Assessment of Cutting Technology Above Seabed for Cost Reduction Purpose

by

Nor Zafry bin Nor Salim

Dissertation submitted in partial fulfilment of
the requirements for the

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CERTIFICATION OF APPROVAL

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Approved by,

(Assoc. Prof. Dr Noor Amila binti Wan Abdullah Zawawi)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

SEPTEMBER 2017

CERTIFICATION OF ORIGINALITY

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

(NOR ZAFRY BIN NOR SALIM)

ABSTRACT

At the end of offshore structure design life, decommissioning offshore platform should be execute as one of the legislative requirement in offshore installation. Malaysia decommissioning activities increasing as the number of offshore platform reach their design life approximately about 360 platforms. The execution of offshore decommissioning need to be properly planned as the risk is huge due to the lack of expert in decommissioning field. Decommissioning cost has taken into consideration in project planning to increase the profit gain by the operator. The scope of this paper is to propose cutting technology above sea bed for cost reduction purpose. Selection of cutting technology is important to reduce the cost element involve in jacket removal. Diamond wire saw, Abrasive Water Jet and Diver Torch are selected for the non-explosive cutting method technology. In order to get the best cutting technology, study of Qualitative analysis on the selected technologies based on the safety, technical, cost and environmental impact are done. The factors are measured by indicating score of each technology and ranked. Indirect cost of the technologies calculated and compared which the cheapest cost is Diamond Wire Saw. Furthermore, Diamond Wire Saw is the best cutting technology based on the score of safety, technical, cost and environmental impact. The cost reduction is measured based on case study on a platform with different cutting technologies used. The cost reduction is compared between several cases on a platform with the actual case and the cost reduction take about 29%. In conclusion, the cost reduction for cutting technology above seabed is by using Diamond Wire Saw.

ACKNOWWLEDGEMENT

First and foremost, I want to express my honest gratitude to the God Almighty that with his blessing, finally able to complete my dissertation successfully.

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Through every obstacles and hardship that I encounter, I would like to give my greatest appreciations to parents for always supporting me during completing this project**.**

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CHAPTER 1

INTRODUCTION

1.1 Background study

Demand in oil and gas productions are getting higher day by day. New exploration and production need to be done to satisfy those demand from the industries. In order to explore and produce oil and gas, installation of new platform has to be constructed at offshore areas. Meanwhile, the platform which has exceeded their lifespan shall be decommissioned using the proper method. Many platforms have been abandoned and need to be decommissioned in the future. The decommissioning activities for fixed offshore platforms in Malaysia are expected to rise significantly. For many of the approximate 300 oil platforms, their service life is approaching the end (Zawawi, 2012). The normal design life for an offshore structure shall not be less than 20 years or the required service life if this exceeds 20 years (A. Stacey, et al., 2008). According to OSPAR Decision 98/3, disused offshore installation must normally be removed and disposed on land (Øen Sigrun, et al., 2011). Hence, study for decommissioning of offshore structure is fatal to overcome the marine pollution from abandoned platforms.

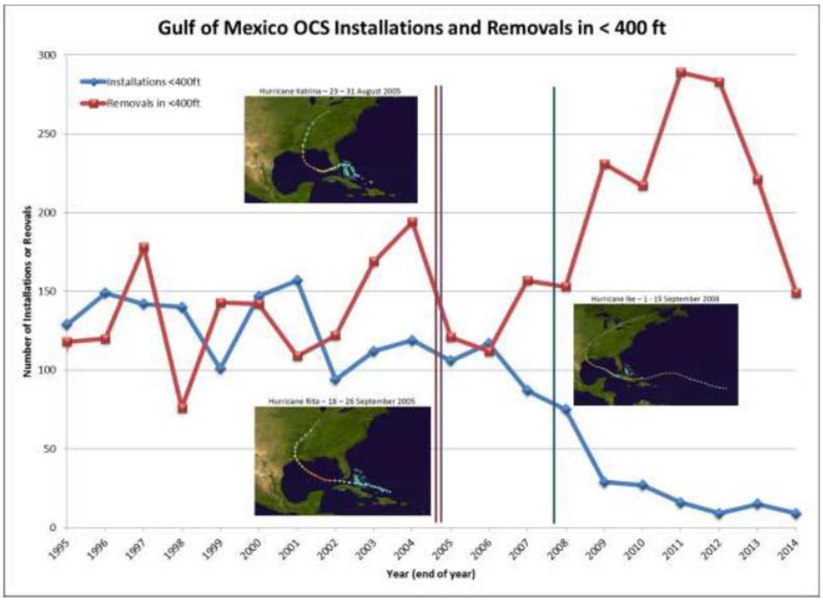


FIGURE 1 PLATFORM INSTALLATIONS AND REMOVALS AFTER MAJOR STORMS RETRIEVED FROM ICF INCORPORATED

Lot of preliminary work need to be planning properly by the project management to ensure the smoothness of work in future. There is a standard procedure for decommissioning of structure need to be done by contractor, owner and consultant. Contractor need to submit the Decommissioning Options Assessment proposal to PETRONAS for review and approval (Karim, 2006). In the proposal, contractor need to include removal method options, ranking of the methods based on strength and weakness and estimated cost for decommissioning project. Beside the approved decommissioning option should not pose any adverse impact to the environment, it should properly balance the considerations of environmental protection, safety and cost (Karim, 2006). Therefore, selection of method for decommissioning need to consider the cost and health safety factor as it gives a huge impact to the surrounding.

Selection of method for decommissioning platform structure must consider the age of platform, location and water depth, type of platform and seabed condition. Decommissioning has 2 options which are structure removal or artificial reef. Artificial reefs maybe defined as 'submerged structures placed on the seabed deliberately, to mimic some characteristics of natural reefs' (Chandler&Techera, 2015). Manmade structure will give benefit to the marine life as it will degrade in time and it will provide permanent ecosystem. It will allow coral reef and seaweed to grow on a sink structure where it is suitable for marine life to breed. The life span of structure reef varies from different location as it will affect the corrosion rate. It is estimated that the life span of a cathodically unprotected platform will range from a minimum of 100 to more than 300 years (M. Schroeder*&S. Love, 2004). Artificial reef is the typical method used for decommissioning as it low cost, but it limits to certain water depth and need proper marine management planning.

Structure removal is the alternative method for platform decommissioning. There are two options for removal which is partial and complete removal. Usually partial removal will remove most of the topside of platform and leave jacket to reef while complete removal will lift topside and jacket. Removal topside from jacket and place on the barge, where it will be dissembling at the onshore. It was assumed that small jackets in shallow water (less than 60 metres water depth) could be lifted as a single item and transferred to shore (Bemment, 2001). The larger jacket in deeper water will be cut and removed in sections depending on type of jacket. The cost for both methods are different depend on the type of platform for decommissioning. Hence, selection for removal decommissioning method vary from process of decommissioning and cost depending on the type of platform itself.

One of the complete removal method for the pile and conductor is by explosive. The explosive tools are driven inside the pile or conductor into certain depth below seabed. The most commonly used technique for explosive cutting of piles and conductors is with bulk explosives such as C-4 or Comp B (Continental Shelf Associates, Inc. 2004). Even though the cost for explosion is lowest, delay is possible if protected marine life is found in the area (ICF Incorporated, 2013). It is the easiest and safest method for explosion because it can be moulded at the location. Besides, diameter of conductor is different as it goes deeper, it will give difficulty to the explosion tools to travel from top to the bottom of seabed. It is clearly shown that explosion method is not suitable for decommissioning where there is a marine life beneath structure.

Cutting technology is the alternative of complete removal method for offshore structure. There is a lot of new cutting technology has been invented through time. The conductor will be cut section by section in certain length until it reaches the seabed. It is either by advance technology of using machine or manually cutting using divers with respect to the size and diameter of the conductor. The common cutting method is by diamond wire because of its flexibility. Currently diamond wire tooling is available and proven for subsea cut up to a maximum diameter of three metres (120 inches), but this does require significant access around the site for the cutting package itself (Oil&Gas UK Aberdeen, 2012). It is the recommended method for cutting technology for fixed offshore structure as it gives less impact on the marine life.

Cost of overall decommissioning offshore structure is affected from well plugging and abandonment, pipeline decommissioning, umbilical decommissioning, conductor removal, platform decommissioning, subsea structure decommissioning, site clearance and verification and material disposal (ICF Incorporated, 2013). The cost of overall decommissioning can be reduced mostly from removal selection method, time consuming for the decommissioning process and type and location of the platform itself. Besides, environmental and safety factor shall be considered for each stage in decommissioning process to protect the marine life. Hence it is important to find the suitable technology for decommissioning process of the structure as it will reduce the cost and protect the marine life at the location.

1. 2 Problem Statement

Lack of decommissioning expert in Malaysia about decommissioning project causes major problems to determine the suitable cutting technology above seabed. The problem will lead to cost overrun in jacket removal and it contribute about 17-18% from overall cost in decommissioning project. Based on several previous decommissioning projects in Malaysia, the total cost is very expensive as lack of experts. One of the problem is unsuitable cutting technology selection on the platform. The overall project has to be delay for a new cutting technology come from overseas. Thus, increase in marine spread cost and workers vigorously. The alternative to avoid this problem from happening in the future is by selecting suitable cutting technology where it also can lead to cost reduction for jacket removal.

1.3 Objective

This study has two objectives to be achieved at the end. There are as follows:

1. To explore the feasibility of cutting above seabed for cost reduction and less impact on health and safety environment during decommissioning of offshore structure.

2. To select the best cutting technology above seabed based on Qualitative Analysis

1.4 Scope of Study

This study will be conducted based on Malaysia offshore location and only for fixed offshore structure that exceed their design life. The scope of existing cutting technology is selected from non-explosive method to fulfil legislative requirement in Malaysia. Besides, cost reduction for cutting technology is focus in the jacket removal cost percentage. Hence the selection of cutting technology is analyse based on Qualitative analysis and Relative Importance Index.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction for cutting method

In this research, only cutting method for decommissioning is review and analyse for it cost. There is a several procedures need to follow before cutting the platform. First, detailed engineering is carried out to determine the specific procedures, vessels, equipment, and
manpower that may be used in the decommissioning process (ICF Incorporated, 2013). The detailed design will evaluate the weight of structure that need to be lift and transport to the onshore. There are two options for cutting method which is complete removal or partial removal. All the elements of the platform are removed to shore for salvage and it involves cutting up the structure into small pieces and then recycling the scrap steel (Ayoade, 2002). Meanwhile, partial removal would leave the lower part of the structure in its pile condition (PETRONAS Procedure and Guideline for Upstream Activities Decommissioning Guideline, 2006). The removal of structure depends on the analysis result taken from engineering detailed to choose either total removal or partial removal.

Pile cutting is one of the options to be consider in offshore decommissioning. The options were evaluated by assessing environmental impacts and energy analyses of offshore and onshore components (Gerrard, etc.al, 1999). The impact of decommissioning to the environment and oceanic profile at the location are the factors involve in decision making for pile cutting. Pile cutting does not execute due to the greater current strength and vice versa in weaker current strength. The structural stability for pile cutting will be disturb by the greater current strength, does make the process of decommissioning more complex and time consuming. Hence, pile cutting is necessary if the stability of the structure is not being disturb by the forces imposed from the environment during decommissioning process.

2.2 Decommissioning guideline

There is no standard guideline and reference for cutting decommissioning method to be followed. Based on the previous decommissioning project around the globe, every cutting method guideline is from case by case study as long as the safety and environmental impact take into consideration. Culwell, 1997 stated that the deck package and jacket structure were removed in sections weighing from 100 to 400 tons. Furthermore, the selection of a crane vessel will be made in conjunction with the proposed lifting method (ASCOPE Decommissioning Guideline for Oil and Gas Facilities, 2012). Beside the pile removal guideline is based on the platform location and soil properties. All the piles and conductor are severed 15 feets below mudline (Thornton, 2000). Meanwhile, the depth of cutting shall be a minimum of one (1) meter below the mudline subject to cutting method and seabed conditions such as siltation rate, erosion rate, type of soil, etc (PETRONAS Procedure and Guideline for Upstream Activities Decommissioning Guideline, 2006). Hence, the guideline and reference for cutting method is based on case by case study of the structure inclusive the safety factor and environmental impact.

2.3 Fixed offshore platform

As ICF Incorporated, 2015 stated that fixed platforms are built on concrete or steel legs, or both, anchored directly onto the seabed, and support a deck with space for drilling rigs, production facilities and crew quarters. The design life of structure based on the design life of the well production. The support structure for the topside is called jacket legs. Design of the jacket legs is based on the total weight to be support from topside. The installation of fixed offshore platform mainly at the shallow water depth. However, these platforms cannot be used in extremely deep water; it simply is not economical to build legs that long (Sadeghi, 2007). In this research only, fixed offshore platform will be study for the decommissioning process.

FIGURE 2 TYPICAL FIXED PLATFORM (ICF INCORPORATED, 2015)

2.4 Cutting Technology

2.4.1 Abrasive water-jet cutting system

Abrasive water-jet cutting is a significant advance method used in cutting steel structure below mean water level. The Abrasive Water-Jet Systems consists of the cutting tool or manipulator to control the positioning and movement of the nozzle, the abrasive mixing or dispensing unit, high pressure water pump(s) and supporting hydraulic power unit, control panels and cut monitoring systems (Brandon, etc.al, 2000). Manipulator used for internal and external cutting of the conductor or pile. It is a remotely control system monitored at the surface station with the advance technology for stabilization during execution. The abrasive mixing used by either by direct injection or mix with the high-pressure water stream. This mixing will control water pressure system from surface through nozzles. The advantages from this method is environmentally save, remote operation and flexible cutting for any tubular diameter.

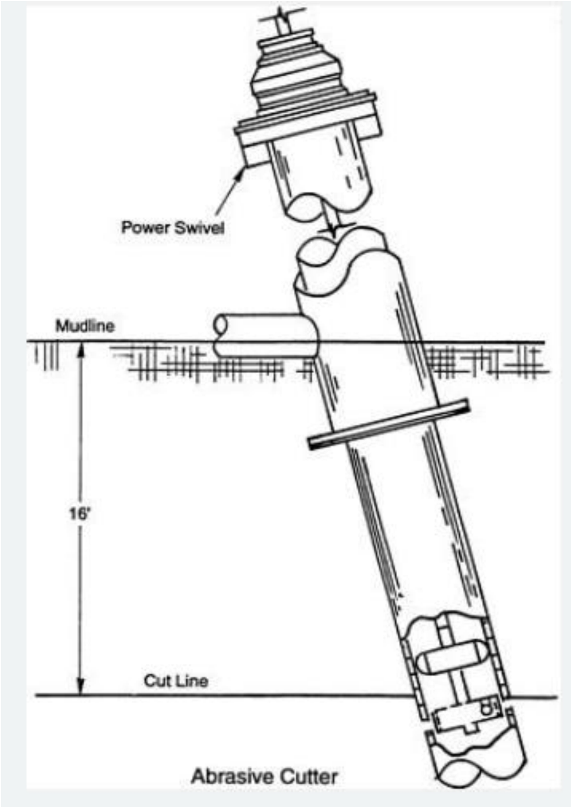


FIGURE 3 SCHEMATIC OF A MECHANICAL CUTTING SYSTEM (SNYDER & BYRD, 2004)

2.4.2 Diamond Wire Cutting System

The Diamond Wire Cutting System utilizes a series of remotely operated machines to perform external cutting operations on steel, concrete or composite materials (Brandon, etc.al, 2000). This system only significant to external cutting process. It is a hydraulic clamping machine that will cut by attached to the structure. The mechanical system implements to the machine in order to trigger a band saw effect of diamond embed wire with the controlled speed depend on the size of the structure. The advantages of this system are safe to operate by ROV machine or divers, no limitation in water depth and ability to cut a variety of materials with different size. Below is attached diamond wire cutting machine (Mokhtar, 2014).

FIGURE 4 DIAMOND WIRE SYSTEM (SNYDER & BYRD, 2004)

2.4.3 Diver Torch Method

In this method, the cutting process will be executed by the divers underwater. In underwater arc cutting, an outside jet of oxygen and compressed air is needed to keep the water from the vicinity of the metal being cut. A tube around the torch tip uses air and gas pressure to create a gas pocket (Byrd&Synder, 2004). The mechanism used in cutting method is by heat cutting under high air pressure. It only efficient for shallow water depth decommissioning project because of the limitation of divers to execute. In addition, diver cuts usually cost far more than other cutting technology and the risk involved to the diver – especially in deep water – makes torch cutting generally less attractive than other removal options (Morrice, 1997). Below is attached the schematic of a diver cutting pile or small caisson.

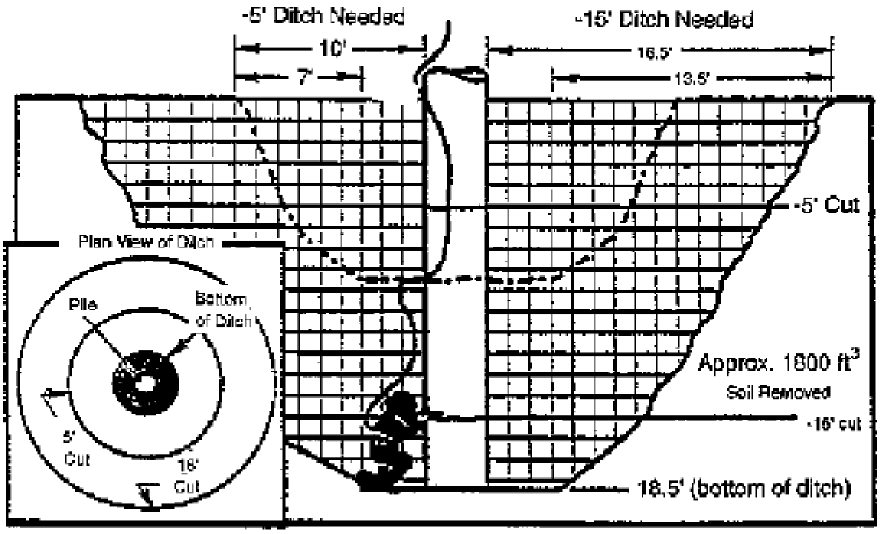


FIGURE 5 SCHEMATIC OF A DIVER EXTERNALLY CUTTING A PILE OR SMALL CAISSON (SNYDER&BYRD, 2004)

2.5 Structural Integrity

Structural integrity is the ability of a structure to perform its required function effectively and efficiently over a defined time period whilst protecting health, safety and the environment (HSE, 2009). The structural integrity is fatal consideration during cutting proses of structure in order to determine failure members. Fixed offshore platforms supported by pile foundations are required to resist dynamic lateral loading due to wave forces (Mostafa&Naggar, 2003). In single lifting of cutting section, structure shall be able to withstand the environment load imposed on it. Thus, safe cutting section has to be implement during offshore decommissioning to avoid any structural integrity failure. In order to analyse the structural integrity, pushover analysis has to be done. One method of identifying the most dominant failure path is by lifting analysis. Hence to ensure the safety method to be used for cutting, the structural integrity need to analyse by using pushover analysis.

2.6 Decommissioning Cost

Decommissioning cost is the major expenditure at the end of the design life for structure. High estimated cost for decommissioning must be consider during initial engineering and construction of an offshore economic analysis. There are several factors affecting decommissioning cost like decommissioning design, manpower, technology and et.al. However, Costs can be reduced during the actual decommissioning work by the contracting strategy, use of previous experience and new technology (Stokes, 2014). Based on the previous experience, the removal of platform can be done by single lifting and section lifting. These two options will give huge different in decommissioning cost as it need different technology, manpower and time consuming throughout the process. Normally the heavier the object, the larger the cost saving (Andresen, 2004). The disposal of offshore structure mainly done at the onshore as it will be transport in single lift from the offshore. Reduction of manpower and time consuming needed will enhance the overall decommissioning cost. Below is attached the cash flow for a North Sea Oil Field (Stokes, 2014).

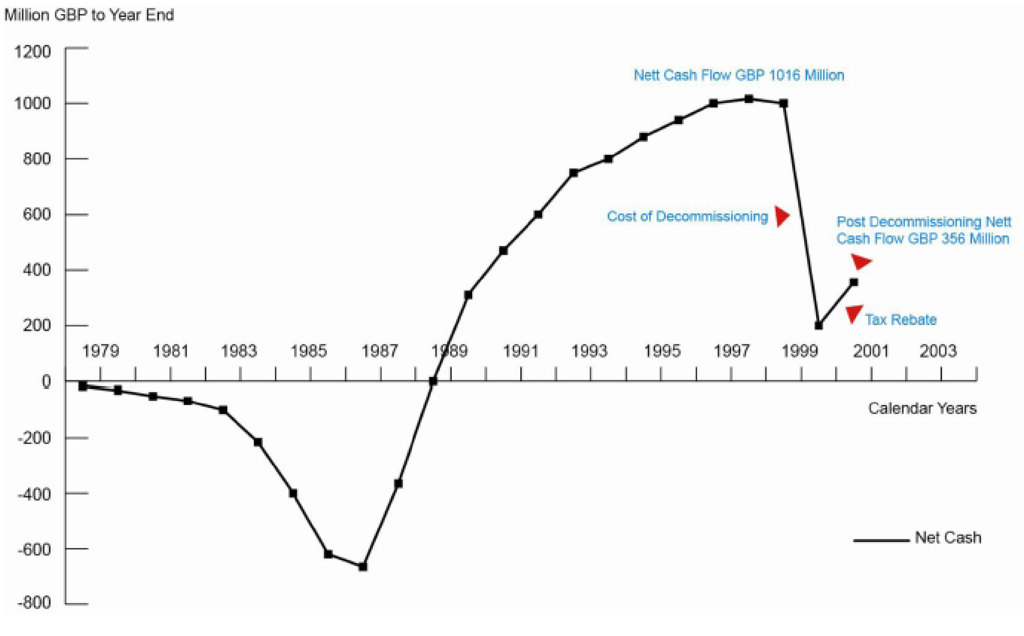


FIGURE 6 CASH FLOW NORTH SEA OIL FIELD (STOKES, 2014)

2.7 Environmental Impact

Environmental impact factor takes into consideration in decommissioning offshore because of the marine habitats underwater. Because oil and gas structures concentrate fishes in high numbers and those individuals tend to remain very close to the structures, explosive removal will continue to kill fishes as abandonment programs progress (Continental Shelf Associates, 2003). The non-explosive method will be focus in this paper in order to avoid any injuries to the marine life. Beside the emission of harmful gas from burning cutting method will affect the marine life. Emission of primarily CO_2, but also smaller quantities of CO, NO_x, SO_x, and VOC, occur during fuel combustion in the vessel used for cutting, lifting, and transportation (Oil&Gas UK, 2012). This factor is fatal to consider in order to maintain the marine ecosystem.

CHAPTER 3

METHODOLOGY

3.1 General Methodology

The methodology used in this research is by documentary analysis which is analysis based on the existing data to achieve objectives stated. Data collected from literature review are based on previous study and research to be extract for improvement in quality of result. Here is the process flow for research methodology:

1. Data collection.

   All the data are collected from previous study and research paper about fixed offshore decommissioning in term of cost, technology used for cutting method and environmental impact.

2. Evaluate

   Data collected in literature review is evaluate based on the efficient technology used for cutting method in fixed offshore decommissioning. The selected technology will be focus and improvise in further research to achieve the objectives stated for this paper. The improvement data is based on the method used in cutting technology.

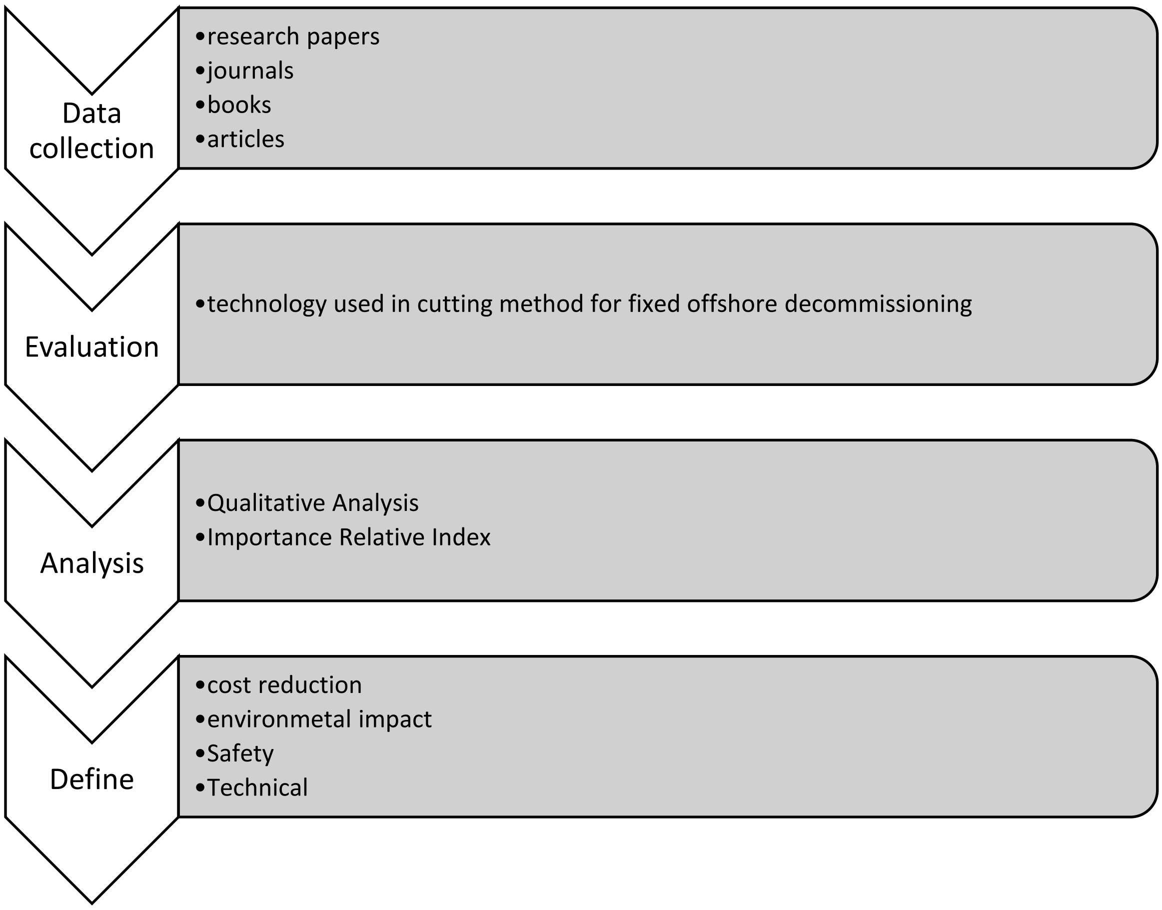
3. Analyse

   The evaluated data will undergo several analyses to be done for the assessment. The analysis used is Best Practicable Environmental Options (BPEO) and Importance Relative Index. The results will be recorded and conclude at the end of this paper.

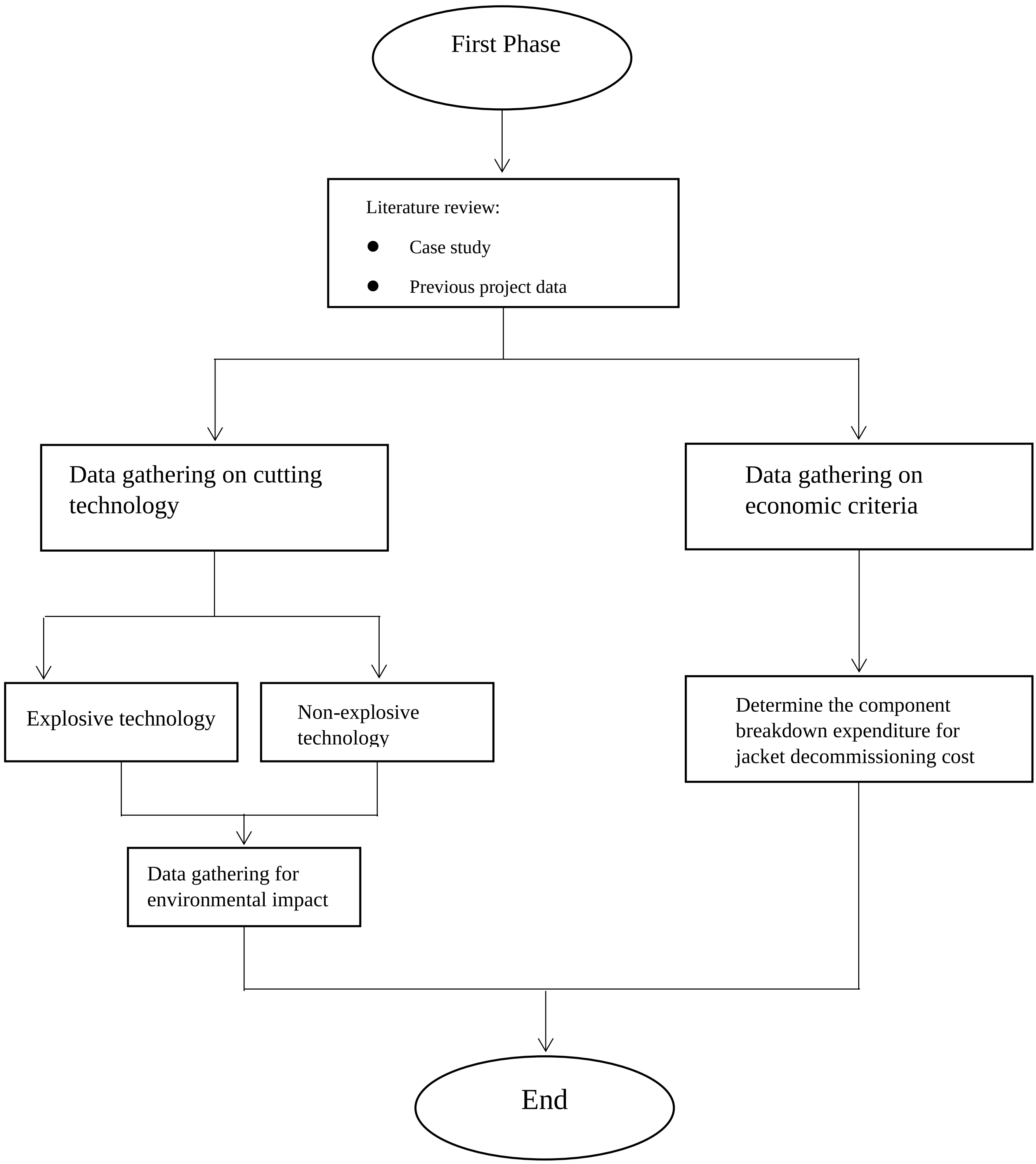
4. Define

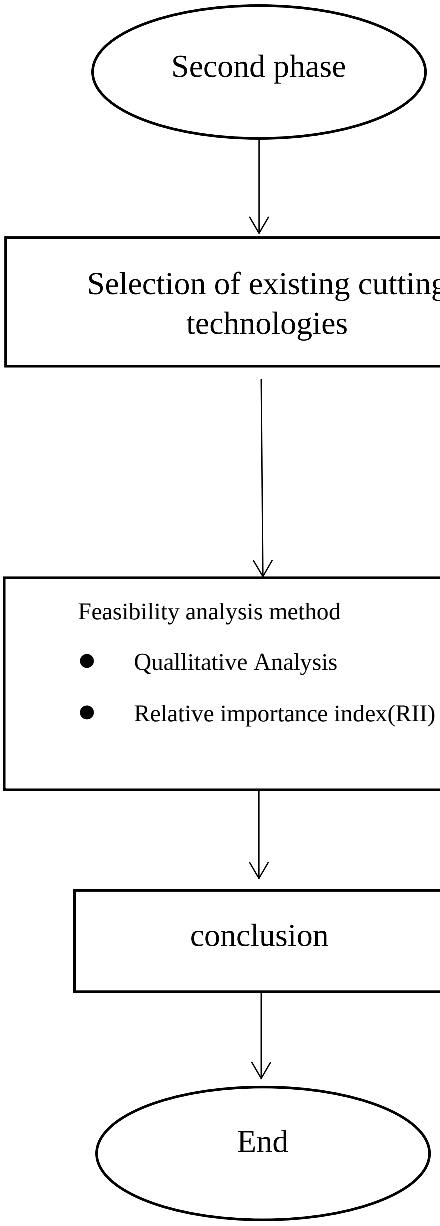
   This is the last part in methodology where the data is defined in term of cost, technical, safety and environmental impact. The reduction or increment value in cost for overall cutting cost will be reviewed to make a conclusion based on the objectives stated.

3.2 Workflow


Data collection
•research papers
•journals
•books
•articles
Evaluation
•technology used in cutting method for fixed offshore decommissioning
Analysis
•Qualitative Analysis
•Importance Relative Index
Define
•cost reduction
•environmetal impact
•Safety
•Technical

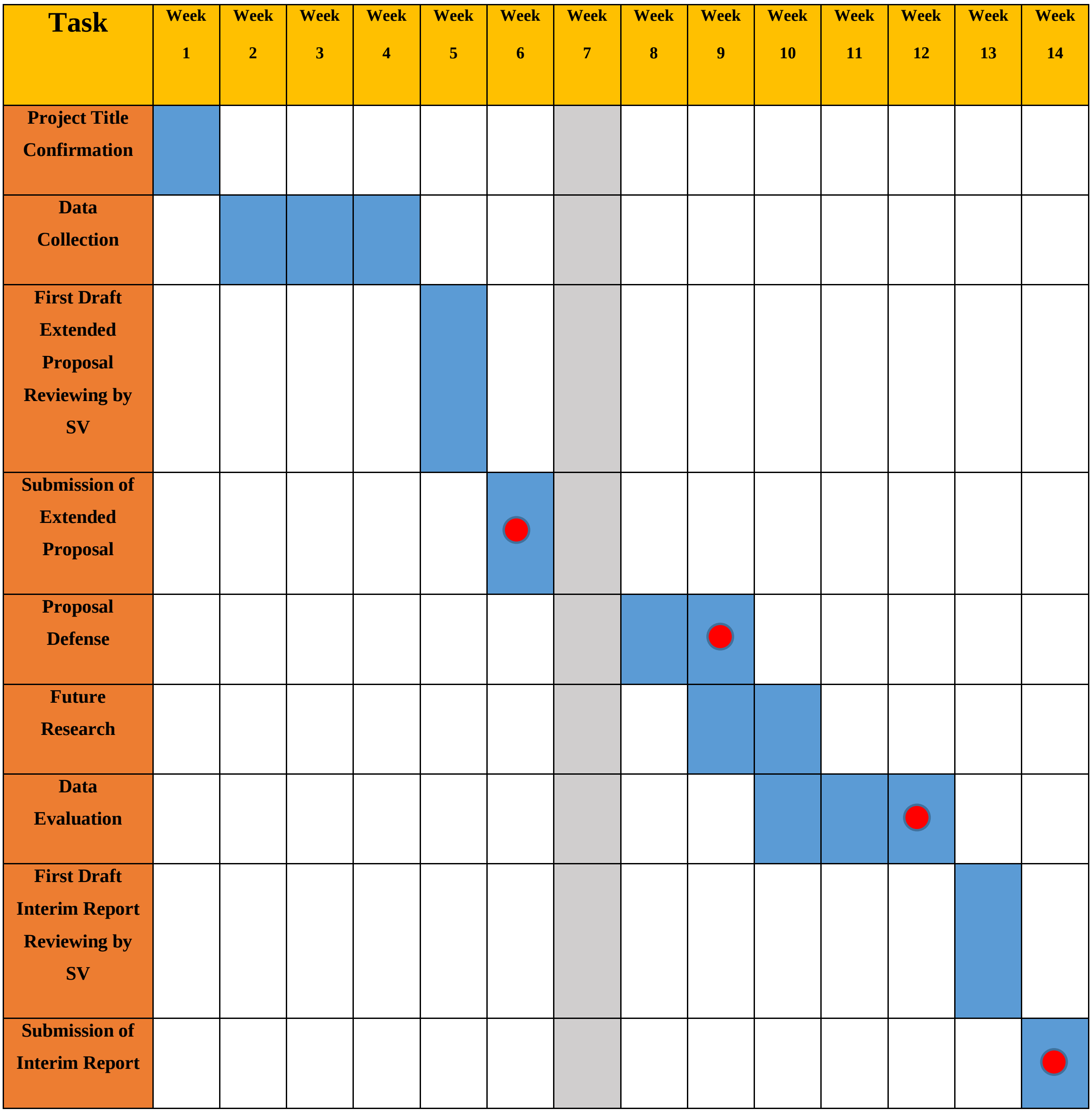
3.3 Methodology




Second phase
Selection of existing cutting technologies
Feasibility analysis method
Quallitative Analysis
Relative importance index(RII)
conclusion
End

3.3 Gant Chart

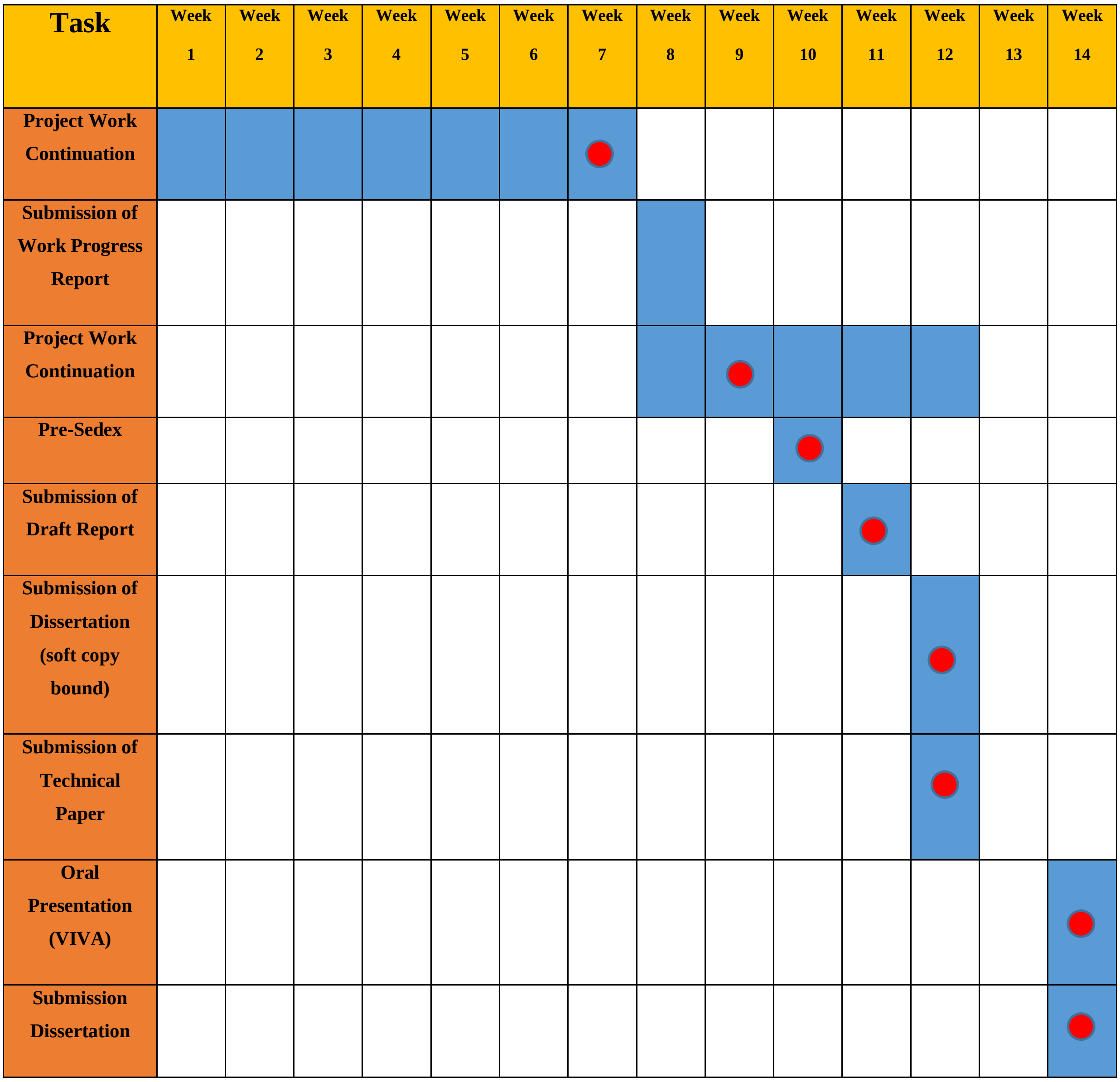
3.3.1 FYP 1 Gant Chart



Key milestone

Gant Chart

3.3.2 FYP 2 Gant Chart



Key milestone

Gant Chart

Chapter 4

RESULT AND DISCUSSION

This section compromise into the factors on the selection of cutting technology above seabed: **(i)** cost **(ii)** technical **(iii)** safety **(iv)** environmental effect. The cutting technology only focus on the non-explosive method which apply to the offshore fixed platform in Malaysia.

4.1 Cost Summary

The cost involve in conductor removal or jacket removal is about 8% from overall cost for decommissioning as the figure (7) below. The selection of technology used for cutting the conductor will give huge impact on the conductor removal cost. Usually in decommissioning project, cutting work will be done by subcontractor or third party to carry out non-core activities. The operator can manage decommissioning within the company or contract out the requirements to a third party which specializes in project management or provides decommissioning management as part of an integrated service package (Kaiser&Byrd, 2005). The strategy used by the operator to ensure the decommissioning project flow smoothly and reduce time to carry out specific work plan.

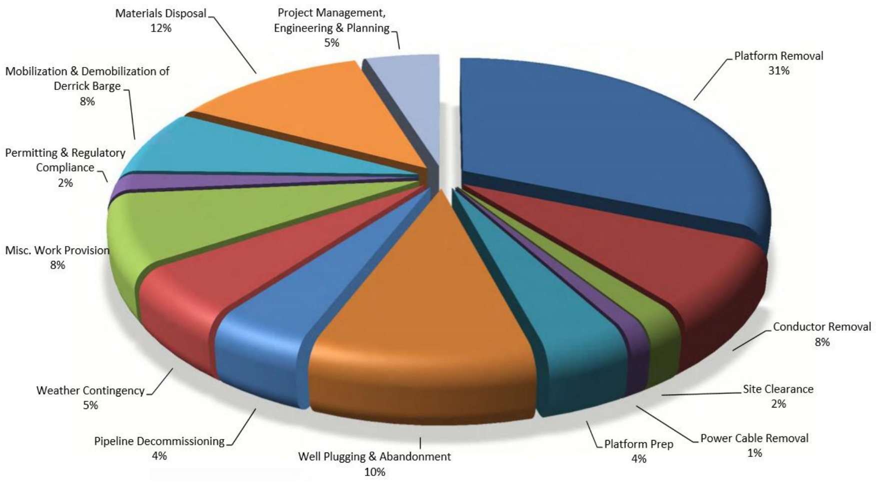


FIGURE 7 DECOMMISSIONING COST PERCENTAGE BY CATEGORY (TSB OFFSHORE, INC.)

Normally, lump sum bid for cutting work is offer to the contractor where they responsible to furnish all the labour, equipment and materials. The total cost for cutting work determine by number of cutting, conductor diameter and water depth as shown in the figure (8) and figure (9). Each cutting technology in market give different overall cost for cutting work as the time taken for cutting work is different. In general characteristic of service contract, it to be split to two cost which are fixed cost and variable cost. Fixed cost is those that do not vary with the service provided while variable cost result from the cost incurred when service is requested (Kaiser, etc., 2005). The cost breakdown for each technology is stated below:

Platform	Water Depth	Conductor Count	Conductor Length (ft)	Total Conductor Length (ft)	Removal Cost w/ Casing Jacks (USD)
A	188	55	268	14,740	$4,461,149
B	190	57	270	15,390	$4,646,643
C	192	43	272	11,696	$3,608,703
Edith	161	23	241	5,543	$1,757,793
Ellen	265	63	345	21,735	$6,280,334
Elly	257	0	0	0	$0
Eureka	700	50	780	39,000	$10,538,628
Gail	739	27	819	22,113	$6,123,643
Gilda	205	64	285	18,240	$5,505,252
Gina	95	12	175	2,100	$819,314
Grace	318	36	398	14,328	$4,238,620
Habitat	29	20	370	7,400	$2,297,302
Harmony	1,198	52	1,278	66,456	$18,183,128
Harvest	675	25	755	18,875	$5,319,490
Henry	173	24	253	6,072	$1,965,108
Heritage	1,075	49	1,155	56,595	$15,542,468
Hermosa	603	16	683	10,928	$3,177,260
Hidalgo	430	14	510	7,140	$2,188,946
Hillhouse	192	52	272	14,144	$4,330,534
Hogan	154	39	234	9,126	$2,906,310
Hondo	842	28	922	25,816	$7,252,563
Houchin	163	35	243	8,505	$2,706,725
Irene	242	26	322	8,372	$2,621,044
Totals	-	**810**		**404,314**	**$116,470,957**

FIGURE 8 CONDUCTOR REMOVAL COST (TSB OFFSHORE, INC.)

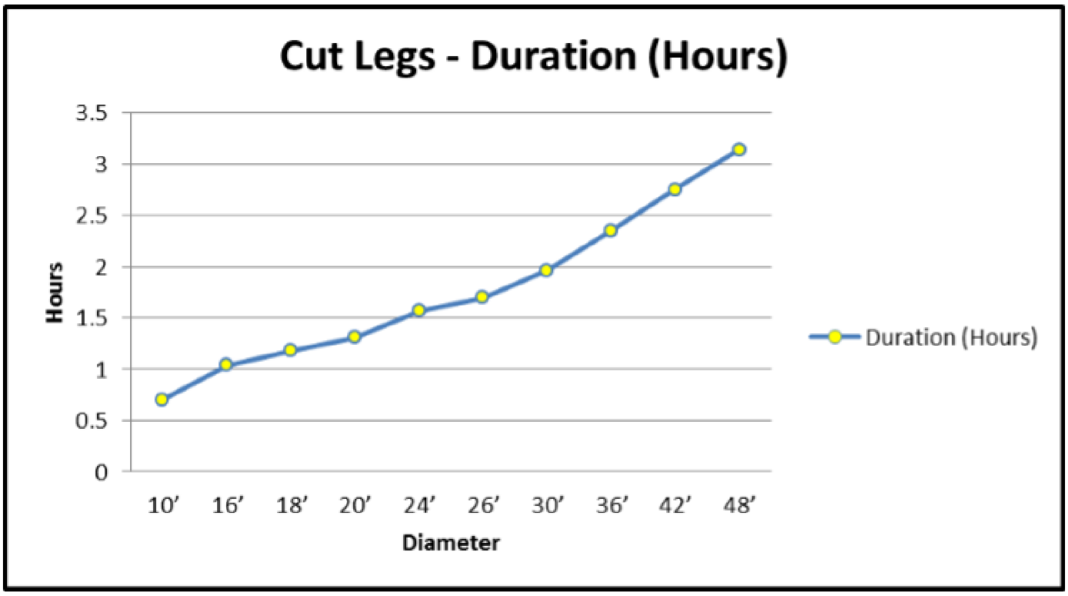


FIGURE 9 DECK LEG CUTTING DURATION (TSB OFFSHORE, INC.)

4.1.1 Abrasive Water Jet (AWJ)

Estimation of AWJ cost in cutting work can be determine by several elements with the time and material basis take into consideration (Kaiser, etc., 2005):

- Mobilization/Demobilization to/from dock site(s)
- Equipment
- Price per cut
- Personnel
- Equipment standby onshore
- Personnel standby onshore
- Idle time
- Document preparation

Different contractor provides different configuration charge to the operator. Charge upon the diver to operate cutting service is calculated as personnel charged on a per-day basis. Usually for AWJ maintain a 3-4-person crew per 24-h shift (Kaiser, etc., 2005). subcontractor will provide 24-h service availability. The cost per day for AWJ cutting is on the order of $10,000/day regardless of the job type (Kaiser, etc., 2005).

4.1.2 Diamond Wire

Estimation cost element for diamond wire is like the AWJ cutting work where the different charge is upon several elements due to the execution of technology used. The annual market value for mechanical/sand cutting operations is in the order of $400,000-$600,000 per year (Kaiser, etc., 2005).

4.1.3 Diver Torch

Divers who are working in offshore decommissioning can categorized into two which are air divers and saturation divers. Saturation divers usually deal in deep water where they will stay in the chambers. These divers use special tools for cutting where it increases the cost for cutting job. A lot of manpower needed to employee where the minimum number allowed for divers is four but extra two divers is needed for worst case.

4.1.3 Cost Comparison between Technologies

The early cost comparison is determined through the terms of contract where the portion come from the subcontractor. The values are inclusive the fixed cost and all the variable cost of decommissioning Gulf of Mexico operation. Table below show the typical abrasive and diamond wire contract parameters for Gulf of Mexico service subcontractors (Kaiser, etc., 2005):

TABLE 1 TYPICAL ABRASIVE AND DIAMOND WIRE CONTRACT PARAMETERS (KAISER, ETC., 2005)

Contract parameter	Abrasive Water Jet ($1000)	Diamond wire ($1000)
Mobilization from dock site	6-10	7-8
Equipment /day	3-5	1-3
Price per cut	1-3	1.5-3.5
Equipment standby onshore /day	3-4	1-2
Personnel standby onshore	2-3	0.75-1.25
Idle time /day	0.3-0.5	1-2
Equipment testing /test	1-3	1.5-3.5
Document preparation	3-5	3-4

From the data taken, we can make cost comparison in some of the parameters involved based on current currency of 4.2 USD per MYR. The inflation rate (CPI) in Mexico used is 3.36 for 2016 and 3.33 in 2005. The present cost will be calculate based on the formula below:

Price in 2016 = price in 2005 × $\frac{cpi\ 2016}{cpi\ 2005}$

TABLE 2 HISTORIC INFLATION MEXICO - CPI INFLATION

Year	Inflation rate (CPI)
2005	3.33
2006	4.05
2007	3.76
2008	6.53
2009	3.57
2010	4.4
2011	3.82
2012	3.57
2013	3.97
2014	4.08
2015	2.13
2016	3.36

TABLE 3 COST SUMMARY IN 2005

Cost parameter	Abrasive water jet (MYR)	Diamond wire (MYR)
Equipment/day	12,600-21,000	4,200-12,600
Personnel standby/day	8,400-12,600	3,150-5,250
Mobilization from dock site	25,200-42,000	29,400-33,600
Total cost/day	46,200-75,600	36,750-51,450

TABLE 4 COST SUMMARY IN 2016

Cost parameter	Abrasive water jet (MYR)	Diamond wire (MYR)	Diver Torch (MYR)
Equipment/day	12,713-2,1189	4,238-12,713	11,000-25,000
Personnel standby/day	8,476-1,2713	3,178-5,297	20,000-28,000
Mobilization from dock site	25,427-42,378	29,665-33,902	18,000-26,000
Total cost/day	46,616-76,280	37081-51912	49,000-79,000
Average Total cost/day	61,448	44,497	64,000

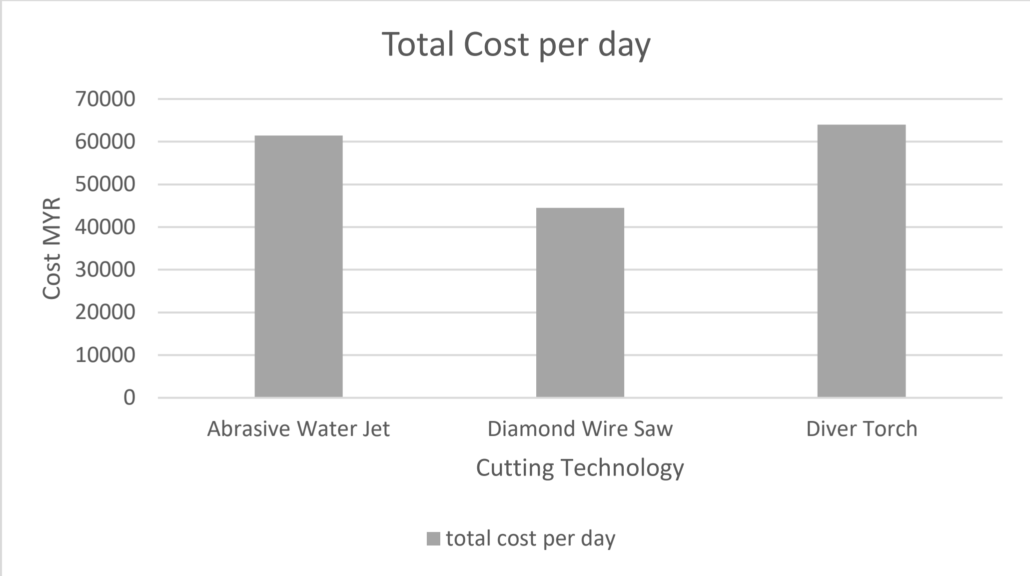


FIGURE 10 TOTAL COST OF CUTTING TECHNOLOGY PER DAY

TABLE 5 COST SUMMARY

Cost Aspect	Technology	Cost level
Total Cost per Day	Abrasive Water Jet	5 (Fair)
	Diamond Wire Saw	8 (Excellent)
	Diver Torch	4 (Bad)

Based on the comparison in the table, the diamond wire technology is cheaper compare to the abrasive water jet and manual divers. This assumption made for a single cut, in a day and the same decommissioning project. The cost data based on direct cost in cutting works. Water depth and diameter of member factors will give huge different to the values. Hence, accurate values for the cost of these technology is depend on the subcontractor and project management on how they deal with the price.

4.2 Technical summary

TABLE 6 TECHNICAL SUMMARY

Technical aspect	Technology	Remarks	Technical level
Cutting Finishing	Abrasive Water Jet	Has good cutting finishing as the high abrasive pressure create smooth cutting process	8 (Excellent)
	Diamond Wire Saw	Good cutting finishing with less efficient due to the diamond embedded diamond condition	7 (Good)
	Diver Torch	Totally depend on the diver's skill	5 (Fair)
Difficulty	Abrasive Water Jet	Difficult to operate as the equipment is big and need proper handling on the abrasive mixture	6 (Good)
	Diamond Wire Saw	Easy to install and operate underwater	9 (Excellent)
	Diver Torch	Limitation of divers to work alone and need extra equipment to operate	6 (Good)
Water depth	Abrasive Water Jet	Can install and operate more than 100m water depth	8 (Excellent)
	Diamond Wire Saw	Can install and operate more than 100m water depth	7 (Good)
	Diver Torch	Only applicable in shallow water depth	4 (Fair)

Cutting range (diameter)	Abrasive Water Jet	More than 1.5m internal and external cutting	9 (Excellent)
	Diamond Wire Saw	More than 1.2m external cutting	8 (Excellent)
	Diver Torch	Less than 0.8 m external cutting	5 (Fair)

4.2.1 Abrasive water jet

AWJ technology is used for offshore decommissioning since 80's centuries. The incisive penetrating cutting action of AWJ is suitable for both surface and subsea application (Oil States MCS LTD). Clean cut for any conductor member is assure with a proper handle of the equipment and planning. The abrasive mixer units, which designed, built, maintained and operated exclusively are rated to a pressure more than 1000 bar or 14500 psi (Oil States MCS LTD). The flexibility of this technology can operate internal and external cutting up to 1-6 meter below mudline. In addition, AWJ performs in out-of-round tubulars and transitional changes in diameter with the range of six inches to 84 inches and 18 inches internal cutting (Brandon, etc.al, 2000). Current technology of AWJ can be operate using ROV and monitor through computer where is no water depth limitation.

4.2.2 Diamond wire cutting

Diamond wire technology is being develop day by day to increase the function. This technology is flexible to cut diameter depending on the project requirement, the materials selection and design can be made to optimize the machine with respect to weight and sizes (Brandon, etc.al, 2000). to execute diamond wire can be done either by ROV or manually by diver. Diver will clamp the machine to the cutting section below mean water level while ROV is monitor from the topside. The process of execution of diamond wire is depending on the project requirement as the charge from contractor is vary. Currently, diamond wire tooling is available and proven for subsea cuts up to a maximum diameter of three metres (120 inches), but this does require significant access around the site for the cutting package itself (Oil States MCS LTD). It is can cut up to the deep-water depth range which is about 1000 metres.

4.2.3 Diver Torch

Manual divers need to perform underwater cutting requires several equipment where it mostly applicable in shallow water. Dive vessel used to support dive crew from water surface and transportation. While performing under water cutting, divers must be supported by ROV and positioning equipment such as GPS. Furthermore, severing work is by burning torch manually handle by divers. Cutting finishing is hard to determine as it depend on the divers cutting tools and credibility.

4.3 Safety summary

TABLE 7 SAFETY SUMMARY

Safety aspect	Technology	Remarks	Safety level
Personnel	Abrasive Water Jet	Safely operate under ROV	9 (Excellent)
	Diamond Wire Saw	Installation by diver for clamping and operate automatically	7 (Good)
	Diver Torch	Full risk on the personnel	3 (Bad)

4.3.1 Abrasive water jet

In few decade of decommissioning offshore platform, abrasive water jet technology has seen moderately practice as non-explosive method for cutting work. It is important to realize the development in abrasive methods, especially in water jet cutting which is a remotely operated vehicle (Suni, 2017). The cutting tools is connected to the surface control equipment and deployed from vessel crane into the water. ROV pilot controlled from the top to align the cutting tool for clamping it in position. Once installed, the cutting tools will perform its remote operation. The safety consideration in this technology is while lifting the equipment inside the water. There are no divers needed for this cutting technology.

4.3.2 Diamond wire saw

Diamond wire technology used similar concept as abrasive water jet where it is remote control at the topside. It relates to umbilical wire and running by hydraulic power. Uniqueness of this technology is designed for auto adjust auto feed system. The wire tension control can be adjusted and automatically matching the speed rate. The manpower needed to run this technology is only at the topside. Hence less safety precaution needed for diamond wire saw technology.

4.3.3 Diver Torch

Commercial divers can be categorised into two which are air divers and saturation divers. Air divers usually work on the deck while saturation divers are underwater. In normal cutting job, 4-6 divers needed as divers cannot withstand the water pressure in a long time. They need to shift working from time to time. Only qualified divers are hired to do underwater cutting as the need to handle torch machine for cutting. It is the riskiest job for cutting technology below sea bed as it operates manually by human.

4.4 Environment summary

TABLE 8 ENVIRONMENT SUMMARY

Environment aspect	Technology	Remarks	Environment level
Discharge to sea	Abrasive Water Jet	carbon concentration residue	7 (Good)
	Diamond Wire Saw	carbon concentration residue	8 (Excellent)
	Diver Torch	Hot cutting release harmful gas	5 (Fair)
Underwater noise	Abrasive Water Jet	Loud noise underwater from pressure created	5 (Fair)
	Diamond Wire Saw	Loud noise from friction process during cutting	4 (Fair)
	Diver Torch	Silent cutting process	6 (Good)

4.4.1 Abrasive water jet

Abrasive water jet commonly used in pile and conductor cutting in decommissioning offshore. Normally, process of pile cutting using this technology will create a loud noise in the water or noise pollution. In other word, it creates seabed disturbance in physical. Fouling of sediments and potential smothering of benthic communities and habitat because of redistribution the cutting pile across a large area of seabed (study of management). Besides, discharge to sea is measured as environmental pollution due to cutting process in decommissioning. The cutting residue such as carbon concentration to the sea has potential impact for marine species and water quality.

4.4.2 Diamond wire

Diamond wire mechanism is close to the abrasive water jet. The noise pollution is louder than abrasive water jet as it is using mechanical cutting. The friction between diamond wire saw will create loud noise depend on conductor diameter and wall thickness. The residual discharge is crucial in diamond wire technology as it create lot of carbon residual from frictional process.

4.4.3 Diver Torch

Divers use hot cutting mechanism in offshore decommissioning. The main consideration in this technology is amount of discharge to sea. The use of hazard chemical in this process give huge impact to environmental. In sea bed disturbance measure, the environmental aspect relate to this technology is present of dropped object during offshore decommissioning. It can affect marine habitat on the seabed in physical accident.

4.5 Result

4.5.1 BPEO Analysis

Based on the BPEO analysis on technical, safety, cost and environment factors, ranking analysis of the technologies is shown below:

TABLE 9 RANKING TABLE

	Score					
Technology	Technical	Safety	Environmental	cost	Total	Ranking
Diamond wire	31	7	12	8	58	1
Abrasive water jet	31	9	12	5	57	2
Diver Torch	20	3	11	4	34	3

The marks of each factor are direct sum of the breakdown score in Qualitative table and total score is sum of the total factors scores. The ranking is sort by the highest score to the lowest. Hence the best cutting technology to be used in cutting works is diamond wire saw based on safety, technical, cost and environment factors.

4.6 Cost Reduction analysis

In cost reduction analysis, it has been calculated from case study on a platform in Malaysia. In this case study, several technologies are selected for the cutting section and the total cost are calculated on each case. Besides, the constant variable is set for 2 cutting sections on 36 inches member diameter with the water depth less than 100m. As National Academy of Science, 2017 stated the cutting duration data for each technology is shown in the table below. In addition, the contingencies for cutting technology is 100% where the number of cutting tools is double. Hence, total cost for each case is calculated based on price per technology per day, total duration for cutting, number of technology used and number of cutting members. Below are the details of the platform:

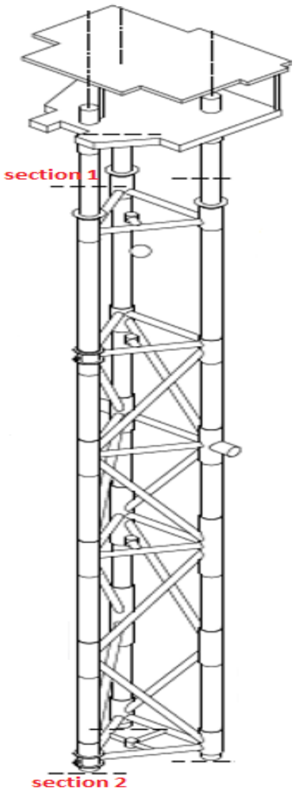


FIGURE 11 PLATFORM A

TABLE 10 PLATFORM A DETAILS

	Section 1	Section 2
Member size (inch)	36	36
Number of members	3	3
Elevation from Mean Water Level (m)	+10	-50

TABLE 11 CUTTING TECHNOLOGY DURATION

Technology	Member size	Cutting duration
Abrasive water jet	48 inches	2.5 h
Diamond wire	42 inches	1.25 h
Diver torch	48 inches	<4 h

4.2.1 Actual Case

From the actual case, the cutting section is 2 and the elevation are +10m and -50 from mean sea level. The technology used are Abrasive Water Jet and Diver Torch for the cutting works. The cost data is taken from table 4 and cost calculation is shown below:

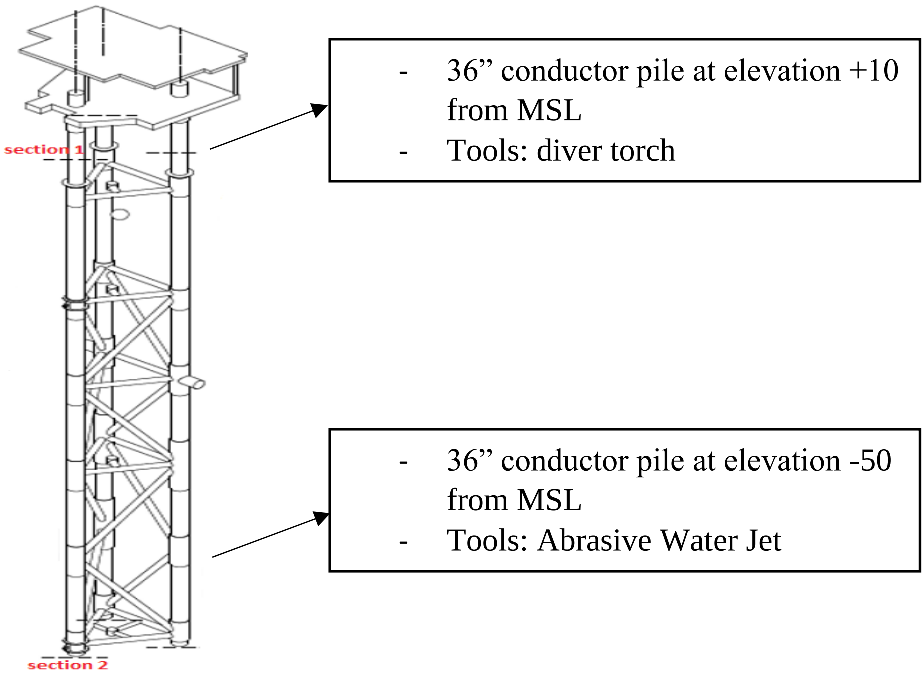


TABLE 12 ACTUAL CASE SUMMARY

Jacket structure	Number cutting	Cutting duration (hour)	Number of tools	Cost/day (RM)
Section 1 (Diver)	3	12 (two days)	4	128000
Section 2 (AWJ)	3	7.5	2	122,896
Total	6	19.5	2+4 divers	250896

4.2.2 Case A

The cutting section for case A is fix as the actual case where the tools or technology used only Abrasive Water Jet. The cost calculation shown in the table below:

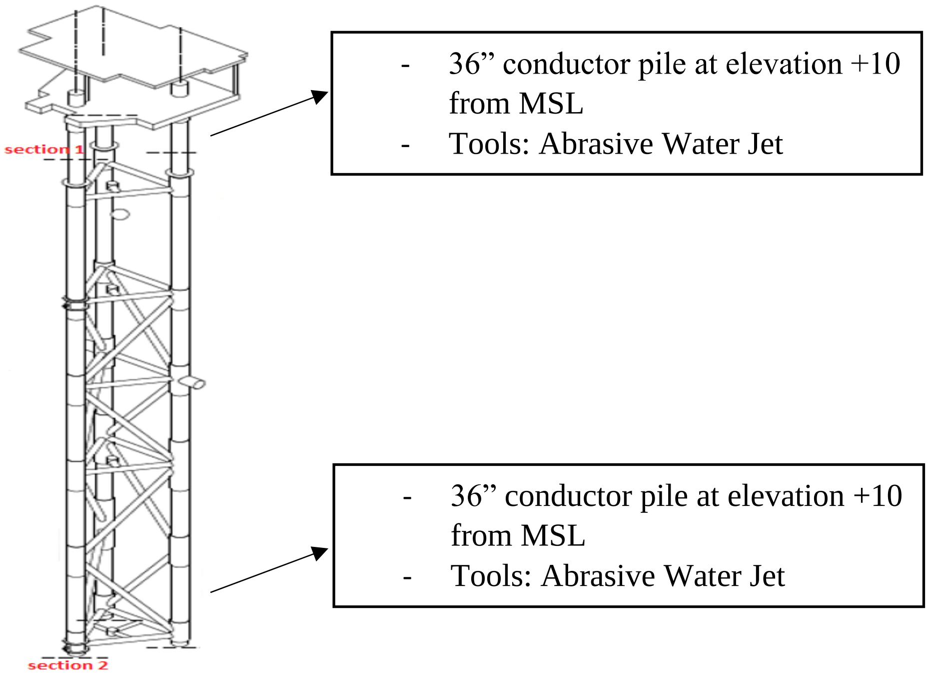


TABLE 13 CASE A SUMMARY

Jacket structure	Number cutting	Cutting duration (hour)	Number of tools	Cost/day (RM)
Section 1	3	7.5	2	122,896
Section 2	3	7.5	2	122,896
Total	6	15	4	245,792

4.2.3 Case B

In case B, the technology or tools used is Diamond Wire Saw only. The cost calculation is shown below:

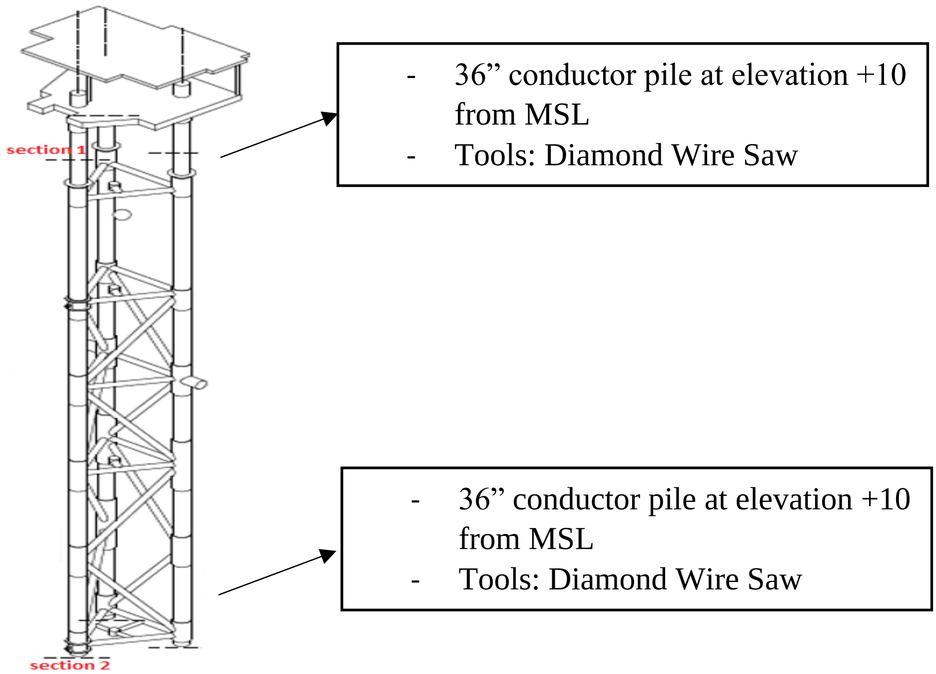


TABLE 14 CASE B SUMMARY

Jacket structure	Number cutting	Cutting duration (hour)	Number of tools	Cost/day (RM)
Section 1	3	3.75	2	88,994
Section 2	3	3.75	2	88,994
Total	6	7.5	4	177,988

4.2.4 Case C

In this case, the technology or tools used are Diver Torch and Diamond Wire Saw. The cost calculation is shown below:

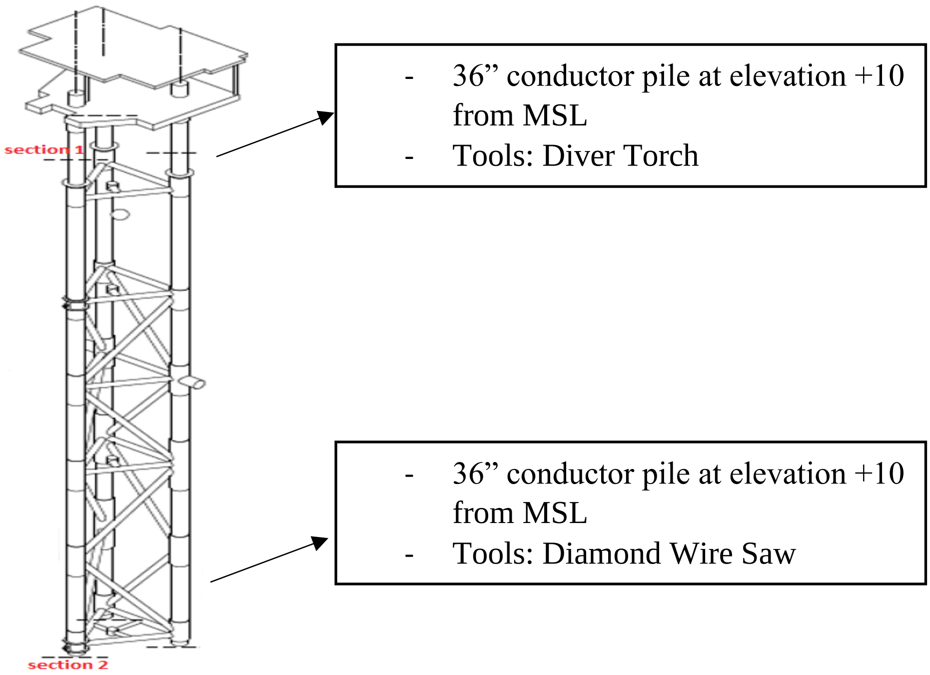


TABLE 15 CASE C SUMMARY

Jacket structure	Number cutting	Cutting duration (hour)	Number of tools	Cost/day (RM)
Section 1 (Diver)	3	12 (two days)	4	128000
Section 2 (DWS)	3	3.75	2	88,994
Total	6	15.75	2+4 divers	216994

4.2.5 Cost Comparison

The total cost per day for each case is compare and tabulated in the table and chart below. From the data calculated, the lowest cost is Case B which is RM 177,988 compare to the Actual Cost Case which is RM 250,896. Thus, the cost reduction for the Case B is about 29% from actual cost. Below is the calculation for the cost reduction analysis:

TABLE 16 COST COMPARISON BETWEEN CASES

Case	Cost/day (RM)
Actual	250,896
A	245,792
B	177,988
C	216994

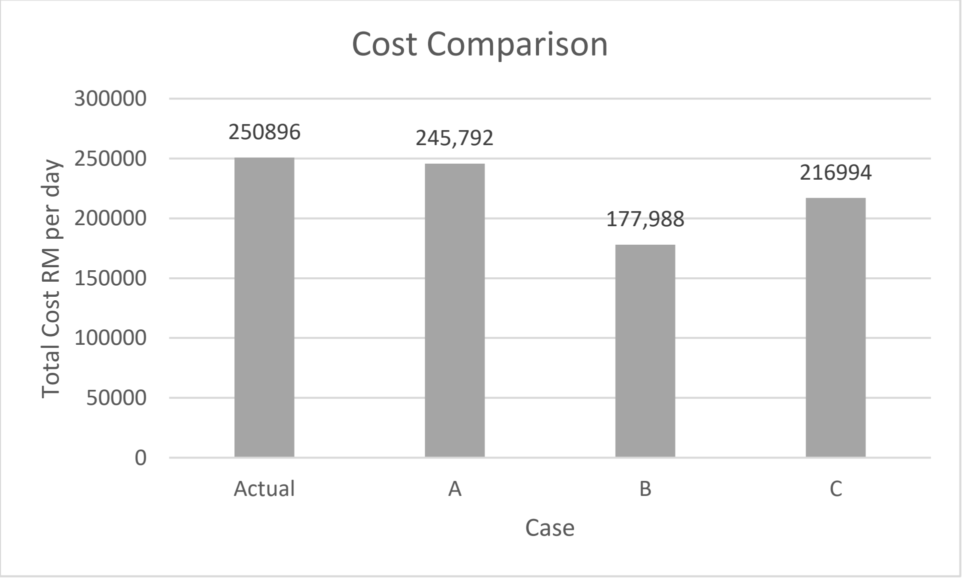


FIGURE 12 COST COMPARISON BETWEEN CASES

Calculation:

Actual cost = RM 250,896

Case B cost = RM 177,988

Cost difference = Actual cost – Case C cost

= RM 72908

Percentage difference = $Cost\ difference\ Actual\ Cost$ × 100

= 72908/250896 × 100

=29%

CHAPTER 5

CONCLUSION

Decommissioning of offshore structure is an important issue that requires careful consideration during planning phase in a project. High expenditure cost for decommissioning need to be allocated in economic analysis at the end of the design life. The cost reduction for offshore decommissioning can be reduced by reduction in cutting cost. Referring to the discussion and analysis above, the recommended cutting technology is Diamond Wire Saw in terms of safety, cost, technical and environment.

The cost reduction is compared between several cases on a platform with the actual case and the cost reduction take about 29%. Thus, the cost reduction for cutting technology above seabed is by using Diamond Wire Saw. In conclusion, all the objectives stated in this paper are achieved to explore cutting technologies feasibility and select the best cutting technology for cost reduction.

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