Sensorveiledning BYG570 prosjekt

Guideline for examination and grading of the "BYG570 life extension of ageing structures" project.

In the project the students are to use an existing ageing structure to exemplify the topics of the course, including:

- How structures change with age (incl. degradation and damages but also other types of changes)
- Inspection and monitoring of structures to determine their condition
- Uncertainty in structural engineering and modelling of uncertain parameters
- Assessment of ageing structures for life extension, process and requirements
- Calculation of strength of degraded and damaged structural members
- Structural reliability analysis of ageing structures
- Repair of deteriorated and damaged structures

Instructions to the students

- Written report on relevant topic for the course (30 pages).
    - An ageing structure of your choice, real or imaginary. If you can get information about a real structure that is good, but lecturer can help with possible structures if wanted
    - Focus on a small part (beam, column, etc) - this is not a master thesis
    - Good choices for civil engineers: bridge component, building beam or column
    - Good choices for offshore engineers: jacket structure members, semi-submersibles component, ship-shaped structure component
    - Good choices for mechanical engineers: crane pedestal, crane bolt connection
- Groups of up to 4 students may collaborate on the projects.
- To be presented to class and evaluator (~last week of lectures).
- Written version to be submitted no later than Friday 24:00 on week before presentation.
- Project layout should follow general scientific report guidelines, including:
    - Introduction,
    - Problem description,
    - Theory (only explain theory you are using in the project),
    - Analysis, studies, evaluations performed as part of the project,
    - Discussions,
    - Conclusions,
    - References
- The project should include:
    - Description of the chosen structure and the issue to investigated
    - Description of typical degradations and aging mechanisms for this type of structure and material
    - Description (qualitative) of the most important uncertainties for this type of structure (loads, strength, use, accidents,…), including uncertainties related to ageing
    - Mathematical modelling of at least one of the uncertain parameters, plotting this in probability paper for selected distribution and discussion

- Describe how the actual structure could be inspected and assessed to reveal condition, loads and other conditions.
- Perform simple inspections of real structure if possible or obtain inspection reports. Discuss the significance of these findings for the construction (qualitatively). Make educated guesses (with supervisor) about these if you can't do real measurements.
- Perform strength calculations of the at least one structural element with the damages and degradations that have been revealed based on literature, own analytical derivations or FEM analyses.
- Safety evaluation of the structure by partial factor method and SRA (Monte Carlo simulations, Cornell's method or FORM) in typically three stages:
  - As new
  - As degraded
  - As repaired or mitigated

  For uncertain parameters beyond the one that have been modelled, simplified assumptions in accordance with the JCSS probabilistic code or similar is ok.
- The use of Bayesian updating of a parameter e.g. as a result of inspection, material testing, load measurements etc should be performed.
- Suggestions for the repair of the structure or the element for the damage and degradation that has been found (or assumed), including simple strength assessment for the repaired structure.

The evaluation of the project

Topic	Weight	Required content and evaluation criteria
General	10%	The choice of structure – relevance Description of chosen structure – clarity Problem description – clarity Theory – relevance and clarity References – accuracy Report form, layout, figures and tables - quality
Ageing mechanisms / changes relevant for chosen structure	10%	Typical degradation and damages for structural type and material – relevance and quality Examples from similar structures to add insight to the problem Statistics on damage and degradation and other issues is a bonus
Inspection - Describe how the actual structure should be inspected and assessed to reveal condition, loads and other conditions. - Perform simple inspections of real structure if possible or obtain inspection reports.	10%	Inspection needed to determine the condition – should show that the students have a general understanding of how to find the degradation and damage types relevant for this structure. Inspection methods and tools – suggested choices should be relevant for the damage and degradation type, the material and structural type. Performing simple inspections OR giving summary of inspection reports – Performance of simple visual

- Discuss the significance of these findings for the construction (qualitatively).		inspections with photos are sufficient if they are performing inspections. If they use reports: What, where, how ++ and the results should be summarized. Discussing significance of findings – should be evaluated based on the students understanding of how this influences the structure under evaluation. As inspection may be hazardous or impossible for many structures, the students are allowed to alternatively make educated guesses. These should be evaluated based on relevance and realism.
Uncertainty	15%	Overview of uncertainties for this type of structure – completeness, relevance and description. Mathematical modelling of one of the uncertain parameters, evaluated based on: - relevance of data, - the correctness of the statistical analysis, - the use of probability paper to check the chosen distribution, - the evaluation of the fit to the distribution, - the ability to evaluate the result (e.g. compare with characteristic values in standards). The discussion and interpretation of these analyses should be evaluated wrt the students understanding of the topic.
Strength calculations of damaged or degraded structural element	15%	100% score is given for a proper analytical calculation, based on a literature search or development of own equations. A calculation with FEM analysis gives reason for an additional bonus. Simplified variants with uniform corrosion and loss of cross section can give ~80% if they make sense. Well-justified reduction factors can give 50-70% if they make sense. Unjustified reduction factors give a maximum of 30%. No reduction for damage or degradation gives 0%. If the chosen structure does not have any damage and degradation, a reasonable and sufficiently severe damage and degradation shall be assumed, and this cannot be used as an excuse not to perform these analyses.
Structural reliability analysis (SRA) of the structure Note to external examinators: The course provides a brief introduction to SRA, and many topics are not included. It is expected at least a simple Monte Carlo simulations including the various uncertain variables	20%	100% score is given if the analysis is described clearly, including: - how the analyses are performed (g-function clear and distinct), - the distributions used for each uncertain parameter, - which parameters (e.g. mean and SD) have been used and that these are sensibly calculated, - that the modelled uncertain parameter is correctly included,

according to their probability distribution function + Cornell's beta with all variables are assumed to be normally distributed. The best students may also be able to do a simple FORM analysis. The correct combination of loads has only been mentioned and is not expected to be modelled correctly. For uncertain parameters beyond the one they have modelled mathematically, it is permitted to make simple recalculations from characteristic value to mean value and standard deviation using k-values for assumed distribution and CoV values from John Dalsgaard Sørensen's lectures on assumed distributions and CoV values in Danish standards.		- both intact and degraded / damaged construction is calculated - both MCS and Cornell's method are used as calculation methods. Cornell's beta calculation alone may give a maximum of 40% if it is correct in all other matters. Analysis results with no description of input and how the analysis was performed, in a form where the evaluator can understand it, count as 0%. Errors that indicate lack of insight and understanding count as negative. Other errors are ignored. Clearly important parameters that are not properly modelled count as negative. A simple and reasonable evaluation of the Strength of knowledge should be included. A check by the limit load and the partial factor method in addition should be performed for comparison. Analyses beyond this, such as system assessments, updates based on test loads or inspection findings… gives a bonus
Bayesian updating	10%	Reasonable attempt of updating a parameter as a result of inspection, material testing, load measurement or similar will count as fulfilling this.
Repair	10%	100% score requires a clear relation between the damage that has been observed or assumed and the suggested repair method + That it is shown by calculations (or reference to experimental data) that the repair method can re-establish the capacity of the structure. Discussion of other mitigating actions (load reduction, increased level of inspection, etc) is positive. Bonus if probabilistic calculation of repaired solution has been carried out and compared with probabilistic calculation of intact structure.
Bonus		A certain bonus (maximum 15%) can be given to student groups based on the following guidelines: - Single students in a group are automatically given 5% bonus due to the workload increase. - Any relevant work performed beyond the requirements provides a bonus based on assumed workload and relevance.

Universitetet i Stavanger

BYG 570 Life Extension of Structures

Project Report on

Life Extension of Jacket Structure Subject to Corrosion in The Offshore Environment

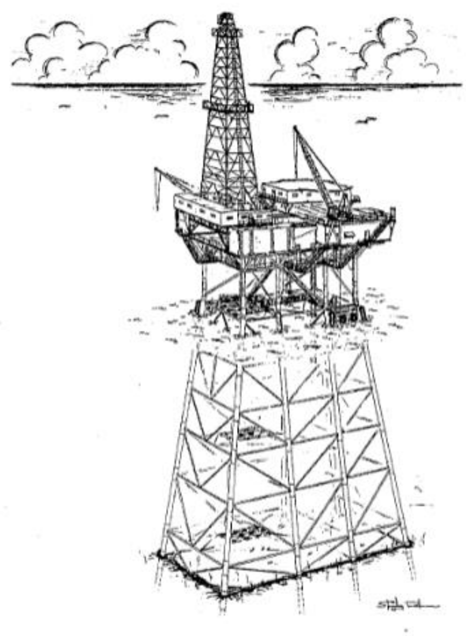

Figure 1-1. Typical Offshore Stucture Composed of Tubular Members.
[T. Dawson, Offshore Structural Engineering, 1983]

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Abstract:

The North Sea is known for its extreme weather conditions which contain severe storms, high winds, and large waves which are responsible for putting significant stress on offshore structures. The North Sea experiences strong and frequent winds, particularly during storms. These winds impose significant dynamic forces on offshore structures. In addition, the wave height in the North Sea is among the highest globally, especially during the winter months. Large waves, combined with strong ocean currents exert enormous forces on offshore platforms, increasing the risk of fatigue and structural degradation. In this report, the investigation was initiated as a consequence of the discovery of corrosion damage on the member during a routine inspection. As the North Sea's water is salty, cold, and oxygen-rich it accelerates the corrosion of steel components, and the occurrence of corrosion is a very common phenomenon in the following environment. Over time corrosion can compromise the integrity of critical structural components. The initial aim of this research work is to assess the residual strength of the corroded member under the presence of combinations of wind and wave loads. This required deep analysis of historical wind and wave data to understand the wind and wave patterns and their direct application on the structural integrity of the jacket member. The purpose of this analysis is to get a proper understanding of the dynamics of wind and wave data on an offshore structure. Another major purpose of this research is to implement and use the application of the structural reliability analysis method which is the core objective of studying this course and using those methods to find out the probability of failure under extreme wind-wave combined load conditions. This study is very important to evaluate the probability of failure under extreme wind and wave load conditions. This study also emphasized figuring out the risks associated with the ongoing operation of the corroded structure and its resistance against environmental load-induced stress (e.g. wind and wave load). After the analysis, based on the analysis some corrective measures have been provided to mitigate the corrosion damage and provide reinforcement for further safe use of the structure to extend the operation life of the offshore jacket. The findings from this research can be of significant value for developing more durable and safe offshore installations and extending their operational duration especially located in a crucial location like the North Sea where wind, wave load, and corrosional damage are significant concerns.

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1. Introduction:

The marine environment of the North Sea is particularly aggressive subjected to significant wind and wave forces. Sea water with its high salt content acts as an electrolyte that facilitates electrochemical reactions leading to corrosion. Analysis of statistical data shows that corrosion of metal structures of offshore oil and gas facilities causes 50% of the damage (Shcherban and Mazur, 2022). Steel for offshore oil and gas structures corrodes in two stages (NACE SP0176, 2007; Shcherban and Mazur, 2022). The initial stage takes place when the object enters seawater conditions. The stage of the long-term operation occurs when the object is under specific conditions for extended periods and other factors come to the fore in the weight of influence (Shcherban and Mazur, 2022). In this project, the study was initiated when corrosion was found in a member of the offshore jacket structure during a routine inspection. A specific structural support member identified with corrosion is shown in the right figure below.

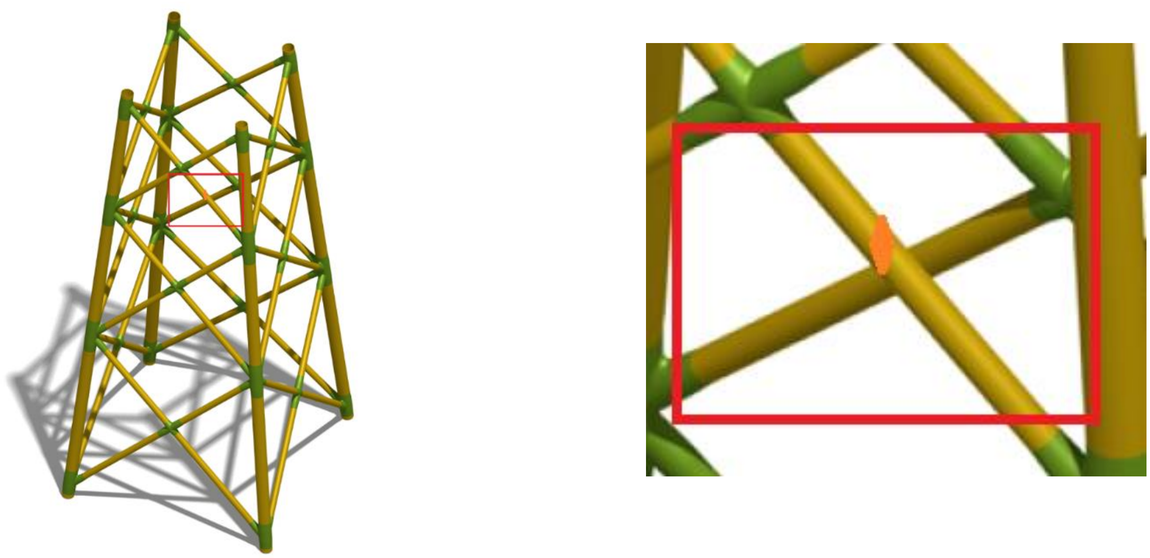


Figure 1: Model of jacket structure with corrosion shown on the right

Corrosion leads to the gradual loss of material reduction in the axial strength of a bracing member due to the reduced cross-section area thus diminishing the overall strength of the structure. This study aims to assess the strength of the degraded member and analyze the probability of failure for extreme wind and wave loads using structural reliability analysis. The analysis incorporates advanced computational modeling and simulation techniques to accurately simulate the effects of dynamic loading caused by wind and waves. Furthermore, we address the corrective measures taken to mitigate any identified vulnerabilities, ensuring the structure can withstand the rigorous demands of its operational environment. The bracing member in this study is considered a slender element and will have a buckling as a failure mode when loaded with compressional axial loads and yield when it faces the tensile force.

1.1. Fundamentals of offshore jacket structure:

Based on [1], The origin and principal applications of offshore engineering up to the present time are associated with the exploration and production of oil and gas. These activities include many key contributory elements other than offshore structures, such as process (e.g. drilling of wells) and the equipment (e.g. oil treatment facilities) involved.

Figure 2: A large wave crashing on a plaftorm (AI-generated photo, only for illustration)

In this project, we will focus only on the structural aspects of offshore engineering. The offshore jacket that we will examine in this study is a typical fixed bottom platform, this is a widely adopted solution in the oil and gas industry for offshore exploration, drilling, and production activity. These platforms are specifically designed to provide a stable and strong foundation in challenging marine environments for both deep and shallow water conditions. This type of design is engineered to distribute loads efficiently while maintaining a high degree of strength, stability, and flexibility to endure the dynamic forces encountered in offshore environments. The tubular steel members form a rigid skeletal framework that not only supports operational facilities—such as drilling rigs, production units, and crew accommodations—but also allows the structure to withstand a variety of environmental forces. These forces include wave action, ocean currents, and wind loads, all of which place significant stress on the structure. The steel members are designed to resist corrosion, ensuring long-term durability despite constant exposure to seawater and harsh conditions. In the context of this study, the offshore jacket structure is situated in the North Sea, one of the world's most demanding environments for offshore operations. Known for its unpredictable and often severe weather, the North Sea presents a unique set of challenges that significantly influence the design, maintenance, and safety protocols of these structures. The region is particularly ill-reputed for its high wind speeds and wave height. Which can reach extreme levels during storms and gales, subjecting offshore platforms to tremendous environmental pressure. As a result, wind and wave loads become a primary consideration in the structural design process. Engineers must account for both the static and dynamic forces generated by wind, ensuring that the jacket structure can flex and adapt without compromising its overall integrity or safety.

1.2. Wind load impact on Offshore structure:

In this study, the focus is placed on the influence of wind loads on the structural bracing members of offshore jacket platforms. These members are critical for maintaining the overall rigidity and strength of the structure. However, when exposed to high wind pressures, particularly in corroded sections, the risk of fatigue significantly increases. The combined effect of wind and corrosion can weaken the steel, reducing its load-bearing capacity and making it more susceptible to cracks and eventual failure. This is especially relevant in the North Sea, where structures are subjected to sustained high winds over prolonged periods, adding continuous stress to critical structural elements. To address these concerns, a detailed analysis is conducted, taking into account factors such as wind speed, direction, and the aerodynamic profile of the jacket's members. By utilizing historical wind data from the North Sea, this research models the typical and extreme wind conditions that structures might encounter. These simulations help in understanding how wind forces interact with the jacket's geometry, particularly its lattice-like framework, which is designed to diffuse wind loads across the structure. However, when corrosion sets in, especially on bracing members, these loads are concentrated in weakened areas, increasing the potential for structural damage.

1.3. Wave load impact on offshore structures:

In addition to wind loads, offshore platforms in the North Sea must contend with significant wave loads. The oceanic forces generated by waves place dynamic pressures on the jacket structure, especially its lower sections, which are in direct contact with the water. Waves exert both horizontal and vertical forces, causing oscillations and vibrations that can compromise the structural integrity if not adequately managed. The interaction between wave loads and offshore structures is particularly challenging in the North Sea due to its rough seas and frequent storms. Wave loads are highly variable, influenced by wave height and frequency. The cumulative effect of wave and wind loads in the North Sea creates a highly dynamic environment that tests the limits of offshore structures. The combined action of these forces results in complex stress patterns that can cause localized fatigue, leading to cracks, deformations, or even catastrophic failure if not properly accounted for in the design phase.

1.4. Tubular joints and its critical role in the offshore jacket structure:

Tubular connections are the backbone of offshore jacket structures, serving as the critical junctions where steel tubular members—such as legs, braces, and horizontal beams—come together to form a robust lattice framework. These joints are designed to withstand the immense forces exerted by environmental loads such as wind, waves, and tidal currents. However, while they are essential for maintaining the integrity and stability of offshore platforms, tubular connections are also highly vulnerable to **corrosion**, a major threat in marine environments. Near the splash zone, tubular joints are particularly susceptible to corrosion due to constant exposure to seawater and airborne salts. This corrosion can weaken the structural integrity of the joints, making them more prone to failure under stress.

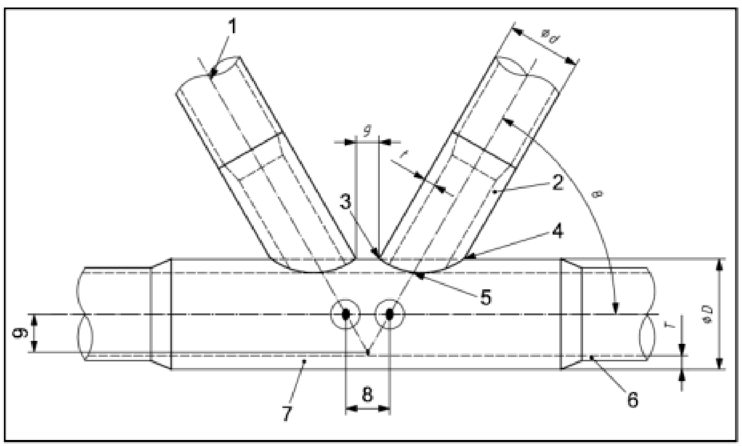


Figure 3 Simple tubular joint (ISO 19902,2007)

2. Factors Contributing to Ageing in Offshore Jacket Structures:

The offshore structures are exposed to harsh marine environments, where constant interaction with natural forces and operational demands are facing various aging mechanisms that can degrade their integrity and operational lifespan. Understanding the aging mechanism in offshore structures is crucial for ensuring safety, optimizing maintenance strategies, and prolonging the life of these essential infrastructures.

2.1. Ageing factors in offshore

John F. Kennedy said once, “Change is the law of life”. Not only humans but also structures change with time. From the day a structure gets fabricated it will change and it’s important to control and check if it’s safe. Fatigue, corrosion, material degradation, changes in loads and weight on the structure, and how the structure is used are some examples of factors that can influence the structure.

There are a lot of different changes which can be categorized into four groups, physical changes, changes to structural information, changes to knowledge and safety requirements, and technical changes. These four groups can be put together in two groups to make it easier to follow, physical and non-physical. Physical and technological changes have a direct impact on safety and functionality, while structural information- and changes to knowledge and safety requirements are the understanding of safety and functionality.

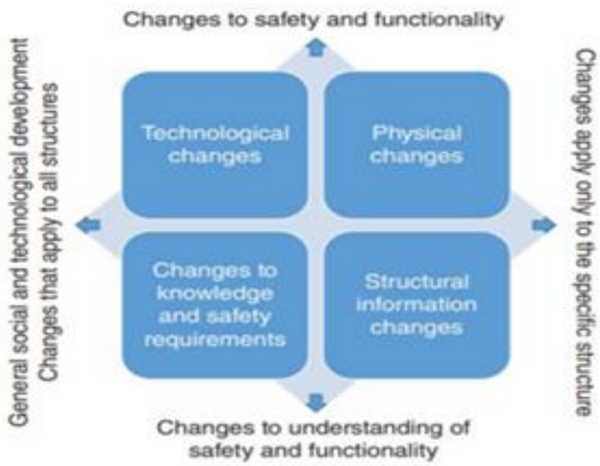


Figure 4 Four elements of aging (Aging and life extension of offshore structure, Gerhard Ersdal)

2.1.1. Physical changes:

Like it's mentioned earlier, visible changes are the easiest to detect. Physical changes are the first problems someone would think of when something gets older. Corrosion is caused by dents, fatigue, or damage from accidents, and with time it will get worse and reduce in quality. Another problem is overloading the structure by adding more equipment, which can reduce the stability and affect the durability. The weather also plays a major role when the structure gets exposed to and not taken good care of.

2.1.2. Technological changes

Aging systems are becoming obsolete. To keep up with the modernized world, old machines get replaced with something new. The reasons for that are simple, old parts are out of production, compatibility issues, and difficult to repair. When structures are built, they use the technology that's accessible today, and when new technology emerges the gap between something old and new gets wider. The disadvantage with that is older technology will be labeled unsafe. Early offshore structures were designed conservatively, with extra materials.

2.1.3. Structural information changes

This is not about the physical aspect but more about knowledge and information. Important information about the structure, loads on the structure, material used, and inspected areas are key knowledge and essential to keep the structure safe. Nothing lasts forever, the same applies to employees. They retire, being promoted or retire. Archives get lost or exist in outdated formats. That's why it's important to keep all the data stored somewhere safe.

2.1.4. Changes to knowledge and safety requirements

The world is advancing and so do science and technology. Concerning that, methods for evaluating and analyzing must be upheld. When these methods get updated, it also improves the safety assessments. Structures that used to be safe aren't satisfying the new standards. The reason for this is accidents that have occurred with similar structures, prompting engineers to re-evaluate them. The safety regulations are getting stricter.

2.2. Degradation

Something getting worse is the easiest way to explain degradation. It's a huge problem and can result in wall thinning, cracking, material properties changing, and changes in geometry.

Effect	Metal loss/ wall thinning	Cracking	Changes to material properties	Geometric changes
Degradation mechanism	Corrosion (chemical) –General –Pitting –Crevice –Corrosion under insulation –Galvanic –Stress corrosion cracking –Bacterial Flow induced metal loss (mechanical) –Erosion from solids Wear and tear	Fatigue Hydrogen related cracking –Blistering –HE –Stress corrosion cracking Creep	Hydrogen embrittlement Hardening –Overloads –Accumulated plastic deformation Environmental deterioration –Exposure period –Temperature –Bacterial	Dents from impacts Bowing (out of alignment) Permanent plastic deformations Corrosion

General idea about corrosion

The chemical process between metal and the environment is corrosion. Three conditions must be fulfilled to make the process occur.

- A metal surface is exposed to a potentially damaging environment.
- The presence of a suitable electrolyte able to conduct an electrical current
- An oxidant can cause corrosion.

These conditions must be fulfilled to start the corrosion process. Two types of corrosion that occur a lot at offshore platforms are pitting and MIC corrosion.

2.2.1. Pitting corrosion:

One type of corrosion on offshore jackets is pitting corrosion. Its small deep pits on the tubular metal surface are caused by the corrosion. This type of corrosion is more dangerous than uniform corrosion, because of its unpredictable nature. It is difficult to identify, anticipate, and create protection against. It can cause huge damage to areas with heavy loads. (AMP) KILDE

2.2.2. Microbiological-influenced corrosion:

Another type of corrosion is MIC, which is a small microorganism degrading material. This is a huge problem in the marine environment, especially for offshore jackets. There are two types of microorganisms, sulfate-reducing bacteria and iron-oxidation bacteria. SRB weakens the sulfate to hydrogen sulfide and then causes sulfide stress cracking and corrosion. Iron oxidation bacteria is self-explanatory. The bacteria are targeting iron atoms to oxidize and cause rust formation and biofilm buildup. Biofilm is a pile of bacteria clumped together on a surface. They will feed off the environment and create a corrosive environment.

2.3. Cracking

Some well-known fatigues are fatigue cracks, stress corrosion cracks, and hydrogen-induced cracks.

2.3.1. Fatigue crack:

The gradual buildup of small damage over time on the material will cause it to be dysfunctional, and that is characterized as fatigue. When ocean waves repeatedly strike the offshore platform, they can eventually cause cracking. Some of the reasons are reduced section area, stress concentrations, reduced ductility, and water ingress.

2.3.2. Hydrogen-induced stress cracking:

Hydrogen embrittlement (HE) is also called hydrogen-induced stress cracking (HISC). On the metal surface hydrogen atoms will combine with other atoms and combine too hydrogen molecules. This will create internal pressure and reduce the ductility and tensile strength. In the worst case cracking the material. Corrosion and cathodic protection are rich sources of hydrogen. It’s very important to monitor and control the structure, if not, it will corrode.

2.3.3. Stress corrosion cracking:

Stress corrosion cracking (SCC) is a combination of a corrosive environment and tensile stress.

2.3.4. Geometrical changes:

Not only corrosion and fatigue, but also damage from collision, dropped objects and bad weather can lead to dents and cracks in the structure. With time the dent will reduce the buckling and load bearing capacity. That’s why it’s important to do a regular checkup if something unusual happens like an accident. Not all accidents will be detected, and these will later cause problems.

3. Inspection and its methods:

An inspection is an organized examination or formal evaluation exercise. It involves the measurement, tests, and gauges applied to determine the characteristics of the structure. The results are usually compared to specified requirements and standards for determining whether the structure is in line with these targets.

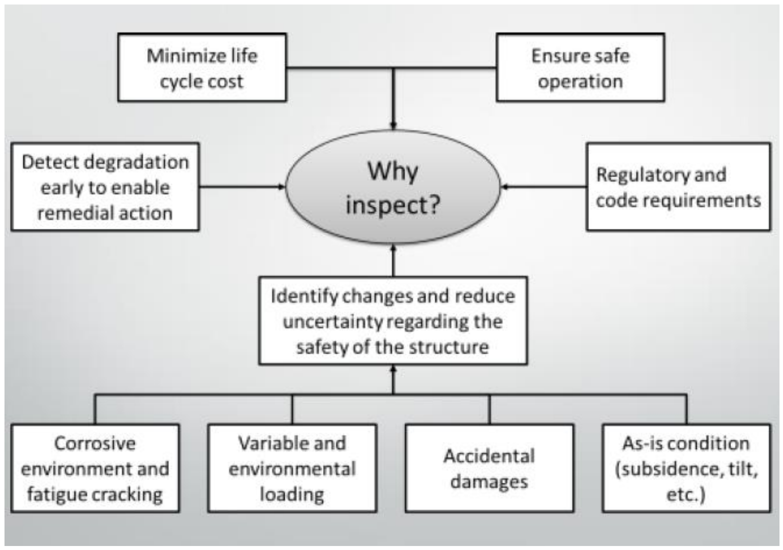
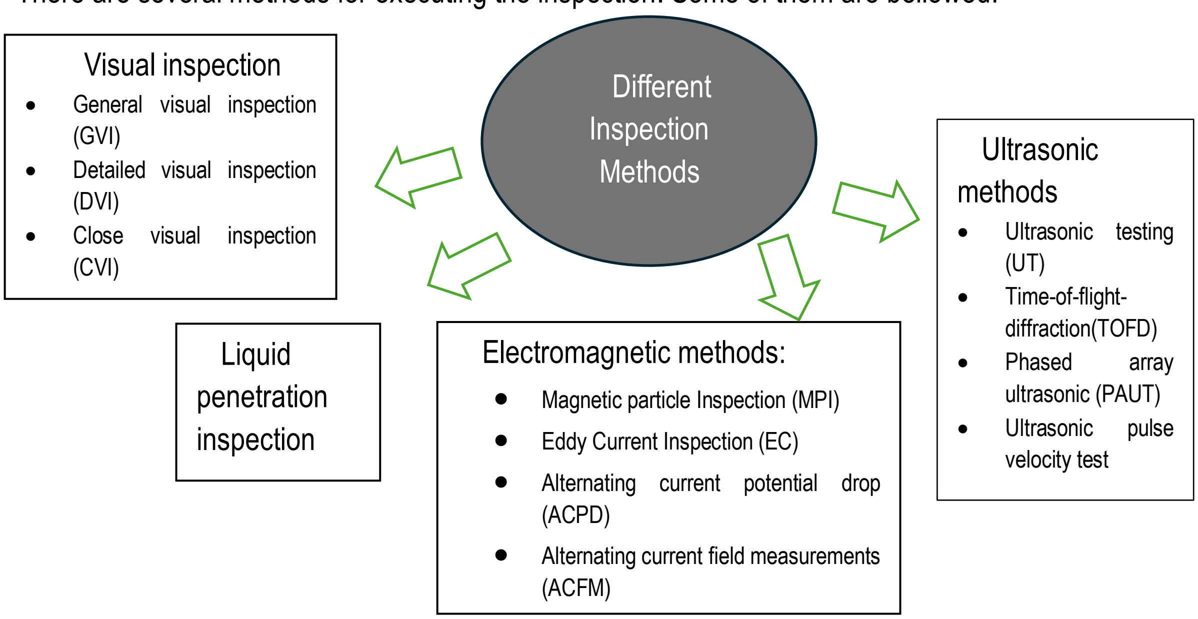


Figure 5: Necessity of the inspection. [5]

Ensuring the integrity and safety of offshore structures, such as platforms and jackets, requires a combination of inspection techniques. These techniques help identify physical defects, material deterioration, and other potential issues.

There are several methods for executing the inspection. Some of them are bellowed:



3.1. Visual Inspection:

Visual inspection is often the first line of assessment for offshore structures and is considered one of the simplest and most cost-effective methods. This technique involves trained personnel examining the surface of structural components to identify visible defects such as cracks, corrosion, and damage from external impacts. Visual inspections can be carried out manually by divers or remotely using robotic systems equipped with cameras. Visual inspection is generally inspection using the human senses. Visual inspection may not require specialized inspection equipment. Magnifying glass, crack mapping ruler, photograph, etc. is an effective way to inspect defects in the structure.

Figure 6: Remote operated vehicle (ROV) for visual inspection, Source: DeepOcen

According to DNV GL (2020), "Visual inspections provide a direct method for detecting surface anomalies and can offer preliminary insights into the overall condition of an offshore structure. However, this method alone may not be sufficient for detecting subsurface flaws." Thus, while visual inspection is critical for routine checks, it is often supplemented with more advanced non-destructive testing (NDT) techniques.

Visual inspection can be divided into the following divisions:

3.1.1. General visual inspection (GVI):

This inspection method is the most fundamental and widely used to create an assessment of offshore structures to evaluate the structure's state. Non-destructive tests rely on this method. In the offshore industry, GVI is This method does not include the cleaning process which reduces the cost. It's a swim around for a general assessment of the condition. Performed on both topside and subsea components of platforms, jackets, risers, pipelines, and support beams. This is the fastest way to identify the problem before it escalates into significant failure and allows operators to schedule timely repairs.

3.1.2. Detailed visual inspection (DVI):

Unlike GVI, detailed visual inspection involves a closer and more thorough examination of specific components or areas of the suspect to find out or identify the issues that may not be possible to identify immediately by the naked eye or camera. DVI requires minimum cleaning for inspection.

3.1.3. Close Visual Inspection (CVI):

This inspection aims to find out the fine details like minor cracks, corrosion, or surface details that are not easily detectable from a distance or through general inspection. It requires a cleaning process to bare metal. Small defects may be missed in this process also. Video and still photography are typically used, in addition to optical tools, extension mirrors, gauges, calipers, length gages, etc. This type of inspection is performed by certified inspectors who document findings and may recommend further analysis using non-destructive testing (NDT) if it seems required.

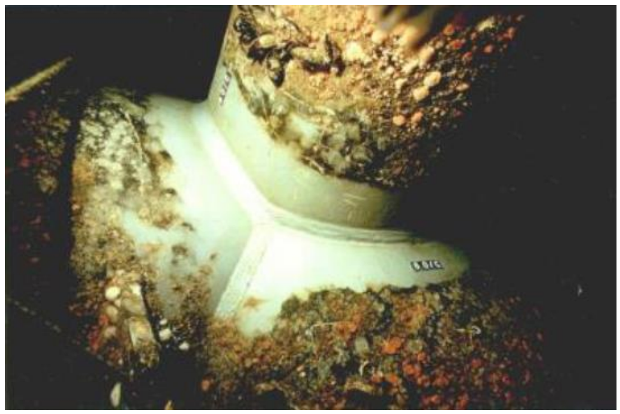


Figure 7: Close visual inspection (CVI) of welding after cleaning.

3.2. Liquid penetration inspection:

This is the most used method to check surface-breaking defects in all nonporous materials (metals, plastics, or ceramics). It can indicate flaws regardless of the size, properties, internal structure, and chemical composition of the inspected material. This liquid penetration can seep into various types of minute surface openings (as fine as 0.1 µm in width by capillary action.

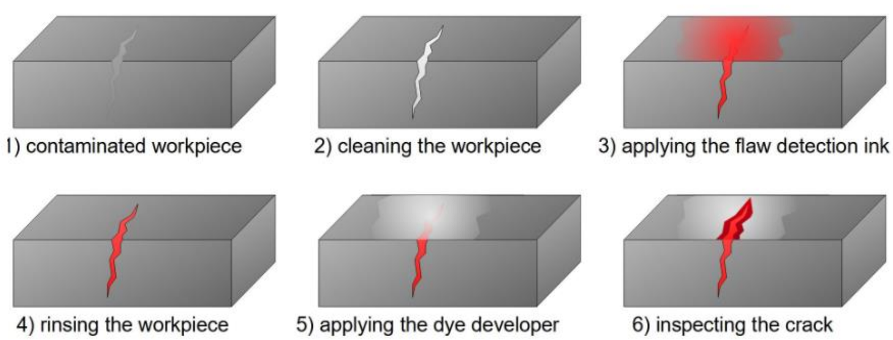


Figure 8 Liquid penetration test procedure. (Soruce:Tec-science.com)

3.3. Electromagnetic methods:

In this process, electric current is passed or introduced into a metallic material so an electromagnetic field is created which is sensitive to defects. By creating the variation in the magnetic field the defects in the metallic body can be found.

Output from the electromagnetic method is as follows:

- It can explore surface defects and near-surface defects.
- Measure the crack length and location of the defects.
- Depth and other parameters of the crack and faults.

3.3.1. Magnetic Particle Inspection (MPI):

The result of this inspection process is initiated by magnetizing the part and applying ferrous particles, which gather at any discontinuities, making themselves visible. MPI is very effective for identifying cracks and flaws in the weld and structural components. It's a widely used method for reliability and simplicity. It provides immediate results and is commonly used alongside other inspection methods.

3.3.2. Eddy current inspection (EC):

Principles of electromagnetic induction are used in this testing mechanism. A coil carrying an alternating current creates a magnetic field and introduces eddy currents in the test material. Flaws in the material such as cracks or corrosion disrupt these currents and alter the electromagnetic response and signaling defects. This process is widely used for inspecting nonferrous metal and weld. Valued for its ability to detect defects without direct contact with the material surface.

3.3.3. Alternating current potential drop (ACPD):

It's an effective test method for both ferrous and non-ferrous metals. It detects cracks by passing the alternating current through the material and measuring the potential drop to identify the faults. This is a method that is sensitive to surface and near-surface defects and provides data about the properties of the crack.

3.3.4. Alternating current field measurements:

It's a non-contacting method capable of detecting defects through coatings. In this process, electric current is induced in the material and the associated electromagnetic field is measured. The presence of disturbance in the magnetic field can be related to measuring the size of a defect. This is becoming the most widely used method for detecting surface defects as it's a single handheld probe containing field induction and measurement sensors. It's also very accurate for sizing defects up to 25mm in depth is claimed.

3.3.5. Ultrasonic method (UT):

In this method, high-frequency sound is created by a probe and transmitted through the test material to measure distances to reflecting surfaces, which can be internal defects and the back wall.

There are generally four types of Ultrasonic methods:

- Ultrasonic testing (UT)
- Time-of-flight-diffraction (TOFD)
- Phased array ultrasonic (PAUT)
- Ultrasonic pulse velocity test

UT, TOFD, and PAUT can be used for detecting internal defects and thickness measurements in steel structures.

For concrete structures, an ultrasonic pulse velocity test can be used to assess the uniformity and quality of concrete. It can also identify the presence of voids and cracks.

Advantages and use of the Ultrasonic method:

- Ultrasonic inspection is performed by using frequencies between 1 and 25 MHz.
- It's used for thickness measurements and to monitor the components of floating structures to detect corrosion.
- It can be used underwater by a ROV. But generally, it's very useful to inspect internally in hull and compartments and the top side of the structure.
- The energy reflected from various interfaces and flaws is used to identify the presence and position of flaws, the thickness, and the depth beneath a surface.

4. Load and Strength calculations:

4.1. Wind and Wave Load Statistics:

The behavior of wind loads on offshore structures is highly complex, as wind interacts with the exposed surfaces of the platform. To calculate the load on a bracing element we have used the wind and wave data from NORA10_6572N_0763E to calculate the axial loads acting on the corroded bracing member. The data consists of the wind speed, significant wave height, and peak wave period for every 3 hours, from September 1, 1957, to July 31, 2019. The histograms of the wind and wave data are presented in Figure 9.

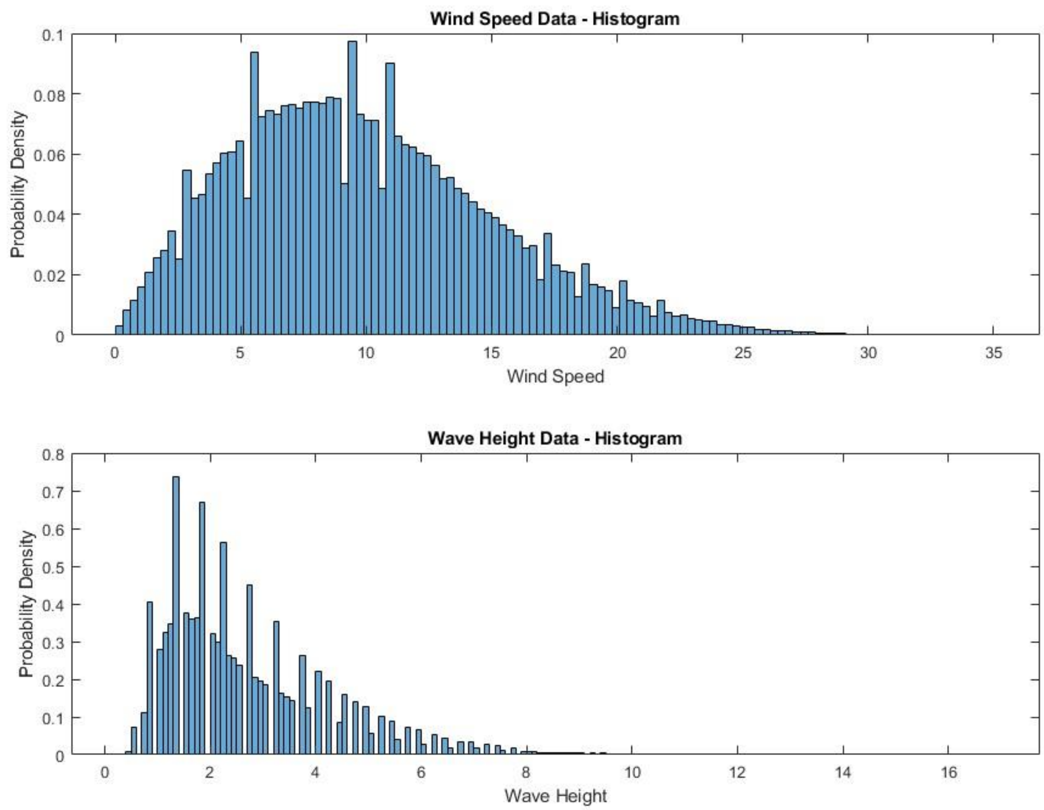


Figure 9: Histogram of Wind Speed and Wave Height Data

Wind loading and wave loading have a great deal of influence on the design of the structures both onshore and offshore due to the nature of these loads being significantly varying in direction and speed producing both static and dynamic effects (Mohammadi, 2013). Since the surface roughness offshore is rather low, and the scope of this project won't allow for a dynamic wind-wave interaction analysis, the sea surface effects will be ignored.

4.1.1. Kolmogorov-Smirnov Test

Kolmogorov-Smirnov (K-S) test is a non-parametric statistical test used to compare a sample distribution with a reference probability distribution. As a first step, the K-S Test was applied to applied to the data to determine the best distribution.

$$D = max|F_1(x) - F_2(x)|$$

Where:

- $F_1(x)$ Is CDF of the reference distribution
- $F_2(x)$ Is the CDF of the sample

The following results were obtained with MATLAB's built-in function kstest:

Table 1 Kolmogorov-Smirnov Test Results

Sample	Normal Distribution	Weibull Distribution	Gumbel Distribution
Wind Speed	0.0000	0.0000	0.0000
Wave Height	0.0000	0.0000	0.0000

Due to large data sample size results were inconclusive.

4.1.2. Probability Papers

Probability papers are special types of graph papers or plotting templates used to assess whether a dataset follows a particular probability distribution. They allow for a visual comparison of a dataset against a theoretical distribution.

Typically:

- Axes are scaled based on the theoretical cumulative distribution function (CDF) of the chosen probability distribution.
- If points form a straight line, then the dataset follows the distribution

Probability papers for Normal, Weibull, and Gumbel distributions are presented below.

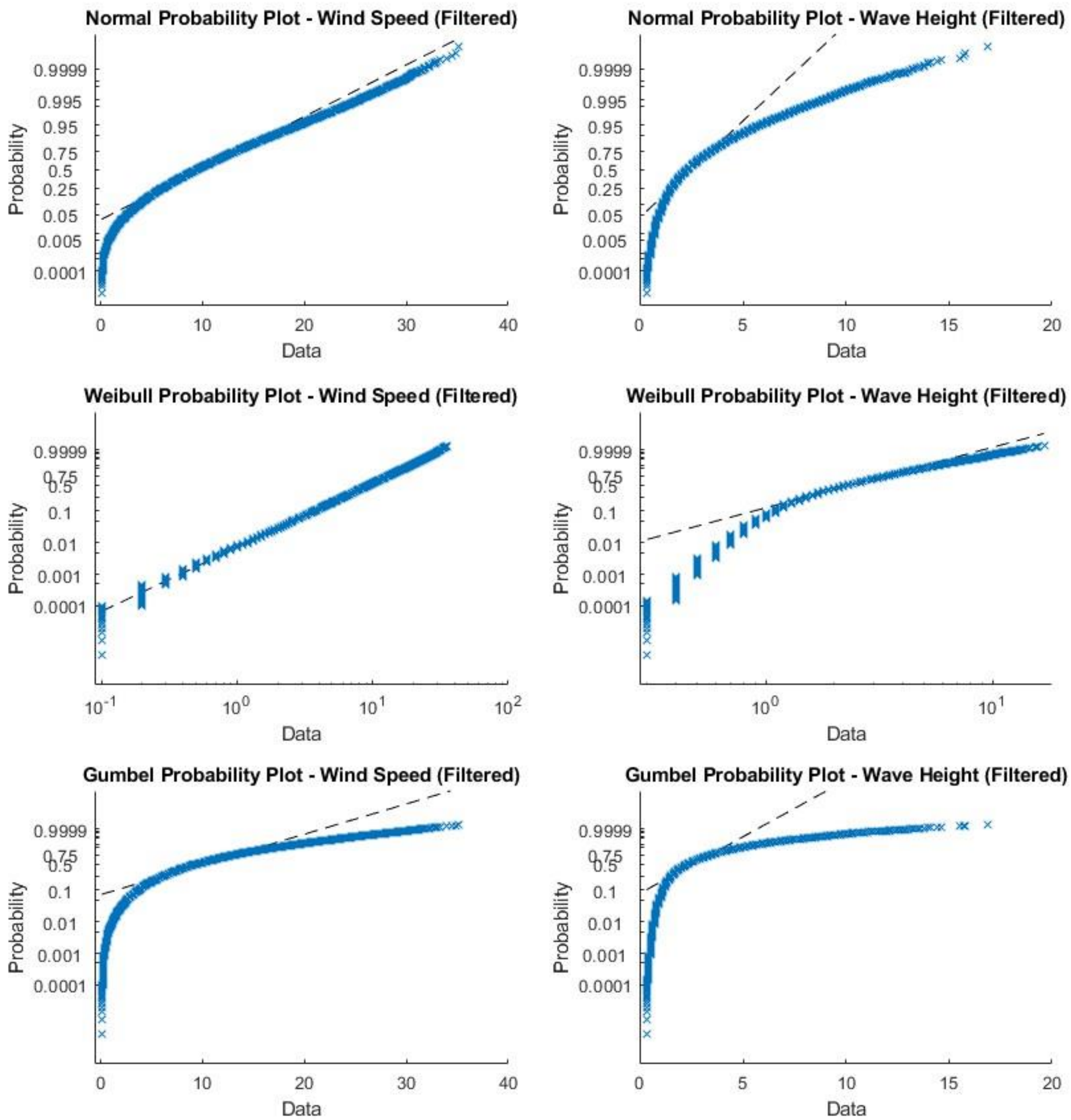
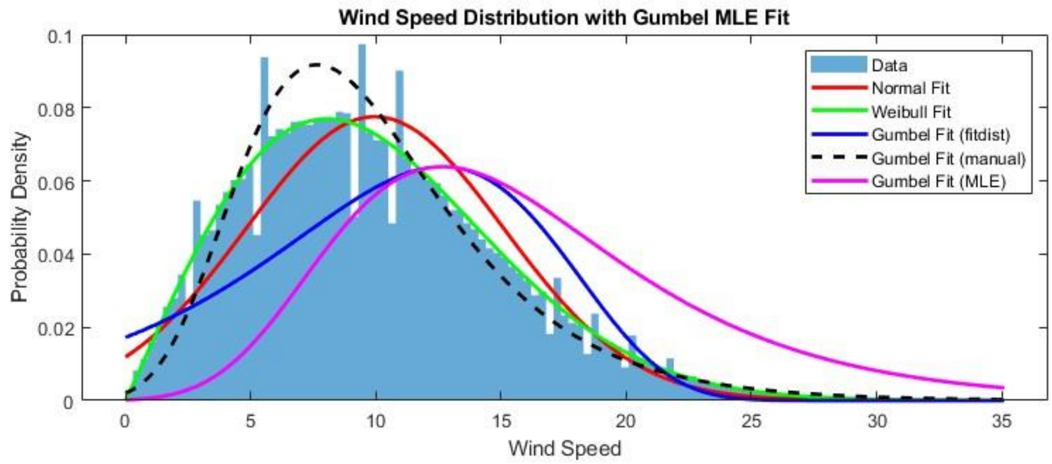


Figure 10 Probability Papers For Different Distributions

As can be observed from Figure 10, the extreme values in the upper tail seem to be best fitted to the Weibull Distribution.

Furthermore, different distributions were plotted with a histogram of the wind and wave data which are presented in figure 11. Again it can be observed that the Weibull seems to be the best fit for both wind and wave data.



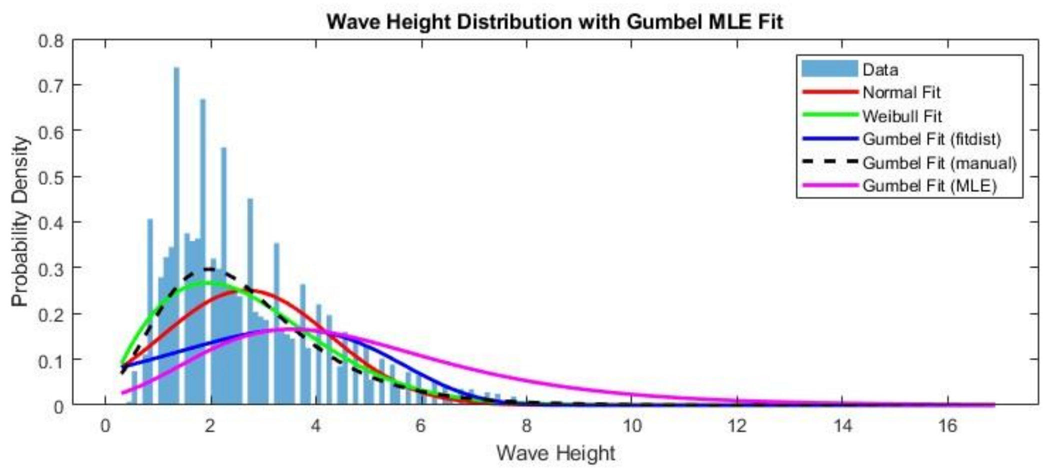


Figure 11 Distribution Plots over Histogram of the Dataset

4.1.3. Weibull Distribution

Then the scale and shape parameters of the Weibull distribution were calculated (in MATLAB):

Table 2 Weibull Distribution Parameters

Sample	Scale (A)	Shape (B)
Wind Speed	11.2437	2.0281
Wave Height	3.0261	1.8124

Also, wind speed and wave height corresponding to the ULS and ALS of the data were calculated with return periods of 100 and 10000 years respectively.

Table 3 ULS and ALS Wind Speed and Wave Height

Sample	ULS	ALS
Wind Speed	39.15 m/s	65.69 m/s
Wave Height	13.76 m	23.99 m

4.1.4. Gumbel Max Distribution

In the scope of this project corroded condition of the structure is subjected to extreme wind and wave conditions, which were selected to be the monthly maximum wind speed and significant wave height.

Monthly maximum wind speed and significant wave height were sorted and fitted with a Gumbel Max Distribution. Gumbel max distribution plotted with the histogram of the monthly maxima and over the histogram of the entire data set is presented in Figure 12 and Figure 13, respectively.

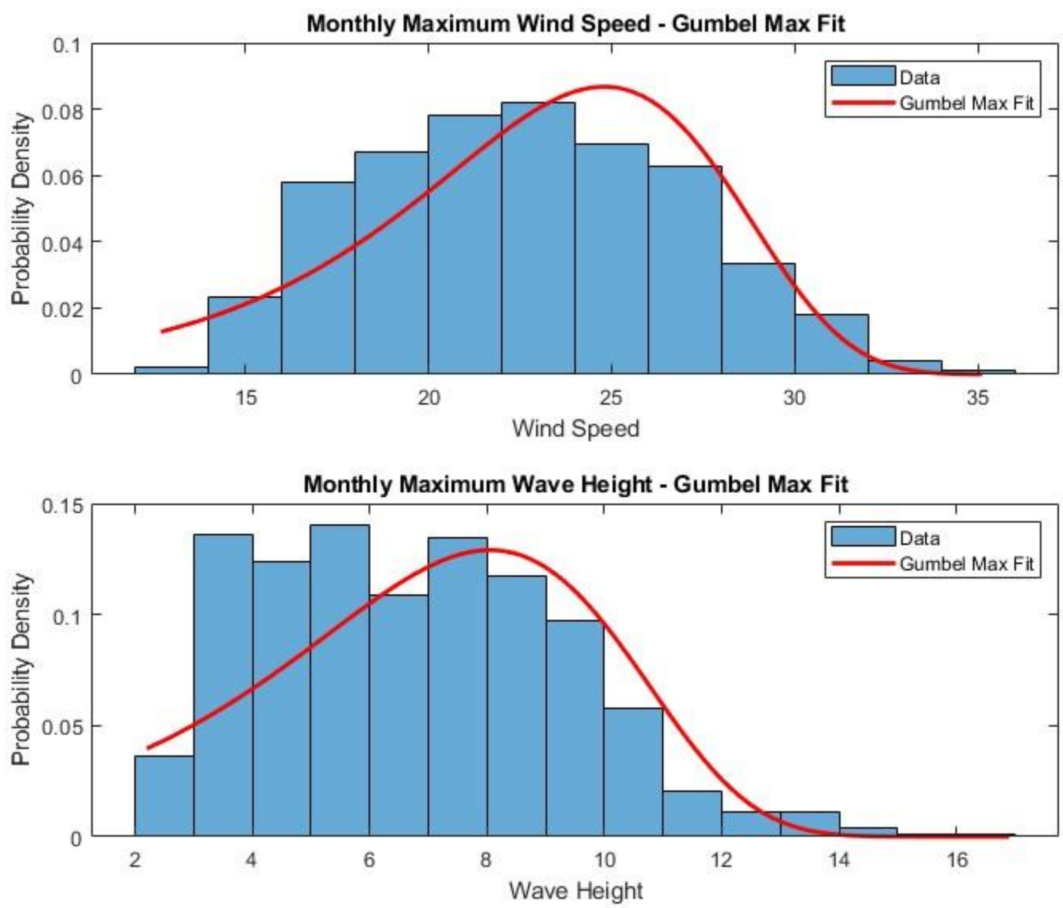


Figure 12 Gumbel Max Plot against Monthly Maximum Histogram

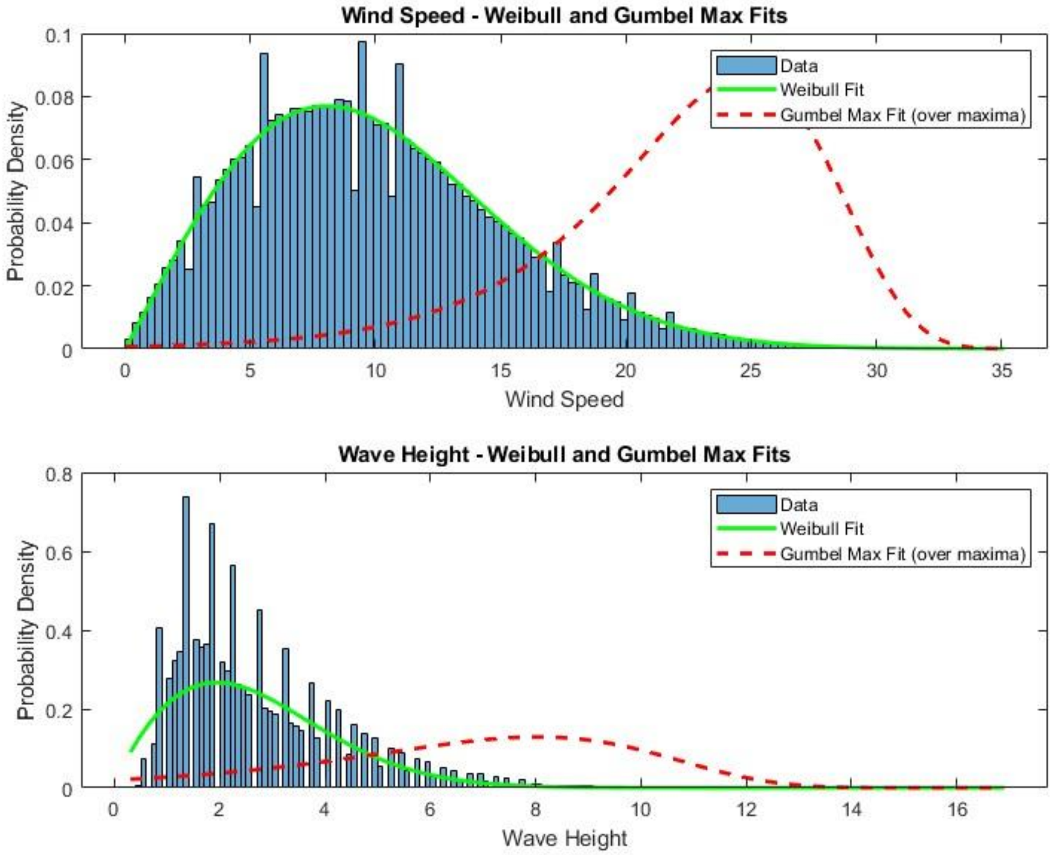


Figure 13 Gumbel Max against the Weibull Distribution with Data Set Histogram

The correlation between wind speed and the significant wave height is a well-known phenomenon. For this reason, the correlation coefficient was calculated and found to be 0.7568 for the data set.

The calculated correlation coefficient indicated a very strong correlation between wind speed and wave height as expected.

4.2. Wind and Wave Load Calculations

DNV (Det Norske Veritas) provides standards, including the calculation of wind load on offshore structures. The calculation of wind load is often based on principles derived from fluid dynamics and may follow the general equation to determine the force exerted by wind on an exposed structural member.

The general equation for wind load on a structural member, according to DNV [2], is based on drag force theory and is expressed as:

$$F_{wind} = \frac{1}{2} * \rho_{air} * U_{wind}^{2} * C_d * A$$

Where;

$F_{wind} = Wind\ Force\ (N)$

$\rho_{air} = Air\ Density\ (typically\ 1.225\ \ kg/m^3$

$U_{wind} = Wind\ Speed\ (m/s)$

$C_d = Drag\ Coefficient\ (dimensionless), depends\ on\ the\ shape\ and\ roughness\ of\ structure$

$A = Projected\ area\ of\ the\ structure\ (m^2)$

To calculate the wind load on a steel jacket structure. The shape coefficient for a rectangular platform shape is assumed as Cd≈1.2 which is used for flat surfaces facing wind direction in practical applications like DNV-RP-C205, the shape coefficient is very similar or equivalent to the drag coefficient for certain types of structures (e.g., circular or rectangular cross-sections) because the drag force of the structure is primarily determined by the shape. In our case, we will also use the Cd value as the average value of 1.2 since in the scope of this project the platform area on top is assumed to be a flat surface. The wind load on the platform is assumed to be action on the bracing in question directly because of the time and scope of the project.

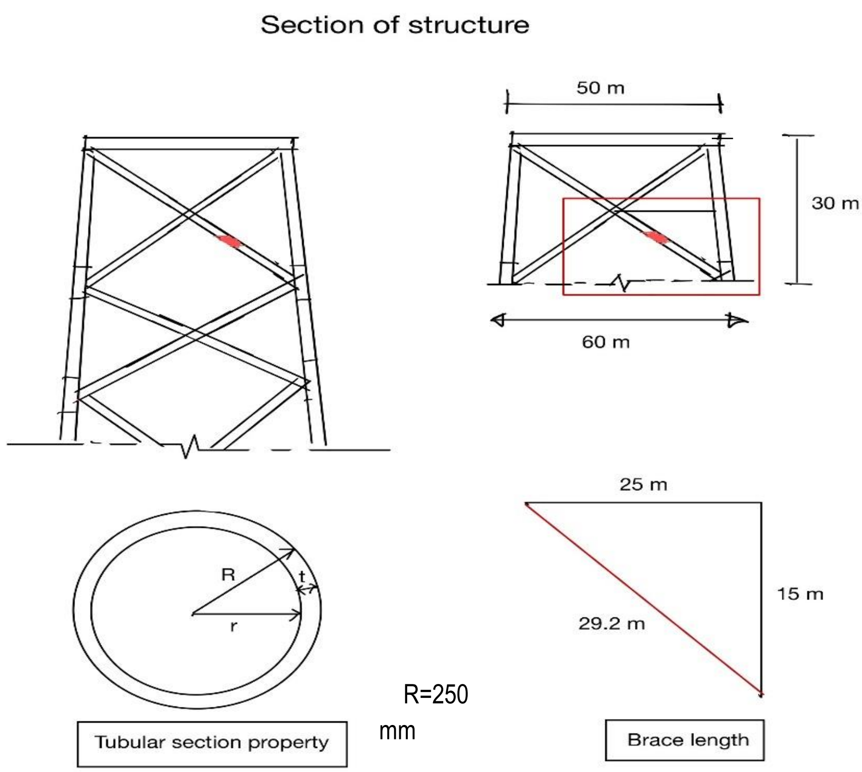


Figure 14, Dimension of structural member

Table 4 Wind Force on Platform

Force	Value	Unit
Force on the platform	1731.065	KN
Force on the bracing member	1731.065	KN

In the case of wave load, it's very critical to analyze the loads applied on the structure due to very extreme weather conditions. In this project, we are using hindcast significant wave height data from a field in the North Sea to calculate the axial load acting on the selected corroded bracing member. The data consists of the significant wave height (*Hs*) for 3-hour periods, from September 1, 1957, to October 31, 2018, for waves coming from a direction of 225 to 315 degrees, and accounts for 47.2% of the whole data set, but as a simplification, all the wave loads with their respective significant wave height and peak period are assumed to be acting on our structure leg from the direction shown in below figure. The direction of the waves concerning the jacket structure can be seen in Figure below.

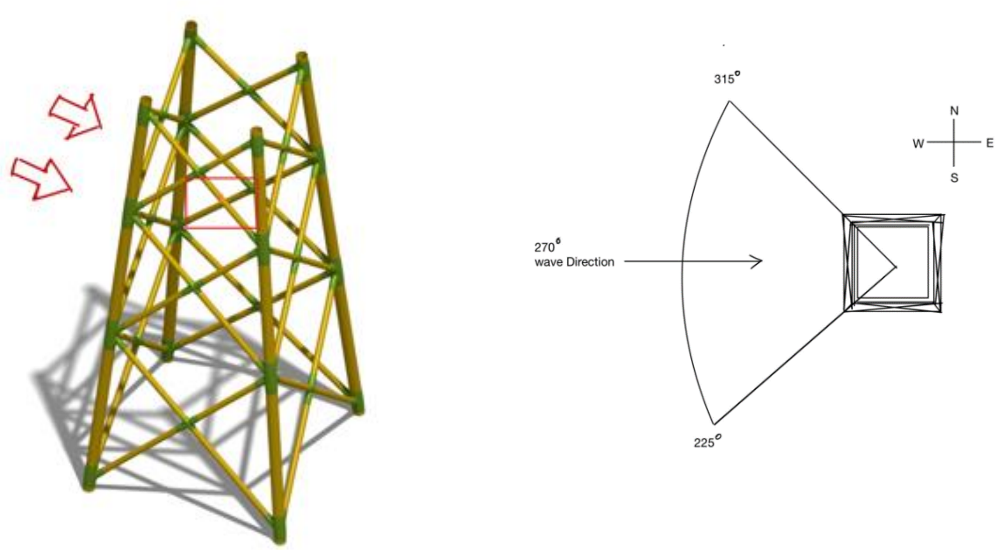


Figure 15: Direction and positon of wave load

The Morrison Formula is a widely used empirical formula for calculating wave loads on slender structures, such as offshore jacket structures. It is particularly applicable to structures where the dimensions are small relative to the wavelength, meaning that the waves interact with individual components of the structure (such as legs and braces) rather than the entire structure. According to the [3], The wave load on a horizontal cylinder may be computed by an empirical equation of the form:

$$F_{wave} = \frac{1}{2} * \rho_{water} * U_{wave}^{2} * C_d * D$$

Where;

$F_{wave} = Wave\ Force\ (N)$

$\rho_{water} = Water\ Density\ (typically\ 1025\ \ kg/m^3$

$U_{wave} = Wave\ Speed\ (m/s)$

$C_d = Drag\ Coefficient\ (dimensionless), depends\ on\ the\ shape\ and\ roughness\ of\ structure$

$D = Leg\ Diameter\ (m)$

The objective of the bracing in this structure is to transfer the horizontal load to the foundation. We are considering the columns are perpendicular to the foundation.

Wave Force	Value	Unit
Force on the leg	482.043	KN
Force on the bracing member	482.043	KN

4.3. Strength Calculation:

In this project, we analyze tubular bracing subjected to varying forces in axial compression and tension, which fluctuate according to external load directions, like wind. These alternating load conditions require strength calculations that account for both compressive and tensile stresses to ensure the bracing can withstand a full range of potential forces. When the tubular bracing is in an intact, undamaged state, determining its strength is relatively straightforward. This is due to the availability of established formulas in design codes, such as Eurocodes and NORSOK standards (notably the NORSOK N-004 standard, Norge, 2004), which provide comprehensive guidelines for such calculations. However, assessing the strength of bracing becomes considerably more complex when degradation, particularly corrosion, impacts the tubular members. Corrosion reduces the cross-sectional area of the material, diminishing its load-bearing capacity and introducing new complexities in the calculation of strength. Although design codes, including the NORSOK N-004 standard (2004), contain specific formulas to calculate the strength of corroded tubular members, these codified approaches have shown a tendency toward conservatism when compared with experimental testing outcomes. Earlier work by Vo, Hestholm, Ersdal, Oma, and Sivertsvik (2019), has revealed that these formulas may often underestimate the true strength of corroded members. This conservative bias can lead to overly cautious design choices or unnecessary repairs, underscoring a discrepancy between theoretical predictions and experimental findings. To bridge this gap, this project applies a refined analytical methodology to produce more accurate strength calculations for corroded tubular members. This approach leverages two primary analytical components: the 1st Principal theory and the Perry-Robertson equation. By integrating these methods, the analysis can more accurately account for the loss in the cross-sectional area resulting from uniform corrosion around the circumference of the tubular member. Adjusting the net cross-sectional area in this way provides a more realistic estimate of the bracing's remaining load-bearing capacity, even under corroded conditions. This customized analytical approach not only enhances the accuracy of strength predictions for corroded tubular members but also improves the alignment of theoretical calculations with empirical data. By implementing these tailored adjustments, this methodology offers a more dependable and comprehensive understanding of the structural integrity of tubular bracing, especially in environments where corrosion-related degradation is a significant concern.

The member assessed has corrosion damage, according to Figure 11 with various corrosion thicknesses and angles.

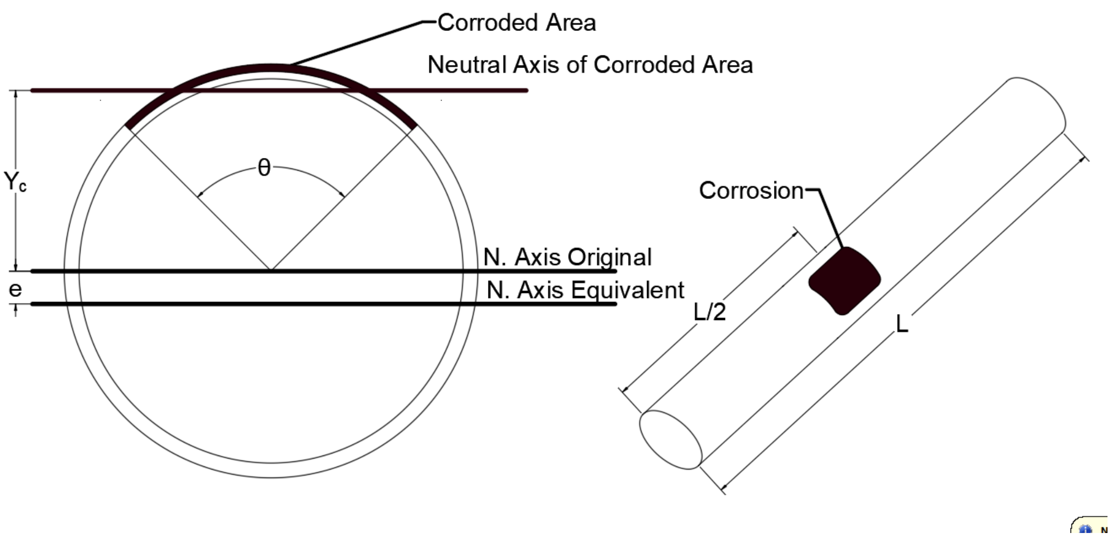


Figure 16 Corrosion damage and position

The Perry Robertson equation is used to calculate the compressive capacity of the member using the following properties:

Yield strength	f_y	355 Mpa
Young modulus	E	200 Gpa
Diameter	D	500 mm
Thickness	t	30 mm
Length	L	29.2 m
Effective length factor	k	0.7 (according to NORSK N-004 K-bracings [4])

$$\frac{N}{N_{ULT}} + \frac{N * (e_0 + e_c)}{M_{ULT} * (1 - \frac{N}{N_E})} \leq 1$$

Where:

N_{ULT} = Ultimate axial strength

M_{ULT} = Ultimate moment capacity

e_o = Geometric imperfection, chosen as L/1000 in this project

e_c = Eccentricity due to corrosion

N_E = Euler load

The compressive capacity with corrosion thickness with increasing steps of 5 mm is shown below in the figure,

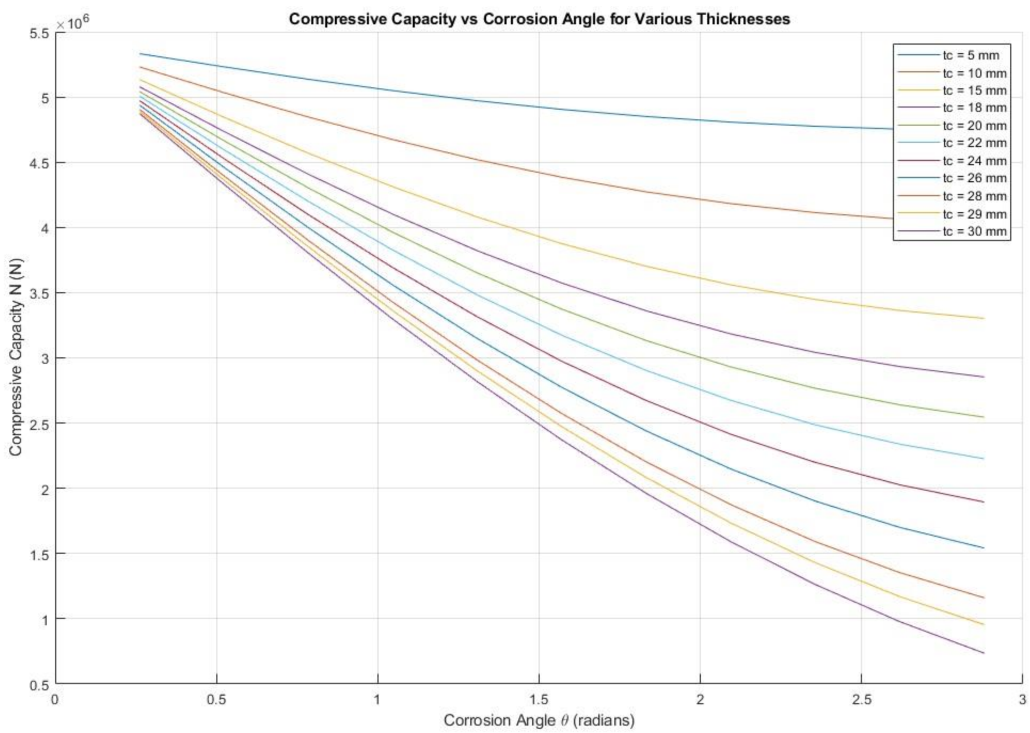


Figure 17 Compressive Capacity vs Corrosion Angle For Various Thicknesses

Combined stress in outer fiber due to axial load and bending moment according to used axial tension capacity general formula, should be less or equal to one.

$$\frac{N}{N_{ULT}} + \frac{N}{M_{ULT}} \leq 1$$

We can rewrite this equation as,

$$N = \frac{f_y}{\frac{1}{A_{net}} + \frac{(e_0 + e_c)}{W_p}} \leq 1$$

The tensile capacity with corrosion thickness with steps of 5 mm is shown in the figure.

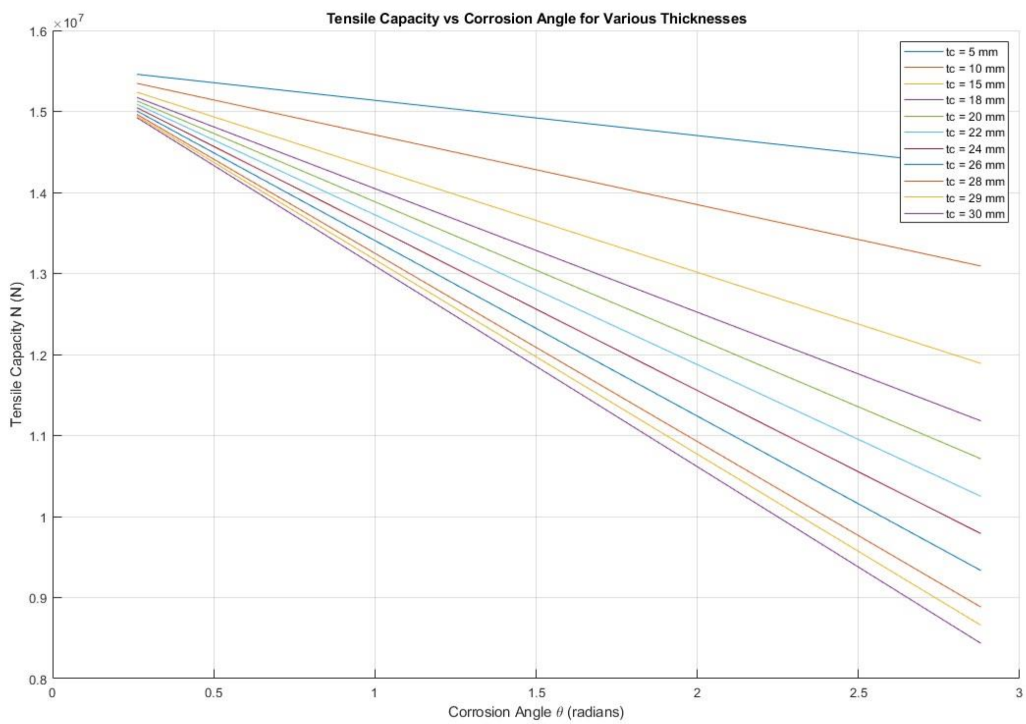


Figure 18 Tensile Capacity vs Corrosion Angle for Various Thicknesses

4.4. Resistance Uncertainties

A COV of 5% for the corroded area was used in this analysis. Also, a COV of 10% was used for the steel according to material, geometric, and load variables.

The nominal yield strength is typically 5% lower quantile. A mean value of 355 MPa and a standard deviation of 10 MPa was assumed for the bracing material.

Then it was assumed that 5 tests were conducted on similarly corroded members in the initial stages of the corrosion with test results of 310 Mpa, 295 Mpa, 370 Mpa, 300 Mpa, and 325 Mpa the mean and standard deviation of the yield strength could be updated with Bayesian Inference.

$$posterior(x) = \frac{(prior(x)) * (likelihood(x))}{\int_{-\infty}^{\infty} (prior(x)) * (likelihood(x))}$$

Table 5 Updated Yield Strength

Parameter	Prior	Posterior
Yield Strength Mean	355 MPa	351.51 MPa
Yield Strength Standard Deviation	10 MPa	9.49 MPa

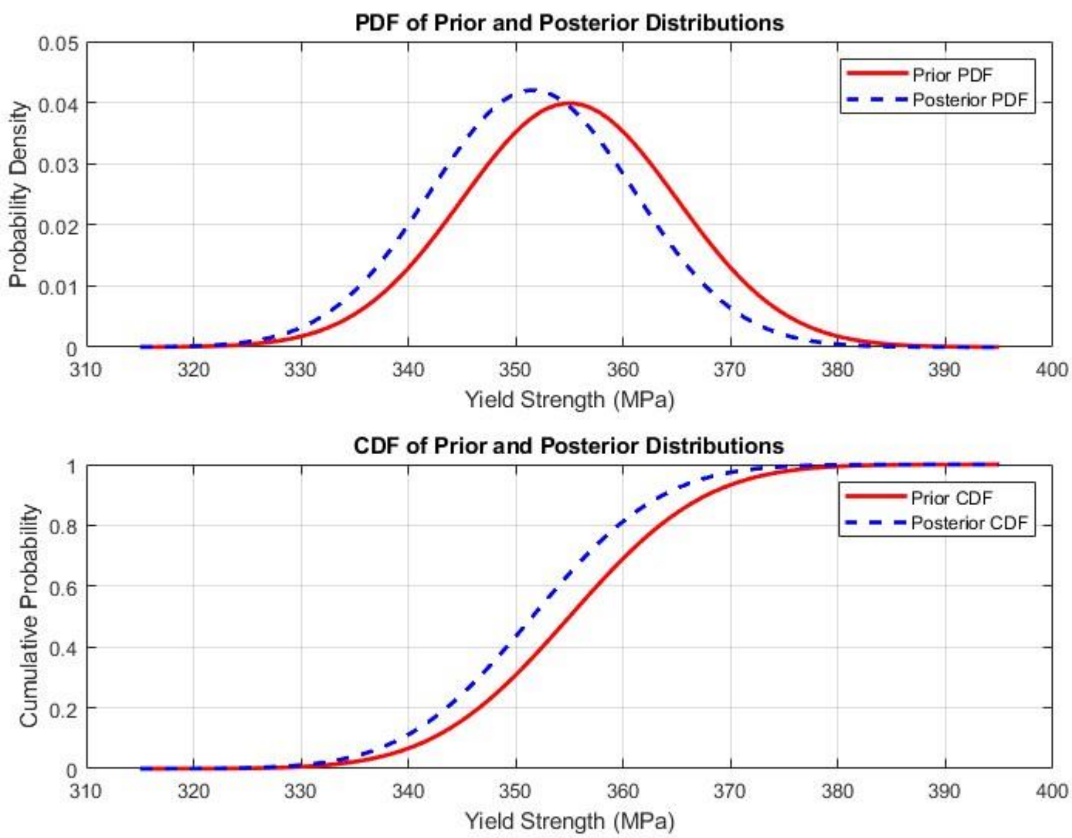


Figure 19 PDF of Prior and Posterior Distributions of Yield Strength

5. Target safety index:

The target safety index (β) for offshore structures as specified by DNV (Det Norske Veritas) is mainly combined and based on the reliability principles outlined in standards like DNV-RP-C205, DNV-ST-F101, and other relevant offshore standards. These target indices are typically determined considering the consequence of failure, the design life of the structure, and its operational context.

5.1. Target Safety Indices from DNV Standards

The safety index β, values are primarily derived for **ultimate limit states (ULS)** and are aligned with the failure probability P_f as follows:

Table 6. Consequences with different B values

Consequences	Different β values
High consequence of failure (manned structures or significant environmental impact)	β ≈ 4.7 Corresponds to an annual failure probability $P_f \approx 10^{-6}$
Medium consequence of failure (e.g., unmanned structures with moderate economic or safety impact)	β ≈ 3.8 Corresponds to an annual failure probability $P_f \approx 10^{-4}$
Low consequence of failure (e.g., less critical offshore components)	β ≈ 3.3 Corresponds to an annual failure probability $P_f \approx 10^{-3}$

5.1.1. Specific Guidance for Offshore Structures

For offshore structures, DNV emphasizes that the target safety index β should be chosen based on:

- **Risk level**: Higher risks demand higher β values.
- **Exposure type**: Manned vs. unmanned facilities.
- **Design lifetime**: Reliability requirements are calibrated for the design period (e.g., 20, 50, or 100 years).

These target indices align closely with international standards, such as ISO 19902 and EN1990, In EN1990 Guidance for the target safety index is given below:

Consequences class	Description	Examples of building and civil engineering works
CC3	**High** consequences for loss of human life, or economic, social or environmental consequences **very great**	Grandstands, public buildings where consequences of failure are high (e.g. a concert hall)
CC2	**Medium** consequences for loss of human life, economic, social or environmental consequences **considerable**	Residential and office buildings, public buildings where consequences of failure are medium (e.g. an office building)
CC1	**Low** consequences for loss of human life, and economic, social or environmental consequences **small or negligible**	Agricultural buildings where people do normally enter (e.g. storage buildings), greenhousses

Figure 20: Consequence classes according to EN 1990 (2002) (Kala, 2015)

Table 7 Recommended minimum values for reliability index p (ultimate limit states), EN 1990

Reliability Class	Minimum values for β	
	1-year reference period	50 years reference period
RC3	5.2	4.3
RC2	4.7	3.8
RC1	4.2	3.3

5.2. Safety Index-Monte Carlo Simulation (MCS):

To determine the probability of limit state exceedance for corrosion in the targeted member we used the Monte Carlo simulation (MCS). The steps followed are given below:

1. Variables in resistance R and load S are randomly generated by keeping the order of their respective distributions.
2. A total of 1 million simulations are executed in the Monte Carlo simulation. The limit function G=R-S is computed for each set of generated variables.
3. Counting the number of limit state exceedances in the entire simulation.
4. Using the formula, compute the probability of failure.

$$P_f = \frac{total\ no. of\ limit\ state\ exceedances\ (G < 0)}{total\ no. of\ simulations}$$

5. Compute safety index $\beta = -normcd\ f^{-1}\ (P_f\ )$

The following figures show the R, S, and G distributions for the corrosion scenarios:

- At t = 1 year (Assumed as-built condition)
- At t = 5 years
- At t = 10 years
- At t = 15 years
- At t = 20 years
- At t = 25 years
- At t = 30 years
- At t = 35 years
- At t = 40 years
- At t = 45 years
- At t = 50 years

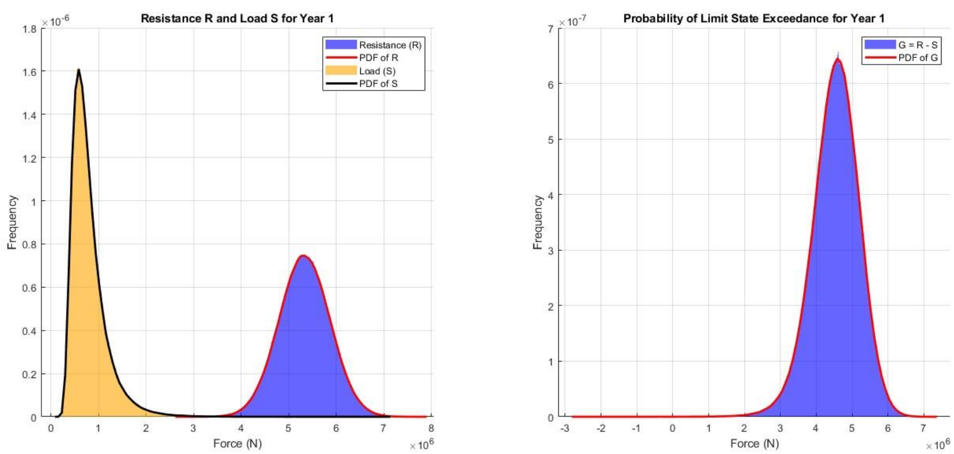


Figure 21 R, S, and G distributions for t=1

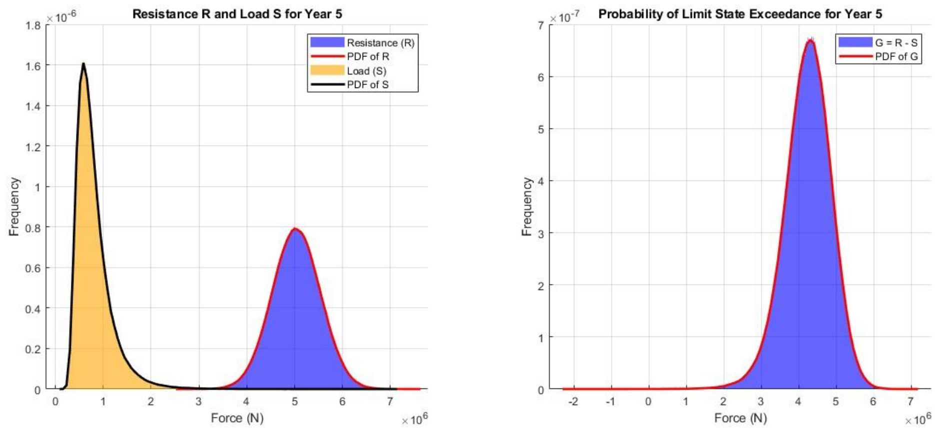


Figure 22 R, S, and G distributions for t=5

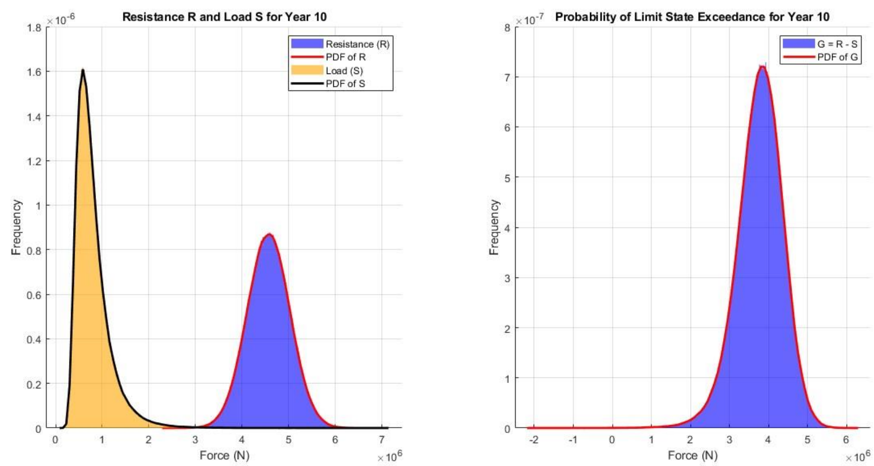


Figure 23 R, S, and G distributions for t=10

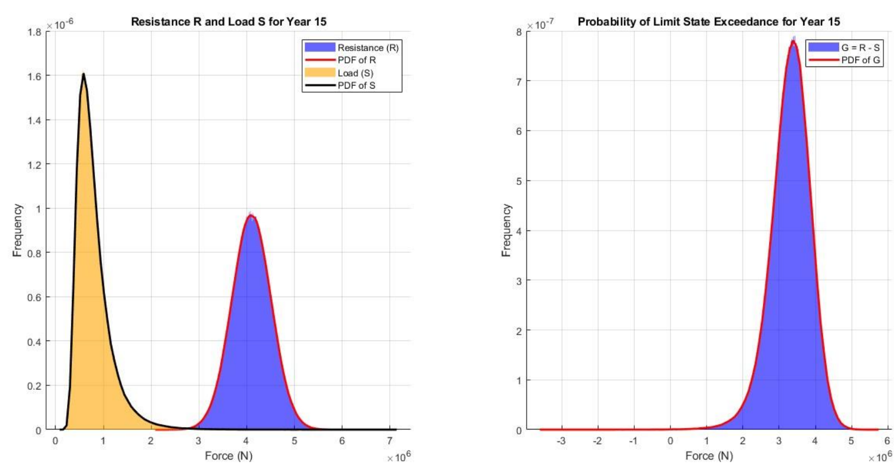


Figure 24 R, S, and G distributions for t=15

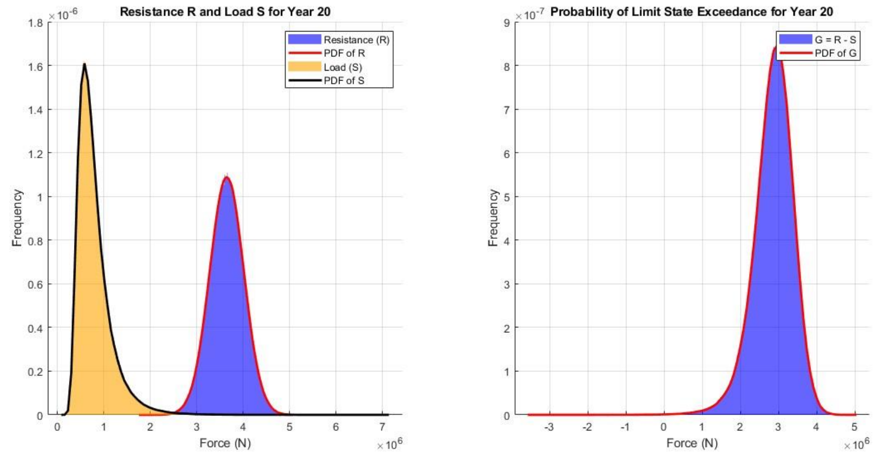


Figure 25 R, S, and G distributions for t=20

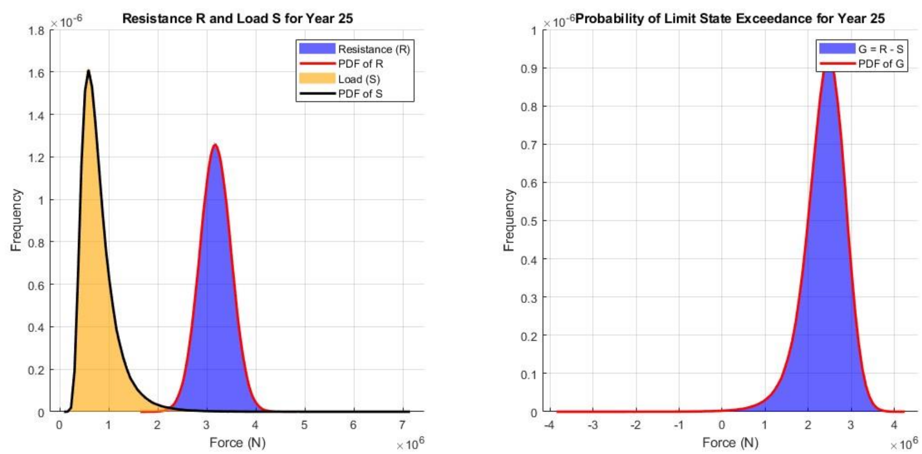


Figure 26 R, S, and G distributions for t=25

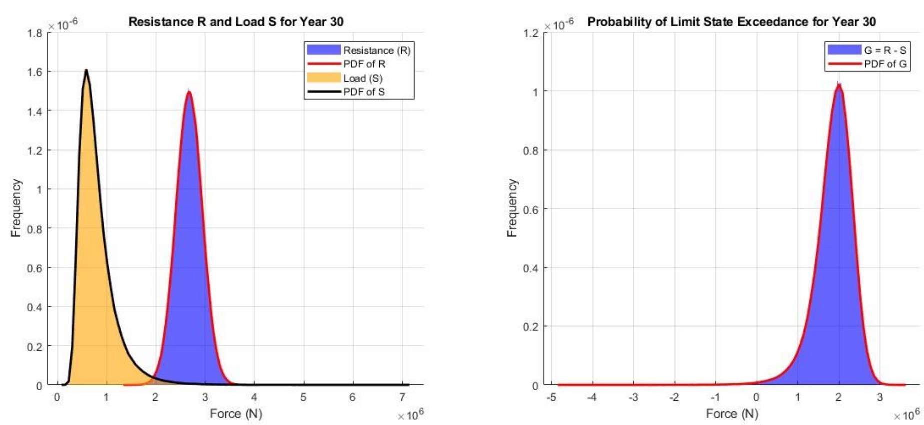


Figure 27 R, S, and G distributions for t=30

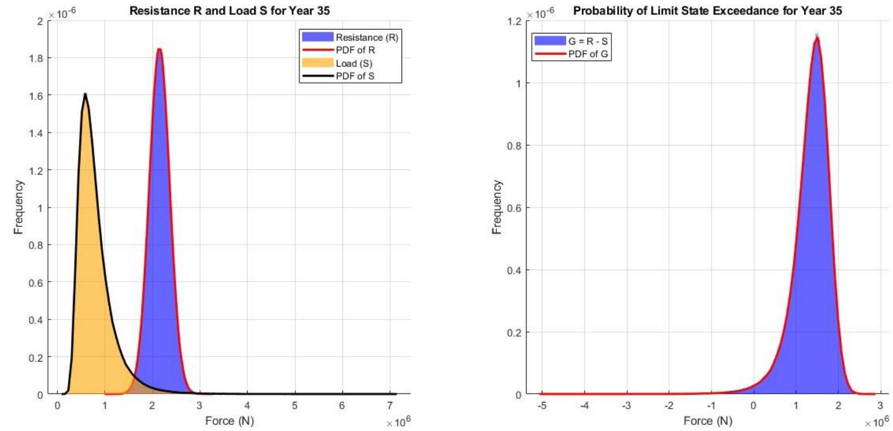


Figure 28 R, S, and G distributions for t=35

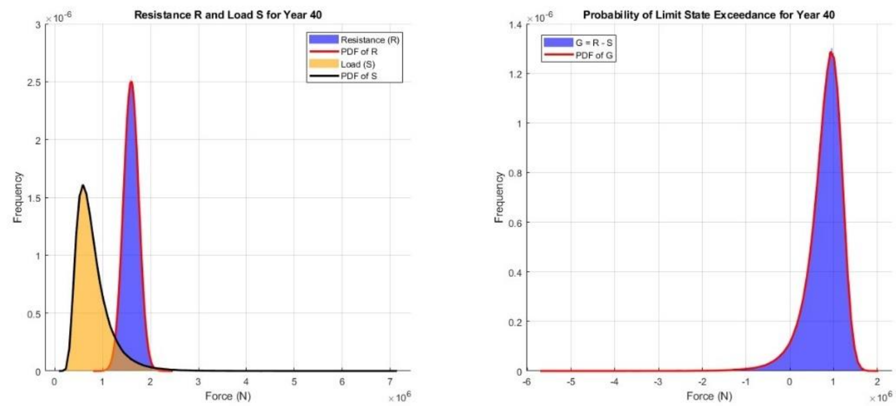


Figure 29 R, S, and G distributions for t=40

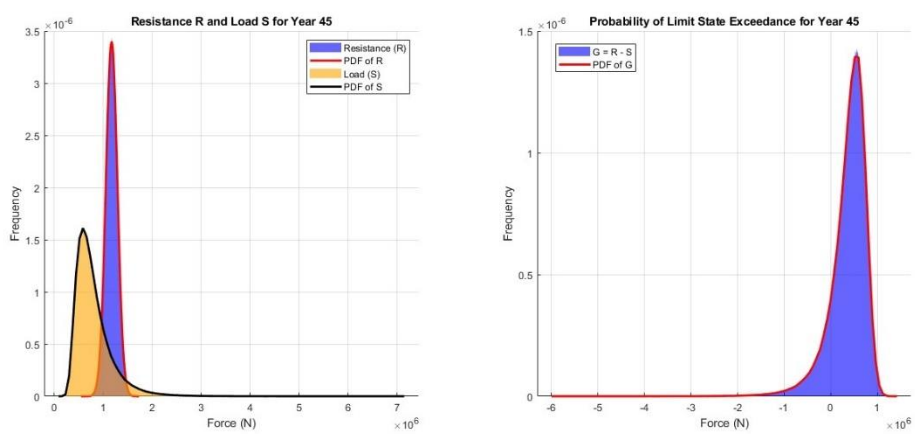


Figure 30 R, S, and G distributions for t=45

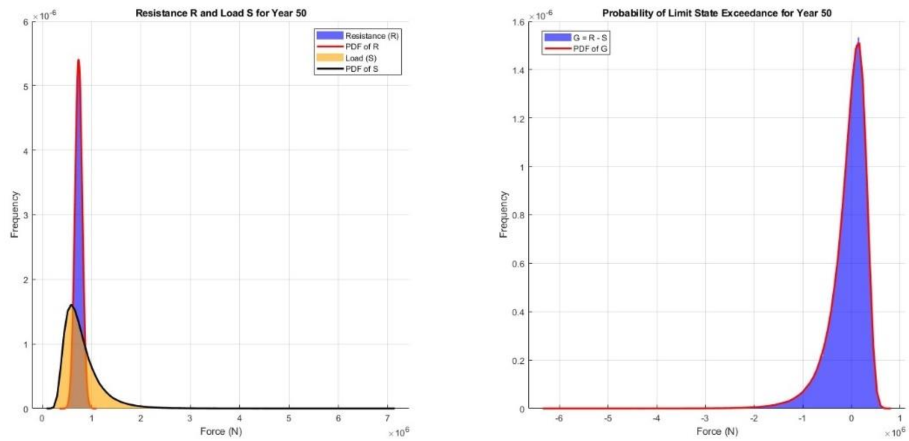


Figure 31 R, S, and G distributions for t=50

From the preceding figures 21 to 31, the probability of failures (limit state exceedance) is as follows.

Table 8 Monte Carlo Probabilities of Failure and Beta Values

Year	Probability of Failure	β Values
1	0.000033	3.9903
5	0.000059	3.8502
10	0.000120	3.6727
15	0.000259	3.4713
20	0.000504	3.2883
25	0.001248	3.0238
30	0.003433	2.7033
35	0.010793	2.2976
40	0.042095	1.7269
45	0.134082	1.1073
50	0.471269	0.0721

Also, the above table can be observed visually from the following figure. For Tensile, compressive, and total probability of failure. Here structure is considered failed if *either* compressive *or* tensile cases fail, and the total probability of failure is the largest of the two cases.

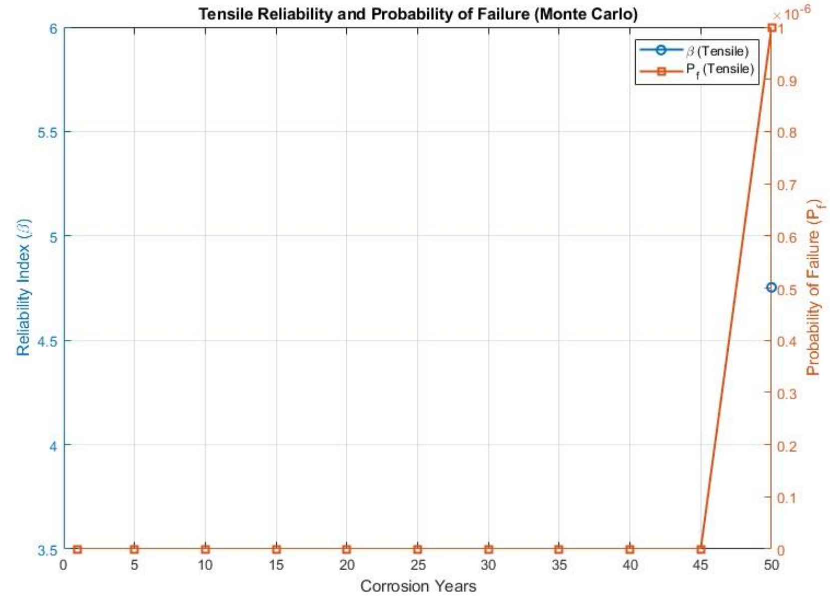


Figure 32 Monte Carlo Probability of Failure Beta - Tensile Case

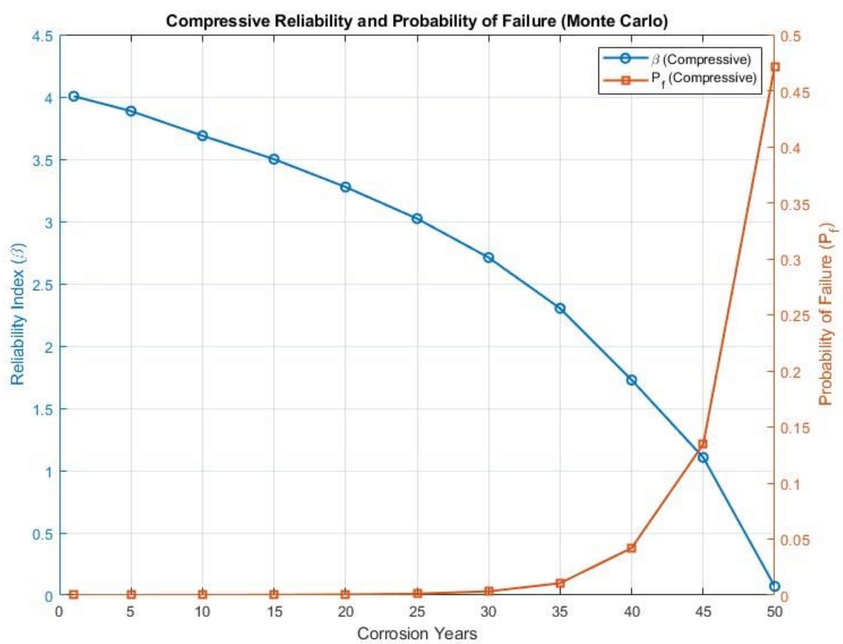


Figure 33 Monte Carlo Probability of Failure vs Beta-Compressive Case

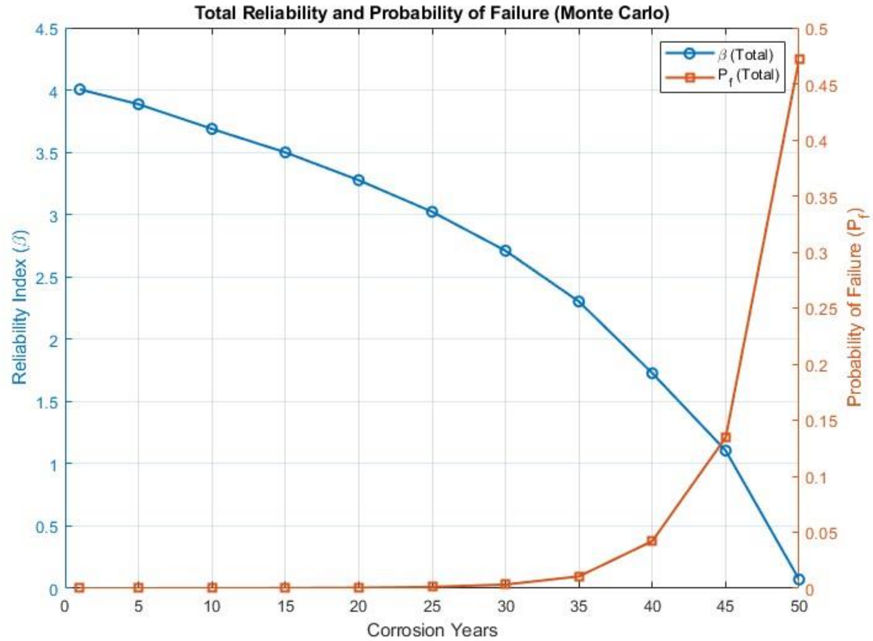


Figure 34 Monte Carlo Probability of Failure vs Beta - Total

The distribution of G (limit state function) is in the relatively safe zone until t=5, with a corrosion thickness of 10 mm and corrosion angle of 30° since the assumed corrosion thickness and areas are going rather larger values affecting the capacity significantly.

5.2.1. **Effects from the** number of MCS simulations:

The number of simulations plays an important role in keeping the accuracy of the MCS.

The following equation (Ersdal, 2022) illustrates the relationship between standard error and number of simulations:

$$N = \frac{P_f}{(1 - P_f)s^2}$$

Where:
N = number of simulations
S = standard error
P_f = probability of failure (limit state exceedance)

Normally, a standard error of 5% is acceptable. In the scope of this project, as the probability of failure is large for most of the corrosion time scenarios, the required number of simulations to achieve a 5% standard error is enough. Moreover, the current number of simulations (1 million) is more than sufficient to give accurate MCS results. According to the above formula with the 1 million number of simulations, the standard error is S≈0.000005745 or approximately 0.0005745 %.

5.2.2. Beta Value; A Discussion

To verify our beta values from the Monte Carlo Simulations against Figure 35 at t=1, the beta of 3.9903 probability of limit state exceedance is 0.000033 which is not agreeable with Figure 27 with LSE of 10^{-9}.

Table 9 Monte Carlo Probabilities of Failure and Beta Values

Year	Probability of Failure	β Values
1	0.000033	3.9903
5	0.000059	3.8502
10	0.000120	3.6727
15	0.000259	3.4713
20	0.000504	3.2883
25	0.001248	3.0238
30	0.003433	2.7033
35	0.010793	2.2976
40	0.042095	1.7269
45	0.134082	1.1073
50	0.471269	0.0721

Figure 35 Plot of Safety Index against Probability of Failure (Ersdal, 2022)

Our values of beta from MCS are high, the following might be the reasons for this.

- The analysis indicates that the corrosion model with the assumptions in this project might be overestimating the corrosion rate (much higher than actual values). Maybe with the actual corrosion data, the impact of corrosion might be lower.

- Simplification in the application of the wind and wave loads (assumption of direct application of wind and wave loads) directly to the bracing without considering other members and load redistribution might overestimate loads that the member is subjected to then in the actual structure
- Also, the wave loads coming from all directions were assumed to be in the direction of application assumed in this project, in reality only a percentage of those loads would effectively act on the member while the rest would be applied to other members.

5.3. Cornel Safety Index

The cornel safety index for this project was calculated with formulas from the lecture notes from (Ersdal, 2024) which can be seen from the figure.

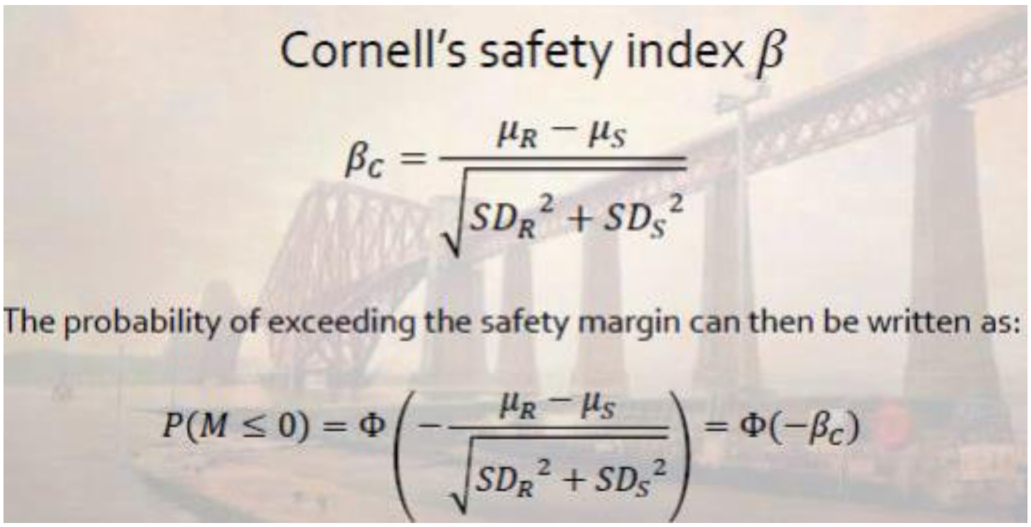


Figure 36 Cornell Safety Index Beta

Table 10 Cornell Safety Index

Year	Probability of Failure	β Values
1	0.000000000001	6.993364208080
5	0.000000000006	6.787287004602
10	0.000000000067	6.421491676250
15	0.000000001063	5.987926764728
20	0.000000019297	5.497167492031
25	0.000000525004	4.882027141910
30	0.000019268407	4.116081468071
35	0.000777234449	3.164317925071
40	0.024022943335	1.976962345214
45	0.167456249826	0.964266164973
50	0.563597255148	-0.160095952228

5.4. FORM Safety Index

According to (Ersdal, 2017) a reliability index β can be determined when the stochastic variables are correlated and non-normally distributed, using the reliability method which is also named the "First Order Reliability Method" (FORM).

The cumulative distribution function and the probability density functions of the actual variables and the equivalent normal variables should be equal at the design point (x_1, ……, x_n) on the failure surface. Considering each statistically independent non-normal variable individually and equating its CDF with an equivalent normal variable at the checking point results in:

$$\Phi\left(\frac{x_i^* - \mu_{x_i}^N}{SD_{x_i}^N}\right) = \Phi(U_i) = F_{x_i}(X_i)$$

Where $\Phi(U_i)$ Is the CDF of the standard normal variate, $\mu_{x_i}^N$ and $SD_{x_i}^N$ are the mean and standard deviation of the equivalent normal variable at the design point, and $F_{x_i}(X_i)$ is the original non-normal distribution function for X_i. Given a realization of u of U a realization $\bar{x}$ of X can be determined by:

$$x_i = F_{x_i}^{-1}(\Phi(u_i))$$

Again the common distributions of the CDFs and Inverse CDFs are given in figure 37.

Distribution	CDF$(= u_i)$	Inverse CDF
Normal	$F_X(x) = \Phi\left(\frac{x-\mu}{\sigma}\right)$	$x_i = \left(\Phi^{-1}(u_i) \times \sigma\right) + \mu$
Lognormal	$F_X(x) = \Phi\left(\frac{\ln x - \lambda}{\xi}\right)$	$x_i = \exp\left[\left(\Phi^{-1}(u_i) \times \xi\right) + \lambda\right]$
Uniform	$F_X(x) = \frac{x-a}{b-a}$	$x_i = a + (b-a)u_i$
Exponential	$F_X(x) = 1 - \exp(-\lambda x)$	$x_i = -\frac{1}{\lambda}\ln(1-u_i)$
Extreme Type I (largest), "Gumbel"	$F_X(x) = \exp(-\exp(-\alpha(x-u)))$	$x_i = -\frac{1}{\alpha}\ln(-\ln u_i) + u$
Extreme Type II (largest)	$F_X(x) = \exp\left(-(u/x)^k\right)$	$x_i = u(-\ln u_i)^{-1/k}$
Extreme Type III (smallest), "Weibull"	$F_X(x) = 1 - \exp\left[-\left(\frac{x-\varepsilon}{w-\varepsilon}\right)^k\right]$	$x_i = (-\ln(1-u_i))^{1/k}(w-\varepsilon) + \varepsilon$

Figure 37 Common Distributions, CDFs, and Inverse CDFs

Table 11 FORM Probabilities of Failure and Beta Values

Year	Probability of Failure	β Values	Shortest Distance To Failure Surface
1	0.000000000001	6.9934	104901.0240
5	0.000000000006	6.7873	149.0623
10	0.000000000067	6.4215	1069.0873
15	0.000000001063	5.9879	366.7232
20	0.000000019297	5.4971	365.4370
25	0.000000525191	4.8820	369.5123
30	0.000019275941	4.1160	381.2009
35	0.000777534218	3.1642	360.4515
40	0.024030646074	1.9768	452.6527
45	0.167496131719	0.9641	346.5762
50	0.563668892105	-0.1603	341.1740

Also, plots of design points (shortest distance from the failure surface) of the failure surface were tried to be plotted and a representative plot for the t=5 is presented in Figure 38.

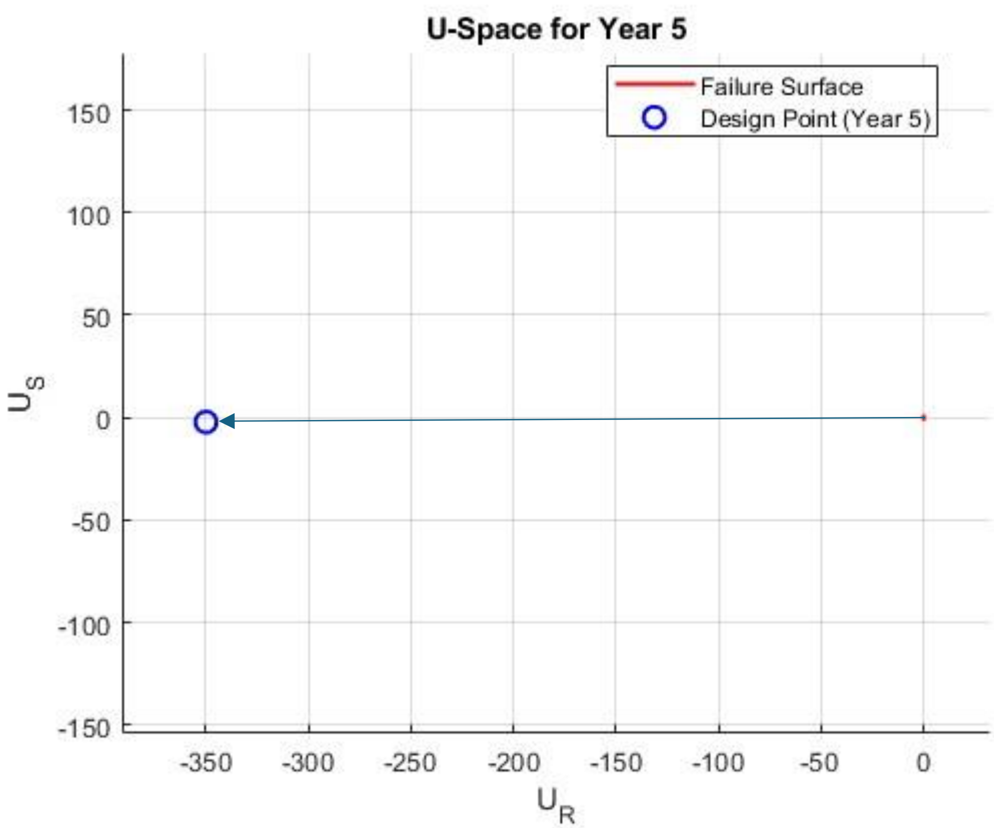


Figure 38 Design Point t=5

5.5. Comparison of safety index – MCS, FORM, Cornell

The safety index obtained so far will be compared in this section and decide which one seems more reasonable.

Since Cornell's method assumes the load and resistance to be normally distributed, which in reality is not the case, the same FORM in this project assumes the load to be normally distributed and resistance to be lognormal distributed do not reflect the situation.

MCS reflects the best possible results in this project since MCS considers the actual distributions of the resistance and load. While FORM and Cornell's methods might be computationally efficient, they do not capture higher-order effects. FORM approximates G linearly and Cornell assumes normality. Also since we have a large non-normal distribution of the data set MCS ensures a reliable estimate of the probability of failure and beta values. A comparison of these values can be seen in the figure below.

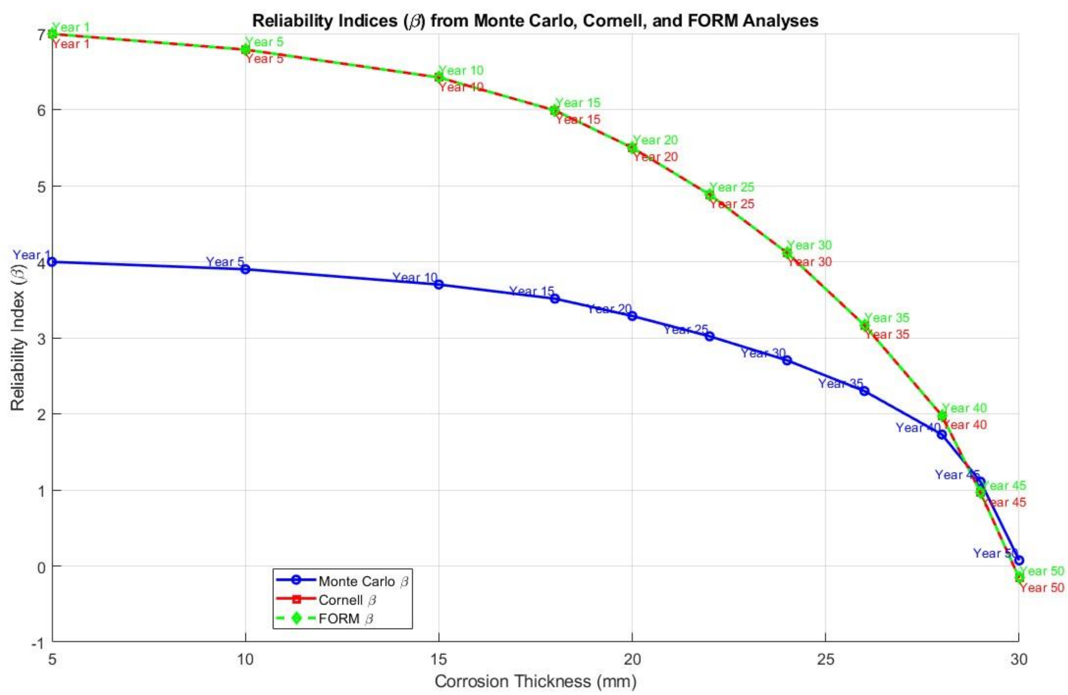


Figure 39 Reliability Indices (beta) from MCS, FORM, and Cornell

6. Reparation Methods

Maintaining offshore structures under challenging environmental conditions requires addressing damage through systematic strategies. These approaches include repairing weakened members, replacing severely compromised components, and minimizing the external forces acting on the structure. Each method is chosen based on the extent of damage and operational constraints.

6.1. Repair of Structural Members

Repairing structural members is often the most economical and efficient approach to maintaining structural integrity. This method focuses on restoring the strength and stability of damaged components without resorting to full replacement. Despite its cost-effectiveness, repairing offshore members presents technical challenges, particularly for submerged components, requiring robust solutions to ensure long-term reliability.

6.1.1. Surface Treatment of Members

Before any repair can commence, thorough surface preparation is essential to ensure the effective application of subsequent repair techniques. Removing marine growth, such as algae or barnacles, is typically accomplished using high-pressure water jets. For more severe cases of corrosion, abrasive processes like grinding or sandblasting are applied to clean the steel surface and create a foundation for repair. These tasks may be performed by divers or remotely operated vehicles (ROVs) in inaccessible areas.

6.1.2. Implementation of Cathodic Protection

To prevent further corrosion, cathodic protection systems can be retrofitted or replaced. Sacrificial anodes, made from zinc, aluminum, or magnesium, corrode preferentially, shielding the steel from damage. Alternatively, impressed current cathodic protection (ICCP) systems use a controlled electrical current to mitigate corrosion effectively. While cathodic protection slows down the degradation process, it does not restore lost strength and is often combined with other repair methods.

6.1.3. Reinforcement with Welded Plates

For localized damage, welding steel plates over weakened sections can significantly improve load-bearing capacity. This technique involves attaching reinforcement plates to redistribute stress away from damaged areas. Wet welding is commonly used for underwater repairs, although it is typically regarded as a temporary solution. For more extensive damage, alternative strategies may be necessary.

6.1.4. Strengthening Using Clamps

Clamps provide an alternative solution for stabilizing corroded members. These devices are particularly useful in situations where welding is impractical or impossible, such as on severely degraded surfaces or under high-pressure underwater conditions. Clamps are available in several designs, including neoprene-lined or grout-filled variants, which offer strong mechanical support and adaptability to varying levels of damage.

6.1.5. Grout Filling for Dent Repairs

When dents are present, grout filling is a viable option for restoring the structural integrity of affected members. By injecting grout into the damaged area, the material provides additional support and stabilization. Combined with clamps, this method can effectively address localized defects, although it is unnecessary for members without significant dent damage.

6.2. Replacement of Structural Members

In cases where a member is too severely damaged for repairs to be effective, replacement is the only viable option. This process involves the complete removal of the damaged component and the installation of a new, fully functional replacement. While more expensive and technically demanding than repair, replacement ensures that the structure meets all operational and safety requirements.

The process begins with an evaluation of the structure's overall stability, ensuring it can handle load redistribution during the replacement phase. Temporary supports are often installed to stabilize adjacent components while the damaged member is removed. Precision tools, such as water jet cutters or diamond wire saws, are employed for clean, controlled cuts. Once removed, the replacement member is carefully positioned and secured using welding or bolting techniques, with rigorous post-installation testing to verify structural integrity.

6.3. Modifying Load Paths for Strengthening

When repairs or replacements are impractical, modifying the load paths within the structure is an alternative method for maintaining stability. This approach involves reconfiguring the structural system to redirect forces away from weakened components and toward stronger sections. Engineers achieve this by adding braces or stiffeners, or by altering the geometry of existing members to distribute stress more effectively. This strategy not only extends the lifespan of the structure but also mitigates the risk of localized failure.

6.4. Reducing External Loads

Reducing the environmental and operational loads acting on the structure is another key strategy for maintaining its integrity. Offshore platforms are often subjected to high wind and wave forces, which exacerbate stress on structural components. Removing marine growth, such as barnacles and algae, reduces hydrodynamic drag while repositioning or lightening equipment on the topside minimizes gravitational stress. In some cases, deflectors or barriers are installed to absorb wave energy and reduce its impact on critical members. By reducing the forces acting on the structure, these measures help prevent overloading and extend its operational life.

7. Conclusion

This report analyzed the structural reliability of an offshore jacket structure under the effect of extreme environmental conditions taking into account the wave loading on the jacket leg and wind loading on the platform applied directly to the bracing member in question which had a uniform corrosion with no visible cracks during routine check. Visibility of the corrosion is high since the bracing member in question is located in the splash zone, where corrosion is highly likely due to the wearing effect of the waves (slamming of the waves) removing the protective coating and exposing the metal to seawater.

Failure criteria for the bracing analyzed in this project were determined to be tensile yielding and compressive buckling since the bracing in question is under the effect of these types of loading. Wave and wind loading were considered in the scope of the project since these types of loading are dominant in offshore conditions. Current loading was neglected in this study since compared to wave and wind loading current loading is not dominant in terms of buckling or tensile yielding.

Monte Carlo Simulations, the first-order Reliability Method, and the Cornell Safety Index were used for structural reliability analyses. Varying corrosion thickness (5mm to 30 mm) and angles (15 degrees to 165 degrees) were considered for the bracing member and MCS was used to check the probability of load exceeding the resistance of the structure. A total of 1 million simulations were carried out for each thickness and range of corrosion state and respective probabilities of failure and safety index β values were calculated.

The corrosion rate for the bracing member and simplifying assumptions in loading considered in this project predicted a low safety margin for the structure and the bracing member needed repair in a rather short time t=5 years. SRA with MCS indicated a low safety index compared to Table 7. FORM and Cornell safety index provided rather inconsistent results which significantly deviated from the results of MCS. Since the FORM safety index assumes a lognormal distribution of resistance and a normal distribution of load and Cornell assumes a normal distribution for both loading and resistance, results were well in the expected range. MCS using values of load from a distribution (Weibull) of the real data provides more consistent and accurate results. Although FORM and Cornell safety indices underestimated the loading with increased corrosion thickness and range All of the safety indices predicted certain failure of the structure.

In conclusion, member is in dire need of repairs in order to be able to continue functioning and repairs strongly recommended to restore load carrying capacity. Repair method can be decided based from the repairs method mentioned in previous chapter based on the budget and time constraints.

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Appendix A – Matlab code

Due to size of the Matlab Code and the accompanying data file and ease of use by the instructor, they are uploaded as separate files.