SCREENING METHODOLOGY FOR SEISMIC RISK ASSESSMENT OF STRUCTURES IN OIL & GAS PLANTS

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A project report submitted in partial fulfillment of the requirements for the award of Master of Engineering (Mechanical)

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DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

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ABSTRACT

With the issuance of Malaysian National Annex 2017 as a part of MS EN 1998-1:2015, the seismic mapping of Malaysian Peninsular including Sabah and Sarawak has undergone some changes in terms of the Peak Ground Acceleration (PGA) value. The revision to the PGA has raised concern on the safety of Oil and Gas onshore structures as these structures were not designed to accommodate the new PGA values which are much higher than the previous values used in the original design. In view of the high numbers of structures and buildings to be re-assessed, a risk assessment methodology has been developed to prioritize and rank the assets in terms of their criticality against the new seismic loading. To-date such risk assessment method for Oil and Gas onshore structures is lacking and it is the main intention of this project to devise the risk assessment methodology and finalize via Delphi Method, the scoring for the risk elements. The finalized risk assessment methodology and the values used to rank the risk elements are the result of years of relevant experience on the subject matter and in addition to the various rigorous discussions facilitated by the student, with the identified panel of experts in the industry. The risk scoring is mapped against the risk matrix (i.e. the Likelihood of Failure versus the Consequence of Failure) and hence, the overall risk for the assets can be obtained. The overall risk can be used to prioritize and optimize integrity assessment, repair and strengthening work against the new seismic mapping of the country.

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LIST OF SYMBOLS / ABBREVIATIONS

PGA	Peak Ground Acceleration
OBE	Operating Base Earthquake
SSE	Safe Shutdown Earthquake
ECA	Equipment Criticality Assessment
SCE	Safety Critical Elements
PSHA	Probabilistic Seismic Hazard Assessment
RVS	Rapid Visual Screening
LOF	Likelihood of Failure
COF	Consequence of Failure
PEAR	People, Environment, Asset and Reputation
PTS	PETRONAS Technical Standards
MS	Malaysia Standards
BS	British Standards
EN	Euro Codes Standards
ASCE	American Association of Civil Engineers
UBC	Uniform Building Code
FEMA	American Federal Emergency Management Agency
P.E.	Professional Engineer

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CHAPTER 1

INTRODUCTION

1.1 Problem Statement

The issuance of Malaysian National Annex 2017 as a part of MS EN 1998-1:2015 has seen some changes to the seismic mapping of Peninsular Malaysia, Sabah and Sarawak. The increase in the value of the Peak Ground Acceleration (PGA) throughout Malaysia has raised a concern on the integrity of Oil and Gas structures.

These structures were either not designed to sustain any earthquake or were designed to the previous PGA value which was lower than the current one as specified in the Malaysian National Annex 2017. Based on this concern, the problem statement is defined and require further study to find a solution to it. This dissertation is undertaken to find the required solution to the problem statement which can further be categorized into the following questionnaires:

1. What is the level of integrity of existing structures in Oil and Gas plants against the new seismic loading?

2. What is the impact of structural degradation on the integrity of aging structures against the new seismic loading?

3. Due to the large numbers of structures involved, what would be the best method to prioritize and rank these structures for further seismic assessment? This is important in order to optimize structural integrity assessment and any structural retrofitting work required.

1.2 Objectives of project

The objectives of the dissertation project are given as follows:

- To develop a screening methodology for seismic risk assessment, and risk ranking of existing structures in oil and gas plants (The established methodology is proposed to be published in PETRONAS Technical Guidelines (PTG) for seismic risk assessment of existing structures).
- To establish and finalize via Delphi Method, the weightage scoring for risk components and risk elements considered in the seismic risk assessment.

This dissertation project will deliver the followings:

- Visual screening method for existing structures based on the assessment of the elements that could pose risk to the structures.
- Risk ranking of various types of structures in the plant based on scoring method established and agreed via Delphi Method.
- Definition of various levels of risk (i.e. Low, Medium, High and Very High) with respect to the risk scoring.

1.3 Significance of project

By establishing the methodology and procedure for seismic risk assessment and risk ranking of existing structures, the plant owners can prioritize and optimize the maintenance and retrofitting work for the structures. All effort, resources and materials can be allocated and focused on high priority items to prevent failure of the structures in the event of an earthquake and hence prevent process safety incidents from happening (i.e. fire, blast, leakage of hydrocarbons, toxic gas release etc.).

1.4 Limitations of project

All structures in plant normally support pipes and equipment. The vulnerability of pipes and equipment supported by the structure will also form a risk to structural integrity in terms of product leakage, fire and blast hazard due to pipe and equipment failure. However, this risk will not be assessed and quantified for this project. Only the risk generated by the design and integrity of structures, will be assessed.

A spreadsheet is also being developed separately to embed all logarithms for calculation of risk scoring. The spreadsheet is required to facilitate the application of seismic risk assessment. Nevertheless the spreadsheet will not be included as a part of deliverables for this project. It is attached as for information only.

The range of scoring as given in Table 10, to define the 4 levels of risk (i.e. LOW, MEDIUM, HIGH and VERY HIGH) is given for information only. The purpose of sharing the scoring range is to share the indication on scoring distribution for various combinations of risk.

It should also be pointed out that, the screening assessment method developed from this project is mainly to be used for accessible assets. For inaccessible assets it is recommended to put the risk as VERY HIGH until a shut-down window can be allocated for further inspection and assessment.

CHAPTER 2

LITERATURE REVIEW

2.1 Review of relevant study and publication

Following the major earthquake (of 9.0 Richter scale) and tsunami that occurred off coast of Acheh Sumatra in 2004, The Boards of Engineers Malaysia (BEM) and the Institution of Engineers Malaysia (IEM) have proposed short term and long term measures to monitor and enhance seismic performance of buildings in the country.

These measures are given as below:

The 5 short-term measures to be taken by the government of Malaysia:

1. The need for more seismic monitoring stations
2. Instrumentation installation for measuring seismic response of structures
3. The need for seismic vulnerability studies for existing important structures
4. Review of current engineering design and construction standards and practices.
5. Site specific ground motions for design of structures with more than 7 stories of height.

The 5 long-term measures to be taken by the government of Malaysia:

1. Develop or adopt a suitable code of practice for seismic design.
2. Sensitive and important structures shall be checked for seismic vulnerability
3. Introduce earthquake engineering education curriculum in institutions of higher learning
4. Secure grant for earthquake engineering research including monitoring and risk assessment study
5. Continuous education in earthquake engineering

While the local authority and local building industry has initiated and taken appropriate actions on the assessment of residential and commercial buildings, the oil and gas industry in Malaysia is yet to take adequate action to address the above measures. This is mainly due to the unconfirmed Peak Ground Acceleration (PGA) values based on current trend of earthquake.

However in January 2018, The Department of Standards Malaysia which is under the purview of the Ministry of Energy, Science, Technology, Environment and Climate Change (MESTECC) has issued a revised seismic mapping for Malaysia. This seismic mapping is contained in the National Annex 2017 which is a part of MS EN 1998-1:2015 Standards. The revised mapping showed an increase on the Peak Ground Acceleration (PGA) especially around Niah and Bekenu area in Sarawak, from 0.075g originally to more than 0.075g. The seismic zone that was used in the previous design for Oil and Gas facilities is given in Fig. 1 below (courtesy of Uniform Building Code 1997) while the revised seismic mapping is given in Fig. 2 and Fig. 3 below (courtesy of MS EN 1998-1:2005: National Annex 2017).

ZONE	1	2A	2B	3	4
Z	0.075	0.15	0.20	0.30	0.40

Fig. 1: Zones of earthquake as used in previous design. Malaysia is sited within Zone 1.

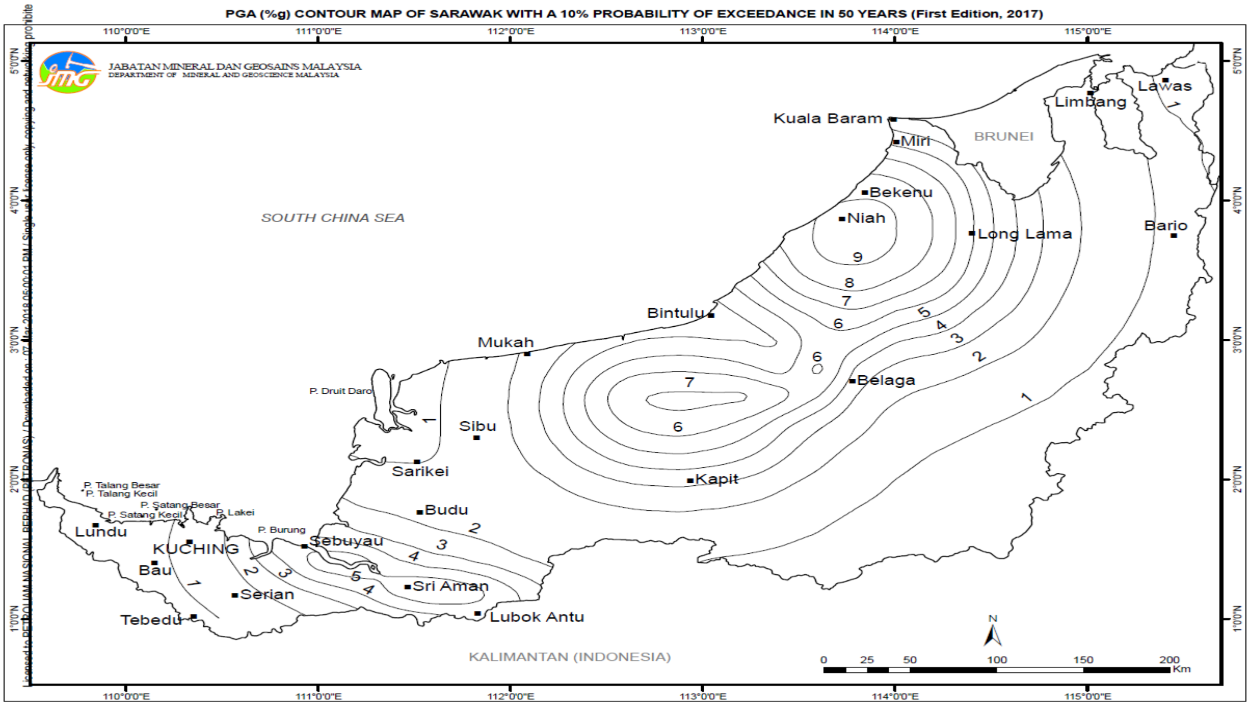

Fig. 2: Latest seismic mapping of Sarawak as given in MS EN 1998-1:2015; National Annex 2017

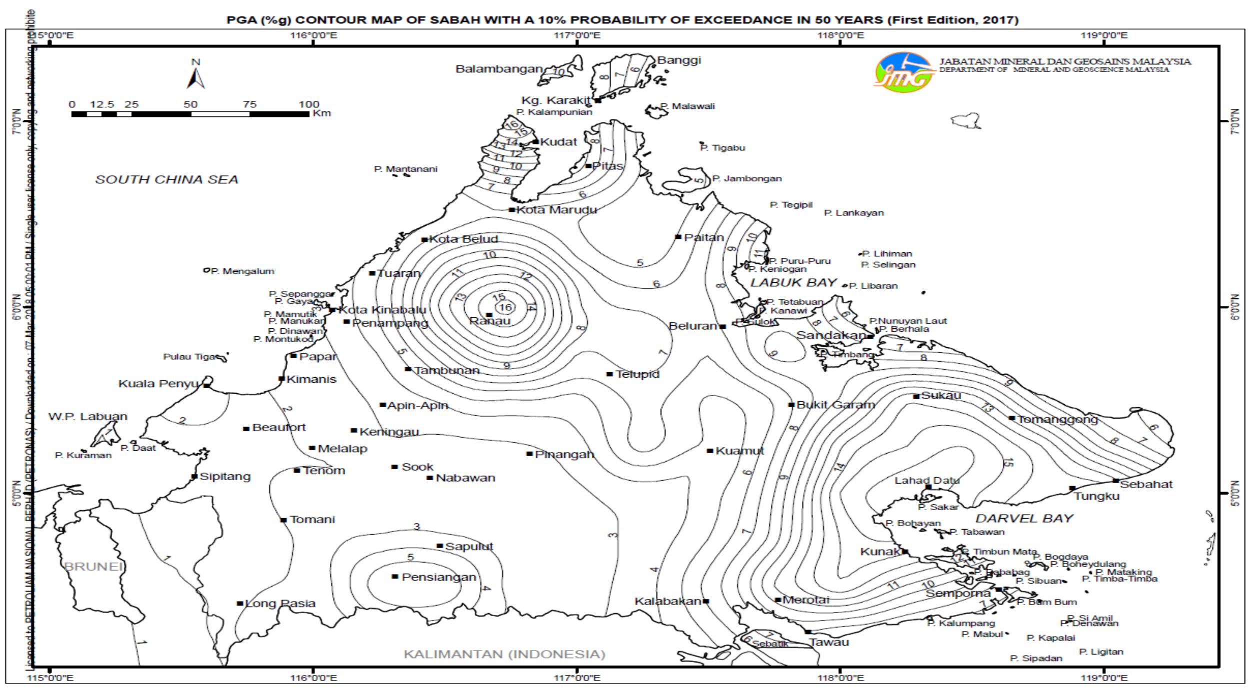

Fig. 3: Latest seismic mapping of Sabah as given in MS EN 1998-1:2015; National Annex 2017

For the context of residential and commercial buildings, attention should be given to the PGA value of 8 and above as these regions represent the increase in PGA from the original 0.075g (Note: PGA value of 8 refers to 0.08g). For the context of Oil and Gas facilities, attention should be given to the PGA value of 4 and above (Note: PGA value of 4 refers to 0.04g). There are two seismic design levels to be considered for the design of Oil and Gas facilities i.e. OBE and SSE. The definition of OBE and SSE in accordance with ASCE7, Maximum Design Loads for Buildings and Other Structures, is briefly described below.

OBE refers to a probable earthquake to which a facility can be subjected during its design life. The facility is expected to remain in operation when subjected to OBE. OBE corresponds to a return period of 500 years. All PGAs given in Fig. 1, Fig. 2 and Fig. 3 correspond to OBE values.

SSE is defined as the "Maximum Considered Earthquake (MCE) ground motion". SSE corresponds to a return period of 2500 years. SSE is normally estimated to be approximately two times of OBE value.

It was a common design method previously, to adopt 0.075g regardless of whether the required seismic level for design was OBE or SSE. This was due to the fact that Malaysia was located in lower seismicity zone of UBC (i.e. Zone 1). Assets that are required to be designed against SSE are those classified as SCE and Criticality 1 assets. For Criticality 2 and Criticality 3 assets, they are required to be designed against OBE only. The classification for asset criticality is defined in the "Equipment Criticality Assessment (ECA) Guidelines" published by the Integrated Plant Operations Capability System (iPOCS) of PETRONAS.

As mentioned above, the necessary effort has been taken to address seismic vulnerability of residential and commercial buildings. For example, JKR buildings in Sabah are currently being assessed by The University of Technology Malaysia (UTM). On the other hand, the assessment for structures and facilities in onshore oil and gas plant is yet to be adequately addressed. Request from PETRONAS Operating Units in Sabah and Sarawak has been made to PETRONAS Center, for the assessment of onshore structures. The student who has been in Onshore Civil & Structure Division of

PETRONAS for the past 25 years, can confirm that no such assessment methodology has been established locally.

The risk of earthquake for onshore facilities is considered as the third major risk for onshore plants (see Figure 4 below). It is also proven through literature review that such assessment methodology is also lacking worldwide. The main reason for the absence of the methodology is because the facilities sited within earthquake zone should have already been designed to sustain earthquake load and there was likely no revision to the seismic mapping of the particular country prior to 2018. This dissertation is in response to the Malaysian new seismic mapping that requires Oil and Gas asset owners to re-assess their facilities due to the revised PGA values. Originally all Oil and Gas facilities in Malaysia were designed to the PGA of 0.075g in accordance with Zone 1 of the Uniform Building Code (UBC) as shown in Fig. 1 earlier. Nevertheless this PGA value was revised in the Malaysian Annex issued by the Department of Standards Malaysia.

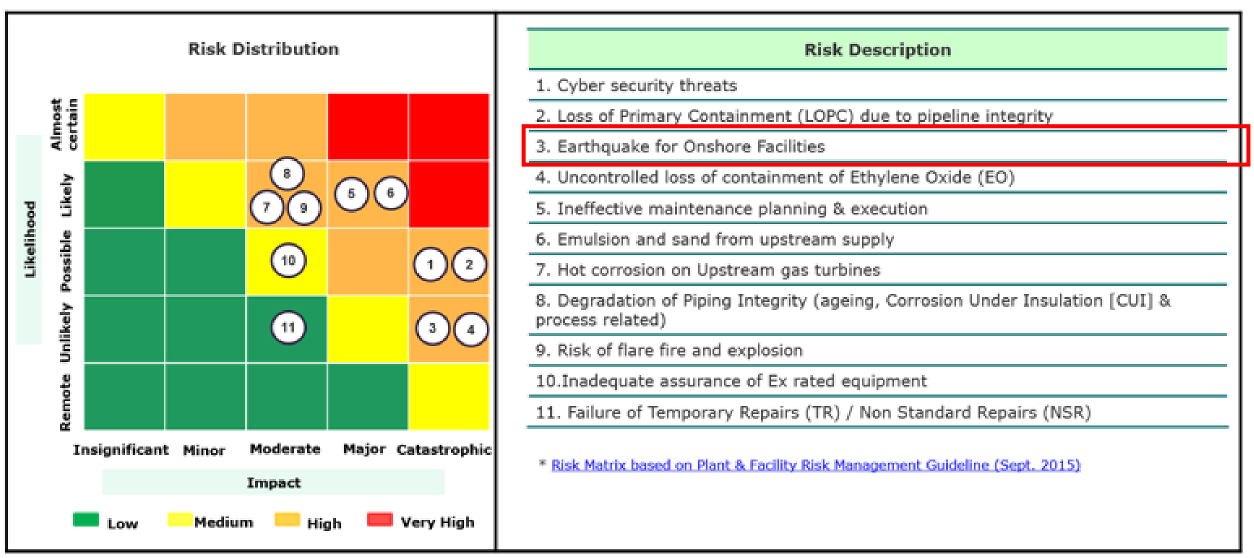

Fig. 4: List of risk distribution for Oil and Gas onshore plants

Fig. 4 above shows that the risk of earthquake for onshore facilities is considered as HIGH even though its occurrence can be categorized as UNLIKELY but the consequence should the event happen, is catastrophic.

Due to the vast numbers of existing structures in existing onshore plants in Malaysia, a risk based approach to rank the structures for inspection and integrity assessment, is much required. Ultimately the optimization for inspection, integrity assessment and retrofitting can be achieved through implementation of this risk based program.

It is anticipated that the established methodology will pave the way for more studies and research on the subject, and will further refine seismic risk assessment for onshore oil and gas structures.

In elevating the importance of seismic design and assessment, the Institution of Engineers Malaysia (IEM) has invited the experts in this field to express their view and at the same time, publish papers in IEM official journal, JURUTERA. Such experts were Professor Dr. Nelson Lam from University of Melbourne, Australia and Professor Dr. Azlan Adnan from Engineering Seismology and Earthquake Engineering Research (SEER), the University of Technology Malaysia (UTM).

Nelson Lam et al (2016) discussed on the requirement of Euro Code 8 (EC8) on seismic design. The requirement called for all buildings to satisfy either one of the two criteria i.e. No Collapse (NC) or Damage Limitations (DL). Critical and sensitive buildings were to be designed against NC requirement. The paper also recommended for all parts of Malaysia to be designed against earthquake regardless of the level of seismicity (of which the practicality of this recommendation was argued by some of the prominent experts in Malaysia). While the paper stressed on the NC requirement, it lacked clarification on the reason for such recommendation. Some arguments against the paper are that, the risk of collapse for buildings in low seismicity area is less and as such the buildings may not require full seismic design. Prevention of total collapse (NC) is not practical, but rather the damage can be controlled and minimized by proper design. Wind load is normally taken to be more severe as compared to seismic load, for such areas. For Oil and Gas structures, blast load is considered as more severe than seismic load. As such the structures designed to sustain blast do not require the checking against seismic load.

Based on the paper by Nelson Lam et al, we can conclude that onshore structures, which are categorized as critical and sensitive structures based on the consequence of failure, shall be designed to fulfill No Collapse criteria. In other words, these structures shall stand and remain intact when subjected to earthquake i.e. the primary columns and beams shall not fail whereas the secondary and tertiary members may be allowed to fail.

IEM again reiterated in its main article on the need to have a National Annex to EC8 addressing the following local seismic design parameters (2015):

1. Basic performance requirement and compliance criteria
2. Rules for seismic actions and their combinations with other actions (i.e. load combinations)
3. Design related to base isolation (foundation isolation)
4. Specific rules for building materials

The National Annex was developed and issued by The Department of Standards Malaysia in January 2018 and it contained the revised seismic mapping of Malaysia.

Based on the latest seismic mapping, some Oil and Gas onshore facilities were sited within the area where PGA is more than 0.075g. As the original seismic design parameter was normally set at 0.075g, any value greater than 0.075g will raise a concern on the integrity of the structures when subjected to earthquake. The onshore facilities in East Malaysia are of concern due to the higher PGA value.

Azlan Adnan et al. (2008) developed micro zonation map of Kuala Lumpur for seismic design of buildings. Shear wave propagation analysis was done by using two hazard levels to represent 10% and 2% Probability of Exceedance (PE) in a design time of 50 years or correspond to a return period of approximately 500 and 2500 years, respectively. While the geotechnical study was comprehensively done, the effect of voids and gaps in the limestone formation, on seismic performance of foundations was not clarified further. This effect needs to be clarified in order to calculate the risk of foundation failure founded in such soil condition.

Though there is no Oil and Gas facility sited within Kuala Lumpur, the fact that comprehensive geotechnical study was performed to quantify the soil parameter for seismic design, is relevant. Structural failure may also be contributed by the failure of foundation. Foundation and soil condition is not visible and as such they cannot be assessed easily during the walk-about assessment. To quantify the risk of structural failure, soil data shall be assessed to check for possible voids that may be present and may collapse during the shaking of ground. Soil liquefaction is another important geotechnical criteria that needs to be checked to avoid structural collapse due to soil failure.

The significance of return period was deliberated in detail by Tu Yong Eng (2008). Fisher-Tippet distribution method in accordance with BS 6399 and Monte Carlo simulation was used to establish return period. The concept of return period is an important aspect in design. It is used to assess the risk and protection level that the design provides.

Normal and non-critical structures in oil and gas plants are designed for 500 years return period, whereas for critical structures, they are designed for 2500 years return period and in the case of LNG plants, the structures are designed for 5000 years return period. The higher the return period is, the higher the PGA value for design.

Seismic vulnerability study, as proposed by IEM in its Position Paper, requires inspection and screening of structures and buildings for risk ranking purposes. A method called Rapid Visual Screening (RVS) was established by the American Federal Emergency Management Agency (FEMA) through issuance of FEMA 154 and FEMA 155, in 2015. These guidelines are only limited to inspection of residential and commercial structures and buildings. They are not meant for structures in oil and gas plants. RVS method enables engineers or surveyors to identify the characteristic of structures and buildings, and screen their capability and damage potential when subjected to possible earthquake. RVS is the first level screening method, beyond which, further evaluation by experts is needed. RVS is an easy-to-use method based on scoring system and the structural evaluation forms can be prepared quickly by anyone (and not necessarily by structural engineers). The evaluation method has been utilized in the

United States for about 25 years. Nevertheless, the physical evaluation of buildings normally does not involve review of drawings and calculations and the survey is, most of the time, done on the exterior of buildings. This means the outcome of RVS finding is incomprehensive and inaccurate. Interior review is always desirable but may not possibly be achieved due to access limitation. In summary, RVS is a method that requires the surveyor to first classify the type of the building (from 17 known types given in FEMA) and to assign appropriate score attributed to building checking criteria (i.e. level of building irregularity and soil types). The range of score has already been established by FEMA and was included in its screening form. However the basis for such scores are not clarified in the document.

RVS as established in FEMA can become the basis for this dissertation project. While FEMA provides for residential and commercial structures, the proposed methodology as established by this dissertation project, will cater for onshore oil and gas structures. The proposed methodology will also be based on the different risks and Process Safety hazards of oil and gas industry.

Seismic performance of a building depends significantly on the types and condition of soil the building is founded on. O-Kegyes-Brassai and R.P.Ray (2016) analyzed 60 boreholes, Map Shear Wave Velocity of soil (MASW) and Cone Penetration Test (CPT) of the city of Gyor in Hungary. Response Spectrum charts for 7 different types of soil were established. STRATA software was used to generate and analyze the charts. Probabilistic Seismic Hazard Assessment (PSHA) was performed to establish the PGA for the city which was then calculated to be 0.12g. RVS was performed to identify the risk of building damage and collapse in corresponding to the PGA established. The method addressed both geotechnical and structural influence on the performance of buildings during earthquake. While effort had been made to classify the soil into major groupings, the actual geotechnical performance might not be 100% accurate due to the mixture of several types of soil. Also, only a handful of buildings were able to be analyzed due to the vast number of buildings within the area. Nevertheless, the result obtained can still be accepted in giving the authority the overall view of building capability and safety against earthquake.

Based on the above paper, we can conclude that geotechnical and structural influence on the integrity of structures shall be taken into consideration in deriving the overall risk of earthquake on the structures.

FEMA 154 was applied for seismic vulnerability study in India by Th. Kiranbala Devi and NganthoiNaorem (2015). In addition to FEMA 154, European Micro-seismic Scale (EMS-98) was also used for damage classification. While the method was applicable to Indian environment and the results were acceptable, another factor that was omitted in the assessment and was lacking in the RVS method was the impact of structural defects and degradation on seismic performance of the structure. In general, RVS method tends to ignore structural degradation and assume the structure is of good shape and condition. This does not reflect the actual risk of the structure when subjected to earthquake.

Based on the above paper, the impact of structural defects and degradation will be taken into consideration in deriving the overall risk of the structure. Defects and degradation have direct impact on the structural integrity. For example, rigorous shaking of the structures that produces variable stress over time, can aggravate defects such as cracks. Cracks propagation may occur under such condition. The methodology developed in this dissertation project will address the impact of defects and degradation on structural integrity.

The omission on the impact of structural degradation on structural performance was also adopted by Masami Oshima and Takashi Kase (2004) in their study on the behavior of moment resistant reinforced concrete structure supporting two vertical vessels, in a refinery plant. They applied “Importance Factor” based on structural material, configuration, types of supported equipment and its content. Two types of analysis with regards to loadings (including seismic load) arrangement of the structure and equipment, were used. Aged deterioration was not considered and the structures and equipment was assumed to be in good shape and condition. Without consideration of structural deterioration, the risk of structural failure when subjected to earthquake as concluded by the paper, might not be accurate.

The approach taken by Masami Oshima and Takashi Kase (2004) by applying "Importance Factor" was excellent since it could further magnify the criticality of critical structures and segregate critical and non-critical structures. This concept of "Importance Factor" will also be applied by the student in this dissertation.

RVS has also been applied in assessing the buildings in Bangladesh by M.M.Ahmed et al. (2014). 945 buildings were assessed and it was found that concrete moment frame was the most vulnerable to earthquake, along with residential houses and low-rise apartments. Concrete is known as a brittle material with low ductility and does not adapt well to rigorous ground shaking due to earthquake. Residential houses in Bangladesh were normally built close to each other and prone to collide with one another during earthquake. Low-rise apartment with parking basement at ground floor gave rise to "soft-story" formation that was vulnerable to earthquake. "Soft-story" refers to significant difference in stiffness between one story and the next story (either at above or below level) due to the absence of walls, columns or restraints. For the study performed by M.M.Ahmed et al. (2014), only Level 1 of RVS (i.e. exterior assessment of buildings) was performed. The scoring system was qualitative in nature and it was based on the judgment of engineers. While the result might be good to give the overall picture of building performance under earthquake, it needs more refinement (by means of the implementation of Level 2 RVS).

Structural degradation on seismic performance of structures was considered by A.A. Fatemi et al. (2013) for assessment of buildings in Bandar Abbas, Iran. Though the study did not specifically check on the direct impact of structural degradation, but its visible presence was noted in the list of criteria for seismic field survey of buildings. The buildings were classified into low, medium and high vulnerability. The distribution of building vulnerability was compared to seismic hazard mapping that was based on the PGA calculated. The final distribution of buildings vulnerability against the mapping of PGA values were helpful in concluding the hazard imposed on the buildings. The scoring for building vulnerability was done based on qualitative assessment. Similar to previous studies as referred above, statistical data on the actual performance of buildings in earthquake was limited. Data of actual building performance when subjected to earthquake needs to be collected in order to check and calibrate the qualitative scoring approach.

UgurAlbayrak et al. (2015) applied screening assessment on 1643 buildings in Turkey. The same list of criteria as in other similar studies, was considered in addition to another criteria i.e. age of building. An Earthquake Risk Score (ERS) was calculated to classify the vulnerability of the buildings. One major finding was on the high possibility of collision of structures due to their close proximity to each other. Similar to other studies, the scoring was done based on qualitative approach through visual assessment. Also, no destructive test and non-destructive test (DT/NDT) and other detailed site survey was done to verify and further investigate the visual inspection findings.

Attempt to quantify the risk for structures in oil and gas plants has been taken by M.N.Mustafa et al (2015). The five by five matrix of likelihood of failure (LOF) against the consequence of failure (COF) was used. Criteria such as process safety hazards (i.e. toxic gas release, fire and explosion), exposure to chemicals and hot steam, variations in temperature, presence of abnormal loadings, structural defects etc. were assessed in assigning the risk. Weightage system was used to rank the criteria in terms of the importance level. Qualitative approach was adopted in view that statistical data on actual performance of structures, was not available. While the risk assessed can be used in the decision making for inspection and maintenance work, its accuracy was debatable due to unavailability of data on the actual performance of structures. Also seismic load and its impact as well as seismic performance of such structures were not studied.

The use of weightage system to enhance Importance Factor was also applied by Romeu Vicente et al. (2014) for the assessment of 53 buildings in Portugal. The weightage ranged from 0.5 to 1.5. Score modifiers were applied to quantify the risk. The overall outcome of the study included vulnerability assessment and risk scenarios, potential damage mapping and loss scenarios. The weightage used was based on qualitative approach and judgment of engineers. Similar to other studies as referred above, statistical data needs to be collected and compiled for checking and calibrating the accuracy of such weightages.

S.Tesfamariam and M.Saatcioglu (2008) introduced the Fuzzy based modeling to translate qualitative knowledge into numerical reasoning. Fuzzy logic integrated descriptive or linguistic knowledge and numerical data into Fuzzy model. It used approximate reasoning algorithms to propagate the uncertainties throughout the decision process. Fuzzy inference system (FIS) contained 3 basic features:

1. Linguistic variables instead of numerical variables.

2. Relationship between the variables in terms of IF-THEN rules.

3. An inference mechanism that used approximate reasoning algorithms to formulate relationship.

As opposed to RVS, Fuzzy modeling required a competent structural engineer to interpret building data and its performance when subject to earthquake. Also, Fuzzy modeling was only tested on 2 types of structural system i.e. reinforced concrete frame and reinforced concrete shear wall. It was yet to be tested on other types of structural configuration especially steel structure.

It is good to note on the use of Fuzzy based modeling to translate qualitative approach into numerical scoring. Nevertheless, this dissertation will not dwell into such method but rather adopting qualitative approach as the first step in developing the methodology for seismic risk assessment for oil and gas structures. The use of Fuzzy based modeling for seismic risk assessment can become a potential field for research in the future.

Olivier Monge et al. (2000) introduced scale indices representing the value of buildings at risk, which were based on the purpose, function and intrinsic values of the buildings. The buildings were categorized into two types of risk i.e. normal and special risk. Building attributes (e.g. occupancy level, building value, content value etc.) were also considered in classifying the risk. While attempt has been made to consider the risk, some other risks during an earthquake event were left unattended such as the potential toxic and flammable gas release, fire and explosion, flash flood due to failure of drainage system etc.

PTS 11.10.02 Seismic Hazard Assessment for Onshore Facilities, specifies that the Performance Standards required for Oil and Gas structures and buildings can be divided into 3 categories as follows:

- Functionality. The structure shall be operational during the event of earthquake (without failure or collapse). Minor repair should be allowed after the event.
- Containment. The structure may not be functional and in operation during the event, but leakage of containment (supported by the structure) shall be avoided. Major repair may be required after the event.
- Structural Integrity. The structure may fail during the event but will not collapse. Evacuation and rescue operation can be done safely. The structure may not be repairable after the event.

Hazard to plant operators and building occupants can also be divided into 3 categories as follows:

- Low hazard (i.e. low hazard to human life in the event of failure)
- Substantial hazard (includes high occupancy buildings and structures supporting hazardous containment. If the structure fails, it will fail in the manner that precludes the release of hazardous material to public)
- Essential hazard (similar to the requirement for substantial hazard but the building and structure will remain functional after an earthquake event).

The above requirements for Oil and Gas structures, are best illustrated in Table 1 below.

Table 1: Performance objectives for different occupancy categories for Oil and Gas structures

Occupancy category	Performance Objectives		
	Maintain Structural Integrity	Maintain containment of hazardous materials	Maintain functions
Low Hazard	Yes	N/A	No
Substantial Hazard	Yes	Yes	No (1)
Essential Hazard	Yes	Yes	Yes (2)

Based on the above occupancy categories, the seismic risk assessment outlined in this dissertation project is best to address the structures with substantial hazard and essential hazard (or also known as critical structures). In ECA, substantial hazard and essential hazard correspond to criticality 1 and SCE assets respectively.

2.2 Conclusion of literature review

Based on the literature review, the followings can be concluded:

I. The trend of earthquake in Malaysia is changing. More earthquake with higher intensity was recorded for the past 10 years.
http://www.met.gov.my, (2018). List of Earthquake, Official website of Malaysian Meteorological Department, Ministry of Science, Technology and Innovation. [online] [Accessed 31 Oct 2018].

II. Local parameters for seismic design needs to be established for Malaysia. The Department of Standards Malaysia has issued the National Annex to MS EN 1998-1:2015 in January 2018. All seismic design should comply with the latest seismic parameters and mapping as given in the National Annex.

III. The scoring system for all of the technical papers reviewed, was based on qualitative approach. This was because of the lack of statistical data on the actual performance of buildings and structures when subjected to earthquake. To overcome this, structural monitoring in terms of instrumentation and devices are needed to record the actual performance of buildings and structures.

IV. While many of the seismic studies are being performed for residential and commercial buildings, the seismic study for oil and gas assets is still inadequate. The areas of potential study for oil and gas assets include screening, risk assessment, risk ranking, the impact of materials degradation on seismic performance, risk reduction, damage control, retrofitting method for an operating plant while minimizing the risk and interruption to plant operation etc.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Overview of research methodology

As stated in Chapter 1.2, the objectives of this dissertation project are to develop a screening methodology for seismic risk assessment and risk ranking of existing structures in oil and gas plants.

The deliverables of this dissertation project are as follows:

- Visual screening method for existing structures based on the assessment of the elements that could pose risk to the structure.
- Risk ranking of various types of structures in the plant based on scoring method established and agreed via Delphi Method.
- Definition of various levels of risk (i.e. Low, Medium, High and Very High) with respect to the risk scoring.

To achieve the above deliverables, the steps in Section 3.1.1 onwards will be implemented.

3.1.1 Overview of Delphi Method and its selection for use

Skulmoski, G.J., Hartman, F.T. and Krahn, J. (2007) performed a study analyzing the use of Delphi method for graduate research. The study outlined the practical consideration for a sampling size when using Delphi method. While there was no strict rules on sampling size, the paper suggested that when the sampling group was homogeneous, a smaller sample between ten and fifteen people could be used to give sufficient reliable results. The paper further suggested that the numbers of iteration can be in the order of two to three iterations. Nevertheless iterations of more than three can be applied if the result had much diversity. The paper also cautioned on possible lower rate of response from the participants if the iteration of more than three was used. It was further concluded that Delphi method was a flexible research technique well suited when there was incomplete knowledge about the problems, opportunities, solutions and forecasts of a research area. Validation might also be required for a reliable result.

Linstone and Turloff (1975) stated in their paper that the Delphi method's flexibility was evident in the way it had been used. The paper concluded that the method was used for structuring a group communication process to facilitate group problem solving and to structure models. The method can also be used as a judgment, decision-aiding or forecasting tool (Rowe and Wright, 1999). The Delphi method can be used when there is incomplete knowledge about a problem or phenomena (Adler and Ziglio, 1996).

Scapolo, F. and Miles, I. (2004) made a comparison between Delphi method and Cross-Impact system and Matrices (SMIC) to predict on the future European transport system. Standard questionnaires with two rounds of iterations were used for Delphi method. This method is fairly flexible and could contain as many questions as the facilitator would like to ask. Parente and Anderson Parente (1987) suggests that twenty-five questions should be the maximum to ensure the exercise is manageable both for the facilitator and the panel of experts. On the other hand the SMIC method has a limitation in the numbers of questions, with a maximum of six questions due to its detailed nature of the questions.

Scapolo, F. and Miles, I. (2004) concluded that while SMIC can focus on a few detailed questionnaires, Delphi method has the limitation in the form of losing participation levels over lengthy questionnaires. Complicated questionnaires could also increase the drop-out rate. The questionnaires should also exclude superfluous words and should have the maximum of 30 words per questionnaires. It was also concluded that the task of completing SMIC questionnaires is considered as more difficult, complex and time consuming as compared to completing Delphi method. It is also difficult to assess cross impact of SMIC questionnaires. However SMIC is more precise due to its nature of detailedness.

Mitchell (1991) indicated that the minimal size of the panel of experts to involve in a Delphi exercise should not be less than eight to ten members. Sackman (1975) informed that the panel of experts may not provide carefully considered responses as compared to younger panelists.

As such based on the above, the followings can be concluded:

- Delphi method will be used as the tool of assessment for this project
- Since the panel of experts consist of people with the same background and interest, the sampling number will be limited between ten and fifteen numbers.
- The panel of experts will consist of a mixture of two groups of expert i.e. senior experts with 20 to 30 years of experience, and younger experts with 5 to 15 years of experience. This is to ensure the balance between expertise and good responses.
- Questionnaires should be be limited to a maximum to 25-30 numbers with a maximum of 30 words per questionnaire.
- The number of iteration will be limited to two to three numbers depending upon the consensus reached between the panels of experts.

3.1.2 Identification of Risk Components and Risk Elements

Identify all risk components and risk elements that can have direct impact to the overall risk of the structure. The list will be established and proposed by the student and will be included as an item of discussion with the identified panel of experts prior to finalizing the overall list.

The risk elements (hazards) that need to be inspected, recorded and assessed (for scoring) are as below. These risk elements are summarized in Table 4.

I. Magnitude of potential seismic load for the area. This can either be obtained from Response Spectrum Analysis or refer to MS EN 1998-1:2015; National Annex 2017 (refer to Fig. 2 and Fig. 3).

II. Geotechnical data and possible soil failure when subject to seismic load:

- Possible liquefaction of cohesion-less soils (saturated, poorly graded, loose granular deposits with low fines content are most susceptible to liquefaction).
- Possible soil subsidence and differential settlement
- Possible presence of voids and gaps in soil
- Possible changes in groundwater pressure due to ground shaking
- Possible collapse of soil formation due to soil cracking and soil crumbling when subjected to earthquake (e.g. possible collapse of limestone)
- Possible change of soil types and profile over width and length of asset (structure)
- Possible slope failure and landslides
- Type of foundation (shallow or deep foundation)

In assessing the above possible soil failure, apart from performing visual inspection, field soil data such as Penetration Resistance, Relative Density, Particle Size Distribution, Atterberg Limit, Moisture Content and Degree of Saturation need to also be assessed.

III. Structural layout, configurations, loadings and materials of construction.

- Types of structural frame (e.g. moment resisting frame etc.)
- Structural restraints (e.g. gratings) and its impact on stiffness
- Ratio of height over width
- Types of load and load eccentricity
- Alternate load paths
- Structural redundancy

- Hinges formation for a *collapse mechanism* (No. and positions of structural hinges)
- Impact of different types of steel grades on stiffness and ductility
- Structural regularity and symmetry
- Uniformity and continuity of structural members
- Standardization of members (i.e. no sudden dimensional change that could cause stress concentration)
- Monolithically cast members (to avoid cold joint and point of weakness)
- Mass irregularities
- Flexibility of joints (including presence of slotted holes).
- Presence of "weak story" and "soft story"
- Content of pipes & equipment supported by the structure (i.e. check liquid sloshing effect in containment).
- Vulnerability of pipes and equipment supported by the structure will also form a risk to structural integrity in terms of product leakage, fire and blast hazard due to pipe and equipment failure (most likely due to joint failure). However, this risk will not be assessed and deliberated in this research (refer to Section 1.4, Limitations of dissertation project).

IV. Structural modification

- Addition and deletion of members
- Addition and deletion of loads
- Change in building or structural dimensions and layout

V. Types and degree of structural degradation (defects)

- Corrosion, cracks, bent, dent.
- Degree (severity) is divided into “major, medium and minor”.

VI. Structural deformation

- Deflection, settlement, tilting, torsional deformation

VII. Proximity to adjacent structure and equipment (as close proximity will cause structural collision in the event of earthquake).

3.1.3 Use of Delphi Method for score finalization

Once the list of risk components and risk elements have been agreed and finalized, the scoring for each risk components and elements will be discussed with the panel of experts. Several rounds of discussion will be done separately between the student and each expert, before the final scoring values can be concluded and agreed with all the experts. Delphi Method will be utilized to finalize all the scoring values of the risk components and risk elements.

3.1.4 Identification of risk barriers for LOF

Risk barriers to LOF need to be identified in order to normalize the final value of risk scoring. Risk barriers will reduce the possibility of risk by acting as filters to reduce the likelihood of failure. The list of risk barriers for LOF will be established and proposed by the student and will be included as an item of discussion with the panel of experts prior to finalizing the overall list. The list of risk barriers are:

I. Management of Change (MOC) procedure (i.e. to control changes to layout, structure, load etc.)

II. Professional Engineer endorsement of structural design.

III. Inspection and maintenance procedure.

IV. Structural Integrity Assessment

V. Strengthening and repair procedure.

VI. Margin for “over-design” (i.e. Factor of Safety (FOS) & structural utilization ratio).

VII. Allowance for future load (normally 20-30% extra load to cater for future expansion).

Refer to Table 5 for further descriptions on the risk barriers.

3.1.5 Impact of risk barriers on LOF

The impact of Risk barriers on the overall LOF risk scoring values will be discussed between the student and the panel of experts prior to finalization. Several risk scenarios will be defined in order to establish the range of risk scoring for LOF.

3.1.6 Identification of risk barriers for COF

Risk barriers to COF need to be identified in order to normalize the final value of COF. These risk barriers will dampen the COF. The list of risk barriers to COF will be established and proposed by the student and will be included as an item of discussion with the panel of experts prior to finalizing the overall list. The risk barriers to COF are as follows:

I. Emergency shutdown procedure

II. Fire proofing & firefighting system (active & passive)

III. Emergency evacuation procedure.

Refer to Table 6 for further descriptions on the risk barriers.

3.1.7 Impact of risk barriers on COF

The impact of Risk barriers on the overall COF risk scoring values will be discussed between the student and the panel of experts and will be finalized. COF will be assessed on 4 major elements i.e. People, Environment, Asset and Reputation (PEAR). The impact of risk barriers to PEAR will be discussed with the panel of experts and finalized.

3.1.8 Definition of various risk levels

Various levels of risk have been defined for seismic risk assessment. These are LOW, MEDIUM, HIGH and VERY HIGH. The segregation of these risks are in accordance with the range of scores obtained by multiplying all relevant risk components and risk elements as defined in Section 3.1.2 above.

3.1.9 Risk Matrix

Risk matrix consists of LOF against COF and given in Table 9.

3.2 Expected research outcome

The expected outcome of the research is the establishment of a screening methodology for seismic risk assessment of existing structures in oil and gas plants and facilities in Malaysia.

By having such methodology for seismic risk assessment and risk ranking of existing structures, the plant owners can prioritize and optimize the maintenance and retrofitting work for the structures. All effort, resources and materials can be allocated and focused on high priority strengthening, retrofitting and repair work to prevent structural failure in the event of an earthquake.

The deliverables of this dissertation project are as defined in Section 3.1.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Delphi Method and its application

The student based on his 25 years of experience in Oil and Gas industry, has outlined the proposed methodology and scoring for seismic risk assessment. Concurrently, a group of panel experts that consists of senior and professional engineers from various background has been set up to answer the student's questionnaires as prepared by the student, with regards to seismic risk assessment. Each professionals provide the answers from their points of view and based on their experience.

Three rounds of assessment by the professionals are conducted with the student acts as the facilitator. The professionals are encouraged to revisit their answer in light of the reply received from others. The process is stopped when all professionals agree with a range of common answers to address the issue. It is also worth to note that the professionals that are chosen for this study, have come from various background. They have brought with them diversified experience, exposure and knowledge which is beneficial for the success of this study.

The scopes of the professionals engaged in the survey are to review and provide feedback on the followings that are proposed by the student:

1. The list of risk components and elements.

2. The score and weightage for each risk component and element.

3. The list of risk barriers that can reduce the overall risk score.

5. The score and weightage for each risk barrier.

6. The proposed risk matrix (Likelihood versus Consequence).

7. The range of score for Likelihood and Consequence (i.e. for Very High, High, Medium and Low risk).

4.2 Panel of experts

Table 2: The chosen panel of experts

No.	Panel of experts	Background and Experience
1	Dr Azhar Ahmad	An ex-lecturer of UM and currently performing adjunct lecturing at various universities. Over more than 30 years of experience in teaching steel structure at UM. Has retired and currently a project leader for RAPID Project in Johor.
2	Ari Sudarso Sadewo	An expatriate from Indonesia. A Master degree holder in the field of Earthquake Engineering. Over 25 years of experience in Oil & Gas consultancy. Has vast experience in the field of Earthquake Engineering.
3	Ir Kalaikumar Vallyutham	An ex-lecturer of UTP and currently performing adjunct lecturing at UTP. Over 10 years of experience in teaching structural analysis at UTP. A Master degree holder in the field of Structural Analysis.
4	Ir Lim Chin Chiat	Over 20 years of experience with TECHNIP Consultant in Oil and Gas industry. An expert in Structural Engineering.
5	Adam Abdel Karim	An expatriate from Sudan. A Master degree holder from UPM in the field of Construction Engineering. Over 20 years of experience

No.	Panel of experts	Background and Experience
		and currently working as a Technical Professional in MRCSB Plant in Melaka.
6	Ir Khairani Abas	A Master degree holder from UiTM in the field of Geotechnical Engineering. Over 15 years of experience with JKR as a geotechnical engineer.
7	Jamil Jamaluddin	A Technical Professional in Civil & Structural Engineering department of GTS. He has 15 years of experience in Civil Engineering field and has involved in numerous integrity assessment of Civil assets in plants. He is also one of the facilitators for Civil Engineering courses for PETRONAS group-wide.
8	Pedram Hatami	A Malaysian-Iranian descent with 8 years of relevant working experience. Trained by MINCO Consultant in infrastructure design that includes high rise buildings design. Currently lead Civil Engineering design for buildings project of PETRONAS.
9	M Fakhrur Razi A Faizul	A UTP graduate with 5 years of relevant working experience in Civil & Structural Engineering and currently attached as a Construction Engineer for the Refinery and Petrochemical Integrated Complex Project in Johor. Majoring in Offshore Engineering.

No.	Panel of experts	Background and Experience
10	Sek Chin Yong	Trained by Sepakat Setia Perunding in the field of Hydraulics and Hydrology design. 15 years of relevant experience in design and construction field. Currently attached as the Construction cum Maintenance Engineer for Sabah-Sarawak Gas Pipeline project.
11	Liew Chee Hong	A Technical Professional in PETRONAS with 15 years of relevant working experience. Previously attached for 12 years as the Plant Engineer at the Gas Processing Plant in Kerteh. Currently involved in the preparation of Standards for Plant Expansion Layout.

4.3 Outcome of Delphi Method

There is a lack of information and reference on the level of priority and level of importance of the risk components and risk elements, with respect to structural failure caused by earthquake. The series of engagement with the panel of experts to discuss and clarify the level of importance and hence the scoring, were done in accordance with Delphi Method. After 3 series of engagement, the scoring was finalized and given by the weightages W1 and W2 in Table 4.

4.3.1 Development process for finalization of weightages

The development of final scoring for risk components and risk elements is shown in Appendix C and Appendix D.

Table 3: Issues raised and discussed with panel of experts

No.	Issues discussed with panel of experts	Details of discussion and way forward
1	Possibility of unavailability of data required.	Concern on whether all risk elements data are readily available. Unavailability of data can cause the whole process to be interrupted and the assessment may get stuck. Some plants may not have a complete set of As-built drawings and soil investigation (S.I) data. For structural details, since they are mostly visible, they can easily be checked at site. But for Geotechnical details, absence of S.I data can hinder completion of assessment. This issue was deliberated between the student (as the facilitator) and the panel of experts and it was proposed that for the case of unavailable data, the worst case scenario should be considered. However only 50% of the worst case scenario score will be considered for LOF. The 50% score to compromise the risk due to data unavailability.
2	Simplification of the methodology due to differing levels of experience & skills of assessors in Plants.	The issue was deliberated and it was proposed that the methodology should not be simplified but rather the skills of assessors should be upgraded. In-house trainings for assessors will be conducted to streamline the understanding on the methodology. Only certified assessors can conduct the assessment. As a mandatory criteria, the

No.	Issues discussed with panel of experts	Details of discussion and way forward
		assessors shall have at least an engineering degree (in the field of Civil & Structural or Mechanical Engineering). The certification can only be given by the highest level of technical authority in the company.
3	COF	It was agreed by all experts that probable failure scenario, which become the basis of COF, should be deliberated for each asset (i.e. structure or building). At least two assessors are needed to jointly discuss and propose the probable failure scenario for each asset to ensure for a check and balance on the proposal. It was also agreed by the experts that the best method to adopt for deciding on the probable failure scenario is the "what-if" analysis. E.G. If one primary column fails in the event of earthquake, what will happen to the pipes that the structure is supporting? This requires a competent engineer to assess the presence of an alternate load path and structural utilization ratio (from original calculation).
4	Overall risk	Panel of experts raised the issue of the definition of tolerable risk. Overall risk is divided into four categories i.e. Low, Medium, High and Very High. It was agreed that tolerable risk is defined as Low and Medium risk. Low risk structure is defined as the structure that remains intact with negligible

No.	Issues discussed with panel of experts	Details of discussion and way forward
		damage when subjected to earthquake. Medium risk structure is defined as the structure that remains intact with minor damage to secondary and tertiary members, when subjected to earthquake.
5	Barriers	The issue on how to address risk barriers was deliberated with the panel of experts. It was agreed that the barriers should consist of MOC, P.E endorsement, I&M procedure, Structural Integrity Assessment, Strengthening & Repair procedure and margin for "over-design". The student also proposed to include the allowance for future load (normally taken as 20-30%). However upon deliberation with the experts, the allowance for future load was omitted as this can also be regarded as over-design. The student also proposed to include emergency shutdown, emergency evacuation and fire proofing and fire-fighting, as barriers. It was earlier proposed that these barriers shall be considered for LOF. Upon deliberation with the experts, it was agreed that these barriers shall be applied for COF as they have direct impact on people safety, potential environmental pollution, assets repair and company's reputation. It was also deliberated that more consideration for risk should be given to engineering controls (e.g.

No.	Issues discussed with panel of experts	Details of discussion and way forward
		compliance to codes) over administration controls (e.g. formatting of documents, report writing skill etc.).
6	Change of use & change of design intent	The student proposed that change of structural use became an item of risk assessment for the structure. This was because the change might lead to changes in loadings and stress levels in the members. However upon deliberation with the experts, changes in structural use might not lead to risk accumulation if it is done properly e.g. with P.E endorsement. Proper design check performed by P.E will ensure that the stress induced is within capacity of members. As such, this item (change of use) was dropped. It was considered that the risk due to change of use, was embedded in the barrier "P.E endorsement".
7	No. of story	The student proposed that height of building should be one of the elements for risk. However the limit of height beyond which, risk should be considered, needed to be established. Since buildings in Oil and Gas plants are mostly one story, it was agreed to set the limit at one story. Buildings with more than one story are not allowed in Process area. They are only allowed in administration building complex located outside non-process area.
8	Age	The issue of age of the plant was raised since age

No.	Issues discussed with panel of experts	Details of discussion and way forward
		can affect the integrity of assets. However upon deliberation, age is not an issue due to: • Degradation rate for Steel and Concrete can be controlled by a proper maintenance program e.g. scheduled painting and coating. • Onshore structure is seldom subjected to fatigue loading, unlike offshore structure. As such, duration of use or age is not an issue.
9	Destructive and Non-Destructive Tests (DT and NDT)	The need for DT and NDT was raised during the engagement session with the experts. It was concluded that DT and NDT are not required to be done since at this stage, the assessment is based on quick screening and visual assessment. For the next stage of assessment, once the list of structures has been prioritized based on risk, detailed structural modeling and analysis will be done. At this stage, DT and NDT may be done as required to ascertain the physical properties of the materials.
10	Blast Load	The need for blast resistant buildings to be assessed against seismic load was discussed. Some buildings in Oil and Gas Plants are designed to sustain blast load of 10 kPa and above due to their close vicinity to potential source of explosion. For these buildings, it was agreed that seismic load

No.	Issues discussed with panel of experts	Details of discussion and way forward
		assessment was not required since blast load was more severe than seismic load.
11	Seismic load	It was discussed that for seismic load, the reference should be made in the following hierarchy: • Specific seismic hazard assessment for the area • Latest seismic mapping as given in Malaysian Annex • Uniform Building Code zoning for earthquake. It was also agreed that the SSE is approximately twice the value of OBE, based on the experts' experience. All experts agreed that the scoring for seismic load should take the highest order as compared to other risk elements. The final average scoring of 9.5 corrected to the final score of 10, was agreed by all experts.
12	Load Eccentricity	It was raised that the pipes supported by structures, may shift laterally due to aging and corroded pipe shoe. Pipe shoe is to hold the pipe and prevent it from moving laterally. It was discussed whether the condition of pipe shoe needed to be included as one of the risk elements. Upon discussion, it was agreed that for this stage, the assumption that pipe

No.	Issues discussed with panel of experts	Details of discussion and way forward
		shoe is well maintained, needs to be made. This is because Mechanical maintenance program for an Oil and Gas Plant is normally quite comprehensive. Also, to inspect pipe shoe is not an easy task since they are normally located at high elevations.
13	Load path	The experts questioned on the need to include load path as one of the risk elements. All loads will subsequently be transferred to foundations through columns. It was raised that there should not be load path discontinuities since all structures have already been designed properly. Upon discussion, it was agreed that the idea of load path is to differentiate between cantilevered structure and non-cantilevered structure. Cantilevered structure poses higher risk of collapse as compared to non-cantilevered structure.
14	Column splices	It was discussed whether the locations of column splices need to be included in the risk elements. Columns splices should not be placed at the points of highest bending moment and shear force. Upon discussion, it was agreed not to include column splice since the splice should have been designed adequately to sustain any load regardless of where it is located along the structural member.
15	Presence of pipes & equipment load	For the pipe load, it was discussed on the range of pipe diameter to be considered in the risk

No.	Issues discussed with panel of experts	Details of discussion and way forward
		assessment. Smaller pipes e.g. 2” or 3” diameter will not produce significant loads on the structure. It was agreed that the minimum pipe diameter to be considered should be 10”.
16	Content of pipes & equipment (i.e. hazardous & flammable)	It was discussed that the flammability needs to be defined by ignition temperature of the pipe content. It was agreed to adopt the definition and criteria of hazardous and flammable liquid or gas based on the definition and specification as specified by Process Safety discipline.
17	Stiffness irregularities. Presence of “strong beam weak columns”.	The experts have suggested to include “strong beam weak columns” as one of the risk elements. This is because the phenomena of “strong beam weak columns” can lead to failure of the structure since in this case, column will fail first prior to beam. The student agreed to this and has included it in the overall risk elements.
18	Effect of non-structural elements on seismic performance.	It was discussed whether the architectural features e.g. cladding, handrails, parapet wall, raised floor, stairs etc. should be included in the list of risk elements. The failure of these architectural features may not cause structural integrity problem, but can pose a hazard to building occupants. Upon discussion, it was agreed not to include architectural elements in the risk assessment. This is because the risk assessment is assessed against structural collapse due to integrity issue.

No.	Issues discussed with panel of experts	Details of discussion and way forward
		Architectural elements failure will not have any impact on structural integrity.
19	Condition of foundation?	The experts raised their concern on the condition of foundation. If the foundation cracks, or attacked by acidic ground water, the strength and capacity of the foundation is reduced. Upon discussion, it was agreed that the underground part of foundation is not easy to be inspected. Excavation is needed to expose some parts of the foundation but performing excavation in a live plant is hazardous. As such, it was agreed to embed the risk of foundation degradation into geotechnical risk assessment. E.g. the risk of foundation degradation due to acidic ground water will not be considered. Instead the risk of acidic soil and groundwater based on soil investigation data, will be considered and given a risk weightage.
20	Structural fatigue due to earthquake or other vibrating load?	The issue of possible structural fatigue was discussed. Structural fatigue can lead to failure of structure. However, onshore structures are seldom subjected to fatigue loading unlike offshore structures. Seismic load is not a long term continuous loading that could cause fatigue. As such, fatigue loading is not included in the risk assessment.
21	Presence of active or passive fire proofing on structure.	Fire proofing protects the structure in the event of fire. Fire could occur when leakage of flammable

No.	Issues discussed with panel of experts	Details of discussion and way forward
		product happens during earthquake event due to pipe bursting. Fire could lead to structural failure. With the presence of fire proofing, the structure could at least stand for 30 min (depending on the duration of protection designed). This would allow building occupants to escape and evacuate the building in the event of fire. Originally, in the earlier questionnaire, the student has put fire proofing as a barrier to ensure better structural integrity. Upon discussion with the experts, it was agreed as suggested by the experts, that the impact of fire proofing is more on COF rather than LOF. Fire proofing allows the structure to stand for some time (normally for minimum 30 min.) and provide ample time for occupants to escape. This can reduce the possibility of people trapped in the building, which can lead to injury or fatality.
22	Percentage of structural or building damage.	It was raised that the risk of structural collapse should be defined by probable percentage of structural damage during earthquake. For e.g. an estimated damage of 75% and above would give a high risk to the structure in the event of earthquake. However upon discussion, it is not easy to estimate structural damage unless modeling and simulation is made. Since, the risk assessment is a screening process, modeling and simulation is not required, and as such the estimated structural

No.	Issues discussed with panel of experts	Details of discussion and way forward
		damage cannot be quantified at this stage.
23	Structures within containment dykes?	A concern was raised on the structures located within containment dykes. These structures are mainly pipe supports. These structures will be subjected to the screening method established to determine their risk in the event of earthquake.
24	Siting of structures within the Process Plant.	It was raised that the siting of structures in the plant, will also carry some weight on the risk. This is true, however the screening method will be applied to the group of highly critical structures as determined by Process Safety. Among the criteria used by Process Safety to classify criticality of structures are the locations of the structures and the level of criticality of the equipment supported by the structures. Highly critical structures could amount to hundreds, and this screening method will be used to further prioritize the highly critical structures for further risk assessment.
25	Corrosion of pipes under insulation (pipes supported by structures)	The issue of pipes corrosion under insulation was raised. However, this issue is to be addressed by Piping discipline. Piping inspection and maintenance is being done regularly and this issue should have been addressed in the inspection and maintenance program.
26	Risk due to construction & fabrication work? E.g. Out of	This issue was raised but it was assumed that all structures fabricated and erected should have passed the quality check prior to approval. As

No.	Issues discussed with panel of experts	Details of discussion and way forward
	tolerance	such, this issue can be put to rest.
27	Since leakage on pipes most likely to happen at flanges, is the risk of structures supporting pipes dependent on the availability of flanges on the structures?	The failure of pipe flanges will very much depend on the integrity of pipe supports. If we can assure that the support integrity is maintained during earthquake, then the possibility of pipe leakage either at flanges or other locations along the pipe can be minimized. The integrity of structures is not dependent on the availability of pipe flanges on the structures.
28	How to assess the risk for inaccessible structures?	A concern was raised on inaccessible structures e.g. flare structure. It was agreed that the screening will only be used for accessible structures, while for inaccessible structures, the risk will automatically put to VERY HIGH risk until a shut-down window can be allocated for inspection and assessment.
29	What hazard will platform gratings pose to people safety and to possible damage of piping & equipment should the gratings are detached during earthquake?	The issue of gratings detachment during earthquake was raised. It was discussed that gratings are attached by clips and restrained by special restrainers welded to the structural supports. As such the possibility of gratings detachment and the possibility of equipment damaged by gratings is minimum.

The summarized framework for the risk assessment is given in Table 4 below. This table tabulates and summarizes the risk components and risk elements as discussed in Section 3.1.2.

Table 4: Risk assessment framework and final weightage for risk components and risk elements

<u>Note:</u>

W1: Weightage for Risk Components (0-100)

W2: Weightage for Risk Elements (0-10)

No.	**Risk Components**	**W1**	**Risk Elements**	**Sub-Risk Elements**	**W2**	**Eng. Parameters**	**Score**
1a	Load	60	Blast load		-	> 20 kPa	If *Yes*, no further seismic assessment is required. Otherwise please proceed to the next stage
1b			Seismic Load	- OBE	10	< 0.075g	1
						> 0.075g	3
				- SSE	10	< 0.15g	1

No.	Risk Components	W1	Risk Elements	Sub-Risk Elements	W2	Eng. Parameters	Score
						> 0.15g	3
1c			Load Eccentricity	P-Δ Effect	8	Yes No	2 1
1d			Load Path	- Continuous	5	Yes No	1 3
				- Alternate	5	Yes No	1 3
1e			Operating Pipes & Equipment Load	Presence of Load	3	Yes No	3 1
1f			Pipe & Vessel Content	Hazardous & Flammable Hydrocarbon	6	Yes No	3 1

No.	Risk Components	W1	Risk Elements	Sub-Risk Elements	W2	Eng. Parameters	Score
2a	Geotechnical	55	Soil Properties	Liquefaction	8	Yes No	3 1
2b				Soil Cavities	7	Yes No	3 1
2c				Limestone	7	Yes No	3 1
2d				Pore Water Pressure	5	Yes No	3 1
2e				Soil Variations	4	>50% <50%	3 1
2f			Adjacent Slope Parameters	Max. 6m height, Slope 1:1, set back dist. 5m min.	5	Yes No	1 3

No.	Risk Components	W1	Risk Elements	Sub-Risk Elements	W2	Eng. Parameters	Score
2g			Foundation Types	- Shallow - Deep	8 8		2 1
3a	Structural Geometry	65	Height of Structure	Single story (max. 5m)	5	Yes No	1 2
3b			Structural Stability	Height to width ratio (1 to 0.5)	6	Yes No	1 2
3c			Structural Regularity & Symmetry	Regular & symmetrical?	6	Yes No	1 3
3d			Mass Irregularities	Uniform mass distribution over the structure?	8	Yes No	1 3
3e			Stiffness Irregularities	- Soft story & Weak story	8	Yes	3

No.	Risk Components	W1	Risk Elements	Sub-Risk Elements	W2	Eng. Parameters	Score
				- Strong beam weak column	8	No Yes No	1 3 1
3f			Structural Drift	Exceed allowable value?	6	Yes No	3 1
3g			Proximity to adjacent structures	Minimum 1 m	4	Yes No	1 2
4a	Structural Design	60	Types of Structural Frame	- Moment Resisting - Pinned Joints - Laterally Braced - Cantilevered	6 6 6		1 3 1 3

No.	Risk Components	W1	Risk Elements	Sub-Risk Elements	W2	Eng. Parameters	Score
				Columns - Combinations of above	6 6		1
4b			Structural Restraints	Components that contribute to structural stiffness e.g. gratings, vessels etc.	5	Yes No	1 2
4c			Structural Redundancy	Availability of redundant members	6	Yes No	1 2
4d			Uniformity & continuity of structural	Uniform & no sudden change in	5	Yes No	1 2

No.	Risk Components	W1	Risk Elements	Sub-Risk Elements	W2	Eng. Parameters	Score
			members	size?			
5	Construction	40	Method of casting concrete	Monolithic construction?	4	Yes No	1 2
6	Structural Modifications	45	Changes in structural layout & loadings		6	Yes No	3 -
7a	Structural Degradation	45	Steel Defects	- Corrosion	6	Severe Medium Minor	3 2 1
				- Other defects	6	Yes No	3 -
				- Missing bolts	7	Yes No	3 -

No.	Risk Components	W1	Risk Elements	Sub-Risk Elements	W2	Eng. Parameters	Score
7b			Concrete Defects	- Cracks	6	Severe Medium Minor	3 2 1
				- Corroded Reinforcement	6	Yes No	3 -
				- Spall	4	Severe Medium Minor	3 2 1
8	Structural Deformation	55		- Settlement, Deflection, Torsion, Tilt	6	Yes No	3 -

No.	Risk Components	W1	Risk Elements	Sub-Risk Elements	W2	Eng. Parameters	Score
				- Missing Structural Members	8	Yes No	3 -

4.4 Risk barriers framework

The summarized risk barrier framework for the risk assessment is given in Table 5 and Table 6. These barriers are assessed, and their availability or unavailability can reduce or further escalate the overall risk.

The risk barriers are divided into 2 categories:

1. Barriers that have direct impact on Risk Components (i.e. the presence of barriers can reduce the LOF and hence reduce the overall risk). The list of barriers is given in Table 5.

2. Barriers that have direct impact on the Consequence of Failure (COF) and hence can reduce the overall risk. The list of barriers is given in Table 6.

Table 5: Risk barriers that have direct impact on Risk Components

Risk Barriers for LOF	Risk reduction to the following Risk Components for LOF (See also Table 4)	Remarks
Management of Change (MOC)	Loads, Structural Geometry, Structural Design, Structural Modifications	MOC is the detailed assessment of any changes applied to process system, utilities, facilities design etc. It involves the risk assessment for the change, detailed design, cost, schedule & constructability.
Professional Engineer Endorsement	Loads, Geotechnical, Structural Geometry, Structural Design	P.E endorsement ensures all design basis, parameters, methods, findings & conclusion are reliable and in accordance with the Codes & Standards. Only P.E endorsement on "As-

Risk Barriers for LOF	Risk reduction to the following Risk Components for LOF (See also Table 4)	Remarks
		built” and/or Modification drawings is considered for this barrier.
Inspection & Maintenance Procedure	Structural Degradation, Structural Deformation	I&M procedure ensures the inspection and maintenance work are systematically done, in accordance with the approved Standards and schedule. It also ensures that the inspection findings will be analyzed by competent professionals.
Structural Integrity Assessment	Structural Modifications, Structural Degradation, Structural Deformation	Structural Integrity Assessment involves the inspection of elements that could impair the integrity of structures, and calculation of structural utilization ratio with respect to loadings imposed.
Strengthening, Modification & repair	Structural Modifications, Structural Degradation, Structural Deformation	SMR procedure provides standardized SMR methods, which is reviewed & approved by competent people. The methods have taken into considerations the oil & gas, and live plant environment.

Risk Barriers for LOF	Risk reduction to the following Risk Components for LOF (See also Table 4)	Remarks
Over-design	Loads, Structural Design.	Over-design provides extra capacity against accidental loads e.g. impact load, and integrity impairment e.g. structural defects.

Table 6: Risk barriers that have direct impact to COF

Risk Barriers for COF	Risk reduction to COF (See also Section 3.1.6)	Remarks
Emergency shutdown	People, Environment, Asset, Reputation	Emergency shutdown during earthquake will ensure that the process system is shut down, valves closed, electrical supply is terminated etc. This is to ensure that the impact is minimized should the structure fail during earthquake.
Emergency evacuation	People	This is to ensure escape & emergency response fits within shortest time possible, in line with the evacuation philosophy.
Fire proofing & fire fighting	People, Asset	Fire-fighting is to control & extinguish the escalation of fire should fire outburst occur during

Risk Barriers for COF	Risk reduction to COF (See also Section 3.1.6)	Remarks
		earthquake. Fire proofing is provided to prolong the integrity of structure during a fire event. Both fire proofing & fire-fighting system is meant to minimize the impact due to earthquake.

4.5 Rules for risk barriers application

Based on the series of engagement with the panel of experts, the rules for Risk Barriers application are set up as follows.

4.5.1 Barriers that have direct impact on risk components for LOF

Refer to Table 5 for the list of barriers.

The barriers will reduce the risk scoring by qualitatively 50%. E.g. if the score for the risk component, LOADS, is 4000, with the presence of a risk barrier MOC, the score will be less by 50% i.e. 2000. If another risk barrier exists e.g. P.E endorsement for "As-built" and/or Modification drawings, then the score is further reduced by 50% of the original score i.e. another 2000. The total reduction now is 4000 and the final score now is 0. However the minimum score shall be 10% of the original score i.e. in this case, 10% of 4000 is 400. As such, in this particular case, the final score is 400 and not 0.

The application of score reduction by barriers is best illustrated in Table 7 below.

Table 7: Illustration of score reduction by barriers for LOF

Note:

B1: Barrier 1 i.e. Availability of MOC

B2: Barrier 2 i.e. P.E endorsement for "As-built" and/or Modification drawings

B3: Barrier 3 i.e. Inspection & Maintenance Procedure

B4: Barrier 4 i.e. Structural integrity assessment

B5: Barrier 5 i.e. Strengthening, modification and repair

B6: Barrier 6 i.e. Over-design

Risk Component	**Assumed Total Score**	**B1**	**B2**	**B3, B4, B5 & B6**	**Reduced Total Score due to barriers**	**Final Score for the Risk Component**
LOAD	4000	Available. Score reduction = 2000	Available. Score reduction = 2000	NA	4000 – 4000 = 0	10% of 4000 = 400

The concept of 50% score reduction and final 10% score reduction is based on the following concept:

- With the presence of risk barrier, the overall risk will be reduced.
- However, as the risk barrier is also controlled by human and subjected to human errors, the overall risk reduction shall be minimum.
- Majority of the risk is still present, even with the presence of risk barriers.

Hence based on the above factors, it is agreed with the panel of experts that qualitatively, the risk reduction concept above is reasonable.

4.5.2 Barriers that have direct impact to COF

The barriers will reduce the COF by one risk stage as illustrated below. Take an example of the Emergency Shutdown barrier. It has a direct impact to all COF elements i.e. People, Environment, Asset and Reputation (PEAR). The presence of the barrier (Emergency Shutdown) will reduce all COF risk (as shown as "X") to a stage lower (as shown as "Y"). To get the final risk, the most severe COF will be considered i.e. in this case, it is "PEOPLE" with the risk of "MAJOR" as shown in Table 8 below.

Table 8: Illustration on reduction to COF due to presence of barriers.

COF	Insignificant	Minor	Moderate	Major	Catastrophic
PEOPLE			**Y**	**X**	
ENVIRONMENT		**Y**	**X**		
ASSET	**Y**	**X**			
REPUTATION		**Y**	**X**		

The proposed risk reduction is based on the following concept:

- With the presence of barriers, the overall COF will be reduced.
- However COF reduction shall be controlled since even with the presence of barriers, the COF shall remain significant for a conservative risk assessment.

As such, it is agreed with the panel of experts that a one stage reduction is reasonable.

4.6 Risk Matrix

A spreadsheet is currently being developed based on the above agreed concept and finalized data.

However it is not the intention of this project, to include the spreadsheet in this report. As mentioned under Section 1.2, the main objective of this project is to establish and agree via Delphi Method, the concept of risk assessment and finalize the weightage of risk components and risk elements. The spreadsheet is being developed for the purpose to facilitate the implementation of seismic risk assessment.

The risk matrix to be adopted for this risk assessment is as shown in Table 9 below and it consists of LOF against COF. LOF is defined in 5 categories (A, B, C, D and E) and COF is defined in 4 elements (i.e. PEAR).

Table 9: Risk Matrix

		SEVERITY	1 Insignificant	2 Minor	3 Moderate	4 Major	5 Catastrophic
Consequence		People	Slight Injury	Minor Injury	Major Injury Major Health Effects*	Single Fatality Permanent Total Disability*	Multiple Fatalities Permanent Total Disability*
		Environment	Slight Impact	Minor Impact	Moderate Impact	Major Impact	Massive Impact
		Asset	Slight Damage	Minor Damage	Local Damage	Major Damage	Extensive Damage
		Reputation	Slight Impact	Limited Impact	Considerable Impact	Major National Impact	Major International Impact
LIKELIHOOD	E Almost Certain	Incident has occurred several times per year in OPU	E1	E2	E3	E4 VERY HIGH	E5
	D Likely	Incident has occurred in OPU; or more than once per year in PETRONAS	D1	D2	D3	D4 HIGH	D5
	C Possible	Incident has occurred in PETRONAS; or more than once per year in industry world wide	C1	C2	C3 MEDIUM	C4	C5
	B Unlikely	Incident has occurred in industry, world-wide	B1	B2 LOW	B3	B4	B5
	A Remotely likely to happen	Never heard of in industry world-wide but could occur	A1	A2	A3	A4	A5

* For chronic health effects

The risk are categorized as Low, Medium, High and Very High.

The different categories of risk (i.e. Low, Medium, High and Very High) depends on the risk scoring based on various scenarios. These scenarios are developed based on various combinations of risk components and risk elements. The calculations to obtain the scoring range are done separately in a separate spreadsheet. The range of the scoring are given in Table 10. It gives the indication on scoring distribution for various possible combinations of risk.

Table 10: The range of scores for LOF categories

LOF	Description	Scoring
E – Almost Certain	Incident has occurred several times per year in OPU (Operating Units)	12200 and above
D - Likely	Incident has occurred in OPU, or more than once per year in an organization (e.g. PETRONAS)	9400-12199
C - Possible	Incident has occurred in an organization (e.g. PETRONAS), or more than once per year in industry world wide	6600 - 9399
B – Unlikely	Incident has occurred in industry world wide	3800-6599
A – Remotely likely to happen	Never heard of in industry world-wide but could occur	1000-3799

4.7 Definition of risk categories

The summarized definition of risk categories is given in Table 11. The definition is derived from the various possible combinations of risk and in line with the concept of seismic risk assessment as presented in this project.

Table 11: Definition of risk categories

RISK	Description
Low	The structure is intact when subjected to earthquake. Negligible damage may occur e.g. minor concrete cracks, spall, secondary or tertiary structural members displaced which do not impact the overall integrity of the structure and the loads (pipes & vessels) that it sustains. Structural defects due to degradation, are mostly negligible.
Medium	The structure is intact when subjected to earthquake, however minor structural failure may occur. This failure may occur on secondary and tertiary structural members, and to some extent the primary members. Primary members may be dented or bent beyond its elastic limit. However the primary members are not loaded to their ultimate strength and structure is safe from collapse. Structural defects due to degradation, are mostly within the category of "Medium defects". Note that the category of structural defects are clearly defined in Reference 5, M.N.Mustafa et al (2015).
High	Localized structural failure may occur due to some primary members are loaded to their ultimate strength. Some other primary members may have greater design margin of structural utilization and hence preventing them from reaching their ultimate strength. Even though localized failure can occur, total collapse is not imminent. Structural defects due to degradation, are mostly within the category of "Severe defects".
Very High	The capacity of structure is exceeded and total collapse is imminent. Structural defects due to degradation, are mostly within the category of "Severe defects". Documentations on the original design and the changes applied to the structure since its

RISK	Description
	completion, are mostly not available. Maintenance program and scheduled integrity assessment performed by competent engineers, are also lacking.

CHAPTER 5

CONCLUSION

The conclusions that can be drawn from this dissertation project are as follows:

1. There are 8 no. of seismic risk components and these components can be ranked as shown in Table 12, in terms of their level of importance.

Table 12: Ranking of seismic risk components

Rank	Risk Components	Weightage (0-100)
1	Structural Geometry	65
2	Structural Design	60
3	Load	60
4	Geotechnical	55
5	Structural Deformation	55
6	Structural Modifications	45
7	Structural Degradation	45
8	Construction	40

2. Structural geometry is the most critical risk component for possible structural failure due to earthquake. Structural geometry consists of:

- Height of structure
- Structural stability
- Structural regularity and symmetry
- Mass irregularities
- Stiffness irregularities

- Structural drift
- Proximity to adjacent structures

3. If the structure has been designed to sustain blast load, then no further seismic risk assessment is required. This is because blast load is more critical than earthquake load.

4. As far as seismic risk elements are concerned, the seismic load that consists of OBE and SSE have the highest weightage (i.e. the value of 10). This indicates that seismic load is the most important risk element for possible structural collapse due to earthquake.

5. It is also concluded that the screening assessment method developed from this project is mainly to be used for accessible assets. For inaccessible assets it is recommended to put the risk as VERY HIGH until a shut-down window can be allocated for further inspection and assessment.

6. Due to the high technical understanding and capability required, only assessors with the Degree in Civil and Structural (C&S) Engineering, or the Degree in Mechanical Engineering should be allowed to assess the assets using this screening method. Diploma holders can also be allowed to become the assessors but with close supervision of engineers. The engineers are required to submit all assessment reports to the regional Technical Authorities for endorsement. All potential assessors shall attend a basic course conducted by C&S Engineering fraternity of PETRONAS. The course will outline the technical requirements of the assessment in line with this screening method. The course learning plan has been prepared and the full content is currently being developed by the fraternity. The course is expected to be rolled out in quarter three (July-Sept) 2019. In essence, the course will be held for 2 days, open to all potential assessors and will stress on the theory of structures and design of mechanical assets, and a practical will be held in class room based on photos of actual plant assets, to facilitate the understanding and implementation of the screening method. Process Safety criteria in classifying the assets in accordance with their criticality will also be discussed. It is anticipated that after having attended this course, the assessors can conduct the assessment effectively and in an efficient manner.

CHAPTER 6

RECOMMENDATION

Criticality of structure or building is based on the criticality of the equipment that are supported by the structure or building. Criticality is divided into 3 categories i.e. Criticality 1 (most critical), 2 and 3 (least critical). The criticality of equipment is determined via the methodology outlined in the "Equipment Criticality Assessment (ECA) Guidelines" published by the Integrated Plant Operations Capability System (iPOCS) of PETRONAS. As such it is recommended that only highly critical structures (or Criticality 1 structures) need to be assessed for seismic risk.

Criticality 1 assets are those having the consequence class of EXTREME or HIGH in accordance with ECA Guidelines, as shown in Table 13.

Table 13: Definition of Criticality 1 assets

Consequence Class	Health & Safety	Environment	Financial Impact	Criticality
VERY HIGH or EXTREME	Permanent disability or fatality	Extensive damage	> RM 10 mil	1
HIGH	Lost time injury (LTI)	Major damage	RM 1-10 mil	1

Based on the risk obtained via the risk matrix, it is recommended that maintenance and retrofitting work should be focused on assets with HIGH and VERY HIGH risk, in accordance with the Risk Matrix as given in Table 9.

It is recommended to put a VERY HIGH risk for inaccessible assets e.g. flare structure, until a shut-down window can be allocated for further inspection and assessment.

It is also recommended for a future research to be undertaken on Fuzzy based modeling to translate qualitative knowledge of seismic risk assessment into numerical reasoning, for a more accurate risk assessment approach.

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