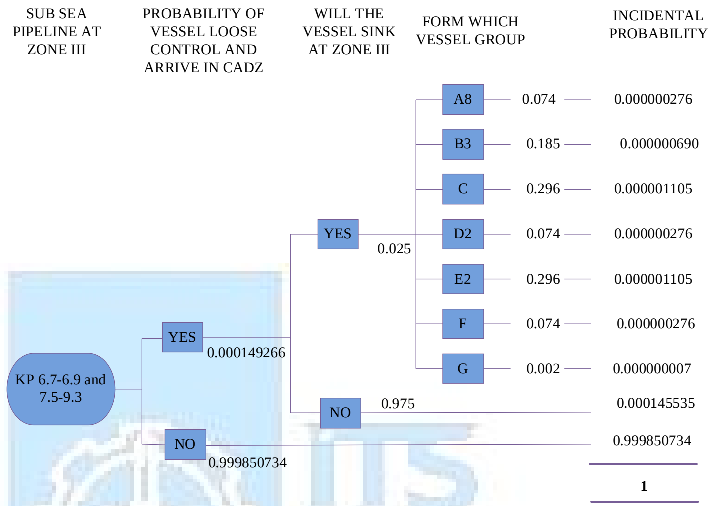

Figure 4.4 (a) ETA for 1st scenario of sub group vessels.

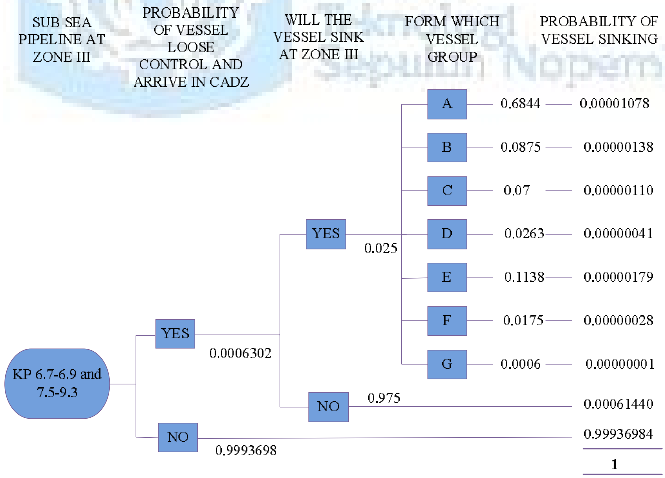

Figure 4.4 (b) ETA for 1st scenario of group vessels.

From the result of ETA given in figure 4.4 (a) and figure 4.4 (b), the individual incidental probability for sub vessel group and the group vessel are ranked as shown in table 4.8. The ranking criterion used is in accordance with the DNV RP F107 standard.

Table 4.8 Ranking for the sub group and the group vessel

1st Scenario Ranking							
Ship Group	Probability	Rank	Category	Ship Group	Probability	Rank	Category
A8	0.000000276	1	Improbable	A	0.00001078	1	Occasional
B3	0.000000690	1	Improbable	B	0.00000138	1	Occasional
C	0.000001105	1	Remote	C	0.00000110	1	Occasional
D2	0.000000276	1	Improbable	D	0.00000041	1	Improbable
E2	0.000001105	1	Remote	E	0.00000179	1	Remote
F	0.000000276	1	Improbable	F	0.00000028	1	Improbable
G	0.000000007	1	Improbable	G	0.00000001	1	Improbable

With the same methodology the incidental probability calculations for the 1st scenario above, the same procedure can be used to calculate the other scenarios from the 2nd to the 27th scenario for the sub group vessels and the group vessels. The summarized manual simulations of the 1st to the 27th scenario probability of the sub group vessel can be summarized as shown in table 4.9 (a), (b) and (c) below. *(See Attachments I for the summarized incidental probability of the 27th scenarios).*

Table 4.9(a) Summarized incidental probability for the 1st to the 9th scenario for the sub group vessels

Probability of Vessel Loose control		**0.025**		
Will the Vessel Sink		**0.025**	**0.05**	**0.075**
Sub Group Vessel	**Velocity of Vessel**			
A8	5 knots	0.000000276	0.000000552	0.000000276
B3		0.000000690	0.000001381	0.000000690
C		0.000001105	0.000002209	0.000001105
D2		0.000000276	0.000000552	0.000000276

Continuation of table 4.9 (a)

Probability of Vessel Loose control		**0.025**		
Will the Vessel Sink		**0.025**	**0.05**	**0.075**
Sub Group Vessel	**Velocity of Vessel**			
E2	**5 knots**	0.000001105	0.000002209	0.000001105
F		0.000000276	0.000000552	0.000000276
G		0.000000007	0.000000015	0.000000007
A8	**7.5 knots**	0.000000184	0.000000368	0.000000034
B3		0.000000460	0.000000920	0.000000085
C		0.000000736	0.000001473	0.000000136
D2		0.000000184	0.000000368	0.000000034
E2		0.000000736	0.000001473	0.000000136
F		0.000000184	0.000000368	0.000000034
G		0.000000005	0.000000010	0.000000001
A8	**10 knots**	0.000000414	0.000000276	0.000000414
B3		0.000001036	0.000000690	0.000001036
C		0.000001657	0.000001105	0.000001657
D2		0.000000414	0.000000276	0.000000414
E2		0.000001657	0.000001105	0.000001657
F		0.000000414	0.000000276	0.000000414
G		0.000000011	0.000000007	0.000000011

Table 4.9 (b) Summarized incidental probability for the 10th to the 18th scenario for the sub group vessels

Probability of Vessel Loose control		**0.05**		
Will the Vessel Sink		**0.025**	**0.05**	**0.075**
Sub Group Vessel	**Velocity of Vessel**			
A8	**5 knots**	0.000000552	0.000000552	0.000001657
B3		0.000001381	0.000001381	0.000004142
C		0.000002209	0.000002209	0.000006627
D2		0.000000552	0.000000552	0.000001657
E2		0.000002209	0.000002209	0.000006627
F		0.000000552	0.000000552	0.000001657
G		0.000000015	0.000000015	0.000000045
A8	**7.5 knots**	0.000000368	0.000000736	0.000016569
B3		0.000000920	0.000001841	0.000041421
C		0.000001473	0.000002946	0.000066274
D2		0.000000368	0.000000736	0.000016569

Continuation of table 4.9 (b)

Probability of Vessel Loose control		0.05		
Will the Vessel Sink		0.025	0.05	0.075
Sub Group Vessel	Velocity of Vessel			
E2	7.5 knots	0.000001473	0.000002946	0.000066274
F		0.000000368	0.000000736	0.000016569
G		0.000000010	0.000000020	0.000000448
A8	10 knots	0.000000138	0.000000552	0.000000828
B3		0.000000345	0.000001381	0.000002071
C		0.000000552	0.000002209	0.000003314
D2		0.000000138	0.000000552	0.000000828
E2		0.000000552	0.000002209	0.000003314
F		0.000000138	0.000000552	0.000000828
G		0.000000004	0.000000015	0.000000022

Table 4.9(c) Summarized incidental probability for the 19th to the 27th scenario for the sub group vessels

Probability of Vessel Loose control		0.075		
Will the Vessel Sink		0.025	0.05	0.075
Sub Group Vessel	Velocity of Vessel			
A8	5 knots	0.000000828	0.000000276	0.000002485
B3		0.000002071	0.000000690	0.000006213
C		0.000003314	0.000001105	0.000009941
D2		0.000000828	0.000000276	0.000002485
E2		0.000003314	0.000001105	0.000009941
F		0.000000828	0.000000276	0.000002485
G		0.000000022	0.000000007	0.000000067
A8	7.5 knots	0.000000552	0.000001105	0.000001657
B3		0.000001381	0.000002761	0.000004142
C		0.000002209	0.000004418	0.000006627
D2		0.000000552	0.000001105	0.000001657
E2		0.000002209	0.000004418	0.000006627
F		0.000000552	0.000001105	0.000001657
G		0.000000015	0.000000030	0.000000045
A8	10 knots	0.000000414	0.000000828	0.000001243
B3		0.000001036	0.000002071	0.000003107
C		0.000001657	0.000003314	0.000004971
D2		0.000000414	0.000000828	0.000001243

Continuation of table 4.9 (c)

Probability of Vessel Loose control		**0.075**		
Will the Vessel Sink		**0.025**	**0.05**	**0.075**
Sub Group Vessel	**Velocity of Vessel**			
E2	**7.5 knots**	0.000001657	0.000003314	0.000004971
F		0.000000414	0.000000828	0.000001243
G		0.000000011	0.000000022	0.000000034

From table 4.9 (a), (b) and (c) the incidental probability of each individual scenario ranked in accordance with the DNV RP F107 as shown in table 4.10.

Table 4.10 Ranking incidental probability of the 1st to the 27th for sub group vessels

Probability of vessel loose control		**0.025**			**0.05**			**0.075**		
Will the Vessel Sink		**0.025**	**0.05**	**0.075**	**0.025**	**0.05**	**0.075**	**0.025**	**0.05**	**0.075**
Sub vessel group	**Velocity of vessel**									
A8	**5 Knots**	1	1	1	1	1	1	1	1	1
B3		1	1	1	1	1	1	1	1	1
C		1	1	1	1	1	1	1	1	1
D2		1	1	1	1	1	1	1	1	1
E2		1	1	1	1	1	1	1	1	1
F		1	1	1	1	1	1	1	1	1
G		1	1	1	1	1	1	1	1	1
A8	**7.5 Knots**	1	1	1	1	1	1	1	1	1
B3		1	1	1	1	1	1	1	1	1
C		1	1	1	1	1	1	1	1	1
D2		1	1	1	1	1	1	1	1	1
E2		1	1	1	1	1	1	1	1	1
F		1	1	1	1	1	1	1	1	1
G		1	1	1	1	1	1	1	1	1
A8	**10 knots**	1	1	1	1	1	1	1	1	1
B3		1	1	1	1	1	1	1	1	1
C		1	1	1	1	1	1	1	1	1
D2		1	1	1	1	1	1	1	1	1
E2		1	1	1	1	1	1	1	1	1
F		1	1	1	1	1	1	1	1	1
G		1	1	1	1	1	1	1	1	1

Likewise, the probability for the group vessel from the 1st scenario to the 27th scenario for the group vessel can be seen from table 4.11 (a), (b) and (c).

Table 4.11(a) Summarized incidental probability for the 1st to the 9th scenario for the group vessels

Probability of Vessel Loose control		**0.025**		
Will the Vessel Sink		**0.025**	**0.05**	**0.08**
Sub Vessel group	**Velocity of vessel**			
A	**5 Knots**	0.00002156	0.00003235	0.00003235
B		0.00000276	0.00000414	0.00000414
C		0.00000221	0.00000331	0.00000331
D		0.00000083	0.00000124	0.00000124
E		0.00000359	0.00000538	0.00000538
F		0.00000055	0.00000083	0.00000083
G		0.00000002	0.00000003	0.00000003
A	**7.5 Knots**	0.00000719	0.00001438	0.00000133
B		0.00000092	0.00000184	0.00000017
C		0.00000074	0.00000147	0.00000014
D		0.00000028	0.00000055	0.00000005
E		0.00000120	0.00000239	0.00000022
F		0.00000018	0.00000037	0.00000003
G		0.00000001	0.00000001	0.00000000
A	**10 knots**	0.00001617	0.00001078	0.00001617
B		0.00000207	0.00000138	0.00000207
C		0.00000165	0.00000110	0.00000165
D		0.00000062	0.00000041	0.00000062
E		0.00000269	0.00000179	0.00000269
F		0.00000041	0.00000028	0.00000041
G		0.00000001	0.00000001	0.00000001

Table 4.11(b) Summarized probability for the 10th to the 18th scenario for the group vessels

Probability of Vessel Loose control		**0.05**		
Will the Vessel Sink		**0.025**	**0.05**	**0.075**
Sub Vessel group	**Velocity of vessel**			
A	**5 Knots**	0.00002156	0.00002156	0.00006469
B		0.00000276	0.00000276	0.00000827
C		0.00000221	0.00000221	0.00000662
D		0.00000083	0.00000083	0.00000249
E		0.00000359	0.00000359	0.00001076

Continuation of table 4.11(c)

Probability of Vessel Loose control		0.05		
Will the Vessel Sink		0.025	0.05	0.075
Sub Vessel group	Velocity of vessel			
F	5 knots	0.00000055	0.00000055	0.00000165
G		0.00000002	0.00000002	0.00000006
A	7.5 Knots	0.00001438	0.00002875	0.00064692
B		0.00000184	0.00000368	0.00008271
C		0.00000147	0.00000294	0.00006617
D		0.00000055	0.00000110	0.00002486
E		0.00000239	0.00000478	0.00010757
F		0.00000037	0.00000074	0.00001654
G		0.00000001	0.00000003	0.00000057
A	10 knots	0.00000539	0.00002156	0.00003235
B		0.00000069	0.00000276	0.00000414
C		0.00000055	0.00000221	0.00000331
D		0.00000021	0.00000083	0.00000124
E		0.00000090	0.00000359	0.00000538
F		0.00000014	0.00000055	0.00000083
G		0.00000000	0.00000002	0.00000003

Table 4.11(c) Summarized incidental probability for the 19th to the 27th scenario for the group vessels

Probability of Vessel Loose control		0.075		
Will the Vessel Sink		0.025	0.05	0.075
Sub Vessel group	Velocity of vessel			
A	5 Knots	0.00003235	0.00002952	0.00009704
B		0.00000414	0.00000377	0.00001241
C		0.00000331	0.00000302	0.00000992
D		0.00000124	0.00000113	0.00000373
E		0.00000538	0.00000491	0.00001614
F		0.00000083	0.00000075	0.00000248
G		0.00000003	0.00000003	0.00000009
A	7.5 Knots	0.00004313	0.00004313	0.00006469
B		0.00000551	0.00000551	0.00000827
C		0.00000441	0.00000441	0.00000662
D		0.00000166	0.00000166	0.00000249

Continuation of table 4.11(c)

Probability of Vessel Loose control		**0.075**		
Will the Vessel Sink		**0.025**	**0.05**	**0.075**
Sub Vessel group	**Velocity of vessel**			
E	**7.5 knots**	0.00000717	0.00000717	0.00001076
F		0.00000110	0.00000110	0.00000165
G		0.00000004	0.00000004	0.00000006
A	**10 knots**	0.00003235	0.00003235	0.00004852
B		0.00000414	0.00000414	0.00000620
C		0.00000331	0.00000331	0.00000496
D		0.00000124	0.00000124	0.00000186
E		0.00000538	0.00000538	0.00000807
F		0.00000083	0.00000083	0.00000124
G		0.00000003	0.00000003	0.00000004

Table 4.12 Ranking of the incidental probabilities of the group vessels

Probability of Vessel Loose control		0.025			0.05			0.075		
Will the Vessel Sink		0.025	0.05	0.075	0.025	0.05	0.075	0.025	0.05	0.075
Group Vessel	**Velocity of vessel**									
A	**5 Knots**	1	1	1	1	1	1	1	1	1
B		1	1	1	1	1	1	1	1	1
C		1	1	1	1	1	1	1	1	1
D		1	1	1	1	1	1	1	1	1
E		1	1	1	1	1	1	1	1	1
F		1	1	1	1	1	1	1	1	1
G		1	1	1	1	1	1	1	1	1
A	**7.5 Knots**	1	1	1	1	1	1	1	1	1
B		1	1	1	1	1	1	1	1	1
C		1	1	1	1	1	1	1	1	1
D		1	1	1	1	1	1	1	1	1
E		1	1	1	1	1	1	1	1	1
F		1	1	1	1	1	1	1	1	1
G		1	1	1	1	1	1	1	1	1
A	**10 knots**	1	1	1	1	1	1	1	1	1
B		1	1	1	1	1	1	1	1	1
C		1	1	1	1	1	1	1	1	1
D		1	1	1	1	1	1	1	1	1
E		1	1	1	1	1	1	1	1	1
F		1	1	1	1	1	1	1	1	1
G		1	1	1	1	1	1	1	1	1

4.5 Data Analysis for Consequency Estimation

This section is the data analysis section for consequency estimation as follows using the pipe specifications data and the weight of the vessel.

4.5.1 Consequency Estimation.

To estimate the impact energy of the sinking vessel that will rupture the pipe due to its sinking impact requires the calculation of the kinetic energy. Most impacts are expected to result in a relatively smooth dent shape. The dent-absorbed energy relationship for steel pipelines can be calculated using equation (1) as stated in the DNV RP F107 standard. The dent percentages are stated in the DNV RP F107 standard.

4.5.1.1 Non Coating Resistive Energy of the Pipe

The normal energy of the pipe without coating that can resist the impact of sinking vessels can be calculated as using equation 1 given in chapter 3 as follows.

$$E = 16 \cdot \left(\frac{2\pi}{9}\right)^{1/2} \cdot m_P \cdot \left(\frac{D}{T}\right)^{1/2} \cdot D \cdot \left(\frac{\delta}{D}\right)^{3/2} \quad \ldots\ldots (1)$$

Where:

E = Impact energy on the pipeline in joules (J)

m_P = Plastic moment capacity of the wall ($= \frac{1}{4} \cdot \sigma_y \cdot r^2$)

δ = Pipe deformation, dent depth

t = Wall thickness (normal)

σ_y =Yield strength

D = Steel outer diameter

At the dent percentage of 5%, the impact energy of the pipe can be calculated using equation 1 as follows. The Impact energy of the denting percentage of 1% to 22% can be calculated in the same way as shown in table 4.13 below.

$$m_p = \frac{1}{4}.\sigma_y.r^2$$

$$= 448x10^6 x(16.8x10^{-3})^2$$

$$= 316.1088$$

$$E = 16.\left(\frac{2\pi}{9}\right)^{1/2}.m_P.\left(\frac{D}{T}\right)^{1/2}.D.\left(\frac{\delta}{D}\right)^{3/2}$$

$$= 16x\left(\frac{2x3.14}{9}\right)^{1/2} x316.1088x\left(\frac{0.457}{16.8x10^{-3}}\right)^{1/2} x0.457x\left(\frac{0.05}{0.457}\right)^{3/2}$$

$$= 5170420.7\ joules$$

$$= 5170.42kJ$$

Table 4.13 Impact energy at various denting percentages

DENT (%)	E(Joule)	E(kJ)
1	462456.48	462.46
2	1308024.46	1308.02
3	2402994.38	2402.99
4	3699651.87	3699.65
5	5170420.67	5170.42
6	6796694.48	6796.69
7	8564813.93	8564.81
8	10464195.70	10464.20
9	12486325.06	12486.33
10	14624158.07	14624.16
11	16871741.02	16871.74
12	19223955.02	19223.96
13	21676337.33	21676.34
14	24224952.05	24224.95
15	26866293.89	26866.29
16	29597214.95	29597.21
17	32414867.79	32414.87
18	35316660.48	35316.66

Continuation of table 4.13

DENT (%)	E(Joule)	E(kJ)
19	38300220.48	38300.22
20	41363365.36	41363.37
21	44504078.67	44504.08
22	47720489.93	47720.49

4.5.1.2 Coating Energy of the Pipe

As illustrated in figure 4.5, the impacting crushing energy of the pipe coating can be calculated using equation (2) as follows.

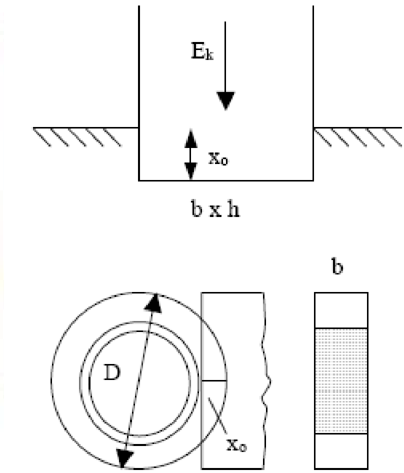

Figure 4.5 Impact on the concrete coating

$$E_k = y \, . \, b \, . \, h \, . \, X_0 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

Where:

- $E_k = 3x35Mpa = 105x10^6 \, N/m^2$ Kinetic energy

- $y = 3x35\ Mpa = 105\ x10^6\ N/m^2$ (Pressure of the pipe in N/m^2)
- $.b =$ 24.48 m (With of the average breath vessel that fractures the pipe)
- $h =$ 122.2 m (Length of the vessel)
- $X_0 =$ 0.03m is the coating thickness of the pipe

$$E_k = y.b.h.X_0$$
$$= 105\ x10^6\ x\ 24.8\ x122.2\ x\ 0.03$$
$$= 9423193325\ joules$$
$$= 9423193.33\ kJ$$

The Impact energy of both coating and non-coating at denting percentage of 5%, 10%, 15% and 20% can be calculated in the same way as shown in table 4.14 below.

Table 4.14 Non coating and coating energy of the pipe

Dent (%)	E(kJ)	Non-Coating (kJ)	Energy Total (kJ)
1	9423193.33	462.46	9423655.78
2	9423193.33	1308.02	9424501.35
3	9423193.33	2402.99	9425596.32
4	9423193.33	3699.65	9426892.98
5	9423193.33	5170.42	9428363.75
6	9423193.33	6796.69	9429990.02
7	9423193.33	8564.81	9431758.14
8	9423193.33	10464.20	9433657.52
9	9423193.33	12486.33	9435679.65
10	9423193.33	14624.16	9437817.48
11	9423193.33	16871.74	9440065.07
12	9423193.33	19223.96	9442417.28
13	9423193.33	21676.34	9444869.66

Continuation of table 4.14

Dent (%)	E(kJ)	Non-Coating (kJ)	Energy Total (kJ)
14	9423193.33	24224.95	9447418.28
15	9423193.33	26866.29	9450059.62
16	9423193.33	29597.21	9452790.54
17	9423193.33	32414.87	9455608.19
18	9423193.33	35316.66	9458509.99
19	9423193.33	38300.22	9461493.55
20	9423193.33	41363.37	9464556.69
21	9423193.33	44504.08	9467697.40
22	9423193.33	47720.49	9470913.81

From table 4.14, the non coating and coating energy ranged on the denting percentage between 0%-5%, 5-10%, 10-15%, 15-20% and the dent percentage greater than 20%. Table 4.15 shows the ranking of the categorical energy based on the energy category.

Table 4.15 Consequency Ranking

Consequency Ranking			
Rank	Dent/Diameter (%)	Energy (kJ)	
		Non Coating	Coating
1	<5	<5170.42	<9428363.75
2	5-10	5170.42-14624.16	9428363.75-9437817.48
3	10-15	14624.16-26866.29	9437817.48-9450059.62
4	15-20	26866.29-41363.37	9450059.62-9464556.69
5	>20	>41363.37	>9464556.69

4.5.1.3 Impact Energy of the Sinking Vessel on the Pipe

After the ranging the non-coating and coating energy of the pipe, the kinetic energy of the sinking vessel is calculated using equation 3 and 4 respectively. The sinking velocity of the sinking vessel can be calculated using equation 3 as follows.

$$((m - V).\rho_{water}).g = \frac{1}{2}\rho_{water}.C_D.A.V_t^2 \quad \text{.......... (3)}$$

- m = Mass of the sinking vessel (kg)
- g = Gravitational acceleration, (9, 81 m/s^2)
- V = Volume of the vessel (m^3), where the density of steel is 7850 kg/m^3/ by the mass of vessel
- ρ_{water} = Density of sea water (i.e. 1025 kg/m^3)
- C_D = 1.5 Drag coefficient of the object
- A = Projected area of the object in the flow direction (m^2) L x B of the vessel, see table 4.17).
- V_t^2 = Terminal velocity through the water (m/s)

For Example for the vessel type PFS = 2500000 kg/7850 kg/m^3 = 318.4713m^3, (see table 4.16).

$$((m - V).\rho_{water}).g = \frac{1}{2}\rho_{water}.C_D.A.V_t^2$$

$$= ((2500000 - 318.417\,m^3)x1025\,kg/m^3)x9.81\,m/s^2$$

$$= \frac{1}{2}x1025\,kg/m^3x1.3x2088.96\,m^2xV_t^2$$

$$V_t = 2398.38\,m/s$$

Table 4.16 Dimensions and projection area of the vessels

No	Ship Type	Weight (ton)	L(m)	B(m)	H(m)	Area
1	PFS	2000.00	108.80	19.20	4.70	2088.96
2	PFM	6000.00	170.00	27.80	6.27	4726.00
3	PFL	15000.00	157.20	26.30	7.20	4134.36
4	SVS	1000.00	108.00	17.50	7.07	1890.00
5	SVM	15000.00	134.00	23.50	8.30	3149.00
6	SVL	35000.00	190.00	30.50	10.00	5795.00
7	TVM	10000.00	234.00	42.50	12.25	9945.00
8	TVL	30000.00	314.00	58.00	22.20	18212.00
9	CTL	35000.00	206.16	32.20	11.00	6638.35
10	CTX	70000.00	262.00	40.00	12.00	10480.00
11	NVM	20000.00	122.20	24.48	9.20	2991.46
12	NVL	30000.00	135.60	28.00	10.44	3796.80
13	FVS	<50	4.40	1.00	0.50	4.40
14	FVM	100.00	33.00	4.13	-	136.13
15	FVL	200.00	56.60	7.07	-	400.16
16	TUG	100.00	22.00	3.30	-	72.60
17	TNKP	90000.00	234.00	41.20	13.10	9640.80
18	TNKT	1000.00	72.80	12.95	4.10	942.76

(Source: (D.G.M. Watson, 1998)

The sinking velocity for the vessel type PFS can be calculated using this formular as shown above. Likewise, the sinking velocity for other vessels can also be calculates in the same way and the results are shown in table 4.17 below.

Table 4.17 Sinking velocity of each vessel

No	Ship Type	m	V	ρ_{water}	g	0.5	ρ_{water}	C_d	A	v_t
1	PFS	2500000	318.4713	1025	9.81	0.5	1025	1.3	2088.96	2398.38
2	PFM	7500000	955.414	1025	9.81	0.5	1025	1.3	4726	4783.628
3	PFL	18750000	2388.535	1025	9.81	0.5	1025	1.3	4134.36	12786.16
4	SVS	1250000	159.2357	1025	9.81	0.5	1025	1.3	1890	1260.73
5	SVM	18750000	2388.535	1025	9.81	0.5	1025	1.3	3149	14650.69
6	SVL	43750000	5573.248	1025	9.81	0.5	1025	1.3	5795	25199.64
7	TVM	12500000	1592.357	1025	9.81	0.5	1025	1.3	9945	5496.049
8	TVL	37500000	4777.07	1025	9.81	0.5	1025	1.3	18212	12184.16
9	CTL	43750000	5573.248	1025	9.81	0.5	1025	1.3	6638.352	23544.58
10	CTX	87500000	11146.5	1025	9.81	0.5	1025	1.3	10480	37477.48
11	NVM	25000000	3184.713	1025	9.81	0.5	1025	1.3	2991.456	20042.03
12	NVL	37500000	4777.07	1025	9.81	0.5	1025	1.3	3796.8	26684.89
13	FVS	62.5	0.007962	1025	9.81	0.5	1025	1.3	4.4	1.306462
14	FVM	125000	15.92357	1025	9.81	0.5	1025	1.3	136.125	469.7687
15	FVL	250000	31.84713	1025	9.81	0.5	1025	1.3	400.162	547.9805
16	TUG	125000	15.92357	1025	9.81	0.5	1025	1.3	72.6	643.2573
17	TNKP	112500000	14331.21	1025	9.81	0.5	1025	1.3	9640.8	50238.77
18	TNKT	1250000	159.2357	1025	9.81	0.5	1025	1.3	942.76	1785.058

The kinetic energy of the object E_E, of the sinking vessel can be calculated using the formular given in chapter 3 as follows. For the type vessel PFS can be calculated as follows.

$$E_E = E_T + E_A = \frac{1}{2}(m + m_a).V_t^2 \quad .(4)$$

Where:

- m_a = Is the added mass (kg) found by:

$$m_a = \rho_{water} + C_a + V$$

$$= 1025 \ kg / m^3 \ x \ 1 \ x \ 318.4713 \ m^3$$ (See table 4.18)

$$= 326443.121 \ kg$$

- m = Total weight of ship
- g = Gravitational force (9.81m/s^2)
- v = Volume of ship (m^2)
- ρ_{water} = density of the sea water, 1025 kg/m^3
- C_a = coefficient of the area (m^3)
- A = projection of the area, m^2
- V_t = velocity of the vessel sinking, m/s^2

Table 4.18 Hydrodynamic mass of the sinking vessel in water

No	P_{water}	Ca	V	m_a
1	1025	1	318.47	326433.12
2	1025	1	955.41	979299.36
3	1025	1	2388.54	2448248.4
4	1025	1	159.24	163216.56
5	1025	1	2388.54	2448248.4
6	1025	1	5573.25	5712579.6
7	1025	1	1592.36	1632165.6
8	1025	1	4777.07	4896496.8
9	1025	1	5573.25	5712579.6
10	1025	1	11146.5	11425159
11	1025	1	3184.71	3264331.2
12	1025	1	4777.07	4896496.8
13	1025	1	0.01	8.16
14	1025	1	15.92	16321.66
15	1025	1	31.85	32643.31
16	1025	1	15.92	16321.66
17	1025	1	14331.21	14689490
18	1025	1	159.24	163216.56

The kinetic energy calculated as shown in table 4.18 can then be ranked accordingly in accordance with the denting percentage ranking of DNV RP F107 as shown in table 4.19 below.

Table 4.19 Kinetic energy of the vessel and their ranking

No	Vessel Group	Total weight of vessel(kg)	m_a	V	EE (joules)	kJ	Rank	
							Non Coating	Coating
1	A1	2500000.00	326433.12	2398.38	3389429941.68	3389429.94	5	1
2	A2	7500000.00	979299.36	4783.63	20280907041.74	20280907.04	5	5
3	A3	18750000.00	2448248.41	12786.16	135522094582.91	135522094.58	5	5
4	A4	1250000.00	163216.56	1260.73	890842299.43	890842.30	5	1
5	A5	18750000.00	2448248.41	14650.69	155284432819.31	155284432.82	5	5
6	A6	43750000.00	5712579.62	25199.64	623219596582.68	623219596.58	5	5
7	A7	12500000.00	1632165.61	5496.05	38835539132.06	38835539.13	5	5
8	A8	37500000.00	4896496.82	12184.16	258282761390.36	258282761.39	5	5
9	B1	43750000.00	5712579.62	23544.58	582287788570.87	582287788.57	5	5
10	B2	87500000.00	11425159.24	37477.48	1853732956280.92	1853732956.28	5	5
11	B3	25000000.00	3264331.21	20042.03	283237279265.71	283237279.27	5	5
12	C	37500000.00	4896496.82	26684.89	565672910519.53	565672910.52	5	5
13	D1	62500.00	8.16	1.31	40832.26	40.83	1	1
14	D2	125000.00	16321.66	469.77	33194244.30	33194.24	4	1
15	E1	250000.00	32643.31	547.98	77441507.98	77441.51	5	1
16	E2	125000.00	16321.66	643.26	45453090.96	45453.09	5	1
17	F	112500000.00	14689490.45	50238.77	3194921666131.50	3194921666.13	5	5
18	G	1250000.00	163216.56	1785.06	1261337066.72	1261337.07	5	1

4.6 Risk Matrix

In order determine the risk level of the sinking vessel either low, medium or high risk over the subsea pipeline at zone III, the incidental probability ranking calculations from 1st scenario to the 27th scenario and the consequency ranking are plotted respectively for the non-coating and coating conditions of the pipe. From the scenario ranking from 1st until 27th, the categorical rank for both the sub group vessel and the group vessel, all have a rank value of 1. The categorical rank value of 1 can be categorized as improbable. This means the probability of occurrence of the event is very low and can be considered negligible based on the DNV RP F107 standard criteria.

From the consequency estimation of kinetic energy impact of the sinking vessel analysis in table 4.19, the result indicates that both the sub vessel group and the group vessel has a high ranking value of 5. The high ranking value of 5 is categorized as major. This means that if one of the vessels sinks on the subsea pipeline and hits the untrenched pipeline, the pipeline, the sinking vessel can be completely rupture the pipeline based on the DNV RP F107 standard criteria. This means that the sinking vessels impact on the pipeline is very high.

Based on the calculation of summarised incidental probability rank values of table 4.10 of the sub group vessels and table 4.12 of the group vessels of the 1st scenario rank values are plotted against rank values for both the non coating and coating given in table 4.19. After the plotting, the risk level can be seen table 4.20(a) for sub group vessel and table 4.20(b) under non costing conditions of the pipeline for group vessels respectively.

Table 4.20(a) Risk matrix plot for the sub group vessel at non coating conditions

Risk Matrix Plotting for Sub Group Vessels					
Frequency Degree	1st Scenario				
	Consequency Degree				
	1	2	3	4	5
1					A8,B3, C, E2,D2,F,G
2					
3					
4					
5					

Table 4.20 (b) Risk matrix plot for the group vessel at non coating conditions

Vessel group					
Risk Matrix Plotting for Group Vessels					
Frequency Degree	1st Scenario				
	Consequency Degree				
	1	2	3	4	5
1					A,B,C,D,E,F,G
2					
3					
4					
5					

And the risk level at the condition where the pipe is coated is show at table 4.21(a) for sub group vessels and 4.21(b) for group vessels.

Table 4.21(a) Risk matrix plot for the sub group vessel at coating conditions

Risk Matrix Plotting for Sub Group Vessels					
Frequency Degree	1st Scenario				
	Consequency Degree				
	1	2	3	4	5
1					A8,B3, C, E2,D2,F,G
2					
3					
4					
5					

Table 4.21(b) Risk matrix plot for the group vessel at coating conditions

Vessel group					
Risk Matrix Plotting for Group Vessels					
Frequency Degree	1st Scenario				
	Consequency Degree				
	1	2	3	4	5
1					A,B,C,D,E,F,G
2					
3					
4					
5					

4.6.1 Risk Matrix Analysis

From the risk matrix plot in table 4.20 (a), under non coating condition of the pipe, the sub group vessels A8, B3, D2, F,G and C falls in the medium risk level

From the risk matrix plot in table 4.20 (b), under non coating condition of the pipe, the group vessel A, B, C, D, E, F and G falls in the medium risk level

For the coating condition of the pipe, the sub group vessels have the same risk level as the group vessels. From the risk matrix plot in table 4.21 (a), where the condition of the pipeline is coated, the sub group vessels A8, B3, D2, E2,F and G falls in the medium risk level.

From the risk matrix plot in table 4.22 (b) and where the condition of the pipeline is coated, the group vessels A, B, C, D, E, F and G medium risk level.

In the same way we can plot the risk level for the other scenarios from the 1st to the 27th in the same way.

Under such conditions where the risk level is medium the pipeline is vulnerable of being ruptured and leakage can occur if any of the vessels is sinks over zone III at any of the 13 segmented CADZ area and hits the untrenched pipeline. This can be a major treat for the normal operation for the pipeline and can be disastrous and can halt the normal operation of the pipeline. Such medium risk requires further safety precaution measures that will protect the pipeline from the medium risk level.

Although the probability of the 27th scenarios simulated indicates that the probability of the vessel sinking over the CADZ area is improbable, still there is a likeliness of the incident occurring. From the risk matrix plot the incidental probability of the event occurring is very low. On the other hand the consequency estimation of the impact of the sinking vessel on the pipeline is very high. As such conditions exists, the plotting of the risk level using the DNV RP F 107 risk matrix table has an indication that the risk level is medium specifically in this condition.

Although the pipeline has an external protective coating, from the calculation shown in table 4.19, it shows that the impact energy of the sinking vessel is much greater. This can result in the complete rupture of the pipeline. As such conditions are liable to exist there is a need to mitigate the medium risk through a technical mitigation process. The technical mitigation process can neutralize the impact of the sinking vessel so that the pipeline is unharmed and protected from the impact of the sinking vessel.

CHAPTER FIVE
RISK MITIGATION PROCESS AND COST ANALYSIS

4. Risk Mitigation Process

After the risk level being identified, mitigating such medium risk level is significantly important. The only way of reducing the risk level is through:

- Reducing the incidental probability by reducing the annual frequency of the number of vessels crossing over the subsea gas pipeline at zone III.
- Reducing consequence impact on the subsea pipeline. This can be done through the application of protective pipeline covers that shields the untrenched pipeline from the impact of the sinking vessels as well as dropped objects over zone III of the untrenched subsea gas pipeline at zone III.
- Risk retention to third parties such as insurance companies. However, this cannot reduce the risk level being identified. Risk retention is to compensate for the damages that will occur if such accidents occur.

Reducing the annual frequency of the vessel crossing the subsea pipeline this sort of conditions is impossible. This is because the pipeline is located in between the Island of Java and Madura. The strait between these two Islands is just 1000m. The vessels entering and exiting the main wharf cannot be re-routed and very big vessels stated so far cannot get close to these Islands as the depth of the sea is very low. In such situation it is impossible to reduce the annual frequency. As more vessels of the same group enters and exits the main wharf, the incidental probability is likely to increase.

In the risk retention process, the risk level cannot be reduced. The level of risk is consistent throughout. It is just transferring the risk level in terms of money values on a regular basis to insurance companies based on the value of the asset as risk retention is basically concerned. This is the most expensive exercise and if an accident occurs, the amount of money paid will be based on the amount of damage done. This does not include the costs involved in halting entire processing time on the onshore processing plant.

As such conditions exist, it is better to mitigate the high risk level to an ALARP region through the design of pipeline protective structures that will protect the pipeline from the hitting impact of the sinking vessels.

4.1 Technical Mitigation Process

To mitigate the medium risk level of the sinking vessels impact on the subsea pipeline, three technical mitigation pipe shield protective covering methods were taken into consideration to mitigate medium risk level. The pipe shield protective cover acts as an external cover that resists the impact of the sinking vessel from hitting the pipe. The pipe shield external cover acts as a protection and shields that pipeline. Any external materials such as sinking vessels are resisted by this pipeline shield cover. The pipeline is protected and unharmed. As such, the applications of the following technical mitigation processes in covering the untrenched pipeline considered include the following.

4.1.1 Submat Flexiform Concrete Mattresses Method

Submat Flexiform concrete mattress shown in figure 5.1 is designed to provide a high quality, low cost solution for stabilization, protection of subsea pipelines and structures. Submat Flexiform concrete mattress shown in figure 5.1 consists of high strength concrete segments linked together with a network of high strength polypropylene ropes to provide a highly resistant and effective stabilization system as shown in figure 5.2. Submat Flexiform Concrete Mattresses by virtue of individually profiled concrete segments is able to provide a high degree of flexibility in two planes and as such allows for complete stabilization and protection in most applications i.e. straightforward pipeline cover, at pipeline bends intersections on trenched and untrenched pipelines, for counter-action to seabed scouring. Submat Flexiform can be installed with a simple quick release installation beam frame using barge cranes with hooks.

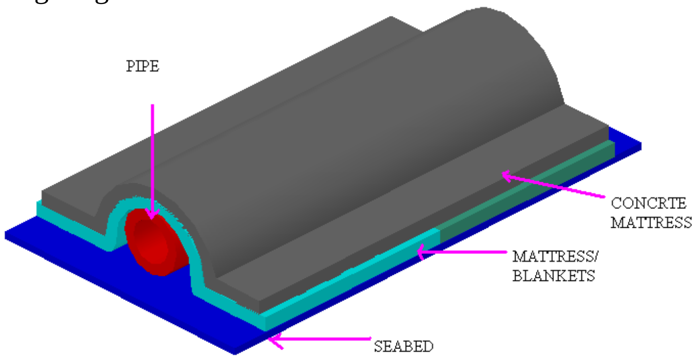

Figure 5.1 Submat Flexiform Concrete Mattress Method

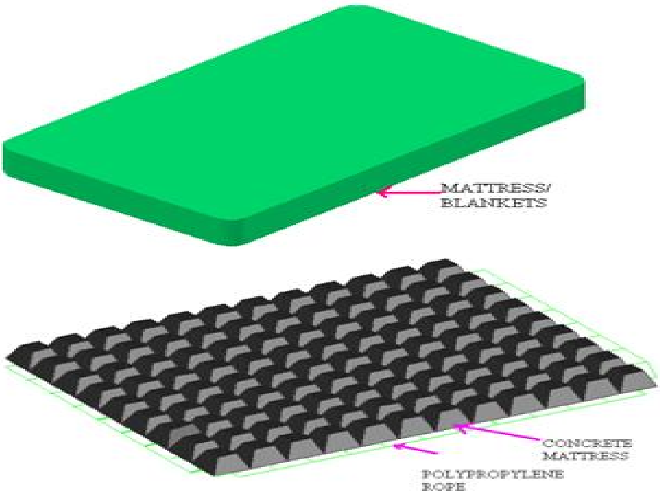

Figure 5.2 Showing the flexiform mattress and the concrete attached together by polypropylene rope.

4.1.2 U- Type Pre-Cast Method

The U-type Pre-cast method is one of the best known methods where a pre-cast concrete block is placed over the pipeline as shown in figure 5.3. This concrete acts as a structure that will protect sinking vessel as well as dropped objects impact energy from hitting pipeline. As the vessel sinks it lands on the concrete and the pipeline is shield off by this concrete structure. Sand bags and stones are placed side by side ensuring stabilization of the concrete from moving apart.

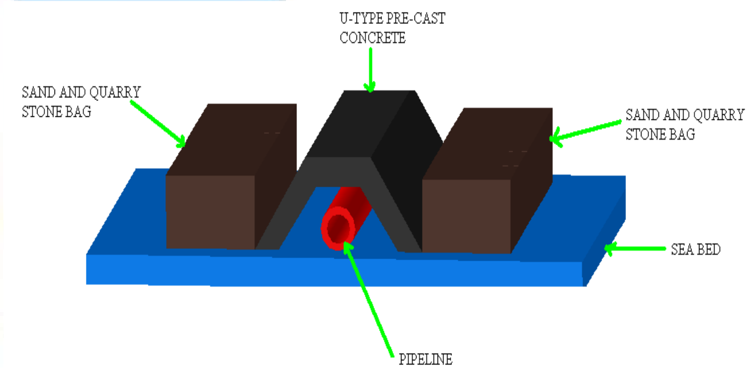

Figure 5.3 U Type-Pre-Cast Method.

The front cross sectional detailed dimensions of the U Type Pre-Cast is shown in figure 5.31 (a).

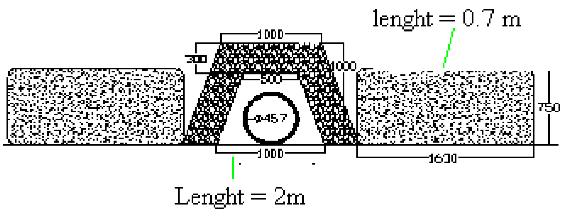

Figure 5.31 (a) Cross-sectional dimensions of the U Type Pre-Cast Concrete method.

Figure 5.31(b) and figure 5.31(c), shows the framework of the steel structure of before the pre-cast concrete cement is poured onto the steel. The steel frames are bend together and are fastened together before ready mix concrete cement can be casted over this frame.

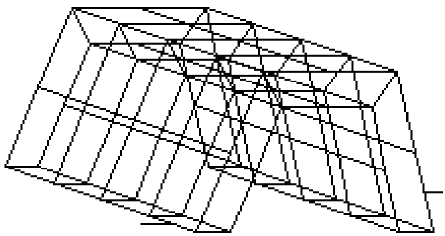

Figure 5.31(b) Framework of the Pre-Cast steel.

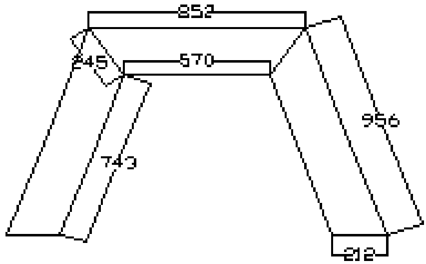

Figure 5.31(c) Dimensions of the Pre-Cast framework

4.1.3 Massive Mess Pre-Cast Method

This mitigation method uses sand bags and quarry stone that are laid over the pipeline as shown in figure 5.4. Geo bags are filled with quarry stones and sand lay on top of the pipe and at the sides. The pre-cast concrete is laid just above the sand and geo bags containing sand and stone. This is shown in figure 5.5 on how to stabilize and keep the sand and quarry stone geo bags intact.

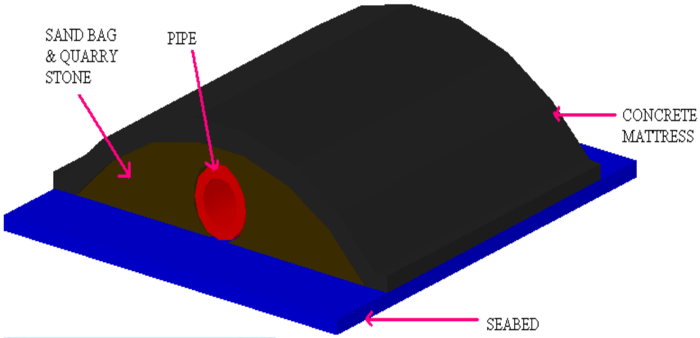

Figure 5.4 Massive Mess Concrete Method

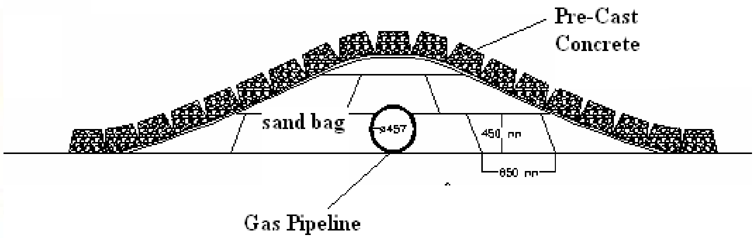

Figure 5.5 Front view of the Massive Mess Pre-Cast Method.

Figure 5.51and 5.52 shows the framework for concrete and the dimensions for one concrete. The individual concrete are attached together by a polypropylene ropes and are placed over the sand bags and quarry stone. The polypropylene ropes hold the concretes together. This enables the sand and quarry stone from falling apart due to sea currents. If the vessels sink, it lands on top of the Massive Mess Pre-Cast Concrete. This shields pipe from being hit by the sunken vessels crushing impact energy.

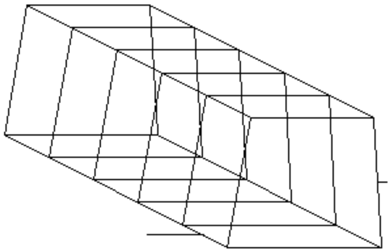

Figure 5.5.1Showing the framework of the pre-cast.

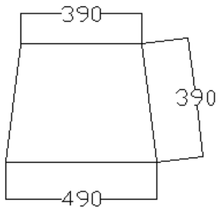

Figure 5.5.2 Showing the dimensions of the pre-cast.

5.1.4 Other Types of Pipeline Protection Methods

Other types of subsea pipeline protection methods include the following methods as internationally recognized. And these include :(source: www.pipeshield.com)

a. Spool Spill Covers
b. Impact Protection Covers
c. Pipe shield (semi-circle).

These methods are internationally recognized standards widely used protecting untrenched subsea pipeline under this sort of conditions. *(See attachment II for photos)*.

4.2 Material and Installation Cost Analysis

The material and installation cost estimation analysis for the three methods is as follows.

4.2.1 Submat Flexiform Concrete Mattress

The concrete mattress cost analysis can be calculated as shown in table 5.1.

Table 5.1 Submat flexiform concrete mattresses and costing

No	Calculation for Submat Flexible Concrete Mattress Requirements				
	Description	**Variable**	**Formulation**	**Result**	**Units**
1	Submat Flexible Concrete Mattresses	A	-	1	Set
2	Length	B	-	5	m
3	With	C	-	3	m
4	Height	D	-	0.30	m
5	Area	E	BxC	15	m2
6	Volume	F		4.50	m3
7	Density	G	-	2,400	kg/m3
8	Length of pipe	H	-	2,600	m
9	Total Number of Flexible Mattress	I	H/C	866.67	-
10	Unit price per 5 m	J	-	425	$
11	Purchasing price	K	IxJ	368,333.33	$
12	Purchasing price in Rp	L	Kx10000	3,683,333,333.33	Rp
13	Shipment Cost in $	M	-	300,000.00	$
14	Shipment Cost in Rp	N	Mx10000	3,000,000,000.00	Rp
15	**Total Cost**		**L+N**	**6,683,333,333.33**	**Rp**

4.2.2 U Type Pre-Cast

Table 5.2 Material list for making U Type Pre-Cast

Price List for Materials for making Pre-cast					
No	**Material**	**Type**	**Unit Requirements**	**Unit Price**	**Mixture per m3 beton(kg)**
1	Cement	Special Blended Cement	40 kg	46,000.00	487

2	Sand	Ocean Sand	1m3	150,000.00	577
3	Stone	Quarry stone	1m3	180,000	1,121.00

Table 5.3 Estimation Cement requirements

Calculation for Cements Requirements					
No	**Description**	**Variable**	**Formulation**	**Result**	**Units**
1	Cement Requirement per m^3 beton	A	-	487.00	kg
2	Pre-Cast Area	B	-	0.77	m2
3	Pre-cast Length	C	-	2.00	m
4	Pre-cast Volume	D	BxC	1.53	m3
5	Cement Requirement per Pre-cast	E	-	747.00	kg
6	Length of Pipeline	F		2,600.00	m
7	Total Pre-cast	G	F/C	1,300.00	-
8	Total Cement Requirements	H	ExG	971,100.00	kg
9	Cement Bags	I	H/40	24,277.50	Rp
10	Price of Cement per 40kg	J	-	46,000.00	Rp
11	Purchasing Cost	K	IxJ	**1,116,765,000.00**	**Rp**

Table 5.4 Sand estimation requirement

Calculations for sand requirements					
No	**Description**	**Variable**	**Formulation**	**Result**	**Units**
1	Sand Requirement per m3 beton	A	-	577.00	kg
2	Precast Area	B	-	0.77	m2
3	Precast length	C	-	2.00	m
4	Volume precast	D	BxC	1.53	m3
5	Weight of Sand	E	-	2,733.00	kg/m3
6	Sand Requirement per precast	F	AxD	883.96	kg
7	Volume of sand	G	F/E	0.32	m3

8	Length of pipe	H	-	2,600.00	m
9	Total Precast	I	H/C	1,300.00	-
10	Total Sand requirements	J	GxI	420.47	m3

Continuation of table 5.4

Calculations for sand requirements					
No	**Description**	**Variable**	**Formulation**	**Result**	**Units**
11	Price of Precast per m3	K	-	150,000.00	Rp
12	Purchasing cost	L	JxK	**63,070,976.95**	**Rp**

Table 5.5 Sand bag estimation

Sand Bag Estimation Calculations					
No	**Description**	**Variable**	**Formulation**	**Result**	**Units**
1	Length of Geo Bag	A	-	2.38	m
2	Width of the Geo Bag	B	-	1.45	m
3	Height of the sand bad	C	-	0.75	m
4	Length of sand bag	D	A-C	1.63	m
5	Width of sand bag	E	B-C	0.7	m
6	Volume of the sand bag	F	CxDxE	0.86	m^3
7	Length of the pipeline	G	-	2,600	m
8	Total number of geo bag requirements	H	2(G/E)	7,428.57	-
9	Price of geo bag	I	-	370,000	Rp
10	Volume of sand required	J	HxI	2,748,571,428.57	Rp
11	Price of geo bag per m^3	K	FxH	6,357	m^3
12	Purchasing price of geo bag	L	-	150,000	Rp
13	Purchasing cost of geo bag	M	KxL	**953,550,000**	**Rp**
14	Purchasing cost of sand bags	N	J+M	**3,702,121,428.57**	**Rp**

Table 5.6 Quarry stone estimation

Calculation Quarry Stone Requirements					
No	**Description**	**Variable**	**Formulation**	**Result**	**Units**
1	Sand Requirement per m^3 beton	A	-	1,121	kg
2	Precast Area	B	-	0.77	m^2
3	Pre-cast length	C	-	2	m
4	Volume pre-cast	D	BxC	1.53	m^3
5	Density of sand	E	-	2,677	kg/m^3
6	Sand Requirement per pre-cast	F	AxD	1,717.37	kg
7	Volume of sand	G	F/E	0.64	m3
8	Length of pipe	H	-	2,600	m
9	Total pre-cast	I	H/C	1,300	-
10	Total Sand requirements	J	GxI	833.99	m^3
11	Price of Pre-cast per m^3	K	-	180,000	Rp
12	Purchasing cost	L	JxK	**150,117,686.96**	**Rp**

Table 5.7 Steel length framework estimation

Pre-Cast Framework Estimation Calculation					
No	**Description**	**Variable**	**Formulation**	**Result**	**Units**
1	Length of the first frame	A	-	2	m
2	Total number of the first frame for each pre-cast	B	-	14	-
3	Total number of pre-cast	C	-	1,300	-
4	Total number of frame for all the pre-cast	D	BxC	18,200	-
5	Length of the beton	E	-	12	m
6	Total number of	F	E/A	6	-

	Beton for each frame				
7	Number of beton required	G	D/F	3,033.33	-

Continuation of table 5.7

Pre-Cast Framework Estimation Calculation					
No	**Description**	**Variable**	**Formulation**	**Result**	**Units**
8	Price for beton 13mm	H	-	55,000	Rp
9	Purchasing price	I	GxH	**166,833,333.33**	**Rp**

Table 5.8 Steel crossing estimation

Steel Frame Estimations Calculations					
No	**Description**	**Variable**	**Formulation**	**Result**	**Units**
1	Length of the steel	A	-	5.9	m
2	Total number of steel	B	-	10	-
3	Total number of pre-cast	C	-	1,300	-
4	Total number of for all pre-cast	D	BxC	13,000	-
5	Length of the beton	E	-	12	m
6	Total number of steel for each beton	F	E/A	2.03	-
7	Beton required	G	D/F	6,391.67	-
8	Price of beton	H	-	30,000	Rp
9	Purchasing price of beton	I	GxH	**191,750,000.00**	**Rp**

Table 5.9 Total material costing for U Type Pre-Cast

	Total Material Costing	
No	**Type of Material**	**Total Cost(Rp)**
1	Cement	1,116,765,000.00
2	Sand	63,070,976.95
3	Sand Bag	3,702,121,428.57
4	Stone	150,117,686.96
5	Steel frame bars	191,750,000.00
Grand Total (Rp)		**5,223,825,092.48**

4.2.3 Massive Mess Pre-Cast

For the Massive Mess Pre-Cast Method, the material cost can be evaluated as follows.

Table 5.10 Estimated material list for Massive Mess Pre-Cast

Price List for Materials for making Pre-cast					
No	Material	Type	Unit Requirements	Unit Price	Mixture per m^3 beton(kg)
1	Cement	Special Blended Cement	40 kg	46,000.00	487
2	Sand	Ocean Sand	1m3	150,000.00	577
3	Stone	Quarry	1m3	180,000.00	1,121

Table 5.11 Cement requirement for Massive Mess Pre-Cast

Calculation for Cements Requirements					
No	Description	Variable	Formulation	Result	Units
1	Cement requirement per m^3 beton	A	-	487	kg
2	Pre-cast area	B	-	0.18	m2
3	Pre-cast length	C	-	2	m
4	Pre-cast volume	D	BxC	0.36	m3
5	Cement Requirement per pre-cast	E	-	175.32	kg
6	Total pre-cast	F		2,600.00	m
7	Total pre-cast	G	F/C	1,300.00	-
8	Total cement requirements	H	ExG	227,916.00	kg
9	Number of Cement Bags Required	I	H/40	5,697.90	Rp
10	Price of cement per 40kg	J	-	46,000.00	Rp
11	Purchasing Cost	K	IxJ	**262,103,400.00**	**Rp**

Table 5.12 Sand Requirement for Massive Mess Pre-Cast

Calculations for sand requirements					
No	**Description**	**Variable**	**Formulation**	**Result**	**Units**
1	Sand requirement per m3 beton	A	-	577	kg

Continuation of table 5.12

Calculations for sand requirements					
No	**Description**	**Variable**	**Formulation**	**Result**	**Units**
2	Pre-cast area	B	-	0.18	m^2
3	Pre-cast length	C	-	2	m
4	Volume pre-cast	D	BxC	0.36	m3
5	Density of the sand	E	-	2,733.00	kg/m^3
6	Sand Requirement per pre-cast	F	AxD	207.72	kg
7		G	F/E	0.08	m^3
8	Length of pipe	H	-	2,600.00	m
9	Total pre-cast	I	H/C	1,300.00	-
10	Total sand requirements	J	GxI	98.81	m^3
11	Price of pre-cast per m^3	K	-	150,000.00	Rp
12	Purchasing cost	L	JxK	14,820,856.20	Rp

Table 5.13 Sand bag requirement for Massive Mess Pre-Cast

Calculation for Sand Bag					
No	Description	Variable	Formulation	Result	Units
1	Length of geo bag	A	-	1.45	m
2	Width of the geo bag	B	-	1.3	m
3	Height of the sand bad	C	-	0.45	m
4	Length of sand bag	D	A-C	1	m
5	Width of sand bag	E	B-C	0.85	m
6	Volume of the sand bag	F	CxDxE	0.38	m^3
7	Length of the pipeline	G	-	2,600.00	m

8	Total number of geo bag requirements	H	10(G/D)	26,000.00	-
9	Price of geo bag	I	-	225,500.00	Rp
10	Volume of sand required	J	HxI	5,863,000,000.00	Rp

Continuation of table 5.13

Calculation for Sand Bag					
No	Description	Variable	Formulation	Result	Units
11	Price of geo bag per m^3	K	FxH	9,945.00	m^3
12	Unit price of geo bag	L	-	150,000.00	Rp
13	Purchasing cost of geo bag	M	KxL	1,491,750,000.00	Rp
14	Purchasing cost of sand bags	N	J+M	7,354,750,000.00	Rp

Table 5.14 Quarry stone estimation for Massive Mess Pre-Cast

Calculation for Quarry Stone Requirements					
No	**Description**	**Variable**	**Formulation**	**Result**	**Units**
1	Sand requirement per m^3 beton	A	-	1,121.00	kg
2	Precast area	B	-	0.18	m2
3	Pre-cast length	C	-	2	m
4	Volume pre-cast	D	BxC	0.36	m3
5	Density of Sand	E	-	2,677.00	kg/m3
6	Sand requirement per pre-cast	F	AxD	403.56	kg
7	Volume of Sand	G	F/E	0.15	m3
8	Length of pipe	H	-	2,600.00	m
9	Total pre-cast	I	H/C	1,300.00	-
10	Total stone requirements	J	GxI	195.98	m3
11	Price of pre-cast per m^3	K	-	180,000.00	Rp
12	Purchasing cost	L	JxK	35,275,696.68	Rp

Table 5.15(a) Steel length framework estimation for Massive Mess Pre-Cast

Calculation for the framework Skeleton of the Precast					
No	Description	Variable	Formulation	Result	Units
1	Length of the first frame	A	-	2	m
2	Total number of the first frame for each precast	B	-	4	-
3	Total number of pre-cast	C	-	1,300.00	-
4	Total number of frame for all the precast	D	BxC	5,200.00	-
5	Length of the beton	E	-	12	m
6	Total number of beton for each frame	F	E/A	6	-
7	Number of beton required	G	D/F	866.67	-
8	Price for beton 13mm	H	-	55,000.00	Rp
9	Purchasing price	I	GxH	47,666,666.67	Rp

Table 5.15 (b) Steel crossing estimation for Massive Mess Pre-Cast

Calculation for frame for steel crossing					
No	Description	Variable	Formulation	Result	Units
1	Length of the steel	A	-	1.45	m
2	Total number of steel rod	B	-	10	-
3	Total number of pre-cast	C	-	1,300.00	-
4	Total number of steel rod for all pre-cast	D	BxC	13,000.00	-
5	Length of the beton	E	-	12	m

6	Total number of steel for each beton	F	E/A	8.28	-
7	Beton required	G	D/F	1,570.83	-
8	Price of beton 10mm	H	-	30,000.00	Rp
9	Purchasing price of beton	I	GxH	47,125,000.00	Rp

Table 5.16 Total material costing for Massive Mess Pre-Cast

No	Total Material Costing	
	Type of Material	**Total Cost(Rp)**
1	Cement	262,103,400.00
2	Sand	14,820,856.20
3	Sand bag	7,354,750,000.00
4	Stone	35,275,696.68
5	Steel framework bars	47,666,666.67
6	Steel rods	47,125,000.00
Grand Total (Rp)		**7,761,741,619.54**

4.3 Installation Cost Analysis

Installation cost analysis involves in the mitigation process. The installation cost is based on the sequential activities involved. This sequence of activities can be represented using on an Activity Flow Chart as shown in figure 5.5 below.

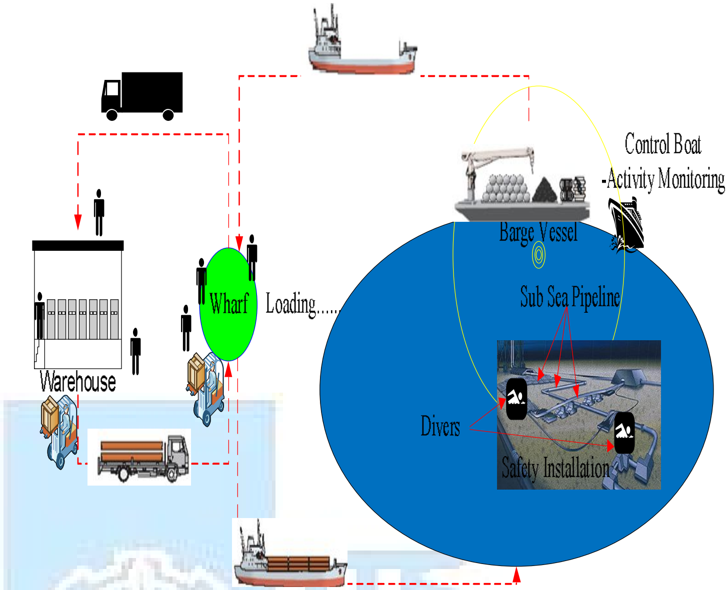

Figure 5.5 Installation activity flow chart

Figure 5.6 is scenario of the installation process. Considering the installation process as a construction process where the basic principles of project management are involved. Figure 5.6 can be broken down into activities based on:

1. The type of job to be performed
2. The type of material used
3. Number of workers involved
4. Type of equipments used
5. Location of the task to be performed and so forth.

In determining the installation costs, the scope of determining the installation cost is includes:

1. The cost of all the equipments used
2. The type and form of equipment to be used

3. The workforce required and their expertise based on hourly rates or monthly fixed salaries
4. Hourly rates of the type of equipments and transportation used
5. Administrative costs involved.
6. The duration of the installation is based on expertise view and can vary depending on the sea bed profile and its surface.

4.3.1 Installation Rates

To calculate the installation cost for the three types of mitigation process methods, table 5.17 shows the hourly rate of the individual rates of the equipments used as well the hourly rates of the certain qualified personals such as divers, engineers and safety equipments.

Table 5.17 Hourly rates for qualified personals and equipments

No	Name	Hourly Rate($)	Fixed Cost($)	Source
1	Crane Barge	235		Mt.Vernon Barge Services
2	Forklifts	120		Mt.Vernon Barge Services
3	Wharf Crane	45		Mt.Vernon Barge Services
4	Escort Vehicle	40		Mt.Vernon Barge Services
5	Supply Vessel Medium	235		Mt.Vernon Barge Services
6	Safety Helmets		9.76	http://www.prosafetyequipment.com/
7	Safety Boots		109.95	http://www.prosafetyequipment.com/
8	Earmuffs		22.15	http://www.prosafetyequipment.com/

9	Working Gloves		18	http://www.prosafetyequipment.com/
10	Safety Glasses		10	http://www.prosafetyequipment.com/
11	Work Shirts		45	http://www.prosafetyequipment.com/
12	Working Overalls		54.95	http://www.prosafetyequipment.com/
13	Safety Vests		10	http://www.prosafetyequipment.com/
14	Masks(dust)		10	http://www.prosafetyequipment.com/
15	Flexiform Mattress		425	www.slp-eng.com/Submat
16	Engineers Rate		120	http://houston.kijiji.com
17	Divers Rate		150	http://houston.kijiji.com -
18	Diving Equipments		574.23	http://www.joediveramerica.com

The rates shown in table 5.17 are the currents rates and may vary in the future depending on the rate of dollars. For the current installation cost analysis, the rates given in table 5.17 have been used.

4.3.2 Installation Cost for Submat Flexiform Concrete Mattress

At an installation rate of 9 meters per hour for the U Type Pre-cast Method, the maximum time required for the installation to complete the 2600m is about 289 hours. If 8 working hours are available each day, then the installation is expected to complete in 37 days. (520hrs/8hrs/day = 37 days of installation) or 1months and 1week. As such the installation cost of the Submat Flexiform Concrete Mattress can is estimated to be Rp 16,043,588,100.00. *(See attachment III for detail calculations for the Installation costs)*

4.3.3 Installation Cost Analysis for the U Type Pre-Cast Method

The installation cost for the Submat U Type Pre-Cast method can be calculated as follows.

At an installation rate of 5 meters per hour for the U Type Pre-cast Method, the maximum time required for the installation to complete the 2600 is about 520 hours. If 8 working hours are available each day, then the installation is expected to complete in 65 days. (520hrs/8hrs/day = 65 days of installation) or 2 months. The installation cost of the U Type Pre-cast Method can is estimated to be Rp 29,747,297,300.00. *(See attachment III for detail calculations)*

4.3.4 Installation Cost Analysis for Massive Mess Pre-Cast

At an installation rate of 4 meters per hour for the Massive Mess Pre-cast Method, the maximum time required for the installation to complete the 2600 is about 650 hours. If 8 working hours are available each day, then the installation is expected to complete in 82 days. (650 hrs/8hrs/day = 82 days of installation) or 2 months and 3 weeks. The installation cost of the Massive Mess Pre-Cast Method is estimated to be Rp 37,027,435,100.00. (*See attachment III for detail calculations)*

4.3.5 Total Material and Installation Costs

The total material and the installation cost can be calculated as shown in table 5.18. Table 5.18 shows the estimated material and installation costs for the three types of mitigation process methods analysed in this final project.

Table 5.18 Overall materials and installation cost

SUMMARY OF THE MATERIAL AND INSTALLATION COST					
NO	MITIGATION METHOD	MATERIAL COST	INSTALLATION COST	GRAND TOTAL (Rp)	GRAND TOTAL($)
1	CONCRETE MATTRESSE	6,683,333,333.33	16,043,588,100.00	22,726,921,433.33	2,272,692.14
2	U TYPE PRE-CAST	5,223,826,092.48	29,747,297,300.00	34,971,123,392.48	3,497,112.34
3	MASSIVE MESS PRE-CASR	7,761,741,619.54	37,027,435,100.00	44,789,176,719.54	4,478,917.67

4.3.6 Cost Level Analysis

From table 5.18, the material and installation cost analysis of the three types of methods can be summarized as shown in table 5.19 below.

Table 5.19 Cost level analysis of the three methods

NO	COST ANALYSIS	
	METHOD	LEVEL
A	CONCRTE MATTRESSES	
1	Material cost	low
2	Installation cost	low
3	Total Material and Installation Cost	low
B	U TYPE-PRE-CAST	
1	Material cost	medium

Continuation of table 5.19

NO	COST ANALYSIS	
	METHOD	LEVEL
2	Installation cost	medium
3	Total Material and Installation Cost	medium
C	MASSIVE MESS PRE-CAST	
1	Material cost	high

2	Installation cost	high
3	Total Material and Installation Cost	high

As shown in table 5.19, that the material and installation cost analysis of concrete mattress is low. The material and installation cost for the U Type Pre-Cast method is medium and for the Massive Mess Pre-Cast method has a high cost of material and installation.

4.3.7 Advantages and Disadvantages Analysis

The advantages and disadvantages can be analysed as follows for individual methods.

A. Concrete Mattress

- *Advantages*
  - Cheap material and installation cost compared to the other two methods
  - Require short period of installation
  - Corrosive resistive
  - Good for areas with high sea currents
- *Disadvantages*
  - Can scratch the pipeline coating if not installed properly
  - Cannot resist the impact of heavy weights and is suitable for light weights such as anchor drop etc
  - Cannot be produced locally and has a high shipment cost if ordered abroad.
  - Require high technology for construction and fabrication

B. U Type Pre-Cast

- *Advantages*
  - Suitable for resisting heavy weights such as sunken vessel weights
  - Easy to make and Install. Can be produced locally
  - Medium material and installation cost

- Does not require skilled labour for construction
- Good stability structure

- *Disadvantages*
  - Require heavy machinery and equipments
  - More time consumed compared to concrete mattresses method.

C. Massive Mess Pre-Cast

- *Advantages*
  - Suitable for resisting heavy weights such as sunken vessel
  - Can be produced locally
  - Does not require skilled labour for construction
  - Good stability structure
- *Disadvantages*
  - Not easy to make and install.
  - High material and installation cost
  - Long period of installation
  - Require more labour force
  - Require heavy machinery and equipment
  - High installation and material costs

4.3.8 Alternative Selection

To select the best alternative from the three types of mitigating processes, Brown Gibson Method is used. This method is used to analyse the best alternative forgone based on the concept of "*Preference of Measurements*". The Preference of Measurement combines the objective (quantitative) and subjective (qualitative) factors together.
The steps involved in this method include:

a. Determining the Performance of Measurements from objective factors

Given the total material and installation cost in table 5.18 above, the performance of measurements from each alternative can be calculated using the following formular.

$$OF_i = \frac{1}{\left[C_i \Sigma(\frac{1}{Ci}) \right]}$$

Where:
Ofi = Objective factor
C(i) = is the total material and installation cost for the three alternatives.
The ojective factor can be calculated using the objective function formular as shown above.The result is tabled in table 5.20 below.

Table 5.20 Objective factor (OFi)

Alternative	**Material and Installation Cost**	**Total**	
	C(i)($)	**1/C(i)**	**OF(i)**
A	1486769.6	0.00000067	0.4256807
B	2033432.9	0.00000049	0.4256807
C	2405711.7	0.00000042	0.2630777
Total		**0.00000158**	**1.114439**

b. Determine the subjective factor that has significantly influence in determining the best alternative among the three. To find the subjective factor SF(i), the following formular is applied.

SFi = (W1xR1)+ (W2xR2)+ (W3xR3)+...+ (WixRi)

Where:
SFi = subjective factor.
Wi = rating factor for each subjective factor

Ri = rating factor for each alternative based on each subjective factor

The subjective factors considered are the factors of:
a. Skills and knowledge
b. Material processing
c. Technology requirement

The next step is to determine the subjective factors can be evaluated for the three (3) mitigation processes. The subjective factors for the process, technical and others can rated as shown in the following tables 5.21

Table 5.21 Ratting factor for each subjective factor

Evaluation of factor Subjective					
Subjective Factor	**Pairwise Comparism**			**Total Score**	**Ri**
	a	***b***	***c***		
a	1	0	0	1	0.17
b	1	1	1	3	0.50
c	1	0	1	2	0.33
Total				**6**	**1**

From the table 5.21, it can be seen that:

i. The factor skills and knowledge is more important than the factor material processing
ii. Material processing is better than factor skills and knowledge
iii. Both material processing and technology requirement are same.

Table 5.22 Comparing the alternatives with vessel weight

Skills and Knowledge			
Subjective Factor	**Pairwise Comparism**	**Total Score**	**Wi**

	A	B	C		
A	1	1	1	3	0.43
B	0	1	1	2	0.29
C	0	1	1	2	0.29
				7	1

Table 5.23 Comparism for the alternatives with technical factor

Material Process					
Subjective Factor	**Pairwise Comparism**			**Total Score**	**Wi**
	A	**B**	C		
A	1	0	0	1	0.17
B	1	1	1	3	0.5
C	1	0	1	2	0.33
Total				6	1

Table5.24 Comparing the alternatives with the process factor

Technology Requirement					
Subjective Factor	**Pairwise Comparism**			**Total Score**	**Wi**
	A	**B**	C		
A	1	0	0	1	0.17
B	1	1	0	2	0.33
C	1	0	1	2	0.33

Total	5	1

Table 5.25 Subjective factor values

Subjective Factor	W1R1	W2R2	W3R3	SF(i)
1	0.07	0.03	0.03	0.13
2	0.14	0.25	0.17	0.56
3	0.10	0.11	0.11	0.32

Table 5.26 Subjective and objective values

Factor	Value
Objective (k)	0.75
Subjective	0.25

APMi = k (OFi) + (1-k)(SFi)

Table 5.27 Alternative preference measurement

Alternative	k	OFi	(1-k)SFi	APMi
A	0.75	0.426	0.03	0.35
B	0.75	0.426	0.14	0.46
C	0.75	0.263	0.08	0.28
Total				1

4.3.9 Alternative Selection Analysis

The best alternative forgone is the alternative with the highest Alternative Performance Measurements (APMi) value. From the table 5.27 above the value with the highest APMi value is the alternative B with a value of 0.46, where alternative B is the U type Pre-Cast Method. So the type of mitigation process most preferred is the U Type Pre-Cast Method.

Although the U Type Pre-Cast Method has medium material and installation cost compared to the Submat Flexiform Concrete Mattress, we cannot make the judgements based on the cost analysis only. The APM value for U Type Pre-Cast Method in table 5.22 from the subjective and objective factor analysis indicates that the U Type Pre-Cast Method is the best alternative forgone.

The U Type Pre-Cast Method from the structural and reliability scene is a good method also. The U Type Method is reliable to withstand the impact of the sinking vessel from hitting the gas pipeline. This method of pipeline protection is reliable to resist the impact of the sinking vessels with great tonnage weights.

Also from the constructive point of view, the U Type Pre-Cast Method can be made locally as the material used for the construction can be found locally. There is no import of other materials like the flexiform mattress.

As such, the best alternative selected among the three types of mitigation process is the U Type Pre-Cast Method suitable for application in zone III.

CHAPTER SIX
CONCLUSION AND SUGGESTIONS

This chaper contains two section. The first being the conclusion of the reseach and the second contains the suggesions for this final project.

1.1 Conclusion

The conclusion points made is based on the data analysis for this final project are elaborated as follows.

a. The potential risk to be caused by sinking vessels on the subsea pipeline for Amerada Hess at zone III is a medium risk level. The risk level is categorized as medium risk level due to the potential impact of the sinking vessels can be a major treat in rupturing the subsea pipeline and can only be accepted with a technical mitigation process applied. As such, to protect the pipeline from the medium risk level, Amerada Hess is required to shield the untrenched pipeline using the U-Type Pre-Cast method or any other pipe protective precautions that can resist the weight of the sinking vessels impact from hitting the pipeline.

b. From the frequency estimations, the results of the incidental probability from the combination of the three factors where:
   - The velocity of the vessel at 5 knots, 7.5 knots and 10 knots
   - The percentages used for the vessel loose control conditions and arriving at the CADZ are at 2.5%, 5% and 7.5% in accordance with Lloyds' registry number
   - The percentage probability of the vessel sinking to be 2.5%, 5% and 7.5% in accordance with Lloyds' registry number.

The combination of the three factors ranking results for the twenty-seven (27) scenarios indicates that the ranks for the 27 scenarios are all 1. So the degree rank is constant throughout the 27^{th} scenarios. However, as the number of vessels crossing over the subsea pipelines at zone III increases, the incidental probability of the increases and the ranking decree is likely to increase from 1 to 5.

c. For the Consequency Estimation, the ranking consequency of the vessels all falls at ranking of 5. Acceptation for vessels with small weights. As the weight of the vessel increases the impact energy of such vessels sinking hitting the subsea pipeline is very high and at a point of rupturing the pipeline. As such, the outcome of the vessel sinking and hitting the pipeline can result in leakages and the complete rupture of the pipeline at zone III.
d. The estimated material and installation cost for the Submat Flexiform Concrete Mattress Method is $2,272,692.14 (Rp 22,726,921,433.33), U Type Pre-Cast Method at $3,497,112.34 (Rp 34,971,123,392.48) and Massive Mess Pre-Cast Method at $4,478,917.67 (Rp44, 789,176,719.54).
e. Comparing the three types of methods based on the objective and subjective factors using Brown Gibson Method, the most preferred type is the U Type Pre-Cast Method where it has the highest Alternative Performance Measurement value of 0.46. This indicates that U Type Pre-Cast Method is the best preferred Method.

1.2 Suggestions

Several Suggestions that can be taken into account from this final project are as follows:

a. There is a need to calculate the incidental probability of individual of the different types of vessels crossing over the subsea pipeline at zone III due to the changes in the annual frequency of the vessels crossing over the pipeline in the future.
b. Re-evaluate the consequency again as there might be vessels with greater weights passing through apart from the types of vessels stated in this final project.
c. The re-design of a better technical mitigation process that is more reliable and cost effective if the Submat Flexiform Concrete Mattress, U Type Pre-Cast and the Massive Mess Pre-Cast Methods are considered expensive based on material and cost analysis and reliability performance of the design.

The need to estimate the reliability and maintenance cost of the U Type Pre-Cast method on timely basis to maintain the safety of the pipeline during the long run of the supply of the gas.

ATTACHEMENT III

INSTALLATION COST ANALYSIS FOR THE THREE MITIGATION PROCESSES

A. INSTALLATION COST ANALYSIS FOR SUBMAT FLEXIFORM CONCRETE MATTRESS

Installation Cost for Submat Flexiform Concrete Mattress

At an installation rate of 9 meters per hour for the U Type Pre-cast Method, the maximum time required for the installation to complete the 2600m is about 289 hours. If 8 working hours are available each day, then the installation is expected to complete in 37 days. (520hrs/8hrs/day = 37 days of installation) or 1months and 1week. As such the installation cost of the Submat Flexiform can is estimated to be $1,587,388.81 or Rp 15,873,888,100.00. *(See attachment III for detail calculations for the Installation costs).*

Table 9 Submat Flexiform Concrete Mattress installation Cost Estimations

ALTERNATIVE 1: SUBMAT FLEXIFORM CONCRETE MATTRESS								
ACTIVITY	**TYPE OF EQUIPMENT/PERSONAL**	**TOTAL**		**HRLY RATE ($)**	**FIX COST($)**	**TOTAL HRS**	**TOTAL COST($)**	**TOTAL COST(Rp)**
ACITIVITY		**MACHINE**	**MAN**					
a. WAREHOUSE								
Loading	Forklifts	1		120		289	34,680.00	346,800,000.00
	Forklift Controllers		1		200	289	57,800.00	578,000,000.00
Transportation	Trucks	4	2	80		289	92,480.00	924,800,000.00
Escorting	Small vehicle	1		40		289	11,560.00	115,600,000.00
Material set up	Worker		6		300	289	520,200.00	5,202,000,000.00
Protection and Control	Security Guards		2		200	289	115,600.00	1,156,000,000.00
b. WHARF								
Unloading	Forklifts	1		120		289	34,680.00	346,800,000.00
	Forklift Controllers		2		200	289	115,600.00	1,156,000,000.00
	Worker			6	300		1,800.00	18,000,000.00
	Wharf Crane	1		120		289	34,680.00	346,800,000.00
Shipment to Zone III	Supply Vessel Medium	1		235		289	67,915.00	679,150,000.00
	Workers on Vessel		4		300		1,200.00	12,000,000.00
Protection and Control	Security Guards		2		200		400.00	4,000,000.00
c. ZONE III								
Unloading from Supply Vessel	Barger Vessel with Crane (25 ton)	1		235		289	67,915.00	679,150,000.00
Setting up on Barge Vessel	Workers		6		200	289	1,200.00	12,000,000.00
Activity Controlling (boats)	Control Boats		2	100		289	57,800.00	578,000,000.00
	Controllers		1	200		289	57,800.00	578,000,000.00
Meal Preparation for workers on board	Chefs		2		250	289	500.00	5,000,000.00

Continuation of table 9

ALTERNATIVE 1: SUBMAT FLEXIFORM CONCRETE MATTRESS								
ACTIVITY	**TYPE OF EQUIPMENT/PERSONAL**	**TOTAL**		**HRLY RATE ($)**	**FIX COST($)**	**TOTAL HRS**	**TOTAL COST($)**	**TOTAL COST(Rp)**
ACITIVITY		**MACHINE**	**MAN**					
d. UNDERWATER INSTALLATION								
Diving	Divers		4	150		289	173,400.00	1,734,000,000.00
	Diving Equipments (2Sets)/diver	8			574.23		4,593.84	45,938,400.00
Engineering	Engineers (Construction & Marine)		2	150		289	86,700.00	867,000,000.00
Welding	Welders	2			200		400.00	4,000,000.00
	Welding rods and Equipments	2			3000		6,000.00	60,000,000.00
TOTAL NO.OF WOKERRS			**36**					
e. OTHERS								
Food and Drinks	Breakfast		37		8	38	11,248.00	112,480,000.00
	Lunch		37		10	38	14,060.00	140,600,000.00
	Dinner		37		15	38	21,090.00	210,900,000.00
Safety Equipments	Safety Helmets		37		9.76		361.12	3,611,200.00
	Safety Boots		37		109.95		4,068.15	40,681,500.00
	Earmuffs		37		22.15		819.55	8,195,500.00
	Working Gloves		37		18		666.00	6,660,000.00
	Safety Glasses		37		10		370.00	3,700,000.00
	Work Shirts		37		45		1,665.00	16,650,000.00
	Working Overalls		37		54.95		2,033.15	20,331,500.00
	Safety Vests		37		10		370.00	3,700,000.00
	Masks(dust)		37				-	
Administration							3,000.00	30,000,000.00
TOTAL INSTALLATION COST FOR FLEXIFORM MATTRESSES							**1,604,654.81**	**16,046,548,100.00**

B. INSTALLATION COST ANALYSIS FOR U TYEP PRE-CAST METHOD

The installation cost for the U Type Pre-Cast Method can be calculated as follows.
At an installation rate of 5 meters per hour for the U Type Pre-cast Method, the maximum time required for the installation to complete the 2600 is about 520 hours. If 8 working hours are available each day, then the installation is expected to complete in 65 days. (520hrs/8hrs/day = 65 days of installation) or 2 months. The installation cost of the U Type Pre-cast Method can is estimated to be $2,943,899.73 or Rp 29,438,997,300.00. *(See attachment III for detail calculations).*

Table 10 U Type Pre-Cast Method installation Cost Estimations

ALTERNATIVE 1: U-TYPE-PRE-CAST								
ACTIVITY	**TYPE OF EQUIPMENT/PERSONAL**	**TOTAL**		**HRLY RATE ($)**	**FIXED COST($)**	**WORKING HOURS/PER MONTH**	**TOTAL COST($)**	**TOTAL COST(Rp)**
ACITIVITY		**MACHINE**	**MAN**					
a. WAREHOUSE								
Loading	Forklifts	2		120		289	69,360.00	693,600,000.00
	Forklift Controllers		2		200	289	115,600.00	1,156,000,000.00
Transportation	Trucks	5		80		289	115,600.00	1,156,000,000.00
Escorting	Small vehicle	1		40		289	11,560.00	115,600,000.00
Material set up	Worker		6		300	289	520,200.00	5,202,000,000.00
Protection and Control	Security Guards		2		200	289	115,600.00	1,156,000,000.00
b. WHARF								
Unloading	Forklifts	2		120		289	69,360.00	693,600,000.00
	Forklift Controllers		2		200	289	115,600.00	1,156,000,000.00
	Worker			8	300		2,400.00	24,000,000.00
	Wharf Crane	1		120		289	34,680.00	346,800,000.00
Shipment to Zone III	Supply Vessel Medium	1		235		289	67,915.00	679,150,000.00
	Workers on Vessel		6		300		1,800.00	18,000,000.00
Protection and Control	Security Guards		2		200		400.00	4,000,000.00
c. ZONE III								
Unloading from Supply Vessel	Barger Vessel with Crane (25 ton)	1		235		289	67,915.00	679,150,000.00
Setting up on Barge Vessel	Workers		6		200	289	1,200.00	12,000,000.00
Activity Controlling (boats)	Control Boats		2	100		289	57,800.00	578,000,000.00
	Controllers		2	200		289	115,600.00	1,156,000,000.00
Meal Preparation for workers on board	Chefs		2		250	289	500.00	5,000,000.00
d. UNDERWATER INSTALLATION								
Diving	Divers		6	150		289	260,100.00	2,601,000,000.00
	Diving Equipments (2Sets)/diver	12			574.23		6,890.76	68,907,600.00
Engineering	Engineers (Construction & Marine)		2	150		289	86,700.00	867,000,000.00
Welding	Welders	4			200		800.00	8,000,000.00
	Welding rods and Equipments	4			3000		12,000.00	120,000,000.00
TOTAL NO.OF WOKERRS			**40**					
e. OTHERS								
Food and Drinks	Breakfast		40		8	38	12,160.00	121,600,000.00
	Lunch		40		10	38	15,200.00	152,000,000.00
	Dinner		40		15	38	22,800.00	228,000,000.00
Safety Equipments	Safety Helmets		40		9.76		390.40	3,904,000.00
	Safety Boots		40		109.95		4,398.00	43,980,000.00
	Earmuffs		40		22.15		886.00	8,860,000.00
	Working Gloves		40		18		720.00	7,200,000.00
	Safety Glasses		40		10		400.00	4,000,000.00
	Work Shirts		40		45		1,800.00	18,000,000.00

Continuation of table 10

ALTERNATIVE 1: U-TYPE-PRE-CAST									
ACTIVITY	TYPE OF EQUIPMENT/PERSONAL	TOTAL		HRLY RATE ($)	FIXED COST($)	WORKING HOURS/PER MONTH	TOTAL COST($)	TOTAL COST(Rp)
ACITIVITY		MACHINE	MAN					
Safety Equipments	Work Shirts		40		45		1,800.00	18,000,000.00
	Working Overalls		40		54.95		2,198.00	21,980,000.00
	Safety Vests		40		10		400.00	4,000,000.00
	Masks(dust)		40				-	
Administration							3,000.00	30,000,000.00
TOTAL INSTALLATION COST FOR FLEXIFORM MATTRESSES							1,913,933.16	19,139,331,600.00

C. INSTALLATION COST ANALYSIS FOR MASSIVE MESS PRE-CAST METHOD

At an installation rate of 4 meters per hour for the Massive Mess Pre-cast Method, the maximum time required for the installation to complete the 2600 is about 650 hours. If 8 working hours are available each day, then the installation is expected to complete in 82 days. (650 hrs/8hrs/day = 82 days of installation) or 2 months and 3 weeks. The installation cost of the Massive Mess Pre-Cast Method can is estimated to be $3,663,743.51 or Rp 36,637,435,100.00. (*See attachment III for detail calculations)*

Table 11 Massive Mess Pre-Cast installation Cost Estimations

ALTERNATIVE 1: MASSIVE MESS PRE-CAST								
ACTIVITY	TYPE OF EQUIPMENT/PERSONAL	TOTAL		HOURLY RATE ($)	FIXED COST($)	WORKING HOURS/PER MONTH	TOTAL COST($)	TOTAL COST(Rp)
ACITIVITY		MACHINE	MAN					
a. WAREHOUSE								
Loading	Forklifts	2		120		289	69,360.00	693,600,000.00
	Forklift Controllers		2		200	289	115,600.00	1,156,000,000.00
Transportation	Trucks	6	2	80		289	138,720.00	1,387,200,000.00
Escorting	Small vehicle	1		40		289	11,560.00	115,600,000.00
Material set up	Worker		6		300	289	520,200.00	5,202,000,000.00
Protection and Control	Security Guards		2		200	289	115,600.00	1,156,000,000.00

Continuation of table 11

ALTERNATIVE 1: MASSIVE MESS PRE-CAST								
ACTIVITY	**TYPE OF EQUIPMENT/PERSONAL**	**TOTAL**		**HOURLY RATE ($)**	**FIXED COST($)**	**WORKING HOURS/PER MONTH**	**TOTAL COST($)**	**TOTAL COST(Rp)**
ACITIVITY		**MACHINE**	**MAN**					
	Safety Vests		50		10		500.00	5,000,000.00
	Masks(dust)		50				-	
Administration							3,000.00	30,000,000.00
TOTAL INSTALLATION COST FOR FLEXIFORM MATTRESSES							2,035,588.18	20,355,881,800.00