SYSTEM F & G - LATERAL BUCKLING MITIGATION SYSTEM DESIGN REPORT

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1 General

1.1 Purpose

The purpose of this document is to present the results of the structural analyses of the Flowlines Lateral Buckling Mitigation System (LBMS).

Structural verifications are performed for the following conditions:

- Transportation on cargo barge
- Lifting in air / lowering in water
- Splash zone slamming impact
- Immediate retrieval
- In-place
- Flowline impact
- Ballast impact and ROV Snagging
- Details verifications
- Instigation system verification

The structural analyses have been performed using SACS ^{TM} Ref [32].

All analysis are performed according to the design data and methodologies presented in the Lateral Buckling Mitigation Device Structural Design Premises Ref [15].

1.2 Field of application

The EGINA field, discovered in 2003, is situated offshore Nigeria within the Oil Mining Lease OML-130, some 200km from Port Harcourt in a water depth ranging from 1150m to 1750m (see Figure 1-1).

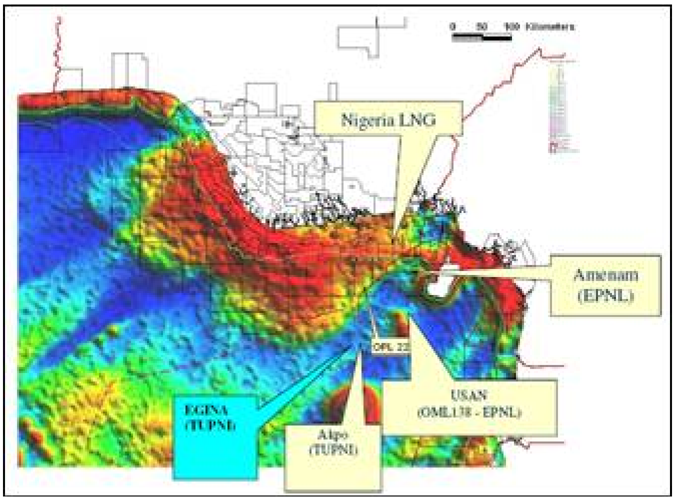


Figure 1-1 : Location of EGINA Field (OML-130)

As part of what is known as the greater EGINA area, two other fields EGINA South and PREOWEI which are situated 20 km and 25 km respectively from the EGINA MAIN field are planned for future developments. The current development will cover the EGINA MAIN field. The two other fields, EGINA South and PREOWEI will be developed as satellites of EGINA MAIN and will be tied back at the end of its plateau. The surface facilities are designed to take into account these future fields (see Figure 1-2).

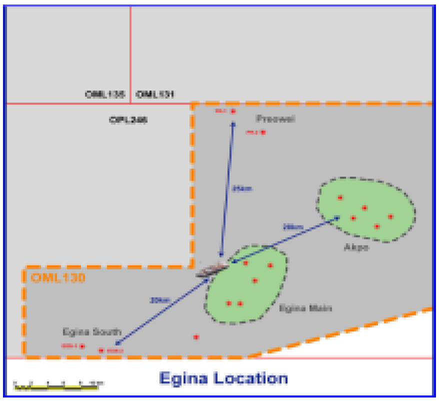


Figure 1-2 : PREOWEI and EGINA South Locations

The development of the EGINA field is based on subsea wells connected to a Floating Production, Storage & Offloading (FPSO) facility and stabilized crude oil export via oil tanker using an offloading buoy.

There is also a gas export pipeline from FPSO to the AKPO gas export pipeline tie-in point. The subsea layout of the EGINA MAIN field is shown below in Figure 1-3:

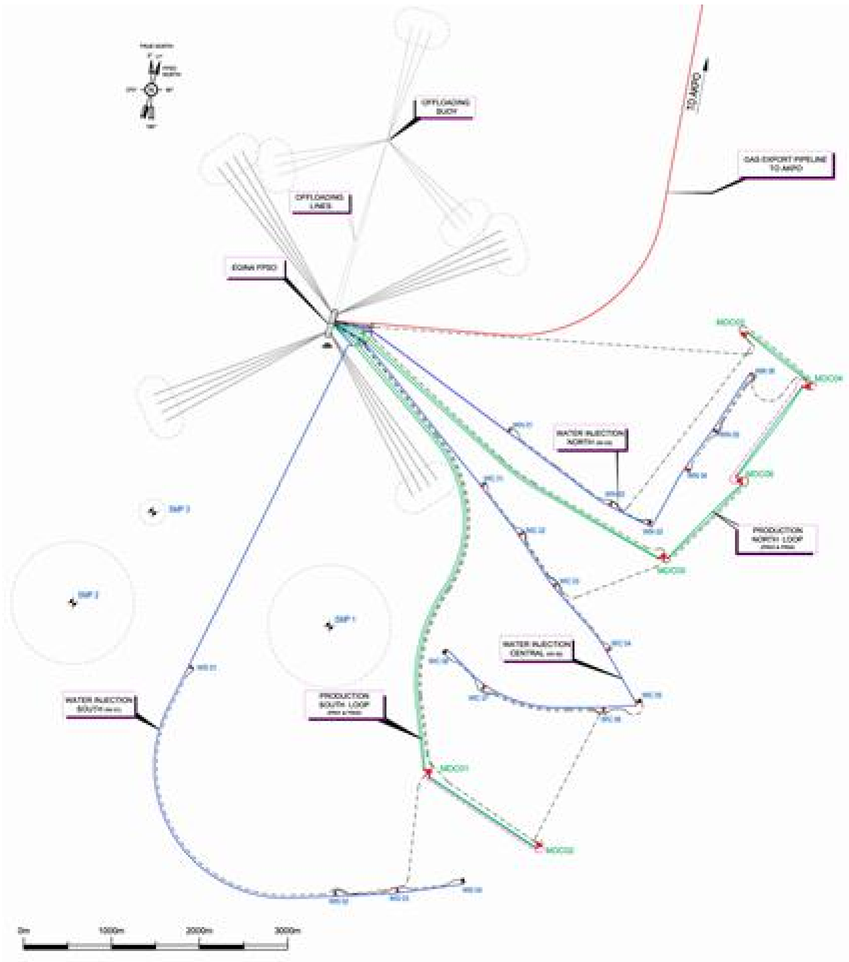


Figure 1-3 : Base Case Layout for EGINA MAIN

The Scope of Work for the Flowlines, Risers, Offloading Systems and Offshore Works (UFR) for the EGINA MAIN Field is as listed below:

- 2off production loops (of about 29 km) thermally wet insulated with flowlines, spools, FLETs. (Note: production manifolds and CRA production well jumpers are COMPANY provided items to be installed);
- 3off water injection lines (of about 23 km) with flowlines, spools, well jumpers, FLETs and ITAs;
- 1off gas export line (of about 20 km) with flowline, spools, FLETs, SIV and PLEM, and tied-in to AKPO export pipeline;
- 4off concentric offset risers for production and gas lift and relevant flexible jumpers;
- 3off water injection risers and relevant flexible jumpers;
- 1off gas export riser and relevant flexible jumpers;

- Installation of 4 main umbilicals and ancillaries for production and water injection wells and telecom link to pre-existing subsea optic fibre network;
- 1 secondary umbilical for GE SIV control and risers monitoring;
- LBL array;
- Oil Offloading Terminal, using an offloading buoy (COMPANY furnished with hoses and hawser) approximately 2 km NNE of FPSO and connected to FPSO via two 20.5-inch ID Oil Offloading lines.

FPSO mooring anchors and the installation of the COMPANY furnished FPSO mooring lines and its hook-up are also involved in the scope of work.

2 Introduction

The primary objectives of the LBMS are as follows:

- Control the pipe by managing the lateral friction factor so that it is as low as possible, thus reducing the level of curvature at the crown of the lateral buckle.
- Maximize the release in axial compression load at the lateral buckle site.
- Provide an out of straightness feature which causes lateral buckling of the flowline at a relative low axial compressive load.

The LBMS structure is composed of:

- A support coated beam (in contact with the flowline)
- A foundation (mudmat)
- A series of stiffeners that transfers the loads from the coated component to the foundation
- A buckling instigation device (clamp, buoy, etc.)

The lateral Buckling Mitigation System consists of a sleeper on which the flowline will be laid.

After the installation of the flowline on the sleeper and before operation, the flowline will be connected to an instigation system made of a clamp, a sling and a buoy, that will laterally pull the pipe along the sleeper to create the lateral imperfection necessary to induce lateral buckling of the flowline at this location.

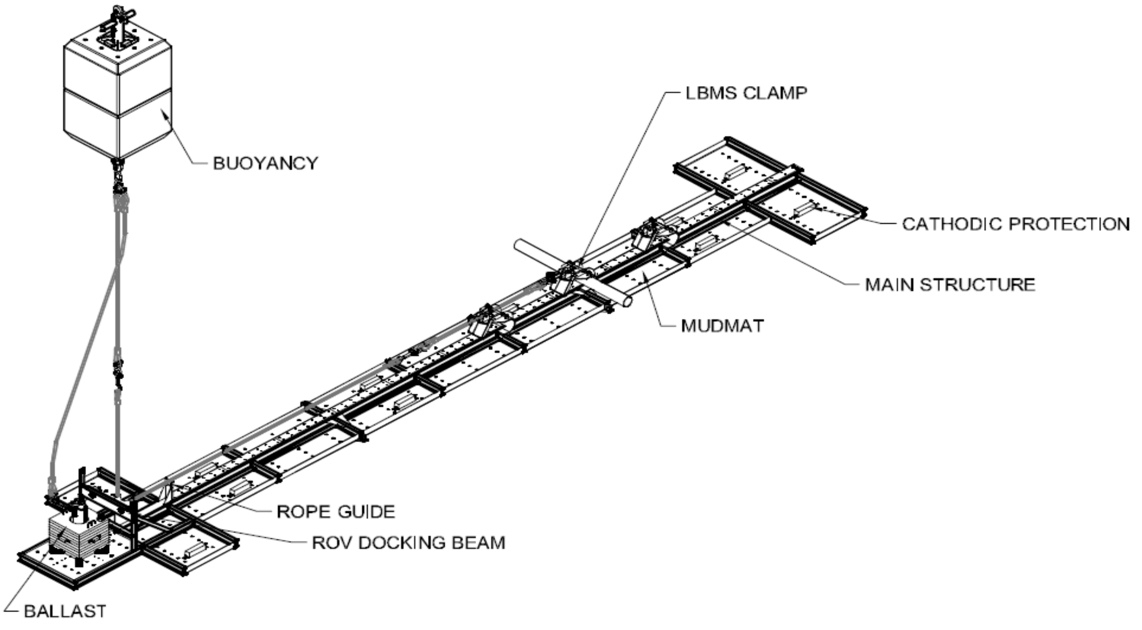


Figure 2-1: LBMS Typical Design.

LBMS are needed for production flowlines and water injection flowlines. Quantity of LBMS for each flowline will be indicated in the Lateral Buckling Report Ref [22]. Same design of the LBMS will be considered for the production and water injection flowline.

3 Summary and Conclusion

3.1 Summary

This report presents the analyses results for the LBMS performed to determine the adequacy of the engineered structure to sustain the different imposed loads through the phases of transportation, lifting in air, lowering in water, retrieval and the operational in place condition analyses.

The structural framing of the LBMS are verified for the conformation with the design requirements of the applicable clauses of API RP 2A Ref. [28] and/or AISC Ref. [26] as relevant.

The member strengths are verified from the standpoints of both buckling and yield.

3.2 Conclusion

Given the assumptions listed in this report and in LBMS Structural Design Premises Ref [15], the LBMS structure is designed to withstand lifting, transportation, installation and operating load conditions.

All unity check values are below unity, the design of the LBMS is therefore acceptable.

3.2.1 In Place Analysis

The results of the in place analysis show that all the member unity check are less than unity with a maximum UC of 0.39 on the UPE section under the ballast weight. Refer to section 10.3.2 for detailed results.

3.2.2 Lifting and Lowering Analysis

The results for the Lift and Lowering Analyses show that all the member unity check are below 1.0 with a maximum UC of 0.97 on the UPE framing members, during lowering analysis. Refer to section 11.3.4 and section 11.4.4 for more details.

3.2.3 Retrieval Analysis

The results of the retrieval show that all the member unity check are below 1 with a maximum UC of 0.77 on the UPE framing Member, during retrieval stage 1.Refer to section12.3.3 and section 12.4.3 for more details.

3.2.4 Transportation Analysis

The results of the transportation analyses show that all the member unity check are below 1 with a maximum UC of 0.43 on the UPE transverse Member. Refer to section 9.5.5 for more details.

3.2.5 Instigation Device Design Check

3.2.5.1 Clamp Design

Two clamps have been designed, one to fit the production flowline external OD (including coating) and another one to fit the water injection flowline.

The clamps are conservatively designed for the maximum buoy pull force while assuming that the flowline is rigid. The result summary is presented in Table 3-1 and Table 3-2.

Clamp UCR – Check	Water Injection	Production Clamp
Max Membrane Stress	0.47	0.57
Max Membrane + bending Stress	0.73	**0.83**
Fillet Weld Check	0.38	
Lifting/Lowering Analysis		
Max Membrane Stress	0.03	0.05
Max Membrane + bending Stress	0.08	0.08

Table 3-1: Clamp Check Summary.

Clamp Round Bar – UCR Check	Shear Stress	Bending Stress
Buoyancy Round Bar Check	0.46	0.66
Bottom Round Bar Check	0.12	0.47
Installation Round bar Check	0.26	0.55

Table 3-2: Clamp Round Bar Check Summary.

The Max unity check ratio for the Clamp check is less than unity; hence the clamp is fit for purpose. Refer to ANNEX3: CLAMP DESIGN for detailed results.

3.2.5.2 Ballast Design

The ballast was designed to withstand its own weight and the ballast plate's weight. The guide tube is designed to withstand an impact of the ballast plates during their installation on the ballast structure.

Ballast Structure	
IPE 220	**0.76**
Ø273.05x19.05mm	0.09
Joint Check	0.18
Pin Guide Check -	
Ø88.9x5.49mm	0.59
Connection to support	0.64
Padeye check	
Eye Check	0.65
Main Plate	0.23
Connection to support pipe	0.21

Table 3-3: Ballast Check Summary.

Refer to ANNEX5: BALLAST DESIGN for detailed results.

3.2.6 Local Checks

3.2.6.1 Lifting Padeye Design

The maximum loading of the padeyes is during retrieval phase. The padeyes are shown to be able to withstand these loads. The result summary is presented in Table 3-4.

Lifting Padeye check		**UCR**
Padeye Check	Shear hole check	0.11
	Diametral bearing check	0.15
	Hertz pressure check	**0.47**
Main Plate Check	Shear Stress	0.37
	Axial Stress	0.03
	Bending Stress Check Out of plane	0.21
	Bending Stress Check in- plane	0.14

	Combined Bending Stress Check	0.38
Cheek Plate weld check	Shear Stress	0.11
Main Plate and Bracket Fillet Weld Check	Shear Stress	0.39

Table 3-4: Padeye Check Summary.

Refer to the ANNEX4: LIFTING PADEYE DESIGN for detailed results.

3.2.6.2 Rope Guide Check

The rope guide is conservatively designed for the maximum buoy pull force neglecting frictional dissipations. The summary of the results for the various checks performed are presented in Table 3-5.

Stress		**UCR**
20 mm thk support plate	Membrane	0.22
	Membrane + bending	0.22
Ø168.3 mm× 12.7 mm thk rope guide tube	Membrane	0.10
	Membrane + bending	**0.41**
Double fillet weld stress		0.14

Table 3-5: Rope Guide Verification Results Summary

Refer to ANNEX6: ROPE GUIDE DESIGN for detailed results.

3.2.6.3 Mudmat Analysis

The mudmat plates have been designed to withstand slamming and bearing forces. The table below details the UCR for all plates checked using Roark's Formulas for Stresses and Strains.

Plate Dimension	**Slamming**		**Bearing**	
	UCR	**Type of calculation**	**UCR**	**Type of calculation**
900×1400	**0.80**	Large displacement	0.47	Large displacement
3000×750	0.59	Large displacement	0.36	Small displacement
2850×750	0.59	Large displacement	0.36	Small displacement
1150×850	0.65	Large displacement	0.39	Small displacement

Table 3-6: Mudmat Plates Analysis Summary

Plate Dimension	Lw/L UCR
900×1400	**0.10**
3000×750	0.09
2850×750	0.09
1150×850	0.09

Table 3-7: Fillet weld Check Summary

Analysis	UCR
Bending	**0.83**
Shear	0.14
Fillet Weld	0.02

Table 3-8: Stiffener Check Summary

Refer to ANNEX7: MUDMAT ANALYSIS for detailed results.

3.2.6.4 Flowline Impact Analysis

The member UCR for the LBMS HEB400 beam and Coating is presented in the table below:

Design case	UCR
Bending	0.82
Shear	**0.97**
UHMW	0.21

Table 3-9: Results summary

Refer to ANNEX8: FLOWLINE IMPACT for detailed results.

3.2.6.5 Snagging Analysis

The table below summarises the results obtained for the impact on the ROV docking beam:

Impact	UCR
Middle (UPN 300)	**0.88**
Side (UPN 300 and docking beam connection)	0.29

Table 3-10: Snagging Impact analyses Summary.

Refer to ANNEX9: BALLAST IMPACT AND ROV SNAGGING for detailed results.

4 Definitions and Abbreviations

4.1 Definitions

COMPANY TOTAL Upstream Nigeria Limited.(TUPNL)

CONTRACTOR Consortium comprising Saipem Contracting Nigeria Limited (SCNL) as Consortium leader, Saipem sa (SAIPEM), Saipem (Portugal) Comércio Marítimo, Sociedade Unipessoal, Lda. (SPCM) and Allied Dominion Oilfield Shipping Services Limited (ADOSS)

4.2 Abbreviations

AISC	American Institute of Steel Construction
API	American Petroleum Institute
ASD	Allowable Stress Design
BC	Boundary Conditions
CoG	Centre of Gravity
DAF	Dynamic Amplification Factor
FEA	Finite element Analysis
FLET	Flowline End Termination
FPSO	Floating Production Storage and Offloading
GS	General Specifications
LBMS	Lateral Buckling Mitigation System
ROV	Remotely Operated Vehicle
SMTS	Specified Minimum Tensile Stress
SMYS	Specified Minimum Yield Stress
SZDC	Splash Zone Down Crossing
TBC	To Be Confirmed
THK	Thickness
UC	Unity Check
UCR	Unity Check Ratio
UHMW	Ultra High Molecular Weight (Polyethylene)
WSD	Working Stress design
WT	Wall Thickness

4.3 S.I Units

SI units has been used for the design of the LBMS.

5 References

In all reference documentation in the sections that follow, unless specifically noted otherwise, the latest revision status of the document shall be the applicable version.

In the event of conflicts between various documents, the following order of precedence shall apply:

5.1 Addendum

Ref	Document No	Document Title	Rev
1.	NG-EGN-20-AEEC-000001	EGINA UFR PACKAGE EGI/133 ADDENDUM TO DESIGN DOSSIER	01

5.2 Project Particular Specifications

No.	Document Number	Designation	Rev
2.	NG-EGN-OF-PENG-000007	Meteocean design data specification	01
3.	NG-EGN-UA-VENG-371046	Flowlines functional specification	09
4.	NG-EGN-SO-VENG-377138	ROV Tooling Design Specification	05
5.	NG-EGN-VA-VENG-371047	FLET and ITAs Functional Specification	05

5.3 COMPANY General Specifications

No.	Document Number	Designation	Rev
6.	GS-EP-STR-001	Weight monitoring and weighing offshore units	07
7.	GS-EP-STR-103	Design and fabrication of Skids and equipment supporting structure	06
8.	GS-EP-STR 100	Offshore Steel Structures (General)	07
9.	GS-EP-STR 401	Loadout, sea fastening, transportation and installation of offshore structures	06
10.	GS-EP-STR 404	Marine aspects for load-out, transportation and installation of offshore structures	03
11.	GS-EP-STR-101	Design of offshore jacket and subsea structures	07
12.	GS-EP-STR 201	Materials for offshore steel structures	06
13.	GS-EP-STR-301	Fabrication of steel structures	04

5.4 CONTRACTOR Reference Documents

No.	Document Number	Designation
14.	NG-EGN-21-SAEC-160010	Systems F & G - Design Basis
15.	NG-EGN-21-SAEC-160080	System F - LBMS structural design premises
16.	NG-EGN-21-SAEC-140090	Systems F & G - Flowline Geotechnical Design Basis
17.	NG-EGN-21-SAEC-602700	Systems F & G - LBMS Installation Procedure
18.	NG-EGN-21-SAEC-602710	System F & G - LBMS Instigation device installation - Procedure
19.	NG-EGN-20-SAEC-620030	All Systems - Transportation analysis Design Premises
20.	NG-EGN-20-SAEC-130040	All Systems – Cathodic Protection Philosophy
21.	NG-EGN-20-SAEC-210111	All Systems - Project Painting Specification
22.	NG-EGN-21-SAEC-101270	System F & G Flowlines Lateral Buckling Report
23.	NG-EGN-21-SAEC-140750	System F & G LBMS Geotechnical design report
24.	NG-EGN-21-SAEC-193560	System F – LBMS – Drawing List

5.5 Codes and Standard Documentation

No.	Designation	Description	Edition
25.	DNV-OS-C201	Structural Design of Offshore Units (WSD METHOD)	2007
26.	AISC Allowable stress Design (ASD)	American Institute of Steel Construction Manual 13th Edition	2005
27.	AISC Allowable stress Design (ASD)	American Institute of Steel Construction Manual 9th Edition	1989
28.	API RP 2A WSD	Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms—Working Stress Design completed with Errata, supplement 1, 2 and 3	2007
29.	DNV RP H103	Modeling and analysis of marine operations	2011
30.	DNV - 158	DNV Rules for planning and execution of marine operations. Part 2 Chapter 5 - Lifting	1996
31.	DNV RP C204	Design against Accidental loads	2010

5.6 Software

No.	Designation	Description
32.	SACS 5.3 V 8i	Structural Analysis Computer System, Bentley Systems Inc.,USA
33.	ABAQUS V 6.12	Proprietary Finite Element Analysis Software marketed by SIMULIA, Dassault Systems, S.A

6 Design Data

The salient design data as noted in the LBMS – Design Premises document, Ref [15], are included in this section, for reference.

6.1 Main dimensions

The minimal length needed is based on a pipeline corridor of 6m (+/- 3m) and a maximum lateral buckling deflection of 9m.In addition to this there are two clearance areas of 3m on both sides reaching 21 m as shown in the Figure 6-1 below.

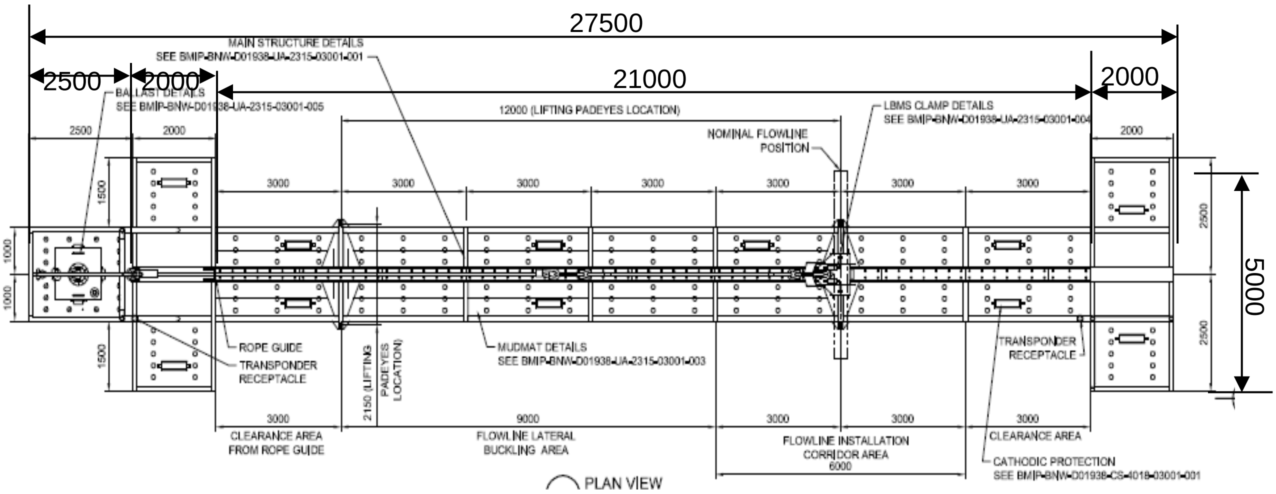


Figure 6-1: LBMS General Arrangement.

The total height of the LBMS structure is 450 mm as shown in Figure 6-2 below:

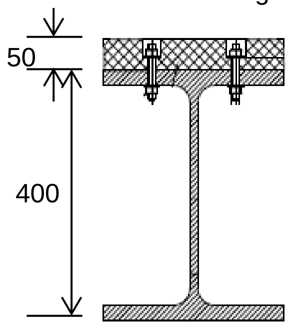


Figure 6-2: LBMS Side View showing height.

6.2 Materials

All structural steel components are made of S355 steel with design properties stated below, as per Ref [15].

Young's modulus	E	=	207000 N/mm^2
Shear modulus	G	=	78000 N/mm^2 $G = \frac{E}{2(1+v)}$
Density	d	=	7850 kg/m^3

Poisson ratio v = 0.3
Seawater density ρ = 1025 kg/m^3

Mechanical properties are in accordance with the values specified in the Table 6-1 below.

Steel Grade	Minimum Yield Strength , YS (N/mm^2)						Minimum Tensile Strength, TS (N/mm^2)	
	Nominal thickness (mm)							
	≤16	>16 ≤40	>40 ≤63	>63 ≤80	>80 ≤100	>100 ≤150	≤100	>100 ≤150
S 355	355	345	335	325	315	295	470-630	460-620

Table 6-1: Steel grade and its variation with thickness.

UHMW mechanical properties are the following:

Young Modulus: 700 MPa

Density: 950 kg/m3

Poisson's ratio: v = 0.46

xLPP/ UHMW friction coefficient: 0.2 to 0.4

Sling Material Properties:

Young's Modulus = 35000 N/mm^2
Density = 0.001 Ton/m^3
Shear Modulus = 13650 N/mm^2

6.3 Design life

The design life of the LBMS system is 25 years operating life + 1 year Standby in line with the life of the flowline as reported in the Design Basis Ref [14].

6.4 Environmental data

The main data are reported in the Table 6-2 below as per Ref [2]:

Data	Design Value
Minimum Seawater Temperature	4 degrees (^{o}C)
Water Depth	1480 m to1610 m
Seawater Density	1025Kg/m^3

Table 6-2: Environmental Data.

6.5 Soil data

The soil data to be used for the design of the LBMS foundation is presented in the LBMS Geotechnical Design Report Ref [23].

The soil behavior is modeled as a series of linear springs attached to the foundations. The global stiffness values considered are listed in the Table 6-3 below:

Stiffness	Lower Bound (kN/m)
Lateral global stiffness (X-Axis)	865
Transversal global stiffness (Y-Axis)	865
Vertical global stiffness (Z-Axis)	5990

Table 6-3: Soil Global Stiffness.

During the retrieval case, the retrieval force considered is 145KN as reported in the Geotechnical Design Report Ref [23].

6.6 Flowline Loading

The flowline loads and instigation device loads to be used for the design of the LBMS are presented in the Lateral Buckling Report Ref [22].

For this analysis the In-Place loading has been considered as:

- Flowline Vertical Load on the Sleeper = 12.7 T

Considering conservatively a friction factor of 0.4

- Flowline Horizontal load (due to friction on the frame) = 12.7 x 0.4 = 5.09T

As shown in Table 6-4 below:

Force (F_1,F_2,…F_6)	Value (KN)
Fx (axial load)	50
Fz (vertical load)	125

Table 6-4: Loads acting on LBMS- In-Place Condition.

Buoy Pulling Force = 5 T

Ballast weight in water = 6.7 T

Ballast is used to avoid uplift of the LBMS framing Structure during In-Place condition.

Refer to Figure 10-2 for position of load application.

7 Design Methodology and Criteria

The engineering design verifications of the LBMS structure have been performed to the design data and methodologies presented within the lateral buckling mitigation devices structural design premises Ref [15].

7.1 Design Analyses Software

The design analysis software for the global analysis of the LBMS shall be SACS TM .The proprietary software developed by EDI Inc. Ref [32] and ABAQUS Ref [33] for local checks.

7.2 Design Codes and Standards

The structural strength and stability assessment of the LBMS shall conform to the requirements of AISC-ASD Ref [26] and API RP 2A-WSD Ref [28] as applicable.

Section Type	Loading	Allowable Stress
Cylindrical / Tubular	Axial Tension	0.60 σ_{ys}
	Axial Compression	Slenderness dependent
	Shear	0.40 σ_{ys}
	Bending (D/t dependent)	0.75 σ_{ys}
Non-Tubular and Rolled	Axial Tension	0.60 σ_{ys}
	Axial Compression	Slenderness dependent
	Shear	0.40 σ_{ys}
	Bending in Plane	0.66 σ_{ys}
	Bending Out of Plane	0.75 σ_{ys}

Table 7-1: API/AISC Design Allowable Stresses

All Finite Element based analysis shall conform to requirements of AISC-ASD Ref [26] and API RP 2A-WSD Ref [28].

The equivalent stresses shall not exceed the maximum allowable stresses as given below:

- Membrane stress $\boldsymbol{\sigma_m = 0.67 \times F_Y}$
- Membrane +Bending $\boldsymbol{\sigma_{m+b} = 0.67 \times F_Y}$

$\mathrm{F}_Y = \text{Material Yield Strength.}$

The unity check ratios are computed by dividing the stress obtained by the associated allowable stress and should always be less than one: $Stress\ Ratio = \dfrac{\sigma_{obtained}}{\sigma_{allowable}} < 1$

7.3 Allowable Stress Modification

No increase in basic allowable stresses has been applied in the structural verification of the LBMS structure.

8 Model Description

8.1 Structure Model

The LBMS structure has been analyzed for the sustained preliminary loading during the lifting, lowering, retrieval and in- service operating conditions.

The framing members of the LBMS are configured using HEB 400, HEB 300, and UPE 300 open sections.

Plate stiffness is conservatively not accounted for in SACS model, only its density is considered to account for its weight in the global model.
Figure 8-1 below details the LBMS as modelled using SACS ™ software. The framing member descriptions are presented in ANNEX1: LBMS FRAMING.

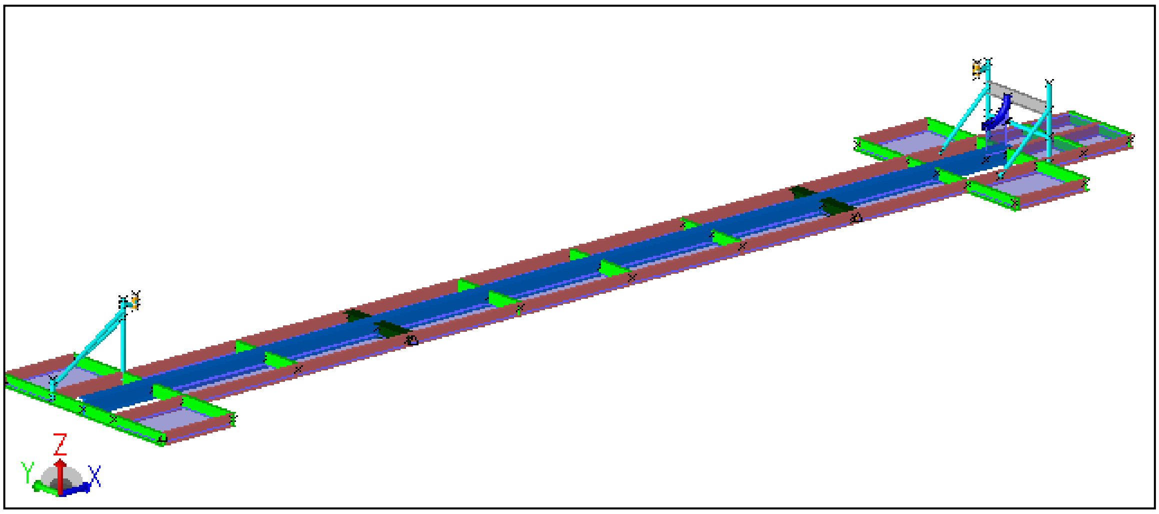


Figure 8-1: LBMS Model Beam Section Detail.

Colour	Group Label	Designation
	BM1	HEB 400
	BM3	UPE300
	BM4	
	BM5	HEB 300
	T01	Ø101.6mm × 8.08mm
	T02	Ø 141.3mm × 12.7mm
	T03	Ø 168.3mm × 12.7mm
	U01	UPN 300
	P01	Plate 6 mm thk

Table 8-1: Member group labelling and dimensions.

It will be shown in this report that the framing members selected for the LBMS structure are capable of sustaining the most probable and onerous load combinations of the imposed loads and satisfying fully the requirements of API RP-2A Ref [28] and or AISC Ref [26] as relevant.

8.2 LBMS Global Coordinate System

The global coordinate system for the LBMS is defined as follows:

- X is along the LBMS axis
- Y is along the flowline axis
- Z is vertical

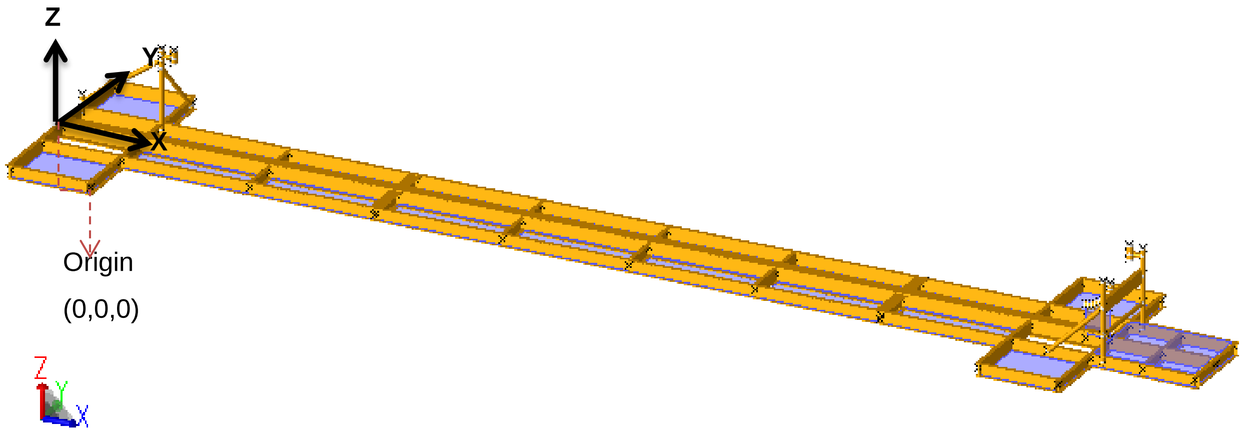


Figure 8-2: LBMS Structure Global Coordinate System

8.3 COG and weight Estimates

Table 8-2 below summarizes the weight, CoG and COB of the LBMS as modelled.

LBMS	COGX	COGY	COGZ	Weight (GRVZ)
LBMS in air	13.897	0.014	0.014	12.79T
LBMS in water	13.923	0.014	0.014	11.12T

Table 8-2: CoG, COB and weight Estimates of Modelled Structure Using SACS™.

8.4 Sling Modeling Properties

The slings are modelled as Prismatic members with relevant cross-sectional area but with notional magnitudes to represent the second moment of area about X, Y, Z axes, typically Ixx=Iyy=Izz=10 cm^4.

8.5 Buckling Length

The buckling length assigned to the members is as defined in section 4.5 of the LBMS Design premise Ref [15].

9 Transportation Analysis

This section presents the detailed results of the global analysis performed on the LBMS during sea transportation. The frame members were checked in accordance with applicable clauses of API RP 2A WSD Ref. [28], AISC Ref. [26], COMPANY requirements GS EP STR 401 Ref. [9], and the methodologies described in the design premise Ref. [15].

Transportation is carried out from the fabrication yard to the installation site. Large cargo barge is considered with the LBMS conservatively positioned at the extreme of the barge deck as shown in Figure 9-1.

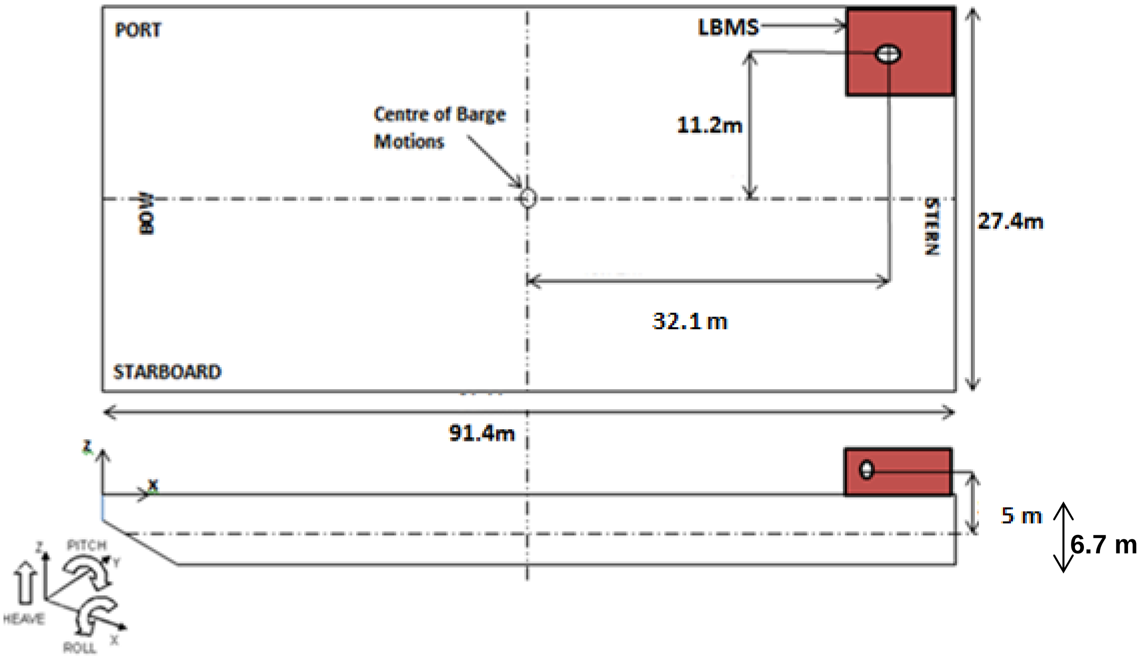


Figure 9-1: LBMS Position on Cargo Barge

9.1 LBMS – Cargo Barge Calculation

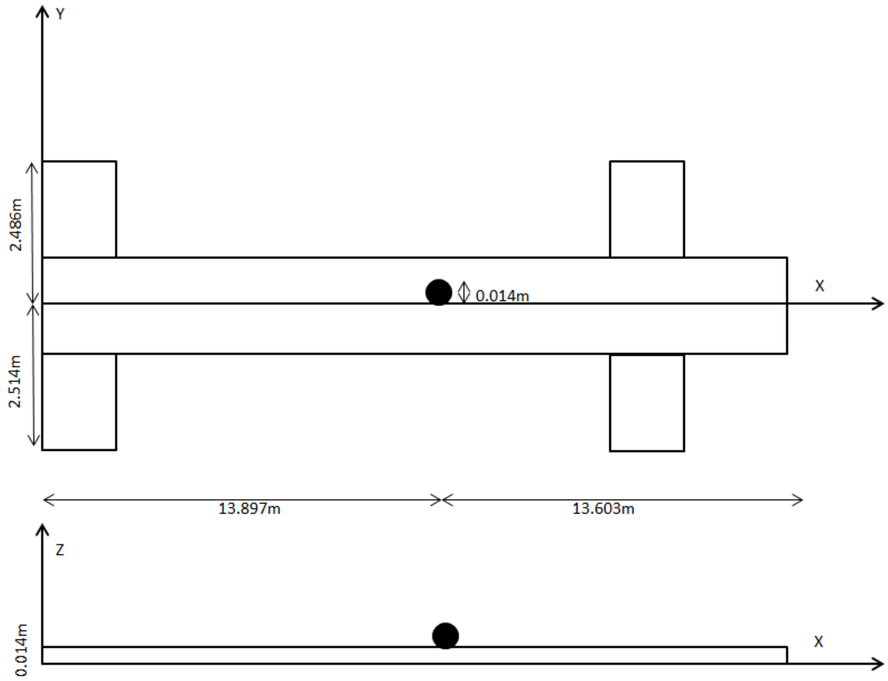


Figure 9-2: LBMS COG Position

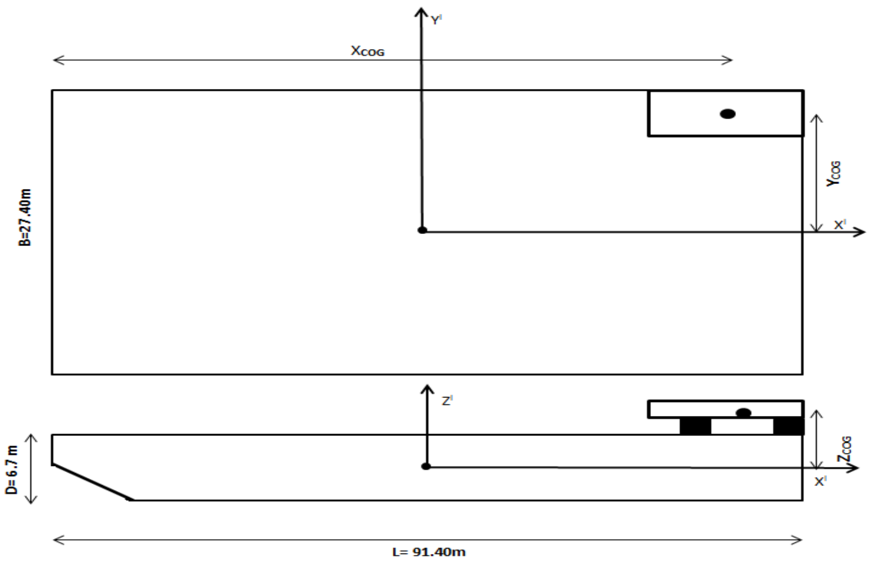


Figure 9-3: Barge Dimensions

9.2 Calculations

9.2.1 X_{COG} Calculation

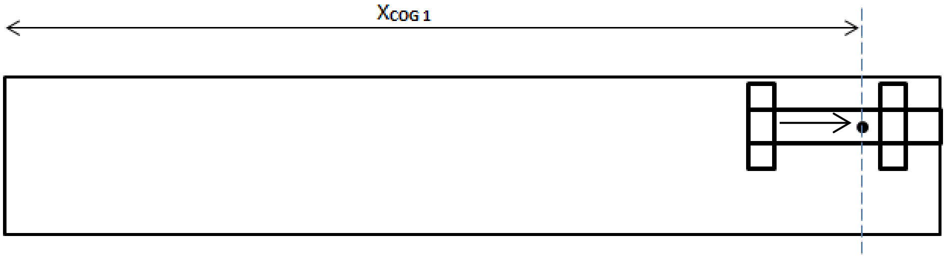


Figure 9-4: Case 1

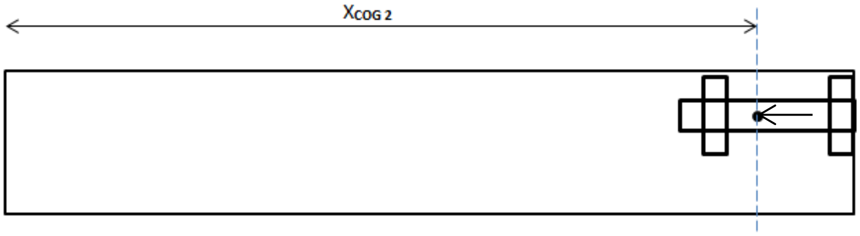


Figure 9-5: Case 2

X_{COG1} = 91.4-27.5+13.897=77.797 m

X_{COG2} =91.4-13.897= 77.503 m

9.2.2 Z_{COG} Calculation

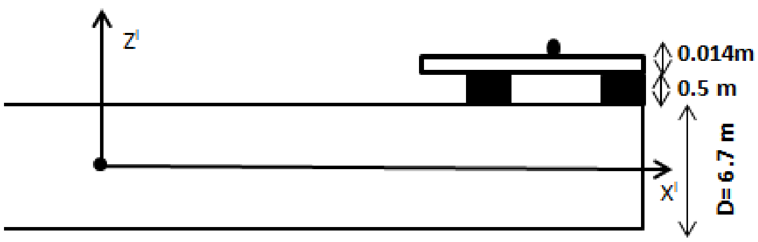


Figure 9-6: Z_{COG} Location

Z_{COG}=0.014+0.5=0.514 m

9.2.3 Y_{COG} Calculation

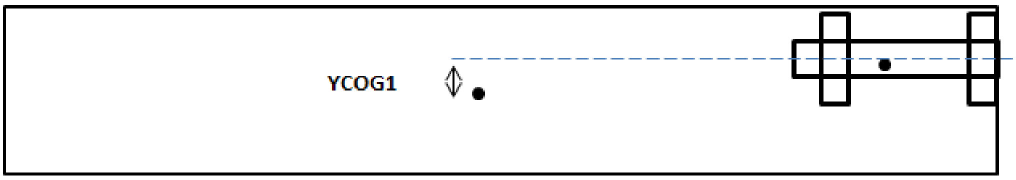


Figure 9-7: Case 1

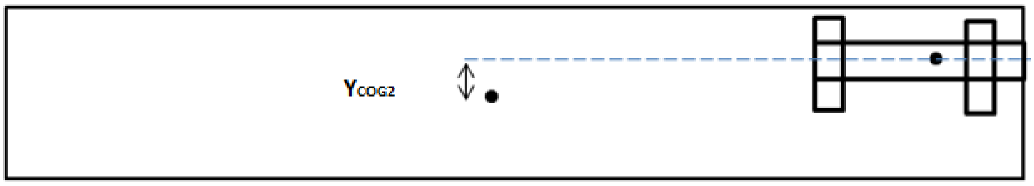


Figure 9-8: Case 2

Y_{COG1} = 27.4/2- 5.0/2- 0.014 =11.186 m

Y_{COG2} =27.4/2- 5.0/2+ 0.014 = 11.214 m

9.3 Boundary Conditions

The stability of the structure on the cargo barge is achieved by the restraining the structure vertically, longitudinally and laterally.

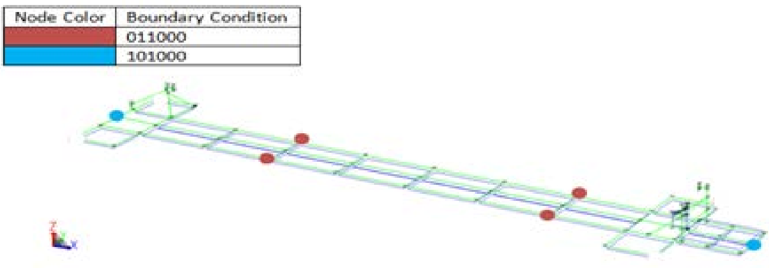


Figure 9-9: Transportation Analysis Boundary Condition.

9.4 Load Combinations

9.4.1 Load Factors

The load factors applicable to transportation analysis are given in Table 9-1

Analysis Type	Typical Members	Weight Contingency Factor
Sea Transport	All structural members	1.10×GRV
GRV is the self-weight of the structure		

Table 9-1: Transportation Analysis Load Factors

9.4.2 Barge Motion

Barge motion criteria presented in Table 9-2 and the acceleration combinations, Table 9-4 are based on the Noble Denton accelerations as mentioned in the design premise Ref [15].

Vessel Type	Single Amplitude			Heave
	Roll	Pitch	Period	
Large Cargo barges or vessels	20°	12.5°	10 sec	0.2g

Table 9-2: Barge Motion Criteria

Motion			
Roll	Pitch	Heave	Period
+/- 100%	0	+/- 100%	10 s
0	+/- 100%	+/- 100%	10 s
+/-80%	+/- 60%	+/- 100%	10 s
+/-60%	+/- 80%	+/- 100%	10 s

Table 9-3: Barge Accelerations Combinations

20% increase is conservatively added to the loads resulting from pitch motion to account for the slamming effect in line with GS EP STR 401.

The detailed manual calculations for the accelerations for each direction are provided in ANNEX10: BARGE MOTION ACCELERATION CALCULATION.

The summary of the load combinations are presented in Table 9-4.

Load Combination			Load Combination ID	Load Factor on SELX	Load Factor on SELY	Load Factor on SELZ
+Roll	-	+Heave	TR01	0	0.344	-0.909
+Roll	-	-Heave	TR02	0	0.480	-1.285
-Roll	-	+Heave	TR03	0	-0.344	-0.594
-Roll	-	-Heave	TR04	0	-0.480	-0.970
-	+Pitch	+Heave	TR05	-0.226	0	-0.443
-	+Pitch	-Heave	TR06	-0.312	0	-0.833
-	-Pitch	+Heave	TR07	0.226	0	-1.119
-	-Pitch	-Heave	TR08	0.312	0	-1.51
+80% Roll	+60% Pitch	+Heave	TR09	-0.132	0.277	-0.686
+80% Roll	+60% Pitch	-Heave	TR10	-0.182	0.387	-1.067
-80% Roll	+60% Pitch	+Heave	TR11	-0.132	-0.277	-0.433
-80% Roll	+60% Pitch	-Heave	TR12	-0.182	-0.387	-0.815
+80% Roll	-60% Pitch	+Heave	TR13	0.132	0.277	-1.091
+80% Roll	-60% Pitch	-Heave	TR14	0.182	0.387	-1.473
-80% Roll	-60% Pitch	+Heave	TR15	0.132	-0.277	-0.839
-80% Roll	-60% Pitch	-Heave	TR16	0.182	-0.387	-1.221
+60% Roll	+80% Pitch	+Heave	TR17	-0.178	0.208	-0.595
+60% Roll	+80% Pitch	-Heave	TR18	-0.246	0.291	-0.980
-60% Roll	+80% Pitch	+Heave	TR19	-0.178	-0.208	-0.405
-60% Roll	+80% Pitch	-Heave	TR20	-0.246	-0.291	-0.791
+60% Roll	-80% Pitch	+Heave	TR21	0.178	0.208	-1.136
+60% Roll	-80% Pitch	-Heave	TR22	0.246	0.291	-1.521
-60% Roll	-80% Pitch	+Heave	TR23	0.178	-0.208	-0.947
-60% Roll	-80% Pitch	-Heave	TR24	0.246	-0.291	-1.332

Table 9-4: Transportation Analysis Load Combination

9.4.3 Wind Load

Wind loads associated with the barge transportation are based on design premise Ref. [15]. The wind speed and directions are presented in Table 9-5.

Wind Speed	Prevailing Directions	Load ID
25m/s	0°	W1
	90°	W2
	180°	W3
	270°	W4

Table 9-5: Wind Speed and Directions

The actual wind load applied on the structure based on the specified wind speed and directions are generated automatically by SACS. They are presented in Section 9.5.3.

9.4.4 Load Combination

The final load combination used in the analysis is presented in Table 9-6, each combined load (WI1 to WI96) combines gravity, acceleration and wind load; a total of 96 load cases are generated.

Final Load Combination	Barge Acceleration Load ID	Wind Load ID
WI01 to WI24	TR01 to TR24	W1
WI25 to WI48	TR01 to TR24	W2
WI49 to WI72	TR01 to TR24	W3
WI73 to WI96	TR01 to TR24	W4

Table 9-6: Transportation Analysis – Load Combinations Including Wind

9.5 Transportation Analysis Results

9.5.1 Basic Load case

The basic load cases generated in SACS output file is extracted and presented in Figure 9-10

****** SEASTATE BASIC LOAD CASE SUMMARY ******
RELATIVE TO MUDLINE ELEVATION

LOAD CASE	LOAD LABEL	FX (KN)	FY (KN)	FZ (KN)	MX (KN-M)	MY (KN-M)	MZ (KN-M)	DEAD LOAD (KN)	BUOYANCY (KN)
1	W1	6.72	0.00	-0.07	0.1	10153.9	-0.1	0.00	0.00
2	W2	0.00	17.27	0.02	-26075.0	-0.1	234.1	0.00	0.00
3	W3	-6.72	0.00	0.07	-0.1	-10153.9	0.1	0.00	0.00
4	W4	0.00	-17.27	-0.02	26075.0	0.1	-234.1	0.00	0.00
5	GRVX	-125.44	0.00	0.00	0.0	-189414.0	1.7	125.44	0.00
6	GRVY	0.00	-125.44	0.00	189414.0	0.0	-1743.8	125.44	0.00
7	GRVZ	0.00	0.00	-125.44	-1.7	1743.8	0.0	125.44	0.00

Figure 9-10: Transport Basic Load Case Summary

9.5.2 Acceleration Loads

The total generated acceleration loads on the structure as extracted from SACS is presented in Figure 9-11.

***** SEASTATE COMBINED LOAD CASE SUMMARY *****
RELATIVE TO MUDLINE ELEVATION

LOAD CASE	LOAD LABEL	FX (KN)	FY (KN)	FZ (KN)	MX (KN-M)	MY (KN-M)	MZ (KN-M)
12	TR1	0.00	-50.31	132.95	75976.5	-1848.3	-699.5
13	TR2	0.00	-70.21	187.95	106013.8	-2612.8	-976.0
14	TR3	0.00	50.31	86.88	-75973.5	-1207.8	699.5
15	TR4	0.00	70.21	141.87	-106009.3	-1972.3	976.0
18	TR5	33.06	0.00	64.79	0.9	49012.9	-0.5
19	TR6	45.63	0.00	121.84	1.7	67213.6	-0.6
20	TR7	-33.06	0.00	163.67	2.3	-52188.9	0.5
21	TR8	-45.63	0.00	220.85	3.0	-71977.6	0.6
22	TR9	19.31	-40.51	100.34	61178.7	27758.2	-563.5
32	TR10	26.62	-56.60	156.06	85473.7	38026.4	-787.3
33	TR11	19.31	40.51	63.33	-61176.4	28272.7	563.0
34	TR12	26.62	56.60	119.20	-85469.9	38538.8	786.5
35	TR13	-19.31	-40.51	159.57	61179.5	-31371.4	-563.0
36	TR14	-26.62	-56.60	215.44	85474.5	-43191.0	-786.5
37	TR15	-19.31	40.51	122.71	-61175.6	-30859.0	563.5
38	TR16	-26.62	56.60	178.59	-85469.1	-42678.6	787.3
39	TR17	26.03	-30.42	87.03	45939.4	38102.7	-423.3
40	TR18	35.98	-42.56	143.34	64271.3	52338.1	-592.2
41	TR19	26.03	30.42	59.24	-45937.4	38489.0	422.6
42	TR20	35.98	42.56	115.69	-64267.7	52722.4	591.2
43	TR21	-26.03	-30.42	166.15	45940.5	-41622.3	-422.6
44	TR22	-35.98	-42.56	222.46	64272.4	-57423.4	-591.2
45	TR23	-26.03	30.42	138.51	-45936.3	-41238.0	423.3
46	TR24	-35.98	42.56	194.82	-64266.6	-57039.1	592.2

Figure 9-11: Generated Acceleration Loads

9.5.3 Combined Load Case

The combined load cases extracted from SACS is presented in Figure 9-12, Figure 9-13 and Figure 9-14

***** SEASTATE COMBINED LOAD CASE SUMMARY *****
RELATIVE TO MUDLINE ELEVATION

LOAD CASE	LOAD LABEL	FX (KN)	FY (KN)	FZ (KN)	MX (KN-M)	MY (KN-M)	MZ (KN-M)
23	WI1	6.72	-50.31	132.89	75976.6	8305.6	-699.6
24	WI2	6.72	-70.21	187.88	106013.9	7541.1	-976.1
25	WI3	6.72	50.31	86.81	-75973.4	8946.1	699.3
26	WI4	6.72	70.21	141.81	-106009.2	8181.6	975.8
27	WI5	39.78	0.00	64.73	1.0	59166.8	-0.6
28	WI6	52.36	0.00	121.77	1.8	77367.4	-0.8
29	WI7	-26.33	0.00	163.60	2.3	-42035.0	0.3
30	WI8	-38.91	0.00	220.79	3.1	-61823.7	0.5
31	WI9	26.03	-40.51	100.27	61178.8	37912.1	-563.6
47	WI10	33.34	-56.60	155.99	85473.8	48180.3	-787.4
48	WI11	26.03	40.51	63.27	-61176.4	38426.6	562.8
49	WI12	33.34	56.60	119.14	-85469.8	48692.7	786.4
50	WI13	-12.58	-40.51	159.51	61179.6	-21217.5	-563.1
51	WI14	-19.90	-56.60	215.38	85474.6	-33037.1	-786.7
52	WI15	-12.58	40.51	122.65	-61175.5	-20705.1	563.4

Figure 9-12: Transportation Combined Load Case Summary – WI1 to WI15

***** SEASTATE COMBINED LOAD CASE SUMMARY *****
RELATIVE TO MUDLINE ELEVATION

LOAD CASE	LOAD LABEL	FX (KN)	FY (KN)	FZ (KN)	MX (KN-M)	MY (KN-M)	MZ (KN-M)
53	WI16	-19.90	56.60	178.52	-85469.0	-32524.7	787.1
54	WI17	32.76	-30.42	86.96	45939.5	48256.6	-423.4
55	WI18	42.70	-42.56	143.27	64271.4	62492.0	-592.3
56	WI19	32.76	30.42	59.17	-45937.3	48642.9	422.4
57	WI20	42.70	42.56	115.63	-64267.6	62876.3	591.1
58	WI21	-19.31	-30.42	166.09	45940.6	-31468.4	-422.7
59	WI22	-29.26	-42.56	222.40	64272.5	-47269.5	-591.3
60	WI23	-19.31	30.42	138.44	-45936.2	-31084.1	423.1
61	WI24	-29.26	42.56	194.75	-64266.5	-46885.2	592.0
62	WI25	0.00	-33.05	132.97	49901.6	-1848.4	-465.4
63	WI26	0.00	-52.94	187.97	79938.8	-2612.9	-741.9
64	WI27	0.00	67.58	86.90	-102048.5	-1207.9	933.5
65	WI28	0.00	87.47	141.89	-132084.2	-1972.4	1210.1
66	WI29	33.06	17.27	64.81	-26074.1	49012.7	233.6
67	WI30	45.63	17.27	121.86	-26073.3	67213.4	233.4
68	WI31	-33.06	17.27	163.69	-26072.7	-52189.0	234.5
69	WI32	-45.63	17.27	220.87	-26071.9	-71977.7	234.7
70	WI33	19.31	-23.25	100.36	35103.7	27758.1	-329.4
71	WI34	26.62	-39.34	156.08	59398.7	38026.3	-553.2
72	WI35	19.31	57.78	63.35	-87251.4	28272.5	797.0
73	WI36	26.62	73.87	119.22	-111544.9	38538.6	1020.6
74	WI37	-19.31	-23.25	159.59	35104.5	-31371.5	-328.9
75	WI38	-26.62	-39.34	215.46	59399.5	-43191.1	-552.4
76	WI39	-19.31	57.78	122.73	-87250.6	-30859.2	797.6
77	WI40	-26.62	73.87	178.60	-111544.1	-42678.7	1021.3
78	WI41	26.03	-13.15	87.05	19864.4	38102.5	-189.2
79	WI42	35.98	-25.29	143.36	38196.3	52338.0	-358.1
80	WI43	26.03	47.69	59.26	-72012.4	38488.9	656.6
81	WI44	35.98	59.83	115.71	-90342.7	52722.3	825.3
82	WI45	-26.03	-13.15	166.17	19865.5	-41622.5	-188.5
83	WI46	-35.98	-25.29	222.48	38197.4	-57423.5	-357.1
84	WI47	-26.03	47.69	138.53	-72011.3	-41238.2	657.4
85	WI48	-35.98	59.83	194.84	-90341.6	-57039.2	826.3
86	WI49	-6.72	-50.31	133.02	75976.5	-12002.1	-699.3
87	WI50	-6.72	-70.21	188.01	106013.7	-12766.7	-975.8
88	WI51	-6.72	50.31	86.95	-75973.6	-11361.7	699.6
89	WI52	-6.72	70.21	141.94	-106009.3	-12126.2	976.1
90	WI53	26.33	0.00	64.86	0.8	38859.0	-0.3
91	WI54	38.91	0.00	121.90	1.6	57059.7	-0.5
92	WI55	-39.78	0.00	163.73	2.2	-62342.8	0.6

Figure 9-13: Transportation Combined Load Case Summary – WI16 to WI55

***** SEASTATE COMBINED LOAD CASE SUMMARY *****
RELATIVE TO MUDLINE ELEVATION

LOAD CASE	LOAD LABEL	FX (KN)	FY (KN)	FZ (KN)	MX (KN-M)	MY (KN-M)	MZ (KN-M)
93	WI56	-52.36	0.00	220.92	3.0	-82131.4	0.8
94	WI57	12.58	-40.51	100.40	61178.6	17604.4	-563.4
95	WI58	19.90	-56.60	156.13	85473.6	27872.5	-787.1
96	WI59	12.58	40.51	63.40	-61176.5	18118.8	563.1
97	WI60	19.90	56.60	119.27	-85470.0	28384.9	786.7
98	WI61	-26.03	-40.51	159.64	61179.4	-41525.3	-562.8
99	WI62	-33.34	-56.60	215.51	85474.4	-53344.8	-786.4
100	WI63	-26.03	40.51	122.78	-61175.7	-41012.9	563.6
101	WI64	-33.34	56.60	178.65	-85469.2	-52832.5	787.4
102	WI65	19.31	-30.42	87.09	45939.3	27948.8	-423.1
103	WI66	29.26	-42.56	143.40	64271.2	42184.2	-592.0
104	WI67	19.31	30.42	59.30	-45937.5	28335.1	422.7
105	WI68	29.26	42.56	115.76	-64267.8	42568.5	591.3
106	WI69	-32.76	-30.42	166.22	45940.4	-51776.2	-422.4
107	WI70	-42.70	-42.56	222.53	64272.3	-67577.3	-591.1
108	WI71	-32.76	30.42	138.58	-45936.4	-51391.9	423.4
109	WI72	-42.70	42.56	194.89	-64266.7	-67193.0	592.3
110	WI73	0.00	-67.58	132.93	102051.5	-1848.1	-933.5
111	WI74	0.00	-87.47	187.93	132088.8	-2612.6	-1210.1
112	WI75	0.00	33.05	86.86	-49898.5	-1207.6	465.4
113	WI76	0.00	52.94	141.85	-79934.3	-1972.2	741.9
114	WI77	33.06	-17.27	64.77	26075.9	49013.0	-234.5
115	WI78	45.63	-17.27	121.82	26076.7	67213.7	-234.7
116	WI79	-33.06	-17.27	163.65	26077.2	-52188.7	-233.6
117	WI80	-45.63	-17.27	220.83	26078.0	-71977.4	-233.4
118	WI81	19.31	-57.78	100.32	87253.7	27758.4	-797.6
119	WI82	26.62	-73.87	156.04	111548.7	38026.5	-1021.3
120	WI83	19.31	23.25	63.31	-35101.5	28272.8	328.9
121	WI84	26.62	39.34	119.18	-59394.9	38538.9	552.4
122	WI85	-19.31	-57.78	159.55	87254.5	-31371.3	-797.0
123	WI86	-26.62	-73.87	215.42	111549.5	-43190.8	-1020.6
124	WI87	-19.31	23.25	122.69	-35100.6	-30858.9	329.4
125	WI88	-26.62	39.34	178.57	-59394.1	-42678.4	553.2
126	WI89	26.03	-47.69	87.01	72014.4	38102.8	-657.4
127	WI90	35.98	-59.83	143.32	90346.3	52338.3	-826.3
128	WI91	26.03	13.15	59.22	-19862.4	38489.2	188.5
129	WI92	35.98	25.29	115.67	-38192.7	52722.6	357.1
130	WI93	-26.03	-47.69	166.13	72015.5	-41622.2	-656.6
131	WI94	-35.98	-59.83	222.44	90347.4	-57423.2	-825.3
132	WI95	-26.03	13.15	138.49	-19861.3	-41237.9	189.2
133	WI96	-35.98	25.29	194.80	-38191.6	-57039.0	358.1

Figure 9-14: Transportation Combined Load Case Summary – WI56 to WI96

9.5.4 Reactions

In order to validate the model, the total reaction forces on the fixed joints shall be showed to be equal to the total load applied on the structure for every load combination. These forces are extracted and shown in Figure 9-15

SACS-IV SYSTEM FIXED JOINTS REACTION FORCES AND MOMENTS SUMMARY
*** MOMENTS SUMMED ABOUT ORIGIN ***

LOAD CASE	******** KN ******** FORCE(X)	FORCE(Y)	FORCE(Z)	******** KN-M ******** MOMENT(X)	MOMENT(Y)	MOMENT(Z)
WI1	-6.723	50.315	-132.887	-2.510	1846.483	699.595
WI2	-6.723	70.206	-187.882	-3.544	2611.008	976.125
WI3	-6.723	-50.315	-86.814	-0.479	1205.991	-699.323
WI4	-6.723	-70.206	-141.809	-0.960	1970.515	-975.853
WI5	-39.779	0.000	-64.728	-0.873	898.502	0.591
WI6	-52.357	0.000	-121.771	-1.658	1691.318	0.765
WI7	26.332	0.000	-163.602	-2.235	2273.937	-0.319
WI8	38.911	0.000	-220.791	-3.022	3069.136	-0.493
WI9	-26.030	40.515	-100.270	-1.925	1392.787	563.629
WI10	-33.343	56.604	-155.997	-2.916	2167.377	787.394
WI11	-26.030	-40.515	-63.266	-0.290	878.360	-562.825
WI12	-33.343	-56.604	-119.138	-0.836	1654.983	-786.388
WI13	12.584	40.515	-159.507	-2.741	2216.814	563.097
WI14	19.897	56.604	-215.380	-3.734	2993.640	786.660
WI15	12.584	-40.515	-122.649	-1.108	1704.420	-563.357
WI16	19.897	-56.604	-178.521	-1.655	2481.246	-787.122
WI17	-32.758	30.423	-86.960	-1.601	1207.663	423.423
WI18	-42.704	42.563	-143.272	-2.545	1990.349	592.325
WI19	-32.758	-30.423	-59.170	-0.374	821.334	-422.434
WI20	-42.704	-42.563	-115.628	-0.983	1606.053	-591.062
WI21	19.312	30.423	-166.089	-2.691	2308.406	422.706
WI22	29.258	42.563	-222.400	-3.635	3091.368	591.333
WI23	19.312	-30.423	-138.445	-1.466	1924.110	-423.151
WI24	29.258	-42.563	-194.756	-2.073	2707.073	-592.053
WI25	0.000	33.047	-132.973	-1.988	1848.316	465.386
WI26	0.000	52.939	-187.968	-3.022	2612.840	741.917
WI27	0.000	-67.582	-86.900	0.044	1207.823	-933.531
WI28	0.000	-87.474	-141.895	-0.438	1972.348	-1210.061
WI29	-33.056	-17.268	-64.814	-0.351	900.334	-233.617
WI30	-45.634	-17.268	-121.857	-1.136	1693.151	-233.444
WI31	33.056	-17.268	-163.688	-1.713	2275.770	-234.528
WI32	45.634	-17.268	-220.877	-2.500	3070.969	-234.701
WI33	-19.307	23.247	-100.356	-1.403	1394.620	329.421
WI34	-26.620	39.336	-156.083	-2.394	2169.209	553.185
WI35	-19.307	-57.783	-63.352	0.232	880.192	-797.033
WI36	-26.620	-73.872	-119.224	-0.314	1656.815	-1020.596
WI37	19.307	23.247	-159.593	-2.219	2218.646	328.889
WI38	26.620	39.336	-215.465	-3.212	2995.472	552.452
WI39	19.307	-57.783	-122.735	-0.586	1706.252	-797.565
WI40	26.620	-73.872	-178.607	-1.132	2483.078	-1021.330
WI41	-26.035	13.155	-87.046	-1.079	1209.495	189.215

Figure 9-15 : Transportation Analysis– Total Reaction Summary.WI1 to WI41

SACS-IV SYSTEM FIXED JOINTS REACTION FORCES AND MOMENTS SUMMARY

*** MOMENTS SUMMED ABOUT ORIGIN ***

LOAD CASE	FORCE(X) (KN)	FORCE(Y) (KN)	FORCE(Z) (KN)	MOMENT(X) (KN-M)	MOMENT(Y) (KN-M)	MOMENT(Z) (KN-M)
WI42	-35.981	25.295	-143.358	-2.023	1992.181	358.117
WI43	-26.035	-47.691	-59.256	0.148	823.166	-656.642
WI44	-35.981	-59.830	-115.714	-0.461	1607.886	-825.270
WI45	26.035	13.155	-166.175	-2.169	2310.239	188.498
WI46	35.981	25.295	-222.486	-3.113	3093.201	357.125
WI47	26.035	-47.691	-138.531	-0.944	1925.943	-657.359
WI48	35.981	-59.830	-194.842	-1.551	2708.905	-826.261
WI49	6.723	50.315	-133.020	-2.550	1850.074	699.323
WI50	6.723	70.206	-188.014	-3.583	2614.598	975.853
WI51	6.723	-50.315	-86.947	-0.518	1209.581	-699.595
WI52	6.723	-70.206	-141.942	-1.000	1974.106	-976.125
WI53	-26.332	0.000	-64.861	-0.912	902.092	0.319
WI54	-38.911	0.000	-121.903	-1.698	1694.909	0.493
WI55	39.779	0.000	-163.735	-2.274	2277.528	-0.591
WI56	52.357	0.000	-220.924	-3.062	3072.726	-0.765
WI57	-12.584	40.515	-100.403	-1.964	1396.377	563.357
WI58	-19.897	56.604	-156.129	-2.955	2170.967	787.122
WI59	-12.584	-40.515	-63.398	-0.330	881.950	-563.097
WI60	-19.897	-56.604	-119.271	-0.876	1658.573	-786.660
WI61	26.030	40.515	-159.639	-2.780	2220.404	562.825
WI62	33.343	56.604	-215.512	-3.773	2997.230	786.388
WI63	26.030	-40.515	-122.781	-1.148	1708.010	-563.629
WI64	33.343	-56.604	-178.654	-1.694	2484.836	-787.394
WI65	-19.312	30.423	-87.093	-1.641	1211.253	423.151
WI66	-29.258	42.563	-143.404	-2.585	1993.939	592.053
WI67	-19.312	-30.423	-59.303	-0.414	824.924	-422.706
WI68	-29.258	-42.563	-115.760	-1.023	1609.644	-591.333
WI69	32.758	30.423	-166.221	-2.731	2311.996	422.434
WI70	42.704	42.563	-222.533	-3.675	3094.959	591.062
WI71	32.758	-30.423	-138.578	-1.506	1927.701	-423.423
WI72	42.704	-42.563	-194.889	-2.113	2710.663	-592.325
WI73	0.000	67.583	-132.934	-3.072	1848.242	933.533
WI74	0.000	87.474	-187.929	-4.105	2612.766	1210.063
WI75	0.000	-33.047	-86.861	-1.040	1207.749	-465.384
WI76	0.000	-52.938	-141.856	-1.522	1972.274	-741.915
WI77	-33.056	17.268	-64.775	-1.435	900.260	234.529
WI78	-45.634	17.268	-121.818	-2.220	1693.077	234.703
WI79	33.056	17.268	-163.649	-2.797	2275.695	233.619
WI80	45.634	17.268	-220.838	-3.584	3070.894	233.446
WI81	-19.307	57.783	-100.317	-2.486	1394.546	797.567

Figure 9-16 : Transportation Analysis– Total Reaction Summary.WI42 to WI81

SACS-IV SYSTEM FIXED JOINTS REACTION FORCES AND MOMENTS SUMMARY
*** MOMENTS SUMMED ABOUT ORIGIN ***

	********************* KN	********************		******************** KN-M	********************	
LOAD CASE	FORCE(X)	FORCE(Y)	FORCE(Z)	MOMENT(X)	MOMENT(Y)	MOMENT(Z)
WI82	-26.620	73.872	-156.043	-3.477	2169.135	1021.332
WI83	-19.307	-23.247	-63.312	-0.852	880.118	-328.887
WI84	-26.620	-39.336	-119.185	-1.398	1656.741	-552.450
WI85	19.307	57.783	-159.554	-3.302	2218.572	797.035
WI86	26.620	73.872	-215.426	-4.295	2995.398	1020.598
WI87	19.307	-23.247	-122.695	-1.670	1706.178	-329.419
WI88	26.620	-39.336	-178.568	-2.216	2483.004	-553.183
WI89	-26.035	47.691	-87.007	-2.163	1209.421	657.361
WI90	-35.981	59.831	-143.318	-3.107	1992.107	826.263
WI91	-26.035	-13.155	-59.217	-0.936	823.092	-188.496
WI92	-35.981	-25.295	-115.675	-1.545	1607.812	-357.123
WI93	26.035	47.691	-166.135	-3.253	2310.164	656.644
WI94	35.981	59.831	-222.447	-4.197	3093.127	825.272
WI95	26.035	-13.155	-138.492	-2.028	1925.869	-189.213
WI96	35.981	-25.295	-194.803	-2.635	2708.831	-358.115

Figure 9-17 : Transportation Analysis– Total Reaction Summary.WI82 to WI96

9.5.5 Member Unity Check Ratio (UCR)

The member unity check for all the member groups are extracted and shown in Figure 9-18.

The maximum UCR for these load cases is 0.43 and it occurs at the UPE 300 transverse member.

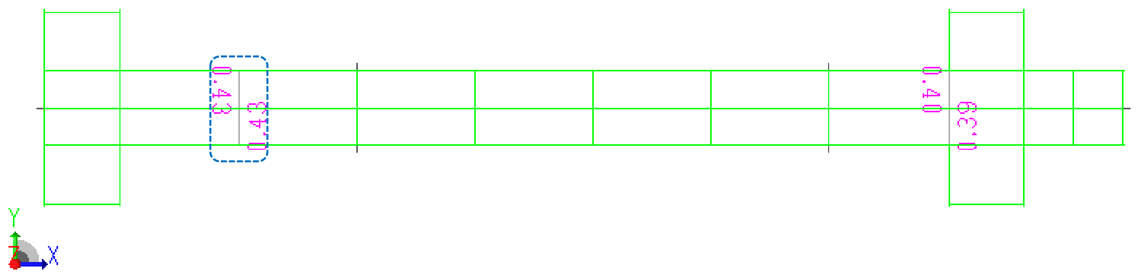


Figure 9-18: Transportation Analysis UCR.

The UCR summary for the member groups are presented in Figure 9-19. Only the load case causing the maximum stresses on each member group are detailed.

SACS IV - * * * M E M B E R G R O U P S U M M A R Y * * *

GRUP ID	CRITICAL MEMBER	LOAD COND	MAX. UNITY CHECK	DIST FROM END m	* APPLIED STRESSES * AXIAL N/mm2	BEND-Y N/mm2	BEND-Z N/mm2	*** ALLOWABLE STRESSES *** AXIAL N/mm2	EULER N/mm2	BEND-Y N/mm2	BEND-Z N/mm2	CRIT COND	EFFECTIVE LENGTHS KLY m	KLZ m	CM * VALUES * Y	Z
BM1	0002-0003	WI74	0.27	3.0	-0.03	14.90	-60.57	177.26	589.37	231.13	314.27	CM+BN	7.9	3.0	1.00	1.00
BM3	0020-0022	WI28	0.31	3.0	-6.47	20.12	-52.63	105.75	134.78	192.05	330.54	CM+BN	7.9	3.0	1.00	1.00
BM4	0020-0002	WI74	0.43	0.9	-0.34	-2.24	138.48	191.57	1344.09	237.92	330.54	CM+BN	0.9	0.9	1.00	1.00
BM5	0030-0007	WI86	0.13	0.9	-0.30	-16.84	-16.23	204.14	8472.86	229.39	312.65	CM+BN	0.9	0.9	1.00	1.00
T01	0080-0082	WI86	0.09	0.0	0.21	-0.08	23.25	207.00	218.12	258.75	258.75	TN+BN	2.3	2.3	0.85	0.85
T02	0059-0057	WI86	0.00	0.2	0.02	-0.02	0.01	207.00	*******	258.75	258.75	TN+BN	0.2	0.2	0.85	0.85
U01	0050-0051	WI74	0.06	1.9	0.05	1.31	16.29	206.59	297.76	226.00	330.54	TN+BN	1.9	1.9	1.00	1.00

Figure 9-19: Transportation Analysis Member Group UCR Summary.

Refer to ANNEX1: LBMS FRAMING for member group properties

10 In-Place Analysis

This section presents details of the global analysis performed on the LBMS for in-service load conditions. The flowline was not modelled, rather, the flowline load were applied as concentrated loads on the beam.

The Model coordinate system is as shown on section 8.2, irrespective of actual orientation of the LBMS in any specific condition.

The members having plate characteristics will be checked separately in ANNEX7: .

Two cases have been considered for the in place analysis as listed below:

Analysis 1: Only flowline weight considered.

Analysis 2: Flowline weight +instigation loads.

10.1 Boundary Conditions

The fixity in SACS has six degrees of freedom. The first three represent the translation degrees of freedom while the other three represent the rotational degree of freedom (DOF). The symbol 1 represents a restrained DOF while 0 represents a free/released DOF.

The soil vertical and horizontal stiffness are modeled as a series of elastic springs supports at the corners of the plated elements. The elastic springs in the global X, Y, Z directions are modeled at each of the plated Mudmat corner nodes as a proportion of the overall mudmat area of the LBMS with each node simulating the tributary contribution from all the plated areas concurrent at a common node. Soil stiffness values are as per section 6.5.

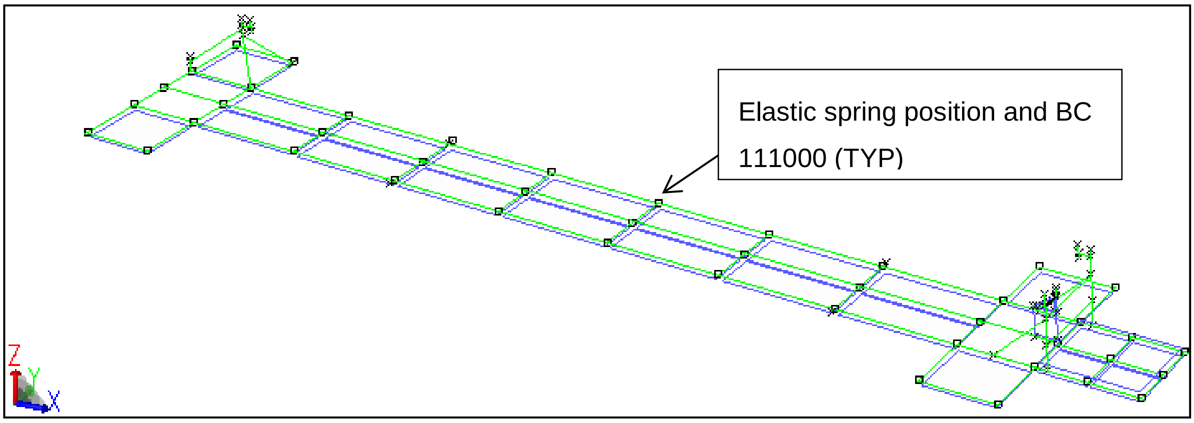


Figure 10-1: In Place Analysis Boundary Condition.

10.2 Load Combinations

10.2.1 Basic Load Case

The loads induced by the flowline on the LBMS are extracted from Ref [22]. Instigation device loads which form the uplift of the buoy and the ballast weight will also be considered with the in-place loads. The following basic load cases were considered in the analysis:

- GRVZ: Gravity Load
- BAL: Ballast Weight
- BUOY: Buoy Horizontal and vertical pull force
- F1: Flowline Force at Position A
- F2: Flowline Force at Position B
- F3: Flowline Force at Position C
- F4: Flowline Force at Position D
- F5: Flowline Force at Position E
- F6: Flowline Force at Position F

Position A to F represents the different positions of the flowlines on the LBMS as shown in Figure 10-2 below

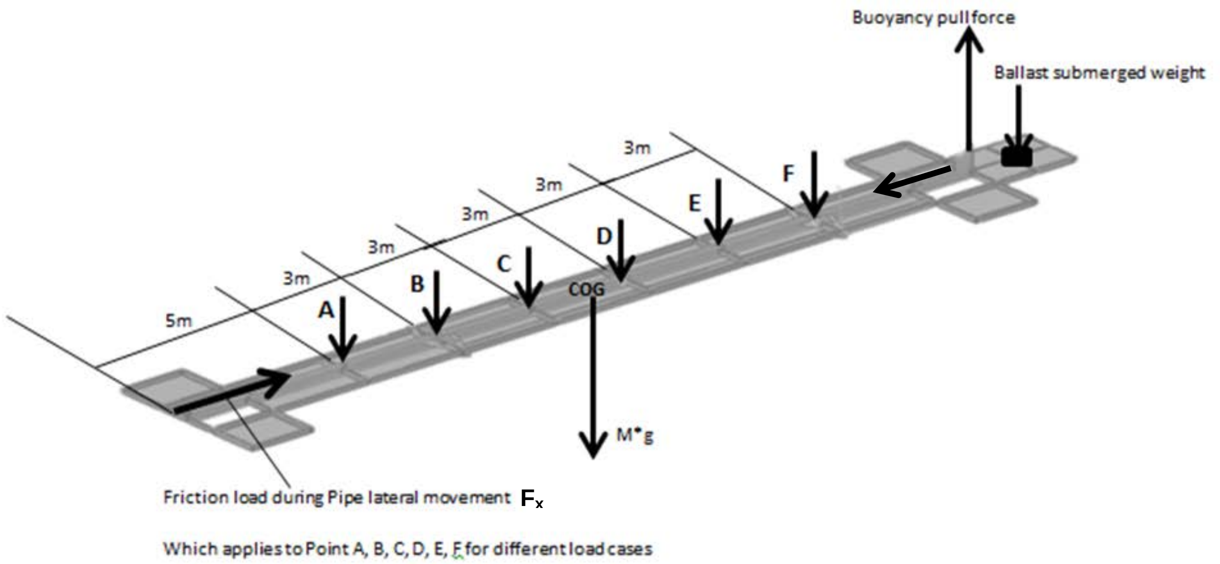


Figure 10-2: In Place Analysis Loading Points

The values for the basic load cases applied to the model are extracted from SACS and shown in Figure 10-3 and Figure 10-4:

****** SEASTATE BASIC LOAD CASE SUMMARY ******
RELATIVE TO MUDLINE ELEVATION

LOAD CASE	LOAD LABEL	FX (KN)	FY (KN)	FZ (KN)	MX (KN-M)	MY (KN-M)	MZ (KN-M)	DEAD LOAD (KN)	BUOYANCY (KN)
1	F1	0.00	0.00	-125.00	0.0	618.1	0.0	0.00	0.00
2	F2	0.00	0.00	-125.00	0.0	993.1	0.0	0.00	0.00
3	F3	0.00	0.00	-125.00	0.0	1368.1	0.0	0.00	0.00
4	F4	0.00	0.00	-125.00	0.0	1743.1	0.0	0.00	0.00
5	F5	0.00	0.00	-125.00	0.0	2118.1	0.0	0.00	0.00
6	F6	0.00	0.00	-125.00	0.0	2493.1	0.0	0.00	0.00
7	BAL	0.00	0.00	-65.28	0.0	1706.6	0.0	0.00	0.00
8	BOUY	-49.03	0.00	49.03	0.0	-6162.5	0.0	0.00	0.00
9	GRVZ	0.00	0.00	-109.03	-1.5	1514.7	0.0	125.44	16.41

Figure 10-3 : In Place Analysis Loads – Basic Load Case without ballast and buoy.

****** SEASTATE BASIC LOAD CASE SUMMARY ******
RELATIVE TO MUDLINE ELEVATION

LOAD CASE	LOAD LABEL	FX (KN)	FY (KN)	FZ (KN)	MX (KN-M)	MY (KN-M)	MZ (KN-M)	DEAD LOAD (KN)	BUOYANCY (KN)
1	F1	50.00	0.00	-125.00	0.0	5618.1	0.0	0.00	0.00
2	F2	50.00	0.00	-125.00	0.0	5993.1	0.0	0.00	0.00
3	F3	50.00	0.00	-125.00	0.0	6368.1	0.0	0.00	0.00
4	F4	50.00	0.00	-125.00	0.0	6743.1	0.0	0.00	0.00
5	F5	50.00	0.00	-125.00	0.0	7118.1	0.0	0.00	0.00
6	F6	50.00	0.00	-125.00	0.0	7493.1	0.0	0.00	0.00
7	BAL	0.00	0.00	-65.20	0.0	1704.4	0.0	0.00	0.00
8	BOUY	-49.03	0.00	49.03	0.0	-6162.5	0.0	0.00	0.00
9	GRVZ	0.00	0.00	-109.03	-1.5	1514.7	0.0	125.44	16.41

Figure 10-4: In Place Analysis Loads – Basic Load Case with ballast and buoy.

Buoy Pull Force is included in the combined force acting at the Flowline positions (from A to F as shown in Figure 10-2).

10.2.2 Combined Load Case

The combined load case is the association of the vertical and horizontal loads applied by the flowline on the LBMS structure.

The design load combinations associated with each analysis represents the appropriate load conditions that produce the most severe effects on the LBMS structure consistent with the probability of their simultaneous occurrence.

The following are the combined load cases used for the in-place analysis excluding Ballast weight and buoy pull force.

- $LF01 = (GRVZ \times WCF) + F1$
- $LF02 = (GRVZ \times WCF) + F2$
- $LF03 = (GRVZ \times WCF) + F3$
- $LF04 = (GRVZ \times WCF) + F4$
- $LF05 = (GRVZ \times WCF) + F5$
- $LF06 = (GRVZ \times WCF) + F6$

WCF = Weight correction factor, which is 1.10.

The following are the combined load cases used for the in-place analysis including Ballast weight and buoy pull force.

- $LC1 = (GRVZ \times WCF) + (BAL \times WCF)$ No Flowline
- $LC2 = (GRVZ \times WCF) + (BAL \times WCF) + Buoy\ Pull\ Force + F1$
- $LC3 = (GRVZ \times WCF) + (BAL \times WCF) + Buoy\ Pull\ Force + F2$
- $LC4 = (GRVZ \times WCF) + (BAL \times WCF) + Buoy\ Pull\ Force + F3$
- $LC5 = (GRVZ \times WCF) + (BAL \times WCF) + Buoy\ Pull\ Force + F4$
- $LC6 = (GRVZ \times WCF) + (BAL \times WCF) + Buoy\ Pull\ Force + F5$
- $LC7 = (GRVZ \times WCF) + (BAL \times WCF) + Buoy\ Pull\ Force + F6$

The values for the combined load cases applied to the model are extracted from SACS and shown in Figure 10-5 and Figure 10-6: and the loads are applied as shown in Figure 10-2:

***** SEASTATE COMBINED LOAD CASE SUMMARY *****
RELATIVE TO MUDLINE ELEVATION

LOAD CASE	LOAD LABEL	FX (KN)	FY (KN)	FZ (KN)	MX (KN-M)	MY (KN-M)	MZ (KN-M)
17	LF01	0.00	0.00	-244.93	-1.7	2284.3	0.0
18	LF02	0.00	0.00	-244.93	-1.7	2659.3	0.0
19	LF03	0.00	0.00	-244.93	-1.7	3034.3	0.0
20	LF04	0.00	0.00	-244.93	-1.7	3409.3	0.0
21	LF05	0.00	0.00	-244.93	-1.7	3784.3	0.0
22	LF06	0.00	0.00	-244.93	-1.7	4159.3	0.0

Figure 10-5: In Place Analysis Loads – Combined Load Case without Ballast and Buoy.

***** SEASTATE COMBINED LOAD CASE SUMMARY *****
RELATIVE TO MUDLINE ELEVATION

LOAD CASE	LOAD LABEL	FX (KN)	FY (KN)	FZ (KN)	MX (KN-M)	MY (KN-M)	MZ (KN-M)
10	LC1	0.00	0.00	-191.65	-1.7	3541.0	0.0
11	LC2	0.97	0.00	-267.61	-1.7	2996.7	0.0
12	LC3	0.97	0.00	-267.61	-1.7	3371.7	0.0
13	LC4	0.97	0.00	-267.61	-1.7	3746.7	0.0
14	LC5	0.97	0.00	-267.61	-1.7	4121.7	0.0
15	LC6	0.97	0.00	-267.61	-1.7	4496.7	0.0
16	LC7	0.97	0.00	-267.61	-1.7	4871.7	0.0

Figure 10-6: In Place Analysis Loads – Combined Load Case with Ballast and Buoy.

10.3 Results

This section presents the detailed results of the analysis performed on the LBMS to sustain loads imposed during in-service condition.

The structural strength and stability assessment of the LBMS shall conform to the requirements of AISC-ASD Ref [26] and API RP 2A-WSD Ref [28] as applicable.

10.3.1 Reactions on springs

In order to validate the model, the total reaction forces on the springs shall be showed to be equal to the total load applied on the structure for every load case. These forces are extracted and shown in Figure 10-7 and Figure 10-8.

SACS-IV SYSTEM SPRING FORCES AND MOMENTS SUMMARY

LOAD CASE	COORD. SYS.	FORCES X (KN)	FORCES Y (KN)	FORCES Z (KN)	MOMENTS X (KN-M)	MOMENTS Y (KN-M)	MOMENTS Z (KN-M)
LF01	GLOB	0.000	0.000	-244.916			
LF02	GLOB	0.000	0.000	-244.916			
LF03	GLOB	0.000	0.000	-244.916			
LF04	GLOB	0.000	0.000	-244.916			
LF05	GLOB	0.000	0.000	-244.916			
LF06	GLOB	0.000	0.000	-244.916			

Figure 10-7 : In Place Analysis without ballast and buoy – Total Spring Reaction Summary.

SACS-IV SYSTEM SPRING FORCES AND MOMENTS SUMMARY

LOAD CASE	COORD. SYS.	FORCES X (KN)	FORCES Y (KN)	FORCES Z (KN)	MOMENTS X (KN-M)	MOMENTS Y (KN-M)	MOMENTS Z (KN-M)
LC1	GLOB	0.000	0.000	-191.638			
LC2	GLOB	0.967	0.000	-267.599			
LC3	GLOB	0.967	0.000	-267.603			
LC4	GLOB	0.967	0.000	-267.603			
LC5	GLOB	0.967	0.000	-267.603			
LC6	GLOB	0.967	0.000	-267.603			
LC7	GLOB	0.967	0.000	-267.599			

Figure 10-8: In Place Analysis with ballast and buoy – Total Spring Reaction Summary.

10.3.2 Member Unity Check Ratio (UCR)

The member unity check for all the member groups are extracted and shown in Figure 10-10 and Figure 10-12.

Member group UCRs for the load cases considering flow line and gravity loads only are shown in Figure 10-9. The maximum UCR for these load cases is 0.28 and it occurs at the HEB 400 longitudinal member under the flowlines weight.

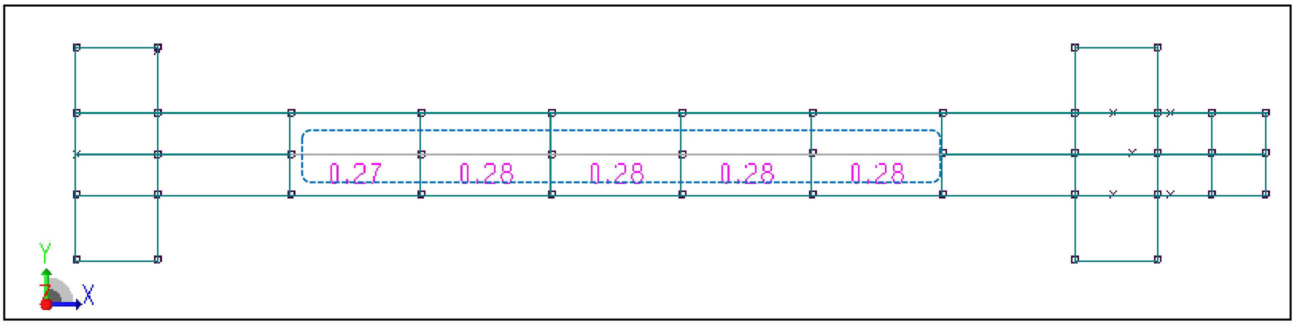


Figure 10-9: In Place Analysis UCR – without ballast and buoy.

The UCR summary for the member groups are presented in Figure 10-10. Only the load case causing the maximum stresses on each member group are detailed.

SACS IV - * * * MEMBER GROUP SUMMARY * * *

GRUP ID	CRITICAL MEMBER	LOAD COND	MAX. UNITY CHECK	DIST FROM END m	* APPLIED STRESSES * AXIAL N/mm2	BEND-Y N/mm2	BEND-Z N/mm2	*** ALLOWABLE STRESSES *** AXIAL N/mm2	EULER N/mm2	BEND-Y N/mm2	BEND-Z N/mm2	CRIT COND	EFFECTIVE LENGTHS KLY m	KLZ m	CM * VALUES * Y	Z
BM1	0003-0004	LF03	0.28	3.0	-1.09	64.28	0.00	184.56	800.59	231.13	314.27	CM+BN	3.0	3.0	1.00	1.00
BM3	0025-0027	LF04	0.25	3.0	2.06	-46.68	0.98	206.59	134.78	192.05	330.54	TN+BN	3.0	3.0	1.00	1.00
BM4	0021-0002	LF01	0.14	0.9	-0.02	33.30	0.83	191.57	1344.09	237.92	330.54	CM+BN	0.9	0.9	1.00	1.00
BM5	0023-0003	LF02	0.05	0.9	-0.01	10.68	-1.08	204.14	8472.86	229.39	312.65	CM+BN	0.9	0.9	1.00	1.00
T01	0017-0090	LF01	0.03	0.0	-0.26	-1.54	6.34	77.19	77.19	258.75	258.75	C<.15	3.9	1.4	0.85	0.85
T02	0059-0057	LF01	0.00	0.2	-0.01	0.00	0.00	205.19	*******	258.75	258.75	C<.15	0.2	0.2	0.85	0.85
U01	0050-0051	LF05	0.00	1.9	-0.02	-0.08	-0.19	152.57	297.76	226.00	330.54	SHEAR	1.9	1.9	1.00	1.00

Figure 10-10: In Place Analysis Member Group UCR Summary – without Ballast and Buoy.

Refer to ANNEX1: LBMS FRAMING for member group properties.

Member group UCRs for all the combined load case (including buoy pull force and ballast weight) are shown in Figure 10-11. The maximum UCR for these combined load cases is 0.39 and it occurs on the UPE sections under the ballast weight.

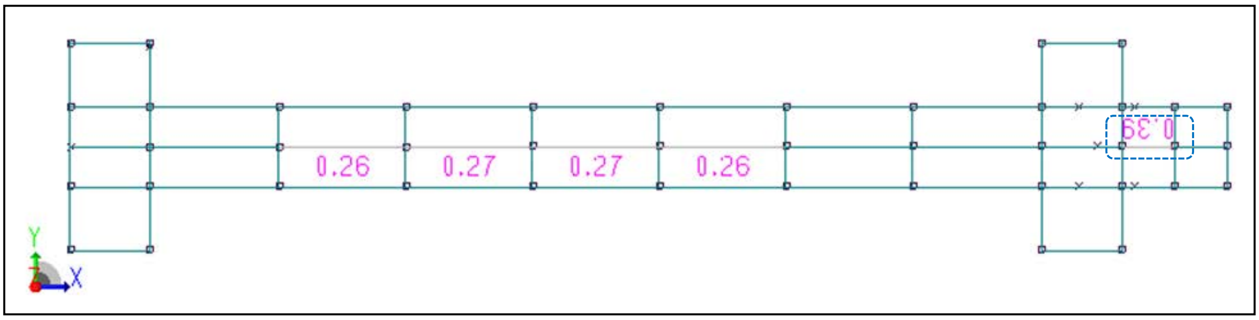


Figure 10-11: In Place Analysis UCR – with ballast and buoy.

The UCR summary for the member groups are presented in Figure 10-12. Only the load case causing the maximum stresses on each member group are detailed.

SACS IV - * * * M E M B E R G R O U P S U M M A R Y * * *

GRUP ID	CRITICAL MEMBER	LOAD COND	MAX. UNITY CHECK	DIST FROM END m	* APPLIED STRESSES * AXIAL N/mm2	BEND-Y N/mm2	BEND-Z N/mm2	*** ALLOWABLE STRESSES *** AXIAL N/mm2	EULER N/mm2	BEND-Y N/mm2	BEND-Z N/mm2	CRIT COND	EFFECTIVE LENGTHS KLY m	KLZ m	CM * VALUES * Y	Z
BM1	0004-0005	LC4	0.27	0.0	-2.98	60.42	0.00	184.56	800.59	231.13	314.27	CM+BN	3.0	3.0	1.00	1.00
BM3	0010-0009	LC3	0.39	1.2	0.89	-91.84	-0.04	206.59	776.35	237.92	330.54	TN+BN	1.2	1.2	1.00	1.00
BM4	0021-0002	LC2	0.16	0.9	-0.03	-33.09	6.40	191.57	1344.09	237.92	330.54	CM+BN	0.9	0.9	1.00	1.00
BM5	0022-0003	LC3	0.07	0.9	-0.01	10.59	-6.81	204.14	8472.86	229.39	312.65	CM+BN	0.9	0.9	1.00	1.00
T01	0046-0048	LC4	0.06	0.0	-0.51	-15.04	-0.05	73.74	73.74	258.75	258.75	C<.15	0.6	4.0	0.85	0.85
T02	0059-0057	LC1	0.00	0.2	-0.01	0.00	0.00	205.19	*******	258.75	258.75	C<.15	0.2	0.2	0.85	0.85
U01	0050-0051	LC6	0.00	1.9	-0.02	-0.06	-0.26	152.57	297.76	226.00	330.54	SHEAR	1.9	1.9	1.00	1.00

Figure 10-12: In Place Analysis Member Group UCR Summary – with Ballast and Buoy.

Refer to ANNEX1: LBMS FRAMING for member group description.

11 Lifting and Lowering Analysis

This section presents details for all offshore lifting in air and lowering in water operations for the LBMS based on the methodology described in the design premises document, Ref [15]. The ballast and the instigation system are not connected at this stage.

Model coordinate system is as shown in section 8.2 irrespective of actual orientation/rotation of the LBMS in any specific condition.

Lifting in air is considered with a tilt angle of 15 degrees as described in the design premises Ref [15].

The members having plate characteristics are not code checked with API RP 2A WSD and/or AISC-ASD.

The slings are modelled as Prismatic members with relevant cross-sectional area but with notional magnitudes to represent the second moment of area about X, Y, Z axes, typically Ixx=Iyy=Izz=10 cm^4. The sling material properties are applied as presented in section 6.2.

The lengths of the slings are shown in Table 11-1.

S/N	LBMS/Sling Configuration	Max. sling length (m)	Min sling length (m)
1	LBMS tilt angle = 15^{o}, sling angle = 55^{o}	16.74	13.91

Table 11-1: Length of Sling.

11.1 Boundary Conditions

The hook node will be fixed in the XYZ direction while fixities will be added in the lateral (X) and transversal (Y) directions for numerical stability.

In order to validate the model, the reactions at the boundary conditions shall be shown to equate the loads applied. Since no lateral or transverse load has been applied, it will be checked that reactions at these fixities will be close to zero for the model to be valid. Also the reaction at the hook point in the vertical direction shall be equal to the total applied weight of the LBMS.

The sling configuration and the applied boundary condition are shown in Figure 11-1.

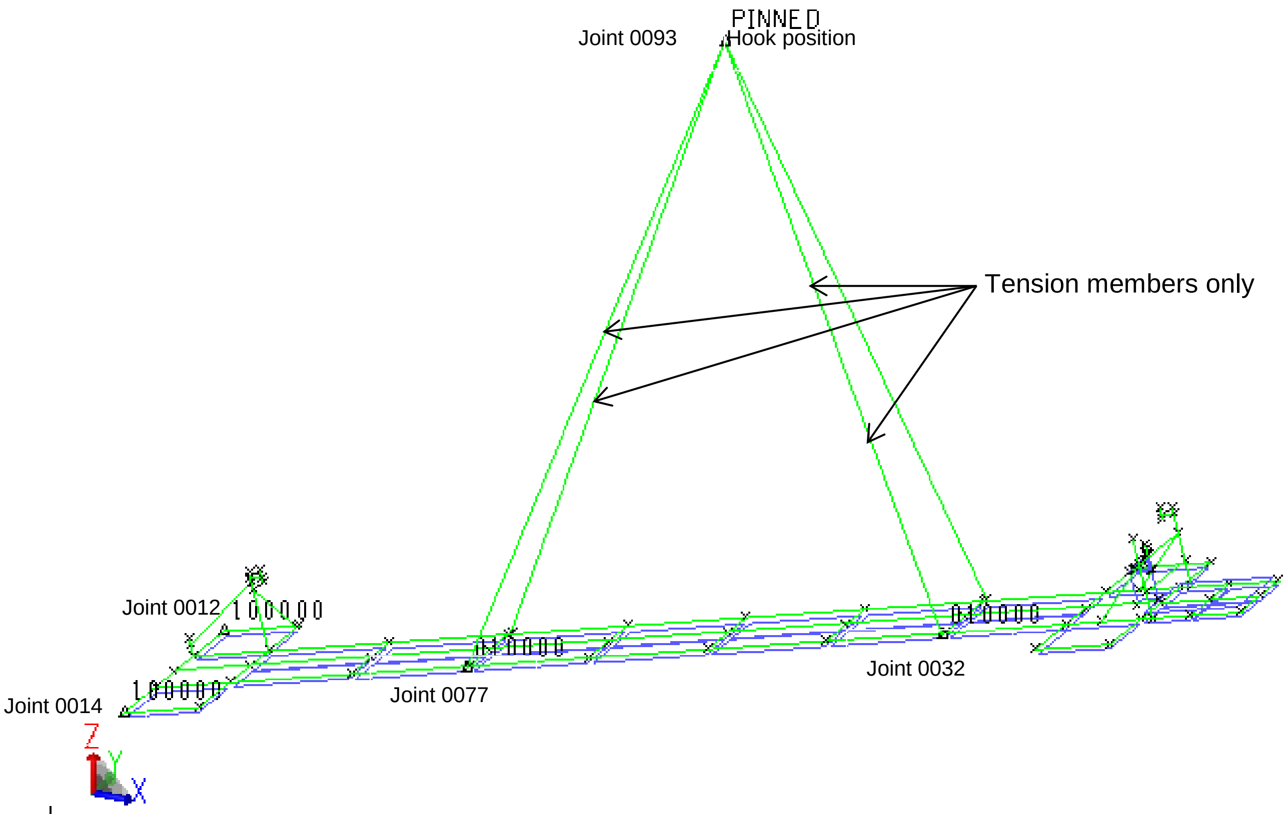


Figure 11-1: Lifting/Lowering Analysis Boundary Conditions.

The slings are defined as tension members only and member releases are applied to release all rotation to prevent transfer of unrealistic moment.

11.2 Load Condition

The design load combinations associated with each analysis represents the appropriate load conditions that produce the most severe effects on the LBMS structure consistent with the probability of their simultaneous occurrence.

Two scenarios were considered in the combined load case; lifting in air and lowering in water. The load combinations factors are as per the design premise document Ref [15].

Load factor	Air	Water
DAF Dynamic Amplification Factor	1.30	2.00
CF Consequence Factor	1.35	1.35
SKL Skew Load Factor	1.33	1.33
WCF Weight Contingency Factor	1.10	1.10
CoG	1.05	1.05
Total	**2.70**	**4.15**

Table 11-2: Design Load Factors.

The loads applied on the model are shown in Table 11-3 for both cases:

Load case	Load Combination	Description
GRVZ		Structure self-weight
SELZ	1.1× GRVZ	Structure self-weight including 10% contingency
LF20	α×SELZ	Where α =2.45 for Lifting in air
LF21	α×SELZ	Where α = 3.77 for lowering in water

Table 11-3: Basic load cases.

11.3 Lifting in Air Results

This section presents the detailed results of the analysis performed on the LBMS to sustain loads imposed during lifting in air.

The structural strength and stability assessment of the LBMS shall conform to the requirements of AISC-ASD Ref [26] and API RP 2A-WSD Ref [28] as applicable.

The LBMS is analysed for the configuration as specified in Ref [15]. The results for the lifting configuration are detailed in the subsequent sections.

11.3.1 Summary of Load Combinations

The figures here below summarizes the basic load cases as detailed in section 4.2

****** SEASTATE BASIC LOAD CASE SUMMARY ******
RELATIVE TO MUDLINE ELEVATION

LOAD CASE	LOAD LABEL	FX (KN)	FY (KN)	FZ (KN)	MX (KN-M)	MY (KN-M)	MZ (KN-M)	DEAD LOAD (KN)	BUOYANCY (KN)
1	GRVZ	0.00	0.00	-125.43	-1.7	1683.8	0.0	125.43	0.00

Figure 11-2: Lift in Air Analysis – Basic Load Summary.

***** SEASTATE COMBINED LOAD CASE SUMMARY *****
RELATIVE TO MUDLINE ELEVATION

LOAD CASE	LOAD LABEL	FX (KN)	FY (KN)	FZ (KN)	MX (KN-M)	MY (KN-M)	MZ (KN-M)
2	SELZ	0.00	0.00	-137.98	-1.9	1852.2	0.0
3	LF20	0.00	0.00	-338.73	-4.7	4547.1	0.0

Figure 11-3: Lift in Air Analysis – Combined Load Summary.

11.3.2 Reactions

The reaction forces & moments at the restrained nodes of the LBMS structure are extracted in Figure 11-4 for the combined load case. Results are extracted based on combined load case LF20 since this is the most critical combined load case for this operation.

- All reaction forces and moments at the hook point are negligible apart from the vertical reaction force which is equal to the vertical load applied on the structure.
- All reaction forces and moments at the lateral and transverse boundary conditions of the LBMS structure are less than 1% of the overall load applied.
- The reaction forces on the model is equal to the applied load, hence the model is validated.

FIXED JOINTS REACTION FORCES AND MOMENT

JOINT	LOAD COND	FORCE(X) (kN)	FORCE(Y) (kN)	FORCE(Z) (kN)	MOMENT(X) (kN-m)	MOMENT(Y) (kN-m)	MOMENT(Z) (kN-m)
0012	LF20	-2.375	0.000	0.000	0.000	0.000	0.000
0014	LF20	2.452	0.000	0.000	0.000	0.000	0.000
0032	LF20	0.000	-1.134	0.000	0.000	0.000	0.000
0077	LF20	0.000	0.905	0.000	0.000	0.000	0.000
0093	LF20	-0.077	0.230	338.733	0.000	0.000	0.000

Figure 11-4: Lift in Air Analysis – Reaction Forces & Moments.

11.3.3 Sling Members Forces

The sling forces for LBMS are shown in Figure 11-5 . They represent the forces acting on the lifting points including all lifting factors and shall be used for the design of the padeyes.

MEMBER FORCES AND MOMENTS

MEMBER NUMBER	MEMBER END	GROUP ID	LOAD COND	FORCE(X) (kN)	FORCE(Y) (kN)	FORCE(Z) (kN)	MOMENT(X) (kN-m)	MOMENT(Y) (kN-m)	MOMENT(Z) (kN-m)
0093-0032	0093	SLI	LF20	82.4589	0.0000	0.0001	0.0000	-0.0007	0.0000
	0032		LF20	82.4589	0.0000	0.0001	0.0000	0.0000	0.0000
0093-0033	0093	SLI	LF20	82.8021	0.0000	0.0001	0.0000	-0.0007	0.0000
	0033		LF20	82.8021	0.0000	0.0001	0.0000	0.0000	0.0000
0093-0076	0093	SLI	LF20	101.6274	0.0000	0.0000	0.0000	-0.0007	0.0000
	0076		LF20	101.6274	0.0000	0.0000	0.0000	0.0000	0.0000
0093-0077	0093	SLI	LF20	100.4340	0.0000	0.0000	0.0000	-0.0007	0.0000
	0077		LF20	100.4340	0.0000	0.0000	0.0000	0.0000	0.0000

Figure 11-5: Lift in Air Analysis – Sling Forces.

11.3.4 Member Unity Check Ratio (UCR)

The member unity check pertaining to load case LF20 for all the member groups are extracted and shown in Figure 11-6 and Figure 11-7.

The maximum UCR for this load case is 0.69 and it occurs on the UPE longitudinal framing member

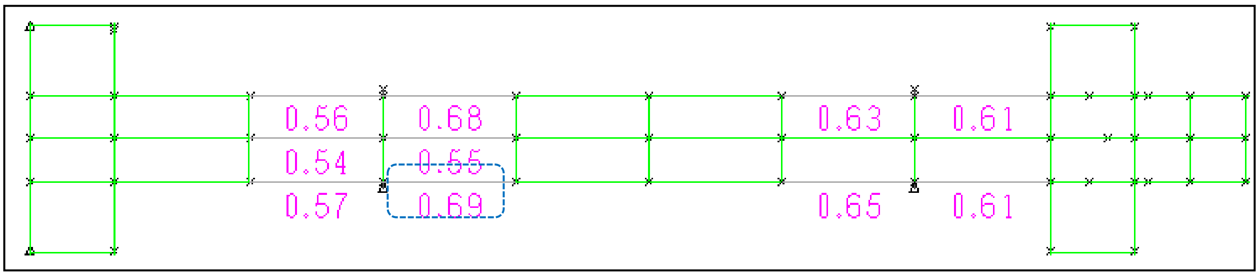


Figure 11-6: Lift in Air Analysis – UCR Summary.

SACS IV - * * * M E M B E R G R O U P S U M M A R Y * * *

GRUP ID	CRITICAL MEMBER	LOAD COND	MAX. UNITY CHECK	DIST FROM END m	* APPLIED STRESSES * AXIAL N/mm2	BEND-Y N/mm2	BEND-Z N/mm2	*** ALLOWABLE STRESSES *** AXIAL N/mm2	EULER N/mm2	BEND-Y N/mm2	BEND-Z N/mm2	CRIT COND	EFFECTIVE LENGTHS KLY m	KLZ m	CM * VALUES * Y	Z
BM1	0003-0004	LF20	0.55	0.0	3.09	-122.15	-2.97	206.59	258.68	231.13	314.27	TN+BN	12.0	3.0	1.00	1.00
BM3	0023-0025	LF20	0.69	0.0	-13.78	102.21	-4.58	89.14	122.56	192.05	330.54	CM+BN	12.0	3.0	1.00	1.00
BM4	0036-0009	LF20	0.24	0.9	0.22	29.55	-37.62	206.59	1344.09	237.92	330.54	TN+BN	0.9	0.9	1.00	1.00
BM5	0031-0007	LF20	0.27	0.9	-0.38	39.07	-30.48	204.14	8472.86	229.39	312.65	CM+BN	0.9	0.9	1.00	1.00
T01	0046-0048	LF20	0.05	0.0	-1.06	-8.65	-0.77	74.12	74.12	258.75	258.75	C<.15	0.6	4.0	0.85	0.85
T02	0059-0057	LF20	0.00	0.2	-0.04	-0.03	0.00	205.19	*******	258.75	258.75	C<.15	0.2	0.2	0.85	0.85
T03	0062-0065	LF20	0.01	0.0	-0.06	-1.62	0.00	184.15	909.11	258.75	258.75	C<.15	1.9	1.9	0.85	0.85
U01	0050-0051	LF20	0.01	1.9	-0.03	-0.17	-2.75	152.57	297.76	226.00	330.54	CM+BN	1.9	1.9	1.00	1.00

Figure 11-7: Lift in Air Analysis – Member Group UCR Summary.

11.4 Lowering in Water Results

This section presents the detailed results of the analysis performed on the LBMS to sustain loads imposed during all the phases considered for the lowering in water operation.

The structural strength and stability assessment of the LBMS shall conform to the requirements of AISC-ASD Ref [26] and API RP 2A-WSD Ref [28] as applicable.

The tilt angle for lowering in water is necessary in order to minimize the slamming loads on the LBMS mudmat due to waves while crossing the splash zone is 15 degrees. The ballast and the instigation system are lowered separately.

11.4.1 Summary Load Combinations

The load input for the lowering in water is shown in Figure 11-8 and Figure 11-9. This load input is in line with the load conditions of section 11.2 for lowering in water.

****** SEASTATE BASIC LOAD CASE SUMMARY ******
RELATIVE TO MUDLINE ELEVATION

LOAD CASE	LOAD LABEL	FX (KN)	FY (KN)	FZ (KN)	MX (KN-M)	MY (KN-M)	MZ (KN-M)	DEAD LOAD (KN)	BUOYANCY (KN)
1	GRVZ	0.00	0.00	-108.31	-1.5	1454.1	0.0	125.44	17.13

Figure 11-8: Lowering in Water Analysis – Basic Load Summary.

		***** SEASTATE COMBINED LOAD CASE SUMMARY *****					
		RELATIVE TO MUDLINE ELEVATION					
LOAD CASE	LOAD LABEL	FX (KN)	FY (KN)	FZ (KN)	MX (KN-M)	MY (KN-M)	MZ (KN-M)
2	SELZ	0.00	0.00	-119.14	-1.6	1599.6	0.0
3	LF21	0.00	0.00	-449.16	-6.2	6030.3	0.0

Figure 11-9: Lowering in Water Analysis – Combined Load Summary.

11.4.2 Reactions

The reaction forces & moments at the restrained nodes of the LBMS structure are extracted in Figure 11-10 for the combined load case. Results are extracted based on combined load case LF21 since this is the most critical combined load case for this operation.

- All reaction forces and moments at the hook point are negligible apart from the vertical reaction force which is equal to the vertical load applied on the structure.
- All reaction forces and moments at the lateral and transverse boundary conditions of the LBMS structure are less than 1% of the overall load applied.
- The reaction forces on the model is equal to the applied loads, hence the model is validated.

		FIXED JOINTS REACTION FORCES AND MOMENT					
	LOAD	***************	kN	****************	**************	kN-m	**************
JOINT	COND	FORCE(X)	FORCE(Y)	FORCE(Z)	MOMENT(X)	MOMENT(Y)	MOMENT(Z)
0012	LF21	-3.151	0.000	0.000	0.000	0.000	0.000
0014	LF21	3.294	0.000	0.000	0.000	0.000	0.000
0032	LF21	0.000	-1.514	0.000	0.000	0.000	0.000
0077	LF21	0.000	1.208	0.000	0.000	0.000	0.000
0093	LF21	-0.143	0.305	449.165	0.000	0.000	0.000

Figure 11-10: Lowering in Water Analysis – Reaction Forces & Moments.

11.4.3 Sling Members Forces

The sling forces for LBMS are shown in Figure 11-11 . They represent the forces acting on the lifting points including all factors and shall be used for the design of the padeyes.

MEMBER FORCES AND MOMENTS

MEMBER NUMBER	MEMBER END	GROUP ID	LOAD COND	FORCE(X) kN	FORCE(Y) kN	FORCE(Z) kN	MOMENT(X) kN-m	MOMENT(Y) kN-m	MOMENT(Z) kN-m
0093-0032	0093	SLI	LF21	109.4332	-0.0007	-0.1893	0.0000	0.5658	0.0097
	0032		LF21	110.0616	-0.0007	0.1079	0.0000	0.0000	0.0000
0093-0033	0093	SLI	LF21	109.8929	0.0005	-0.1892	0.0000	0.5659	-0.0071
	0033		LF21	110.5214	0.0005	0.1078	0.0000	0.0000	0.0000
0093-0076	0093	SLI	LF21	134.8251	0.0005	-0.1800	0.0000	0.5689	-0.0090
	0076		LF21	135.6087	0.0005	0.1120	0.0000	0.0000	0.0000
0093-0077	0093	SLI	LF21	133.2374	-0.0003	-0.1802	0.0000	0.5689	0.0058
	0077		LF21	134.0211	-0.0003	0.1122	0.0000	0.0000	0.0000

Figure 11-11: Lowering in Water Analysis – Sling Forces.

11.4.4 Member Unity Check Ratio (UCR)

The member unity check pertaining to load case LF21 for all the member groups are extracted and shown in Figure 11-12 and Figure 11-13.

The maximum UCR for this load case is 0.97 and occurs on the UPE longitudinal framing Member.

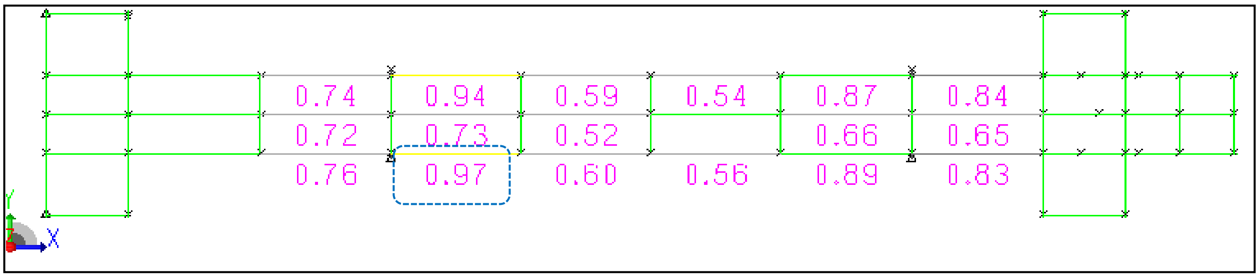


Figure 11-12: Lowering in Water Analysis – UCR Summary.

SACS IV - * * * M E M B E R   G R O U P   S U M M A R Y * * *

GRUP ID	CRITICAL MEMBER	LOAD COND	MAX. UNITY CHECK	DIST FROM END m	* APPLIED STRESSES * AXIAL N/mm2	BEND-Y N/mm2	BEND-Z N/mm2	*** ALLOWABLE STRESSES *** AXIAL N/mm2	EULER N/mm2	BEND-Y N/mm2	BEND-Z N/mm2	CRIT COND	EFFECTIVE LENGTHS KLY m	KLZ m	CM * VALUES * Y	Z
BM1	0003-0004	LF21	0.73	0.0	4.13	-163.13	-3.97	206.59	258.68	231.13	314.27	TN+BN	12.0	3.0	1.00	1.00
BM3	0023-0025	LF21	0.97	0.0	-18.39	136.50	-6.10	89.14	122.56	192.05	330.54	CM+BN	12.0	3.0	1.00	1.00
BM4	0036-0009	LF21	0.32	0.9	0.29	39.45	-50.34	206.59	1344.09	237.92	330.54	TN+BN	0.9	0.9	1.00	1.00
BM5	0031-0007	LF21	0.36	0.9	-0.50	52.16	-40.70	204.14	8472.86	229.39	312.65	CM+BN	0.9	0.9	1.00	1.00
T01	0046-0048	LF21	0.06	0.0	-1.42	-11.43	-0.97	74.12	74.12	258.75	258.75	C<.15	0.6	4.0	0.85	0.85
T02	0059-0057	LF21	0.00	0.2	-0.05	-0.04	0.00	205.19	*******	258.75	258.75	C<.15	0.2	0.2	0.85	0.85
T03	0062-0065	LF21	0.01	0.0	-0.09	-2.17	0.00	184.15	909.11	258.75	258.75	C<.15	1.9	1.9	0.85	0.85
U01	0050-0051	LF21	0.01	1.9	-0.04	-0.24	-3.67	152.57	297.76	226.00	330.54	CM+BN	1.9	1.9	1.00	1.00

Figure 11-13: Lowering in Water Analysis – Member Group UCR Summary.

12 Retrieval Analysis

If the LBMS is not installed into the LBMS target position on the first attempt, retrieval becomes necessary. It consists of raising the LBMS and then moving it into the good position.

This section details the results for the LBMS retrieval. The structural strength and stability assessment of the LBMS shall conform to the requirements of AISC-ASD Ref [26] and API RP 2A-WSD Ref [28] as applicable.

The sling material properties applied are presented in section 6.2. The lengths of the slings are the same as those shown in Section 11, the length of the shorter and tensioned slings are shown in Table 12-1. The slings are defined as tension only members and member releases are applied to release all rotation to prevent transfer of unrealistic moments.

S/N	LBMS/Sling Configuration	sling length (m)
1	Two tensioned slings lift point	13.91

Table 12-1: Length of Sling.

Two retrieval configuration/stages (Ref [15]) were analysed and reported.

Stage 1 Description

The LBMS is bond to seabed. A retrieval is made with 4 slings connected to the hook, but only two slings are considered tensioned (slings are at 90° with the LBMS X-axis) and the other two are considered slack and are not modelled. The LBMS is not moving.

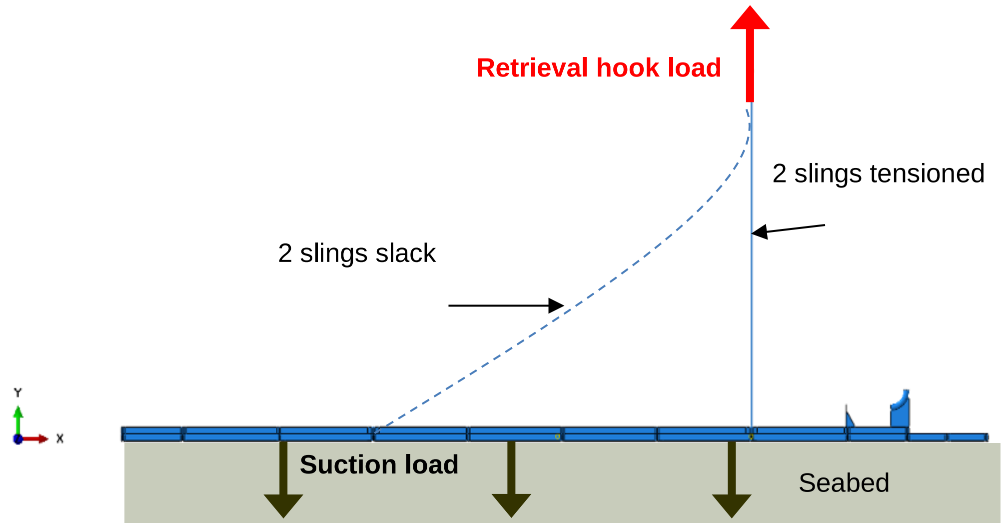


Figure 12-1: LBMS Retrieval Stage 1 – General Overview.

Stage 2 Description

The suction pressure between the mudmat surface and the soil breaks when the hook load exceeds the suction load and lifting is initiated. The LBMS is not bond to the seabed since the suction pressure is broken but soil still supports the LBMS. The sling configuration is still two slings tensioned and two slings slack.

12.1 Boundary Conditions

12.1.1 Stage 1

The hook node has two degrees of freedom fixed: translation in X and Y direction. LBMS extremity is completely fixed to the ground.

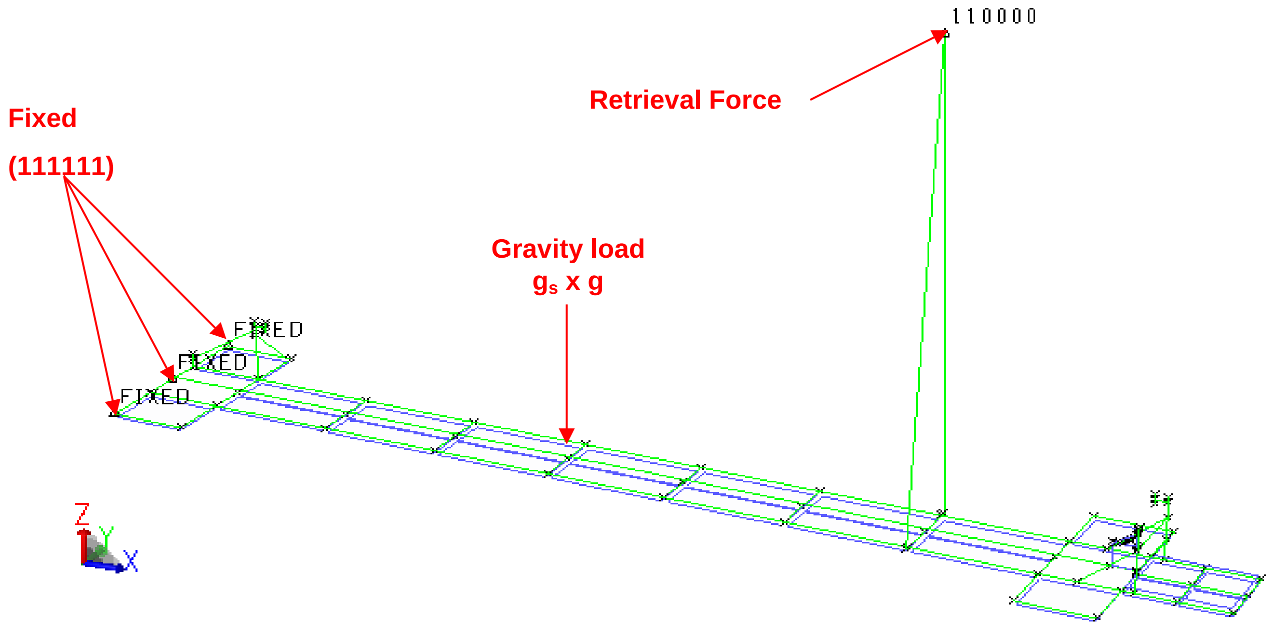


Figure 12-2: Retrieval Analysis (Stage 1) Boundary Conditions

12.1.2 Stage 2

The hook point has three degrees of freedom fixed: translation in X, Y and Z directions. The LBMS extremity previously fixed to ground is now a pivot around Y-axis.

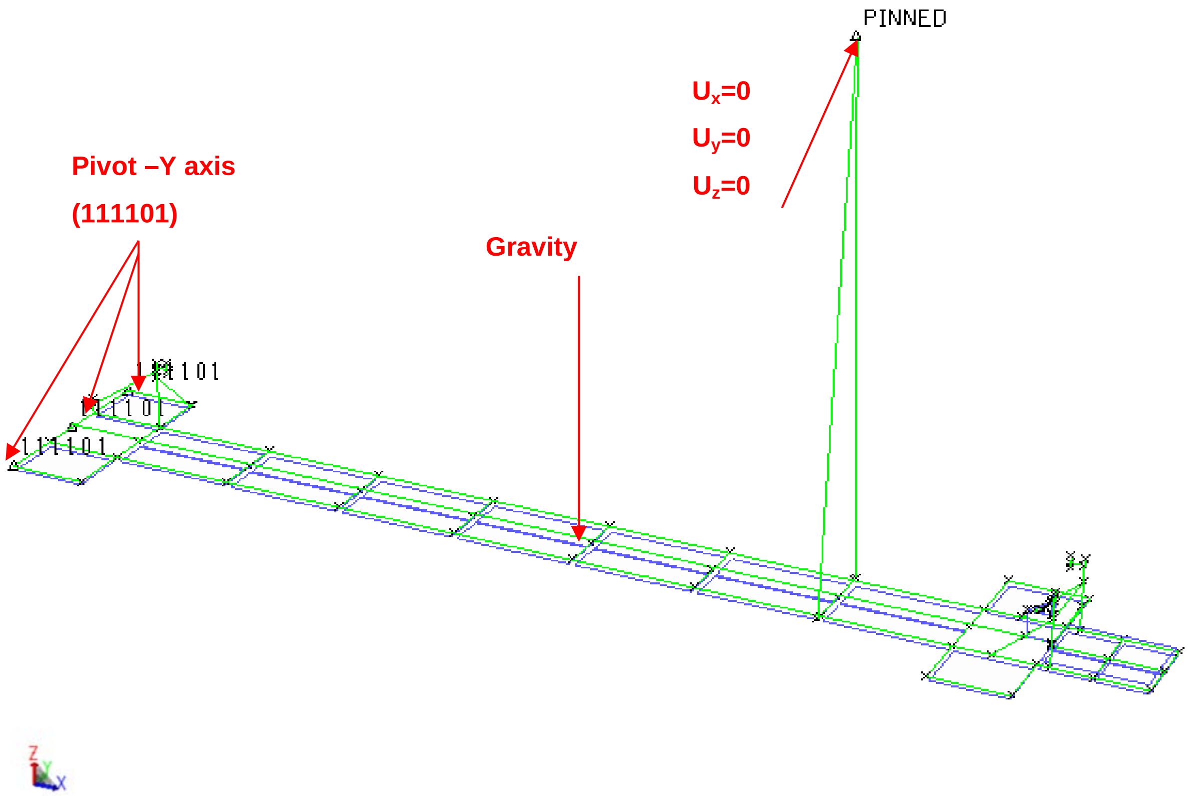


Figure 12-3 : Retrieval Analysis (Stage 2) Boundary Conditions.

12.2 Load Condition

12.2.1 Stage 1 - Load condition

During the retrieval of the LBMS, a suction pressure is developed under the mudmat due to vacuum pressure between the mudmat and the seabed. This suction pressure together with the gravity load tend to resist the hook load and hence the retrieval operation. Sufficient force should therefore be applied to the retrieval cable in order to break this suction pressure and hence allow for lifting of the LBMS out of the water.

Load factor	Water
DAF Dynamic Amplification Factor	2.00
CF Consequence Factor	1.35
SKL Skew Load Factor	1.33
WCF Weight Contingency Factor	1.10
CoG	1.05
Total	**4.15**

Table 12-2: Design Load Factors.

A suction load $F_{suction} = 145kN$ is considered as reported in the LBMS geotechnical report Ref [23]. The weight of the structure in water is considered without the effects of DAF and Skew load factor as the structure is already on the seabed and Is being lifted with two strings during stage 1 of the Immediate retrieval analysis.The retrieval hook load is thus calculated as shown below:

$$F_{hook} = W_s \times \frac{LF_{water}}{DAF_{water} \times SKL} + F_{suction} = 108.9 \times \frac{4.15}{2 \times 1.33} + 145 = 315kN$$

Where:

$W_s = \text{weight of Structure in water}$

$LF_{water} = \text{total design load factors in water}$

$DAF \;= \text{Dynamic Amplification Factor}$

$SKL \;= \text{Skew load factor}$

$F_{\;suction} = \text{Suction load considered}$

A gravity load multiplied by the factor g_s is applied to the structure in order to ensure zero moments about the y axis (My) of the structure.
g_s is calculated as follows:

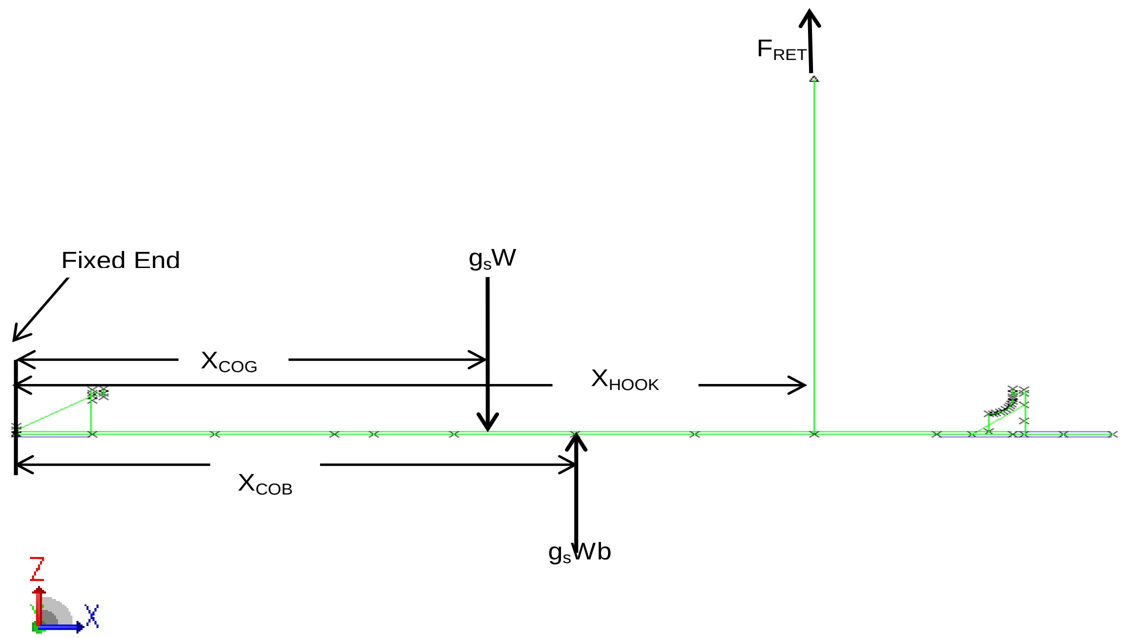


Figure 12-4: Retrieval Analysis Stage 1-LBMS Moment Diagram.

Where:

$X_{COG}\ = Center\ of\ Gravity\ distance\ from\ fixed\ end$

$W\ = Structure's\ weight\ in\ air$

$Wb\ = Structure's\ Bouyancy$

$X_{COB}\ = Center\ of\ Bouyancy\ distance\ from\ fixed\ end$

$F_{RET}\ = Retrieval\ hook\ Load$

$X_{HOOK}\ = Hook\ distance\ from\ fixed\ end = 19.945m$

$g_s\ = Calculated\ factor\ to\ acheive\ zero\ moments\ about\ Y\ axis$

```
****** SUMMARY OF SEASTATE GENERATED DEAD AND BUOYANCY LOADS ******

                    WATER DEPTH =      1500.000 M.

                 TOTAL DEAD WEIGHT   =      125.436 KN
           CENTER OF GRAVITY   -X-   =       13.900 M.
                               -Y-   =        0.014 M.
                               -Z-   =        0.013 M.

   TOTAL BUOYANCY LOAD (DISPLACEMENT) =       16.439 KN
          CENTER OF BUOYANCY   -X-   =       13.919 M.
                               -Y-   =        0.014 M.
                               -Z-   =        0.016 M.
```

Figure 12-5: Structure Dead/Buoyancy loads and COG/COB distance from fixed end

Taking moments about the Fixed End

$$\sum M_Y = 0 \quad \rightarrow \quad g_s W \times X_{COG} - g_s W_b \times X_{COB} - F_{RET} \times X_{HOOK} = 0$$

$$g_s = \frac{F_{RET} \times X_{HOOK}}{(W \times X_{COG} - W_b \times X_{COB})} = \frac{315 \times 19.945}{(125.436 \times 13.900 - 16.439 \times 13.919)} \quad \rightarrow \quad g_s = 4.148$$

The design load combinations associated with each analysis represents the appropriate load conditions that produce the most severe effects on the LBMS structure consistent with the probability of their simultaneous occurrence.

Applied Load case is detailed below:

Load case	Description
GRVZ	Structure Self weight
RETR	Retrieval hook Load

Table 12-3: Load case.

Load Combination is detailed below:

Load Combination	Description
SELZ	Structure Self weight multiplied by factor g_s
LF30	Retrieval Hook load + SELZ

Table 12-4: Load Combinations.

The applied load summary extracted from the SACS model is presented in Figure 12-6 and Figure 12-7

****** SEASTATE BASIC LOAD CASE SUMMARY ******
RELATIVE TO MUDLINE ELEVATION

LOAD CASE	LOAD LABEL	FX (KN)	FY (KN)	FZ (KN)	MX (KN-M)	MY (KN-M)	MZ (KN-M)	DEAD LOAD (KN)	BUOYANCY (KN)
1	GRVZ	0.00	0.00	-109.00	-1.5	1514.8	0.0	125.44	16.44
2	RETR	0.00	0.00	315.05	0.0	-6283.7	0.0	0.00	0.00

Figure 12-6: Retrieval Analysis – Basic Load Summary – Stage 1.

***** SEASTATE COMBINED LOAD CASE SUMMARY *****
RELATIVE TO MUDLINE ELEVATION

LOAD CASE	LOAD LABEL	FX (KN)	FY (KN)	FZ (KN)	MX (KN-M)	MY (KN-M)	MZ (KN-M)
3	SELZ	0.00	0.00	-452.12	-6.2	6283.2	0.0
4	LF30	0.00	0.00	-137.07	-6.2	-0.4	0.0

Figure 12-7: Retrieval Analysis – Combined Load Summary – Stage 1.

12.2.2 Stage 2 - Load condition

A gravity load is applied on the whole structure; the Skew load factor is neglected in calculating the Global design factor because during Stage 2 of the retrieval analysis, only two slings are bearing the submerged weight of the structure at the initiation of lift in line with GS-EP-STR-401 Ref.[9].

$$gravity = \frac{LF\ water}{SKL} \times g = \frac{4.15}{1.33} \times g = 3.12g$$

Applied load case is detailed below:

Load case	Description
GRVZ	Structure Self weight
LF31	α×GRVZ
where α= 3.12 for Retrieval (Stage 2)	

Table 12-5: Load case Retrieval stage 2.

The applied load summary extracted from the SACS model is presented in Figure 12-8 and Figure 12-9:

****** SEASTATE BASIC LOAD CASE SUMMARY ******
RELATIVE TO MUDLINE ELEVATION

LOAD CASE	LOAD LABEL	FX (KN)	FY (KN)	FZ (KN)	MX (KN-M)	MY (KN-M)	MZ (KN-M)	DEAD LOAD (KN)	BUOYANCY (KN)
1	GRVZ	0.00	0.00	-109.01	-1.5	1514.5	0.0	125.44	16.44

Figure 12-8: Retrieval Analysis – Basic Load Summary – Stage 2.

***** SEASTATE COMBINED LOAD CASE SUMMARY *****
RELATIVE TO MUDLINE ELEVATION

LOAD CASE	LOAD LABEL	FX (KN)	FY (KN)	FZ (KN)	MX (KN-M)	MY (KN-M)	MZ (KN-M)
2	LF31	0.00	0.00	-340.10	-4.8	4725.2	0.0

Figure 12-9: Retrieval Analysis – Combined Load Summary – Stage 2.

12.3 Detailed Results (Stage 1)

This section presents the detailed results of the analysis performed on the LBMS to sustain loads imposed during all the phases considered.

The structural strength and stability assessment of the LBMS shall conform to the requirements of AISC-ASD Ref [26] and API RP 2A-WSD Ref [28] as applicable.

12.3.1 Reactions

The reaction forces & moments at the fixed nodes of the LBMS structure are extracted in Figure 12-11 for the combined load case. Results are extracted based on combined load case LF30.

- All reaction forces and moments at the hook point are negligible. This is valid since the hook node was not fixed in the vertical and only vertical loading has been applied to the structure.
- All reaction forces and moments about the Y axis at the lateral and transverse boundary conditions of the LBMS structure are negligible.
- The sum of the vertical reactions at the fixed nodes is equal to the applied load on the model.
- The reaction forces on the model is equal to the applied load hence the model is validated.

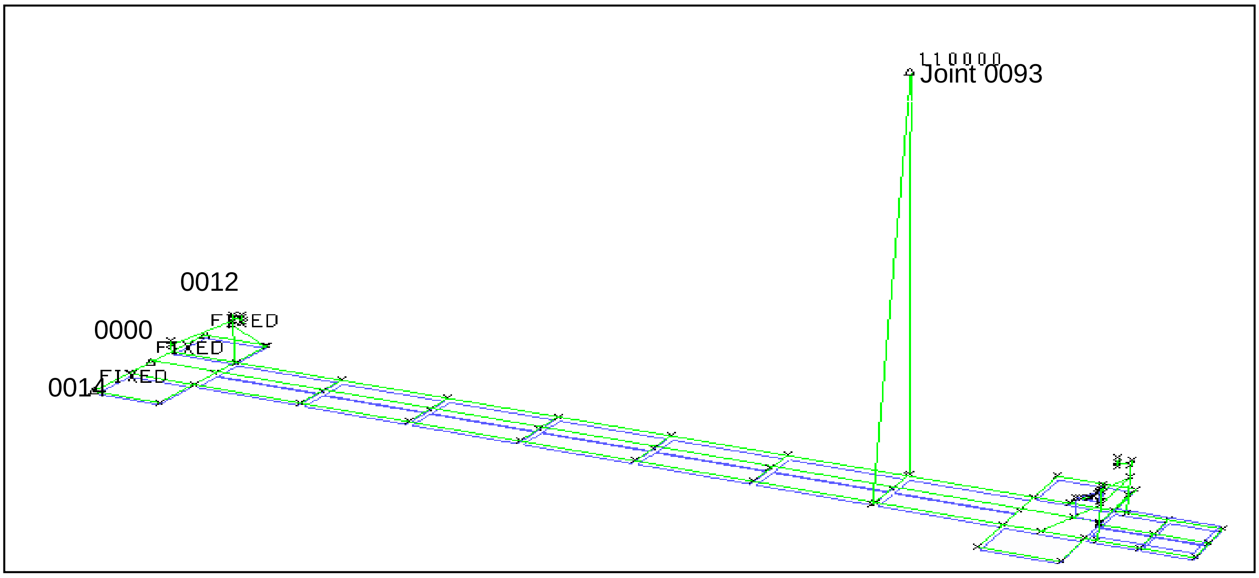


Figure 12-10: Joint Numbering.

FIXED JOINTS REACTION FORCES AND MOMENT

JOINT	LOAD COND	******** kN ******** FORCE(X)	FORCE(Y)	FORCE(Z)	******** kN-m ******** MOMENT(X)	MOMENT(Y)	MOMENT(Z)
0000	LF30	8.625	-0.067	111.324	0.429	9.149	2.497
0012	LF30	-5.277	0.527	13.981	-4.216	-6.368	-1.428
0014	LF30	-3.348	-0.110	11.765	3.936	-3.080	1.187
0093	LF30	0.000	-0.350	0.000	0.000	0.000	0.000

Figure 12-11: Retrieval Analysis – Reaction Forces & Moments – Stage 1.

12.3.2 Sling Members Forces

The sling forces for LBMS retrieval stage 1 are shown in Figure 12-12 . They represent the forces acting on the lifting points including all factors and shall be used for the design of the padeyes.

MEMBER FORCES AND MOMENTS

MEMBER NUMBER	MEMBER END	GROUP ID	LOAD COND	FORCE(X) kN	FORCE(Y) kN	FORCE(Z) kN	MOMENT(X) kN-m	MOMENT(Y) kN-m	MOMENT(Z) kN-m
0093-0032	0093	SLI	LF30	181.7632	0.0000	-0.0282	0.0000	0.0024	0.0000
	0032		LF30	181.8568	0.0000	0.0260	0.0000	0.0000	0.0000
0093-0033	0093	SLI	LF30	182.4608	0.0000	-0.0282	0.0000	0.0024	0.0000
	0033		LF30	182.5543	0.0000	0.0260	0.0000	0.0000	0.0000

Figure 12-12: Retrieval Analysis – Sling Forces – Stage 1.

12.3.3 Member Unity Check (UC)

The member unity check for all the member groups are extracted and shown in Figure 12-13 and Figure 12-14.

- The maximum UCR for this load case is 0.77 and it occurs on the UPE longitudinal framing member attached to the lift point.

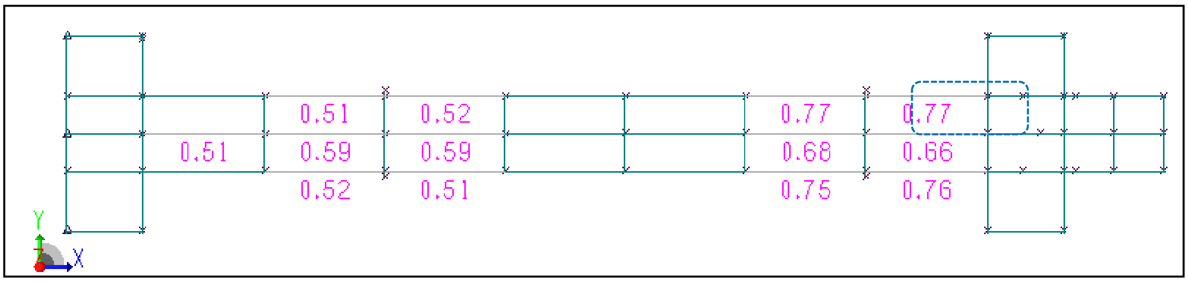


Figure 12-13: Retrieval Analysis – UCR Summary – Stage 1.

SACS IV - * * * M E M B E R G R O U P S U M M A R Y * * *

GRUP ID	CRITICAL MEMBER	LOAD COND	MAX. UNITY CHECK	DIST FROM END m	* APPLIED STRESSES * AXIAL N/mm2	BEND-Y N/mm2	BEND-Z N/mm2	*** ALLOWABLE STRESSES *** AXIAL N/mm2	EULER N/mm2	BEND-Y N/mm2	BEND-Z N/mm2	CRIT COND	EFFECTIVE LENGTHS KLY m	KLZ m	CM * VALUES * Y	Z
BM1	0006-0007	LF30	0.68	3.0	-0.65	-153.26	0.91	79.04	94.06	231.13	314.27	CM+BN	19.9	3.0	1.00	1.00
BM3	0030-0035	LF30	0.77	0.0	-1.22	-140.19	4.43	56.87	72.52	190.68	330.54	CM+BN	15.6	3.0	1.00	1.00
BM4	0019-0000	LF30	0.22	0.9	0.10	13.15	55.99	206.59	1344.09	237.92	330.54	TN+BN	0.9	0.9	1.00	1.00
BM5	0030-0007	LF30	0.42	0.9	-6.38	77.29	-20.54	204.14	8472.86	229.39	312.65	CM+BN	0.9	0.9	1.00	1.00
T01	0017-0090	LF30	0.11	0.0	-1.24	17.41	16.71	77.19	77.19	258.75	258.75	C<.15	3.9	1.4	0.85	0.85
T02	0059-0057	LF30	0.00	0.2	-0.05	0.00	0.00	205.19	*******	258.75	258.75	C<.15	0.2	0.2	0.85	0.85
T03	0062-0065	LF30	0.01	0.0	-0.02	-2.65	0.00	184.15	909.11	258.75	258.75	C<.15	1.9	1.9	0.85	0.85
U01	0050-0051	LF30	0.01	1.9	-0.05	-0.24	-3.36	152.57	297.76	226.00	330.54	CM+BN	1.9	1.9	1.00	1.00

Figure 12-14: Retrieval Analysis – Member Group UCR Summary – Stage 1.

Refer ANNEX1: LBMS FRAMING for group member details.

12.4 Detailed Results (Stage 2)

This section presents the detailed results of the analysis performed on the LBMS to sustain loads imposed during retrieval stage 2.

The structural strength and stability assessment of the LBMS shall conform to the requirements of AISC-ASD Ref [26] and API RP 2A-WSD Ref [28] as applicable.

12.4.1 Reactions

The reaction forces & moments at the fixed nodes of the LBMS structure are extracted in Figure 12-16 for the combined load case. Results are extracted based on load case LF31.

- All reaction forces and moments at the hook point are negligible apart from the vertical reaction force.
- All reaction forces and moments at the lateral and transverse boundary conditions of the LBMS structure are negligible.
- The sum of the vertical reactions at the fixed nodes is equal to the applied load on the model.
- The reaction forces on the model is equal to the applied load hence the model is validated.

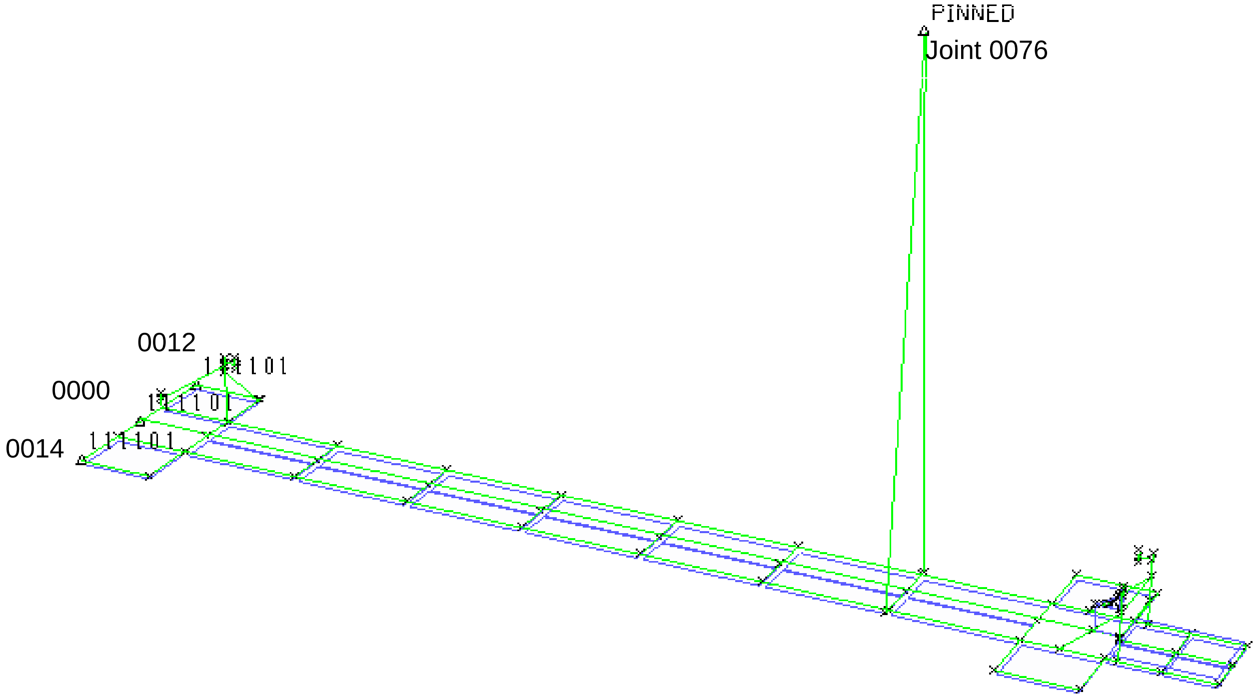


Figure 12-15: Joint Numbering.

FIXED JOINTS REACTION FORCES AND MOMENT

JOINT	LOAD COND	FORCE(X) (kN)	FORCE(Y) (kN)	FORCE(Z) (kN)	MOMENT(X) (kN-m)	MOMENT(Y) (kN-m)	MOMENT(Z) (kN-m)
0000	LF31	11.692	-0.319	87.108	1.240	0.000	2.823
0012	LF31	-7.174	0.792	8.717	-3.501	0.000	-1.807
0014	LF31	-4.518	-0.009	7.333	2.792	0.000	1.745
0076	LF31	0.000	-0.465	236.934	0.000	0.000	0.000

Figure 12-16: Retrieval Analysis – Reaction Forces & Moments – Stage 2.

12.4.2 Sling Members Forces

The sling forces for LBMS retrieval Stage 2 are shown in Figure 12-17 . They represent the forces acting on the lifting points including all factors and shall be used for the design of the padeyes.

MEMBER FORCES AND MOMENTS

MEMBER NUMBER	MEMBER END	GROUP ID	LOAD COND	FORCE(X) (kN)	FORCE(Y) (kN)	FORCE(Z) (kN)	MOMENT(X) (kN-m)	MOMENT(Y) (kN-m)	MOMENT(Z) (kN-m)
0076-0032	0076	SLI	LF31	136.4947	0.0000	-0.0212	0.0000	0.0018	0.0000
	0032		LF31	136.5650	0.0000	0.0196	0.0000	0.0000	0.0000
0076-0033	0076	SLI	LF31	137.4210	0.0000	-0.0212	0.0000	0.0018	0.0000
	0033		LF31	137.4913	0.0000	0.0196	0.0000	0.0000	0.0000

Figure 12-17: Retrieval Analysis – Sling Forces – Stage 2.

12.4.3 Member Unity Check (UC)

The member unity check for all the member groups are extracted and shown in Figure 12-18 and Figure 12-19.

The maximum UCR for this load case is 0.60 and it occurs on the UPE longitudinal framing member attached to the lift point.

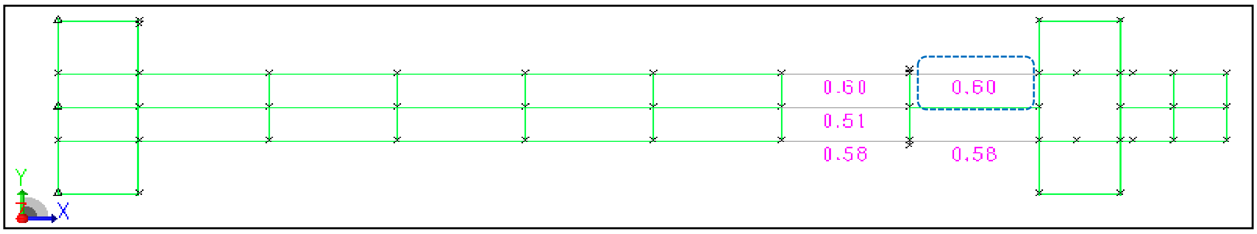


Figure 12-18: Retrieval Analysis – UCR Summary – Stage 2.

SACS IV - * * * M E M B E R G R O U P S U M M A R Y * * *

GRUP ID	CRITICAL MEMBER	LOAD COND	MAX. UNITY CHECK	DIST FROM END m	* APPLIED STRESSES * AXIAL N/mm2	BEND-Y N/mm2	BEND-Z N/mm2	*** ALLOWABLE STRESSES *** AXIAL N/mm2	EULER N/mm2	BEND-Y N/mm2	BEND-Z N/mm2	CRIT COND	EFFECTIVE LENGTHS KLY m	KLZ m	CM * VALUES * Y	Z
BM1	0006-0007	LF31	0.51	3.0	-0.88	-115.21	1.29	145.74	258.68	231.13	314.27	CM+BN	12.0	3.0	1.00	1.00
BM3	0030-0035	LF31	0.60	0.0	-1.71	-106.14	6.04	56.87	72.52	190.68	330.54	CM+BN	15.6	3.0	1.00	1.00
BM4	0017-0001	LF31	0.29	0.9	0.07	-20.82	-66.42	206.59	1344.09	237.92	330.54	TN+BN	0.9	0.9	1.00	1.00
BM5	0030-0007	LF31	0.36	0.9	-4.78	58.15	-28.47	204.14	8472.86	229.39	312.65	CM+BN	0.9	0.9	1.00	1.00
T01	0017-0090	LF31	0.09	0.0	-1.14	16.79	12.18	77.19	77.19	258.75	258.75	C<.15	3.9	1.4	0.85	0.85
T02	0059-0057	LF31	0.00	0.2	-0.04	0.00	0.00	205.19	*******	258.75	258.75	C<.15	0.2	0.2	0.85	0.85
T03	0062-0065	LF31	0.01	0.0	-0.02	-1.99	0.00	184.15	909.11	258.75	258.75	C<.15	1.9	1.9	0.85	0.85
U01	0050-0051	LF31	0.01	1.9	-0.03	-0.14	-1.89	152.57	297.76	226.00	330.54	CM+BN	1.9	1.9	1.00	1.00

Figure 12-19: Retrieval Analysis – Member Group UCR Summary – Stage 2.

Refer to ANNEX1: LBMS FRAMING for member group details.

ANNEXES

ANNEX1: LBMS FRAMING

This appendix details the following at the LBMS Framing:

- Node numbering
- Member Grouping

<u>Node Numbering</u>

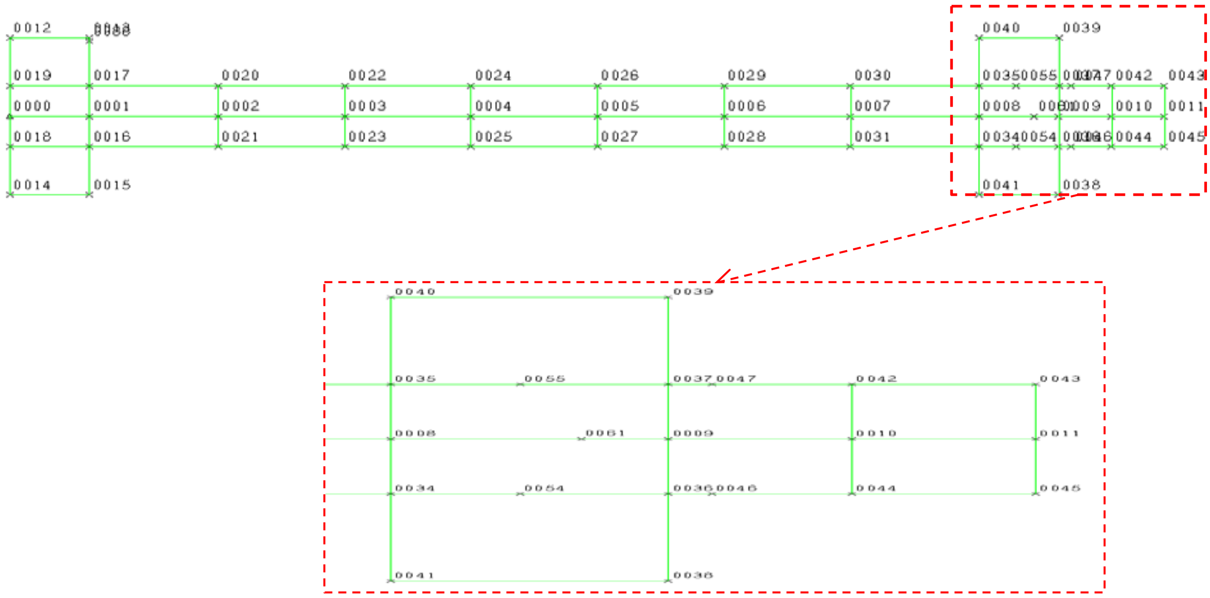


Figure A1- 1:Joint Numbering - Mudmat top view.

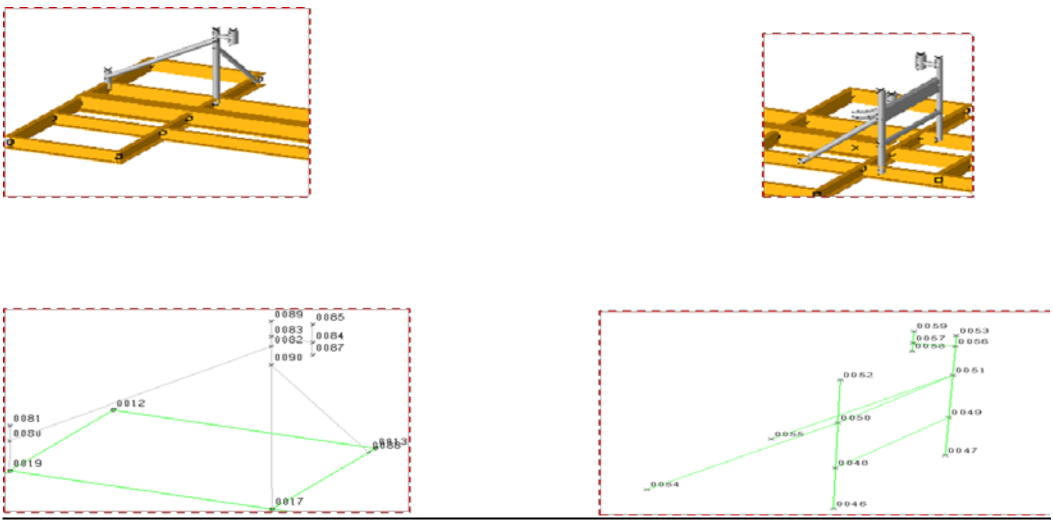


Figure A1- 2:Joint Numbering – ROV docking beam and Transponder frame (3D view).

Member Grouping

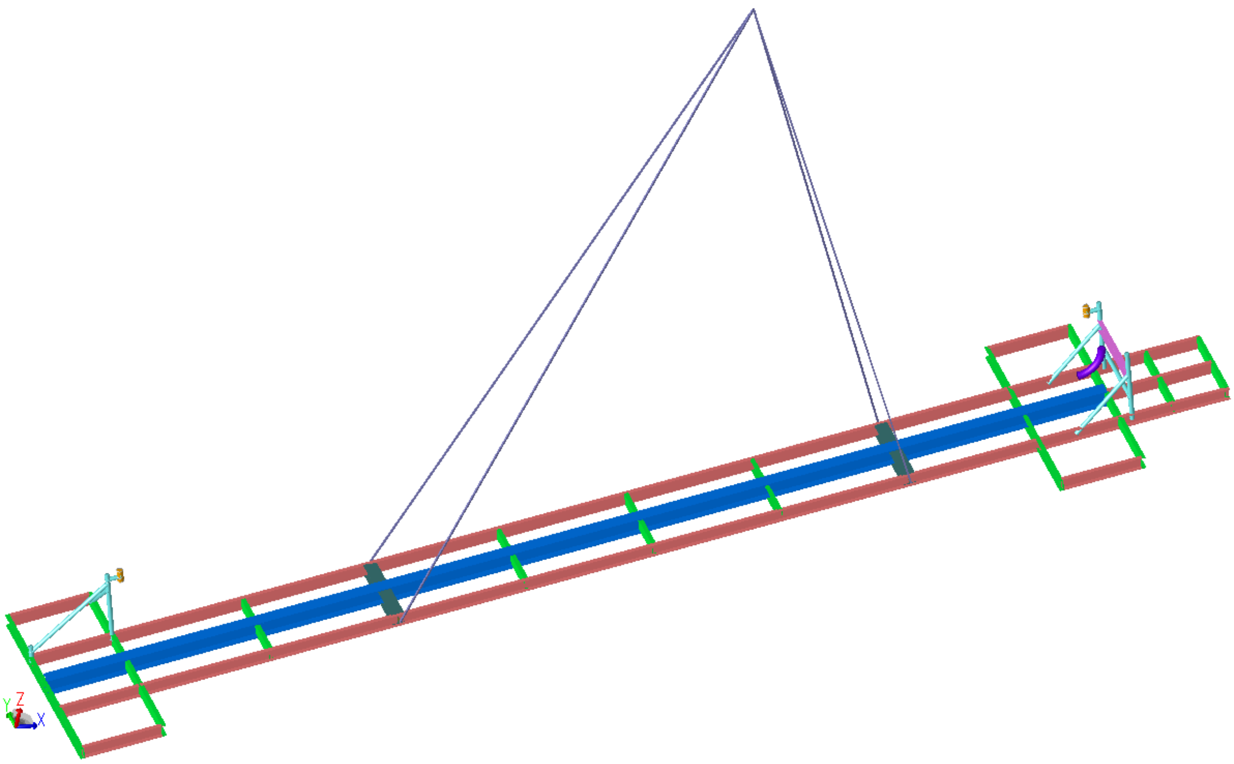


Figure A1- 3: Member Group Label

Colour	Group Label	Designation
	BM1	HEB 400
	BM3	UPE300
	BM4	UPE300
	BM5	HEB 300
	T01	Ø 101.6mm × 8.08mm
	T02	Ø 141.3mm × 12.7mm
	U01	UPN 300
	T03	Ø 168.3mm × 12.7mm

Table A1-1: Member Group Labelling & Dimensions.

ANNEX2: SOIL SPRINGS STIFFNESS EVALUATION

EGINA MAIN INTEGRATED PROJECT
MUDMAT SUPPORT SPRING CONSTANTS EVALUATION
LBMS IN-PLACE ANALYSIS

SPRING VALUES

Kx	865	kN/m
Ky	865	kN/m
Kz	5990	kN/m

MUDMAT DIMENSIONS

First Section length	2.0000	m	Second Section Length	1.305	Third section Length	1.195
First Section Width	1.5000	m	Second Section width	1	Third section width	1
Mudmat Plate Area	3.0000	m^2	Mudmat Plate area	2.61	Mudmat Plate area	2.39
Main Plated Area	42.0000	m^2				
Total Area in m^2	59.0000					

First Section	NODE I.D.				Spring Value Per Node Point		
Node I.D	**section 1**	**Length(m)**	**Width(m)**	**Area(m^2)**	**Kx(kN/m)**	**Ky(kN/m)**	**Kz(kN/m)**
1	0012	1.0000	0.7500	0.7500	11.00	11.00	76.14
2	0013	1.0000	0.7500	0.7500	11.00	11.00	76.14
3	0019	1.0000	0.7500	0.7500	11.00	11.00	76.14
4	0017	1.0000	0.7500	0.7500	11.00	11.00	76.14
5	0014	1.0000	0.7500	0.7500	11.00	11.00	76.14
6	0018	1.0000	0.7500	0.7500	11.00	11.00	76.14
7	0015	1.0000	0.7500	0.7500	11.00	11.00	76.14
8	0016	1.0000	0.7500	0.7500	11.00	11.00	76.14
9	0040	1.0000	0.7500	0.7500	11.00	11.00	76.14
10	0039	1.0000	0.7500	0.7500	11.00	11.00	76.14
11	0035	1.0000	0.7500	0.7500	11.00	11.00	76.14
12	0037	1.0000	0.7500	0.7500	11.00	11.00	76.14
13	0034	1.0000	0.7500	0.7500	11.00	11.00	76.14
14	0041	1.0000	0.7500	0.7500	11.00	11.00	76.14
15	0038	1.0000	0.7500	0.7500	11.00	11.00	76.14
16	0036	1.0000	0.7500	0.7500	11.00	11.00	76.14
Second Section	**NODE I.D.**	**Length(m)**	**Width(m)**	**Area(m^2)**	**Kx(kN/m)**	**Ky(kN/m)**	**Kz(kN/m)**
17	0037	0.5975	0.5000	0.2988	4.38	4.38	30.33
18	0009	0.5975	1.0000	0.5975	8.76	8.76	60.66
19	0036	0.5975	0.5000	0.2988	4.38	4.38	30.33
20	0042	1.2500	0.5000	0.6250	9.16	9.16	63.45
21	0043	0.6525	0.5000	0.3263	4.78	4.78	33.12
22	0011	0.6525	1.0000	0.6525	9.57	9.57	66.25
23	0045	0.6525	0.5000	0.3263	4.78	4.78	33.12
24	0044	1.2500	0.5000	0.6250	9.16	9.16	63.45
25	0010	1.2500	1.0000	1.2500	18.33	18.33	126.91
			CHECK	17.0000	249.24	249.24	1725.93

MAIN FRAME								Spring Value Per Node Point		
Node I.D	**Length A(m)**	**Width A(m)**	**Area A(m^2)**	**Length B(m)**	**Width B(m)**	**Area B(m^2)**	**Total Area(m^2)**	**Kx(kN/m)**	**Ky(kN/m)**	**Kz(kN/m)**
0035	1.5000	0.5000	0.7500			0.0000	0.7500	11.00	11.00	76.14
0030	3.0000	0.5000	1.5000			0.0000	1.5000	21.99	21.99	152.29
0008	1.5000	1.0000	1.5000			0.0000	1.5000	21.99	21.99	152.29
0034	1.5000	0.5000	0.7500			0.0000	0.7500	11.00	11.00	76.14
0031	3.0000	0.5000	1.5000			0.0000	1.5000	21.99	21.99	152.29
0007	3.0000	1.0000	3.0000			0.0000	3.0000	43.98	43.98	304.58
0029	3.0000	0.5000	1.5000			0.0000	1.5000	21.99	21.99	152.29
0006	3.0000	1.0000	3.0000			0.0000	3.0000	43.98	43.98	304.58
0028	3.0000	0.5000	1.5000			0.0000	1.5000	21.99	21.99	152.29
0026	3.0000	0.5000	1.5000			0.0000	1.5000	21.99	21.99	152.29
0005	3.0000	1.0000	3.0000			0.0000	3.0000	43.98	43.98	304.58
0027	3.0000	0.5000	1.5000			0.0000	1.5000	21.99	21.99	152.29
0024	3.0000	0.5000	1.5000			0.0000	1.5000	21.99	21.99	152.29
0004	3.0000	1.0000	3.0000			0.0000	3.0000	43.98	43.98	304.58
0025	3.0000	0.5000	1.5000			0.0000	1.5000	21.99	21.99	152.29
0022	3.0000	0.5000	1.5000			0.0000	1.5000	21.99	21.99	152.29
0003	3.0000	1.0000	3.0000			0.0000	3.0000	43.98	43.98	304.58
0023	3.0000	0.5000	1.5000			0.0000	1.5000	21.99	21.99	152.29
0020	3.0000	0.5000	1.5000			0.0000	1.5000	21.99	21.99	152.29
0002	3.0000	1.0000	3.0000			0.0000	3.0000	43.98	43.98	304.58
0021	3.0000	0.5000	1.5000			0.0000	1.5000	21.99	21.99	152.29
0016	1.5000	0.5000	0.7500			0.0000	0.7500	11.00	11.00	76.14
0001	1.5000	1.0000	1.5000			0.0000	1.5000	21.99	21.99	152.29
0017	1.5000	0.5000	0.7500			0.0000	0.7500	11.00	11.00	76.14
						CHECK	42.0000	615.76	615.76	4264.07
							CHECK	615.76	615.76	4264.07
							TOTAL	865.00	865.00	5990.00

Figure A2-1: Mudmat Supports Spring Stiffness Evaluation Sheet.

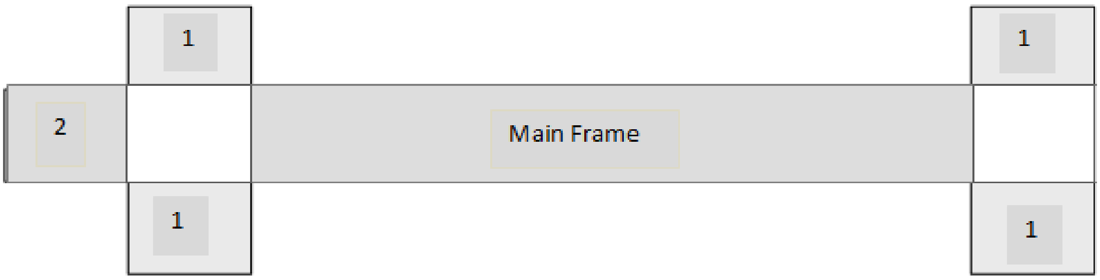


Figure A2- 2: LBMS Mudmat Plate Breakdown Description.

ANNEX3: CLAMP DESIGN

Clamp Design Technical Memo n°F10268-IM-STR#0019:

NG-EGN-21-SAEC-100291_rev01_A01.pdf

ANNEX4: LIFTING PADEYE DESIGN

Lifting Padeye Design Technical Memo n° F10268-IM-STR#0058:

NG-EGN-21-SAEC-10
0291_rev01_A02.pdf

ANNEX5: BALLAST DESIGN

Ballast Design Technical Memo n^{o} F10268-IM-STR#0022:

NG-EGN-21-SAEC-10
0291_rev01_A03.pdf

ANNEX6: ROPE GUIDE DESIGN

Rope guide Design Technical Memo n° F10268-IM-STR#0059.

NG-EGN-21-SAEC-10
0291_rev01_A04.pdf

ANNEX7: MUDMAT ANALYSIS

Mudmat Analysis Technical Memo n° F10268-IM-STR#0024:

NG-EGN-21-SAEC-10
0291_rev01_A05.pdf

ANNEX8: FLOWLINE IMPACT

Flowline impact Technical Memo n° F10268-IM-STR#0023:

NG-EGN-21-SAEC-100291_rev01_A06.pdf

ANNEX9: BALLAST IMPACT AND ROV SNAGGING

Ballast impact and ROV Snagging Technical Memo n° F10268-IM-STR#0025:

NG-EGN-21-SAEC-100291_rev01_A07.pdf

ANNEX10: BARGE MOTION ACCELERATION CALCULATION

EGINA FIELD DEVELOPMENT - SEA TRANSPORTATION MOTION LOADING

For sea transportation analyses, it is necessary to find the loads transferred to the structure caused by the Vessel motion during the tow.

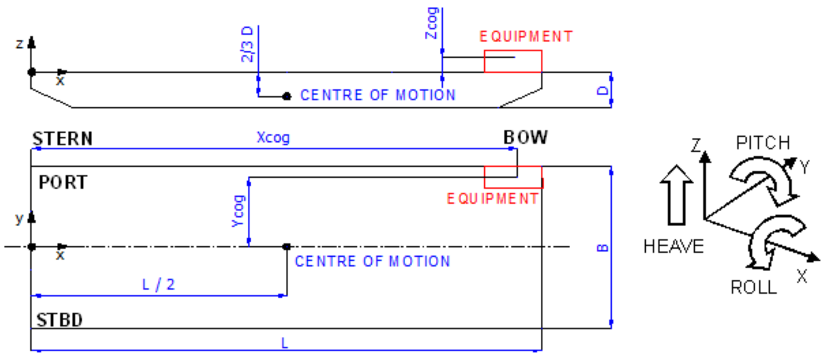
the principle of the motion criteria for a Large Cargo Barge as per GS-EP-STR-401.

The sign convention adopted is for X to be positive in a parallel line to longitudinal bulkheads running from stern to bow. Z is positive upwards and Y is positive to portside. Hence +Roll is to starboard, +Pitch is to bow and +Heave is upwards.

By Company requirement GS-EP-STR-401, Pitch acceleration (X-Direction) is increased by 20% to account for Slamming effects.

Position of the Pile on the vessel is considered at the most onerous location conservatively due the fact that the Vessel layout is yet to be decided.

Definitions & Diagrams



Motion Criteria:

Roll AMP.	$R_{AMP} := 20deg = 0.349 \cdot rad$	Roll Period,	$R_{Period} := 10s$
Pitch AMP.	$P_{AMP} := 12.5deg = 0.218 \cdot rad$	Pitch Period.	$P_{Period} := 10s$
Heave Accel.	$H_{ACC} := 0.20$	(Factor of g)	$g = 9.807 \frac{m}{s^2}$

Principal Formulations:

Rotational Acceleration = Ω x AMP   Where: $\Omega := \frac{4 \cdot \pi^2}{T^2}$ T = Period (s) & AMP in Rad.

Rotation Matrix and Load Combinations

Rotation matrix defined below is used to calculate Rotated Vectors for each case. When considering "Roll" φ= Roll AMP and θ=0 similar, when considering "Pitch" θ=Pitch AMP and φ=0.
for the combination of Roll and Pitch, φ & θ will be the appropriate factor of Roll AMP and Pitch AMP.

$$R = \begin{bmatrix} c_\psi c_\theta & (c_\psi s_\theta s_\varphi - s_\psi c_\varphi) & (c_\psi s_\theta c_\varphi + s_\psi s_\varphi) \\ s_\psi c_\theta & (s_\psi s_\theta s_\varphi + c_\psi c_\varphi) & (s_\psi s_\theta c_\varphi - c_\psi s_\varphi) \\ -s_\theta & c_\theta s_\varphi & c_\theta c_\varphi \end{bmatrix}.$$

Where:

C=COS S=SIN φ=Roll AMP θ=Pitch AMP ψ=Heave AMP (Usually 0)

$$\text{InitialVector} := \begin{pmatrix} 0 \\ 0 \\ n1\cdot g \end{pmatrix}$$

$n1 := (-1 + H_{ACC}) = -0.8$ For +HEAVE

$n2 := (-1 - H_{ACC}) = -1.2$ For -HEAVE

24 number load combinations are considered and explained here.

TR01:	+ROLL		+HEAVE	TR13:	+80%ROLL	-60%PITCH	+HEAVE
TR02:	+ROLL		-HEAVE	TR14:	+80%ROLL	-60%PITCH	-HEAVE
TR03:	-ROLL		+HEAVE	TR15:	-80%ROLL	-60%PITCH	+HEAVE
TR04:	-ROLL		-HEAVE	TR16:	-80%ROLL	-60%PITCH	-HEAVE
TR05:		+PITCH	+HEAVE	TR17:	+60%ROLL	+80%PITCH	+HEAVE
TR06:		+PITCH	-HEAVE	TR18:	+60%ROLL	+80%PITCH	-HEAVE
TR07:		-PITCH	+HEAVE	TR19:	-60%ROLL	+80%PITCH	+HEAVE
TR08:		-PITCH	-HEAVE	TR20:	-60%ROLL	+80%PITCH	-HEAVE
TR09:	+80%ROLL	+60%PITCH	+HEAVE	TR21:	+60%ROLL	-80%PITCH	+HEAVE
TR10:	+80%ROLL	+60%PITCH	-HEAVE	TR22:	+60%ROLL	-80%PITCH	-HEAVE
TR11:	-80%ROLL	+60%PITCH	+HEAVE	TR23:	-60%ROLL	-80%PITCH	+HEAVE
TR12	-80%ROLL	+60%PITCH	-HEAVE	TR24:	-60%ROLL	-80%PITCH	-HEAVE

Input Data

To calculate the acceleration factors, the Mass of Cargo and location on the Vessel as well as vessel O/A dimensions are required.

Cargo Mass: $MASS := 12.79\text{tonne}$

$COG_x := 77.797\text{m}$ $COG_y := 11.214\text{m}$ $COG_z := 0.514\text{m}$

Vessel Dimensions: $L := 91.4\text{m}$ $B := 27.43\text{m}$ $D := 6.7\text{m}$

Centre of Motion: $COM_x := \frac{L}{2} = 45.7\,\text{m}$ $COM_y := 0$ $COM_z := \frac{-2}{3}\cdot D = -4.467\,\text{m}$

Lever Arm Calculation: LA=COG - COM

$LA_x := COG_x - COM_x = 32.097\,\text{m}$ $LA_y := COG_y - COM_y = 11.214\,\text{m}$ $LA_z := COG_z - COM_z = 4.981\,\text{m}$

Load Factors: $LF_{Dead} := 1.0$ $LF_{Env} := 1.0$

Calculations

Rotational Accelerations:

$$R_{RAcc} := \frac{4\cdot\pi^2}{R_{Period}^{2}}\cdot R_{AMP} = 0.1378\,\frac{1}{s^2}\cdot rad \qquad P_{RAcc} := \frac{4\cdot\pi^2}{P_{Period}^{2}}\cdot P_{AMP} = 0.0861\,\frac{1}{s^2}\cdot rad$$

Acceleration on Global Axis (X, Y & Z)

ROLL:

$$R_{AccX} := 0$$

$$R_{AccY} := R_{RAcc}\cdot LA_z = 0.6864\,\frac{m}{s^2}$$

$$R_{AccZ} := -R_{RAcc}\cdot LA_y = -1.5454\,\frac{m}{s^2}$$

PITCH:

$$P_{AccX} := -P_{RAcc}\cdot LA_z\cdot 1.2 = -0.5148\,\frac{m}{s^2}$$

$$P_{AccY} := 0$$

$$P_{AccZ} := P_{RAcc}\cdot LA_x\cdot 1.2 = 3.3174\,\frac{m}{s^2}$$

Load Combination Acceleration Calculation:

*Rotated Vector = Rotation Matrix * Initial Vector*

For TR01 (+ROLL +HEAVE): the following shall be considered:

$$\varphi_1 := 20deg = 0.349\cdot rad \qquad \theta_1 := 0deg = 0\cdot rad \qquad \psi_1 := 0$$

$$R1 := \begin{pmatrix} \cos(\psi_1)\cdot\cos(\theta_1) & \cos(\psi_1)\cdot\sin(\theta_1)\cdot\sin(\varphi_1) - \sin(\psi_1)\cdot\cos(\varphi_1) & \cos(\psi_1)\cdot\sin(\theta_1)\cdot\cos(\varphi_1) + \sin(\psi_1)\cdot\sin(\varphi_1) \\ \sin(\psi_1)\cdot\cos(\theta_1) & \sin(\psi_1)\cdot\sin(\theta_1)\cdot\sin(\varphi_1) + \cos(\psi_1)\cdot\cos(\varphi_1) & \sin(\psi_1)\cdot\sin(\theta_1)\cdot\cos(\varphi_1) - \cos(\psi_1)\cdot\sin(\varphi_1) \\ -\sin(\theta_1) & \cos(\theta_1)\cdot\sin(\varphi_1) & \cos(\theta_1)\cdot\cos(\varphi_1) \end{pmatrix}$$

$$R1 = \begin{pmatrix} 1 & 0 & 0 \\ 0 & 0.94 & -0.342 \\ 0 & 0.342 & 0.94 \end{pmatrix} \qquad InitialVector\_1 := \begin{bmatrix} 0 \\ 0 \\ (-1 + H_{ACC})\cdot g \end{bmatrix} = \begin{pmatrix} 0 \\ 0 \\ -7.845 \end{pmatrix}\frac{m}{s^2}$$

$$RotVec\_1 := R1\cdot InitialVector\_1 = \begin{pmatrix} 0 \\ 2.683 \\ -7.372 \end{pmatrix}\frac{m}{s^2}$$

$$ACC_{X1} := RotVec\_1_{0,0} + R_{AccX} = 0\,\frac{m}{s^2} \qquad ACC_{X1\_g} := \frac{ACC_{X1}}{g} = 0 \qquad FX_1 := MASS\cdot ACC_{X1} = 0\cdot kN$$

$$ACC_{Y1} := RotVec\_1_{1,0} + R_{AccY} = 3.37\,\frac{m}{s^2} \qquad ACC_{Y1\_g} := \frac{ACC_{Y1}}{g} = 0.344 \qquad FY_1 := MASS\cdot ACC_{Y1} = 43.1\cdot kN$$

$$ACC_{Z1} := RotVec\_1_{2,0} + R_{AccZ} = -8.918\,\frac{m}{s^2} \qquad ACC_{Z1\_g} := \frac{ACC_{Z1}}{g} = -0.909 \qquad FZ_1 := MASS\cdot ACC_{Z1} = -114.1\cdot kN$$

By similar above Calculation, Load Factors for TR2, TR3 and TR4 are summurised below:

TR02 (+ROLL -HEAVE)	*TR03 (-ROLL +HEAVE)*	*TR04 (-ROLL -HEAVE)*
$ACC_{X2\_g} = 0$	$ACC_{X3\_g} = 0$	$ACC_{X4\_g} = 0$
$ACC_{Y2\_g} = 0.48$	$ACC_{Y3\_g} = -0.344$	$ACC_{Y4\_g} = -0.48$
$ACC_{Z2\_g} = -1.285$	$ACC_{Z3\_g} = -0.594$	$ACC_{Z4\_g} = -0.97$

For TR05 (+PITCH +HEAVE): the following shall be considered:

$\varphi_5 := 0\text{deg} = 0\cdot\text{rad}$ $\qquad \theta_5 := 12.5\text{deg} = 0.218\cdot\text{rad}$ $\qquad \psi_5 := 0$

$$R5 := \begin{pmatrix} \cos(\psi_5)\cdot\cos(\theta_5) & \cos(\psi_5)\cdot\sin(\theta_5)\cdot\sin(\varphi_5) - \sin(\psi_5)\cdot\cos(\varphi_5) & \cos(\psi_5)\cdot\sin(\theta_5)\cdot\cos(\varphi_5) + \sin(\psi_5)\cdot\sin(\varphi_5) \\ \sin(\psi_5)\cdot\cos(\theta_5) & \sin(\psi_5)\cdot\sin(\theta_5)\cdot\sin(\varphi_5) + \cos(\psi_5)\cdot\cos(\varphi_5) & \sin(\psi_5)\cdot\sin(\theta_5)\cdot\cos(\varphi_5) - \cos(\psi_5)\cdot\sin(\varphi_5) \\ -\sin(\theta_5) & \cos(\theta_5)\cdot\sin(\varphi_5) & \cos(\theta_5)\cdot\cos(\varphi_5) \end{pmatrix}$$

$$R5 = \begin{pmatrix} 0.976 & 0 & 0.216 \\ 0 & 1 & 0 \\ -0.216 & 0 & 0.976 \end{pmatrix} \qquad \text{InitialVector\_5} := \begin{bmatrix} 0 \\ 0 \\ (-1 + H_{ACC})\cdot g \end{bmatrix} = \begin{pmatrix} 0 \\ 0 \\ -7.845 \end{pmatrix} \frac{m}{s^2}$$

$$\text{RotVec\_5} := R5\cdot\text{InitialVector\_5} = \begin{pmatrix} -1.698 \\ 0 \\ -7.659 \end{pmatrix} \frac{m}{s^2}$$

$$ACC_{X5} := \text{RotVec\_5}_{0,0} + P_{AccX} = -2.213\,\frac{m}{s^2} \qquad ACC_{X5\_g} := \frac{ACC_{X5}}{g} = -0.226 \qquad FX_5 := MASS\cdot ACC_{X5} = -28.3\cdot kN$$

$$ACC_{Y5} := \text{RotVec\_5}_{1,0} + P_{AccY} = 0\,\frac{m}{s^2} \qquad ACC_{Y5\_g} := \frac{ACC_{Y5}}{g} = 0 \qquad FY_5 := MASS\cdot ACC_{Y5} = 0\cdot kN$$

$$ACC_{Z5} := \text{RotVec\_5}_{2,0} + P_{AccZ} = -4.342\,\frac{m}{s^2} \qquad ACC_{Z5\_g} := \frac{ACC_{Z5}}{g} = -0.443 \qquad FZ_5 := MASS\cdot ACC_{Z5} = -55.5\cdot kN$$

By similar above Calculation, Load Factors for TR6, TR7 and TR8 are summurised below:

TR06 (+PITCH -HEAVE)	*TR07 (-PITCH +HEAVE)*	*TR08 (-PITCH -HEAVE)*
$ACC_{X6\_g} = -0.312$	$ACC_{X7\_g} = 0.226$	$ACC_{X8\_g} = 0.312$
$ACC_{Y6\_g} = 0$	$ACC_{Y7\_g} = 0$	$ACC_{Y8\_g} = 0$
$ACC_{Z6\_g} = -0.833$	$ACC_{Z7\_g} = -1.119$	$ACC_{Z8\_g} = -1.51$

For TR09 (+80%ROLL+60%PITCH +HEAVE): the following shall be considered:

$\varphi_9 := 80\% \cdot R_{AMP} = 0.279 \cdot \text{rad}$ $\qquad \theta_9 := 60\% \cdot P_{AMP} = 0.131 \cdot \text{rad}$ $\qquad \psi_9 := 0$

$$R9 := \begin{pmatrix} \cos(\psi_9)\cdot\cos(\theta_9) & \cos(\psi_9)\cdot\sin(\theta_9)\cdot\sin(\varphi_9) - \sin(\psi_9)\cdot\cos(\varphi_9) & \cos(\psi_9)\cdot\sin(\theta_9)\cdot\cos(\varphi_9) + \sin(\psi_9)\cdot\sin(\varphi_9) \\ \sin(\psi_9)\cdot\cos(\theta_9) & \sin(\psi_9)\cdot\sin(\theta_9)\cdot\sin(\varphi_9) + \cos(\psi_9)\cdot\cos(\varphi_9) & \sin(\psi_9)\cdot\sin(\theta_9)\cdot\cos(\varphi_9) - \cos(\psi_9)\cdot\sin(\varphi_9) \\ -\sin(\theta_9) & \cos(\theta_9)\cdot\sin(\varphi_9) & \cos(\theta_9)\cdot\cos(\varphi_9) \end{pmatrix}$$

$$R9 = \begin{pmatrix} 0.991 & 0.036 & 0.125 \\ 0 & 0.961 & -0.276 \\ -0.131 & 0.273 & 0.953 \end{pmatrix} \qquad \text{InitialVector\_9} := \begin{bmatrix} 0 \\ 0 \\ (-1 + H_{ACC})\cdot g \end{bmatrix} = \begin{pmatrix} 0 \\ 0 \\ -7.845 \end{pmatrix} \frac{m}{s^2}$$

$$\text{RotVec\_9} := R9 \cdot \text{InitialVector\_9} = \begin{pmatrix} -0.984 \\ 2.162 \\ -7.477 \end{pmatrix} \frac{m}{s^2}$$

$$ACC_{X9} := \text{RotVec\_9}_{0,0} + 60\% P_{AccX} = -1.293 \frac{m}{s^2}$$

$$ACC_{Y9} := \text{RotVec\_9}_{1,0} + 80\% R_{AccY} = 2.712 \frac{m}{s^2}$$

$$ACC_{Z9} := \text{RotVec\_9}_{2,0} + 80\% R_{AccZ} + 60\% P_{AccZ} = -6.723 \frac{m}{s^2}$$

$$ACC_{X9\_g} := \frac{ACC_{X9}}{g} = -0.132 \qquad FX_9 := MASS \cdot ACC_{X9} = -16.5 \cdot kN$$

$$ACC_{Y9\_g} := \frac{ACC_{Y9}}{g} = 0.277 \qquad FY_9 := MASS \cdot ACC_{Y9} = 34.7 \cdot kN$$

$$ACC_{Z9\_g} := \frac{ACC_{Z9}}{g} = -0.686 \qquad FZ_9 := MASS \cdot ACC_{Z9} = -86 \cdot kN$$

By similar above Calculation, Load Factors for LC10 to LC16 are summurised below:

TR10 (+80%ROLL+60%PITCH -HEAVE)	TR11 (-80%ROLL+60%PITCH +HEAVE)	TR12 (-80%ROLL+60%PITCH -HEAVE)
$ACC_{X10\_g} = -0.182$	$ACC_{X11\_g} = -0.132$	$ACC_{X12\_g} = -0.182$
$ACC_{Y10\_g} = 0.387$	$ACC_{Y11\_g} = -0.277$	$ACC_{Y12\_g} = -0.387$
$ACC_{Z10\_g} = -1.067$	$ACC_{Z11\_g} = -0.433$	$ACC_{Z12\_g} = -0.815$

TR13 (+80%ROLL-60%PITCH +HEAVE)	TR14 (+80%ROLL-60%PITCH -HEAVE)	TR15 (-80%ROLL-60%PITCH +HEAVE)
$ACC_{X13\_g} = 0.132$	$ACC_{X14\_g} = 0.182$	$ACC_{X15\_g} = 0.132$
$ACC_{Y13\_g} = 0.277$	$ACC_{Y14\_g} = 0.387$	$ACC_{Y15\_g} = -0.277$
$ACC_{Z13\_g} = -1.091$	$ACC_{Z14\_g} = -1.473$	$ACC_{Z15\_g} = -0.839$

TR16
(-80%ROLL-60%PITCH -HEAVE)

$$ACC_{X16\_g} = 0.182$$

$$ACC_{Y16\_g} = -0.387$$

$$ACC_{Z16\_g} = -1.221$$

For TR17 (+60%ROLL+80%PITCH +HEAVE): the following shall be considered:

$$\varphi_{17} := 60\% \cdot R_{AMP} = 0.209 \cdot rad \qquad \theta_{17} := 80\% \cdot P_{AMP} = 0.175 \cdot rad \qquad \psi_{17} := 0$$

$$R17 := \begin{pmatrix} \cos(\psi_{17})\cdot\cos(\theta_{17}) & \cos(\psi_{17})\cdot\sin(\theta_{17})\cdot\sin(\varphi_{17}) - \sin(\psi_{17})\cdot\cos(\varphi_{17}) & \cos(\psi_{17})\cdot\sin(\theta_{17})\cdot\cos(\varphi_{17}) + \sin(\psi_{17})\cdot\sin(\varphi_{17}) \\ \sin(\psi_{17})\cdot\cos(\theta_{17}) & \sin(\psi_{17})\cdot\sin(\theta_{17})\cdot\sin(\varphi_{17}) + \cos(\psi_{17})\cdot\cos(\varphi_{17}) & \sin(\psi_{17})\cdot\sin(\theta_{17})\cdot\cos(\varphi_{17}) - \cos(\psi_{17})\cdot\sin(\varphi_{17}) \\ -\sin(\theta_{17}) & \cos(\theta_{17})\cdot\sin(\varphi_{17}) & \cos(\theta_{17})\cdot\cos(\varphi_{17}) \end{pmatrix}$$

$$R17 = \begin{pmatrix} 0.985 & 0.036 & 0.17 \\ 0 & 0.978 & -0.208 \\ -0.174 & 0.205 & 0.963 \end{pmatrix} \qquad InitialVector\_17 := \begin{bmatrix} 0 \\ 0 \\ (-1 + H_{ACC})\cdot g \end{bmatrix} = \begin{pmatrix} 0 \\ 0 \\ -7.845 \end{pmatrix} \frac{m}{s^2}$$

$$RotVec\_17 := R17 \cdot InitialVector\_17 = \begin{pmatrix} -1.333 \\ 1.631 \\ -7.557 \end{pmatrix} \frac{m}{s^2}$$

$$ACC_{X17} := RotVec\_17_{0,0} + 80\% P_{AccX} = -1.744 \frac{m}{s^2}$$

$$ACC_{Y17} := RotVec\_17_{1,0} + 60\% R_{AccY} = 2.043 \frac{m}{s^2}$$

$$ACC_{Z17} := RotVec\_17_{2,0} + 60\% R_{AccZ} + 80\% P_{AccZ} = -5.831 \frac{m}{s^2}$$

$$ACC_{X17\_g} := \frac{ACC_{X17}}{g} = -0.178 \qquad FX_{17} := MASS \cdot ACC_{X17} = -22.3 \cdot kN$$

$$ACC_{Y17\_g} := \frac{ACC_{Y17}}{g} = 0.208 \qquad FY_{17} := MASS \cdot ACC_{Y17} = 26.1 \cdot kN$$

$$ACC_{Z17\_g} := \frac{ACC_{Z17}}{g} = -0.595 \qquad FZ_{17} := MASS \cdot ACC_{Z17} = -74.6 \cdot kN$$

By similar above Calculation, Load Factors for CM18 to CM24 are summurised below:

TR18
(+60%ROLL+80%PITCH -HEAVE)

$$ACC_{X18\_g} = -0.246$$

$$ACC_{Y18\_g} = 0.291$$

$$ACC_{Z18\_g} = -0.98$$

TR19
(-60%ROLL+80%PITCH +HEAVE)

$$ACC_{X19\_g} = -0.178$$

$$ACC_{Y19\_g} = -0.208$$

$$ACC_{Z19\_g} = -0.405$$

TR20
(-60%ROLL+80%PITCH -HEAVE)

$$ACC_{X20\_g} = -0.246$$

$$ACC_{Y20\_g} = -0.291$$

$$ACC_{Z20\_g} = -0.791$$

TR21
(+60%ROLL-80%PITCH +HEAVE)

$$ACC_{X21\_g} = 0.178$$

$$ACC_{Y21\_g} = 0.208$$

$$ACC_{Z21\_g} = -1.136$$

TR22
(+60%ROLL-80%PITCH -HEAVE)

$$ACC_{X22\_g} = 0.246$$

$$ACC_{Y22\_g} = 0.291$$

$$ACC_{Z22\_g} = -1.521$$

TR23
(-60%ROLL-80%PITCH +HEAVE)

$$ACC_{X23\_g} = 0.178$$

$$ACC_{Y23\_g} = -0.208$$

$$ACC_{Z23\_g} = -0.947$$

TR24
(-60%ROLL-80%PITCH -HEAVE)

$$ACC_{X24\_g} = 0.246$$

$$ACC_{Y24\_g} = -0.291$$

$$ACC_{Z24\_g} = -1.332$$