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ABSTRACT:

Offshore fixed jacket structures are vulnerable to fatigue damage from hazardous environment in North Sea. In this thesis, an offshore jacket structure was checked for the ULS 100- year return period of wave and checked for FLS using a long-term stress distribution. Sesam software was used to perform analysis for both the limit states. Ultimate limit state analysis shows satisfactory results, but the deterministic fatigue limit state results are not satisfactory for the members and joints in splash zone of the offshore jacket structure. Therefore, the thesis work is extended to see the effect on fatigue life by changing some of the fatigue parameters. Fatigue parameters considered for checking the effect are hydrodynamic property, joint types on structure and SN curves for tubular joint. It was observed that, no significant improvement in fatigue lives even after changing the fatigue parameters. Therefore, Stress concentration factor (SCF), which is the most sensitive parameter in estimation of fatigue life of tubular joint is studied further in this thesis. The SCF parameter is applied on each joint to determine the hot-spot stresses on the intersection region between the chord and brace on a tubular joint. Efthymiou (parametric) equation validity is first checked manually for one of the critical joint on offshore jacket based on the fatigue analysis results. Then the factor is calculated manually and compared to with the SCF calculated from Framework analysis. Discussion and conclusions are made at end of this thesis.

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ACKNOWLEDGEMENT:

Master thesis is one of the requirement for obtaining Master's degree in Mechanical and Structural engineering with a specialization in Offshore structures at the University of Stavanger, Norway. The subject of thesis was proposed in collaboration with my supervisors Sudath C. Siriwardane, Ove Mikkelsen and Ashish Aeran.

During this Master thesis, I have obtained knowledge and experience about the design principles and general behavior of an offshore jacket structure for Ultimate limit state and in Fatigue limit states designs. I also learned how the Sesam-Wajac calculates the wave forces on a jacket structure using the inputs given in Sesam-GeniE model. I also learned to use Sesam-Framework, which performs the fatigue analysis of the considered jacket structure.

I am very grateful to my supervisors, for the excellent guidance during this thesis work, for number of valuable discussions, for showing reference literature and on the draft of this thesis report.

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Sandnes, 15.06.2018
Ramkumar Kannan

1. INTRODUCTION

1.1 Background

Offshore structures are vulnerable to fatigue damage from hazardous environment in the North Sea. Natural phenomena which contribute to structural damage, operation disturbances or navigation failures for marine structures are the wind, waves, current and tides, ref/1/. All these loads are varying and may be quite large on a small area of a beam on a structural jacket framing, developing higher stresses on local points in the structural beam. From the above loads, the wave forces are the most important time dependent loading that causes fatigue in structural beam elements and joints. The occurrence of fatigue due to waves in marine structures is different from fatigue that occur in mechanical machines. The differences are, more number of cyclic loading in marine environment and the wave forces which have no specific pattern, ref/2/.Figure 1 shows that the repeated variation of stress due to cyclic loading on a metal, ref/3/.

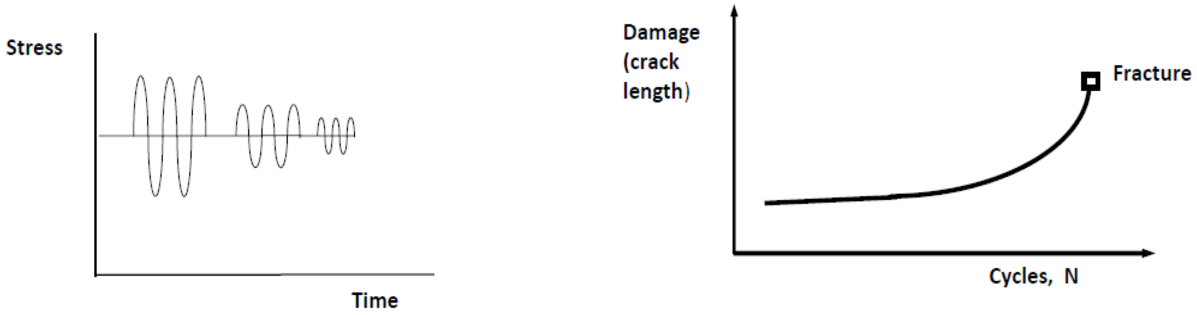


Figure 1 Weakness in a metal caused by repeated variation of stress

More than 25% of structural damage on offshore structures requires repair that is caused by fatigue, ref/4/. Fatigue strength is also significantly reduced by time dependent structural degradation. Fatigue limit state is the most critical limit state and the inaccurate predictions can lead to severe consequences. Therefore, it's very important to perform fatigue verification on structures installed in Marine environment. Performing fatigue analysis of the platform is to determine the relative sensitivity of platform components to fatigue damage so that future inspection programs will put more emphasis on those components that are more susceptible to fatigue damage, ref/3/. Figure 2 showing wave as a major fatigue load for the North Sea platforms.

Figure 2 Waves – Major fatigue load for North Sea platforms, ref/3/

Disaster of Alexander L. Kjelland semi-submersible platform is an example of fatigue induced failures on a structure installed in Marine environment. Main cause of failure was the propagation of fatigue cracks in the platform legs. Brace D6 failure initiated by a gross fabrication defect, progressive ultimate failure braces and loss of column and so progressive flooding of the deck and capsizing, ref/3/.Figure 3 showing structural arrangement of Alexander L. Kjelland platform highlighting the first fracture point on D6 brace.

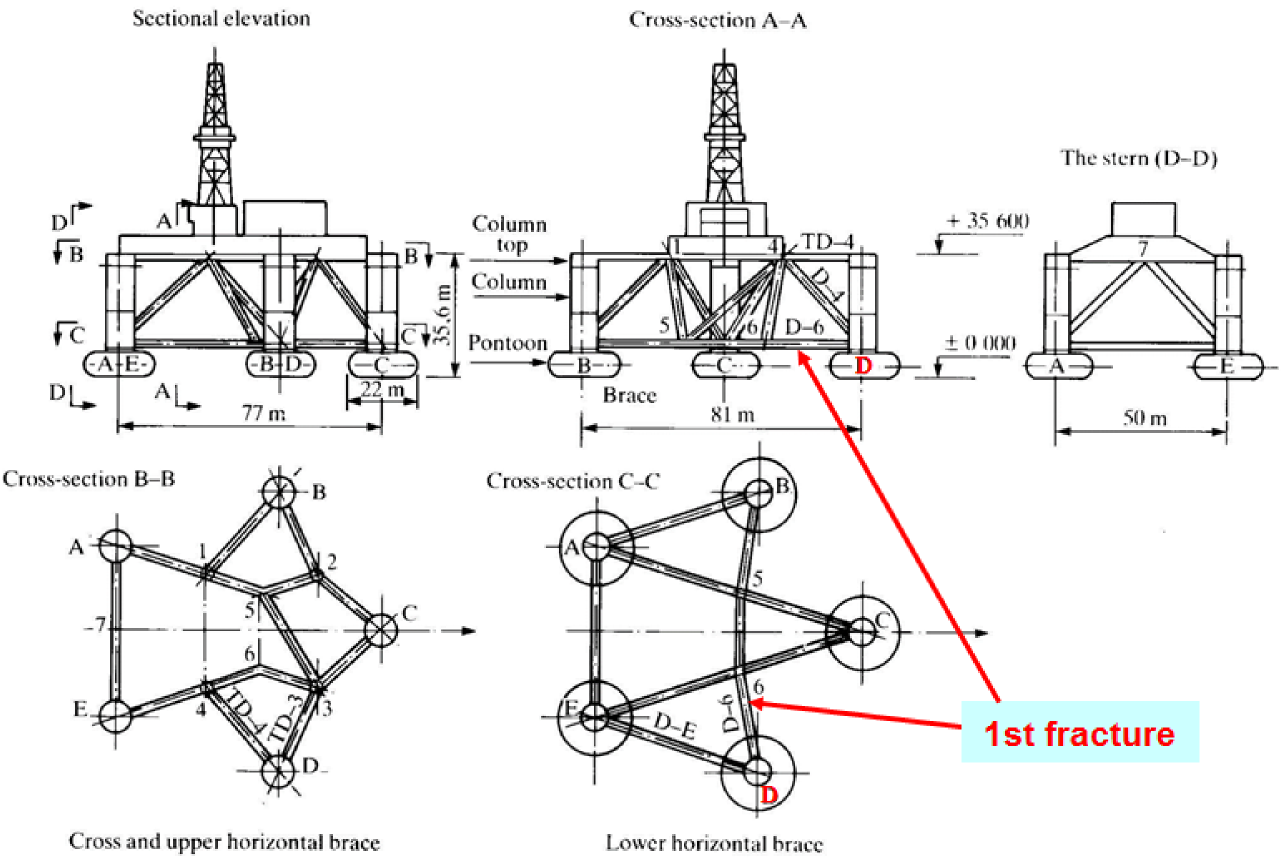


Figure 3 Alexander L. Kjelland structural arrangement (Pentagon design), ref/3/.

It is therefore very important to perform fatigue assessment on offshore structures accurately.

1.2 Objective of thesis

Based on above introduction with a problem description following are the thesis main objectives,

Initial objective of the thesis is to perform a fatigue limit state assessment of a new jacket platform in Sesam software and to investigate the effect of time dependent degradation on remaining fatigue life.

Above initial objective was made in connection with reusing an existing SAP2000 offshore jacket model from previous year Master thesis, ref/5/. It was observed that the existing SAP2000 model cannot be used in Sesam GeniE software due to software restrictions. Some of the thesis days are spent in trying for conversion of model. Therefore, below new objectives are made,

1. To study the loadings on offshore structures along with design considerations and various limit state checks.
2. To understand the basics of fatigue theory in general and fatigue analysis approaches and methods used for offshore structures.
3. To prepare a new finite element analysis model of considered platform in Sesam – GeniE software based on the inputs from the SAP2000 model. Compare the support reactions from operating weight of the topside module in SAP2000 model with Sesam- GeniE model.
4. Perform a global linear FE analysis of offshore jacket structure during ultimate limit state 100year wave using Sesam GeniE - Sestra.
5. Perform fatigue analysis of offshore jacket during fatigue limit state using Sesam – Framework.
6. Perform a time history fatigue analysis of the offshore jacket structure using Sesam - Framework.
7. Due to delays and challenges with deterministic fatigue analysis on Sesam - Framework model, the Objective no.1 to 5 works went beyond plan date. So, the objective no. 6 could not be achieved as per plan. Therefore, with the limited time, studies have been performed to check the effects of fatigue life while changing different fatigue parameters on the available fatigue analysis model.
8. Perform a deterministic fatigue analysis to check the fatigue life by changing hydrodynamic property (wave loading with and without buoyancy), joint type (Load path and Geometry), SN curve (T curve corrosion protection and T curve Free corrosion) and finally to check the stress concentration factor SCF (Efthymiou equation).

1.3 Limitations of the study

The main focus on this thesis is to perform a case study on offshore jacket structure for fatigue assessment. Therefore, the below mentioned items are not taken into consideration in this thesis;

1. Temporary phase's analysis of offshore jacket structure (Transportation and Installation).
2. Winds and Current loading in analysis.
3. Pile-soil analysis.
4. Foundation design.
5. Topside model is a general outline of each module. The model doesn't reflect the SAP2000 model. Therefore, operating weight from topside is scaled to GeniE modelled weights. Information about topside weights and sizes taken from ref/5/

1.4 Organization of thesis

Thesis consists of seven chapters. A short description of each chapter is mentioned below, CHAPTER 2 presents the theoretical background of loadings, design considerations, fatigue analysis methods, finite element method, ultimate limit states and fatigue limit states.

CHAPTER 3 presents the overview of modules inside SESAM software and briefly describing the principles behind GeniE, Sestra, Wajac and Framework.

CHAPTER 4 presents the geometry of considered offshore jacket structure, inputs used in modelling, simulation of loading used for ultimate limit state and loading for fatigue limit state.

CHAPTER 5 presents brief introduction on ultimate limit state, design check of joints and members, effect of buoyancy loads on ULS results and discussion on the obtained results.

CHAPTER 6 presents brief introduction on fatigue limit state, design check of joints and members, effect of buoyancy loads, selected joint type and selected SN curve on FLS results. Study on Stress concentration factor is made for the critical joint on the offshore jacket model. Discussion were made on the obtained results.

CHAPTER 7 presents the discussion, conclusions of the whole thesis work and also the suggestions for future work based on this thesis.

List of references are made with numbers on each chapter of this document, reference list made refer to these numbers.

Appendix presents the maximum base shear and overturning moment from ULS results, Analytical solution of stress concentration factor of a critical joint and the procedures used in different software's for performing the limit state verifications.

2. THEORETICAL BACKGROUND

2.1 Overview of the chapter

This chapter gives an overview of the loadings acting on offshore jacket structure, design considerations, limit states for offshore structure design, fatigue analysis approaches, finite element basics, ultimate limit state and fatigue limit state analysis of jacket structures.

2.2 Offshore jacket structure loadings

Offshore jacket structures generally receive loads from topside (gravity), seismic, accidental and environment, ref/1/. Below list shows various loads in detail,

1. Gravity loads
    a. Structural dead loads
    b. Facility dead loads
    c. Fluid loads
    d. Live loads
    e. Drilling loads

2. Environmental loads
    a. Wind loads
    b. Wave loads
    c. Current loads
    d. Buoyancy loads
    e. Ice loads
    f. Mud loads

3. Seismic loads – Earthquake loads

4. Accidental loads – Boat collision, dropped object, pool fire at sea, extreme environmental actions.

Description of loads that were considered in this thesis is only presented below,

2.2.1 Gravity loads (Structural dead loads)

Dead loads include all fixed items in the platform deck, jacket, bridge and flare structures. It includes all primary steel structural members, secondary structural items such as boat landing, pad eyes, stiffeners, handrail, deck plating and small access platforms.

2.2.2 Gravity loads (Facility dead loads)

These are loads from fixed equipment and not from structural components. They do not have any stiffness to offer in the global integrity of the structure.

2.2.3 Gravity loads (Fluid loads)

These are weight of fluid on the platform during operation. This may include all the fluid in the equipment and piping.

2.2.4 Gravity loads (Live loads)

Live loads are defined as movable loads and temporary in nature. Live loads will only be applied on areas designated for storage either temporary or long term. Other live loads include open areas such as walkways, access platforms, galley areas in the living quarters, helicopter loads in helipad, etc.

2.2.5 Environmental loads (Wave and Current loads)

A body submerged in moving water will experience forces due to the hydrodynamic actions of waves and currents, ref/2/. Two ways the wave loads onto the offshore structures are applied. They are design wave method and spectral method. In design wave method, a discrete set of design waves (maximum) and associated periods are selected to generate loads on the structure. In the spectral method, an energy spectrum of the sea-state for the location are taken and a transfer function for the response will be generated, ref/1/.

2.2.6 Environmental loads (Buoyancy loads)

The offshore structural members are mostly made buoyant by air tight sealing of welds to avoid water entry. This is purposely planned, so that the overall structure has adequate buoyant during installation. Typical example is the offshore jacket structure which requires at least a reserve buoyancy of 10 to 15%. The reserve buoyancy is defined as buoyancy in excess of its weight, ref/1/.

Figure 4 showing forces that act on an offshore jacket structure with topsides that was installed on North Sea.

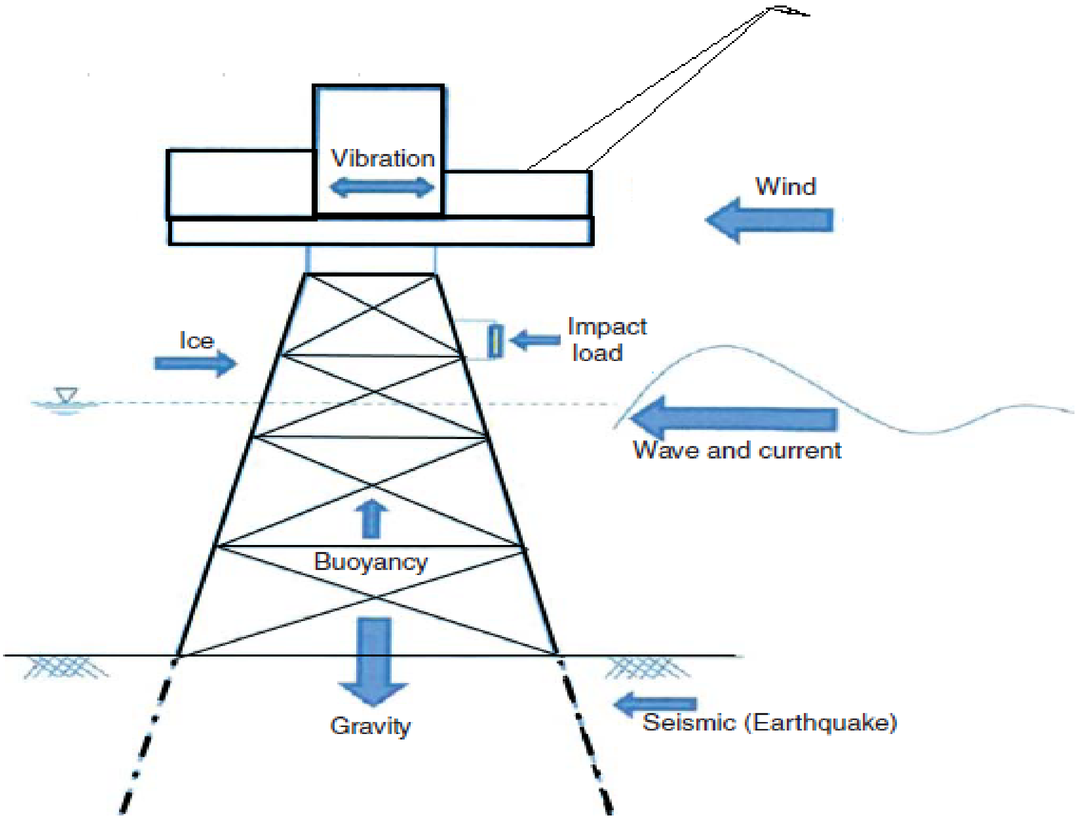


Figure 4 Forces acting on jacket structure, ref/2/

2.3 Design considerations for offshore jacket

Jacket design is generally a complex task among engineers due to installation location and loadings that act on offshore jacket. Hence it has to be designed based on a design basis document, ref/2/.

Generally, a design basis document is prepared to satisfy specific requirements related to field. The document, in this case ref/2/, consists information required to perform structural analysis.

1. Geometry of platform and location in North Sea.
2. Codes, Standards, Project specifications that needs to be followed.
3. Platform design information,
    a. Platform design life
    b. Material properties
    c. Topside loading
    d. Environmental data
        i. Soil condition
        ii. Water depth
        iii. Splash zone limit
        iv. Air gap determination
        v. Wave kinematic and Current blockage factor
        vi. Hydrodynamic coefficient
        vii. Waves and Current data
        viii. Wind data (Hindcast)
        ix. Ice and snow data
        x. Marine growth
    e. Analysis design approaches
        i. In-place analysis
        ii. Transportation analysis
        iii. Seismic analysis
        iv. Fatigue analysis
        v. Load-out analysis
        vi. Pile foundation analysis
        vii. Lifting analysis
        viii. Dropped object analysis
        ix. Boat impact analysis
4. Safety risk assessment

2.4 Limit states for offshore jacket

A limit state is a condition beyond which a structure or part of a structure will no longer satisfy the design requirements for its performance. NORSOK N-001, ref/6/ and ISO19900, ref/7/.

The limit states are divided into the following four categories which, in turn may be subdivided, ref/7/.

1. Ultimate limit state (ULS) that generally correspond to the resistance to maximum applied actions.
2. Serviceability limit state (SLS) that generally correspond to the criteria governing normal functional use.
3. Fatigue limit stare (FLS) that correspond to the accumulated effect of repetitive actions.
4. Accidental limit state (ALS) that correspond to situations of accidental or abnormal events.

All identified failure modes shall be checked within the respective groups of limit state, i.e ULS, SLS, FLS and ALS. It has to be verified that the structure has sufficient ductility to develop the relevant failure mechanism, ref/6/.

Since the thesis objective is to perform ULS and FLS, the SLS and ALS will not be discussed further in this thesis.

2.5 Fatigue analysis approaches and assessment methods for offshore jacket structures

2.5.1 Fatigue analysis approaches

1. Stress life approach
2. Strain life approach
3. Linear fracture mechanics approach

2.5.1.1 Stress life approach (S-N approach)

Stress life approach was developed by Miner and named as Miner's rule of S-N. This rule relates stress ranges (S) to the number of cyclic loading (N). Fatigue analysis should be based on S-N data, determined by fatigue testing of the considered welded detail, and the linear damage hypothesis. If the fatigue life estimate based on S-N data is short for a component where a failure may lead to severe consequences, a more accurate investigation considering a larger portion of the structure, or a fracture mechanics analysis should be performed. All significant stress ranges contribute to fatigue damage. The long-term distribution of stress ranges may be found by deterministic or spectral analysis, ref/8/.

2.5.1.2 Strain life approach (ε-N approach)

Manson and Coffin found that plastic strain-life data could be linearized in log-log scale. This method is based on relating the fatigue life of notched parts to the life of small un-notched specimens cycled to the same strains as the material at the notch root. Expected fatigue life can be determined knowing the strain-time history at the notch root and smooth strain-life fatigue properties of the material, ref/9/

2.5.1.3 Linear fracture mechanics approach

This approach was based on linear fracture mechanics (LEFM) and consists the rate of crack growth as a function of parameters such as crack geometry and loading condition, ref /10/.

2.5.2 Fatigue assessment methods

Based on Stress life approach, Sesam Framework, ref/11/ user manual describes that the fatigue analysis can be performed by following methods,

1. Deterministic method
2. Spectral method
3. Stochastic method
4. Time history method

Offshore jackets in low to moderate water depths are not normally sensitive to dynamic effects, non-linearities associated with wave theory and free-surface effects may be important. A deterministic analysis is recommended for such offshore jacket, ref/6/. Offshore jackets in deep water where the dynamic effects are important, a fatigue analysis in the frequency domain (dynamic stochastic analysis) is recommended, ref/12/.

Since these two analyses differ each other, the fatigue lives calculated by them also differs to some extent. This indicates that uncertainties are associated with the fatigue analysis for the installed condition. The differences are related to the environment condition, the load and response calculation, and how the stress concentration factors (SCFs) at the tubular joints are calculated as a function of loading. The deterministic method has been traditionally preferred for fatigue analysis of jacket structures because North Sea is without significant dynamics. Offshore platform structures are installed in shallow waters, ref/7/.Based on the above methods a comparison in Table 1 and Table 2 was made to see which method shall be used in this case study, ref/11/ and ref/3/.

Table 1 Fatigue analysis methods and comparison - Features

Method	**Type**	**Stress range calculation**	**Output**
Deterministic	Simplified version of spectral method	Sea state using a deterministic wave height and period. Selecting a representative collection of discrete deterministic is challenging.	Results in terms of fatigue induced damage or fatigue life.
Spectral	Direct method	Long-term stress range distribution is calculated from a given (or assumed) wave climate. Involves time domain method, along with the rainflow counting technique to estimate the number of stress cycles based on stress time-history.	Results in terms of fatigue induced damage or fatigue life.
Stochastic	Direct method	Based on transfer functions from linearized frequency domain waves	Results in terms of fatigue induced damage or fatigue life.

Table 2 Fatigue analysis methods and comparison – Advantages and Disadvantages

Method	Advantages	Disadvantages
Deterministic	Suitable for dynamically insensitive structures in shallow to medium water depths where non-linearities in the wave force such as drag, and variable submergence are of importance.	The energy content of the sea states is not directly represented in this method so judgement and experience are required in selecting the discrete waves to include in the analysis.
Spectral	Suitable for dynamically insensitive structures in shallow to medium water depths where non-linearities in the wave force such as drag, and variable submergence are of importance.	This method properly represents the energy content of the sea-states.
Stochastic	Suitable for dynamically sensitive and insensitive structures in deep water where the non-linearities in the wave force are less important. The structural dynamic analysis, if required may be computer intensive.	The method properly represents the energy content of the sea-states.

2.5.3 Selection of suitable method for fatigue analysis:

It is necessary to know when to apply the different methods. Important assessment criteria are the consequences of fatigue damage and experience with similar methods on existing structures.

In general, the deterministic method for fatigue life calculation is assumed to give a good indication as to whether fatigue is a significant criterion for design or not. The reliability of the calculated fatigue lives is assumed to be improved by refinement in the design analysis (direct analysis), ref/3/.

2.6 Basics of Finite element method

The global analysis of offshore steel jacket structure starts from defining the structural geometry, material properties, foundation properties, boundary condition, hinges, operational and environmental loading. Finite element method has been widely used in the design of complex marine structures. Figure 5 illustrates the process of a structural design based on finite element analysis.

Different types of elements are applied to various types of structures and critical areas where loads or stresses are concentrated. For simplified linear analysis of the jacket structure, the 3D-beam element is preferred. This two-node beam has six global degrees of freedom for each mode.

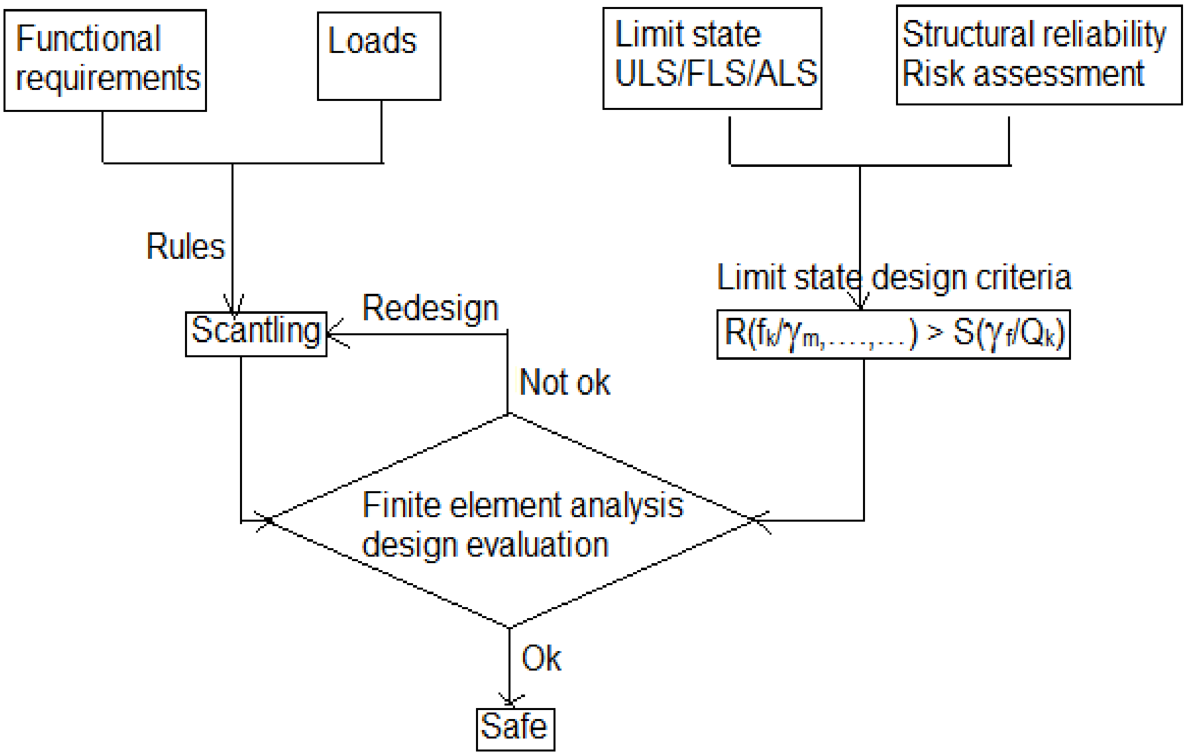


Figure 5 Flow chart showing finite element analysis process, ref/13/

2.7 Ultimate limit state analysis of jacket structures

The structure shall not collapse when subjected to the design load. A structure is estimated to satisfy the ULS criteria if all factored load/action effects are below the factored strength/resistance. In ULS a partial factor/load factor is used for loads/actions, but a reduction factor is used for the strength/resistance of member, ref/2/.

Material factor for steel structures shall be 1.15, this consideration is made for analysis model uncertainties and dimensional variations, ref/6/. The load combinations for a normal operation in ultimate limits state is given in Table 4.

Table 3 gives the action factors to be used in analysis. Two different cases are made on combining dead/live load with an environmental load.

Table 3 Partial action factor on load combinations for the ultimate limit state, ref/6/

Limit state	Action combinations	Permanent action (G)	Variable actions (Q)	Environmental actions (E)	Deformation actions (D)
ULS	a	1.3	1.3	0.7	1.0
ULS	b	1.0	1.0	1.3	1.0

The ultimate strength of structural elements and systems should be evaluated by using a rational, justifiable engineering approach. Recommended wave approach direction for ULS and FLS analysis is shown in Figure 6.

Table 4 Characteristic actions and action combinations, ref/14/

Action	Normal operations				
	Serviceability limit state (SLS)	Fatigue limit state (FLS)	Ultimate limit state (ULS)	Accidental limit state (ALS)	
				Abnormal effect	Damaged condition
Permanent	Expected value				
Variable	Specified value				
Environmental	Dependent on operational requirement	Expected action history	Annual probability of exceedance $=10^{-2}$	Annual probability of exceedance $=10^{-4}$	Annual probability of exceedance $=10^{-2}$
Deformation	Expected value				
Accidental	Not applicable			Annual probability of exceedance $=10^{-4}$	Not applicable

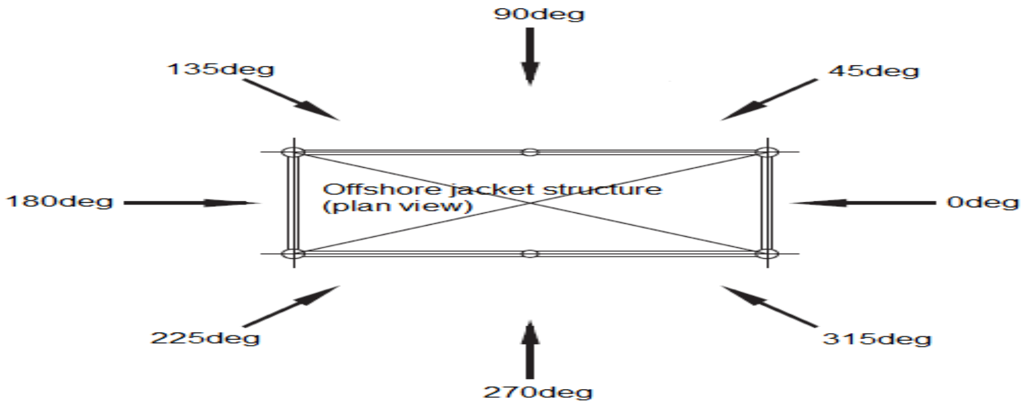


Figure 6 Recommended wave approach directions for ULS and FLS, ref/12/

Jacket bracing dimensioning is based on maximum base shear of wave and current actions. Jacket legs and foundation system dimensioning is based on the maximum overturning moment caused by the base shear of wave and current actions. Detail design analysis should be based on minimum eight wave approach directions. Offshore steel jackets symmetric about two vertical axes shall have reduced number of approach directions, ref/12/.

Horizontal framing members on jacket close to the still water level has to be checked for both horizontal and vertical water particle velocities. The effect of buoyancy shall also be included, ref/12/.

2.8 Fatigue limit state analysis of Jacket structures

Structures are designed to withstand the repetitive (fatigue) actions during the entire life span of the structure. Design fatigue factors are applied for safety and with the objective to reduce life cycle costs, taking into account the need for in-service inspection, maintenance and repair, ref/2/.

Fatigue analysis involves estimating the fatigue demand on a structural element and comparing it to the predicted fatigue strength of the element. The intention is to compute the fatigue damage or expected fatigue life of the structure, ref/15/.

Load combinations for a normal operation in fatigue limit state is shown in Table 5.

Table 5 Characteristic actions and action combinations, ref/14/.

Action	Normal operations				
	Serviceability limit state (SLS)	Fatigue limit state (FLS)	Ultimate limit state (ULS)	Accidental limit state (ALS)	
				Abnormal effect	Damaged condition
Permanent	Expected value				
Variable	Specified value				
Environmental	Dependent on operational requirement	Expected action history	Annual probability of exceedance =10^{-2}	Annual probability of exceedance =10^{-4}	Annual probability of exceedance =10^{-2}
Deformation	Expected value				
Accidental	Not applicable			Annual probability of exceedance =10^{-4}	Not applicable

Table 6 gives the partial action factor that needs to be considered in fatigue limit state analysis.

Table 6 Partial action factor on load combinations for the fatigue limit state, ref/6/

Limit state	Action combinations	Permanent action (G)	Variable actions (Q)	Environmental actions (E)	Deformation actions (D)
FLS	-	1.0	1.0	1.0	1.0

The design fatigue life of the structure components should be based on the structure service life specified by the operator. A short design fatigue life shows shorter inspection intervals, ref/12/.

To make sure that the structure will fulfill the purpose, a fatigue assessment, a detailed fatigue analysis to be carried out for each individual member which is subjected to fatigue loading. Any beam element on structure, welds on joints with stress concentration is a potential source of fatigue crack and have to be considered individually, ref/12/.

Minimum values for the design fatigue factor as per ref/6/. The distinction is made between ‘’substantial and without substantial consequences’’

Substantial consequences is that the structural collapse will lead to

a) Danger that human loss
b) Significant pollution to environment
c) Major financial consequences

Table 7 gives different design fatigue factor based on damage consequence and accessibility for inspection, maintenance and repair. If operator specifies 30years as life time of an offshore platform, then with a DFF of 10 means a design life time of 300years.On Table 7, the accessibility for performing conditional monitoring on an offshore platform is defined as below splash zone, above splash zone and internal splash zone. The splash zone for fixed offshore jacket structures is taken as 4m below the lowest tide and 5m above the highest tide.

Table 7 Design fatigue factor (DFF), ref/6/

Classification of structural components based on damage consequence	Not accessible for inspection and repair or in the splash zone	Accessible for inspection, maintenance and repair and where inspections or maintenance is planned	
		Below splash zone	Above splash zone or internal
Substantial consequences	10	3	2
Without substantial consequences	3	2	1

A deterministic fatigue analysis should include eight wave approach directions, see Figure 6.Each wave direction should also have at least four wave heights. Wave forces to be calculated for at least ten positions in each wave. If specific wave information not available from design basis document, the wave periods shall be determined based on a wave steepness of 1/20, ref/12/.

In order to compute the fatigue damage or fatigue life of a structure, the long-term stress distribution must be found. Having estimated the long-term stress distribution, S-N curves are used to compute the cumulated damage (using Palmgren-Miner rule).

The S-N curve is used to define the fatigue characteristics of a material subjected to a repeated cycle of stress of constant magnitude. The S-N curve gives the number of cycles required to produce failure for a given magnitude of stress. The S-N curves are obtained from fatigue tests and they follow mean-minus-two-standard-deviation curves for relevant experimental data. Therefore, the curves are associated with a 97.7% probability of survival, ref/8/.Figure 7 showing the deterministic analysis procedure i.e. number of waves, hotspot location on a tubular joint, S-N curve and damage calculation.

The procedure schematically shown in Figure 7 is often followed when performing a deterministic fatigue analysis of a fixed structure without significant dynamic response, ref/15/.

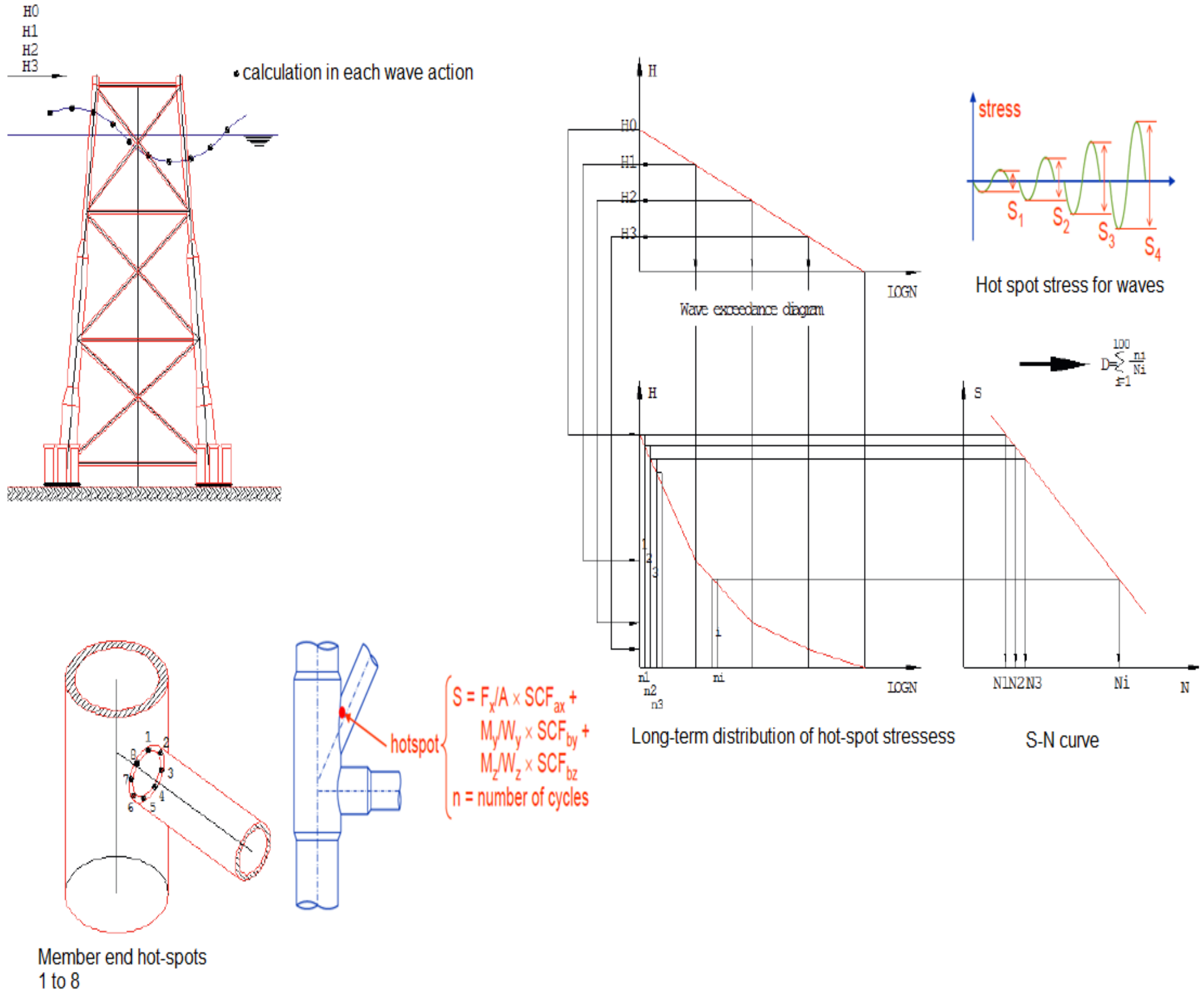


Figure 7 Deterministic fatigue analysis procedure

The wave distribution and directionality are typically accounted by considering various sectors- for example, eight. A wave height exceedance diagram is established within each sector, as indicated in above figure. In each sector, several discrete wave heights are selected for analysis. For each wave height, H_i, a corresponding wave period, T_i, is determined, based on a mean wave steepness curve or on actual data for the area being considered. Stoke's fifth-order theory is recommended for analysis, together with drag and mass coefficients for load calculation, ref/15/.

Forces on the structures are calculated using the Morison equation. Each wave is stepped through the structure at increments in the wave, at a phase angle for calculation of internal forces in each structural element at each joint (axial force, in-plane, bending moments and out-of-plane bending moments).Wave is stepped through the structure in 24 steps that correspond to an increment in phase angle of 15° .The member forces at the tubular joint are used for estimation of the type of tubular joint: X-joint, Y-joint, or K-joint. Tubular joint type is needed for calculating each hot spot stress, which is used for fatigue life calculation on the chord side and the brace side. Each step in the wave analysis, results in a stress at each hot spot and this includes the effect of the stress concentrations for the relevant joint, including the stresses from the axial force, in-plane bending moments and out-of-plane bending moments. The stress range at the considered hot spot is then derived as the difference between the maximum and minimum stress, ref/15/.

The analysis procedure is repeated for all selected wave heights to establish a long-term stress range distribution. At least ten wave heights should be selected for analysis, but the required number also depends on the geometry of the structure, especially the layout geometry in the waterline area. The analysis procedure is repeated for the other sectors so that the long-term stress range distributions for all sectors are determined. The fatigue damage within each long-term stress distribution is calculated using the Palmgren-Miner rule. This is performed by numerical integration in which the long-term stress range distribution is divided into number of blocks – for example, 100-200.Different methods can then be used for integration, using either a trapezoidal integration or a higher-order method, ref/15/.

Finally, the fatigue damage for the hot spot being considered is derived by summation of fatigue damage from the long-term stress range distribution within each sector. The total damage taking into account the different wave direction can be calculates using Equation (1).

$$D = \sum_{i=1}^{ndir} Di \qquad \textit{Eq. (1)}$$

3. SESAM MODULES FOR ANALYSIS OF JACKET STRUCTURES

3.1 Overview of chapter

Sesam software suites for hydrodynamic and structural analysis of ships and offshore structures. It is based on the displacement formulation of the finite element method. Four group of programs preprocessors, hydrodynamic analysis programs, structural analysis programs and post processors, are bound together by a set of Sesam Interface files, ref/16/. Figure 8 showing overview of modules inside Sesam software. The modules used for performing the ultimate and fatigue limit state analysis are highlighted in green colour.

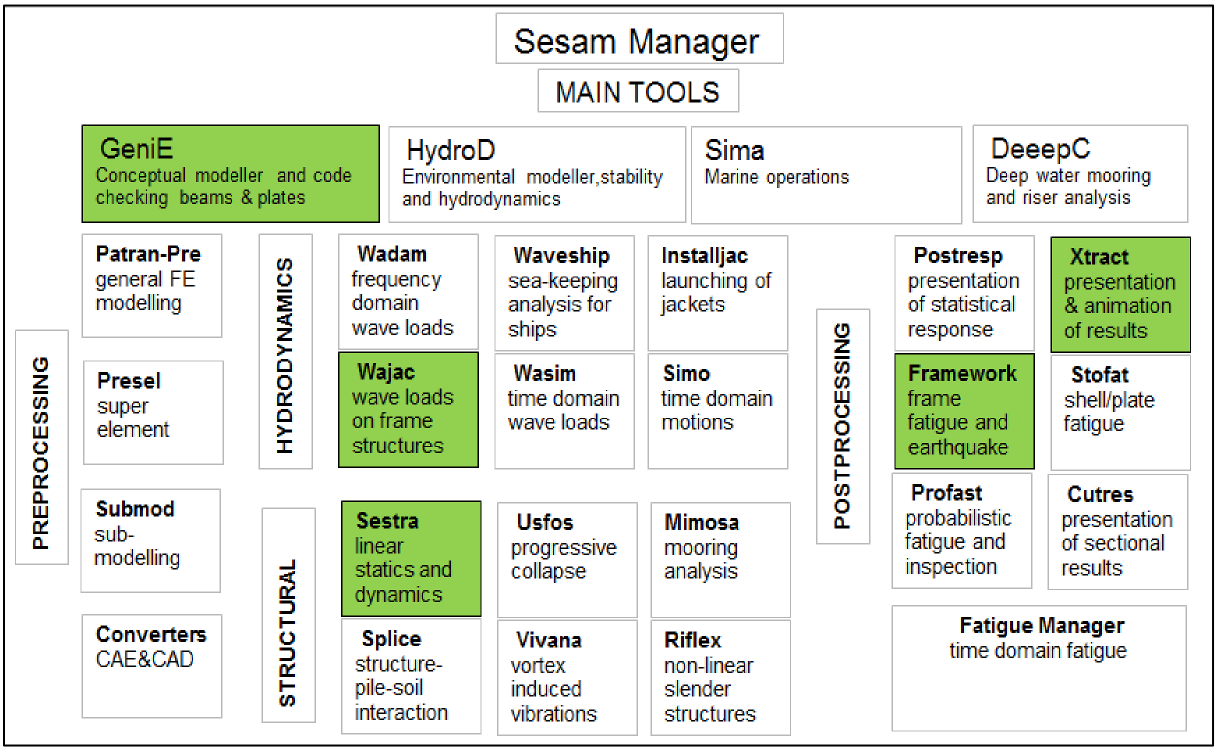


Figure 8 Sesam module overview, ref/17/

Offshore fixed platform structure design shall be carried out in two designs groups,

Topside design shall be carried as follows,

1. GeniE - Modelling,analysis control and code checking.
2. Sestra – Static structural analysis.

Jacket design shall be carried as follows,

1. GeniE – Modelling,analysis control and code checking.
2. Wajac – Computation of wave loads on frame structures.
3. Sestra – Static/dynamic structural analysis.
4. Framework – Fatigue analysis of frame structures.
5. Xtract – Finite element results post processor.
6. Splice – Pile-soil analysis.

In this thesis work we shall use GeniE, Wajac, Sestra, Xtract and Framework.

3.2 Structural modelling and code checks using GeniE module

GeniE is a tool for concept modelling of beams and plates. In this thesis Genie is used for implementing the following functions,

1. Model offshore jacket with topside.
2. Define environment condition.
3. Define linear isotropic material property.
4. Define boundary conditions
5. Define hydrodynamic properties.
6. Operating and wave load application.
7. Define inputs to wave load analysis and run Sestra analysis with primary load cases.
8. Wajac output file created after Sestra analysis.
9. Based on results from Wajac output, make load combinations in GeniE with new workspace.
10. Perform Sestra analysis with load combination.
11. Perform code check based on NORSOK N-004, ref/12/.

Figure 9 shows a representation of an offshore fixed platform model in GeniE. This model is general offshore jacket and topside with wave, sea bed and piles to the soil.

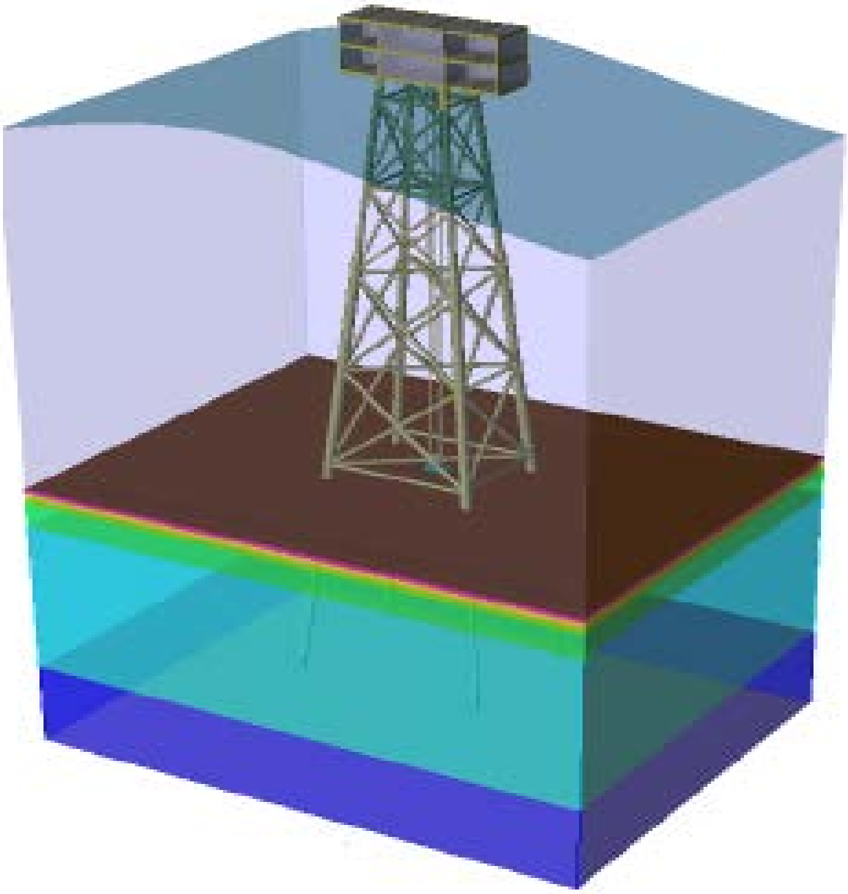


Figure 9 Graphical representation of an offshore fixed platform model in GeniE, ref/17/.

3.3 Linear static structural analysis using Sestra module

Sestra computes structural response to static and dynamic loading. This program is based on the displacement formulation of the finite element method. On linear static analysis, the loads are constant and the structure's response to the loads is linear. Linear response means that it's proportional to load. If the load is doubled then the displacements are also doubled, ref/17/.

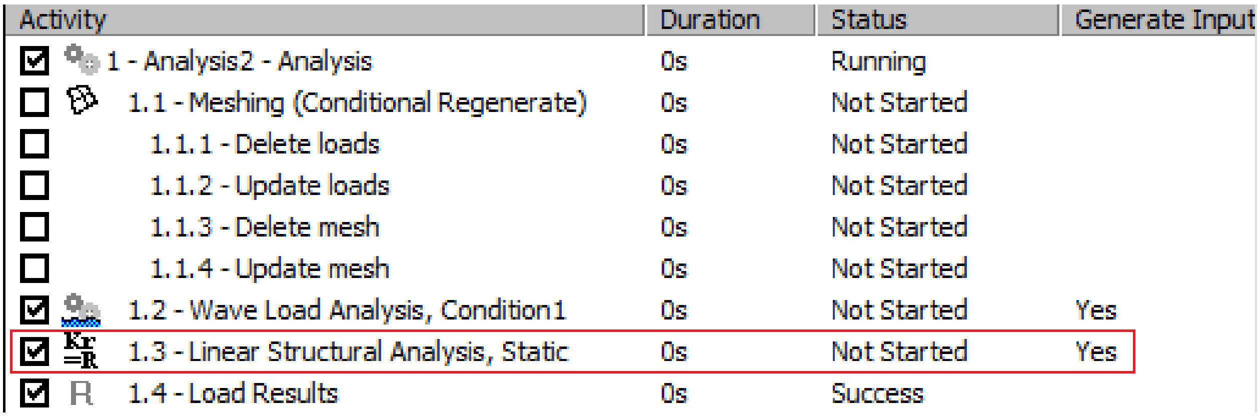
Equation of equilibrium being solved, $K_{x} r = R$ Eq. (2)

K- Stiffness matrix

r- Displacement vector

R- Load vector

Figure 10 showing the dialog box from the analysis page. The analysis will be carried out on ticked boxes on left.



Activity	Duration	Status	Generate Input
☑ 1 - Analysis2 - Analysis	0s	Running	
☐ 1.1 - Meshing (Conditional Regenerate)	0s	Not Started	
☐ 1.1.1 - Delete loads	0s	Not Started	
☐ 1.1.2 - Update loads	0s	Not Started	
☐ 1.1.3 - Delete mesh	0s	Not Started	
☐ 1.1.4 - Update mesh	0s	Not Started	
☑ 1.2 - Wave Load Analysis, Condition1	0s	Not Started	Yes
☑ 1.3 - Linear Structural Analysis, Static	0s	Not Started	Yes
☑ 1.4 - Load Results	0s	Success	

Figure 10 Analysis activity of Sestra inside GeniE

3.4 Wave loads on frame structures using Wajac module

Wajac calculates wave and current loads on fixed and rigid frame structures that have structural members of relatively small cross-sectional dimensions compared to the wave lengths. For Wajac to calculate the wave loads, define wave theory, kinematic factor and buoyancy in the deterministic sea state table, ref/18/.

Wave and current forces are calculated according to Morison equation. This is a semi-empirical formula in which it is assumed that the force may be divided into a sum of an inertia component due to the fluid acceleration and a drag component due to the fluid velocity.

Morison equation is given by, ref/2/ and /18/.

$f(z,t) = f_M + f_D = (\pi D^2/4)\ \rho\ C_M\ \acute{u} + (\tfrac{1}{2})\ \rho\ C_D\ D\ u\ |u|$ Eq. (3)

ρ - Water density.

D – Member diameter at load calculation point.

C_M – Inertia coefficient.

C_D – Drag coefficient.

u – Undistributed velocity component of the fluid normal to the member at the time and point.

|u| - Absolute value of u.

ú – Undistributed acceleration component of the fluid normal to the member at the time and point.

z – Global coordinate of the load calculation point.

t – Time

Three different approaches for load calculations are available in Wajac. Ref/18/.

1. Deterministic load calculation in time domain
2. Force transfer function calculation in the frequency domain
3. Time domain simulation of wave loads for a given short-term sea state.

In this thesis the deterministic load calculation approach is used. Deterministic load calculation is performed in the time domain (wave stepping through structure) and generally used for design purposes in an ultimate limit state analysis and fatigue limit state analysis.

Figure 11 shows how a deterministic load calculation is carried out for the waves acting on an offshore jacket structure.

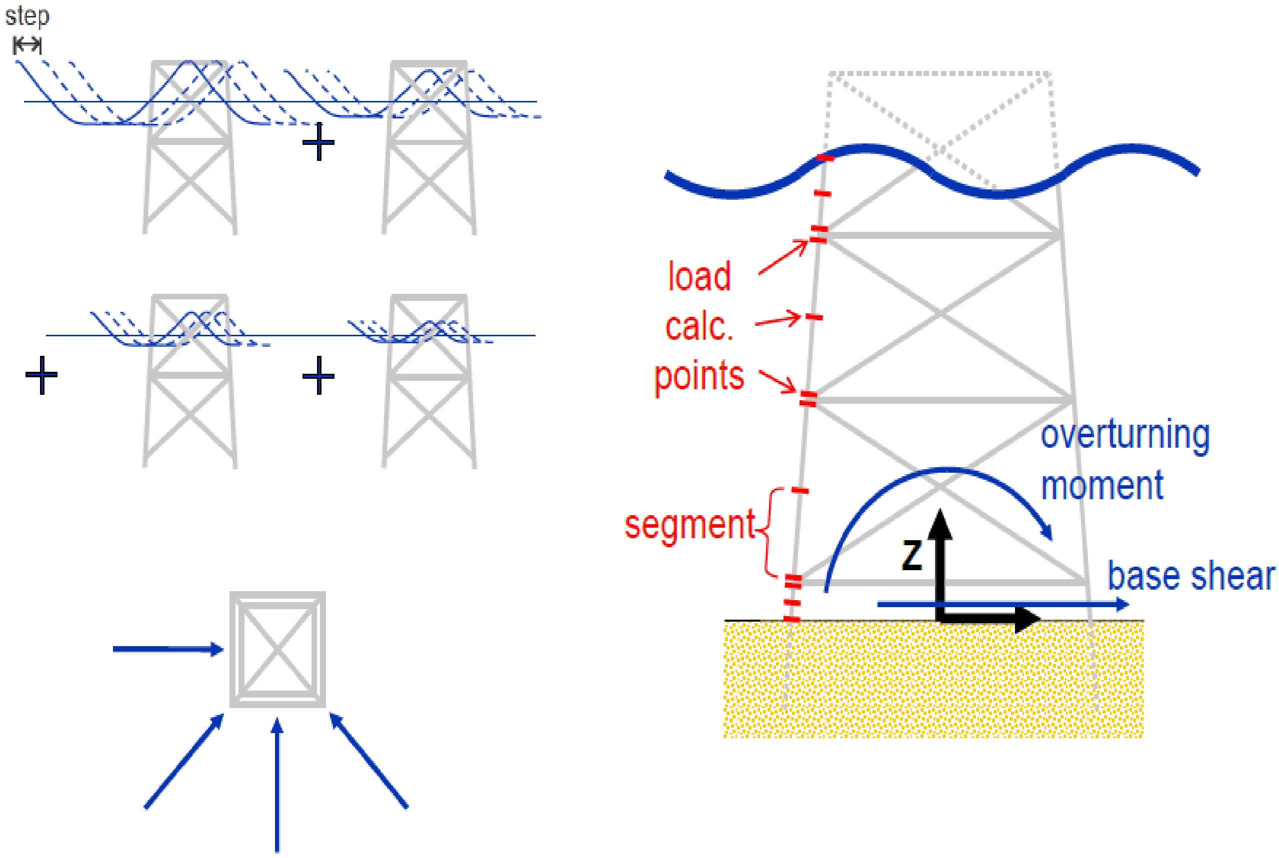


Figure 11 Deterministic load calculation overview, ref/18/

For each sea state, Wajac generates max-min base shear and max-min overturning moment. The characteristic values are selected among the time steps specified.

The minimum base shear is used with the following sign convention i.e +ve load in the wave direction –ve load opposite to the wave direction (180degree off).

3.5 Fatigue analysis of frame structures using Framework module

A fatigue analysis in Framework is performed on a frame structural member in order to assess whether that member is likely to suffer failure due to the action of repeated loading. The assessment is made using Miners rule of cumulative damage, which delivers a usage factor representing the amount of fatigue damage that the member has suffered during a specific period. Ref/11/. Figure 12 shows how the wave load contribution to fatigue load and the development of stresses.

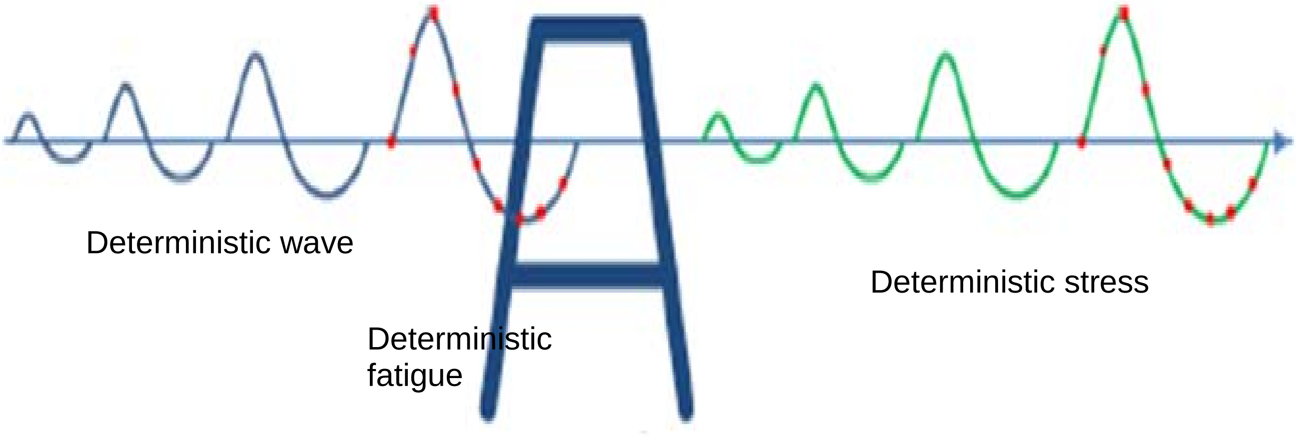


Figure 12 Wave induced deterministic fatigue representation, ref/11/

For performing fatigue analysis in Frame work, prepare a GeniE model with joints that have property of CAN, STUB, CONE and BRACE. Loads for a fatigue analysis must be computed from a hydrodynamic analysis using deterministic approach. Deterministic means the computed loads are real. The Wajac computer program is used to compute hydrodynamic loads and Sestra program used to perform static structural analysis for subsequent fatigue analysis in Framework, Ref/11/.

After analysis using Sestra, from GeniE model produce a Framework model by opening Tools -> Analysis -> Frame code check.

It is important to note that no other loads (e.g. gravity, etc.) should be present in the input interface file during the execution of the static structural analysis.

On Framework, for each of the wave directions specified in the hydrodynamic analysis, total number of waves passing through structure to be specified in Framework. So, a long-term distribution of wave heights is then produced for each of the wave directions. This may be obtained by Weibull distribution or a Piece-wise linear distribution in H-logN space, ref/11/.

The procedure adopted for a deterministic fatigue analysis is as follows,

1. Select the fatigue method that need to be performed.
2. Define fatigue parameters (Target fatigue life, Global SCF, Splash zone limit, etc.).
3. Assign joint type and joint gap/overlap data.
4. Assign Stress concentration factor (SCF).
5. Assign individual wave data i.e. number of occurrences.
6. Execute fatigue analysis.
7. Compare calculated damage with design life accounting for factors of safety.

4. ANALYSIS OF JACKET STRUCTURE USING SESAM MODULES: A CASE STUDY

4.1 Considered structure: Martin Linge platform

The Martin Linge field in the North Sea is an oil and gas discovery that was made in 1975.The field is located 42 kilometers west of Oseberg, at a water depth of 115meters.The platform jacket is installed in 2014 and the production in the field is expected to start in 2019.Equinor became the operator of the Martin Linge field, ref/19/.Figure 13 shows an illustration of Martin Linge platform on North Sea and location of platform.

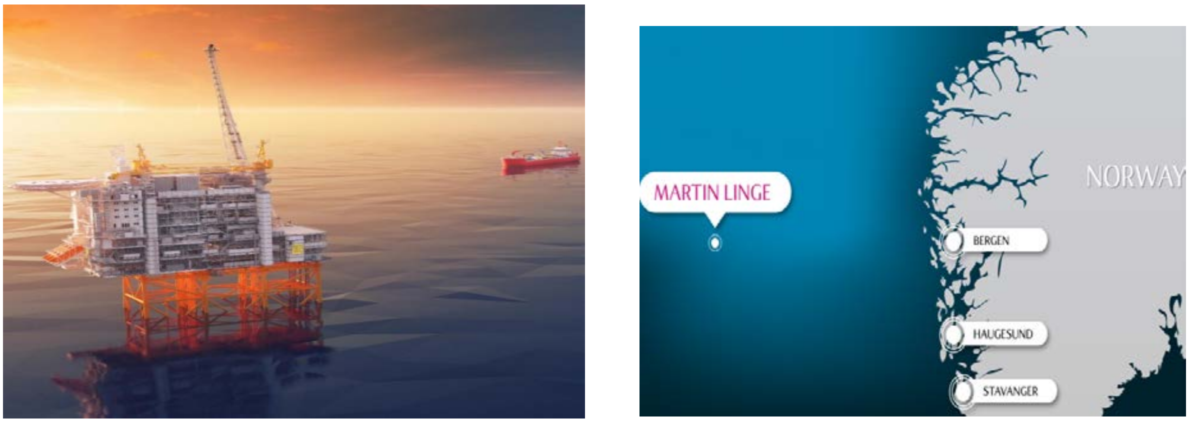


Figure 13 Conceptual illustration of Martin Linge platform and location, ref/19/

The jacket consists of eight main legs and with mainly X-bracing between the six horizontal elevations, defined elevations at +22m, +9.5m,-15m,-44m,-74m and -110m.The jacket is supported to the sea bed by use of 96'' piles, four in each pile clusters, totally sixteen piles with length of approximately 65m.Bottom of jacket outer leg spacing at sea bed is 76mx50m.Top of jacket outer leg spacing to topside footing is 76m x 27.5m, ref/5/.

According to ref/20/, the total offshore jacket weight is 15000tonnes and topside weight is 23600tonnes.

According to ref/21/, the design life of the jacket is 30 years.

Offshore jackets are generally designed to accommodate Risers, Caissons, J-tubes and Conductors.

Interface between Topside and Jacket is followed as per the previous Master thesis, ref/5/. Here it was mentioned total weight of topside as 28000tonnes.So this was considered in Ultimate limit state analysis.

Platform North matches with True North, ref/5/.

4.2 Structural modelling of Topsides and Jacket structure

The considered structure is modelled in GeniE using the existing SAP2000 model and some information from earlier thesis work, ref/5/. Below steps show how the Jacket and Topside are modelled for further analysis, Jacket structure modelling:

1. Specify units and create a new workspace.
2. Platform North is +ve Y axis and East is +ve X axis.
3. Origin of coordinates X, Y to be in geometric center of jacket structure.
4. Model points and beam element from guide plane dialog.
5. Create the whole jacket model with steel framing in all platform grids and Horizontal framing based on dimensions from SAP2000 model, ref/5/.
6. Linear isotropic steel property is assigned for all steel beams.
7. Section property of steel tubulars is assigned.
8. Assign a fixed support point on the four outer main legs.
9. Define Morison constant from design premises report, for members above MSL+2.0m C_D=0.65 and C_M = 1.6. For members below MSL+2m C_D=1.05 and C_M = 1.2.
10. Define all the four main legs are flooded with coefficient 1.0, ref/18/
11. Table 8 gives marine growth information from platform design premises report.

Table 8 Marine growth depth profile

Water depth (m) rel. LAT	Thickness (mm)
Above +2.9	0
From +2.9 to -39.1	60
From -39.1 to Seabed	30

Table 8 gives the Marine growth consideration based on water depth.

Topside structure modelling:

Based on SAP2000 model, ref/5/ the topside consists of structures from cellar deck, module deck, Module 1 to 6 and Living quarters.

1. Interface point between the Jacket frame and topside cellar deck is first made.
2. Modelled different structures of topside based on the SAP2000 model reference.
3. Linear isotropic steel property is assigned for all modelled steel beams.
4. Section property of steel tubulars is assigned.

Figure 14 shows an isometric view of offshore jacket modelled in GeniE software. It also gives information on the platform grid names, platform north direction, support to the sea bed and various horizontal levels on the offshore jacket. Figure 15 shows isometric view of offshore jacket platform with the topside information with different colour code. Topside of this platform consists of a cellar deck on lowest level and module deck above the cellar deck. Over module deck a portion of platform have living quarter and other modules.

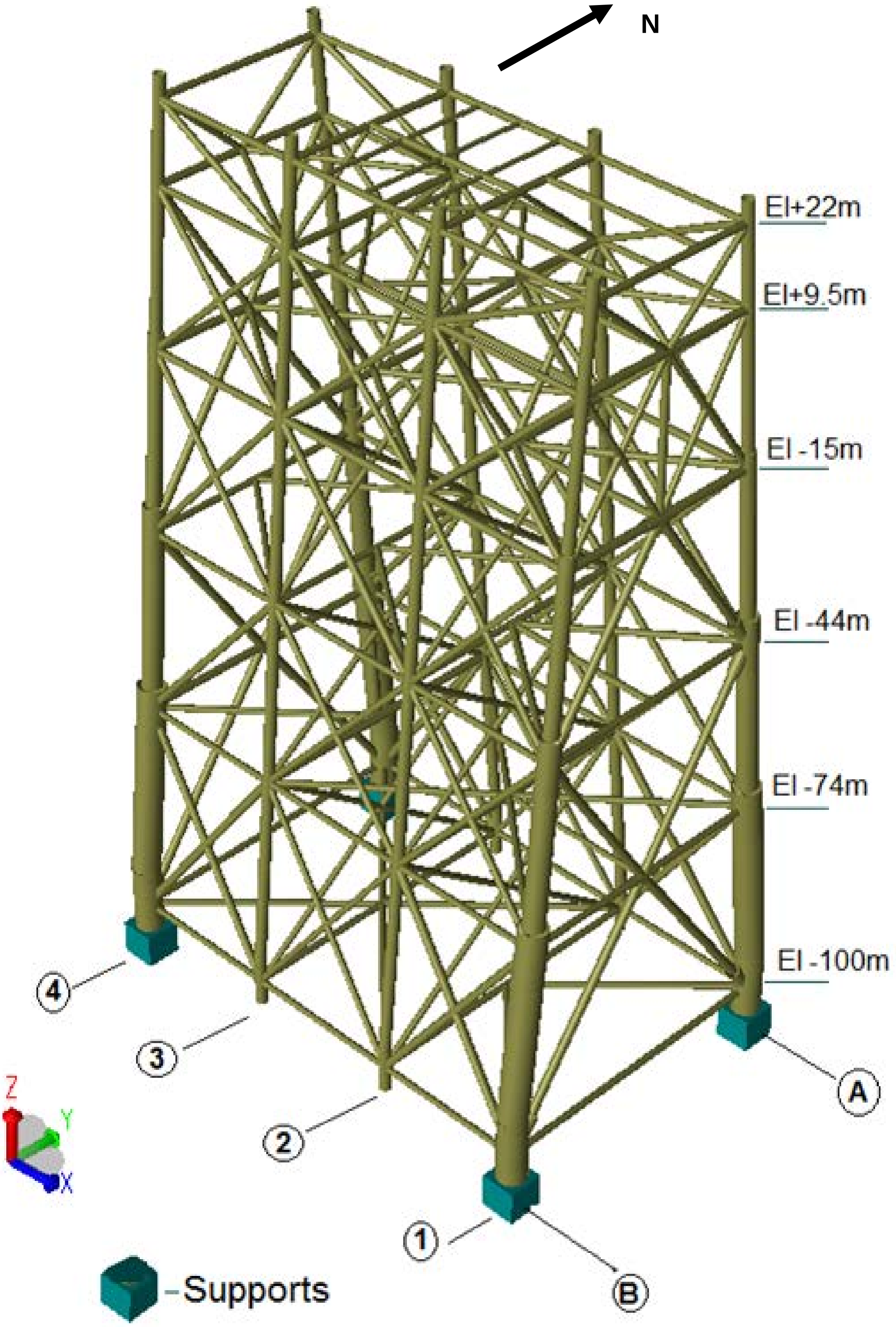


Figure 14 Isometric view of the Jacket model made in GeniE

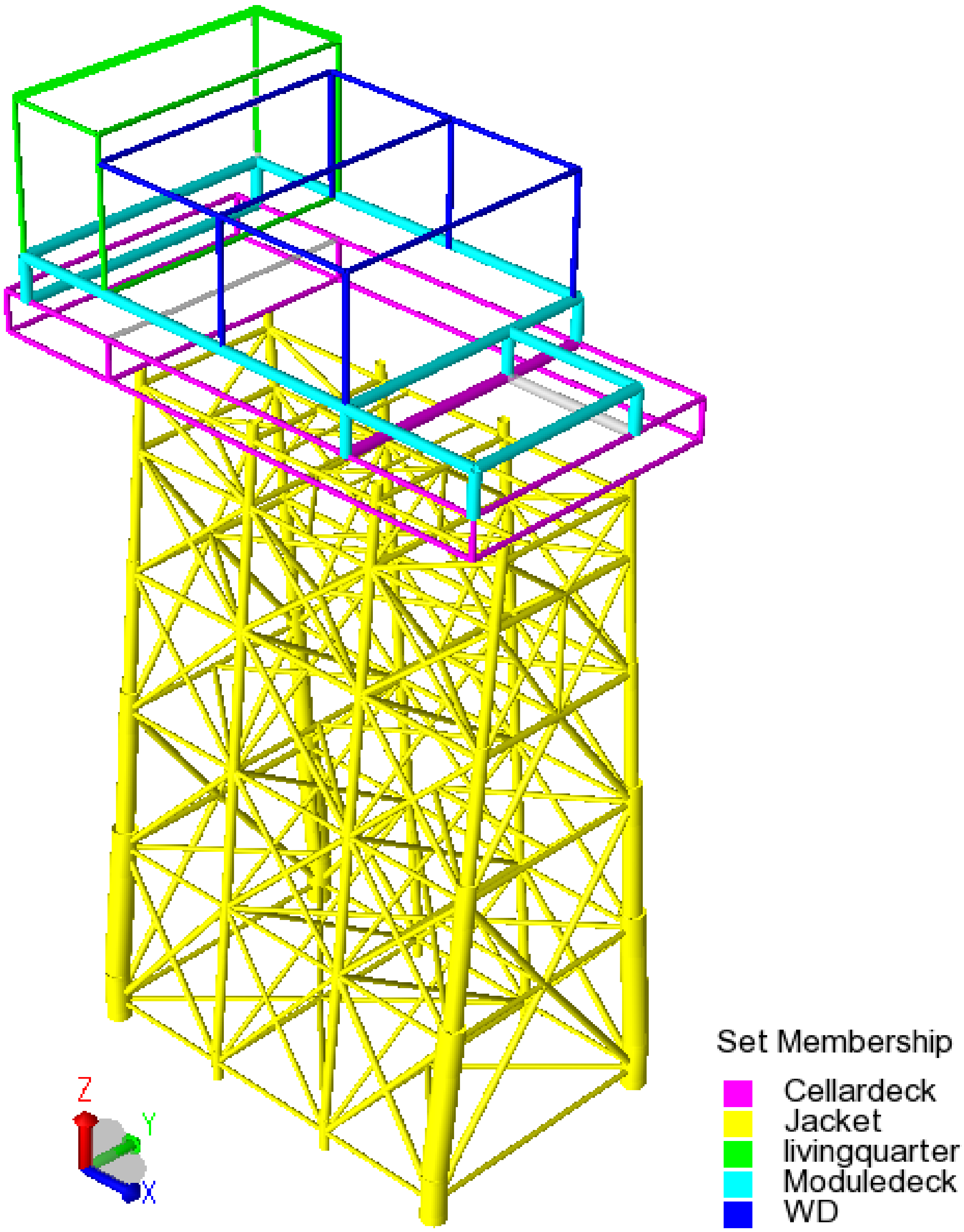


Figure 15 Isometric model showing Topside modules together with Jacket structure

Above model is used for performing ultimate limit state analysis. But this model has to be updated with joints for performing fatigue limit state and ultimate limit state check for joints. The joint is not the same as a node in finite element model. A joint holds information about CHORD (can and cone), BRACE (stud and cone) and GAPS.

For creating joint there are two ways, Automatic and Manual. In this thesis, Automatic approach was used, ref/16/.

Below showing steps for automatic approach.

1. Set rules for joint creation
2. Create joints
3. Set rules for length of cans, stubs, cones and gaps.
4. Add cans and stubs
5. Change cross section for cans and stubs.
6. Automatic assigning of cones.

Figure 16 shows a tubular joint of an offshore jacket comprises of chord, can, stub, brace and cone.

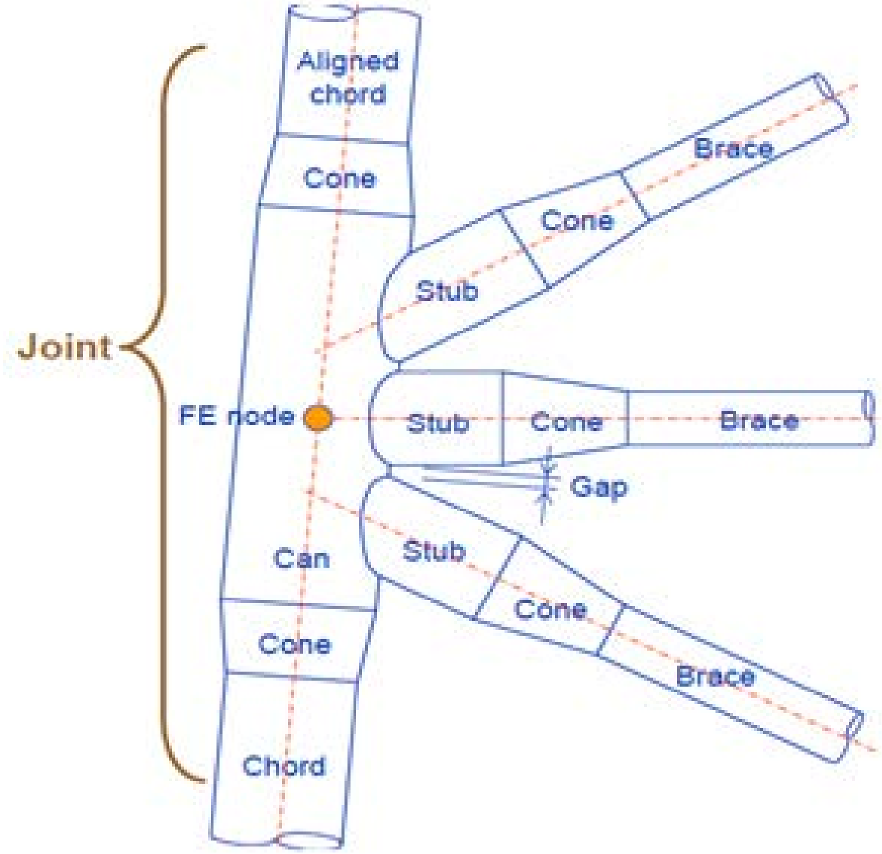


Figure 16 Joint features, ref/16/.

Figure 17 shows tubular joints created automatically on the considered offshore jacket. The automatic joint creation and design default settings are made according to NORSOK, ref/16/.

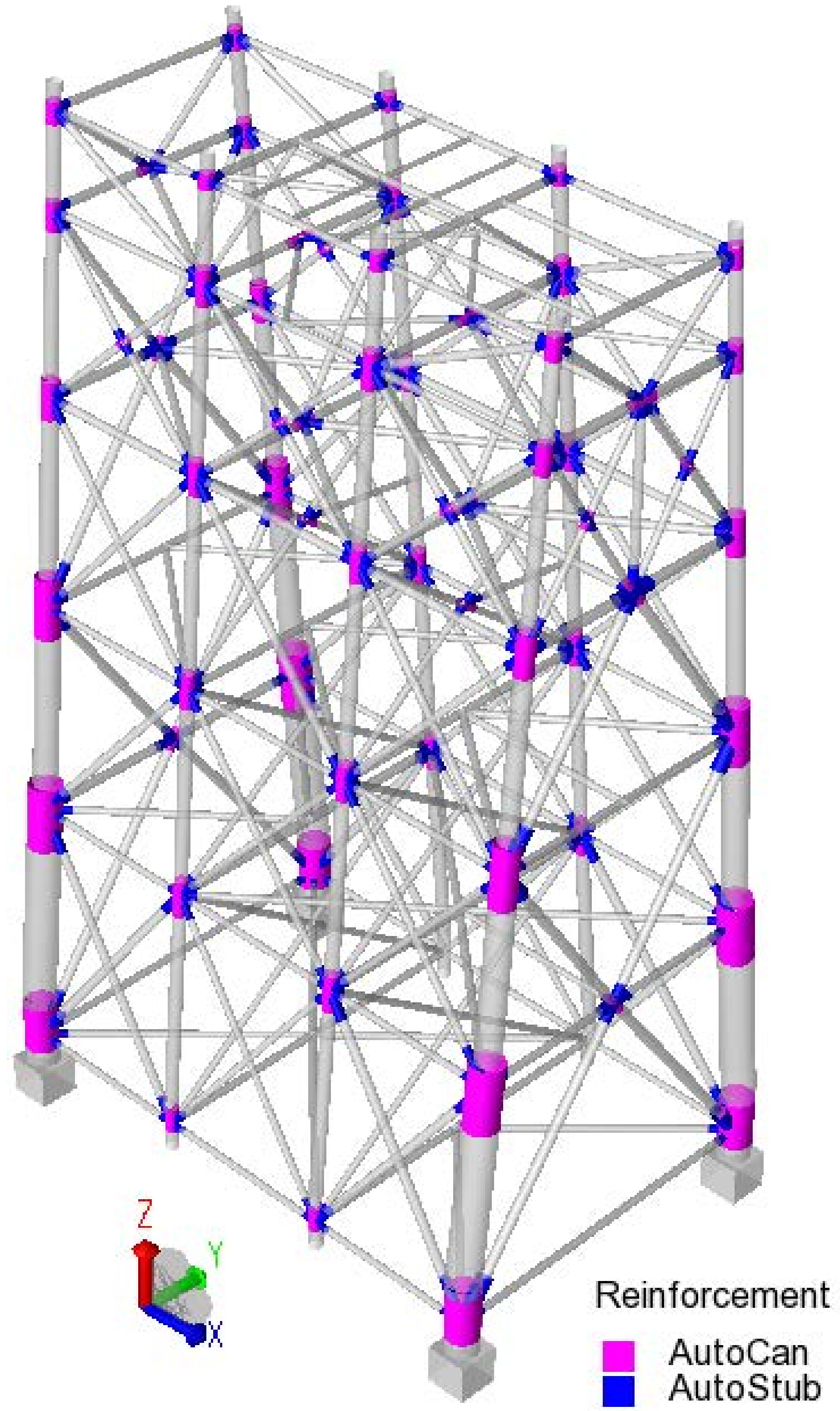


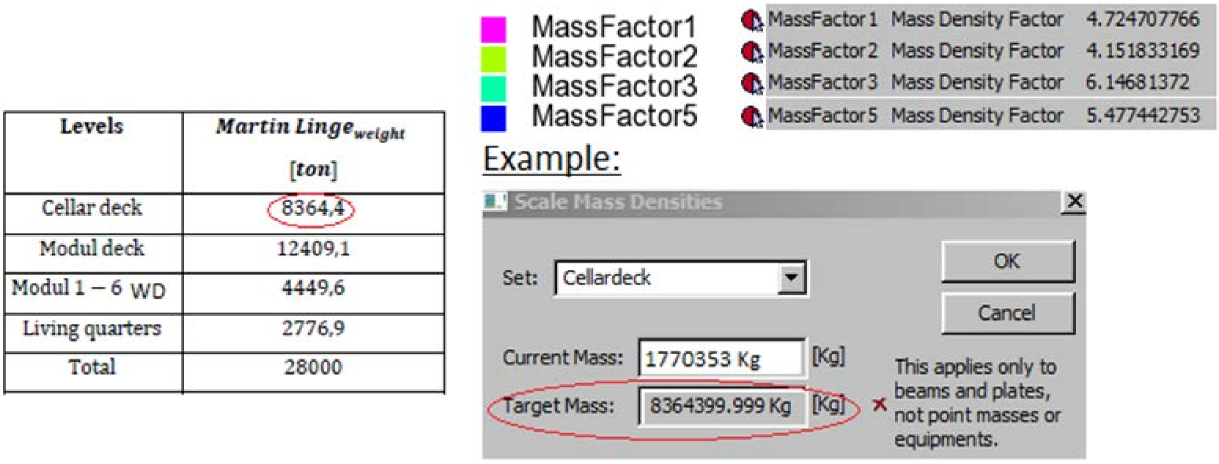
Figure 17 Offshore jacket structure modelled with joints

4.3 Considered loadings for ULS design checks

4.3.1 Permanent and variable loads in the jacket structure

Permanent loads are mainly from mass of jacket, mass of topside and hydrostatic pressure from seawater, ref/13/.

The variable loading is the operating weight which was transferred by increasing the modelled steel work steel density. Sesam-GeniE allows to make sets. By using the set function, the modules can be grouped. Figure 18 showing how the mass density of modelled structure is scaled to each set.



Levels	$Martin\ Linge_{weight}$ [ton]
Cellar deck	8364,4
Modul deck	12409,1
Modul 1 – 6 WD	4449,6
Living quarters	2776,9
Total	28000

🟪 MassFactor1
🟩 MassFactor2
🟩 MassFactor3
🟦 MassFactor5

MassFactor1	Mass Density Factor	4.724707766
MassFactor2	Mass Density Factor	4.151833169
MassFactor3	Mass Density Factor	6.14681372
MassFactor5	Mass Density Factor	5.477442753

Example:

Scale Mass Densities

Set: Cellardeck

Current Mass: 1770353 Kg [Kg]

Target Mass: 8364399.999 Kg [Kg]

This applies only to beams and plates, not point masses or equipments.

Figure 18 Scale mass density to edit the modelled masses

4.3.2 Environment loading on the jacket structure

Waves, Buoyancy and the mass of marine growth are considered as environment loading.

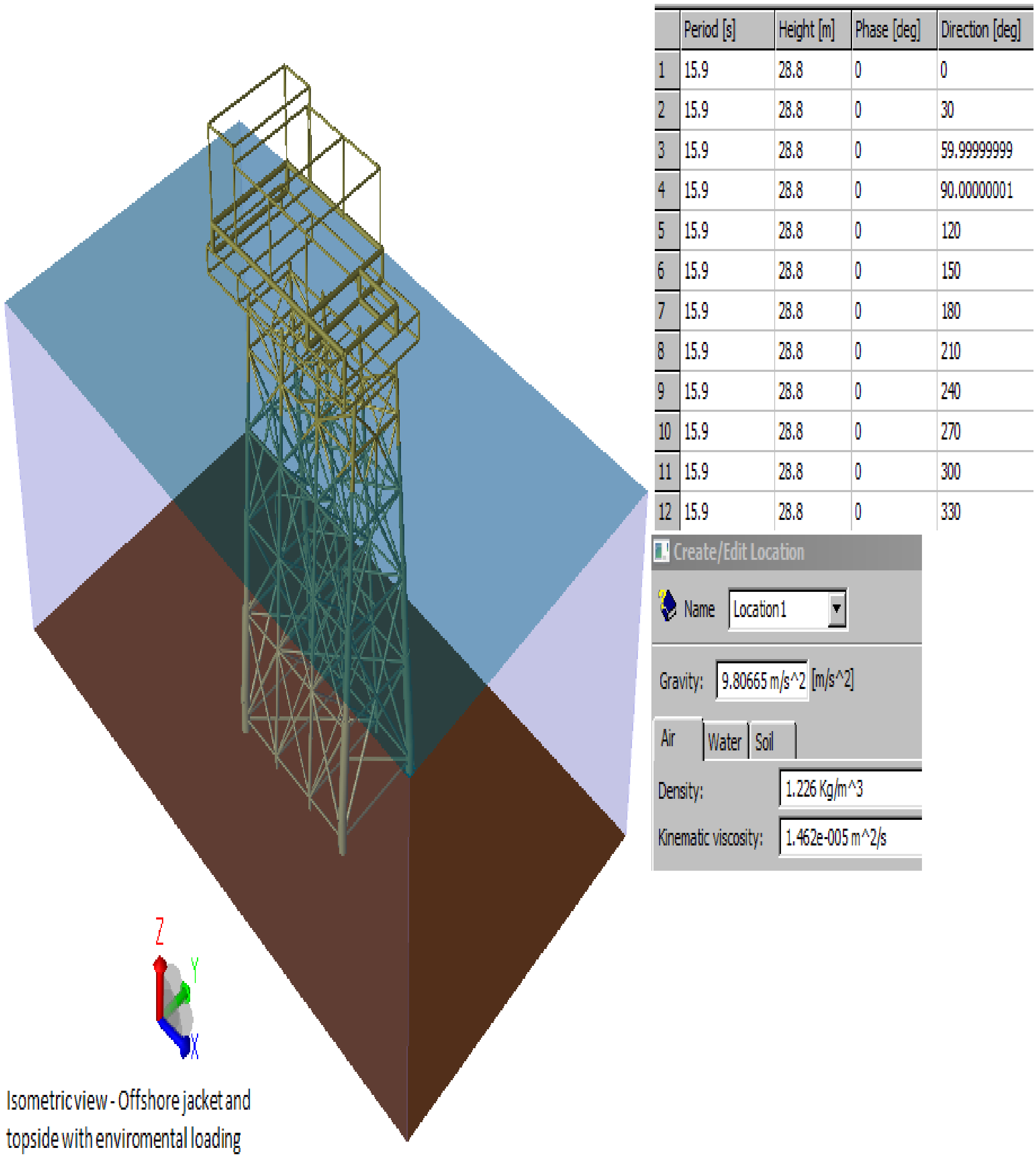
Waves are the met ocean actions. Wave loading is applied using Airy wave theory. The wave particle velocity and accelerations are calculated using these theories. Morison's equation is used to calculate the wave load on jacket members. The hydrodynamic drag and inertia coefficients C_D and C_M are taken from ref/5/.

A 100year return wave with wave height 28.8m and 15.9s is used, ref/5/. The wave load is defined in 12 directions 0deg, 30deg, 60deg, 90deg, 120deg, 150deg, 180deg, 210deg, 240deg, 270deg, 300deg, 330deg.Corresponding load cases are generated in each direction by Wajac.

Buoyancy load calculation is specified inside Wave load run input, so Wajac program calculates wave loads with and without buoyancy for a given sea state.

Similarly, marine growth information is specified in hydrodynamic property of the modelled structure. Wajac program receives input for calculating the extra loads from marine growth on structural jacket members.

Figure 19 shows the applied environment loading on the offshore jacket.100-year return wave loading is considered in twelve directions, ref/22/.



	Period [s]	Height [m]	Phase [deg]	Direction [deg]
1	15.9	28.8	0	0
2	15.9	28.8	0	30
3	15.9	28.8	0	59.99999999
4	15.9	28.8	0	90.00000001
5	15.9	28.8	0	120
6	15.9	28.8	0	150
7	15.9	28.8	0	180
8	15.9	28.8	0	210
9	15.9	28.8	0	240
10	15.9	28.8	0	270
11	15.9	28.8	0	300
12	15.9	28.8	0	330

Create/Edit Location

Name: Location1

Gravity: 9.80665 m/s^2 [m/s^2]

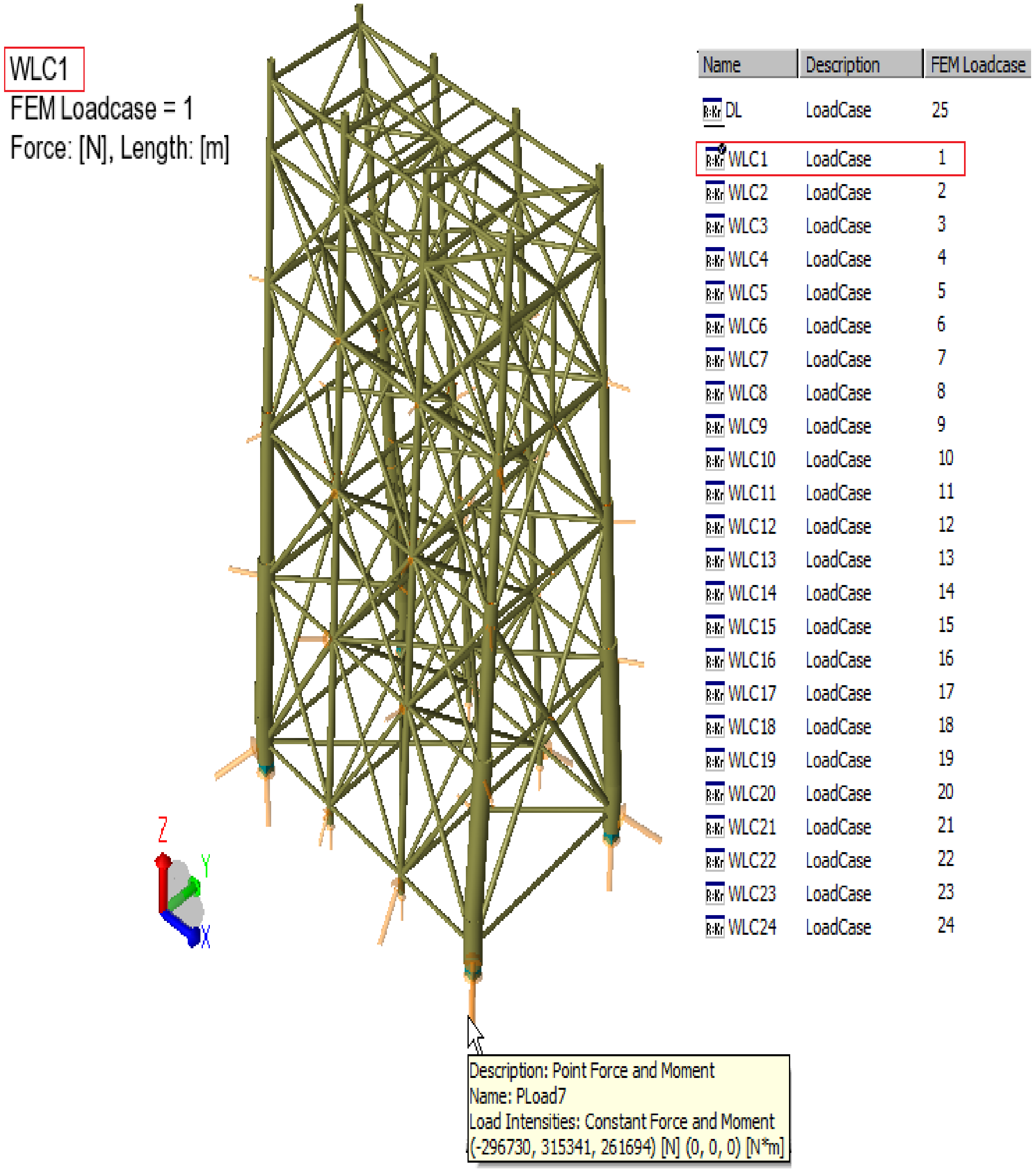
Air | Water | Soil

Density: 1.226 Kg/m^3

Kinematic viscosity: 1.462e-005 m^2/s

Figure 19 Environmental loading and calculated wave forces from Wajac

Based on the inputs with 100-year return wave inputs, Wajac have calculated wave loads on all beam intersection points. Totally twenty-four load cases are developed by the Wajac program for further analysis. Figure 20 shows wave loading calculated from 12 directions with maximum base shear and overturning moment at all intersection points in Jacket. Load combinations are according to Table 3. Using ULSa and ULSb combination, a total of 48 load combinations as shown in Figure 21.Two load combinations are shown in detail. Similar input on load factor is used on other load combinations from primary load cases.



WLC1
FEM Loadcase = 1
Force: [N], Length: [m]

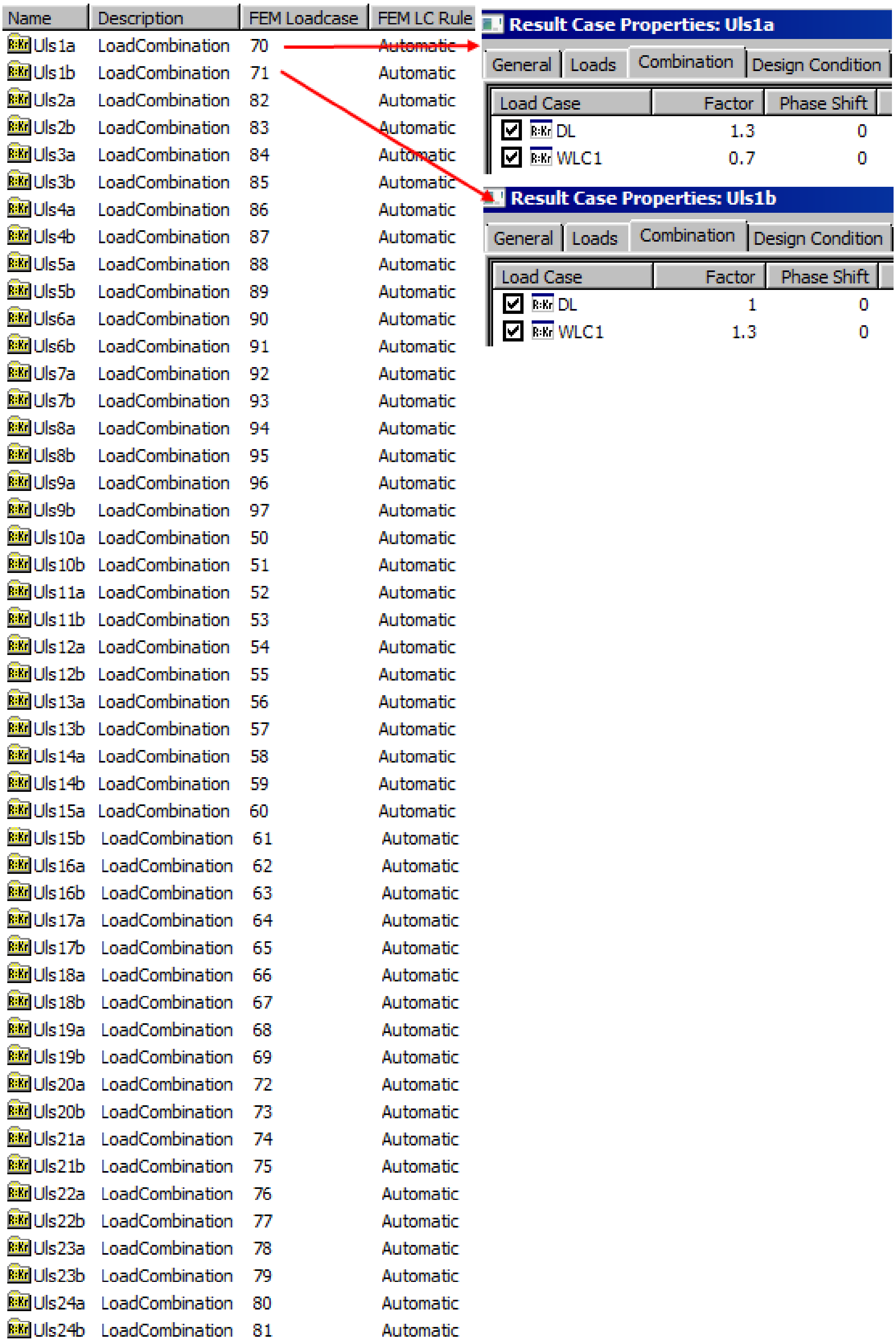
Name	Description	FEM Loadcase
DL	LoadCase	25
WLC1	LoadCase	1
WLC2	LoadCase	2
WLC3	LoadCase	3
WLC4	LoadCase	4
WLC5	LoadCase	5
WLC6	LoadCase	6
WLC7	LoadCase	7
WLC8	LoadCase	8
WLC9	LoadCase	9
WLC10	LoadCase	10
WLC11	LoadCase	11
WLC12	LoadCase	12
WLC13	LoadCase	13
WLC14	LoadCase	14
WLC15	LoadCase	15
WLC16	LoadCase	16
WLC17	LoadCase	17
WLC18	LoadCase	18
WLC19	LoadCase	19
WLC20	LoadCase	20
WLC21	LoadCase	21
WLC22	LoadCase	22
WLC23	LoadCase	23
WLC24	LoadCase	24

Description: Point Force and Moment
Name: PLoad7
Load Intensities: Constant Force and Moment
(-296730, 315341, 261694) [N] (0, 0, 0) [N*m]

Figure 20 Wave loading generated by Wajac (load intensity displayed only from WLC1 on a point)

4.4 Considered loadings for FLS design checks

While performing FLS check, only environmental loading is considered. See chapter 3.5. The main contribution to fatigue actions is normally from the local and global effect of waves and come from moderate stress ranges. Fatigue design requires a description of the long-term variation of local stresses due to wave as well as possible sum-frequency wave actions, variable buoyancy, slamming, wave-or current-induced vortex shedding, or mechanical vibration, ref/14/.



Name	Description	FEM Loadcase	FEM LC Rule
Uls1a	LoadCombination	70	Automatic
Uls1b	LoadCombination	71	Automatic
Uls2a	LoadCombination	82	Automatic
Uls2b	LoadCombination	83	Automatic
Uls3a	LoadCombination	84	Automatic
Uls3b	LoadCombination	85	Automatic
Uls4a	LoadCombination	86	Automatic
Uls4b	LoadCombination	87	Automatic
Uls5a	LoadCombination	88	Automatic
Uls5b	LoadCombination	89	Automatic
Uls6a	LoadCombination	90	Automatic
Uls6b	LoadCombination	91	Automatic
Uls7a	LoadCombination	92	Automatic
Uls7b	LoadCombination	93	Automatic
Uls8a	LoadCombination	94	Automatic
Uls8b	LoadCombination	95	Automatic
Uls9a	LoadCombination	96	Automatic
Uls9b	LoadCombination	97	Automatic
Uls10a	LoadCombination	50	Automatic
Uls10b	LoadCombination	51	Automatic
Uls11a	LoadCombination	52	Automatic
Uls11b	LoadCombination	53	Automatic
Uls12a	LoadCombination	54	Automatic
Uls12b	LoadCombination	55	Automatic
Uls13a	LoadCombination	56	Automatic
Uls13b	LoadCombination	57	Automatic
Uls14a	LoadCombination	58	Automatic
Uls14b	LoadCombination	59	Automatic
Uls15a	LoadCombination	60	Automatic
Uls15b	LoadCombination	61	Automatic
Uls16a	LoadCombination	62	Automatic
Uls16b	LoadCombination	63	Automatic
Uls17a	LoadCombination	64	Automatic
Uls17b	LoadCombination	65	Automatic
Uls18a	LoadCombination	66	Automatic
Uls18b	LoadCombination	67	Automatic
Uls19a	LoadCombination	68	Automatic
Uls19b	LoadCombination	69	Automatic
Uls20a	LoadCombination	72	Automatic
Uls20b	LoadCombination	73	Automatic
Uls21a	LoadCombination	74	Automatic
Uls21b	LoadCombination	75	Automatic
Uls22a	LoadCombination	76	Automatic
Uls22b	LoadCombination	77	Automatic
Uls23a	LoadCombination	78	Automatic
Uls23b	LoadCombination	79	Automatic
Uls24a	LoadCombination	80	Automatic
Uls24b	LoadCombination	81	Automatic

Result Case Properties: Uls1a

Load Case	Factor	Phase Shift
☑ DL	1.3	0
☑ WLC1	0.7	0

Result Case Properties: Uls1b

Load Case	Factor	Phase Shift
☑ DL	1	0
☑ WLC1	1.3	0

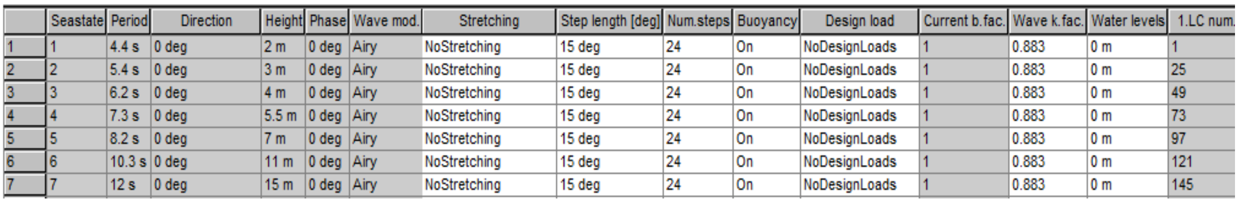
Figure 21 Load combinations for ULS

4.4.1 Wave loading

Hydrodynamic coefficients used on fatigue analysis is similar to the ultimate limit state analysis. Therefore, it was not defined again in this chapter. The wave conditions specified in GeniE prepares an input file for Wajac. The combinations of wave directions, wave heights and wave periods to Wajac for developing total number of sea states to perform wave analysis. For each sea state, a specified number of phase steps through the wave, for force calculations are given. The number of steps for force calculations times the number of sea states gives the total number of load cases in the analysis.

Table 9 shows the sea state for deterministic fatigue analysis. Only 0deg wave direction sea state is shown due to clarity, but in analysis similar wave period and heights are considered for 45deg, 90deg, 135deg, 180deg, 225deg, 270deg and 315deg.

Table 9 Features of fatigue waves from design premises report



	Seastate	Period	Direction	Height	Phase	Wave mod.	Stretching	Step length [deg]	Num.steps	Buoyancy	Design load	Current b.fac.	Wave k.fac.	Water levels	1.LC num.
1	1	4.4 s	0 deg	2 m	0 deg	Airy	NoStretching	15 deg	24	On	NoDesignLoads	1	0.883	0 m	1
2	2	5.4 s	0 deg	3 m	0 deg	Airy	NoStretching	15 deg	24	On	NoDesignLoads	1	0.883	0 m	25
3	3	6.2 s	0 deg	4 m	0 deg	Airy	NoStretching	15 deg	24	On	NoDesignLoads	1	0.883	0 m	49
4	4	7.3 s	0 deg	5.5 m	0 deg	Airy	NoStretching	15 deg	24	On	NoDesignLoads	1	0.883	0 m	73
5	5	8.2 s	0 deg	7 m	0 deg	Airy	NoStretching	15 deg	24	On	NoDesignLoads	1	0.883	0 m	97
6	6	10.3 s	0 deg	11 m	0 deg	Airy	NoStretching	15 deg	24	On	NoDesignLoads	1	0.883	0 m	121
7	7	12 s	0 deg	15 m	0 deg	Airy	NoStretching	15 deg	24	On	NoDesignLoads	1	0.883	0 m	145

Wajac calculates the member forces by stepping the waves through the structure. The forces are computed by a static analysis and stored as load cases for every phase step. Totally 1344 FEM load cases are generated based on the given input.

4.4.2 Long term distribution of wave heights for determining stress ranges

The long-term distribution of wave heights for a deterministic fatigue analysis is derived from the directional scatter diagrams from design premises document. The long-term directional distributions are established using a Forristall wave height distribution. The reason for using Forristall wave height distribution is that it gives good agreement particularly for the headings with the highest waves with the 1-yr design wave. Table 10 gives the directional long-term cumulative wave heights which shall be used for deterministic fatigue analysis. These values are taken from design premises document.

In Framework, the wave occurrences to be specified as a linear distribution with respect to height and direction. Therefore, calculated the occurrences of waves that exceeds each wave heights. Table 11 was prepared and used as input inside Framework program for a piece-wise linear distribution in H – logN. Table 11 gives the number of waves calculated based on the height and cumulative number of wave cycles.

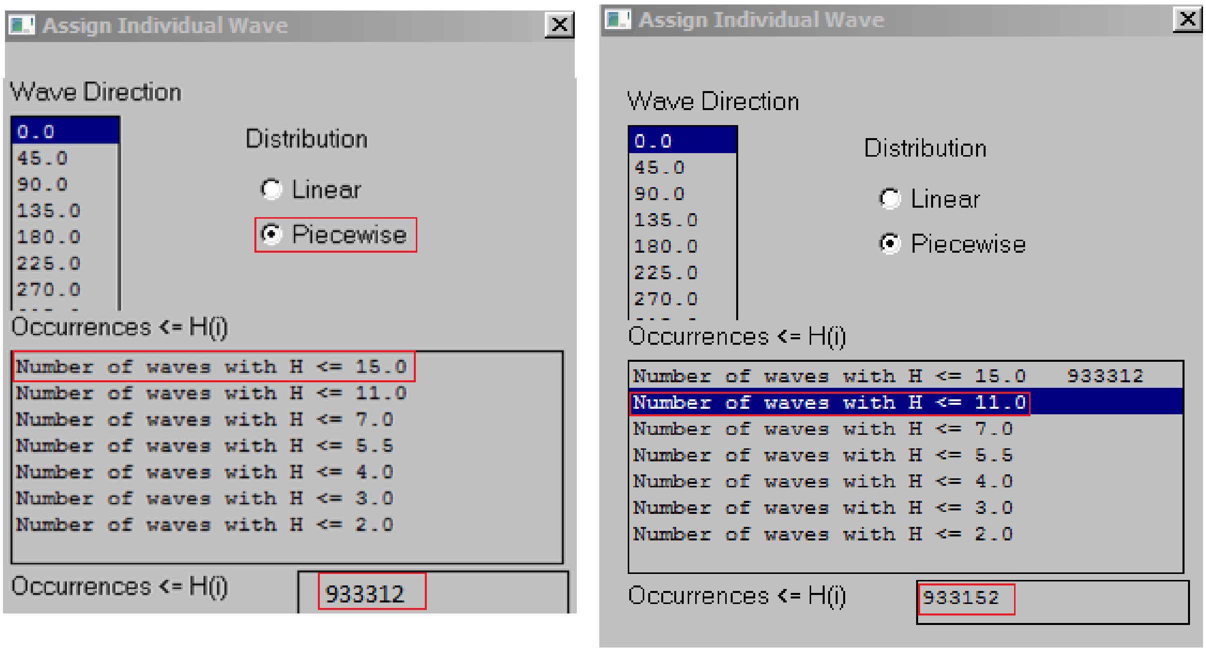
Occurrences of wave is then assigned as individual wave on the fatigue analysis model in Framework, see Figure 22 as example. For a wave direction 0deg and number of waves that are less than or equal to 15m. Similarly, the all the wave occurrences for each wave height and each direction are assigned to the fatigue analysis model. These values are used to calculate the hotspot stress for each wave and then multiplied by number of wave in corresponding direction.

Table 10 Long term cumulative distribution of wave heights in all wave directions

H (m)	T (s)	Cumulative number of cycles							
		W(0^0)	SW(45^0)	S(90^0)	SE(135^0)	E(180^0)	NE(225^0)	N(270^0)	NW(315^0)
15	12	9	13	17	3	0	0	15	19
11	10.3	169	165	314	87	0	0	157	234
7	8.2	3129	2673	4879	1549	0	20	1861	3118
5.5	7.3	10346	8857	15394	4813	10	140	6201	9331
4	6.2	36486	32100	52977	17218	143	1043	25023	30633
3	5.4	86468	76732	124213	43523	647	3910	70720	72728
2	4.4	207092	178203	293665	112797	2700	14218	217227	184463
0	0	933321	631363	1210269	497290	40030	156942	1417606	896501

Table 11 Occurrences of waves

H (m)	W(0^0)	SW(45^0)	S(90^0)	SE(135^0)	E(180^0)	NE(225^0)	N(270^0)	NW(315^0)
H<=15	933312	631350	1210252	497287	40030	156942	1417591	896482
H<=11	933152	631198	1209955	497203	40030	156942	1417449	896267
H<=7	930192	628690	1205390	495741	40030	156922	1415745	893383
H<=5.5	922975	622506	1194875	492477	40020	156802	1411405	887170
H<=4	896835	599263	1157292	480072	39887	155899	1392583	865868
H<=3	846853	554631	1086056	453767	39383	153032	1346886	823773
H<=2	726229	453160	916604	384493	37330	142724	1200379	712038
H<=0	933321	631363	1210269	497290	40030	156942	1417606	896501



Assign Individual Wave

Wave Direction

0.0
45.0
90.0
135.0
180.0
225.0
270.0

Distribution

○ Linear
● Piecewise

Occurrences <= H(i)

```
Number of waves with H <= 15.0
Number of waves with H <= 11.0
Number of waves with H <= 7.0
Number of waves with H <= 5.5
Number of waves with H <= 4.0
Number of waves with H <= 3.0
Number of waves with H <= 2.0
```

Occurrences <= H(i) 933312

Assign Individual Wave

Wave Direction

0.0
45.0
90.0
135.0
180.0
225.0
270.0

Distribution

○ Linear
● Piecewise

Occurrences <= H(i)

```
Number of waves with H <= 15.0   933312
Number of waves with H <= 11.0
Number of waves with H <= 7.0
Number of waves with H <= 5.5
Number of waves with H <= 4.0
Number of waves with H <= 3.0
Number of waves with H <= 2.0
```

Occurrences <= H(i) 933152

Figure 22 Individual wave definition in Framework

5. ULS DESIGN CHECKS FOR CONSIDERED JACKET STRUCTURE

5.1 Introduction to ULS design checks

The jacket components such as legs, primary and secondary braces, horizontal framing and joints are designed to satisfy the strength and stability requirements mentioned in NORSOK N-004, ref/12/.The check is performed using equations presented in this standard that can deliver the usage factor .If the usage factor is greater than 1.0 then the member is overloaded and does not meet the criteria. In GeniE, a member check is performed in five default positions i.e. at two end points, at midpoint and at the quarter positions. Meanwhile, additional code checking positions are determined at variations in section properties or material or locations with maximum moments, ref/13/.

5.2 ULS design checks for Jacket members

A member check on a structural frame is performed to assess whether the member is subjected to acceptable stress levels. Tubular members subjected to axial tension, axial compression, bending, shear, or hydrostatic pressure should be designed to satisfy the strength and stability requirements, ref/12/.

The terms related to buckling of tubular members are

1. Effective buckling lengths.
2. Buckling curves.
3. Effect of external pressure.

In general, the buckling length varies with respect to member frame geometry such as X-braces, K-braces, Single braces, jacket legs and piles. The effective buckling lengths may be defined manually if member results are critical. Because GeniE program uses a default value of 1.0 which a conservative value, ref/13/.The effective length factor also varies with different structural elements.

Table 12 gives the effective length and moment reduction factors of offshore jacket structural members.

Table 12 Effective length and moment reduction factors for member code check, ref/12/.

Structural element	Effective length factor 'k'	Moment reduction factors 'C_m'
Jacket braces - Primary diagonals and Horizontals	0.7	Minimum of {0.6- 0.4(M_s/M_l) or 1.0-0.4(N_{sd}/N_E) or 0.85}
K-braces	0.7	1.0-0.4(N_{sd}/N_E) or 0.85
X-braces	0.8	
Secondary horizontals	0.7	
Jacket legs	1.0	

Member redesign feature is available in GeniE, which shall be used to change a design parameter to bring usage factor below 1.0. Redesign is an iterative process which typically involves the following steps, ref/13/.

1. Code checking parameters are set to default, modify the parameters like buckling parameters, moment amplification factor and safety factor.
2. Modify cross section of steel or material property.
3. Add or remove additional structural members.
4. Update the members.
5. Perform new code check for updated model.

Figure 23 shows the usage factor in colour code obtained from ultimate limit state verification. The result shows offshore jacket legs and vertical bracing is having more utilization.

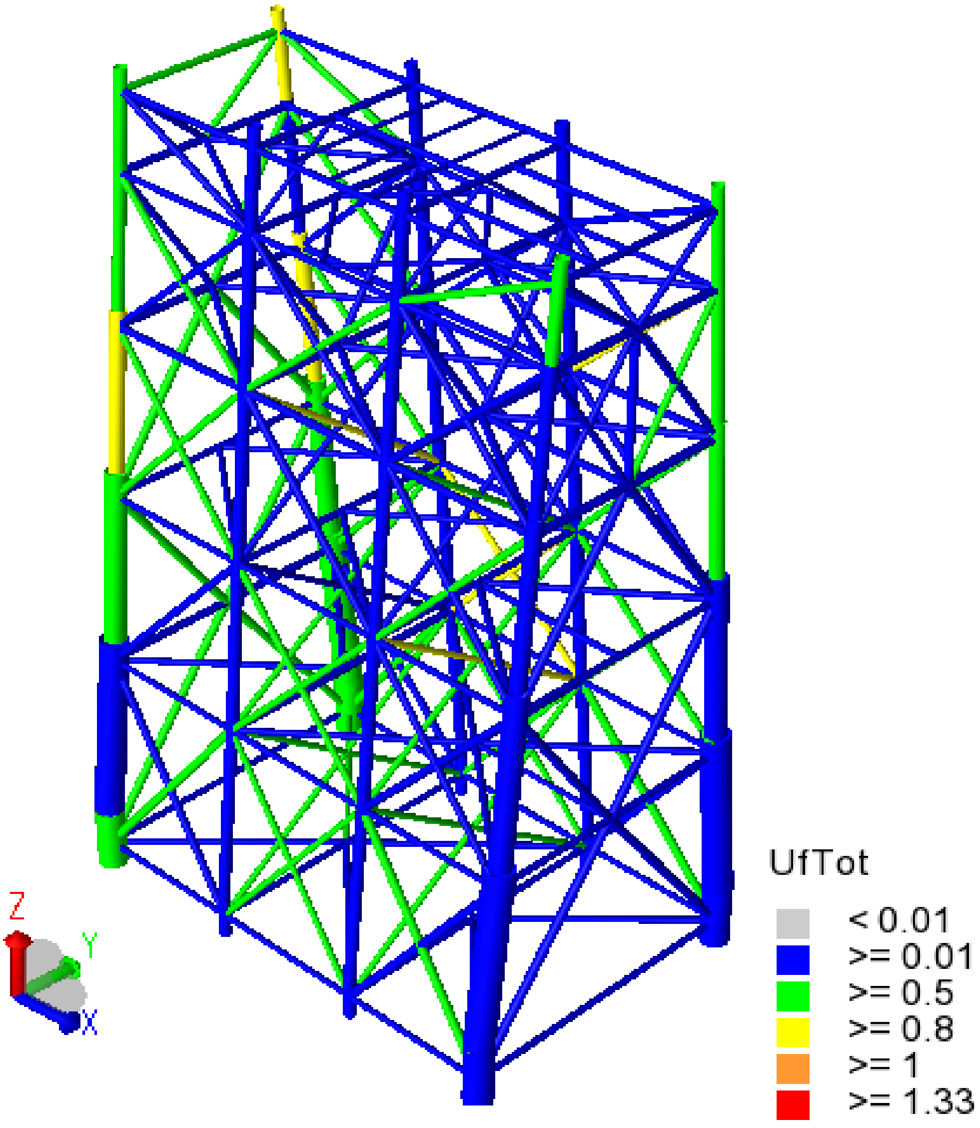


Figure 23 Usage factor of considered offshore jacket during 100year return wave loading

Table 13 gives the maximum beam usage factor with beam number, location and ULS load combination. ULS verification was made with buoyancy loading on jacket structure, where the main jacket legs are flooded.

Table 13 Maximum beam usage factor of considered offshore jacket during ULS

Member identification	Beam nr.	Load comb	Usage factor	Location above/below SWL
Jacket leg 4/B	152	ULS20a	**0.88**	Below
Brace A (2/3)	226	ULS12b	0.85	Below
Leg 4/A	154	ULS8a	0.85	Below
Brace 3 (A/B)	264	ULS8b	0.85	Below
Brace A (2/3)	227	ULS1b	0.85	Below
Brace A (1/2)	218	ULS20a	0.84	Below
Brace 2 (A/B)	272	ULS8b	0.82	Below
Leg 4/A	161	ULS7a	0.81	Above
Brace B (2/3)	203	ULS1b	0.80	Below
Brace B (3/4)	191	ULS5a	0.78	Below
Horz. frame 4 (El.22m)	1	ULS8a	0.75	Above

5.3 ULS design checks for Jacket joints

The capacity model has tubular joints with cans, stubs, cones and gaps. The code checking utilizes the classification based on the load paths in GeniE.

A punching shear check is carried out on the brace member at a joint to assess the shear through the chord. As for the other checks, these assessments are made through the use of a punching shear interaction equation that delivers a usage factor, ref/13/.

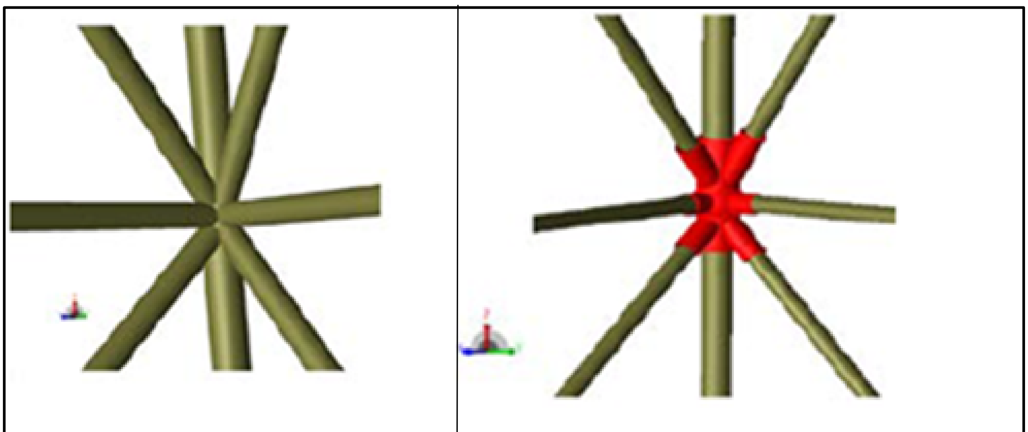
Similar to member redesign, redesign of joint involves following steps, ref/13/

1. Increase the thickness of the CAN and the STUBs at the joint.
2. Add conical transitions between members with different thickness
3. Add gaps between the CAN and the STUBs which represent fabrication-friendly geometries.

Table 14 Maximum joint usage factor of considered offshore jacket during ULS

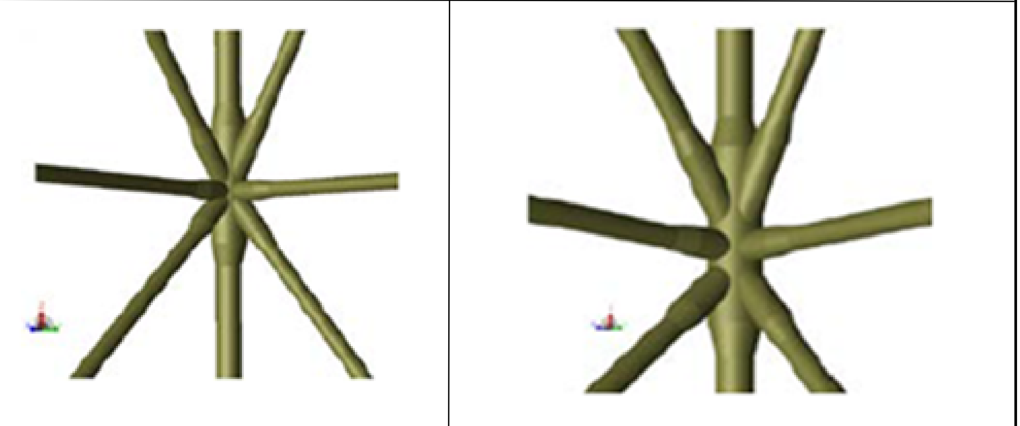
Identification	Joint nr	Load case	Beam nr.	Usage factor	Elevation
Leg/Brace 4A	16	Uls23b	225	**0.57**	-74m
Leg/Brace 1B	18	Uls12b	205	0.56	-74m
Leg/Brace 1A	17	Uls16b	229	0.54	-74m
Leg/Brace 4B	4	Uls3b	201	0.52	-74m
Leg/Brace 4B	5	Uls3b	33	0.41	-44m
Leg/Brace 1B	31	Uls7b	38	0.38	-44m

Figure 24 shows the steps for redesigning a joint incase the original joint design is not ok. Table 14 gives the maximum usage factor of the joints with joint number, beam number, load combination and location. Figure 25 shows the maximum usage factor of joints in offshore jacket for ULS 100-year wave loading. The usage factor is made with colour code represented in figure.



a)Original modelled joint

b)Step 1 - Increase thickness of tubular cross section



c)Step 2 - Add the conical transition

d)Step 3 - Add the gaps and remove eccentricity

Figure 24 Joint redesign steps, ref/13/

5.4 Effect of hydrodynamic properties on ULS design checks

ULS design check on offshore jacket was verified for with and without Buoyancy loading. This shall be achieved by selecting ON and OFF in wave load run dialog box, for the deterministic sea state.

Hydrodynamic properties ‘Flooding’ and ‘Buoyancy area’ plays a major role for calculating buoyancy loads from Wajac program. Wajac calculates buoyancy only if a jacket member is non-flooded. Another way for not to include buoyancy loading is by selecting a smaller buoyancy area.

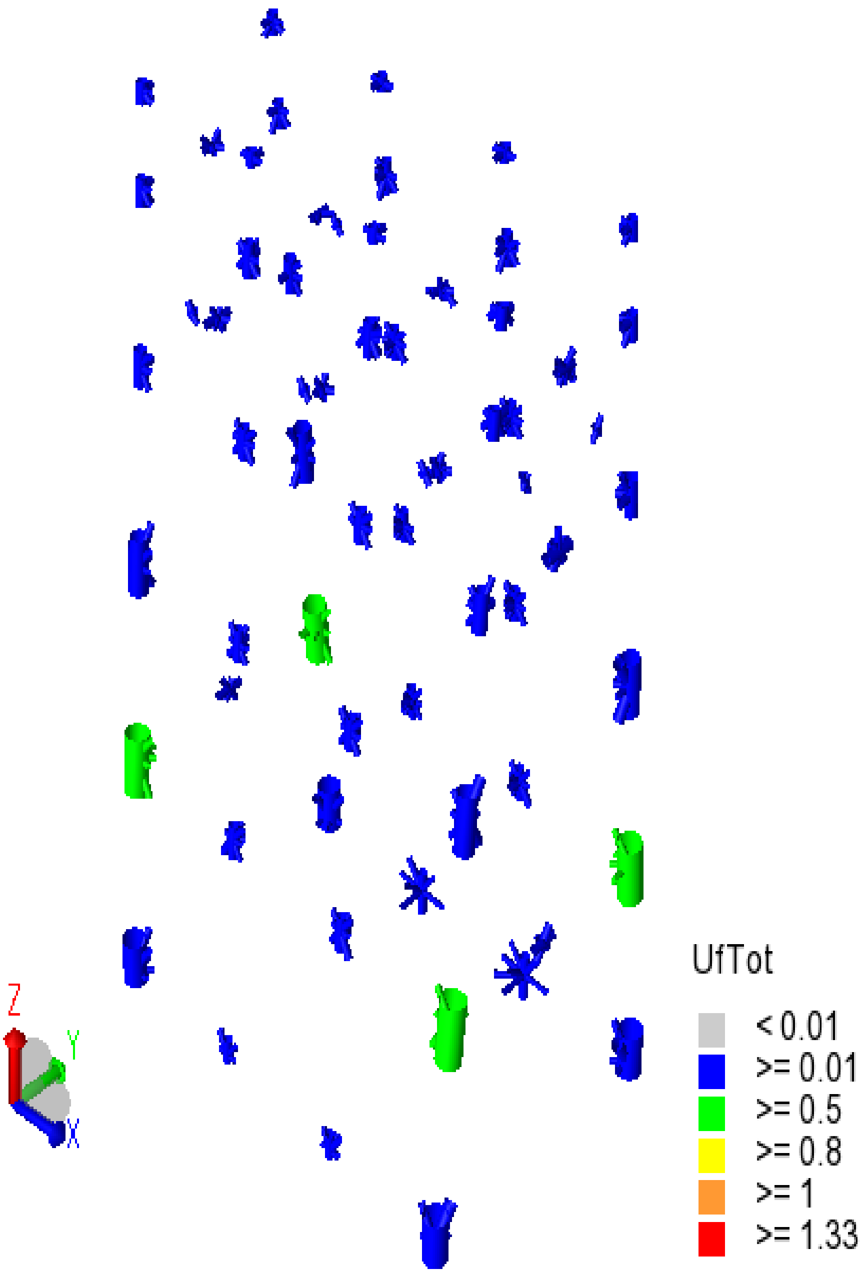


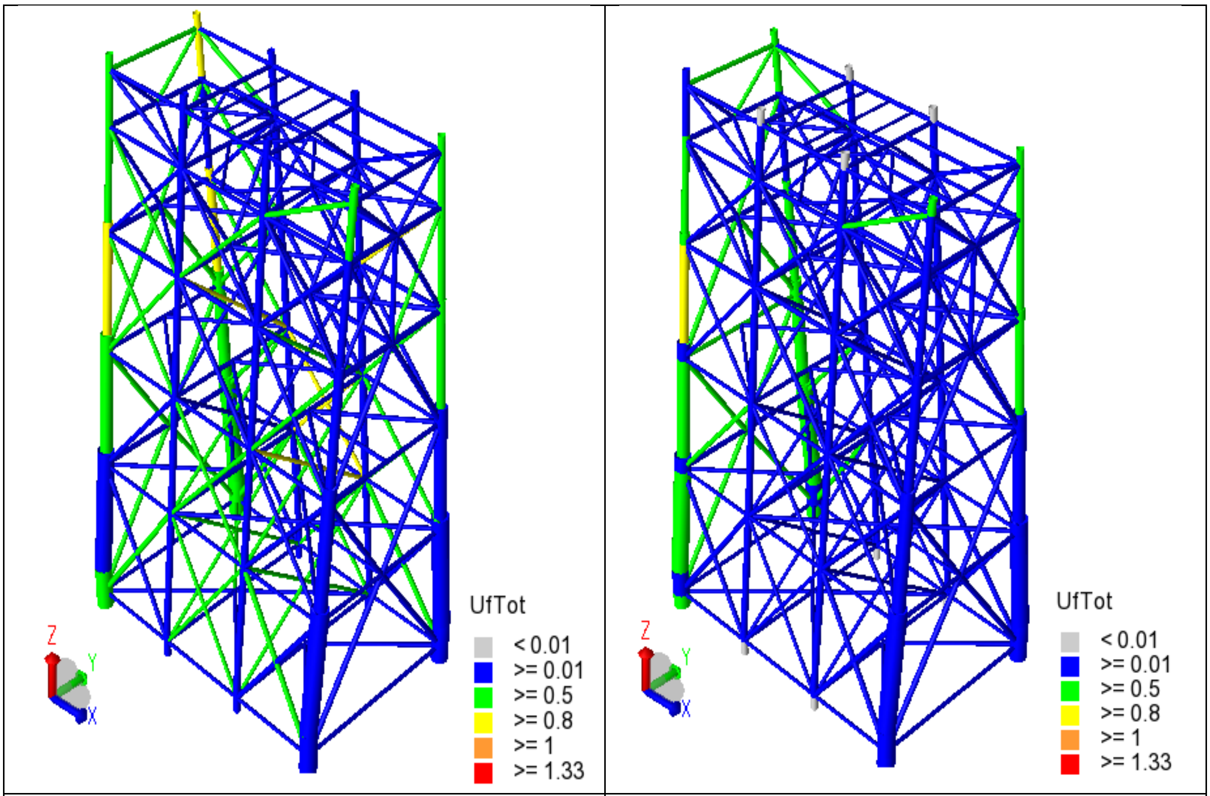
Figure 25 Maximum usage factor of joints during ULS 100year return wave loading

Buoyancy is calculated only for members above the mudline. In a deterministic load calculation, the buoyancy loads may be excluded from the load calculation, ref/18/. But generally, the buoyancy effects are included for all the members above the mudline.

Table 15 gives the maximum usage factor on offshore jacket for with and without buoyancy loads. Figure 26 shows the effect of buoyancy loading on offshore jacket structure during ULS 100-year return wave. Colour code on beams showing the usage factors.

Table 15 Effect of buoyancy on considered offshore jacket structure usage factors

Member identification	Beam nr.	With Buoyancy		Without Buoyancy		Location above/below SWL
		Load comb	Usage factor	Load comb	Usage factor	
Jacket leg 4/B	152	ULS20a	**0.88**	ULS17a	**0.83**	Below
Brace A (2/3)	226	ULS12b	0.85	ULS11b	0.4	Below
Leg 4/A	154	ULS8a	0.85	ULS8a	0.79	Below
Brace 3 (A/B)	264	ULS8b	0.85	ULS11b	0.31	Below
Brace A (2/3)	227	ULS1b	0.85	ULS3b	0.38	Below
Brace A (1/2)	218	ULS20a	0.84	ULS20b	0.46	Below
Brace 2 (A/B)	272	ULS8b	0.82	ULS8b	0.25	Below
Leg 4/A	161	ULS7a	0.81	ULS17a	0.78	Above
Brace B (2/3)	203	ULS1b	0.80	ULS2b	0.37	Below
Brace B (3/4)	191	ULS5a	0.78	ULS8b	0.41	Below
Horz frame 4 (El.22m)	1	ULS8a	0.75	ULS8a	0.75	Above



Usage factor of offshore jacket structure for ULS with buoyancy loading

Usage factor of offshore jacket structure for ULS without buoyancy loading

Figure 26 Maximum usage factor ULS loading with and without buoyancy loading

5.5 Discussion of the results

The results of the total maximum base shear and overturning moment calculations from each sea state by Wajac program is attached in Appendix A. Maximum usage factor on offshore jacket is from the results for ULS 100year return wave loads with the buoyancy included. During code check using NORSOK N-004, ref/12/ a maximum usage factor of 0.88 on jacket leg – grid 4 for ULS20a was found to be satisfactory. See Table 15. The usage factor on leg – grid 4 is found reasonable because the Topside module have overhang outside grid 4. So, the results agree with the geometry of platform structure and loading. Since the maximum usage factor is from Buoyancy included situation, while selecting beams for showing results, priority was given to the maximum usage factor of beams from these results. See Table 15.From Table 15, it was observed that the vertical X-bracings designed with buoyancy have 50% more usage factor than the design without buoyancy. The results agree with Figure 4, because due to buoyancy there will be higher stresses on vertical bracings. Maximum usage factor on joint is based on the ULS 100year return wave with the buoyancy included. Code check was made using NORSOK N-004, ref/12/. Maximum usage factor of 0.57 on jacket leg Grid 4-A during Uls23b was found satisfactory. The maximum usage factor result of joint check location was similar to the member check result. Because both have utilization on grid 4 which was loaded side of the platform. At joints locations with STUB, CAN either diameter or thickness of member is bigger than the member outside the joint region. This causes the usage factor of joints lower than usage factor of member. Therefore, the results agree with this consideration. Figure 27 showing the beam and joint which have maximum usage factor during the ULS loading with buoyancy included.

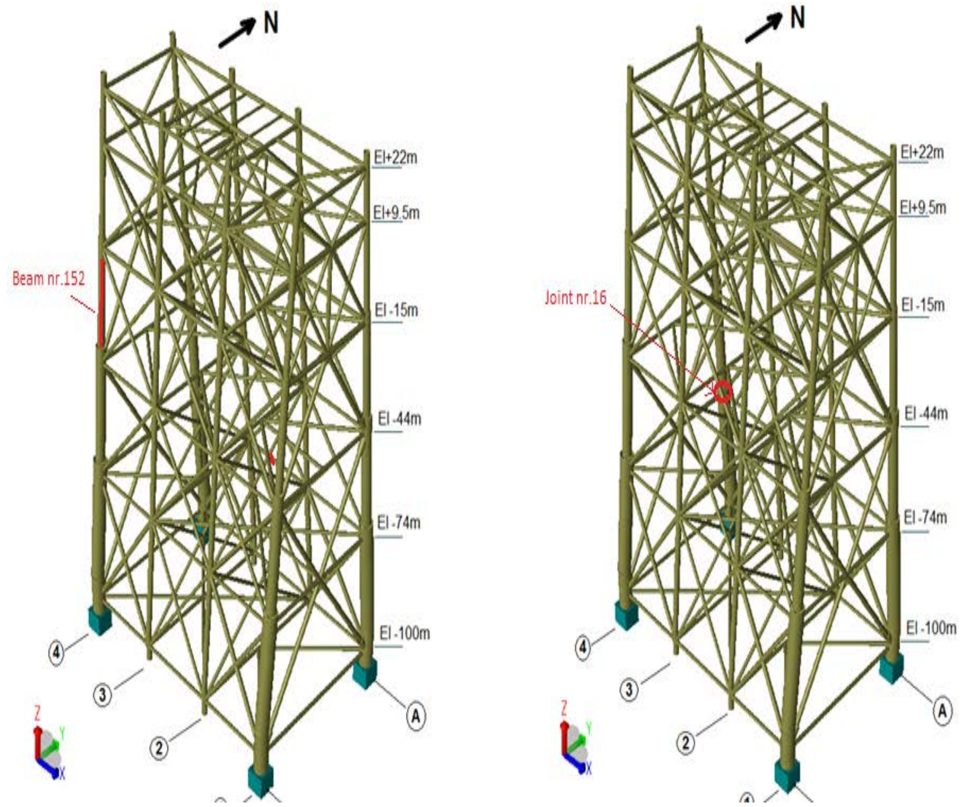


Figure 27 Maximum usage factor for a beam and a joint from the ULS analysis

6 FLS DESIGN CHECKS FOR CONSIDERED JACKET STRUCTURE

6.1 Introduction to FLS design checks

The jacket components such as legs, primary and secondary braces, horizontal framing and joints are checked to satisfy the target fatigue life of 30years using a Design fatigue factor (DFF) 3 and 10.

By default, a single finite element modelled has three check positions, namely both ends and the midpoint of the member. But user may assign code check positions. In this thesis default check position is used.

On the fatigue design checks, most critical members and joints with the low fatigue lives are determined. A critical joint was selected, and a crack was assumed to start in the brace resulting in severance of the member. The fatigue analysis was repeated without the split of member and the new fatigue lives were compared for the other braces connecting to the same joint and the neighboring joints.

6.2 FLS design checks for Jacket members and joints

The analysis demonstrates that redundancy in offshore jacket structure make it unlikely that a single crack at a joint could be unfavorable to the fatigue strength of structure. Hot spot stresses are calculated using the parametric stress concentration factor from Efthymiou equations. See Table B.1 of ref/8/.

Hydrodynamic loading with buoyancy loading included results are taken into account on fatigue analysis, below are the inputs on Framework program:

1. Define fatigue parameters (Target fatigue life -30years, Parametric SCF Efthymiou, Splash zone limit 7m upper elevation and -4m lower elevation).
2. Design fatigue factor is 10 for members on splash zone area and 3 for members outside of splash zone area.
3. Assign joint type – Load path and joint gap/overlap data - Automatic.
4. Assign individual wave data – Use Table 11, Occurrences of wave.
5. Execution of fatigue analysis gives the damage.
6. Compare damage with design life accounting for factors of safety.

Deterministic fatigue analysis shows seven of the vertical bracings between the elevation +9.5m and -15m are having low fatigue life than the expected. Design fatigue factor (DFF) value of 10 may not be required to assign, since the bracing runs between elevation +9.5m and -15m.

Table 16 gives the deterministic fatigue results of the offshore jacket structure. This table shows the beam number, joint number, calculated fatigue life and usage factor.

Table 16 Deterministic fatigue life results for considered offshore jacket

Beam nr.	Joint nr.	Splash zone	DFF	Calculated Fatigue life (years)	Expected fatigue life (years)	Usage factor
243	73	Yes	10	110	300	2.73
246	73	Yes	10	91.5	300	3.28
81	26	No	3	103	90	0.87
190	50	Yes	10	175	300	1.71
219	58	Yes	10	166	300	1.81
195	51	Yes	10	163	300	1.84
214	35	Yes	10	239	300	1.26
216	57	Yes	10	104	300	2.88

6.3 Effect of hydrodynamic properties on FLS design checks

FLS design check on offshore jacket was verified for ‘with and without Buoyancy’. This shall be achieved by selecting ON and OFF in wave load run, for the deterministic sea state. This feature works when hydrodynamic property constants Flooding, or Buoyancy area is modified on selected jacket members.

Table 17 gives the effect of buoyancy on fatigue life of the offshore jacket structure. Results from considering buoyancy and without buoyancy doesn’t show much significant differences.

Table 17 Effect of buoyancy on fatigue life

Beam nr.	Joint nr.	Splash zone	DFF	Expected fatigue life (years)	With Buoyancy		Without Buoyancy	
					Calculated Fatigue life (years)	Usage factor	Calculated Fatigue life (years)	Usage factor
243	73	Yes	10	300	96	3.13	110	2.73
246	73	Yes	10	300	137	2.19	91.5	3.28
81	26	No	3	90	138	0.65	103	0.87
190	50	Yes	10	300	164	1.83	175	1.71
219	58	Yes	10	300	250	1.20	166	1.81
195	51	Yes	10	300	256	1.17	163	1.84
214	35	Yes	10	300	338	0.89	239	1.26
216	57	Yes	10	300	372	0.81	104	2.88

6.4 Effect of selected joint types on FLS design checks

On Framework program, available joint types are Load path, Geometry and Interpolate. In this chapter, effect of fatigue life for different joint type is checked. FLS design check on offshore jacket was verified for joint type – Geometry and Load path. This shall be achieved by selecting the joint type as Geometry or Load path in Framework program.

Table 18 and Table 19 gives the effect of joint type on fatigue life by using the joint type geometry instead of joint type load path. Results show that load path joint type yields better results than geometry joint type. Fatigue lives of the vertical bracing on jacket structures have a significant effect on fatigue lives.

Table 18 Effect of joint type (with Buoyancy) on fatigue life

Beam nr.	Joint nr.	Splash zone	DFF	Expected fatigue life (years)	Geometry		Load path	
					Calculated Fatigue life (years)	Usage factor	Calculated Fatigue life (years)	Usage factor
81	26	No	3	90	65.6	1.37	103	0.87
244	65	Yes	10	300	74.5	4.03	400	0.75
245	65	Yes	10	300	76	3.95	400	0.75
243	73	Yes	10	300	76.9	3.90	110	2.73
246	73	Yes	10	300	83.9	3.58	92	3.28
195	51	Yes	10	300	99.2	3.02	163	1.84
190	50	Yes	10	300	106	2.83	175	1.71
216	57	Yes	10	300	98.6	3.04	104	2.88
192	48	Yes	10	300	117	2.56	120	2.50
219	58	Yes	10	300	104	2.88	166	1.81
218	56	Yes	10	300	170	1.76	170	1.76
215	57	Yes	10	300	169	1.78	170	1.76
98	64	No	3	90	185	0.49	400	0.23

Table 19 Effect of joint type (without Buoyancy) on fatigue life

Beam nr.	Joint nr.	Splash zone	DFF	Expected fatigue life (years)	Geometry		Load path	
					Calculated Fatigue life (years)	Usage factor	Calculated Fatigue life (years)	Usage factor
81	26	No	3	90	65	1.38	138	0.65
244	65	Yes	10	300	73.1	4.10	400	0.75
245	65	Yes	10	300	74.9	4.01	400	0.75
243	73	Yes	10	300	76.3	3.93	96	3.13
246	73	Yes	10	300	79.6	3.77	137	2.19
195	51	Yes	10	300	93.8	3.20	256	1.17
190	50	Yes	10	300	99.8	3.01	164	1.83
216	57	Yes	10	300	106	2.83	372	0.81
192	48	Yes	10	300	114	2.63	427	0.70
219	58	Yes	10	300	118	2.54	250	1.20
218	56	Yes	10	300	178	1.69	378	0.79
215	57	Yes	10	300	180	1.67	400	0.75
98	64	No	3	90	185	0.49	400	0.23

6.5 Effect of selected SN curves on FLS design checks

On Framework program, available SN curves for tubulars joint are in air environment, seawater with cathodic protection, free corrosion and primary type. Elevation above splash zone is a part of structure in air. Elevation below the splash zone is part of structure under sea water with cathodic protection. In between the splash zone in which the structure is assumed to have free corrosion, ref/8/

Since the Primary SN (SN curve DNV2010_T) curves with automatic elevation dependency is available in Framework, effect of fatigue life by selecting different SN curve is checked.

Table 20 and Table 21 gives the effect of SN curve on fatigue life by using SN_T primary curve instead of SN_T seawater cathode protection. Results from using the primary curve shows better results than SN_T sea water cathode protection.

Table 20 Effect of SN curve (with Buoyancy) on fatigue life

Beam nr.	Joint nr.	Splash zone	DFF	Expected fatigue life (years)	SN Curve DNV2010_T-SEACP		SN Curve DNV2010_T	
					Calculated Fatigue life (years)	Usage factor	Calculated Fatigue life (years)	Usage factor
81	26	No	3	90	103	0.87	103	0.87
216	57	Yes	10	300	104	2.88	104	2.88
246	73	Yes	10	300	91.5	3.28	116	2.59
192	48	Yes	10	300	120	2.50	120	2.50
272	89	No	3	90	127	0.71	127	0.71
99	64	No	3	90	130	0.69	135	0.67
243	73	Yes	10	300	110	2.73	138	2.17
68	164	No	3	90	140	0.64	149	0.60
83	144	No	3	90	130	0.69	154	0.58
84		No	3	90	140	0.64	157	0.57
218	56	Yes	10	300	404	0.74	170	1.76
215	57	Yes	10	300	170	1.76	170	1.76
244	65	Yes	10	300	400	0.75	400	0.75
245	65	Yes	10	300	400	0.75	400	0.75
195	51	Yes	10	300	163	1.84	204	1.47
190	50	Yes	10	300	175	1.71	227	1.32
219	58	Yes	10	300	166	1.81	213	1.41
98	64	No	3	90	400	0.23	170	0.53

6.6 Effect of stress concentration factors (SCF) on FLS design checks

On Framework program, available SCF equations are Global, Local, Parametric - Efthymiou, Kuang, Lloyds and Wordsworth.

Stress concentration factor (SCF) is the most sensitive component in estimation of fatigue life of tubular joint. The component is applied to determine the hot-spot stresses on the intersection region between chord and brace. Each derived sets of parametric equations have their own recommended range of validity, which limits their application, ref/8/.

Table 21 Effect of SN curve (without Buoyancy) on fatigue life

Beam nr.	Joint nr.	Splash zone	DFF	Expected fatigue life (years)	SN Curve DNV2010_T-SEACP		SN Curve DNV2010_T	
					Calculated Fatigue life (years)	Usage factor	Calculated Fatigue life (years)	Usage factor
81	26	No	3	90	138	0.65	138	0.65
216	57	Yes	10	300	372	0.81	372	0.81
246	73	Yes	10	300	137	2.19	186	1.61
192	48	Yes	10	300	427	0.70	427	0.70
272	89	No	3	90	400	0.23	900	0.10
99	64	No	3	90	93,8	0.96	366	0.25
243	73	Yes	10	300	96	3.13	127	2.36
68	164	No	3	90	114	0.79	449	0.20
83	144	No	3	90	118	0.76	900	0.10
84		No	3	90	178	0.51	900	0.10
218	56	Yes	10	300	378	0.79	378	0.79
215	57	Yes	10	300	400	0.75	400	0.75
244	65	Yes	10	300	400	0.75	900	0.33
245	65	Yes	10	300	400	0.75	900	0.33
195	51	Yes	10	300	256	1.17	301	1.00
190	50	Yes	10	300	164	1.83	222	1.35
219	58	Yes	10	300	250	1.20	308	0.97
98	64	No	3	90	400	0.23	311	0.29

To see the effect of fatigue life for different SCF from parametric equation, one critical joint receiving maximum usage factor was chosen. Selected joint is checked for validity of parametric equation and compared to the SCF’s from Framework result.

Joint no.73 connecting the beam numbers 243,246,242 and 104 have the highest usage factor than other joints. So, the validity and SCF of this joint is checked manually to compare with SCF from Framework.

Figure 28 shows the elevation of offshore platform grid 1, with red circle on joint number 73 of analysis model. Figure 29 shows the grid 1 elevation view with joint nr. 73. According to figure the joint is close to the splash zone limits. Conservatively the joint is considered inside the splash zone region. Figure 30 showing the joint nr. 73 build up with the joint features CAN and STUB. It also shows that this is a KT –tubular type of joint. Figure 31 shows the results from Framework deterministic analysis. On detail results it shows the calculated values of stress concentration factors by software.

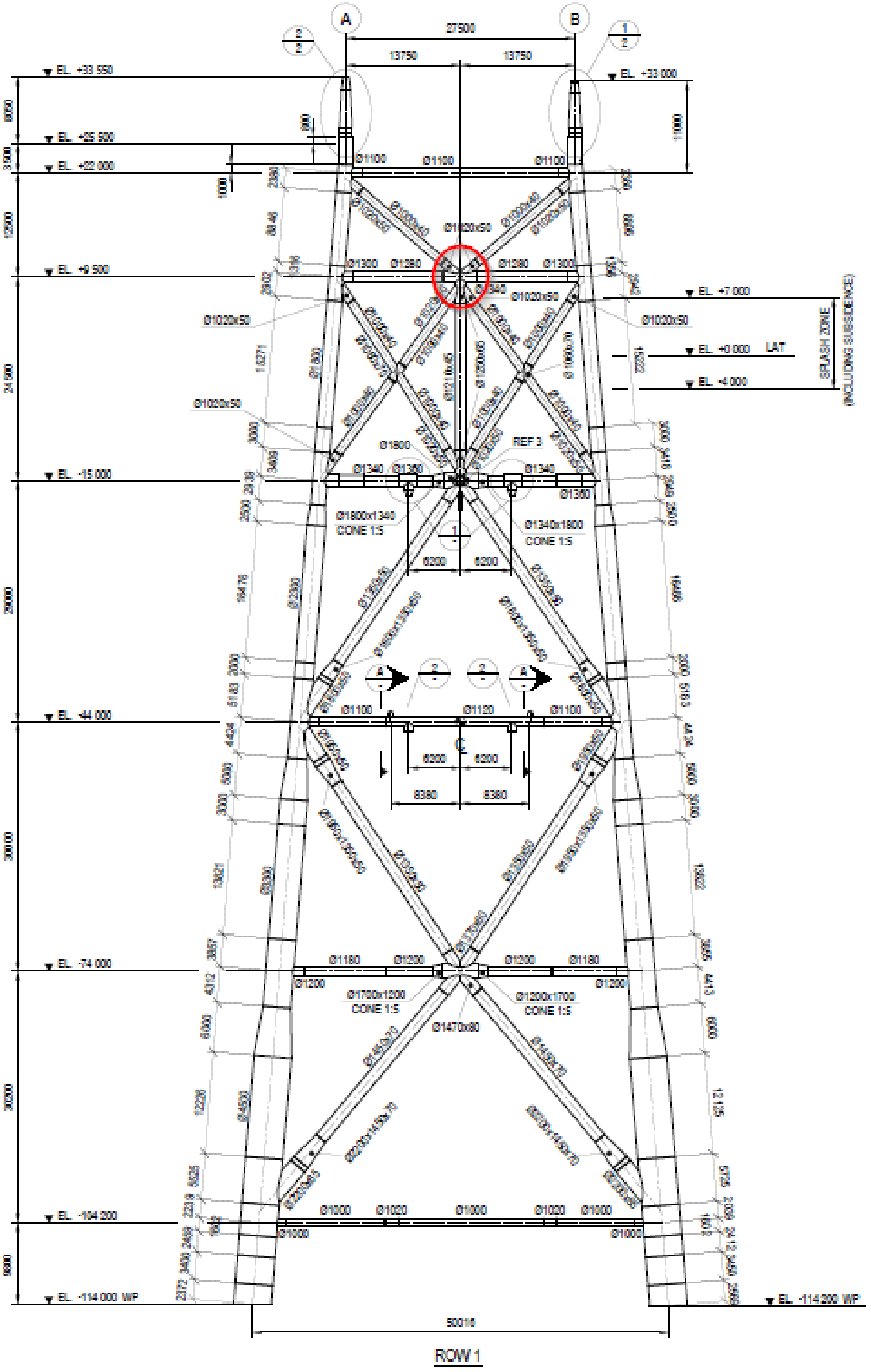


Figure 28 Tubular joint nr.73 is on offshore platform grid 1 on elevation EL+9.5m

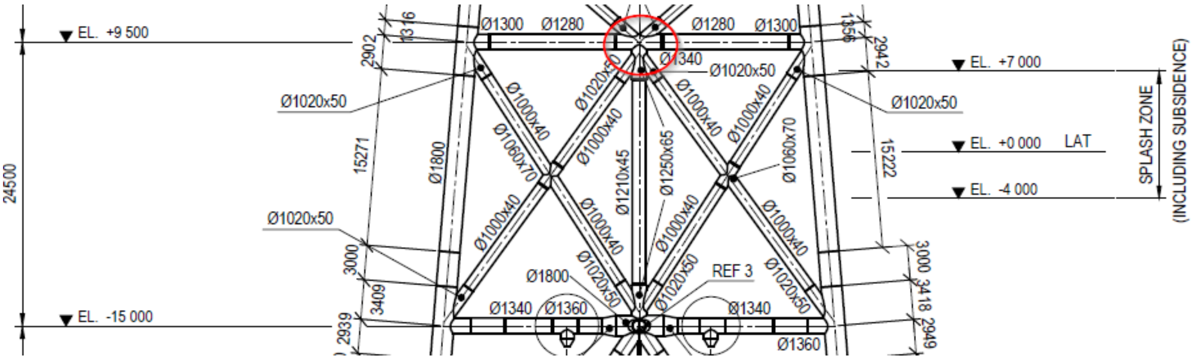


Figure 29 Elevation of grid 1 showing elevations +9.5 and +15m with joint nr.73

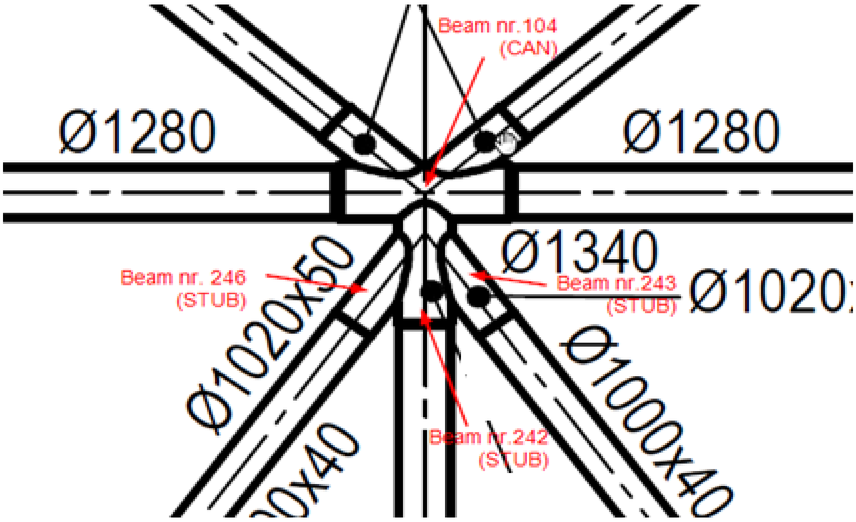
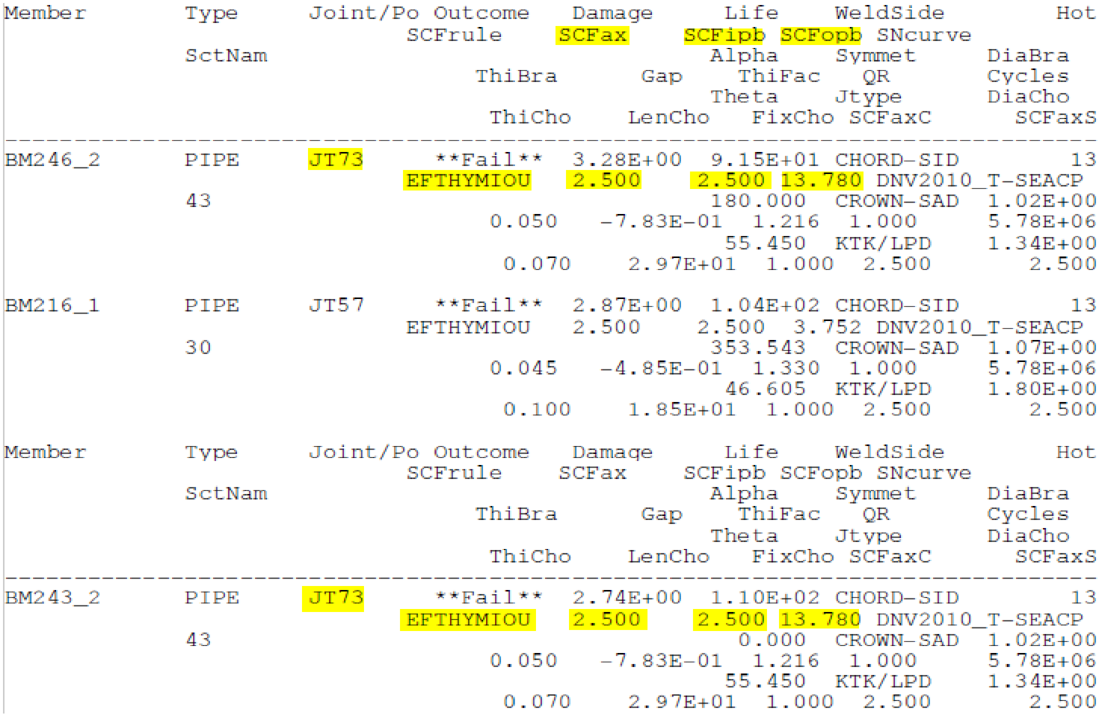


Figure 30 Joint number 73 showing CAN and STUB beam numbers (KT- joint type)



```
Member       Type     Joint/Po Outcome    Damage     Life    WeldSide        Hot
                              SCFrule    SCFax    SCFipb SCFopb SNcurve
             SctNam                                      Alpha    Symmet     DiaBra
                                   ThiBra      Gap    ThiFac   QR        Cycles
                                                    Theta    Jtype      DiaCho
                                    ThiCho    LenCho   FixCho SCFaxC      SCFaxS
--------------------------------------------------------------------------------
BM246_2      PIPE     JT73      **Fail**  3.28E+00  9.15E+01 CHORD-SID        13
                              EFTHYMIOU   2.500    2.500 13.780 DNV2010_T-SEACP
             43                                     180.000  CROWN-SAD  1.02E+00
                                    0.050   -7.83E-01  1.216  1.000     5.78E+06
                                                     55.450  KTK/LPD    1.34E+00
                                     0.070    2.97E+01  1.000  2.500       2.500

BM216_1      PIPE     JT57      **Fail**  2.87E+00  1.04E+02 CHORD-SID        13
                              EFTHYMIOU   2.500    2.500  3.752 DNV2010_T-SEACP
             30                                     353.543  CROWN-SAD  1.07E+00
                                    0.045   -4.85E-01  1.330  1.000     5.78E+06
                                                     46.605  KTK/LPD    1.80E+00
                                     0.100    1.85E+01  1.000  2.500       2.500

Member       Type     Joint/Po Outcome    Damage     Life    WeldSide        Hot
                              SCFrule    SCFax    SCFipb SCFopb SNcurve
             SctNam                                      Alpha    Symmet     DiaBra
                                   ThiBra      Gap    ThiFac   QR        Cycles
                                                    Theta    Jtype      DiaCho
                                    ThiCho    LenCho   FixCho SCFaxC      SCFaxS
--------------------------------------------------------------------------------
BM243_2      PIPE     JT73      **Fail**  2.74E+00  1.10E+02 CHORD-SID        13
                              EFTHYMIOU   2.500    2.500 13.780 DNV2010_T-SEACP
             43                                       0.000  CROWN-SAD  1.02E+00
                                    0.050   -7.83E-01  1.216  1.000     5.78E+06
                                                     55.450  KTK/LPD    1.34E+00
                                     0.070    2.97E+01  1.000  2.500       2.500
```

Figure 31 Framework results showing the SCF’s axial, in-plane and out of plane

Table 22 gives the stress concentration factors (SCF) calculated by the software and through manual calculation by using Mathcad.

Table 22 Comparison of SCF using Framework and analytical solution

Beam nr.	Joint type	Joint nr.	Framework SCF			Manual calculation SCF		
			Axial	In-plane	Out of plane	Axial	In-plane bending	Out of plane bending
243	Brace A	73	2.5	2.5	13.78	4.932	2.528	7.08
246	Brace B	73	2.5	2.5	13.78	4.932	2.528	7.08
104	Chord	73	2.5	2.5	3.903	3.39	2.125	4.586
242	Brace C	73	2.5	2.5	9.436	NA	NA	10.028

6.7 Discussion of the results

On this chapter, the Table 12 result is considered as a standard result for FLS design check. On this verification, the defined fatigue parameters are,

1. SN curve – T_seawater Cathode protection
2. SCF – Parametric Efthymiou
3. Buoyancy loading included– by only flooding the main four legs and non-flooding others beams on platform.
4. Joint type – Load path
5. Joint gap – Automatic
6. DFF = 3 (Members outside splash zone region) 10 (Members in splash zone)

Maximum usage factor of 3.28 is for beam nr. 246 with joint nr.73 on splash zone. Here the expected fatigue life 30years x 10 =300years but the calculated fatigue life is only 91. 5years.Therefore several analyses made to see the effect on fatigue life by changing the fatigue parameters.

a) Table 17 gives the effect of buoyancy on fatigue life of the considered offshore jacket structure. Results from considering buoyancy and without buoyancy loading doesn’t show significant differences on beam and joint utilization’s.
b) Table 18 and Table 19 gives the effect of joint type on fatigue life by using the joint type geometry instead of load path. Results show that load path joint type yields better results than geometry joint type on fatigue analysis. However, it was observed that the vertical bracings have a considerable effect on fatigue life.
c) Table 20 and Table 21 gives the effect of SN curve on fatigue life of offshore jacket structure by using SN_T primary curve instead of SN_T seawater cathode protection (CP). Results from using the primary curve shows better results than SN_T sea water CP.

Figure 32 shows the effect of fatigue parameters like joint type, SN curve and hydrodynamic property on fatigue life of the critical joint nr. 73.

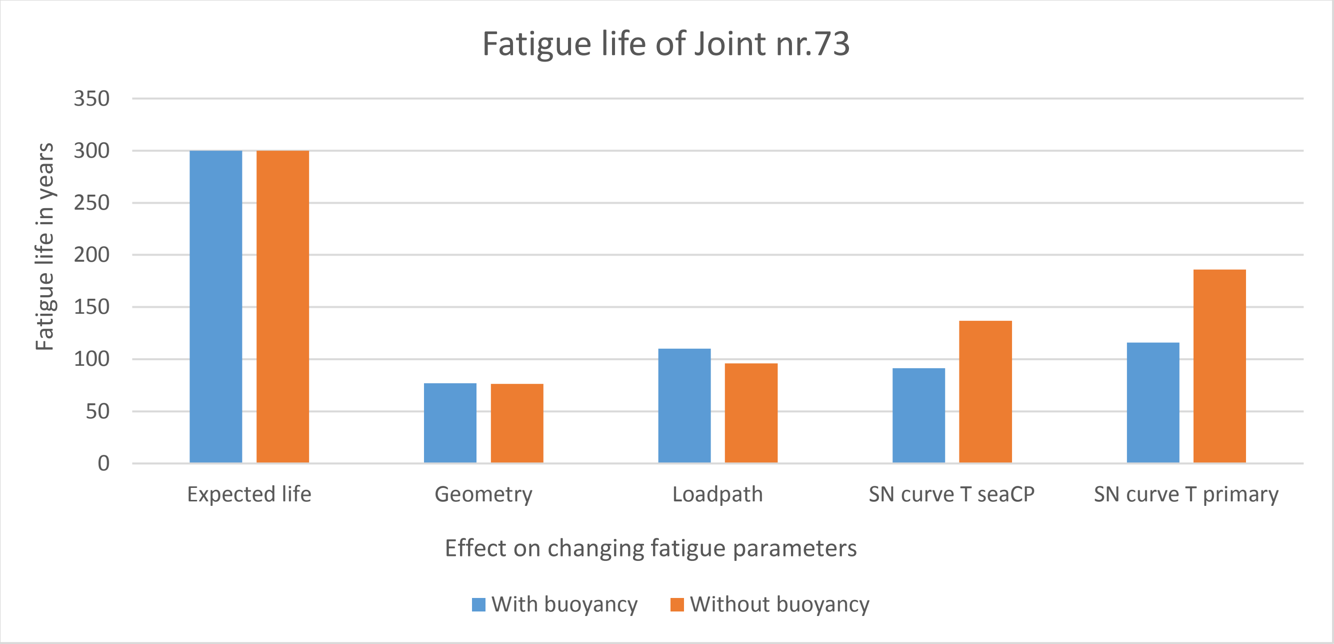


Figure 32 Effect of fatigue parameters on fatigue life of joint nr.73

Table 22 give SCF comparison on Framework and analytical calculation by Mathcad. It was observed that the out of plane SCF calculated by Framework is very high when compared to analytical calculation SCF. Since out of plane SCF is high in vertical braces, the hotspot stress calculated from Framework is also high which leads to less fatigue lives, refer Table 16 to Table 21.

It was noted that the joint (CAN, STUB, CONE) modelling plays an important role in finding the stress concentration factor (SCF). Because while calculating SCF using Mathcad for the joints, it was observed that the joints should satisfy the validity for Efthymiou equation and other parameters like gap and bracing angles. So one have to model the joint carefully w.r.t the detail, instead of using the automatic creation of joints. Otherwise the critical joints shall be modelled manually considering the information from detail drawings.

So, the reason for high, out of plane SCF from Framework is the joint modelling that was made automatic CAN, STUB and CONE production from GeniE software, the gap and angle selection on joint is automatic based on geometry in Framework.

On this thesis work, it was not extended to see effect of manually modelling the joint nr.73 or the other critical joints from fatigue results.

7. DISCUSSION AND CONCLUSIONS

7.1 Discussion

Fatigue assessment is very important for offshore jacket structural design. The assessment generally made for environmental loading on offshore structures. The aim of this case study is to design an offshore jacket that has the capacity to resist selected functional and environmental actions. The selected offshore jacket is one of the heaviest platforms in the Norwegian Continental Shelf. The heavy dead weight is also one of the governing factors for the Jacket design. So, an ultimate limit state check and a fatigue limit state check were made on the selected offshore jacket structure. Before proceeding with analysis, the generated Sesam GeniE model was checked by comparing the support reactions towards the SAP2000 model from previous thesis.

ULS 100year return wave analysis and design of the selected offshore Jacket members and joints is made according to Norsok N004 2013 on GeniE software ref/16/. Environmental loading types were studied before performing an ultimate limit state check. Various types of loading act on the offshore jacket structure. Twelve wave directions are considered with a time period and wave height. Buoyancy of the offshore jacket structure is calculated and analyzed together with the ultimate limit state loading. The four main outer legs are considered as flooded and so the buoyancy is not calculated from the four main legs.

FLS deterministic analysis for the selected offshore jacket members and joints is made according to DNV-RP-C203 T-curve sea water, ref/8/ with cathode protection and Norsok N-004, ref/12/.Environmental loading and the long term distribution of wave heights to calculate the hot spot stress is studied. Based on this a cumulative distribution, individual wave is assigned to structural model with number of wave occurrences. This forms one of the main input while preforming the deterministic analysis. Another set of main inputs were fatigue parameters, they have to be defined before performing fatigue analysis. Fatigue parameters generally depend on the geometry of structure and environmental location. So, all relevant members and joints are assigned with these parameters.

7.2 Conclusions

Based on the work performed in this thesis, the following conclusions are made,

1. Based on the literature review, it is concluded that fatigue limit state is very critical when it comes to offshore structures. Selection of suitable fatigue assessment approach is very important for an accurate estimation of fatigue life. Deterministic or spectral method is recommended for fatigue assessment of jacket structures located in shallow to medium water depths. For deep water structures that are dynamically more sensitive, stochastic method is recommended. However, use of this method can be computationally intensive. In cases where loading histories are available, it is recommended to perform time history analysis for a more accurate prediction of fatigue life.
2. The existing SAP model could not be used for this thesis in Sesam modules and the structure had to be modelled from scratch. This not only consumes a lot of additional time but can also sometimes lead to loss of vital information

from the models. From the experience during this work, it is concluded that the compatibility between several finite element tools is also a key factor especially while reassessing existing structures for life extension studies. Most of the structures in the North Sea are operating beyond their design life and need to be reassessed for possibly further life extension. The original design models might have become outdated in today's world and it is very important to select a suitable finite element tool that can import such models without loss of much information.

3. The ULS checks are performed for the considered jacket structure in Sesam GeniE and the environmental loading is simulated using Wajac. All the members and joints are found to have sufficient capacity. Based on the work done, it is concluded that the hydrodynamic coefficients such as C_D and C_M should be carefully selected for precise calculation of wave loads using Morison's equation. Moreover, special attention should be paid while considering other parameters such as buoyancy loads, marine growth, wave theory, stretching and wave kinematic factor. It is also concluded that selection of correct buckling length factors (k) and moment reduction factors (C_m) is very important for strength checks of members. Lastly, special attention should be paid to modelling of cans, stubs, cones and gaps for strength checks of joints.
4. The FLS checks are also made for the considered jacket in Framework. A deterministic analysis is performed using the long-term distribution of wave heights at the platform location. Few members and joints in the splash zone region are found to have insufficient fatigue life. However, this might be due to the selected approach in this case and no conclusive evidences can be drawn without furthermore detailed analysis in future works. The selected deterministic approach is conservative due to selection of few waves and thereby resulting in lower fatigue lives on a conservative side. These results can be improved using spectral analysis method. Moreover, higher SCF calculation by Framework could also be a reason for insufficient fatigue life of some joints. The members outside the splash zone are found to have sufficient fatigue life. Based on the results, it is concluded that selection of fatigue parameters such as effect of buoyancy, SN curve, joint type, SCFs is very critical for estimation of fatigue life. Among all these parameters, it is concluded that calculation of stress concentration factor (SCFs) effected the fatigue life results the most. It is therefore recommended to pay special attention while determining SCFs.
5. Further investigation is carried out for determination of SCFs in the Framework software. The stress concentration factors from the software were compared with manual calculations using the same given equations such as Efthymiou. Based on this comparison and results, it is concluded that there is some variation in the calculations especially for the out of plane factor. This factor from Framework is almost twice compared to manual calculations for the considered joint. As mentioned above, this could also be a reason for insufficient fatigue life of some joints in the splash zone. Further studies are required to find the reasons for this variation in SCFs. One possible reason for this variation could be the use of older Efthymiou equations in the software.

7.3 Suggestions for future work

Due to time limitation, this work covers fatigue analysis on jacket structure with certain limits. For further work, one could optimize the model to perform,

1. Mitigation measures for the members failing on deterministic fatigue analysis.
2. Local Finite element analysis on locations with low fatigue life shall be performed.
3. Time domain analysis (Spectral) shall be performed for tubular joints/members with insufficient fatigue life.
4. Review and possible update the inspection plan to account for tubular joints with insufficient fatigue life.
5. Categorize joint criticality based on fatigue results and evaluate to implement additional FE results for critical joints to improve reliability of reported fatigue lives.
6. Verification of local tubular joint weld capacity shall be performed.

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Appendix A - Maximum base shear and overturning moment ULS 100 year return wave

Table A1 gives the WAJAC software computed total base shear and overturning moment due to ULS 100year return wave loading on each members of the GeniE model.

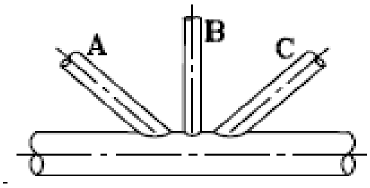
Table A1 Maximum base shear and overturning moment calculated by Wajac, ref/18/.

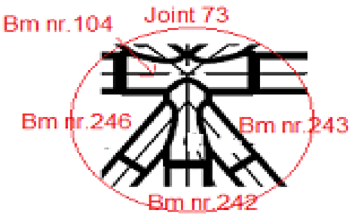
Sea state nr.	Direction (deg)	Maximum base shear (MN)	Maximum overturning moment (MNm)
1	0	29.136	1000
2	30	30.730	996.93
3	60	35.219	994.54
4	90	38.20	980.23
5	120	35.267	957.09
6	150	30.907	942.25
7	180	29.425	945.63
8	210	30.904	944.87
9	240	35.263	961.28
10	270	38.196	975.28
11	300	35.217	988.11
12	330	30.731	993.70

Appendix B - SCF manual calculation for joint nr. 73

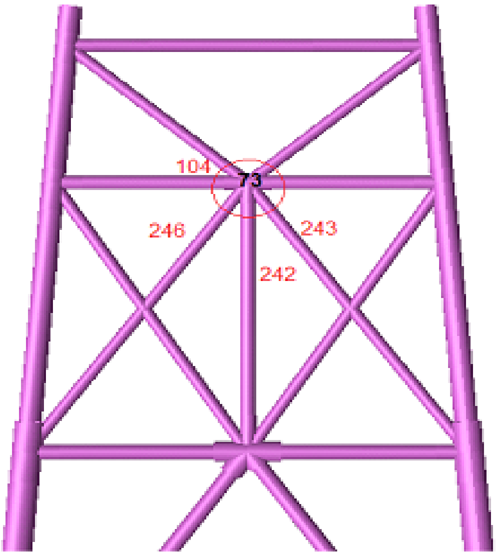
Stress Concentration Factor Calculation for Selected Joint nr- 73

Reference - DNVGL-RP-0005 (RP-C-203)





Bm nr.104 (CAN) -Ø1340x70
Bm nr.242 (STUB) Ø1250X65
Bm nr.246 (STUB) -Ø1020x50
Bm nr.243 (STUB) -Ø1020x50



Row - 1

Geometrical parameters of selected KT joint - Joint nr.73

Chord and brace diameter and thickness

$D := 1.34\text{m}$ $T := 0.070\text{m}$

$d_A := 1.02\text{m}$ $t_A := 0.05\text{m}$

$d_B := 1.25\text{m}$ $t_B := 0.065\text{m}$

$d_C := 1.02\text{m}$ $t_C := 0.05\text{m}$

Gap values and brace angles

$g_{AB} := 0.03\text{m}$ $g_{BC} := 0.03\text{m}$ $\zeta_{AB} := \frac{g_{AB}}{D} = 0.022$ $\zeta_{BC} := \frac{g_{BC}}{D} = 0.022$

$\theta_A := 54\text{deg}$ $\theta_B := 90\text{deg}$

$\theta_C := 54\text{deg}$

$\theta_{max} := 90\text{deg}$

$\theta_{min} := 45\text{deg}$

$$\gamma := \frac{D}{2T} = 9.571$$

$\beta_A := \frac{d_A}{D} = 0.761$ $\beta_B := \frac{d_B}{D} = 0.933$ $\beta_C := \frac{d_C}{D} = 0.761$

$$\beta_{max} := \max(\beta_A, \beta_C) = 0.761$$

$$\beta_{min} := \min(\beta_A, \beta_C) = 0.761$$

$$\tau_A := \frac{t_A}{T} = 0.714 \qquad \tau_B := \frac{t_B}{T} = 0.929 \qquad \tau_C := \frac{t_C}{T} = 0.714$$

Validity range to use equations from Table B-1 to Table B-5 is as follows,

0.2	$\le$	β	$\le$	1.0	Ok
0.2	$\le$	τ	$\le$	1.0	Ok
8	$\le$	γ	$\le$	32	Ok
4	$\le$	α	$\le$	40	Not applicable in this joint
$20°$	$\le$	θ	$\le$	$90°$	Ok
$\frac{-0.6\beta}{\sin\theta}$	$\le$	ζ	$\le$	1.0	Ok

Load type and fixity conditions for determining SCF in each case

1. Balanced Axial Loading

- **SCF factors for the Chord at three locations**

$$SCF_{CA} := \tau_A^{0.9} \cdot \gamma^{0.5} \cdot \left(0.67 - \beta_A^{2} + 1.16\beta_A\right) \sin(\theta_A) \cdot \left(\frac{\sin(\theta_{max})}{\sin(\theta_{min})}\right)^{0.3} \cdot \left(\frac{\beta_{max}}{\beta_{min}}\right)^{0.3} = 1.997$$

$$SCF_{CC} := \tau_C^{0.9} \cdot \gamma^{0.5} \cdot \left(0.67 - \beta_C^{2} + 1.16\beta_C\right) \sin(\theta_C) \cdot \left(\frac{\sin(\theta_{max})}{\sin(\theta_{min})}\right)^{0.3} \cdot \left(\frac{\beta_{max}}{\beta_{min}}\right)^{0.3} = 1.997$$

$$SCF_{chordA} := SCF_{CA} \cdot \left(1.64 + 0.29\beta_A^{-0.38} \cdot \operatorname{atan}(8.\zeta_{AB})\right) = 3.39$$

$$SCF_{chordC} := SCF_{CC} \cdot \left(1.64 + 0.29\beta_C^{-0.38} \cdot \operatorname{atan}(8\zeta_{BC})\right) = 3.39$$

- **SCF factors for the Braces - Brace A and Brace C**

for gap joints, we have $C := 0$ Therefore $C \cdot \beta_A^{1.5} \cdot \gamma^{0.5} \cdot \tau_A^{-1.22} = 0$

$$C \cdot \beta_C^{1.5} \cdot \gamma^{0.5} \cdot \tau_C^{-1.22} = 0$$

$$SCF_{braceA} := \left[1 + \left(1.97 - 1.57 \cdot \beta_A^{0.25}\right) \cdot \tau_A^{-0.14} \cdot \left(\sin\left(\theta_A\right)\right)^{0.7}\right] \cdot SCF_{chordA} = 4.932$$

$$SCF_{braceC} := \left[1 + \left(1.97 - 1.57 \cdot \beta_C^{0.25}\right) \cdot \tau_C^{-0.14} \cdot \left(\sin\left(\theta_C\right)\right)^{0.7}\right] \cdot SCF_{chordC} = 4.932$$

2. In-Plane Bending (Chord crown and Brace crown)

- **SCF factors for the Chord at three brace locations i.e. A and C**

$$SCF_{MIPchordA} := 1.45 \cdot \beta_A \cdot \tau_A^{0.85} \cdot \gamma^{\left(1-0.68\beta_A\right)} \cdot \sin\left(\theta_A\right)^{0.7} = 2.125$$

$$SCF_{MIPchordC} := 1.45 \cdot \beta_C \cdot \tau_C^{0.85} \cdot \gamma^{\left(1-0.68\beta_C\right)} \cdot \sin\left(\theta_C\right)^{0.7} = 2.125$$

- **SCF factors for the Braces - Brace A and Brace C**

$$SCF_{MIPbraceA} := 1 + 0.65 \cdot \beta_A \cdot \tau_A^{0.4} \cdot \gamma^{\left(1.09-0.77\beta_A\right)} \cdot \sin\left(\theta_A\right)^{\left(0.06\gamma-1.16\right)} = 2.528$$

$$SCF_{MIPbraceC} := 1 + 0.65 \cdot \beta_C \cdot \tau_C^{0.4} \cdot \gamma^{\left(1.09-0.77\beta_C\right)} \cdot \sin\left(\theta_C\right)^{\left(0.06\gamma-1.16\right)} = 2.528$$

3. Unbalanced Out-of-Plane Bending

- **SCF factors for the Chord saddle adjacent to diagonal brace A**

will require calculation of balanced out of plane bending SCFc as well

Balanced out of plane bending for chord at location A is SCF_{MOPA} and given as

$$SCF_{MOPA} := \gamma \cdot \tau_A \cdot \beta_A \cdot \left(1.7 - 1.05\beta_A^{3}\right) \cdot \sin\left(\theta_A\right)^{1.6} = 4.586$$

Also balanced out of plane bending for chord at location B and C are given as

$$SCF_{MOPB} := \gamma \cdot \tau_B \cdot \beta_B \cdot \left(1.7 - 1.05\beta_B^{3}\right) \cdot \sin\left(\theta_B\right)^{1.6} = 7.028$$

$$SCF_{MOPC} := \gamma \cdot \tau_C \cdot \beta_C \cdot \left(1.7 - 1.05\beta_C^{3}\right) \cdot \sin\left(\theta_C\right)^{1.6} = 4.586$$

$$x_{AB} := 1 + \zeta_{AB} \cdot \frac{\sin\left(\theta_A\right)}{\beta_A} = 1.024 \qquad x_{BCB} := 1 + \zeta_{BC} \cdot \frac{\sin\left(\theta_B\right)}{\beta_B} = 1.024$$

$$x_{AC} := 1 + \left(\zeta_{AB} + \zeta_{BC} + \beta_B\right)\cdot\frac{\sin\left(\theta_A\right)}{\beta_A} = 2.039 \qquad x_{ABB} := 1 + \zeta_{AB}\cdot\frac{\sin\left(\theta_B\right)}{\beta_B} = 1.024$$

$$P_1 := \left(\frac{\beta_A}{\beta_B}\right)^2 = 0.666 \qquad P_2 := \left(\frac{\beta_C}{\beta_B}\right)^2 = 0.666$$

To simplify long equation in Mathcad,some extra constants are introduced,

$$D_1 := \left[1 - 0.08\cdot\left(\beta_B\cdot\gamma\right)^{0.5}\cdot e^{\left(-0.8\cdot x_{AB}\right)}\right]\cdot\left[1 - 0.08\cdot\left(\beta_C\cdot\gamma\right)^{0.5}\cdot e^{\left(-0.8\cdot x_{AC}\right)}\right] = 0.857$$

$$D_2 := \left[1 - 0.08\cdot\left(\beta_A\cdot\gamma\right)^{0.5}\cdot e^{\left(-0.8\cdot x_{AB}\right)}\right]\cdot\left[2.05\cdot\left(\beta_{max}\right)^{0.5}\cdot e^{\left(-1.3\cdot x_{AB}\right)}\right] = 0.428$$

$$D_3 := \left[1 - 0.08\cdot\left(\beta_A\cdot\gamma\right)^{0.5}\cdot e^{\left(-0.8\cdot x_{AC}\right)}\right]\cdot\left[2.05\cdot\left(\beta_{max}\right)^{0.5}\cdot e^{\left(-1.3\cdot x_{AC}\right)}\right] = 0.121$$

Un-balanced out of plane bending for chord at location A is $SCF_{MOPchordA}$ and given as

$$SCF_{MOPchordA} := SCF_{MOPA}\cdot D_1 + SCF_{MOPB}\cdot D_2 + SCF_{MOPC}\cdot D_3 = 7.489$$

- **SCF factors for the Chord saddle adjacent to central brace B**

$$D_4 := \left[1 - 0.08\cdot\left(\beta_A\cdot\gamma\right)^{0.5}\cdot e^{\left(-0.8\cdot x_{ABB}\right)}\right]^{P_1}\cdot\left[1 - 0.08\cdot\left(\beta_C\cdot\gamma\right)^{0.5}\cdot e^{\left(-0.8\cdot x_{BCB}\right)}\right]^{P_2} = 0.875$$

$$D_5 := \left[1 - 0.08\cdot\left(\beta_B\cdot\gamma\right)^{0.5}\cdot e^{\left(-0.8\cdot x_{ABB}\right)}\right]\cdot\left[2.05\cdot\left(\beta_{max}\right)^{0.5}\cdot e^{\left(-1.3\cdot x_{ABB}\right)}\right] = 0.423$$

$$D_6 := \left[1 - 0.08\cdot\left(\beta_B\cdot\gamma\right)^{0.5}\cdot e^{\left(-0.8\cdot x_{BCB}\right)}\right]\cdot\left[2.05\cdot\left(\beta_{max}\right)^{0.5}\cdot e^{\left(-1.3\cdot x_{BCB}\right)}\right] = 0.423$$

$$SCF_{MOPchordB} := SCF_{MOPB}\cdot\left(D_4\right) + SCF_{MOPA}\cdot\left(D_5\right) + SCF_{MOPC}\cdot\left(D_6\right) = 10.028$$

- **SCF factors for the brace A and C**

$$SCF_{MOP.braceA} := \tau_A^{-0.54}\cdot\gamma^{-0.05}\cdot\left(0.99 - 0.47\cdot\beta_A + 0.08\beta_A^{4}\right)\cdot SCF_{MOPchordB} = 7.08$$

$$SCF_{MOP.braceC} := \tau_C^{-0.54}\cdot\gamma^{-0.05}\cdot\left(0.99 - 0.47\cdot\beta_C + 0.08\beta_C^{4}\right)\cdot SCF_{MOPchordB} = 7.08$$

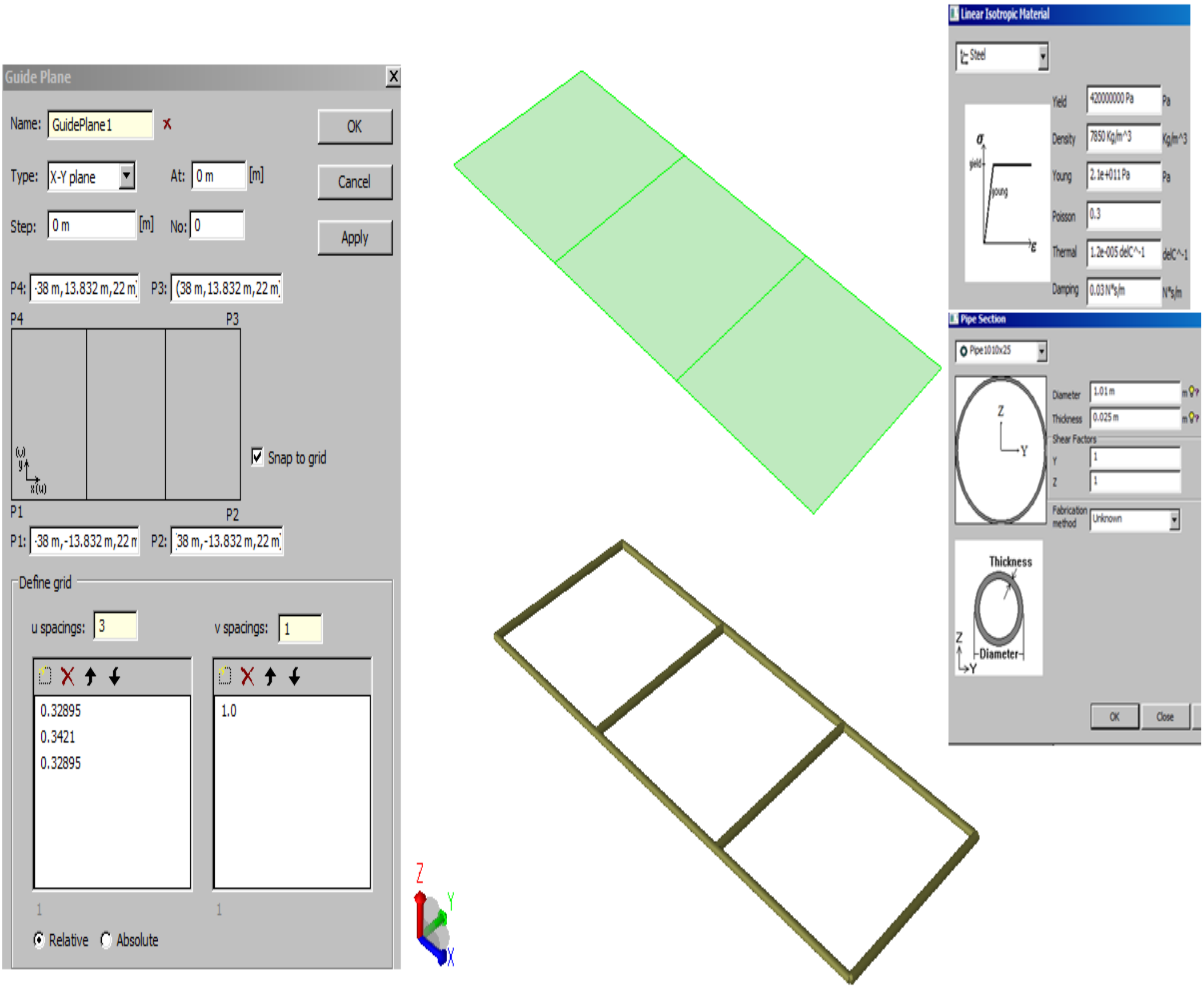
See Table 22 for results from this detailed calculation compared with the values calculated from Framework deterministic fatigue analysis.

Appendix C - GeniE model and code check results

GenieE modelling and code check (ULS)

1. Use guide plane to place points for beam modelling.
2. Assig material and section properties
3. Copy beams, reassign members to make a complete model of jacket and topside.
4. Assign support
5. Assign beam hinges
6. Assign load – Operating
7. Assign Hydro properties
8. Assign load –Wave
9. Run analysis and locate the formatted loads in L1.fem.
10. Copy the calculated wave loads from L1.fem into T1.fem
11. Read T1.fem in new workspace
12. Based on the calculated wave loads, create load combination according to Table 3
13. Code check beam using NORSOK N004
14. Code check beam results.
15. Model joints with STUB,CAN
16. Assign section properties – Similar to step 2
17. Assign joint type
18. Code check joints using NORSOK N004
19. Code check joint results

Figure C 1 showing guide plane on left for beam modelling and assigning material and section properties on right through the GeniE graphical interface.



Guide Plane

Name: GuidePlane1

Type: X-Y plane

At: 0 m [m]

Step: 0 m [m]

No: 0

P4: -38 m,13.832 m,22 m

P3: 38 m,13.832 m,22 m

P1: -38 m,-13.832 m,22 m

P2: 38 m,-13.832 m,22 m

☑ Snap to grid

Define grid

u spacings: 3

0.32895

0.3421

0.32895

v spacings: 1

1.0

● Relative ○ Absolute

Linear Isotropic Material

Steel

Yield: 420000000 Pa

Density: 7850 Kg/m^3

Young: 2.1e+011 Pa

Poisson: 0.3

Thermal: 1.2e-005 delC^-1

Damping: 0.03 N*s/m

Pipe Section

Pipe1010x25

Diameter: 1.01 m

Thickness: 0.025 m

Shear Factors

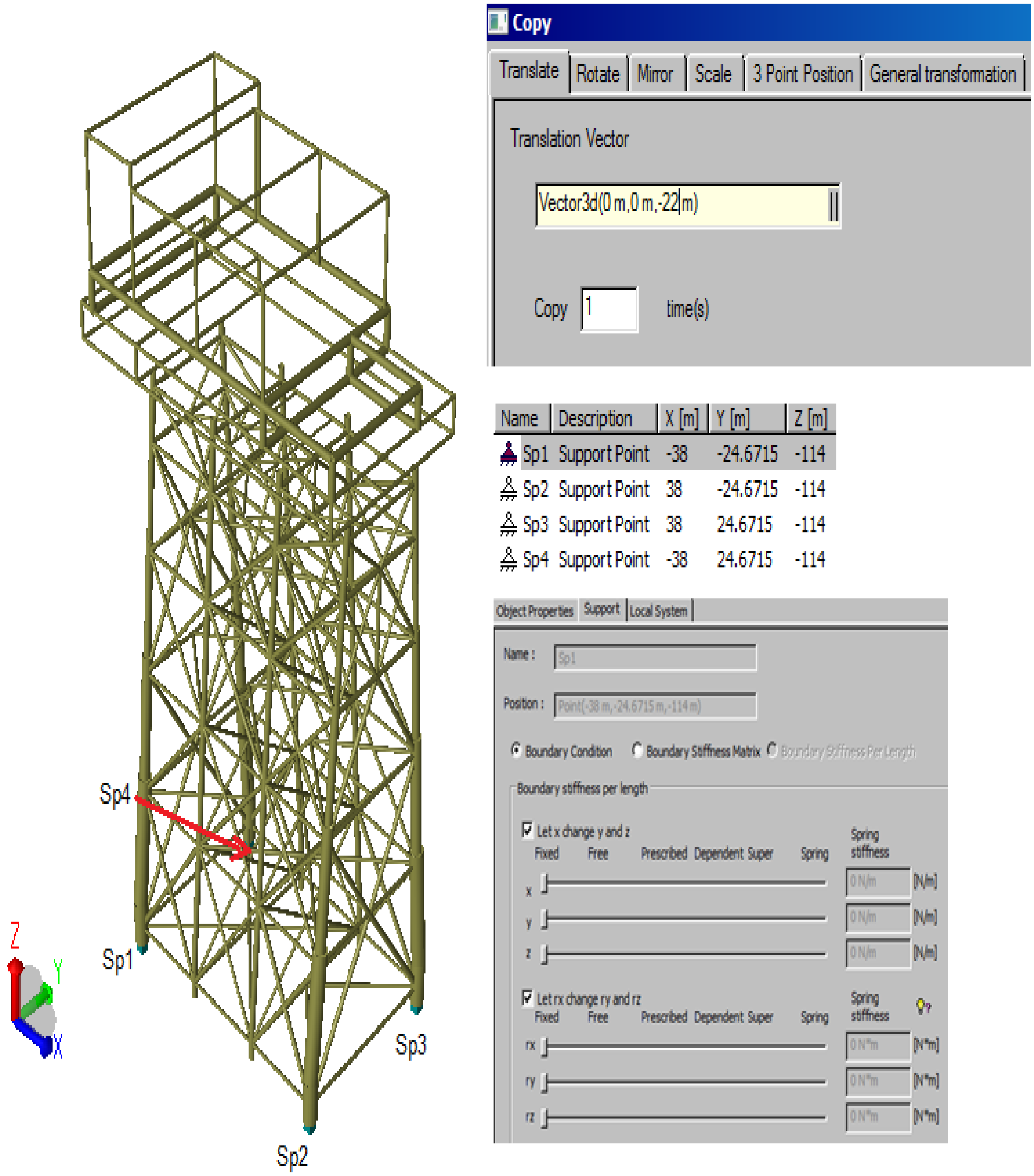
Y: 1

Z: 1

Fabrication method: Unknown

Figure C 1 Step 1 and 2 – Genie modelling

Figure C 2 shows how beams shall be copied to make similar arrangement, reassigning of cross-sections to make a complete model. Assigning boundary conditions on structure.



Translation Vector: Vector3d(0 m,0 m,-22 m)

Copy 1 time(s)

Name	Description	X [m]	Y [m]	Z [m]
Sp1	Support Point	-38	-24.6715	-114
Sp2	Support Point	38	-24.6715	-114
Sp3	Support Point	38	24.6715	-114
Sp4	Support Point	-38	24.6715	-114

Name : Sp1

Position : Point(-38 m,-24.6715 m,-114 m)

● Boundary Condition ○ Boundary Stiffness Matrix ○ Boundary Stiffness Per Length

Boundary stiffness per length

☑ Let x change y and z

x 0 N/m [N/m]

y 0 N/m [N/m]

z 0 N/m [N/m]

☑ Let rx change ry and rz

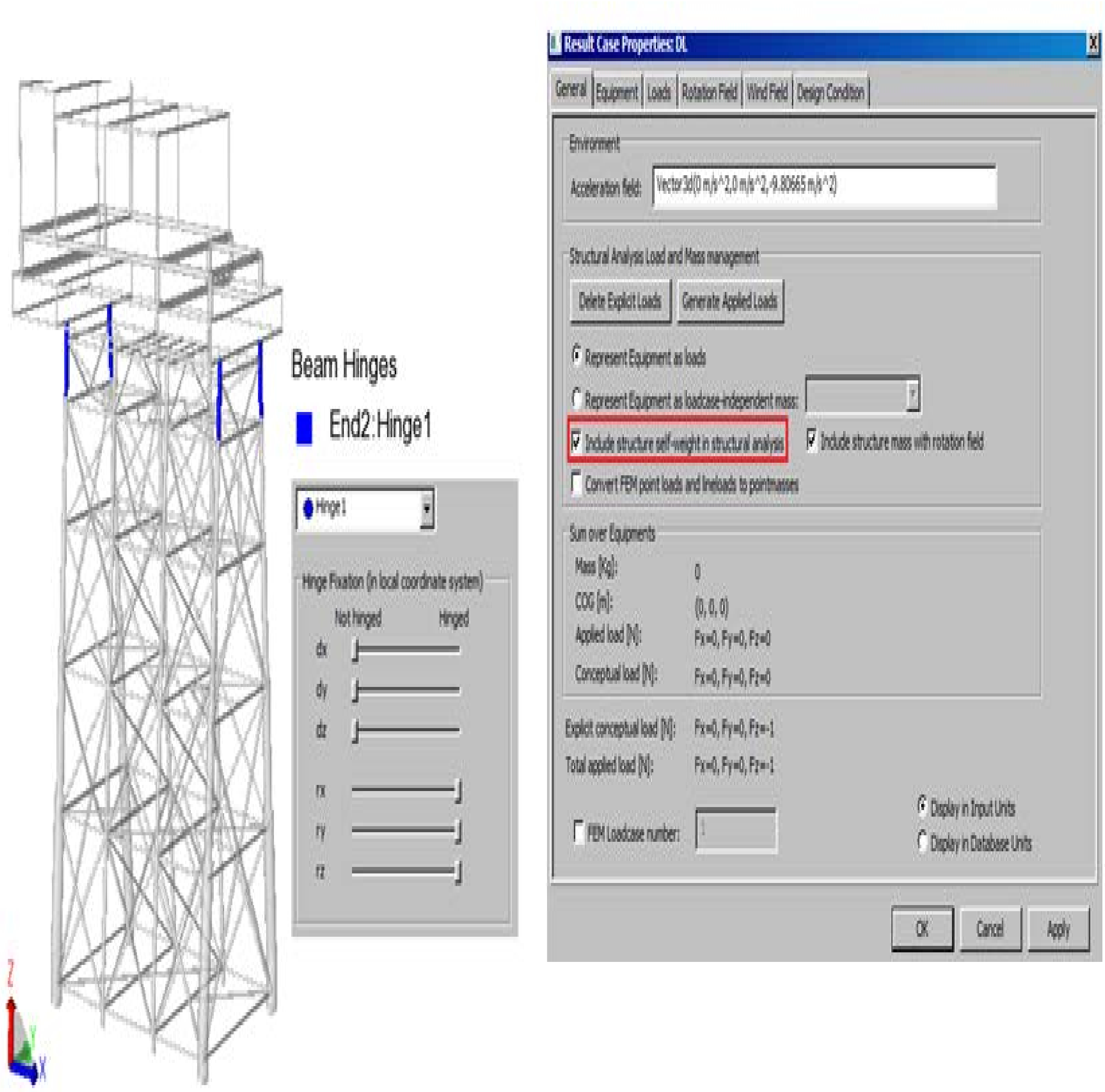
rx 0 N*m [N*m]

ry 0 N*m [N*m]

rz 0 N*m [N*m]

Figure C 2 Step 3 and 4 – Genie modelling

Figure C 3 shows how to assign beam hinges and operating load (topside steel density scaled, see Figure 18).



Environment

Acceleration field: Vector3d(0 m/s^2,0 m/s^2,-9.80665 m/s^2)

Structural Analysis Load and Mass management

● Represent Equipment as loads

○ Represent Equipment as loadcase-independent mass:

☑ Include structure self-weight in structural analysis

☑ Include structure mass with rotation field

☐ Convert FEM point loads and lineloads to pointmasses

Sum over Equipments

Mass [Kg]: 0
COG [m]: (0, 0, 0)
Applied load [N]: Fx=0, Fy=0, Fz=0
Conceptual load [N]: Fx=0, Fy=0, Fz=0

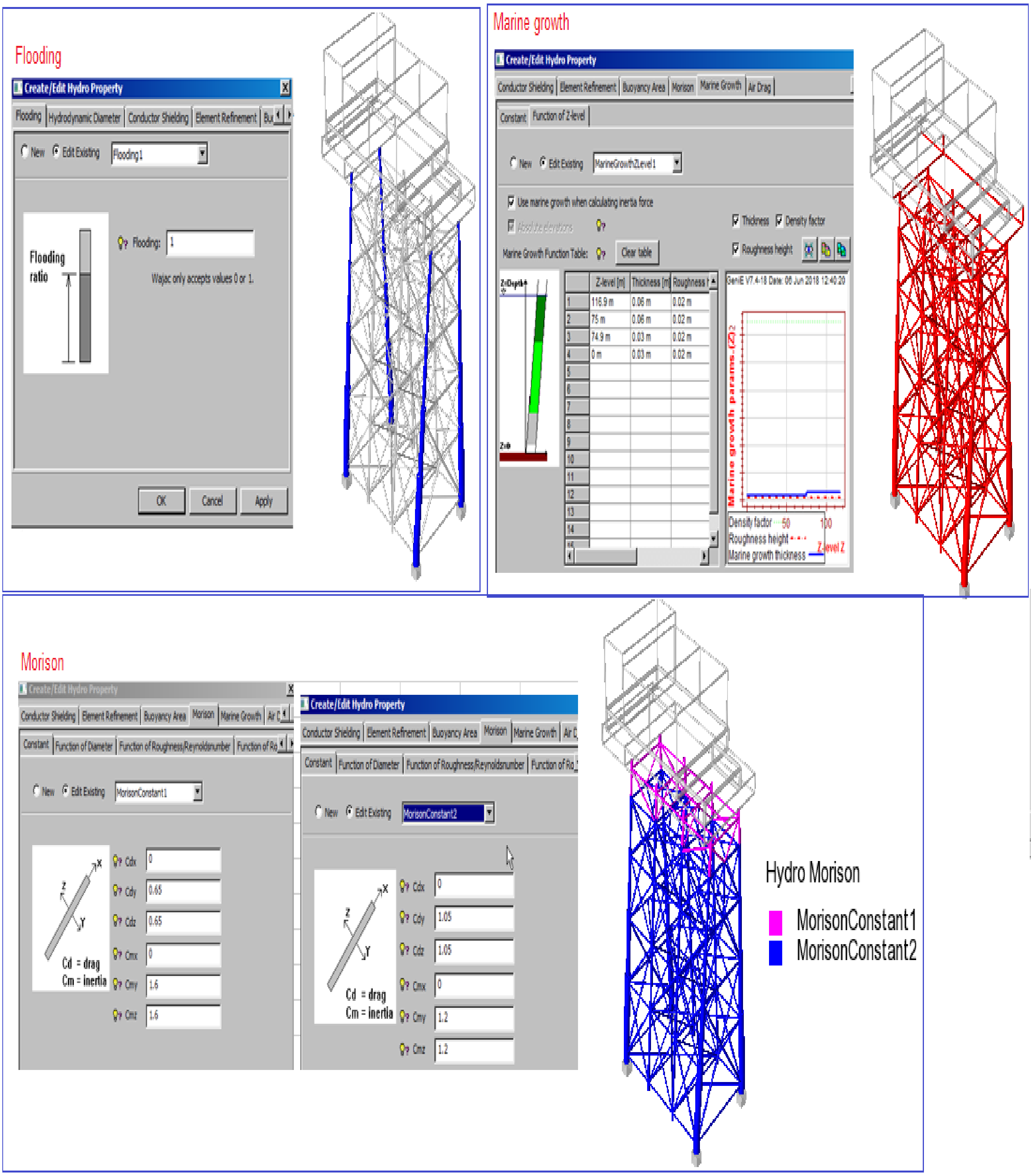
Explicit conceptual load [N]: Fx=0, Fy=0, Fz=-1
Total applied load [N]: Fx=0, Fy=0, Fz=-1

☐ FEM Loadcase number: 1

● Display in Input Units
○ Display in Database Units

Figure C 3 Step 5 and 6 – GeniE modelling

Figure C 4 shows how to assign hydro dynamic properties to the modelled structure. On this thesis the hydrodynamic constants assigned are Flooding, Marine growth and Morison constant.



Flooding

○ New ● Edit Existing Flooding1

Flooding: 1

Wajac only accepts values 0 or 1.

Marine growth

○ New ● Edit Existing MarineGrowthZlevel1

☑ Use marine growth when calculating inertia force

☑ Absolute elevations

☑ Thickness ☑ Density factor

☑ Roughness height

Marine Growth Function Table:

	Z-level [m]	Thickness [m]	Roughness
1	116.9 m	0.06 m	0.02 m
2	75 m	0.06 m	0.02 m
3	74.9 m	0.03 m	0.02 m
4	0 m	0.03 m	0.02 m

GeniE V7.4-18 Date: 06 Jun 2018 12:40:20

Morison

○ New ● Edit Existing MorisonConstant1

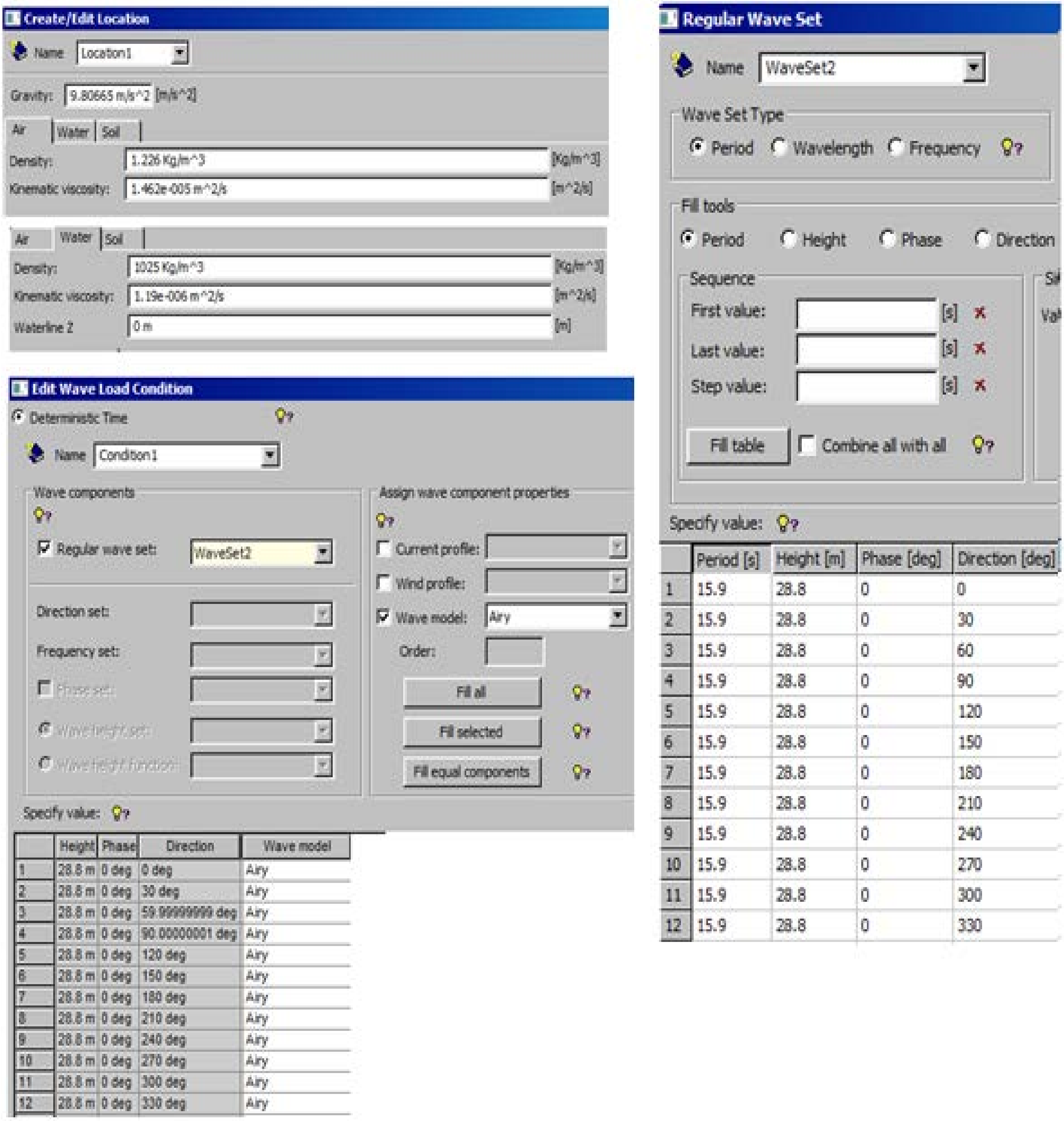
Cdx 0
Cdy 0.65
Cdz 0.65
Cmx 0
Cmy 1.6
Cmz 1.6

○ New ● Edit Existing MorisonConstant2

Cdx 0
Cdy 1.05
Cdz 1.05
Cmx 0
Cmy 1.2
Cmz 1.2

Figure C 4 Step 7 – GeniE modelling

Figure C 5 showing how to model the environmental features and place inputs of a given wave parameters.



Name: Location1

Gravity: 9.80665 m/s^2 [m/s^2]

Density: 1.226 Kg/m^3 [Kg/m^3]

Kinematic viscosity: 1.462e-005 m^2/s [m^2/s]

Density: 1025 Kg/m^3 [Kg/m^3]

Kinematic viscosity: 1.19e-006 m^2/s [m^2/s]

Waterline Z: 0 m [m]

● Deterministic Time

Name: Condition1

☑ Regular wave set: WaveSet2

Direction set:

Frequency set:

☐ Phase set:

● Wave height set:

○ Wave height function:

☐ Current profile:

☐ Wind profile:

☑ Wave model: Airy

Order:

Specify value:

	Height	Phase	Direction	Wave model
1	28.8 m	0 deg	0 deg	Airy
2	28.8 m	0 deg	30 deg	Airy
3	28.8 m	0 deg	59.99999999 deg	Airy
4	28.8 m	0 deg	90.00000001 deg	Airy
5	28.8 m	0 deg	120 deg	Airy
6	28.8 m	0 deg	150 deg	Airy
7	28.8 m	0 deg	180 deg	Airy
8	28.8 m	0 deg	210 deg	Airy
9	28.8 m	0 deg	240 deg	Airy
10	28.8 m	0 deg	270 deg	Airy
11	28.8 m	0 deg	300 deg	Airy
12	28.8 m	0 deg	330 deg	Airy

Name: WaveSet2

Wave Set Type: ● Period ○ Wavelength ○ Frequency

Fill tools: ● Period ○ Height ○ Phase ○ Direction

First value: [s]

Last value: [s]

Step value: [s]

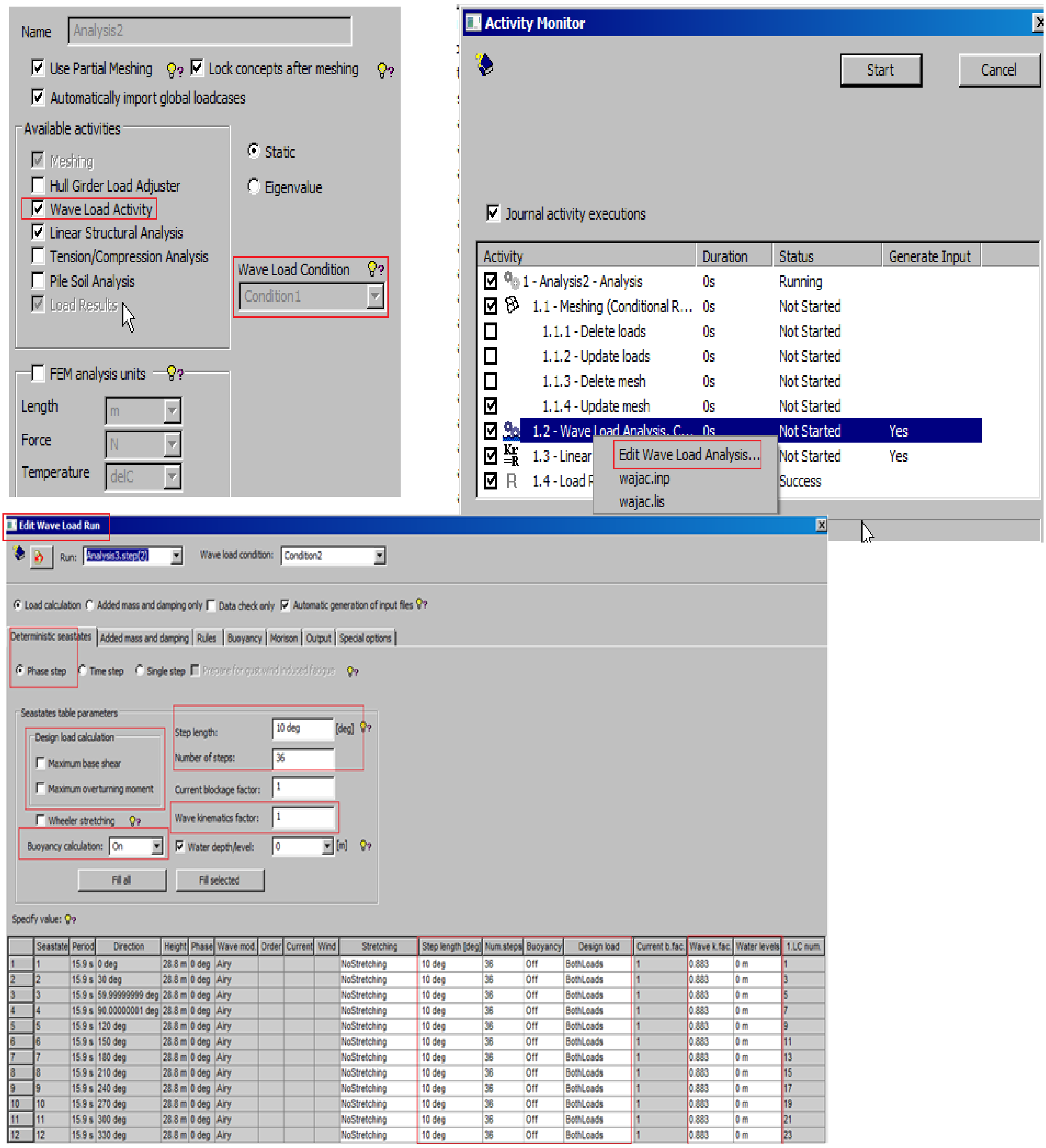
☐ Combine all with all

Specify value:

	Period [s]	Height [m]	Phase [deg]	Direction [deg]
1	15.9	28.8	0	0
2	15.9	28.8	0	30
3	15.9	28.8	0	60
4	15.9	28.8	0	90
5	15.9	28.8	0	120
6	15.9	28.8	0	150
7	15.9	28.8	0	180
8	15.9	28.8	0	210
9	15.9	28.8	0	240
10	15.9	28.8	0	270
11	15.9	28.8	0	300
12	15.9	28.8	0	330

Figure C 5 Step 8 – GeniE modelling

Figure C 6 showing how to assign wave parameters and wave characteristics.



Name: Analysis2

☑ Use Partial Meshing ☑ Lock concepts after meshing

☑ Automatically import global loadcases

Available activities
- ☑ Meshing
- ☐ Hull Girder Load Adjuster
- ☑ Wave Load Activity
- ☑ Linear Structural Analysis
- ☐ Tension/Compression Analysis
- ☐ Pile Soil Analysis
- ☑ Load Results

● Static ○ Eigenvalue

Wave Load Condition: Condition1

☐ FEM analysis units
- Length: m
- Force: N
- Temperature: delC

Activity Monitor

☑ Journal activity executions

	Activity	Duration	Status	Generate Input
☑	1 - Analysis2 - Analysis	0s	Running	
☑	1.1 - Meshing (Conditional R...	0s	Not Started	
☐	1.1.1 - Delete loads	0s	Not Started	
☐	1.1.2 - Update loads	0s	Not Started	
☐	1.1.3 - Delete mesh	0s	Not Started	
☑	1.1.4 - Update mesh	0s	Not Started	
☑	1.2 - Wave Load Analysis, C...	0s	Not Started	Yes
☑	1.3 - Linear		Not Started	Yes
☑	1.4 - Load		Success	

Edit Wave Load Analysis...
wajac.inp
wajac.lis

Edit Wave Load Run

Run: Analysis3.step(2) Wave load condition: Condition2

● Load calculation ○ Added mass and damping only ☐ Data check only ☑ Automatic generation of input files

Deterministic seastates | Added mass and damping | Rules | Buoyancy | Morison | Output | Special options

● Phase step ○ Time step ○ Single step ☐ Prepare for gust wind induced fatigue

Seastates table parameters

Design load calculation
- ☐ Maximum base shear
- ☐ Maximum overturning moment

☐ Wheeler stretching

Buoyancy calculation: On

Step length: 10 deg [deg]

Number of steps: 36

Current blockage factor: 1

Wave kinematics factor: 1

☑ Water depth/level: 0 [m]

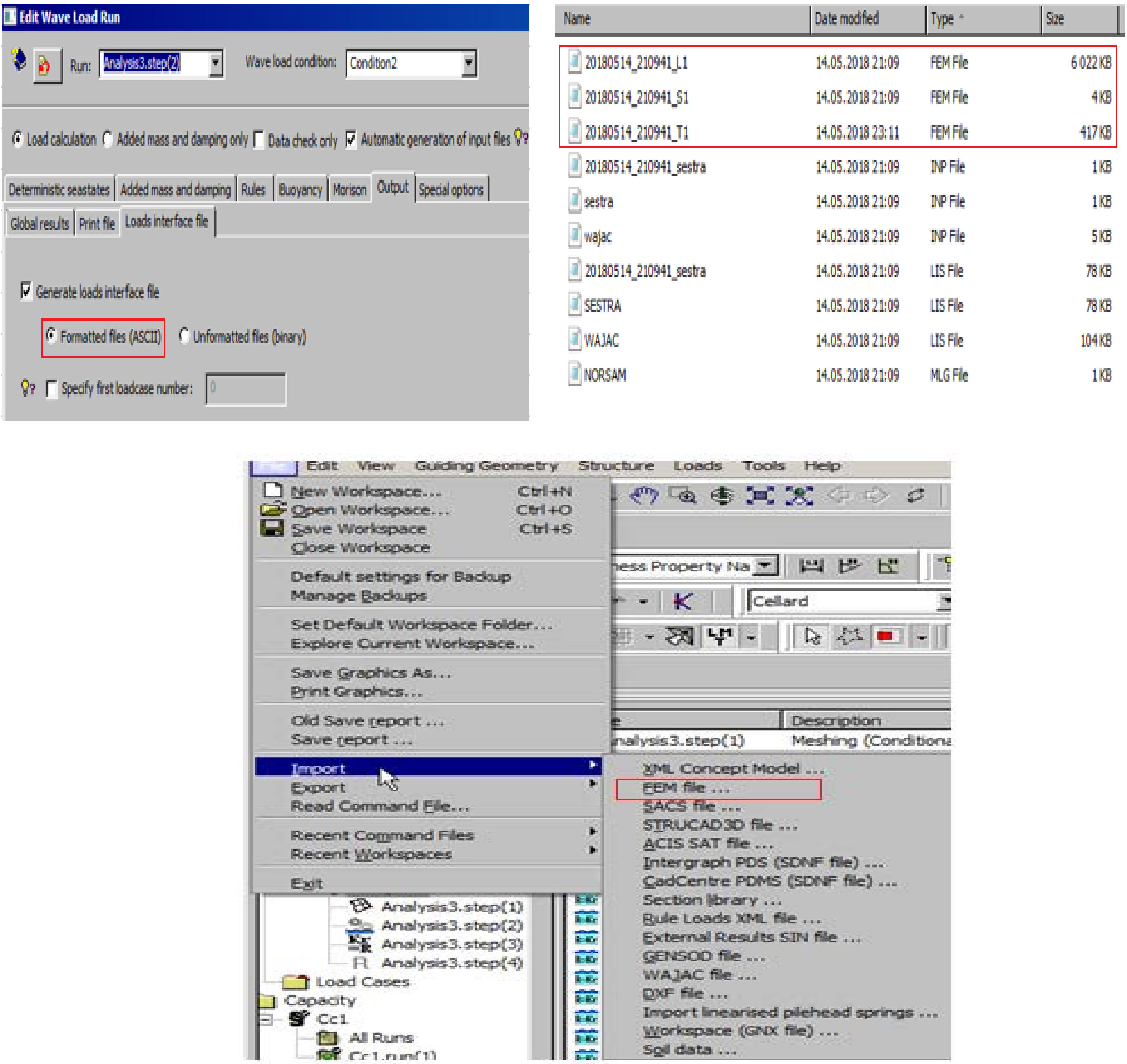
Fill all | Fill selected

Specify value:

	Seastate	Period	Direction	Height	Phase	Wave mod.	Order	Current	Wind	Stretching	Step length [deg]	Num.steps	Buoyancy	Design load	Current b.fac.	Wave k.fac.	Water levels	1.LC num.
1	1	15.9 s	0 deg	28.8 m	0 deg	Airy				NoStretching	10 deg	36	Off	BothLoads	1	0.883	0 m	1
2	2	15.9 s	30 deg	28.8 m	0 deg	Airy				NoStretching	10 deg	36	Off	BothLoads	1	0.883	0 m	3
3	3	15.9 s	59.99999999 deg	28.8 m	0 deg	Airy				NoStretching	10 deg	36	Off	BothLoads	1	0.883	0 m	5
4	4	15.9 s	90.00000001 deg	28.8 m	0 deg	Airy				NoStretching	10 deg	36	Off	BothLoads	1	0.883	0 m	7
5	5	15.9 s	120 deg	28.8 m	0 deg	Airy				NoStretching	10 deg	36	Off	BothLoads	1	0.883	0 m	9
6	6	15.9 s	150 deg	28.8 m	0 deg	Airy				NoStretching	10 deg	36	Off	BothLoads	1	0.883	0 m	11
7	7	15.9 s	180 deg	28.8 m	0 deg	Airy				NoStretching	10 deg	36	Off	BothLoads	1	0.883	0 m	13
8	8	15.9 s	210 deg	28.8 m	0 deg	Airy				NoStretching	10 deg	36	Off	BothLoads	1	0.883	0 m	15
9	9	15.9 s	240 deg	28.8 m	0 deg	Airy				NoStretching	10 deg	36	Off	BothLoads	1	0.883	0 m	17
10	10	15.9 s	270 deg	28.8 m	0 deg	Airy				NoStretching	10 deg	36	Off	BothLoads	1	0.883	0 m	19
11	11	15.9 s	300 deg	28.8 m	0 deg	Airy				NoStretching	10 deg	36	Off	BothLoads	1	0.883	0 m	21
12	12	15.9 s	330 deg	28.8 m	0 deg	Airy				NoStretching	10 deg	36	Off	BothLoads	1	0.883	0 m	23

Figure C 6 Step 8 – GeniE modelling and Sestra analysis

Figure C 7 shows how to perform wave analysis to find the calculated wave loads from Wajac. After running the analysis, locate the formatted loads in L1.fem file. Copy the calculated wave loads from L1.fem into T1.fem, then read the T1.fem in a new GeniE workspace to perform analysis and design.



Edit Wave Load Run

Run: Analysis3.step(2)   Wave load condition: Condition2

● Load calculation ○ Added mass and damping only ☐ Data check only ☑ Automatic generation of input files

☑ Generate loads interface file

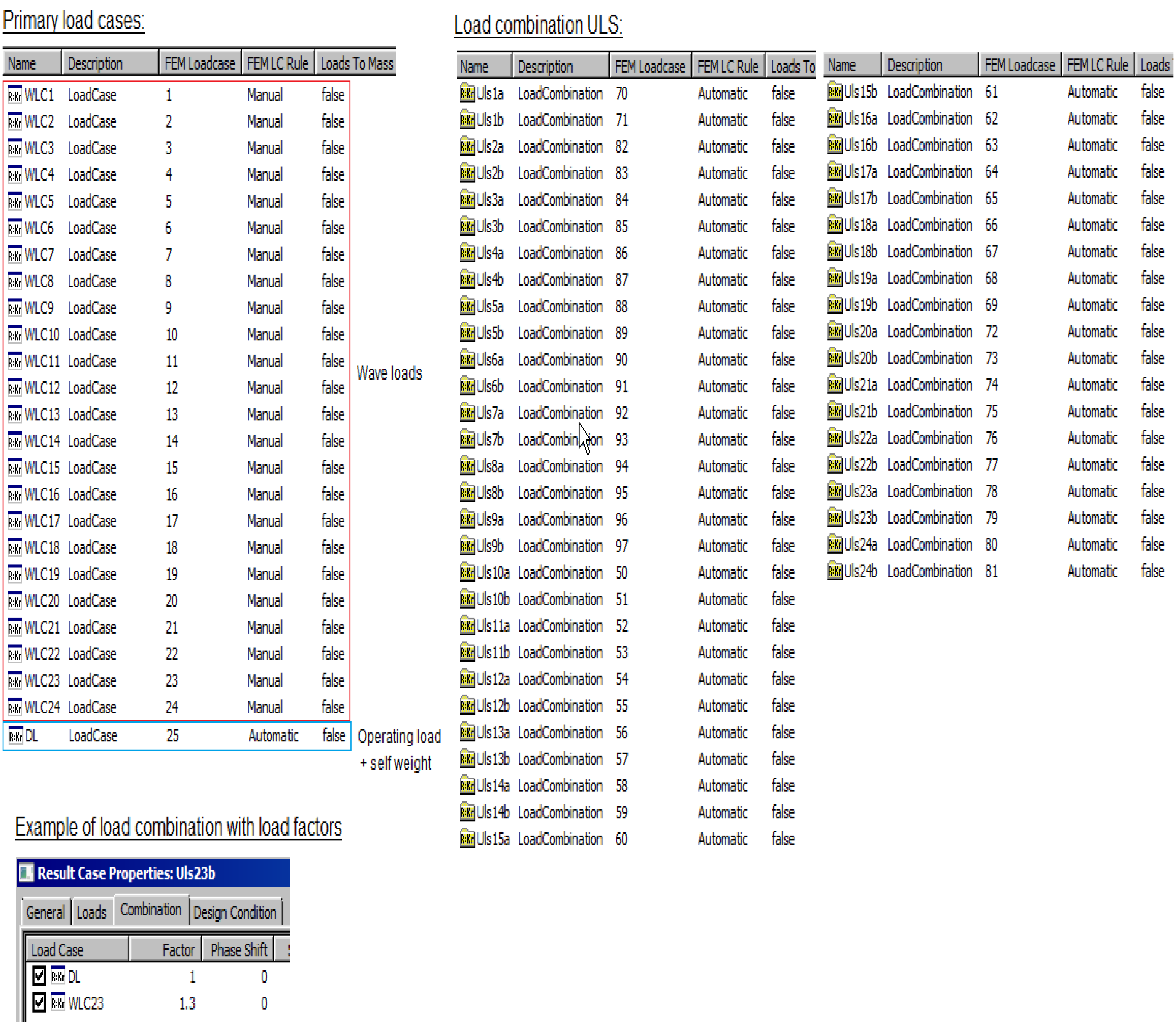
● Formatted files (ASCII) ○ Unformatted files (binary)

☐ Specify first loadcase number: 0

Name	Date modified	Type	Size
20180514_210941_L1	14.05.2018 21:09	FEM File	6 022 KB
20180514_210941_S1	14.05.2018 21:09	FEM File	4 KB
20180514_210941_T1	14.05.2018 23:11	FEM File	417 KB
20180514_210941_sestra	14.05.2018 21:09	INP File	1 KB
sestra	14.05.2018 21:09	INP File	1 KB
wajac	14.05.2018 21:09	INP File	5 KB
20180514_210941_sestra	14.05.2018 21:09	LIS File	78 KB
SESTRA	14.05.2018 21:09	LIS File	78 KB
WAJAC	14.05.2018 21:09	LIS File	104 KB
NORSAM	14.05.2018 21:09	MLG File	1 KB

Figure C 7 Step 9, 10 and 11 GeniE modelling and importing

Figure C 8 shows the primary load cases imported into the new GeniE workspace. Load combinations are prepared with use of primary load cases based on NORSOK.



Primary load cases:

Name	Description	FEM Loadcase	FEM LC Rule	Loads To Mass
WLC1	LoadCase	1	Manual	false
WLC2	LoadCase	2	Manual	false
WLC3	LoadCase	3	Manual	false
WLC4	LoadCase	4	Manual	false
WLC5	LoadCase	5	Manual	false
WLC6	LoadCase	6	Manual	false
WLC7	LoadCase	7	Manual	false
WLC8	LoadCase	8	Manual	false
WLC9	LoadCase	9	Manual	false
WLC10	LoadCase	10	Manual	false
WLC11	LoadCase	11	Manual	false
WLC12	LoadCase	12	Manual	false
WLC13	LoadCase	13	Manual	false
WLC14	LoadCase	14	Manual	false
WLC15	LoadCase	15	Manual	false
WLC16	LoadCase	16	Manual	false
WLC17	LoadCase	17	Manual	false
WLC18	LoadCase	18	Manual	false
WLC19	LoadCase	19	Manual	false
WLC20	LoadCase	20	Manual	false
WLC21	LoadCase	21	Manual	false
WLC22	LoadCase	22	Manual	false
WLC23	LoadCase	23	Manual	false
WLC24	LoadCase	24	Manual	false
DL	LoadCase	25	Automatic	false

Wave loads

Operating load + self weight

Load combination ULS:

Name	Description	FEM Loadcase	FEM LC Rule	Loads To
Uls1a	LoadCombination	70	Automatic	false
Uls1b	LoadCombination	71	Automatic	false
Uls2a	LoadCombination	82	Automatic	false
Uls2b	LoadCombination	83	Automatic	false
Uls3a	LoadCombination	84	Automatic	false
Uls3b	LoadCombination	85	Automatic	false
Uls4a	LoadCombination	86	Automatic	false
Uls4b	LoadCombination	87	Automatic	false
Uls5a	LoadCombination	88	Automatic	false
Uls5b	LoadCombination	89	Automatic	false
Uls6a	LoadCombination	90	Automatic	false
Uls6b	LoadCombination	91	Automatic	false
Uls7a	LoadCombination	92	Automatic	false
Uls7b	LoadCombination	93	Automatic	false
Uls8a	LoadCombination	94	Automatic	false
Uls8b	LoadCombination	95	Automatic	false
Uls9a	LoadCombination	96	Automatic	false
Uls9b	LoadCombination	97	Automatic	false
Uls10a	LoadCombination	50	Automatic	false
Uls10b	LoadCombination	51	Automatic	false
Uls11a	LoadCombination	52	Automatic	false
Uls11b	LoadCombination	53	Automatic	false
Uls12a	LoadCombination	54	Automatic	false
Uls12b	LoadCombination	55	Automatic	false
Uls13a	LoadCombination	56	Automatic	false
Uls13b	LoadCombination	57	Automatic	false
Uls14a	LoadCombination	58	Automatic	false
Uls14b	LoadCombination	59	Automatic	false
Uls15a	LoadCombination	60	Automatic	false
Uls15b	LoadCombination	61	Automatic	false
Uls16a	LoadCombination	62	Automatic	false
Uls16b	LoadCombination	63	Automatic	false
Uls17a	LoadCombination	64	Automatic	false
Uls17b	LoadCombination	65	Automatic	false
Uls18a	LoadCombination	66	Automatic	false
Uls18b	LoadCombination	67	Automatic	false
Uls19a	LoadCombination	68	Automatic	false
Uls19b	LoadCombination	69	Automatic	false
Uls20a	LoadCombination	72	Automatic	false
Uls20b	LoadCombination	73	Automatic	false
Uls21a	LoadCombination	74	Automatic	false
Uls21b	LoadCombination	75	Automatic	false
Uls22a	LoadCombination	76	Automatic	false
Uls22b	LoadCombination	77	Automatic	false
Uls23a	LoadCombination	78	Automatic	false
Uls23b	LoadCombination	79	Automatic	false
Uls24a	LoadCombination	80	Automatic	false
Uls24b	LoadCombination	81	Automatic	false

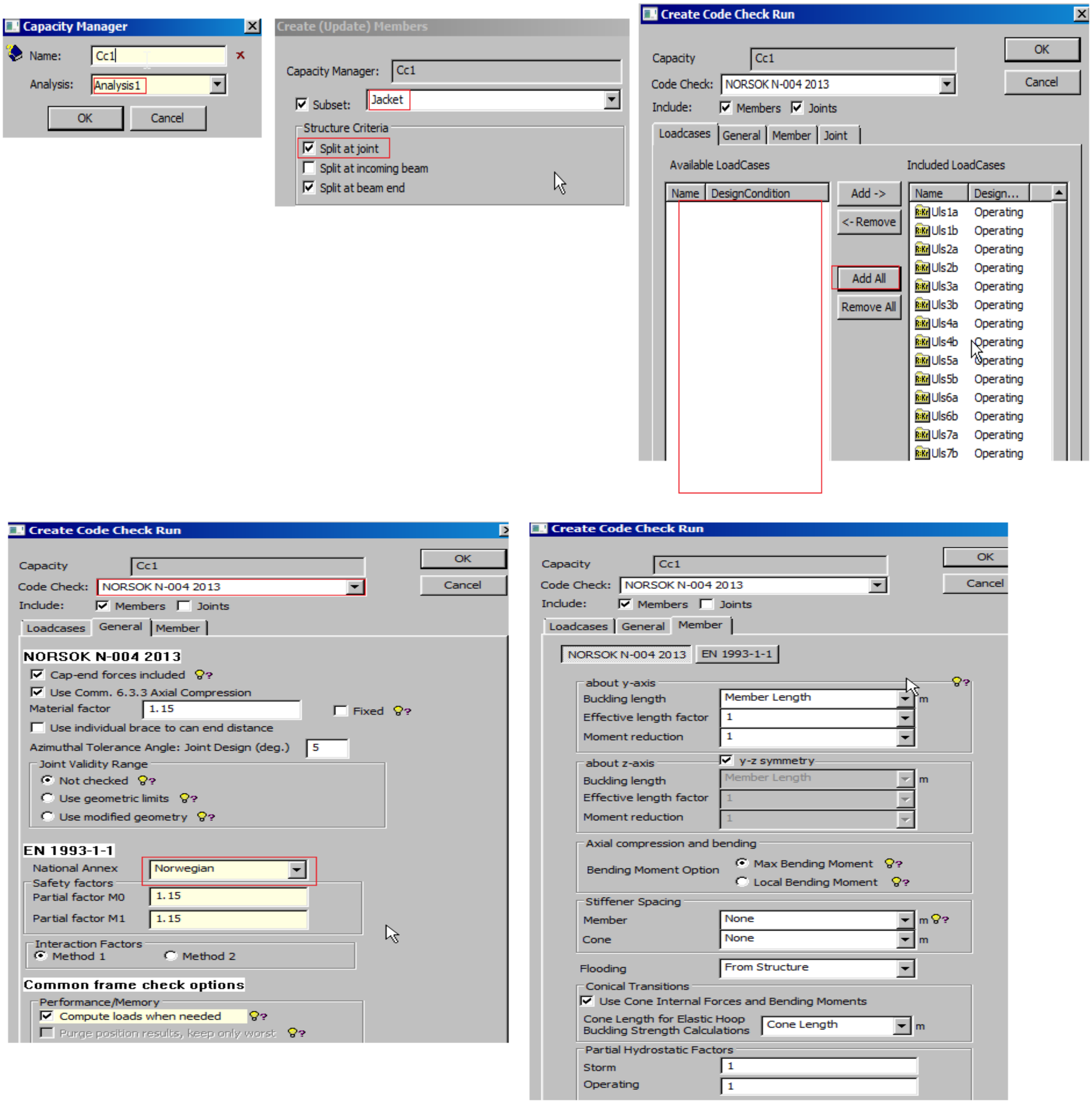
Example of load combination with load factors

Result Case Properties: Uls23b

Load Case	Factor	Phase Shift
☑ DL	1	0
☑ WLC23	1.3	0

Figure C 8 Step 12 – GeniE modelling – loads and load combinations

Figure C 9 and Figure C 10 shows how to perform a code check on considered offshore jacket members and joints.



Capacity Manager

Name: Cc1

Analysis: Analysis1

Create (Update) Members

Capacity Manager: Cc1

☑ Subset: Jacket

Structure Criteria

☑ Split at joint

☐ Split at incoming beam

☑ Split at beam end

Create Code Check Run

Capacity: Cc1

Code Check: NORSOK N-004 2013

Include: ☑ Members ☑ Joints

Name	Design...
Uls1a	Operating
Uls1b	Operating
Uls2a	Operating
Uls2b	Operating
Uls3a	Operating
Uls3b	Operating
Uls4a	Operating
Uls4b	Operating
Uls5a	Operating
Uls5b	Operating
Uls6a	Operating
Uls6b	Operating
Uls7a	Operating
Uls7b	Operating

Create Code Check Run

Capacity: Cc1

Code Check: NORSOK N-004 2013

Include: ☑ Members ☐ Joints

NORSOK N-004 2013

☑ Cap-end forces included

☑ Use Comm. 6.3.3 Axial Compression

Material factor 1.15 ☐ Fixed

☐ Use individual brace to can end distance

Azimuthal Tolerance Angle: Joint Design (deg.) 5

Joint Validity Range

● Not checked

○ Use geometric limits

○ Use modified geometry

EN 1993-1-1

National Annex: Norwegian

Safety factors

Partial factor M0: 1.15

Partial factor M1: 1.15

Interaction Factors

● Method 1 ○ Method 2

Common frame check options

Performance/Memory

☑ Compute loads when needed

☐ Purge position results, keep only worst

Create Code Check Run

Capacity: Cc1

Code Check: NORSOK N-004 2013

Include: ☑ Members ☐ Joints

about y-axis

Buckling length: Member Length m

Effective length factor: 1

Moment reduction: 1

about z-axis ☑ y-z symmetry

Buckling length: Member Length m

Effective length factor: 1

Moment reduction: 1

Axial compression and bending

Bending Moment Option: ● Max Bending Moment ○ Local Bending Moment

Stiffener Spacing

Member: None m

Cone: None m

Flooding: From Structure

Conical Transitions

☑ Use Cone Internal Forces and Bending Moments

Cone Length for Elastic Hoop Buckling Strength Calculations: Cone Length m

Partial Hydrostatic Factors

Storm: 1

Operating: 1

Figure C 9 Step 13 - Code check

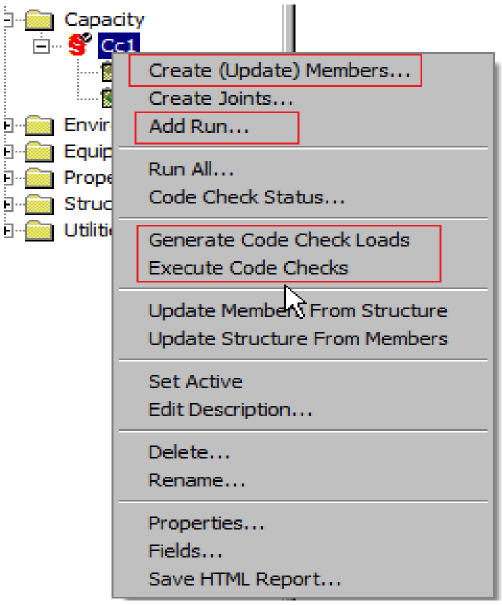
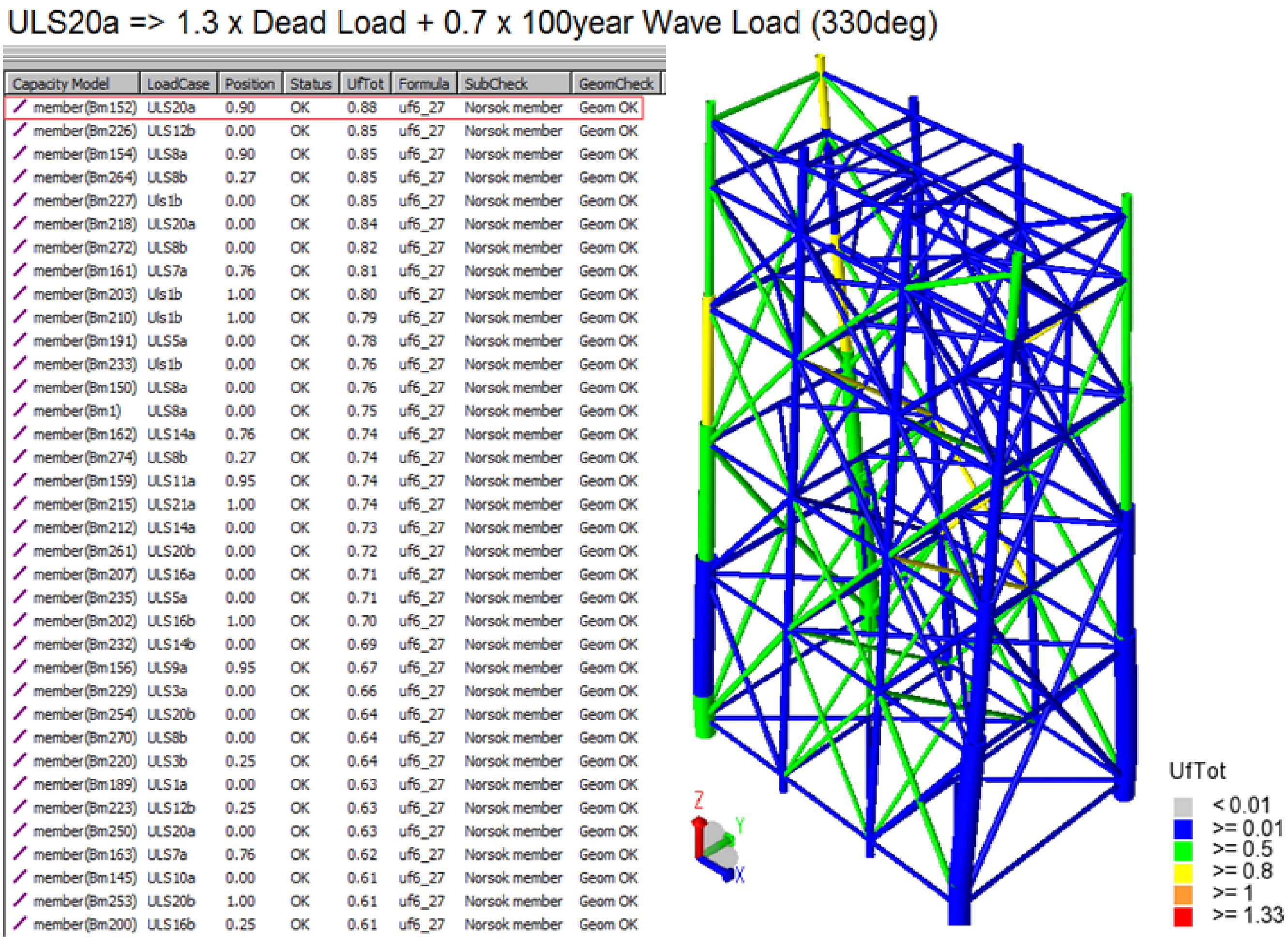


Figure C 10 Step 13 - Code check

Figure C 11 shows the code check results. Colour code is generated based on the usage factors received from code check.

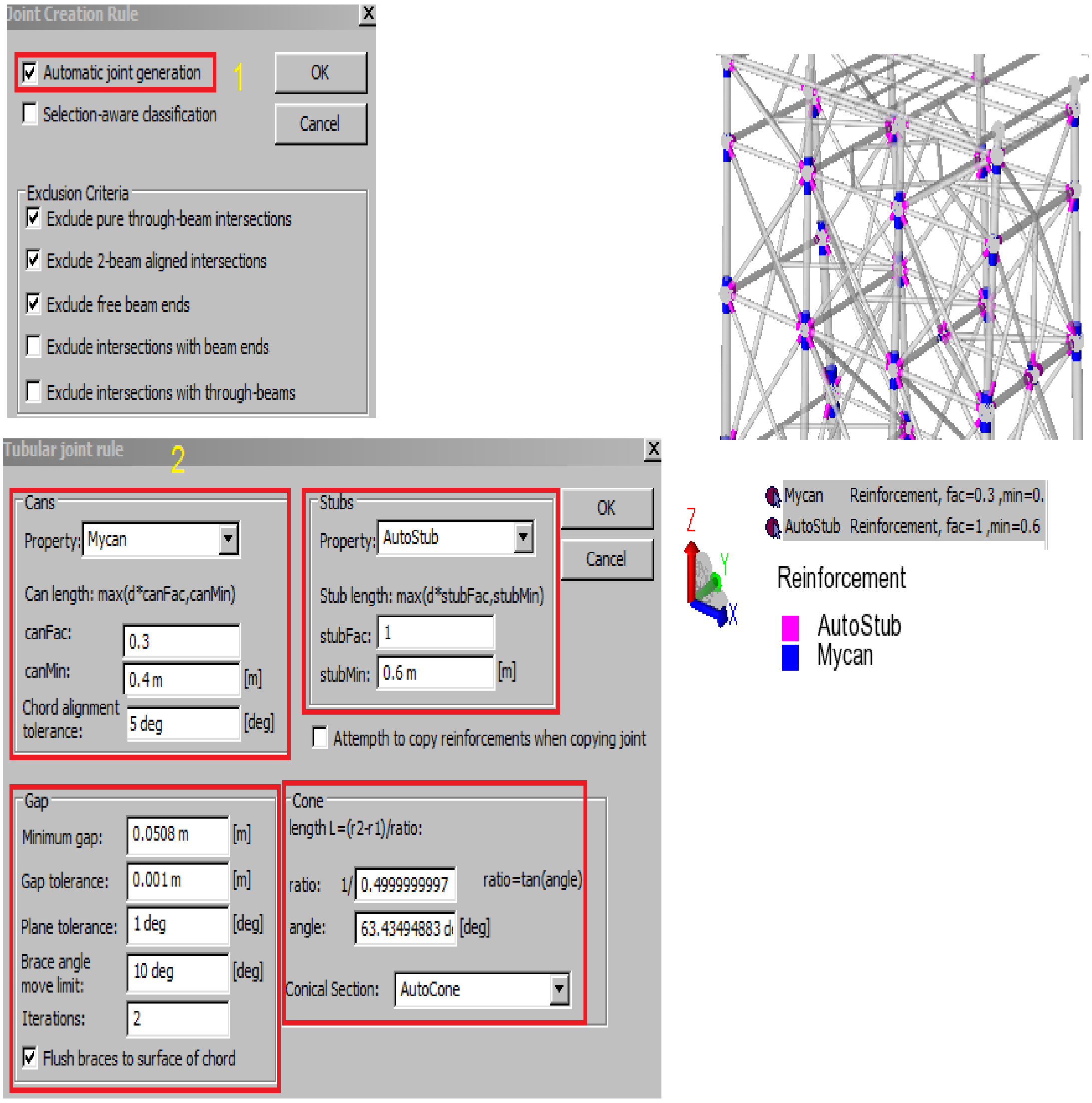


ULS20a => 1.3 x Dead Load + 0.7 x 100year Wave Load (330deg)

Capacity Model	LoadCase	Position	Status	UfTot	Formula	SubCheck	GeomCheck
member(Bm152)	ULS20a	0.90	OK	0.88	uf6_27	Norsok member	Geom OK
member(Bm226)	ULS12b	0.00	OK	0.85	uf6_27	Norsok member	Geom OK
member(Bm154)	ULS8a	0.90	OK	0.85	uf6_27	Norsok member	Geom OK
member(Bm264)	ULS8b	0.27	OK	0.85	uf6_27	Norsok member	Geom OK
member(Bm227)	Uls1b	0.00	OK	0.85	uf6_27	Norsok member	Geom OK
member(Bm218)	ULS20a	0.00	OK	0.84	uf6_27	Norsok member	Geom OK
member(Bm272)	ULS8b	0.00	OK	0.82	uf6_27	Norsok member	Geom OK
member(Bm161)	ULS7a	0.76	OK	0.81	uf6_27	Norsok member	Geom OK
member(Bm203)	Uls1b	1.00	OK	0.80	uf6_27	Norsok member	Geom OK
member(Bm210)	Uls1b	1.00	OK	0.79	uf6_27	Norsok member	Geom OK
member(Bm191)	ULS5a	0.00	OK	0.78	uf6_27	Norsok member	Geom OK
member(Bm233)	Uls1b	0.00	OK	0.76	uf6_27	Norsok member	Geom OK
member(Bm150)	ULS8a	0.00	OK	0.76	uf6_27	Norsok member	Geom OK
member(Bm1)	ULS8a	0.00	OK	0.75	uf6_27	Norsok member	Geom OK
member(Bm162)	ULS14a	0.76	OK	0.74	uf6_27	Norsok member	Geom OK
member(Bm274)	ULS8b	0.27	OK	0.74	uf6_27	Norsok member	Geom OK
member(Bm159)	ULS11a	0.95	OK	0.74	uf6_27	Norsok member	Geom OK
member(Bm215)	ULS21a	1.00	OK	0.74	uf6_27	Norsok member	Geom OK
member(Bm212)	ULS14a	0.00	OK	0.73	uf6_27	Norsok member	Geom OK
member(Bm261)	ULS20b	0.00	OK	0.72	uf6_27	Norsok member	Geom OK
member(Bm207)	ULS16a	0.00	OK	0.71	uf6_27	Norsok member	Geom OK
member(Bm235)	ULS5a	0.00	OK	0.71	uf6_27	Norsok member	Geom OK
member(Bm202)	ULS16b	1.00	OK	0.70	uf6_27	Norsok member	Geom OK
member(Bm232)	ULS14b	0.00	OK	0.69	uf6_27	Norsok member	Geom OK
member(Bm156)	ULS9a	0.95	OK	0.67	uf6_27	Norsok member	Geom OK
member(Bm229)	ULS3a	0.00	OK	0.66	uf6_27	Norsok member	Geom OK
member(Bm254)	ULS20b	0.00	OK	0.64	uf6_27	Norsok member	Geom OK
member(Bm270)	ULS8b	0.00	OK	0.64	uf6_27	Norsok member	Geom OK
member(Bm220)	ULS3b	0.25	OK	0.64	uf6_27	Norsok member	Geom OK
member(Bm189)	ULS1a	0.00	OK	0.63	uf6_27	Norsok member	Geom OK
member(Bm223)	ULS12b	0.25	OK	0.63	uf6_27	Norsok member	Geom OK
member(Bm250)	ULS20a	0.00	OK	0.63	uf6_27	Norsok member	Geom OK
member(Bm163)	ULS7a	0.76	OK	0.62	uf6_27	Norsok member	Geom OK
member(Bm145)	ULS10a	0.00	OK	0.61	uf6_27	Norsok member	Geom OK
member(Bm253)	ULS20b	1.00	OK	0.61	uf6_27	Norsok member	Geom OK
member(Bm200)	ULS16b	0.25	OK	0.61	uf6_27	Norsok member	Geom OK

Figure C 11 Step 14- Beam code check results ULS – with Buoyancy

Figure C 12 showing the automatic joint creation facility inside GeniE software. The joint design default settings/values are according to NORSOK standards.



Joint Creation Rule

☑ Automatic joint generation

☐ Selection-aware classification

Exclusion Criteria

☑ Exclude pure through-beam intersections

☑ Exclude 2-beam aligned intersections

☑ Exclude free beam ends

☐ Exclude intersections with beam ends

☐ Exclude intersections with through-beams

Tubular joint rule

Cans

Property: Mycan

Can length: max(d*canFac,canMin)

canFac: 0.3

canMin: 0.4 m [m]

Chord alignment tolerance: 5 deg [deg]

Stubs

Property: AutoStub

Stub length: max(d*stubFac,stubMin)

stubFac: 1

stubMin: 0.6 m [m]

☐ Attempth to copy reinforcements when copying joint

Gap

Minimum gap: 0.0508 m [m]

Gap tolerance: 0.001 m [m]

Plane tolerance: 1 deg [deg]

Brace angle move limit: 10 deg [deg]

Iterations: 2

☑ Flush braces to surface of chord

Cone

length L=(r2-r1)/ratio:

ratio: 1/ 0.4999999997 ratio=tan(angle)

angle: 63.43494883 d [deg]

Conical Section: AutoCone

Mycan Reinforcement, fac=0.3 ,min=0.

AutoStub Reinforcement, fac=1 ,min=0.6

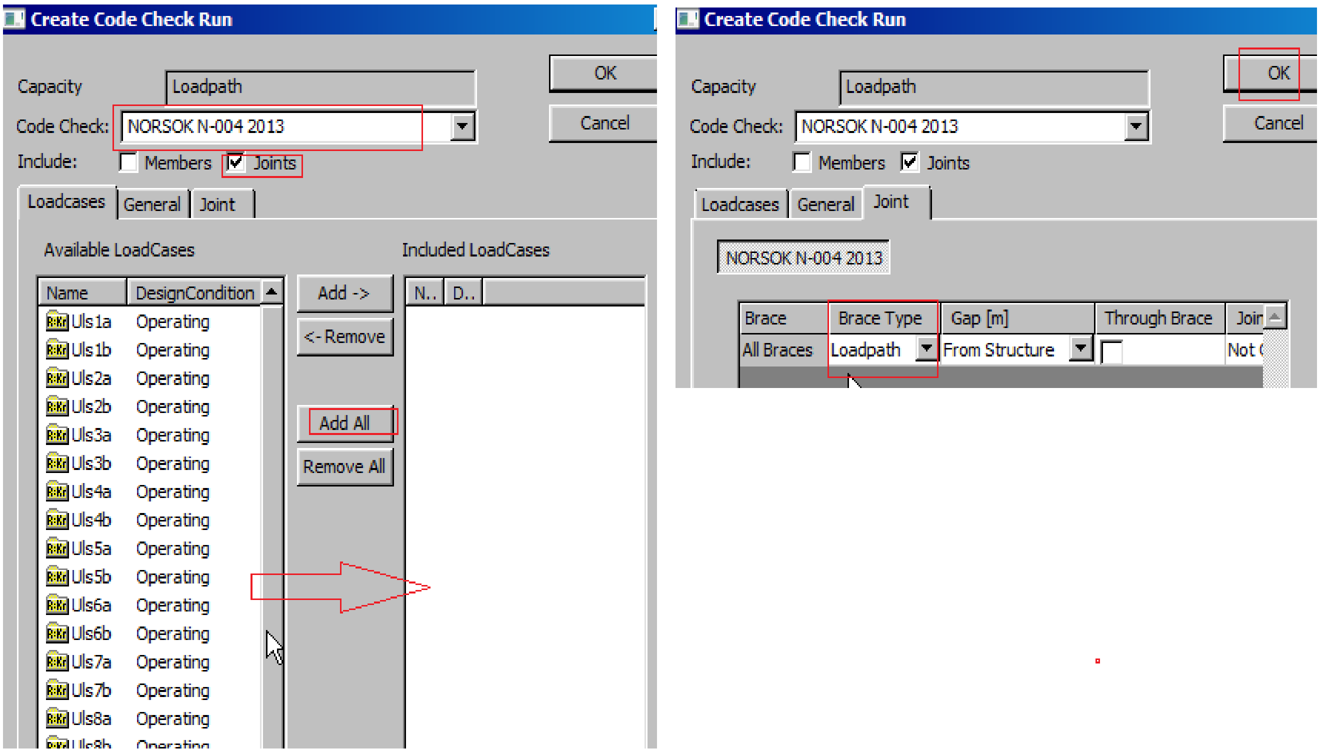
Reinforcement

🟪 AutoStub

🟦 Mycan

Figure C 12 Step 15 – GeniE joint modelling with STUB and CAN

Figure C 13 and Figure C 14 showing how to perform a code check for joint and the results from joint design with usage factor colour code.



Capacity: Loadpath

Code Check: NORSOK N-004 2013

Include: ☐ Members ☑ Joints

Available LoadCases

Name	DesignCondition
Uls1a	Operating
Uls1b	Operating
Uls2a	Operating
Uls2b	Operating
Uls3a	Operating
Uls3b	Operating
Uls4a	Operating
Uls4b	Operating
Uls5a	Operating
Uls5b	Operating
Uls6a	Operating
Uls6b	Operating
Uls7a	Operating
Uls7b	Operating
Uls8a	Operating

Included LoadCases

Capacity: Loadpath

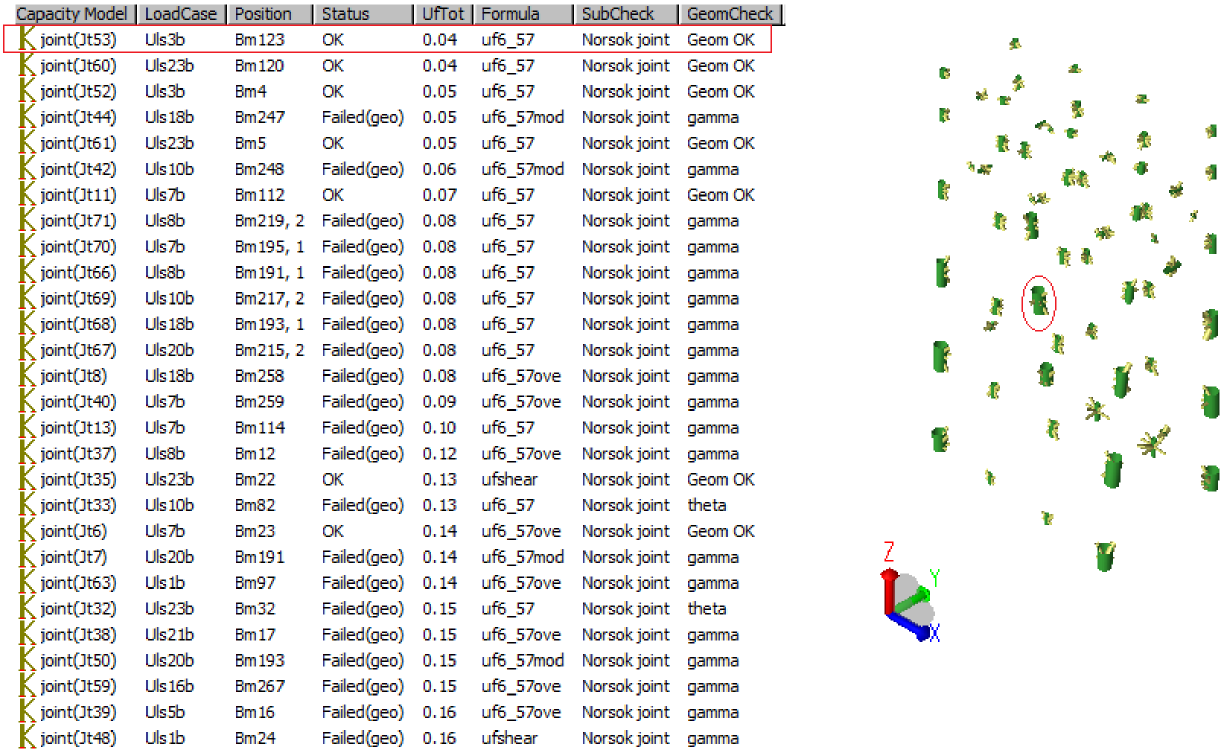
Code Check: NORSOK N-004 2013

Include: ☐ Members ☑ Joints

NORSOK N-004 2013

Brace	Brace Type	Gap [m]	Through Brace	Joir
All Braces	Loadpath	From Structure	☐	Not

Figure C 13 Step 17 and 18 – Assign joint type and perform code check on joints



Capacity Model	LoadCase	Position	Status	UfTot	Formula	SubCheck	GeomCheck
joint(Jt53)	Uls3b	Bm123	OK	0.04	uf6_57	Norsok joint	Geom OK
joint(Jt60)	Uls23b	Bm120	OK	0.04	uf6_57	Norsok joint	Geom OK
joint(Jt52)	Uls3b	Bm4	OK	0.05	uf6_57	Norsok joint	Geom OK
joint(Jt44)	Uls18b	Bm247	Failed(geo)	0.05	uf6_57mod	Norsok joint	gamma
joint(Jt61)	Uls23b	Bm5	OK	0.05	uf6_57	Norsok joint	Geom OK
joint(Jt42)	Uls10b	Bm248	Failed(geo)	0.06	uf6_57mod	Norsok joint	gamma
joint(Jt11)	Uls7b	Bm112	OK	0.07	uf6_57	Norsok joint	Geom OK
joint(Jt71)	Uls8b	Bm219, 2	Failed(geo)	0.08	uf6_57	Norsok joint	gamma
joint(Jt70)	Uls7b	Bm195, 1	Failed(geo)	0.08	uf6_57	Norsok joint	gamma
joint(Jt66)	Uls8b	Bm191, 1	Failed(geo)	0.08	uf6_57	Norsok joint	gamma
joint(Jt69)	Uls10b	Bm217, 2	Failed(geo)	0.08	uf6_57	Norsok joint	gamma
joint(Jt68)	Uls18b	Bm193, 1	Failed(geo)	0.08	uf6_57	Norsok joint	gamma
joint(Jt67)	Uls20b	Bm215, 2	Failed(geo)	0.08	uf6_57	Norsok joint	gamma
joint(Jt8)	Uls18b	Bm258	Failed(geo)	0.08	uf6_57ove	Norsok joint	gamma
joint(Jt40)	Uls7b	Bm259	Failed(geo)	0.09	uf6_57ove	Norsok joint	gamma
joint(Jt13)	Uls7b	Bm114	Failed(geo)	0.10	uf6_57	Norsok joint	gamma
joint(Jt37)	Uls8b	Bm12	Failed(geo)	0.12	uf6_57ove	Norsok joint	gamma
joint(Jt35)	Uls23b	Bm22	OK	0.13	ufshear	Norsok joint	Geom OK
joint(Jt33)	Uls10b	Bm82	Failed(geo)	0.13	uf6_57	Norsok joint	theta
joint(Jt6)	Uls7b	Bm23	OK	0.14	uf6_57ove	Norsok joint	Geom OK
joint(Jt7)	Uls20b	Bm191	Failed(geo)	0.14	uf6_57mod	Norsok joint	gamma
joint(Jt63)	Uls1b	Bm97	Failed(geo)	0.14	uf6_57ove	Norsok joint	gamma
joint(Jt32)	Uls23b	Bm32	Failed(geo)	0.15	uf6_57	Norsok joint	theta
joint(Jt38)	Uls21b	Bm17	Failed(geo)	0.15	uf6_57ove	Norsok joint	gamma
joint(Jt50)	Uls20b	Bm193	Failed(geo)	0.15	uf6_57mod	Norsok joint	gamma
joint(Jt59)	Uls16b	Bm267	Failed(geo)	0.15	uf6_57ove	Norsok joint	gamma
joint(Jt39)	Uls5b	Bm16	Failed(geo)	0.16	uf6_57ove	Norsok joint	gamma
joint(Jt48)	Uls1b	Bm24	Failed(geo)	0.16	ufshear	Norsok joint	gamma

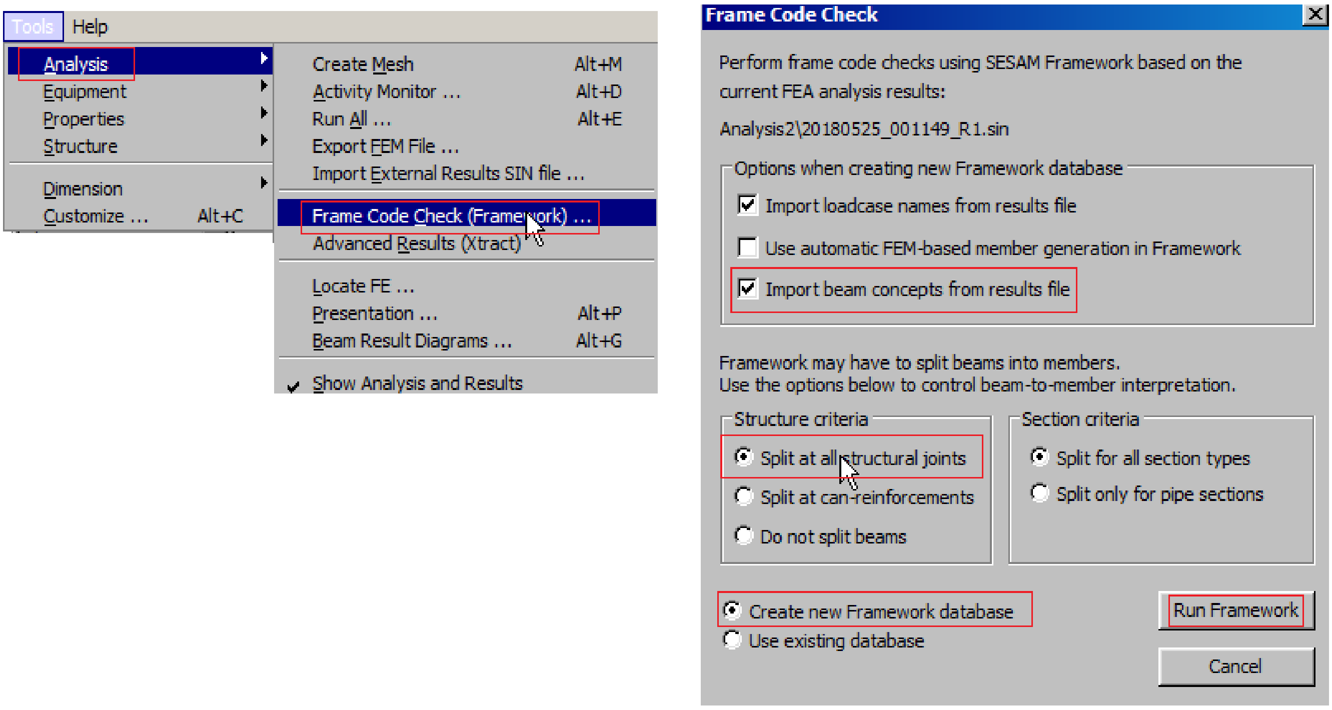
Figure C 14 Step 19 Joint code check results

Appendix D Framework model and fatigue check results

Framework inputs and fatigue check (FLS)

1. Use the final GeniE model with Joints, prepare a new wave set for deterministic fatigue analysis.
2. Assign load similar to ULS steps with Waves as per Table 9.
3. Create load combination according to Table 3Table 6.
4. Run analysis in GeniE.
5. Transfer the results and model to Framework.
6. Select fatigue check type and define fatigue constants
7. Assign individual wave – Piece-wise distribution – See Figure 22
8. Assign SN type for selected joints and members
9. Assign SCF type for selected joints and members
10. Assign joint type
11. Assign joint gap
12. Select members for fatigue assessment
13. Run fatigue analysis
14. Framework results – Only from with Buoyancy loading case.

Figure D 1 showing how to transfer the GeniE model with results to perform a fatigue verification in Framework.



Perform frame code checks using SESAM Framework based on the current FEA analysis results:

Analysis2\20180525_001149_R1.sin

Options when creating new Framework database

☑ Import loadcase names from results file

☐ Use automatic FEM-based member generation in Framework

☑ Import beam concepts from results file

Framework may have to split beams into members.
Use the options below to control beam-to-member interpretation.

Structure criteria

● Split at all structural joints

○ Split at can-reinforcements

○ Do not split beams

Section criteria

● Split for all section types

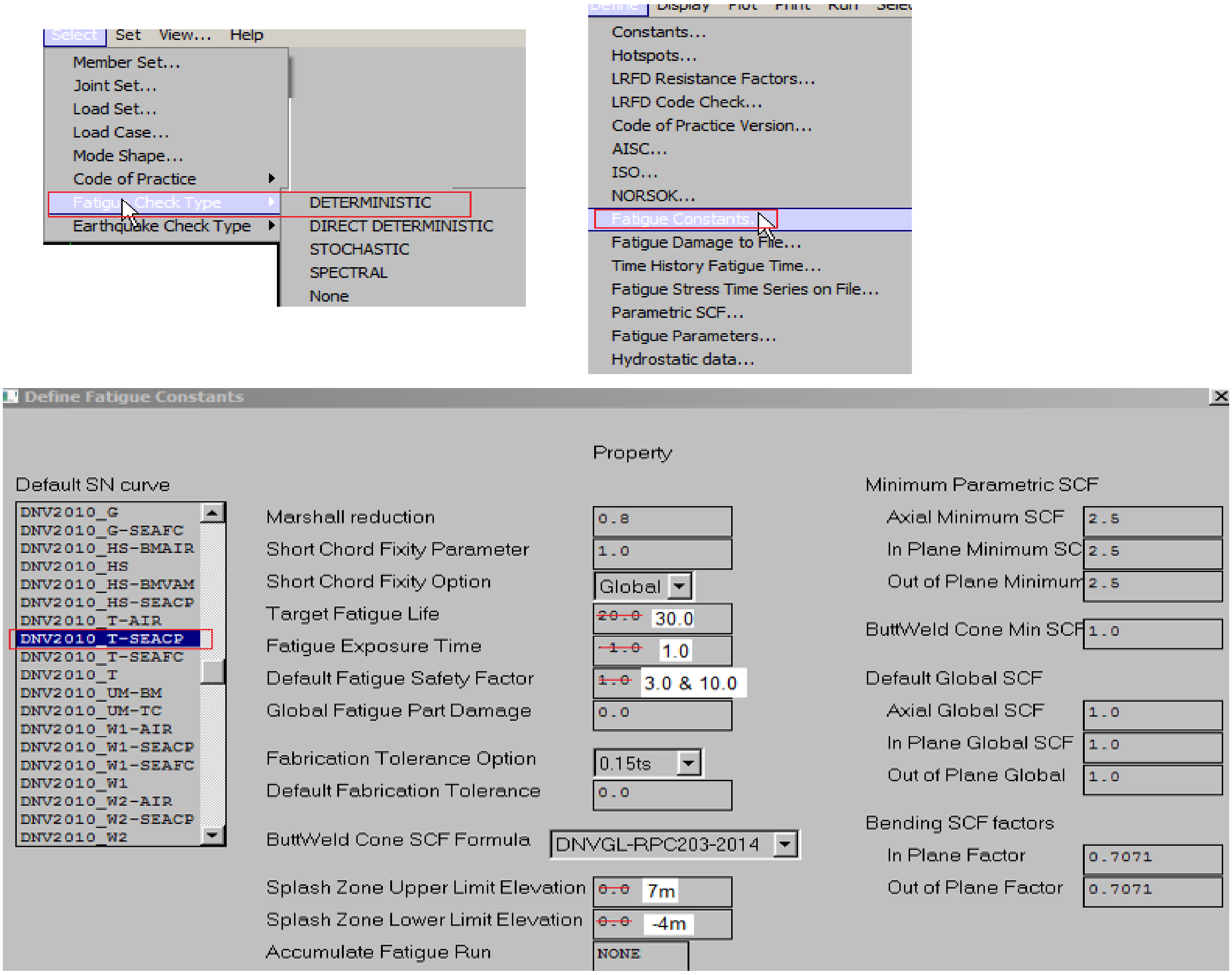
○ Split only for pipe sections

● Create new Framework database

○ Use existing database

Figure D 1 Step 5 – Transfer GeniE model to Framework

Figure D 2 showing how to select the type of fatigue check to be performed in Framework. It also shows a dialog box for defining fatigue constants for whole model.



Default SN curve

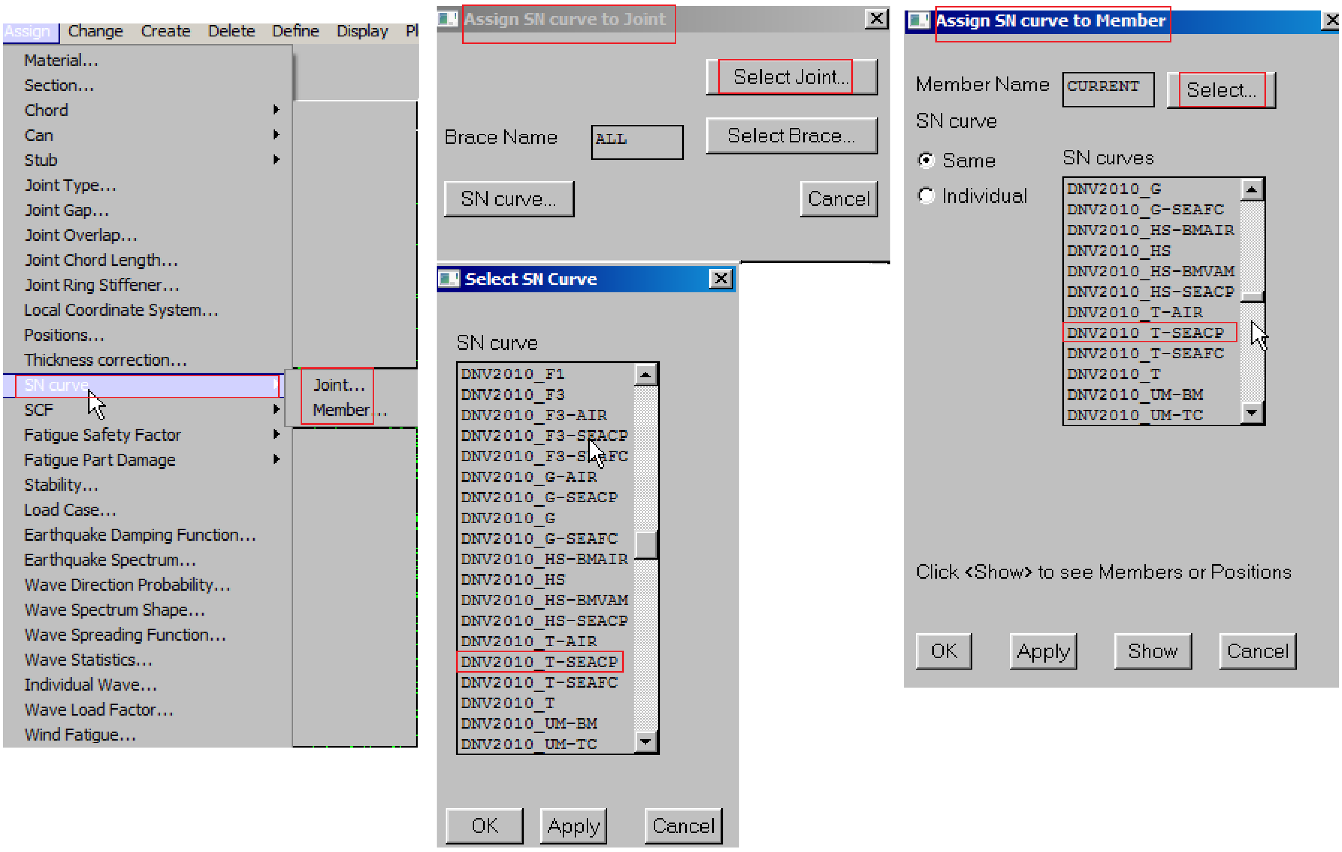
DNV2010_G
DNV2010_G-SEAFC
DNV2010_HS-BMAIR
DNV2010_HS
DNV2010_HS-BMVAM
DNV2010_HS-SEACP
DNV2010_T-AIR
DNV2010_T-SEACP
DNV2010_T-SEAFC
DNV2010_T
DNV2010_UM-BM
DNV2010_UM-TC
DNV2010_W1-AIR
DNV2010_W1-SEACP
DNV2010_W1-SEAFC
DNV2010_W1
DNV2010_W2-AIR
DNV2010_W2-SEACP
DNV2010_W2

	Property
Marshall reduction	0.8
Short Chord Fixity Parameter	1.0
Short Chord Fixity Option	Global
Target Fatigue Life	~~20.0~~ 30.0
Fatigue Exposure Time	~~1.0~~ 1.0
Default Fatigue Safety Factor	~~1.0~~ 3.0 & 10.0
Global Fatigue Part Damage	0.0
Fabrication Tolerance Option	0.15ts
Default Fabrication Tolerance	0.0
ButtWeld Cone SCF Formula	DNVGL-RPC203-2014
Splash Zone Upper Limit Elevation	~~0.0~~ 7m
Splash Zone Lower Limit Elevation	~~0.0~~ -4m
Accumulate Fatigue Run	NONE

Minimum Parametric SCF	
Axial Minimum SCF	2.5
In Plane Minimum SC	2.5
Out of Plane Minimum	2.5
ButtWeld Cone Min SCF	1.0
Default Global SCF	
Axial Global SCF	1.0
In Plane Global SCF	1.0
Out of Plane Global	1.0
Bending SCF factors	
In Plane Factor	0.7071
Out of Plane Factor	0.7071

Figure D 2 Step 6 – Inputs on Framework – Fatigue constants

Figure D 3 shows how to assign SN curve for selected joint or a member on the whole jacket model.



Brace Name: ALL

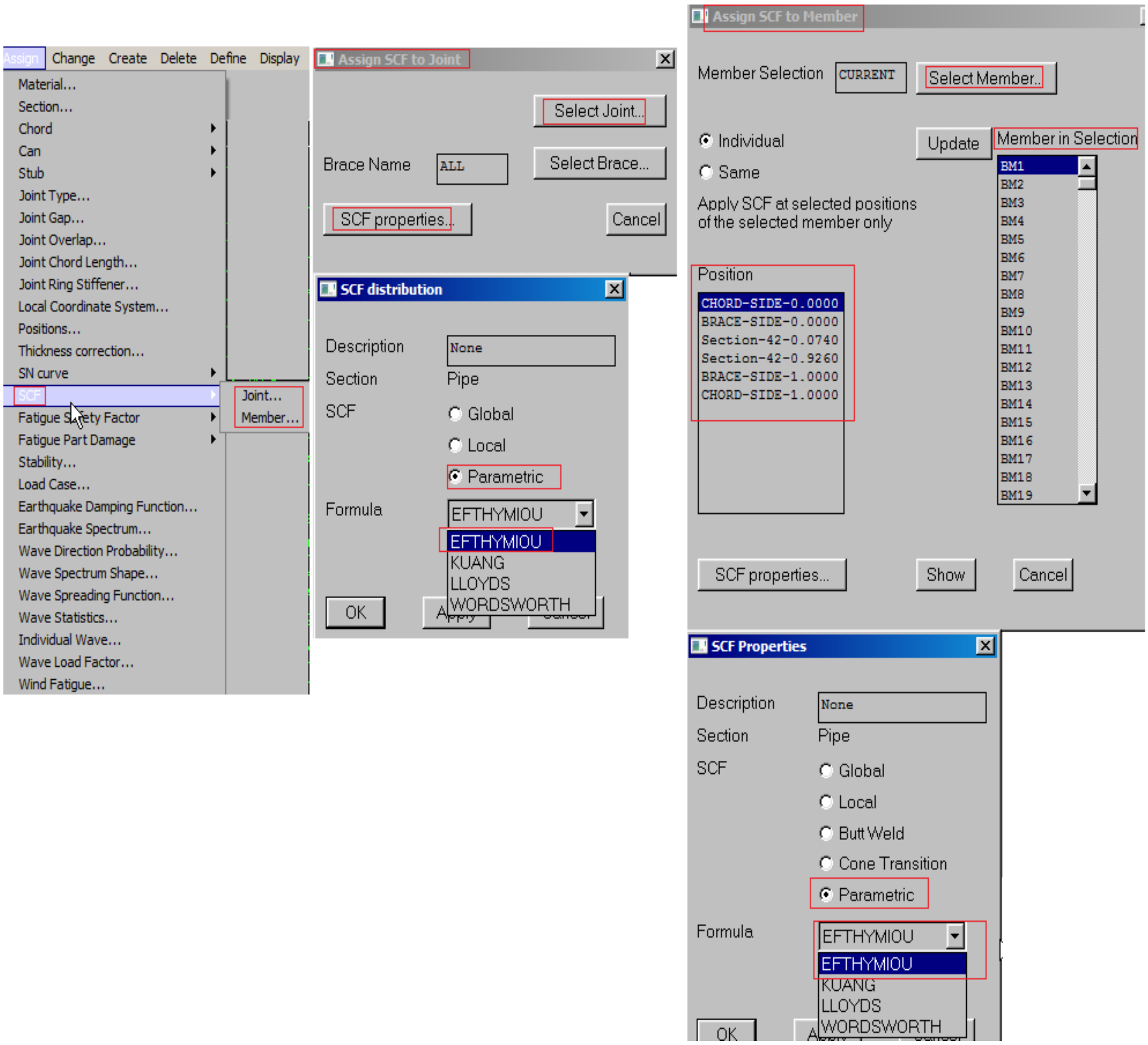
Member Name: CURRENT

● Same

Click <Show> to see Members or Positions

Figure D 3 Step 8 – Inputs on Framework - Assign SN curve

Figure D 4 shows how to assign stress concentration factor for a selected member or a joint on the jacket model. There is a possibility to select type of equations to be followed for calculating the stress concentration factor.



Assign SCF to Joint

Brace Name: ALL

SCF distribution

Description: None

Section: Pipe

SCF: ○ Global ○ Local ● Parametric

Formula: EFTHYMIOU (EFTHYMIOU, KUANG, LLOYDS, WORDSWORTH)

Assign SCF to Member

Member Selection: CURRENT

● Individual

○ Same

Apply SCF at selected positions of the selected member only

Position

```
CHORD-SIDE-0.0000
BRACE-SIDE-0.0000
Section-42-0.0740
Section-42-0.9260
BRACE-SIDE-1.0000
CHORD-SIDE-1.0000
```

Member in Selection: BM1, BM2, BM3, BM4, BM5, BM6, BM7, BM8, BM9, BM10, BM11, BM12, BM13, BM14, BM15, BM16, BM17, BM18, BM19

SCF Properties

Description: None

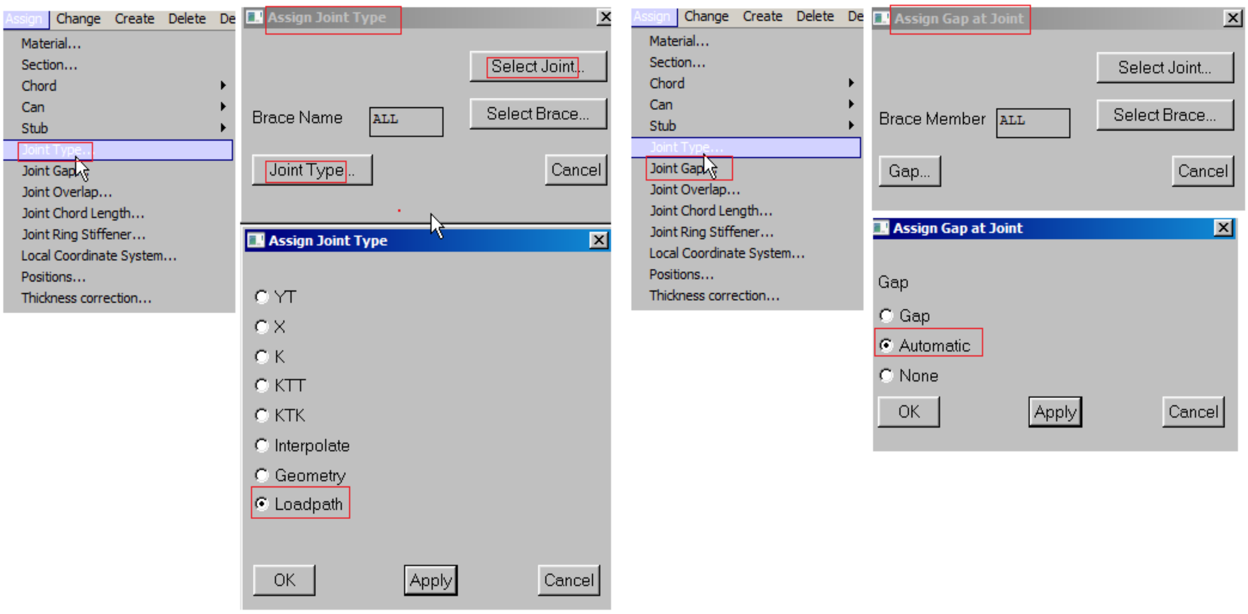
Section: Pipe

SCF: ○ Global ○ Local ○ Butt Weld ○ Cone Transition ● Parametric

Formula: EFTHYMIOU (EFTHYMIOU, KUANG, LLOYDS, WORDSWORTH)

Figure D 4 Step 9 – Inputs on Framework - Assign SCF

Figure D 5 shows how to assign a joint type, joint gap for selected member or a joint in the jacket model.



Brace Name ALL

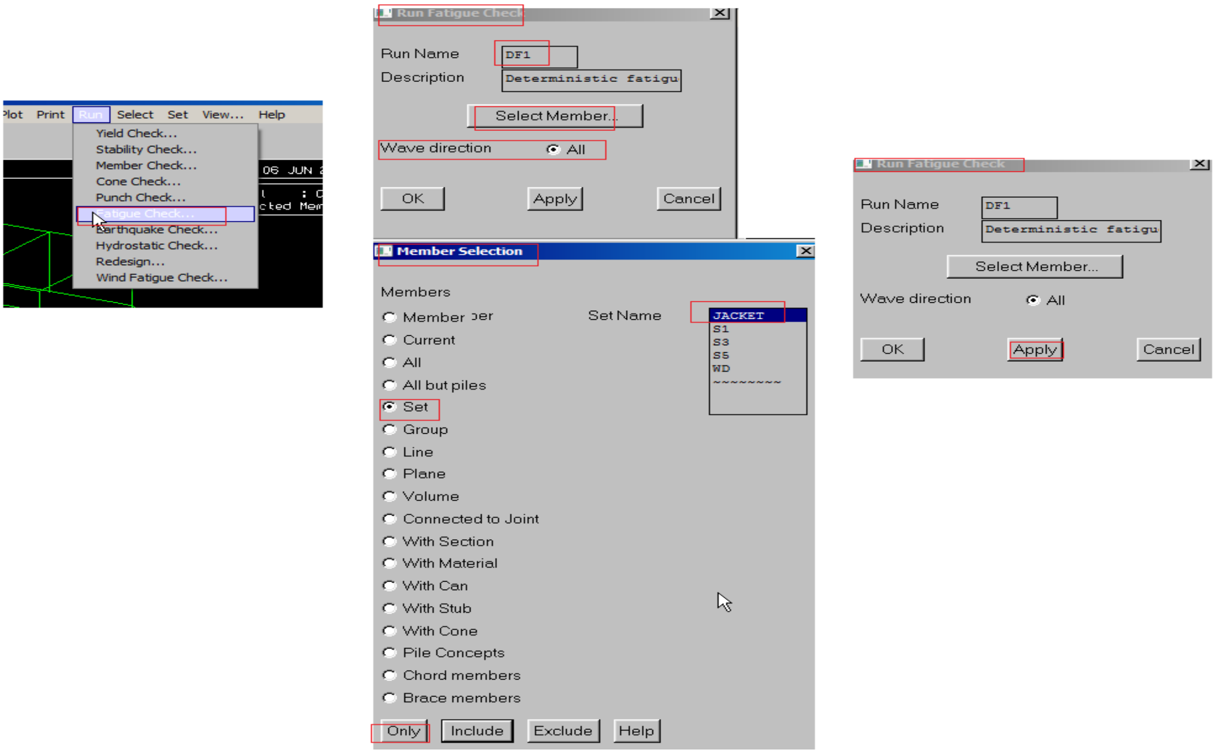
○ YT
○ X
○ K
○ KTT
○ KTK
○ Interpolate
○ Geometry
● Loadpath

Brace Member ALL

Gap
○ Gap
● Automatic
○ None

Figure D 5 Step 10 and 11 – Assign joint type and joint

Figure D 6 showing how to perform a fatigue analysis by selecting the final inputs for making run.



Run Name DF1
Description Deterministic fatigu
Wave direction ● All

Members
○ Member ber
○ Current
○ All
○ All but piles
● Set
○ Group
○ Line
○ Plane
○ Volume
○ Connected to Joint
○ With Section
○ With Material
○ With Can
○ With Stub
○ With Cone
○ Pile Concepts
○ Chord members
○ Brace members

Set Name
JACKET
S1
S3
S5
WD
~~~~~~~~

Figure D 6 Step 12 and 13 – Select members for fatigue analysis and run analysis
~~~~~~~~

Figure D 7 shows the maximum usage factors between 0.1 and 1.0 on the jacket structure analyzed with design fatigue factor of 3.0 on the whole jacket.

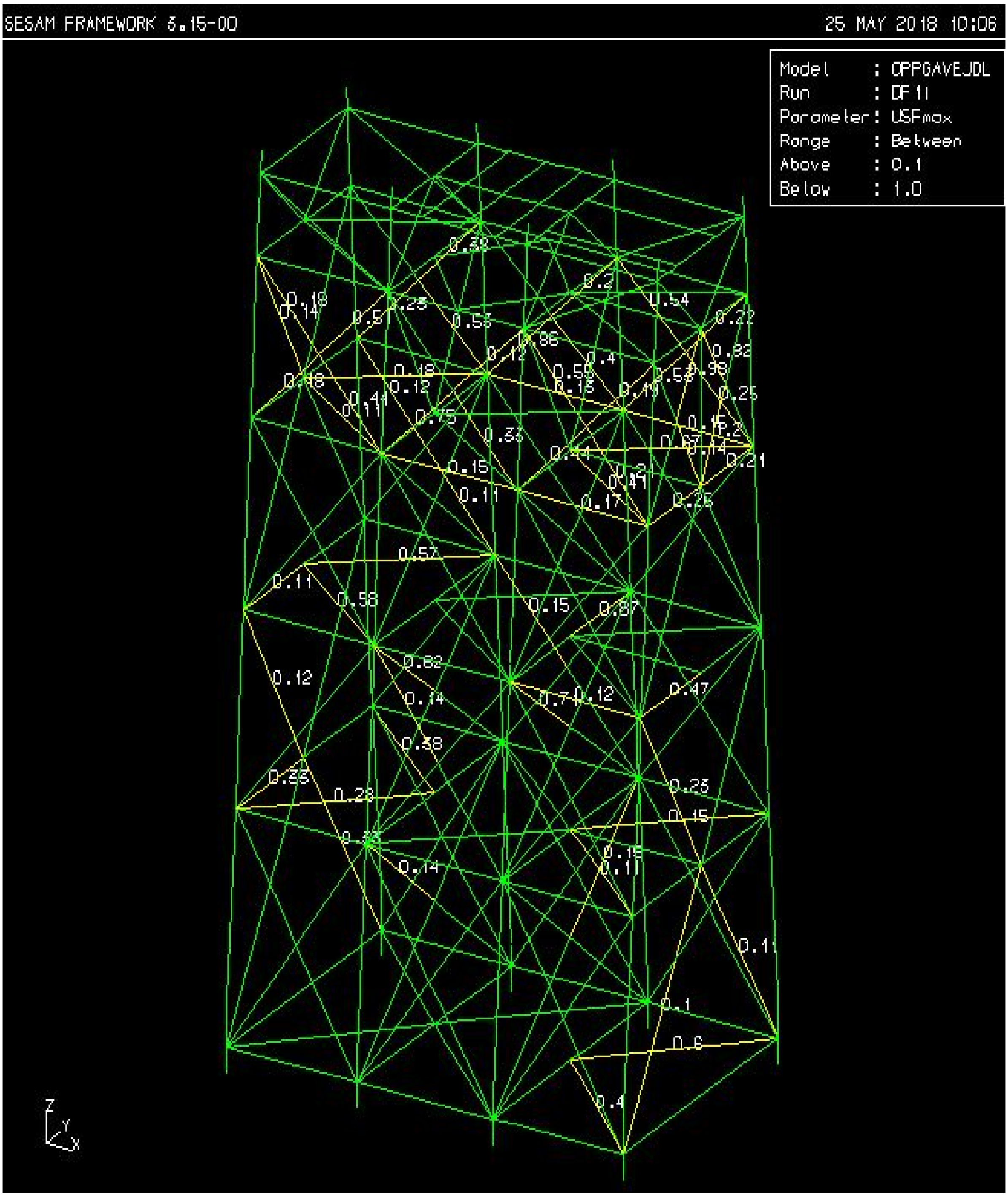
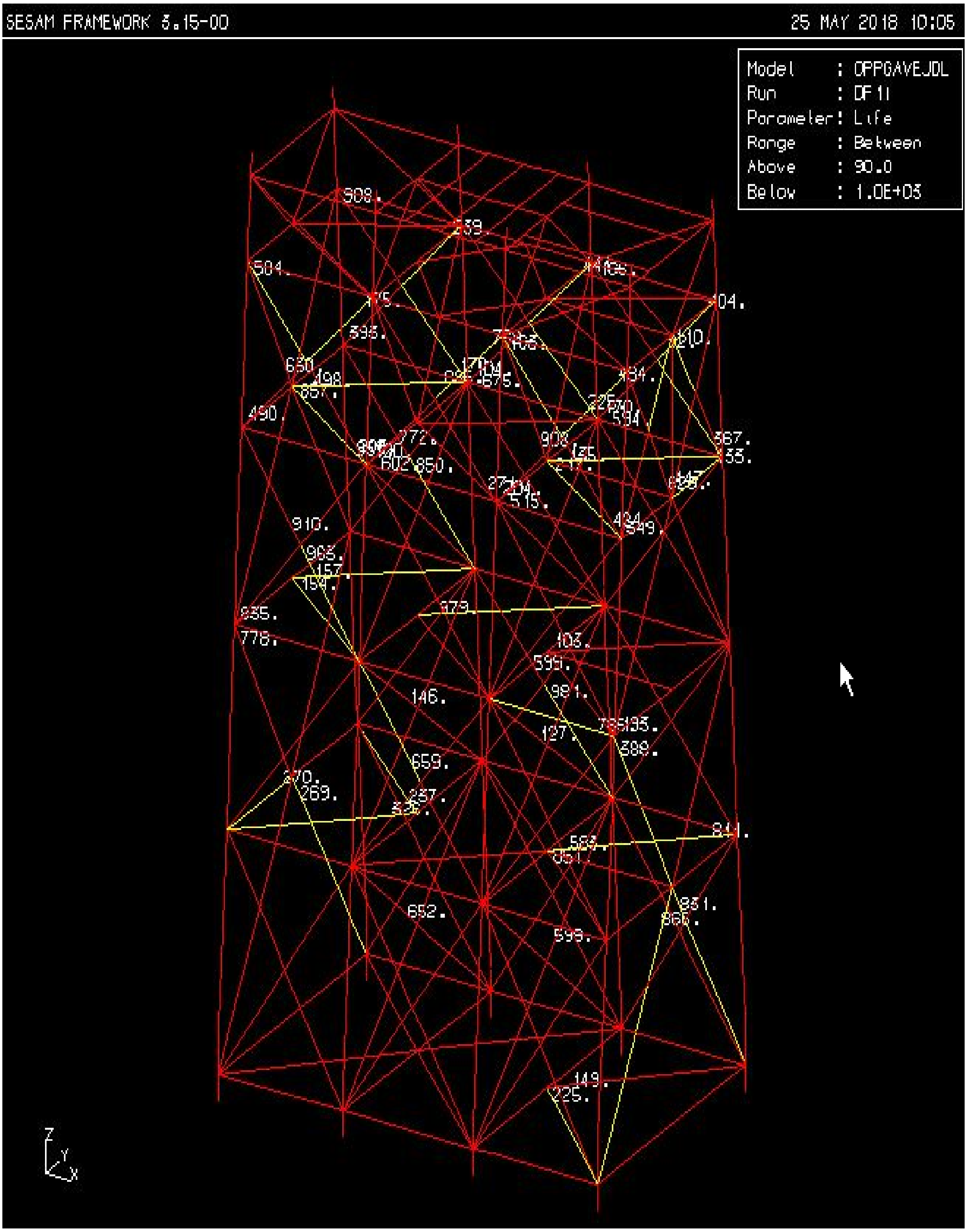


Figure D 7 Fatigue check for jacket structure utilization with Buoyancy

Figure D 8 shows the fatigue lives between 90 and 1000.Other members without the numerical are having a fatigue life above 1000.



SESAM FRAMEWORK 5.15-00

25 MAY 2018 10:05

Model : OPPGAVEJDL
Run : DF 11
Parameter : Life
Range : Between
Above : 90.0
Below : 1.0E+03

Figure D 8 Fatigue life of beams with Buoyancy ON and DFF -3

Figure D 9 shows the maximum usage factors between 0.7 and 4.0 on the jacket structure analyzed with design fatigue factor of 10.0 on the members between elevations +9.0m and -15m.The splash zone is between +7m and -4m.

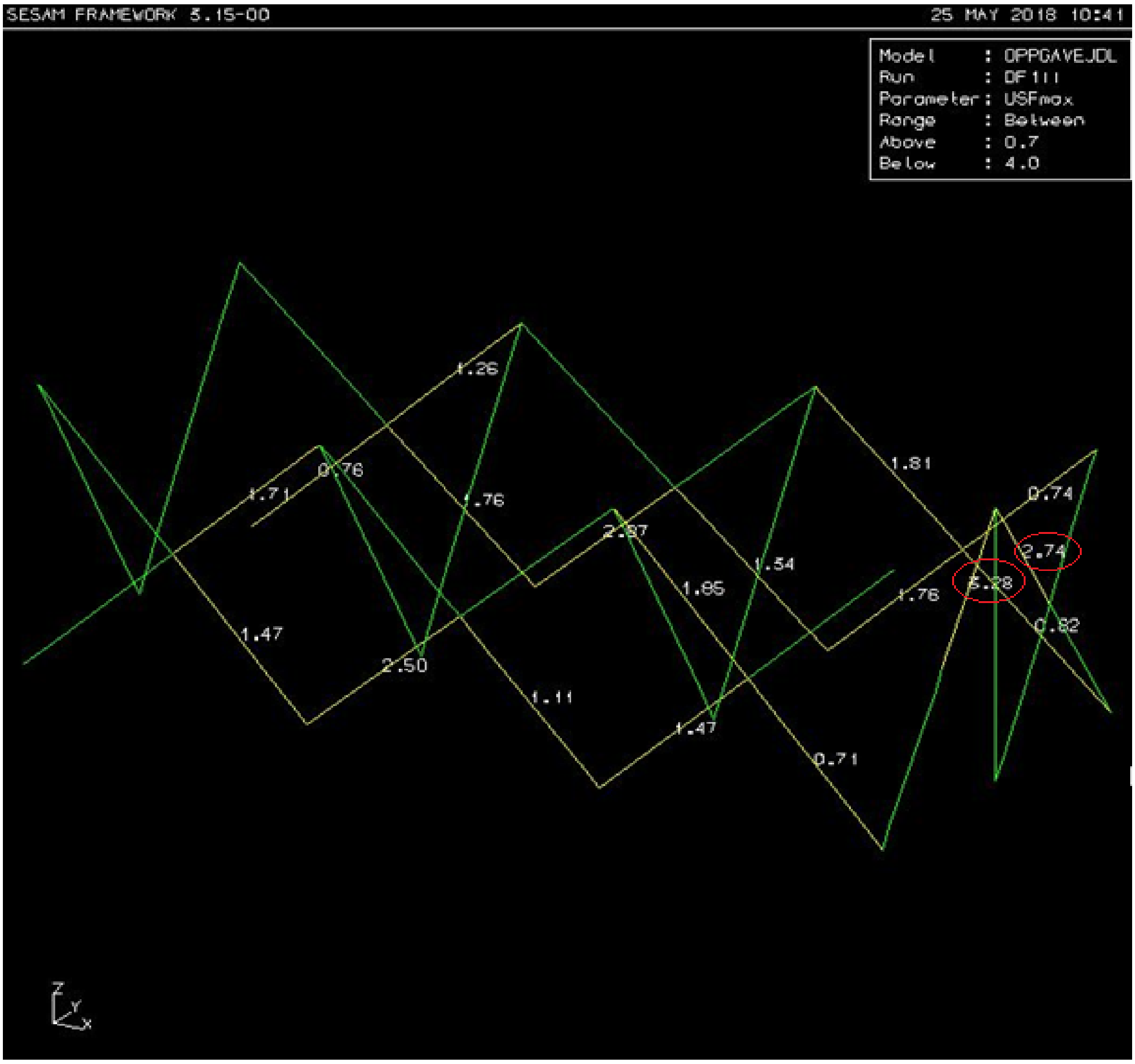
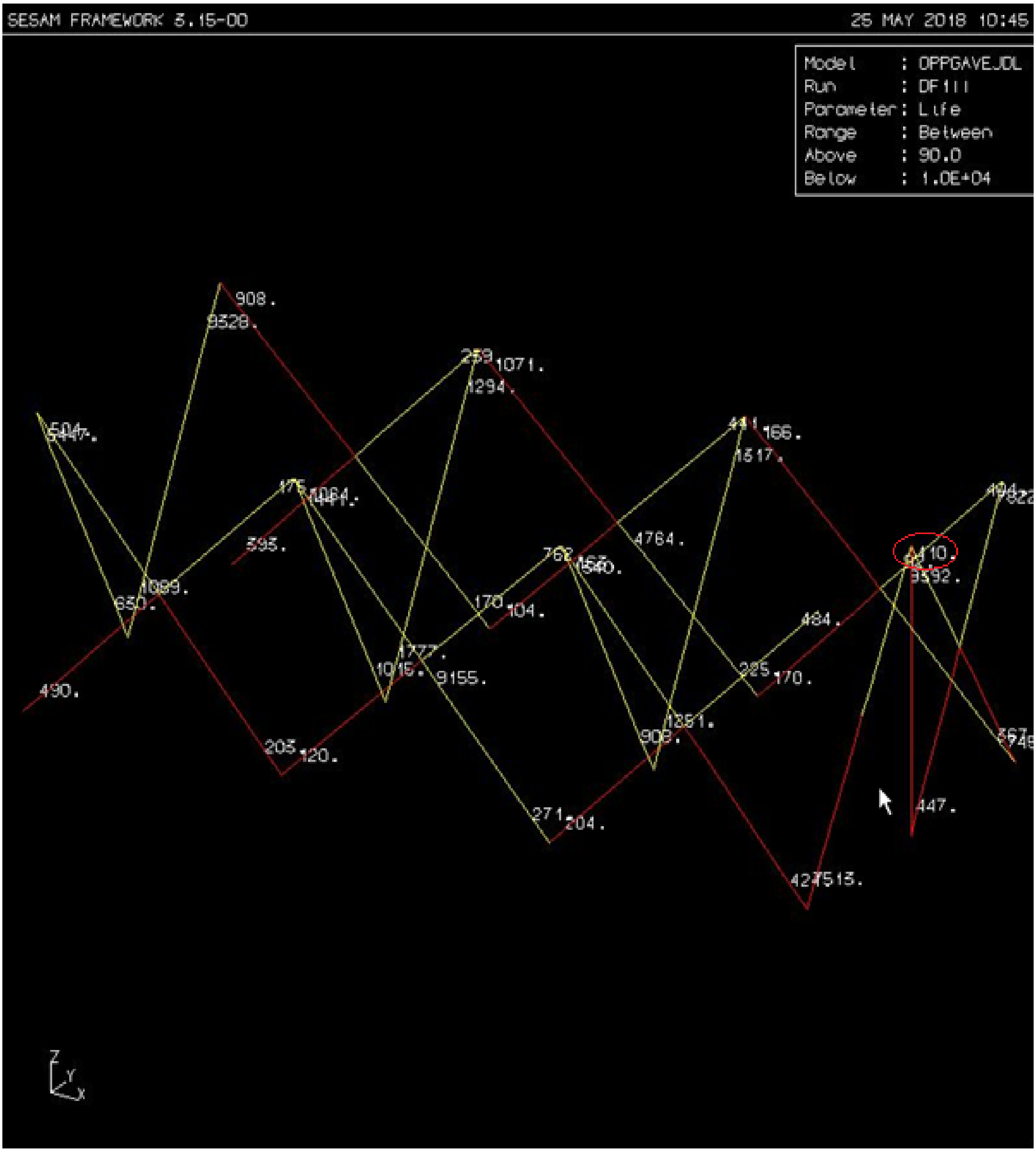


Figure D 9 Fatigue check for beams in splash zone with Buoyancy ON and DFF -10

Figure D 10 shows Fatigue life between 90 to 10000 years on the jacket members in elevation +9.0m and -15m analyzed with DFF 10. The splash zone is between +7m and -4m.



SESAM FRAMEWORK 3.15-00 25 MAY 2018 10:45

Model : OPPGAVEJDL
Run : DF111
Parameter : Life
Range : Between
Above : 90.0
Below : 1.0E+04

Figure D 10 Fatigue life of beams in splash zone with Buoyancy ON and DFF -10