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VERIFICATION OF CSA CODE FOR FIXED OFFSHORE STEEL STRUCTURES

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Sandwell wishes to acknowledge the contribution of British Petroleum, who supported the project by providing a large volume of information relating to the GYDA Platform design. This information provided the benchmark data against which a practical evaluation could be undertaken.

The work undertaken for Verification Project G-1B has been the responsibility of Sandwell Inc., with O'Connor Associates providing geotechnical support for the foundation design.

The overall Verification Program is the responsibility of a Verification Subcommittee, which reports to the CSA Standards Steering Committee for Offshore Structures.

The Scientific Authority for this project was Dr. Ray Smith of the National Energy Board, Calgary, and the Technical Authority was Dr. Laurie Kennedy, Professor of Civil Engineering at the University of Alberta, Edmonton.

Funding for this project was provided by the Environmental Study Research Fund (ESRF) through the auspices of the Canadian Standards Association.

EXECUTIVE SUMMARY

The objective of project G-1B is to evaluate the CSA "Code for the Design, Construction, and Installation of Fixed Offshore Structures" in its application to the design of an actual steel jacket structure. This evaluation is accomplished by comparing the results of a design based on the CSA standards to an existing structure, applying the design criteria and environmental conditions used in the original design. Following from project G-1A, British Petroleum's GYDA platform is again used as a framework for this study. The project focuses on the design of the jacket structure and the pile foundations; topside structures are not included.

The GYDA platform is situated in 66 m of water in the Norwegian sector of the North Sea. It is designed for twenty years of production with an anticipated peak production rate of 60,000 barrels per day. The topsides, weighing 26,500 tonnes, are installed as four major modules and a single flare boom.

The six legged jacket structure is 76 m high and weighs approximately 8,000 tonnes. It has a plan area of 54 m x 25 m at the top and 58 m x 38 m at the base. It is supported by a total of 20 vertically driven piles of 2,134 mm diameter, four at each corner leg and two at each centre leg. The jacket was designed for installation in one piece by heavy lift equipment, with the elimination of all support bracing required for more conventional end launching off a barge. This has resulted in a structure with a very clean profile, and a high degree of constructability.

The project has examined the jacket structure and pile foundations for the in-place conditions only, since the BP original design identified this as the critical phase. The procedures followed in executing the project can be summarized as follows:

- Load determination
- Analysis
- Design checks
- Evaluation

The GYDA platform was designed in accordance with the Norwegian Petroleum Directorate code. However, reference is made to a number of other codes such as DnV and API RP2A and, in some instances, BP has developed project specific requirements. Consequently, the exercise of the CSA Standards are considered in relation to an overall design procedure encompassing a number of codes. For this reason, the GYDA platform is referred to as the BP design.

The results of the comparative analyses and design of the GYDA platform to the CSA code provide the following conclusions:

- The factored loads used in the CSA S471 Standard result in an overall increase of 3 to 9% in global and local forces for the structure, compared to the BP design.

- For the unstiffened tubular members, using the CSA code leads to a plate thickness reduction of approximately 5 mm, for the same capacity as the BP design. This is mainly because the BP method includes shell buckling effects in the force interaction calculations.

- For the tubular joints, using the CSA code results in a joint can thickness increase of approximately 10 mm to achieve the same capacity level as the BP design. This is primarily due to the more complete treatment of in-plane and out-of-plane bending effects in the CSA S473 Standard.

- Differences in the fatigue provisions between the CSA code and the BP design occur in the required design life, the S-N curves, and the joint classification. For the latter, the CSA code evaluates joints on the basis of Safety Class, accessibility and structural importance, whereas BP does not appear to consider any of these parameters. Depending on the assumed joint classification, the CSA code results in 5 to 42 critical joints with high estimated fatigue damage, compared to 23 for the BP design.

- Since the GYDA platform is located in a low seismic zone, the CSA seismic provisions are not fully exercised. However, the global base shear and overturning moments are found to increase by 7.5% and 17.9% respectively using the CSA code. This suggests that these provisions are important for structures located in a high seismic zone and it is recommended that the system ductility aspect be considered in more detail.

RÉSUMÉ

L'objectif du projet G-1B est d'évaluer l'application du "Code for the Design, Construction, and Installation of Fixed Offshore Structures" de la CSA à la conception d'une structure à treillis en acier réelle. Pour effectuer cette évaluation, on compare une structure théorique basée sur les normes de la CSA à une structure existante, en appliquant les critères de conception et les conditions environnementales utilisées dans la conception initiale. Pour faire suite au projet G-1A, l'étude est encore basée sur la plate-forme GYDA de British Petroleum. Le projet porte essentiellement sur la conception du treillis et des fondations sur pieux; les superstructures ne sont pas étudiées.

La plate-forme GYDA est installée par 66 m d'eau, dans le secteur norvégien de la mer du Nord. Elle est conçue pour produire pendant vingt ans, avec un taux maximal prévu de 60 000 barils par jour. Les superstructures, qui pèsent 26 500 tonnes, consistent en quatre modules principaux et un seul bras de torche.

Le treillis à six piles mesure 76 m de hauteur et pèse environ 8 000 tonnes. Il comporte une surface plane de 54 m x 25 m au sommet et de 58 m x 38 m à la base. Il est soutenu par 20 pieux battus verticalement de 2,134 mm de diamètre, quatre à chaque pile dans les coins et deux à chaque pile au centre. Le treillis a été conçu pour être installé en un seul morceau, à l'aide d'un matériel de levage lourd, et tous les supports nécessaires à une installation plus classique à partir d'une barge ont été éliminés. Le résultat est une structure qui possède un profil très net et un degré élevé de constructibilité.

Dans ce projet, on a examiné le treillis et les fondations sur pieux une fois la structure en place seulement car, selon la conception initiale de BP, c'est cette phase qui est critique. La méthode adoptée pour l'exécution du projet peut se résumer de la façon suivante :

- Détermination de la charge
- Analyse
- Vérification de la conception
- Évaluation

La plate-forme GYDA a été conçue selon le code de la Direction norvégienne du pétrole. Cependant, référence est faite à un certain nombre d'autres codes tels que les codes D_HV et API RF2A et, dans certains cas, BP a établi des exigences particulières au projet. Par conséquent, les normes de la CSA sont évaluées par rapport à une conception globale basée sur plusieurs codes. C'est pourquoi l'expression "conception BP" est utilisée pour désigner la plate-forme GYDA.

Les résultats des analyses comparatives et de la conception de la plate-forme GYDA selon le code de la CSA permettent de tirer les conclusions suivantes :

- En ce qui concerne la structure, les charges pondérées utilisées dans la norme CSA S471 se traduisent par une augmentation globale de 3 à 9 % des forces globales et locales, par rapport à la conception BP.

- En ce qui concerne les éléments tubulaires non renforcés, à capacité égale, on observe une réduction de l'épaisseur de la plaque d'environ 5 mm lorsqu'on applique le code CSA. Cela est dû surtout au fait que la conception BP inclut les effets de flambement de l'enveloppe dans le calcul des forces d'interaction.

- Pour les joint tubulaires, lorsqu'on utilise le code CSA, l'épaisseur du joint doit être supérieure d'environ 10 mm pour que l'on obtienne la même capacité que dans la conception BP. Cela est dû surtout au fait que les effets de flexion dans le plan et hors du plan sont traités de façon plus complète dans la norme CSA S473.

- On observe des différences en ce qui concerne la fatigue entre le code CSA et la conception BP, dans la durée de vie nominale requise, les courbes S-N et la classification des joints. En ce qui concerne les joints, le code CSA les évalue en fonction de la classe relative à la sécurité, de l'accessibilité et de l'importance structurale, alors que BP ne semble pas tenir compte de ces paramètres. Selon la classification des joints supposée, on obtient 5 à 42 joints critiques, avec des risques de dommages dûs à la fatigue élevés, lorsqu'on applique le code CSA, contre 23 joints avec la conception BP.

- Étant donné que la plate-forme GYDA est situé dans une zone de faible activité sismique, les dispositions du code CSA relatives aux effets sismiques ne sont pas complètement évaluées. Cependant, lorsqu'on applique le code CSA, on observe des augmentations respectives de 7,5 % et 17,9 % pour les moments globaux de cisaillement de la base et de retournement. Cela signifie que ces dispositions sont importantes pour des structures situées dans des zones de grande activité sismique et il convient d'examiner plus en détails la ductilité du système.

1. INTRODUCTION

1.1 Background

The Canadian Standards Association has directed a number of studies as part of the Verification Program for the CSA "Code for the Design, Construction, and Installation of Fixed Offshore Structures". These studies have reviewed issues such as the load factor calibration, seismic provisions and clause-by-clause application of the individual Standards, with the overall objective of verifying that the combined use of these Standards will result in a rational balance of safety and economy, when applied to a broad range of fixed offshore structures.

The current program comprises a series of studies to undertake comparative designs conforming to the CSA Standards and to an alternative Code or design. This is designed to exercise the design methodologies and clause provisions of the CSA Standards, such that their effect on the final design of typical fixed offshore structures can be identified. The projects in the current program cover the following topics:

- G-1A/B Steel Structures
- G-2A/B Concrete Structures
- J-2 Resistance Factors - Tubular Joints
- J-4 Stiffened Plates
- J-5 Composite Walls
- K-1 Concrete Wall Factors

For the steel structures, project G-1A examined the application of the CSA Standards in comparison with both API and DnV, for jacket and gravity type structures, respectively. The study considered two fixed offshore steel structures; a caisson type structure for deployment in the Beaufort Sea and a jacket type structure suitable for the Scotian Shelf region of the East Coast. As part of this project, Sandwell approached British Petroleum for information on their recently installed GYDA platform, since this structure is designed for a water depth similar to that found on the Scotian Shelf area of the East Coast, and represents a modern jacket structure designed for a comparably severe environment. BP supported the G-1A project by providing Sandwell with a considerable quantity of structural details for the GYDA platform.

This report presents the findings of project G-1B, undertaken by Sandwell to investigate the application of the CSA standards in the design of the GYDA platform in its existing location. It follows directly from project G-1A and is directed at a further, more detailed examination of the CSA standards with the specific emphasis on this platform, since the detailed information for this structure represents an opportunity to evaluate the CSA provisions against a modern jacket design. It differs from project G-1A, in that the CSA Standards are compared with an existing design as a direct benchmark, using the same environmental and foundation conditions for which the structure was originally designed.

1.2 Objectives and Scope of Work

The objective of project G-1B is to evaluate the CSA code in its application to the design of an actual steel jacket structure. This evaluation is accomplished by comparing the results of a design based on the CSA standards to an existing structure, applying the design criteria and environmental conditions used in the original design. Following from project G-1A, the GYDA platform is again used as a framework for this study. British Petroleum provided support for the project by supplying additional documentation of their design. This material was critical to undertaking the project. The project focuses on the design of the jacket structure and the pile foundations; topside structures are not included.

The purpose of this project is to investigate the following issues:

- the practicability of the CSA Standards as a design tool

- the completeness and clarity of the code requirements

- the differences in load cases, load factors and load combinations and the resulting differences in structural design compared to the existing platform

- the allowance for incorporation of new information or different analysis methods

- the flexibility for the creative design of new structures

The scope of work set out in the Request for Proposals is reproduced in Appendix A. The details of the project methodology and tasks were defined in Sandwell's Proposal of 1991 in accordance with this scope.

1.3 Project Methodology

As stated in the scope of work, this project deals with the design of the jacket structure and the pile foundations for the GYDA platform. Although a complete design requires an analysis for all phases of the design life, the design work reported by BP indicates that the conditions for the in-place analysis governed the design of the jacket structure. This result was also considered to be applicable to CSA design conditions, and consequently the design performed in this project has been limited to the in-place conditions. However, some limited consideration has also been directed at the other phases of the design life.

Throughout this project, the methodology employed by BP is used whenever it conforms to the requirements of the CSA code. Where engineering judgement is required in the design, the decisions made by BP are respected unless the CSA standards specify otherwise. As a result, the work concentrates on the differences in design directly attributable to the CSA code requirements. This attempts to minimize differences attributable to legitimate variation in the design process by individual designers.

Figure 1.1 outlines the procedure to carry out the work. It can be divided into four main steps:

- Load determination
- Analysis
- Design checks
- Evaluation

Load Determination

Using the environmental and operational data provided by BP, the design loads are determined following CSA S471. The loads and load combinations of the CSA code are compared with those used in the development of the GYDA platform.

Analysis

The jacket structure is analyzed using the ABAQUS finite element software to determine the member forces and pile reactions for various load combinations. The computer model, first developed for the G1-A study, was refined using additional details obtained from BP for this study. In general, the data supplied by BP has included details of the input criteria and also detailed summaries of the analytical results. However, individual element forces and other intermediate information from the analysis has generally not been reported, and consequently a computer model for the structure has been employed to re-calculate these necessary element forces.

As discussed in Section 3, steps have been taken to filter out differences in results between this project and the original BP design that can be attributed to differences in modelling techniques. This is important, since the object is to identify differences in loads, load combinations and design procedures; all of these can be partially obscured by differences in modelling procedures. Also, it should be noted that a complete re-calculation of the original design was not attempted, and the analysis was generally limited to those conditions reported as critical by BP.

Design Checks

The results of the analysis are used to perform the design of the foundation system and the structural design of key members of the jacket structure, following the requirements of CSA Standards S472 and S473. The design obtained using the CSA Standards is compared to the BP design and the actual GYDA platform and the differences are documented.

Evaluation

The final step is to evaluate the CSA Standards following their use in this design exercise, based on the comparisons with the GYDA platform design performed by BP to other standards.

1.4 GYDA Platform

The GYDA platform is shown schematically in Figure 1.2. It is situated in 66 m of water in the Norwegian sector of the North Sea, approximately 170 miles Southwest of Stavanger, as shown in Figure 1.3. The platform is designed for twenty years of production with an anticipated peak production rate of 60,000 barrels per day. The topsides, weighing 26,500 tonnes, are installed as four major modules and a single flare boom.

The fixed steel jacket, shown in Figure 1.4, is 76 m high and weighs approximately 8,000 tonnes. It is a six legged structure with a plan area of 54 m x 25 m at the top and 58 m x 38 m at the base. It is supported by a total of 20 vertically driven piles of 2,134 mm diameter, four at each corner leg and two at each centre leg. Special features of the jacket include the extensive use of simple un-stiffened joints, the absence of pile guides and the use of cast nodes for selected brace to leg transition joints. Also, the jacket was designed for installation in one piece by heavy lift equipment, with the elimination of all support bracing required for more conventional end launching off a barge. This has resulted in a structure with a very clean profile and a high degree of constructibility.

The jacket can accommodate a total of thirty-two conductors; eight are 508 mm diameter and tied back from a subsea drilling template, the remaining twenty-four are 686 mm diameter platform-run conductors. In addition, there are thirteen caissons of various diameters and lengths and four pre-installed risers with a provision for two more.

The considerable amount of information provided by BP regarding the design of the GYDA platform is summarized as follows:

1) Design Briefs, outlining the methodology for specific aspects of the design:

0901	- In-place Structural Analysis
0902	- Foundation Analysis
0903	- In-place Deterministic Fatigue Analysis
0904	- Seismic Analysis
0905	- Boat Impact
0906	- Progressive Collapse
0907	- Static Strength
0908	- Vortex Shedding
0909	- Wave Slam Analysis
0923	- Member Design
0924	- Transport Fatigue Analysis

2) Jacket Design Reports, summarizing the results of the analysis and design:

Vol. 1	- Summary Report
Vol. 3	- Earthquake Analysis
Vol. 4	- In-place Deterministic Fatigue analysis
Vol. 6	- Wave Slam
	- Abstract from "Jacket Final In-place Analysis", by VERITEC

3) Verification report of the Soil/Pile Analysis, by Fugro-McClelland:

- Engineering Report, Independent Verification, GYDA Field, Block 2/1 North, Norwegian Sector, North Sea.

4) Earthquake Analysis reports, by NGI:

- Earthquake Loading Criteria Assessment
- Copies of Requested References

1.5 Design Codes

1.5.1 CSA Design Codes

For the design performed in this study, the following parts of the CSA Code for the Design, Construction, and Installation of Fixed Offshore Structures have been used:

- Part I - Preliminary Standard S471-M1989, General Requirements, Design Criteria, the Environment, and Loads

- Part II - Preliminary Standard S472-M1989, Foundations

- Part III - Preliminary Standard S473-M1989, Steel Structures.

Reference is also made to the Commentary associated with each Standard.

1.5.2 BP Design Codes

The design of the GYDA jacket was carried out in compliance with the requirements of:

- Regulations for the Structural Design of Fixed Structures on the Norwegian Continental Shelf, Norwegian Petroleum Directorate, October, 1984. (NPD)

Other codes and standards referenced by BP are:

- Norwegian Standard NS3472E Steel Structures Design Rules - Norwegian Standards Association, 2nd Edition, June 1984

- Rules for the Design, Construction and Inspection of Offshore Structures - Det Norske Veritas, 1977. (Reprint with corrections, 1981)

- American Petroleum Institute Recommended Practice 2A (RP2A) Recommended Practice for Planning, Designing and Constructing Fixed Offshore Platforms (Edition 17), April 1987

- Department of Energy, Offshore Installations: Guidance on Design and Construction, 3rd Edition, 1984

Since the platform is located in the Norwegian sector of the North Sea, the design has generally followed the provisions of the NPD. However, reference has been made to other codes for specific design topics and, in some instances, BP has developed project specific requirements. Consequently, the exercise of the CSA Standards cannot be considered in relation to a specific alternate code. In the subsequent sections of this report, the GYDA platform is referred to as the BP design. However, when differences between the CSA Standards and the BP design are discussed and these differences can be attributed to the requirements of alternate codes, then these are identified.

The tabulation below shows the areas of application of the respective codes referenced by BP, as identified from the furnished information.

CODE / ITEM	NPD	DNV	API RP2A
Loads	X	X	
Load Combinations	X		
Member Design	X	X	
Joint Design	X	X	
Conical Transitions			X
Fatigue	X		
Pile Foundation	X	X	X

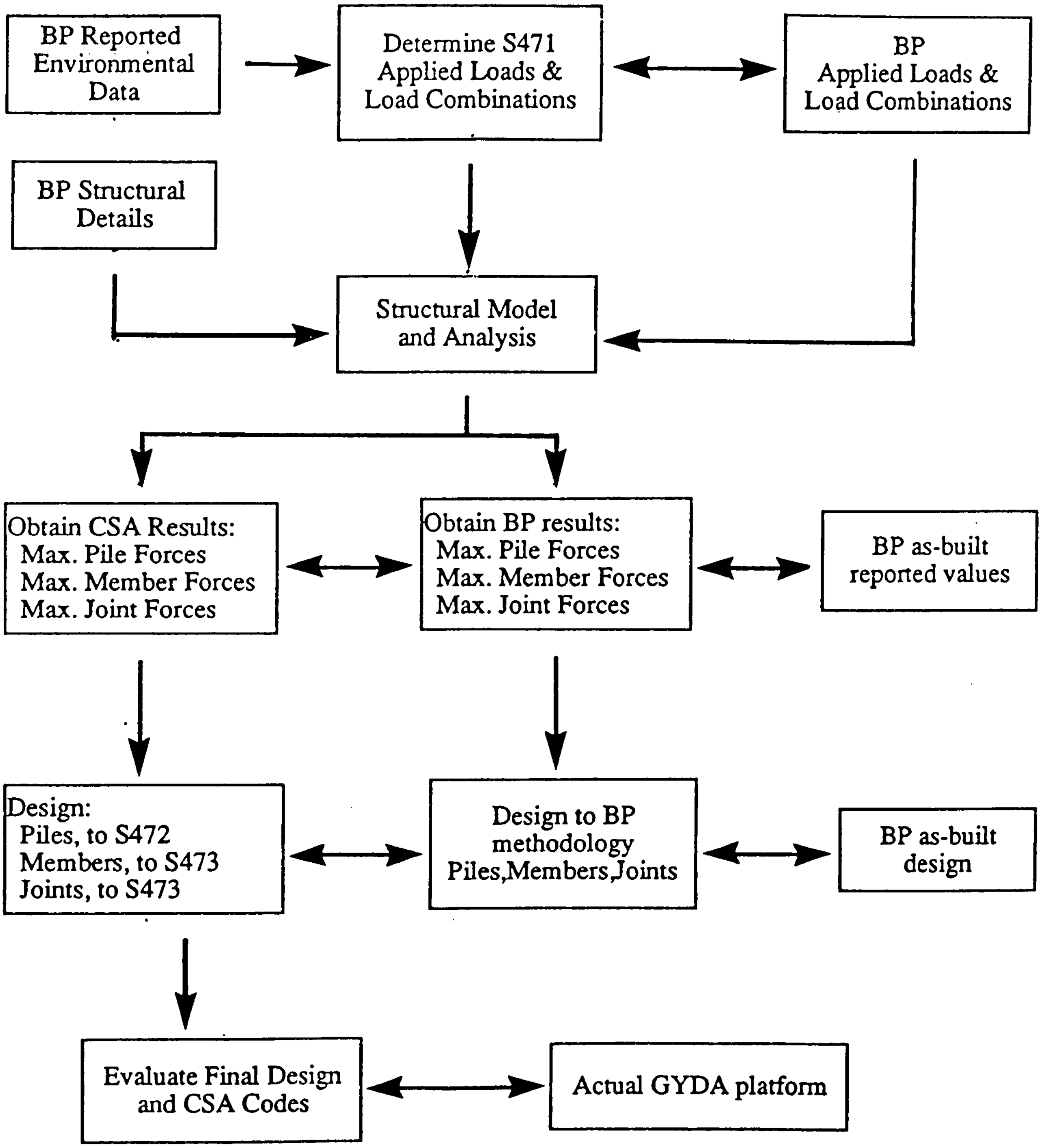


Figure 1.1
Project Methodology

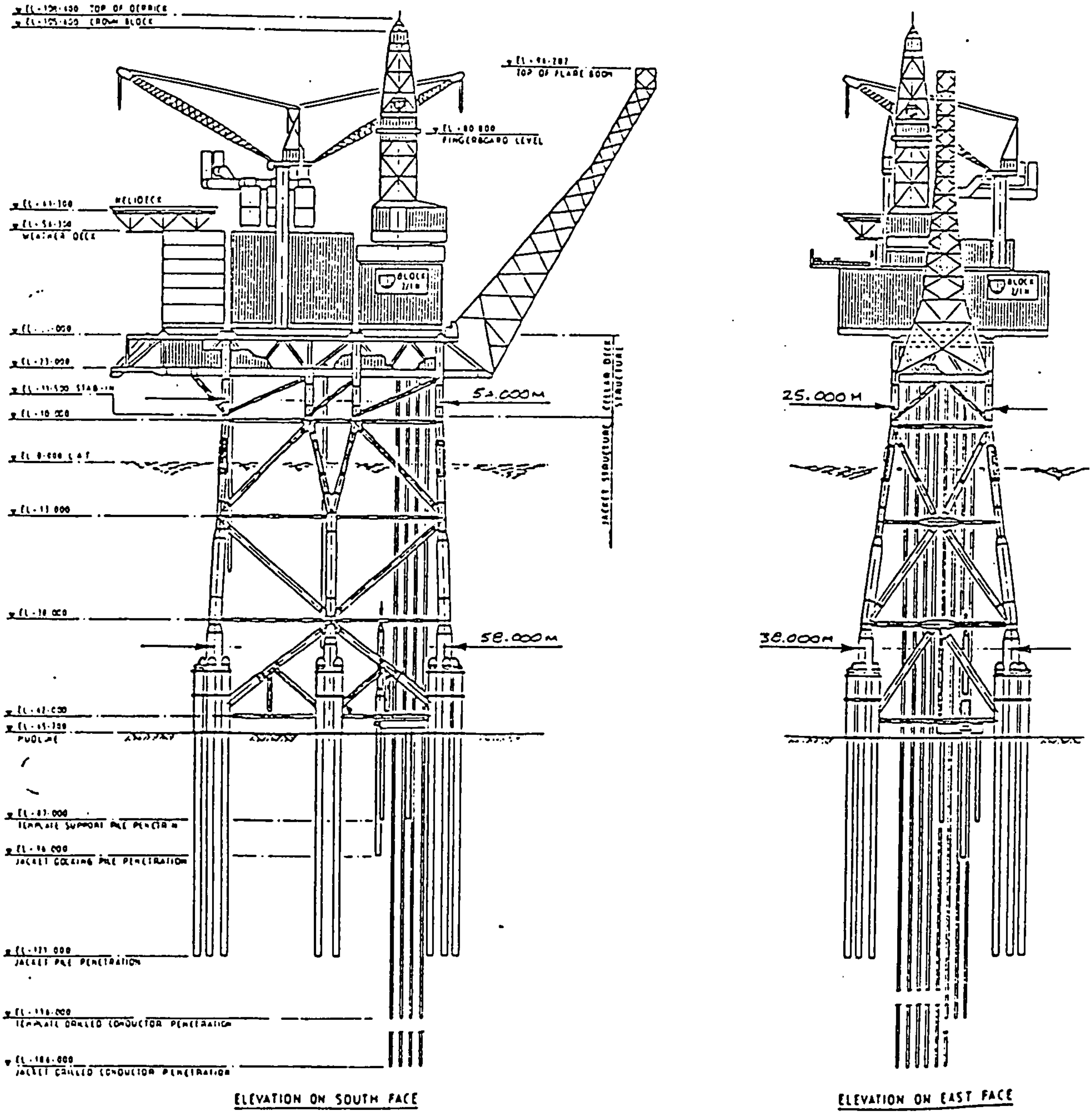


Figure 1.2
GYDA Platform - Elevations
(Source: BP Design Resume)

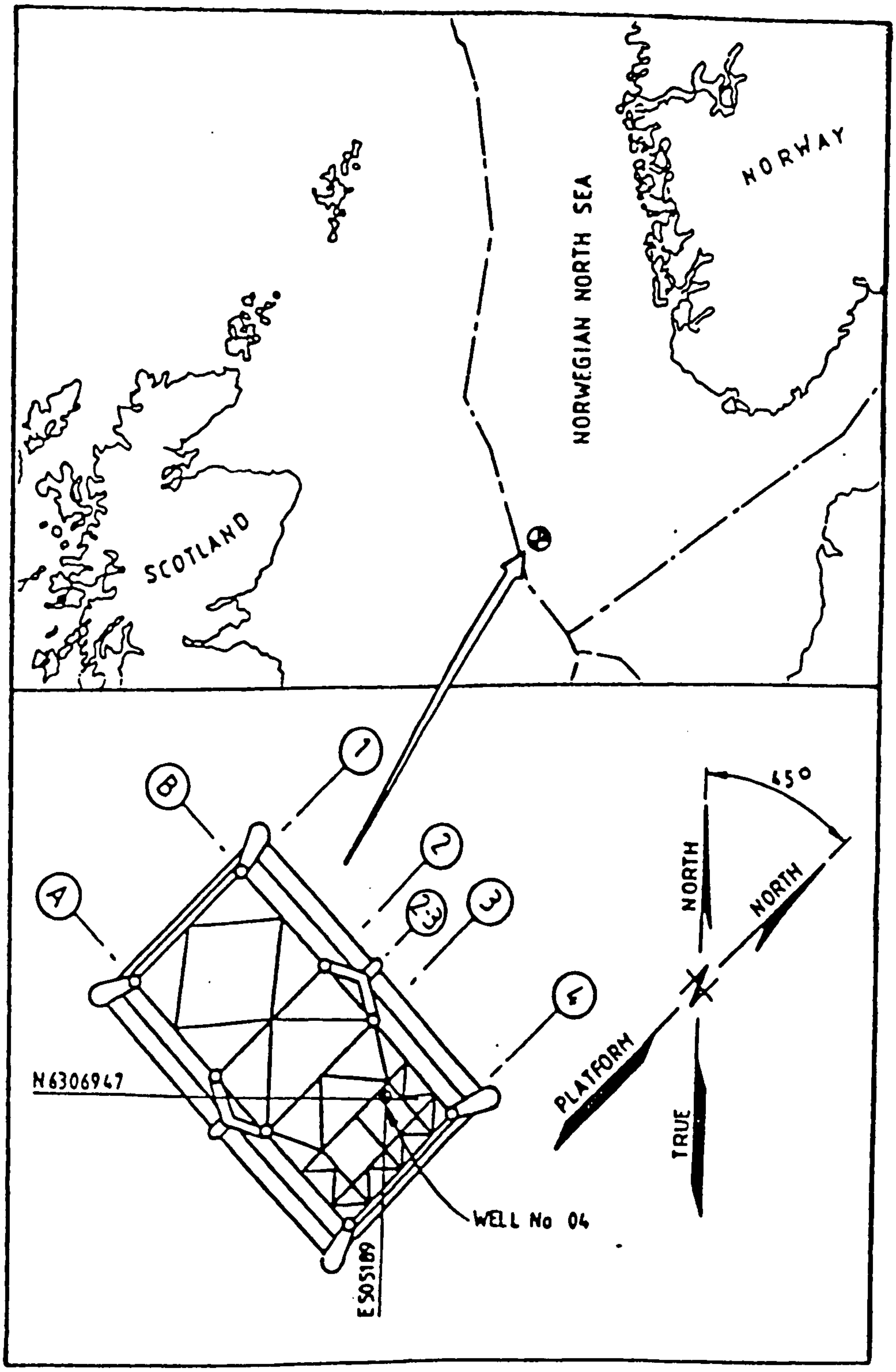


Figure 1.3
GYDA Platform - Location
(Source: BP Design Resume)

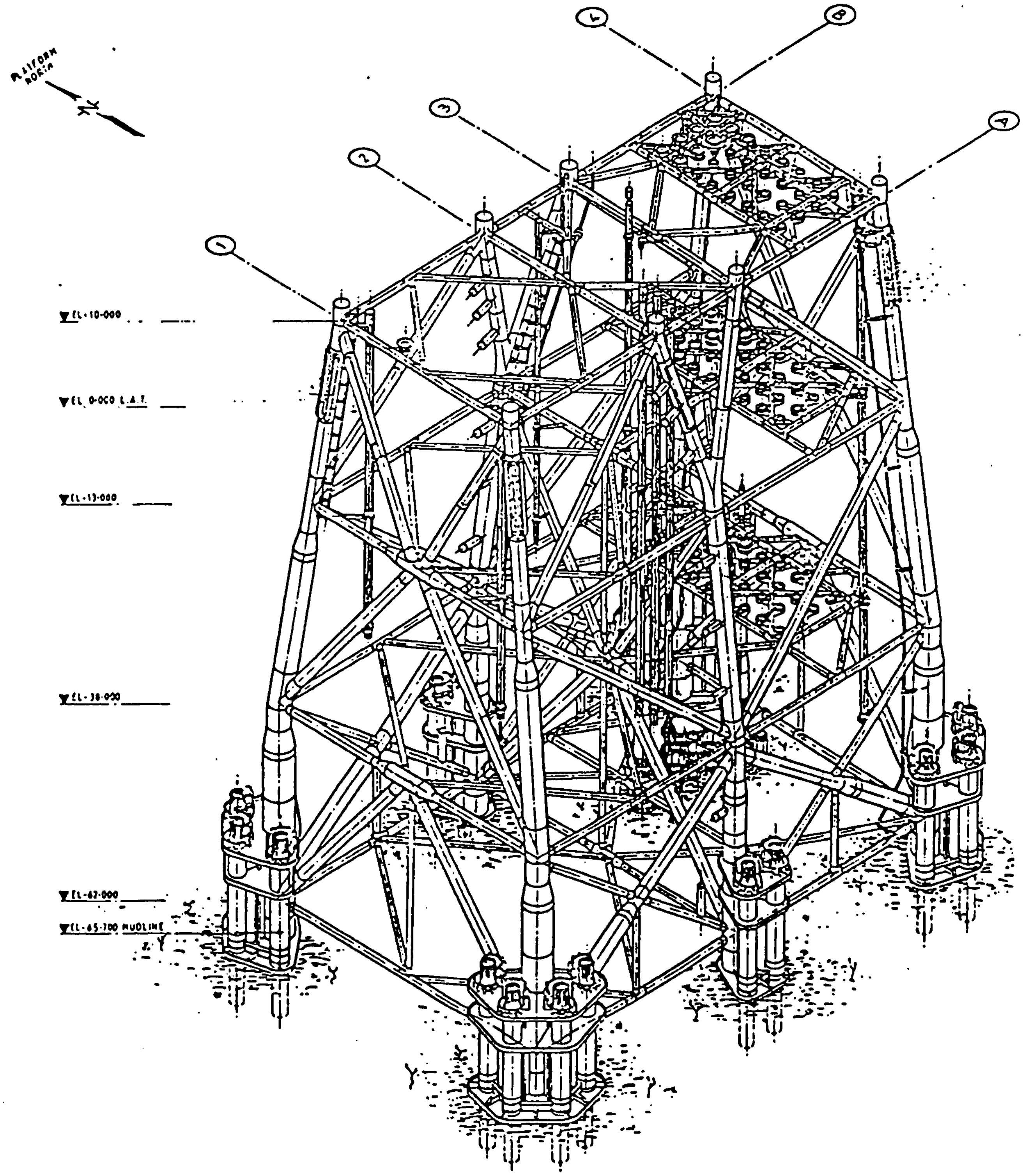


Figure 1.4
GYDA Platform - Jacket Isometric
(Source: BP Design Resume)

2. DESIGN METHODS AND LOADS - CSA/BP

2.1 Design Methods

2.1.1 Limit States Design

Both the CSA code and the Norwegian Petroleum Directorate (NPD) regulations, the latter to which the GYDA platform was designed, use the limit states design method. This section describes the differences in the limit states requirements between the two codes.

<u>CSA Limit States</u>

CSA Standard S471 lists two categories of limit states, **ultimate** limit states and **serviceability** limit states.

Ultimate limit states are those concerning safety and environmental protection and include:

a. loss of equilibrium of the structure or part thereof, eg. overturning, capsizing, sliding,

b. loss of load-carrying capacity of structural elements or of the foundation due to:

- material strength exceeded,
- buckling,
- fracture,
- fatigue,
- fire,
- or deformation,

c. overall instability of the structure, eg. P-Delta effect, flutter,

d. transformation of the structure into a mechanism, ie. plastic collapse.

Serviceability limit states are those that restrict the normal operations and occupancy of the structure or affect its durability and include:

- deflections and rotations,
- vibrations and accelerations,
- local damage,
- global displacements and deformations

<u>BP Design - NPD limit states</u>

The NPD regulations define four categories of limit states:

- serviceability; applicable to normal use or durability,
- fatigue; related to the danger of failure due to cyclic loads,

- ultimate; related to the danger of failure, large inelastic displacements, strains comparable to failure, free drifting, capsizing or sinking,
- progressive collapse; related to the danger of failure due to abnormal load effects.

The NPD fatigue, ultimate and progressive collapse limit states are all included under the CSA definition of "ultimate limit states". The NPD division is based on differences in load types and load factors applicable to each category of limit states.

The ultimate limit states examine failure due to the one-time occurrence of normal loads of a maximum or design magnitude, typically determined for an annual probability of occurrence of 10^{-2}. In contrast, the fatigue limit states examine failure due to repetitive loads, using a range of magnitudes and the frequency of occurrence associated with each.

The progressive collapse limit states examine failure due to the occurrence of abnormal events, either environmental or accidental, defined as having an annual probability of occurrence no greater than 10^{-4}. From this criteria, these events can be considered equivalent to the CSA rare environmental and accidental events.

NPD imposes two requirements for the control of progressive collapse limit states:

1) resistance against abnormal effects; demonstrate that the structure experiences purely local damages,

2) resistance in damaged condition; after damage as in 1), the structure shall still resist specified environmental conditions without extensive failure.

Requirement 1) is covered by S471 under the ultimate limit state, using the check for plastic collapse. However, requirement 2) is not explicitly defined, although some reference is made to this condition in the Commentary, and may be adopted by a prudent designer.

2.1.2 CSA Safety Classes

A particular feature of the CSA code is the definition of two safety classes for the verification of the safety of the structure, or any of its structural elements, for a given loading condition. Table 2.1 summarizes the application of the two safety classes.

Table 2.1
CSA Safety Classes
(Source: S471 Appendix A, Table A2)

	SAFETY CLASS 1		SAFETY CLASS 2	
	Failure would result in great risk to life or a high potential for environmental damage		Failure would result in small risk to life and a low potential for environmental damage	
	Annual Exceedance Probability PE	Load Factor	Annual Exceedance Probability PE	Load Factor
Specified Loads, E_f Based on Frequent Environmental Processes	10^{-2}	1.35	10^{-2}	0.9
Specified Loads, E_r Based on Rare Environmental Processes	10^{-4} to 10^{-3}	1.0	10^{-2}	1.0
Specified Accidental Load, A	10^{-4} to 10^{-3}	1.0	N/A	N/A

Given that the GYDA platform is a manned production structure and that the expected loading conditions are either relatively unpredictable or do not guarantee the possibility of shutdown and evacuation, the structure is considered as Safety Class 1 for in-place conditions.

It is assumed that all primary structural elements would be designated Safety Class 1, although some secondary members may be designated Class 2. For this study, all members examined are considered Safety Class 1.

The Safety Class 2 designation may be appropriate for the design of the less critical phases of transportation, installation, and decommissioning.

2.1.3 System Ductility

CSA S471 recognises the importance of system ductility in the optimal design of the structure undergoing inelastic response when subjected to specified accidental load or rare environmental loads. In the commentary, CSA further clarifies that the need for ductility requirements can be waived if the structural system is shown to be adequate in the elastic range when subjected to extreme environmental and specified accidental loads.

2.2 Environmental Data

BP provided all the environmental data required to determine the loads applicable to this study. This data is presented in terms of design values associated with a given return period, in general 1 in 100 years. The data was found to meet the requirements of CSA S471 and was used, without modification or interpolation to different return periods being necessary, to calculate the loads for the design to CSA.

The environmental data is presented in Appendix B. The following is a brief summary of the key parameters:

- Reference water depth (LAT):	65.7 m above sea bed
- 10^{-2} storm tide and surge:	+2.25 m / -1.06 m
- 10^{-2} omnidirectional wave parameters:	H_{max} = 25.0 m, T_{max} = 16.0 sec
- 10^{-2} maximum surface current:	0.88 m/sec
- 10^{-2} maximum wind velocity:	41.4 m/sec

2.3 Design Loads

The design loading conditions are established according to the requirements of CSA S471, which defines the following four categories of loads:

- permanent
- operational
- accidental
- environmental

The loads applicable to the design of the GYDA jacket are outlined in the following sections. All the loads are calculated using the information provided by BP and, where the S471 provisions result in different loads, then these differences are identified.

2.3.1 Permanent Loads, G

Permanent loads include both dead and deformation loads.

<u>Dead Loads, G_D</u>

Dead loads, G_D, consist of:

a. self-weight of the jacket structure, including marine growth and buoyancy
b. dry installed weight of the topside modules (structure and permanent equipment).

The total weight of the jacket structure has not been explicitly reported by BP, however, from the information provided, the following estimate of the air weight has been developed:

Table 2.2
Estimated Jacket Dry Weight

Jacket Structure	Dry Weight (tonnes)
Base Structure	6,360
Marine Growth	1,160
Pile Connection	3,220
Miscellaneous	1,540
TOTAL	12,280

The topside module weights are added as point masses at the centre of gravity of each module, as shown in Table 2.3.

Table 2.3
Topside Module Weights

Module	Dry Installed Mass (tonnes)
L10 - Living Quarters	2217
M20 - Process/Utilities	4673
M30 - Drilling	3883
C40 - Cellar Deck	4517
M50 - Drilling Derrick	984
F60 - Flare Boom	292
TOTAL	16,566

The total air weight of the complete platform is:

Jacket Structure	12,280
Topsides	16,566
Total	28,846 tonnes

The dead load used in the analyses also includes the effects of buoyancy and hydrostatic pressure. The buoyancy forces are calculated by the analysis program and take into account the variations in water level with wave motion through the structure. The hydrostatic pressure is added to the member forces in the tubular member design calculations, as described in Section 5 of this report.

The above summary does not include added mass effects, which have been included in the dynamic analyses, and are discussed in more detail in Section 3.

Deformation Loads, G_R

Deformation loads, such as those caused by temperature gradients or differential settlement, were not included in the BP design, based on their conclusion that these loads had a negligible effect. This conclusion has been accepted for the CSA load determination, and is consistent with the provisions of S471.

2.3.2 Operational Loads, Q

Operational loads include the loads associated with the occupancy and operation of the platform. These loads were furnished for each module by BP's topsides design group, based on the following categories:

- Gross Inventory; contents of pipes, equipment, stores, personnel,

- Pipe Rack, set back, hook load;

- Reduced General Live Load; laydown and loading on unoccupied deck areas as percentage of total live load,

- Operator's Growth Allowance; permitted maximum increase in loading after commissioning,

- Snow and Ice; although technically an environmental load, it is included here due to its close association with the topside design loads,

- Company Contingency; permitted maximum increase in loading during design.

The total operational load is applied to the centre of gravity of each module, using the values in Table 2.4.

Table 2.4
Topside Operational Loads

Module	Total Operational Load (tonnes)
L10 - Living Quarters	556
M20 - Process/Utilities	1429
M30 - Drilling	4081
C40 - Cellar Deck	2707
M50 - Drilling Derrick	1127
F60 - Flare Boom	35
TOTAL	9935

2.3.3 Accidental Loads

Accidental loads are defined as loads resulting from accidental events. The two accidental loads considered for the GYDA jacket are:

- boat collision
- dropped object

S471 specifies a probabilistic determination of accidental loads whereby the specified load shall have an annual probability of exceedance of 10^{-4} for Safety Class 1 structures. The code does however recognize the non-quantitative nature of some accidental loads.

Boat Collision

The BP analysis for boat collision assumed the following impact criteria:

vessel weight	3,600 tonnes
velocity	2 m/s

The determination of these values is not included in the information received from BP. However, the design conforms to the requirements of the NPD regulations which explicitly require a annual probability of exceedance of 10^{-4} for accidental loads, and is therefore assumed to be consistent with the requirements of CSA S471.

BP considered both stern and broadside impact against the braces and corner legs, respectively. DnV boat impact analyses indicate that bow impact is less onerous than stern, and consequently this condition has not been considered.

BP considered two impact cases, based on the need to avoid progressive collapse due to the loss of load bearing capacity in the main legs:

- grout fill the legs between El. -6m and +9m, and permit a single plastic hinge at the midspan,

- allow the diagonal braces to yield, form plastic hinges and develop membrane tension.

The vessel impact loads are shown on Figures 2.1 and 2.2, and the BP design methodology is discussed in more detail in Section 6.5.

Dropped Object

For the dropped object analysis, the nature of the dropped object was not defined, instead it was assumed to completely remove a brace which may be struck. This approach is considerably simpler than a probabilistic determination and is considered consistent with the intent of the CSA requirements.

Consequently, both accidental loads are considered unchanged for the purpose of the design to CSA.

2.3.4 Frequent Environmental Loads, E_f

The first category of environmental loads defined in S471 are those resulting from frequent environmental processes. For the jacket, the applicable frequent processes are wind, wave and current, all associated with an annual probability of exceedance of 10^{-2}. From Table 6.1 of S471 which defines companion environmental processes, the wind, wave and current effects are to be considered simultaneously.

Wind Loads

CSA Wind Loads

The wind loading on the GYDA platform is calculated following the methodology outlined in S471 Appendix C - Wind Load Determination. For this study, only the horizontal wind forces are calculated and applied normal to the projected area of each topside module, using the design mean wind velocity. A more detailed wind analysis considering effects such as lift, shielding and resonance is not included in this study.

The wind force on each module is calculated as:

$$F = q_{ref}\, C_e\, C_s\, C_d\, A$$

where	q_{ref}	= basic wind pressure	= .869 kPa
	C_e	= exposure factor	= $(Z/10)^{0.24}$
	C_s	= shape factor	= 1.0
	C_d	= dynamic response factor	= 1.49
	A	= projected area	

The above values are obtained as follows:

- q_{ref}, the reference wind pressure, is based on the 10 minute mean wind velocity. It is obtained from the maximum 1 minute mean wind velocity of 41.4 m/s at 10 m above sea level, converted to the 10 minute mean using k = 1.11 from S471, Table C5.1.
- C_e, the exposure factor, is a function of the height, Z_g, taken as the height to the centre of each module above mean sea level.
- C_s, the shape factor, is obtained from Clause C5.1 and is given as 1.0 for the "overall projected area of the platform". The value of 1.5 for "sides of buildings" is not selected as it is assumed to pertain more to the design of the topside modules themselves.
- C_d, the dynamic response factor is calculated according to the procedure of Clause C6.1, S471, considering the deck and superstructure as a whole. The significant parameters used in the calculation are:

  average height, h = 39.5 m
  principal dimension, L = 70 m
  natural frequency, f_o = 0.37 Hz

- A, the projected area of each module, is estimated from topside drawings provided by BP.

The wind load is calculated for two directions: perpendicular to the long axis and perpendicular to the diagonal through the structure, referred to as the broadside and diagonal directions respectively. The forces are summarized in Table 2.5 and the calculations are included in Appendix C of this report.

In accordance with Clause C7.1, S471, the diagonal wind forces are found by combining 80% of the forces in the two principal directions.

Table 2.5
CSA Wind Loads

Module	Force (kN)	
	Broadside	Diagonal (x,y components)
L10 - Living Quarters	1033	2050, 826
M20 - Process/Utilities	1400	0, 1120
M30 - Drilling	690	1133, 552
M50 - Cellar Deck	527	422, 422
F60 - Drilling Derrick	370	296, 296
C40 - Flare Boom	1058	846, 258
TOTAL	5078	5813 (resultant)

BP Wind Loads

The information received from BP did not include any details of the wind loads and their calculation. However, it references the DnV 1977 pressure calculation equation and provides the following correction of wind velocity as a function of height.

$$V_n = V_{10}(h/10)^{0.11}$$

Given the limited information, the BP wind loads are estimated using the provisions of DnV 1977, Appendix A and B.

Since the wind velocity is reported as the 1 minute mean, no conversion is required for use in the DnV calculation. Also, the height coefficient of 0.11 given above is consistent with Clause A1.1 of Appendix A, DnV.

Clauses B1.1.1 and B1.2.1 of Appendix B, DnV, give the equations for the basic wind pressure, q, and the wind force, F_w, respectively. Combining these two equations and using the same terminology as S471, we obtain:

$$F = q_{ref}\, C_e\, C_s\, A \sin \alpha$$

where
- q_{ref} = basic wind pressure = 1.05 kPa
- C_e = exposure factor = $(Z/10)^{0.22}$
- C_s = shape factor from DnV, Table B.5, varies for each module
- A = projected area, normal to the force
- α = angle between the wind direction and the exposed surface

The calculations of the wind force for each module is included in Appendix C of this report and is summarized in Table 2.6. These represent only an estimate of the wind loads used in the BP design.

Table 2.6
Estimated BP Wind Loads

Module	Force (kN)	
	Broadside	Diagonal (x,y component)
L10 - Living Quarters	652	1211, 545
M20 - Process/Utilities	1041	0, 871
M30 - Drilling	408	673, 341
M50 - Cellar Deck	433	237, 362
F60 - Drilling Derrick	348	190, 291
C40 - Flare Boom	934	99, 781
TOTAL	3816	4,000 (Resultant)

Wave and Current Loads

Appendix D of S471, Wave and Current Loads, outlines the recommended method for the determination of wave and current loads. For the jacket structure, the method is based on the use of non-linear wave theory. Stokes' 5^{th} order is considered appropriate for the design wave parameters, as shown in Figure 2.3, and is combined with Morison's equation to obtain wave forces on slender tubular members. The effect of current is included by vectorial addition of the fluid particle velocities applied to the Morison equation.

The calculation of the wave and current forces is performed by the analysis program used for this project which contains the capability for solving the above equations automatically as the design wave is passed through the structure.

The BP design followed the same procedure for its analysis, also using Stokes' 5th order wave theory, and therefore the drag and inertia coefficients developed by BP are considered to be valid for developing the S471 loads and are used without modification. They are listed in Table 2.7 with the effective diameter of tubular member to account for marine growth and appurtenances.

Table 2.7
Wave Force Parameters

Jacket Member	Drag Coefficient C_d	Inertia Coefficient C_m	Effective Diameter $Ø_{eff}$
Tubular Members:			
el +3.0 to wave crest	0.65	2.0	$Ø_{member}$
el +3.0 to -30.0	0.80	2.0	$Ø_{member}$ + 150 mm
el -30 to seabed	0.65	2.0	$Ø_{member}$ + 50 mm
Leg members with timber rubbing strips	1.5	2.0	2.6m
pile clusters	0.8	2.0	max. dimension

The BP design identified the wave parameters for eight points of the compass, for an annual probability of 10^{-2}, and a complete wave load analysis was undertaken for each of these directions. For this project, it was not feasible to duplicate this volume of analysis, and the wave calculations were based on two directions only. These directions are broadside attack and a diagonal wave approach of 56 degrees to the long axis dimension, as shown on Figure 2.4.

The BP results indicate these directions to be the most critical, and this conclusion has been accepted without further analysis. From the BP environmental data, shown on Table B.1 in Appendix B, the following design wave conditions have been established:

	Wave Height (m)	Wave Period (sec.)
Broadside:	20.4	16.1
Diagonal:	24.8	17.8

2.3.5 Rare Environmental Loads, E_r

The second category of environmental loads defined in S471 are those resulting from rare environmental processes such as earthquakes, icebergs, sea ice, and tsunamis. These processes are to be associated with a annual probability of exceedance of 10^{-4} for Safety Class 1 structures.

For earthquake loads, Table 6.1, S471, lists wave, wind and current as companion processes which are stochastically independent and may be determined on the basis of an annual probability of exceedance of 0.95. From the environmental data provided by BP, it is estimated that this would correspond to a calm sea state and therefore these processes are not included in the analysis.

Seismic Hazard Investigation

S471 Appendix F, Earthquakes, summarizes a methodology for seismic hazard investigation. The seismic investigation and the development of design response spectra performed for the BP design are outlined below. These are considered to be consistent with the intent of S471 and therefore the BP response spectra for a probability of exceedance of 10^{-4} is used without modification for the calculation of the CSA earthquake loads.

The earthquake source model for the GYDA field has been defined on the basis of historical as well as recent seismicity information, combined with geological information. The model consists of eleven area sources covering the regional seismicity and four active faults near the site. When combined with an appropriate attenuation model for the area, this model has given an estimate for the bedrock outcrop peak ground acceleration (PGA) of 1.52 m/s^2 for a 10,000 year return period.

Estimates of the pseudo-velocity (PSV) have been obtained in similar ways on the basis of independently established attenuation relationships. These estimates are used as a basis for the design spectra defined with limiting values of 0.18 m in displacement, 0.60 m/s in velocity, and 0.15 m/s^2 in acceleration for a 10,000 year return period. The resulting absolute spectrum at 0.093 m/s reflects a relatively low seismic hazard level.

Site response analyses were performed to evaluate the influence of the local soil and sea water depth on the earthquake motions. Results of the analyses show that the local soil has very little effect on the peak ground acceleration, but it amplifies the mudline earthquake motion by 40-60% in the intermediate frequencies as compared to the bedrock outcrop motion. The sea water depth reduces the vertical mudline motion in the high frequency range.

The 10^{-4} earthquake response spectrum is shown in Figure 2.5.

S471 and BP Design

S471 specifies response spectra amplitude factors of 1 and 2/3 to be applied to the horizontal and vertical responses respectively. The horizontal response is applied in two perpendicular directions simultaneously.

The BP design used amplitude factors of 1.0 and 0.7 for perpendicular horizontal responses and 0.5 for the vertical response. The BP design for earthquake loading appears to follow the requirements of DnV 1977.

The differences between the S471 and BP amplitude factors are summarized below:

	S471	BP
Horizontal - x	1.0	1.0
Horizontal - y	1.0	0.7
Vertical	0.67	0.5

2.3.6 Associated Environmental Processes

Environmental processes of tides, surges, marine growth and ice accretion are taken into account in the determination of loads from both the frequent and rare environmental processes described above.

Snow and ice is included under operational loads for the topside modules.

Marine growth is included as an increase in effective member diameter, as given in Table 2.3.

Tides and surges are included in the determination of water levels for each loading condition, using the environmental data presented in Appendix B, as follows:

- 100 year return water depths:

	Max.	Min.
LAT	65.7	65.7
Tolerance +0.4	-0.4	
Tide and surge	+2.25	-1.06
Reservoir settlement	+0.46	0.0
	68.81 m	64.24 m

- water depth associated with fatigue and 10,000 year earthquake:

LAT	65.7
1/2 tide	+0.46
	66.16 m

2.3.7 Additional Environmental Loads

As well as including the above environmental loads, the BP design also examined loads due to a 10^{-2} earthquake and a 10^{-4} wave.

The inclusion of the 10^{-2} earthquake appears to stem from the requirements of DnV 1977. S471 does not list earthquakes as one of the frequent (annual exceedance probability of 10^{-2}) environmental loads to be considered. As a result, it would not normally be included in a design to the CSA standards.

The consideration of the 10^{-4} wave appears to be a decision by BP, it could not be attributed to any referenced design code. The list of rare (annual exceedance probability of 10^{-4}) environmental loads in CSA S471 does not include waves as a process to be considered. Therefore, the 10^{-4} wave would not normally be included in a design to the CSA standards.

If it was considered that these loads may be critical to the design of a particular structure, Table 6.1 of S471 would suggest the following combinations of companion environmental processes:

10^{-2} earthquake + 0.95 probability of exceedance wave, wind and current
10^{-4} wave + 10^{-2} wind + 10^{-2} current

In contrast, the BP design uses the following combinations of environmental process:

10^{-2} earthquake alone
10^{-4} year wave + 10^{-2} wind + 10^{-1} current

Post-damage Environmental Conditions

In the BP analyses for the 10^{-4} earthquake, the 10^{-4} wave, boat impact and dropped object, environmental conditions are specified for post-damage strength analysis. These are defined as:

10^{-2} return period wave,
10^{-1} wind,
10^{-1} current.

S471 does not specify any environmental conditions to be considered following damage from the extreme earthquake or accidental loads.

2.4 Load Factors and Load Combinations

The load factors and combinations applicable to the design of the jacket have been determined following the requirements of S471, Table 6.2. They are listed below in Table 2.8, along with the comparable BP design load combinations.

A quantitative comparison of these load combinations is performed in Section 3 using the GYDA platform loading.

Table 2.8
Load Combinations

	CSA Load Combinations Ultimate Limit States - Safety Class 1	BP Design Load Combinations (following NPD)
A	(1)$1.25G_D$ + (1)$1.25Q + 0.7E_f$, $E_f = 10^{-2}$ (Wave+Wind+Current)	$1.3G_D + 1.3Q + 0.7E_f$, $E_f = 10^{-2}$ (Wave+Wind+Current) $E_f = 10^{-2}$ Earthquake
B	1.05or $0.9G_D + 1.0Q + 1.35E_f$, $E_f = 10^{-2}$ (Wave+Wind+Current)	$1.0G_D + 1.0Q + 1.3E_f$, $E_f = 10^{-2}$ (Wave+Wind+Current) $E_f = 10^{-2}$ Earthquake
C	1.05 or $0.9G_D + 1.0Q + 1.0E_r$, $E_r = 10^{-4}$ Earthquake, Note: earthquake response factors: horiz. 1.0, 1.0, vert. 2/3	$1.0G_D + 1.0Q + 1.0E_r$, $E_r = 10^{-4}$ Earthquake, $E_r = 10^{-4}$ Wave + 10^{-2} Wind + 10^{-1} Current Note: earthquake response factors: horiz. 1.0, 0.7 vert. 0.5 + post-damage conditions: $1.0G_D + 1.0Q + 1.0E_f$, $E_f = 10^{-2}$ Wave + 10^{-1}(Wind+Current)
D	1.05 or $0.9G_D + 1.0Q + 1.0A$, A = Boat impact A = Dropped object	$1.0G_D + 1.0Q + 1.0A$, A = Boat impact A = Dropped object + post-damage conditions: $1.0G_D + 1.0Q + 1.0E_f$, $E_f = 10^{-2}$ Wave + 10^{-1}(Wind+Current)
E	for fatigue: $1.0G_D + 1.0Q + 1.0E_f$, E_f = Wave+Wind+Current	for fatigue: $1.0G_D + 1.0Q + 1.0E_f$, E_f = Wave+Wind+Current

(1) Use 0.9 when load resists overturning, uplift or reversal of operational load effects.

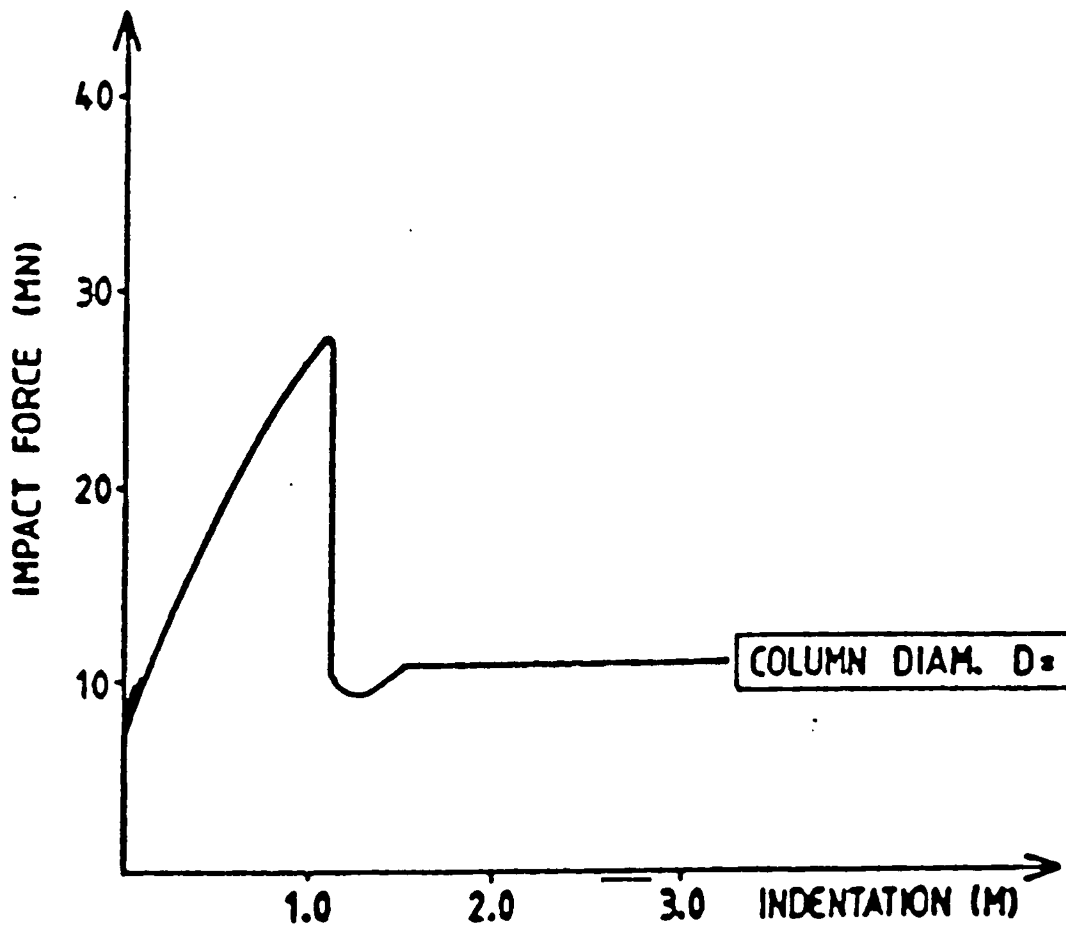


Figure 2.1
Vessel Force - Broadside Impact
(Source: BP Design Briefs)

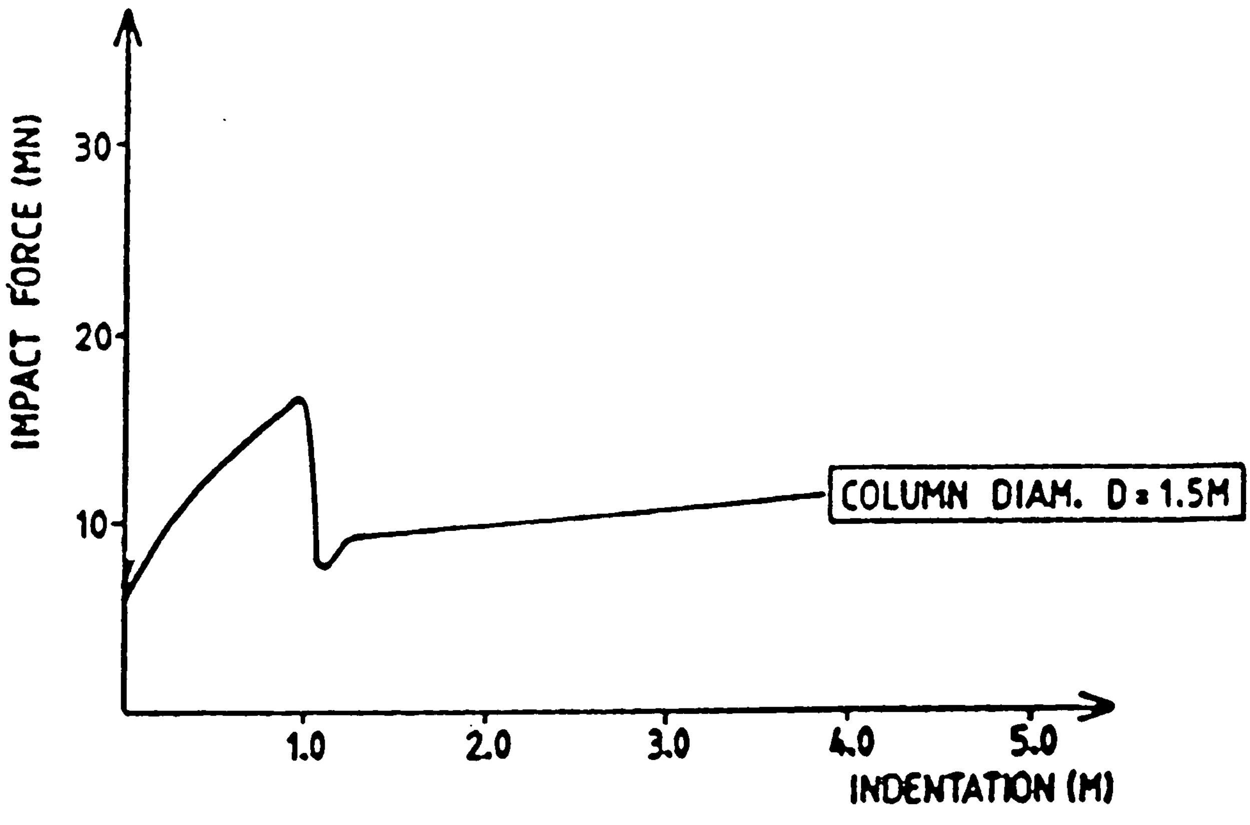


Figure 2.2
Vessel Force - Stem Impact
(Source: BP Design Briefs)

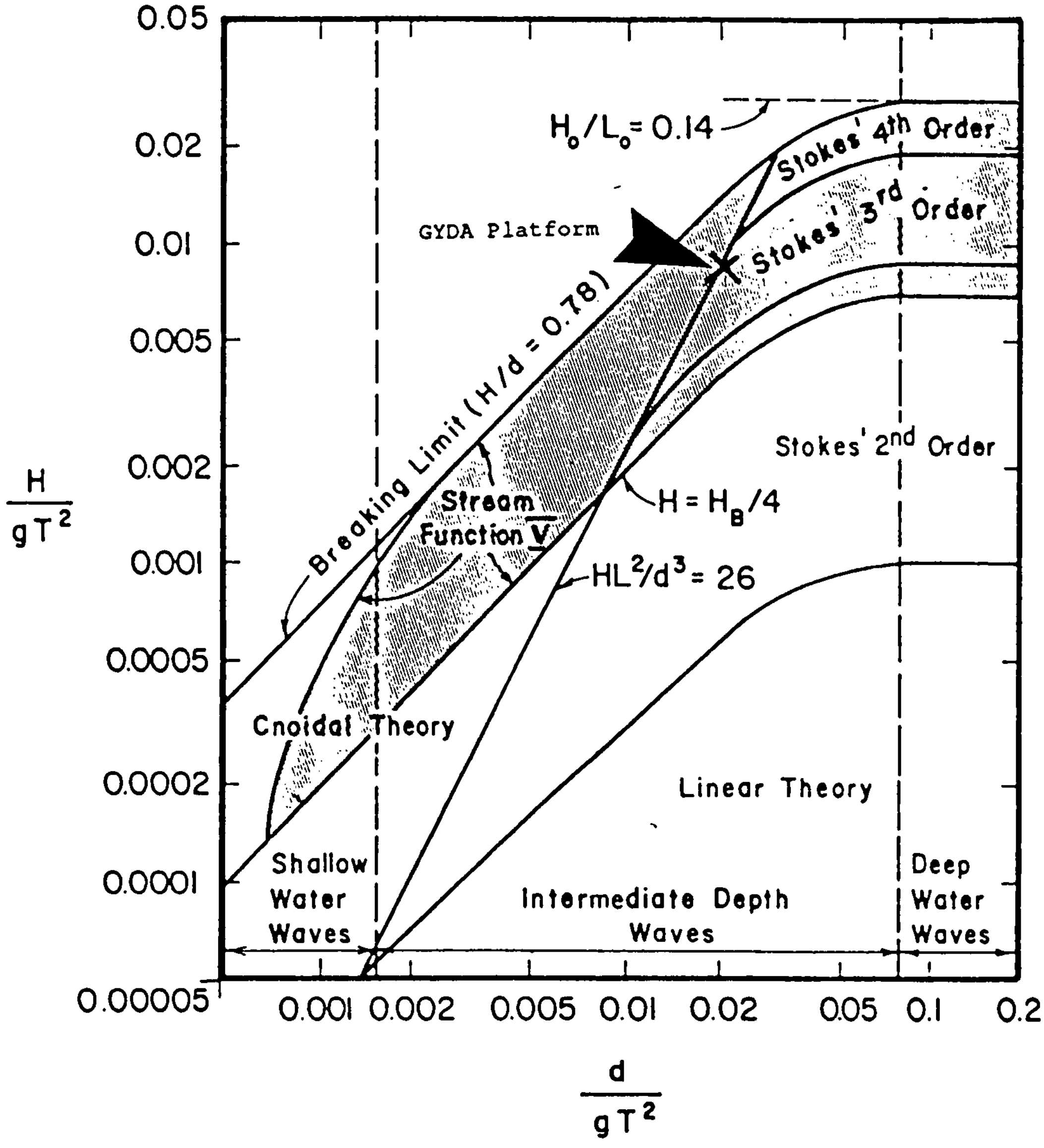
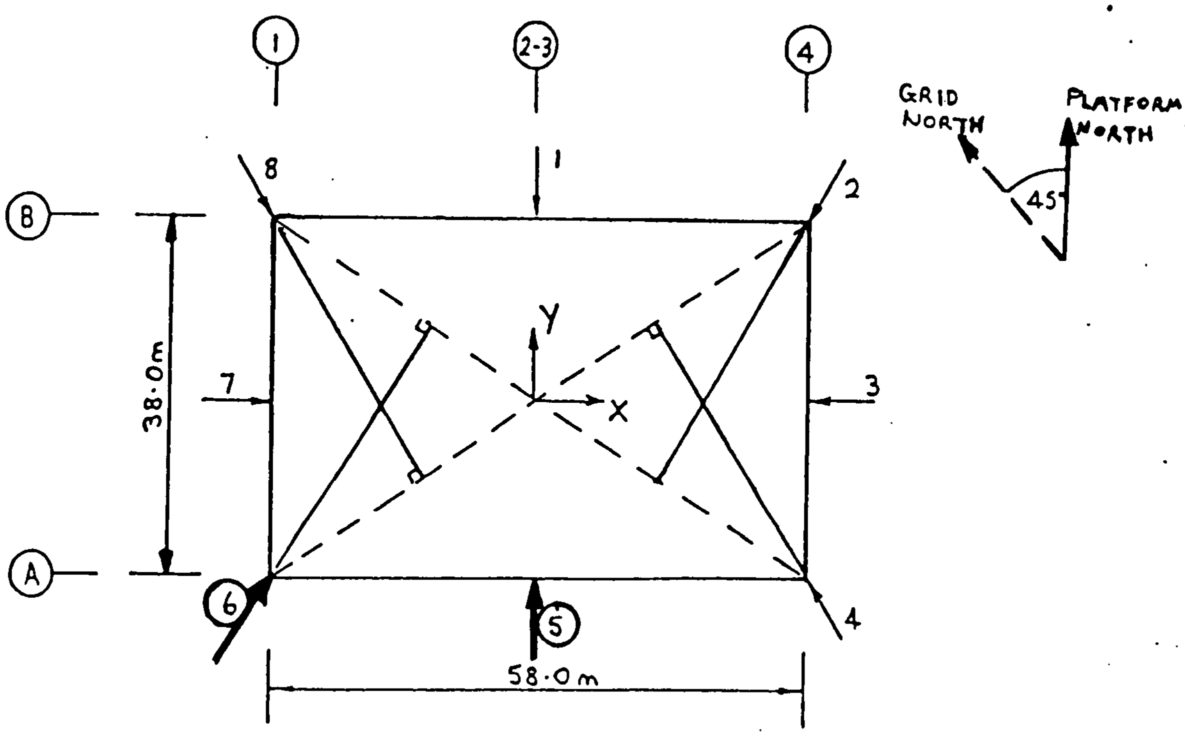


Figure 2.3
Wave Theory
(Source: "Mechanics of Wave Forces on Offshore Structures" by M. Isaacson and T. Surpkaya, 1981)



Wave Reference Relative to Platform North	Wave Height (m)	Wave Period (sec)	Wave Direction Relative to Platform North (°)	Wave Direction Using DAMS Notation (°)
1 (N)	20.2	15.9	0.00	270.00
2 (NE)	20.4	16.1	33.23	236.77
3 (E)	19.9	15.8	90.00	180.00
4 (SE)	22.2	16.8	146.77	123.23
5 (S)	20.4	16.1	180.00	90.00
6 (SW)	24.8	17.8	213.23	56.77
7 (W)	25.0	17.8	270.00	0.00
8 (NW)	24.1	17.5	326.77	303.23

Figure 2.4
Wave Attack Directions
(Source: BP Design Briefs)

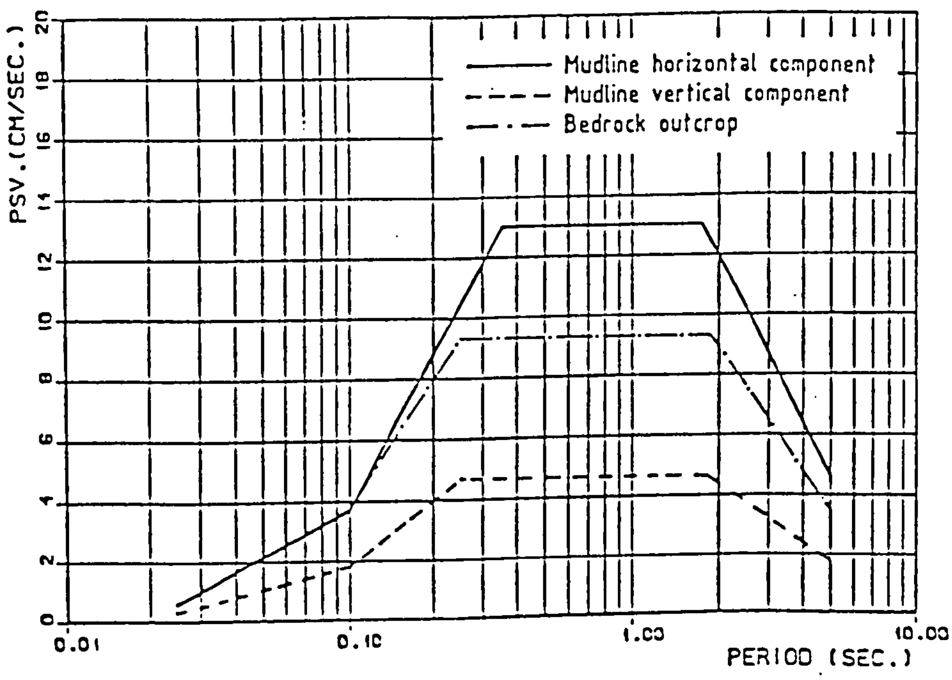


Figure 2.5
10^{-4} Earthquake Response Spectrum
(Source: BP Design Briefs)

3. JACKET ANALYSIS

3.1 Computer Model

3.1.1 Analysis Program

The analysis performed for this study makes use of the GYDA platform model developed for the G-1A study. The G-1A model was modified to incorporate the additional information received from BP for the G-1B study.

The ABAQUS finite element package was selected for this study because of its ability to accurately model the behaviour of the structure in a semi-submerged state. ABAQUS provides for the representation of a calm water surface, a steady current profile and waves of a given amplitude and period. Since the wave effects are a significant component of the existing GYDA platform design, the wave modelling feature was considered an essential requirement for the analysis program.

ABAQUS allows for a wave train to be stepped through the structure in order to determine the wave position causing maximum effects, for any given wave direction. It calculates buoyancy and drag forces on each member taking into account the computed surface elevation at each time step.

3.1.2 Jacket Model

The GYDA jacket consists of unstiffened tubular members and simple unstiffened joints. There is a total of 58 different combinations of pipe diameter and wall thickness throughout the jacket. Also, all tubular joints generally contain some eccentricity, as the braces are joined to the chord members without overlap.

The geometry, including joint eccentricities, of the jacket is modelled according to the structural drawings furnished by BP, with the following exceptions:

- the production riser brace frames are represented by a simpler brace arrangement;
- the length and thickness of some joint cans had to be estimated from known joints as limited information was included in the drawings;
- two joint eccentricities of less than 20 mm were neglected;
- two joint eccentricities were modified by 10 mm to enable complete symmetry between rows A and B of the jacket;
- the cast nodes are modelled as regular tubular members;
- the conical transition pieces are not modelled, an abrupt change in diameter occurs instead.

The model uses pipe elements to represent the tubular members with the variations in diameter and wall thickness matching those indicated on the BP drawings.

The thirty-two production risers and the caissons are modelled independently of the jacket structure with their contribution to the overall loading transferred to the jacket model. In this way, the conductors and caissons do not affect the stiffness of the model. This method is similar to that used by BP and is consistent with current practice.

3.1.3 Topsides

The information received from BP did not include structural details of the topside modules, but did include weights, location of centre of gravity and overall dimensions. As a result, the superstructure is modelled in the following way:

- The cellar deck legs and diagonal braces are modelled with pipe elements, using estimated dimensions. These are connected to a rigid frame representing the remainder of the cellar deck.

- Each module is represented by a point mass applied at its centre of gravity.

- The centre of gravity of each module is connected by four rigid beams to the appropriate support locations on the cellar deck.

BP included more extensive modelling of the topsides within their jacket analyses, primarily due to the difficulty in separating the two components when considering seismic response. This has some implication in comparing the BP seismic loads with those computed for this project. This is discussed later in Section 3.5.

3.1.4 Piles

For the in-place analysis, the 20 piles supporting the jacket are modelled by linear elastic springs. Each pile is represented by a 6 x 6 stiffness matrix connected at the bottom of the pile sleeve. The values for the stiffness matrices are obtained from the information provided by BP.

The pile sleeves and connecting horizontal and vertical shear plates are represented by a very stiff arrangement of rigid beams. This is similar to the procedure reported by BP, although specific details were not provided.

For the earthquake analysis, one linear elastic spring matrix is used at the bottom of each leg to represent the pile group behaviour. The bottom of each leg is also stiffened to represent the pile cluster effects. The foundation spring stiffness matrices for the 10^{-4} earthquake were contained in the BP information.

In a detailed analysis, the non-linear behaviour of the soil/pile interaction must be resolved for each loading condition and direction. This iterative process ensures consistency in forces, deflections and rotations between the jacket model and the pile model. For this study, the pile stiffness matrices are assumed to account for pile/structure interaction and hence the resulting forces are considered accurate for all loading conditions.

3.1.5 Comparison of Computer Models

The following differences between the platform model developed for this project and the one used by BP have been identified:

Project Model	BP Model
- Cellar deck represented by a rigid frame.	- The cellar deck fully modelled.
- Pile clusters modelled by rigid beams.	- Pile clusters modelled by rigid beams and diaphragms.
- Topside mass applied at module centre of gravity.	- Topside mass applied as forces at connection point with cellar deck.
- Conductor, caisson and riser supports not modelled.	- Details of conductor, caisson and riser modelling not provided.
- Forces from conductor and caisson model applied only at horizontal bracing elevations (+10, -23, -38, -62 m LAT).	

The project model is shown in Figure 3.1 and the BP model in Figure 3.2.

3.2 Loads Considered for Analysis

For this project, the GYDA jacket is analyzed for the following loads to obtain forces for the design of tubular members, joints and foundation piles:

- Dead and live
- 10^{-2} wave, wind and current
- 10^{-4} earthquake.

No numerical analysis is performed for the following loads identified in Section 2:

- Accidental loads; boat impact and dropped object

  As discussed in Section 2, for the accidental loading conditions, the analysis and design to the CSA code requirements would be similar to the BP method and therefore the BP results are considered valid.

- Fatigue Cyclic Loads

  The loads and load factors for the fatigue analysis to CSA requirements are the same as those used in the BP design. Therefore, no calculation of stress ranges is performed.

- 10^{-2} Earthquake, 10^{-4} Wave

  The 100 year earthquake and 10,000 year wave are not normally included in a design to S471 requirements. Also, BP reported that these loading conditions did not govern any part of the design. As a result they were not included in the analysis.

3.3 Dead and Live Load Analysis

The self weight of the jacket is calculated by the analysis program based on member dimensions and material properties. A first analysis was performed to obtain an estimate of the jacket weight. This value was then compared to BP's reported weight which includes marine growth. The material density was then increased by an appropriate factor to obtain the desired weight.

The dead and live load due to the topside modules is applied as a point mass located at the respective centre of gravity, using the values listed in Section 2.

The mass of the pile guides, grout and connection is included as a point mass of 140 tonnes applied to the top of each of the 20 piles. The BP model includes the weight of appurtenances such as timber rubbing strips, anodes and leg grout, however, these are considered minor and are not included in the project model. A mass of 1,530 tonnes was added to the cellar deck module to account for caissons and caisson supports, which was estimated from the BP information.

The buoyancy effects are calculated using the water surface at the time of maximum wave loading. The analysis program evaluates the buoyancy using an effective member diameter which includes the marine growth allowance and takes into account the ballast water filling the main jacket legs.

Table 3.1 summarizes the dead and live loads obtained from the project model. BP reported the majority of the weight components of the overall platform, but not the total submerged weight. However, the results of the analysis are considered to be sufficiently accurate for the purpose of this project.

Table 3.1
Dead and Live Loads

Item	Weight (tonnes)	
	Project Model	BP Reported
Jacket - dry weight - buoyancy effect	6,670 -2,770	6,674 -
Topsides	26,500	26,500
Pile Clusters (buoyant wt.)	2,800	2,800
Caissons Addition	1,530	-
Total	34,730	-

3.4 Wave, Wind and Current Load Analysis

3.4.1 Analysis Method

As discussed in Section 2, the wave, wind and current loads are calculated for two directions, broadside and diagonal to the platform. The wave and current loads are calculated by the analysis program using the input listed in Section 2 for the following parameters:

- water depth
- wave height
- wave period
- wave direction
- current profile
- drag and inertia coefficients
- effective member diameter.

The wave and current loads are calculated at 1 second intervals for the full wave period. Figures 3.3 and 3.4 show the total base shear as a function of the wave profile as well as the position of the wave with respect to the structure at the point of maximum base shear.

The wind loads are added directly to the centre of each module using either the S471 or the BP values listed in Section 2. These effects are then combined with the wave loads to obtain the S471 and the BP total environmental loads.

3.4.2 Model Evaluation

The information supplied by BP includes a summary of unfactored forces and maximum factored pile top forces for the storm condition. These values are used as the basis for the comparison of the two models. This comparison is shown in Table 3.2 where the dead and live loads are combined with the wave loads, all obtained from the project model.

Table 3.2
Comparison of Models

Item	Forces (kN, kN-m)		
	Project Model	BP Reported Value	% Difference
Unfactored Forces			
Max. Base Shear	77,001	78,599	-2.0
Max. Overturning Moment	4,516,055	4,254,537	+6.1
Max. Pile Compression	42,062	37,749	+11.4
Max. Pile Tension	none	9,992	-
Factored Forces ($1.0G_D + 1.0Q + 1.3\ E_F$)			
Max. Compression:			
Corner Pile	33,982	33,900	+0.2
Centre Pile	46,948	40,400	+16.2
Max. Lateral Load:			
Corner Pile	6,670	7,100	-6.1
Centre Pile	10,169	9,280	+9.6

Overall, the results obtained from the project model are in good agreement with the values reported by BP. The following general comments can be made regarding the comparison shown in Table 3.2:

- The level of loading is similar, however the location and distribution of loads differs,
- The project model appears to distribute more load to the centre piles and less to the corner piles,
- The project model does not yield any pile tension and it is unclear how BP obtained such a high value.

The information provided by BP does not indicate which loading conditions caused each of the maximum unfactored forces reported. It is assumed that these values apply to the wave loading conditions since this is the reported governing load case. The comparison supports this assumption for all items except the pile tension.

3.4.3 Comparison of Load Factors

The effects of different load factors in the load combinations of S471 and those used by BP are evaluated in Table 3.3 and 3.4. The first Table examines overall loading values, defined by total base shear, overturning moment and maximum pile compression. The second Table compares member forces for a selection of members throughout the jacket structure.

The comparison is performed using only the results obtained from the project model and using the appropriate S471 or BP load factors. The S471 wind loads are included in the S471 load combinations, and the estimated BP wind loads are used in the BP load combinations. Only the maximum of either wave direction is reported.

Table 3.3
Comparison of Load Factors - Overall Forces
(forces in kN, and kN-m)

Loading Condition	Load Combination		% Difference (S471 - BP)
	S471	BP	
Unfactored	$G_D + Q + E_f$	$G_D + Q + E_f$	
Total Base Shear	78,691	77,001	+2.2
Overturning Moment	4,715,668	4,516,055	+4.2
Max. Pile Compression	42,624	42,062	+1.3
A - Operating	$1.25GD+1.25Q+0.7E_F$	$1.3GD+1.3Q+0.7E_F$	
Total Base Shear	54,936	54,922	0.0
Overturning Moment	3,241,614	3,100,116	4.6
Max. Pile Compression	44,013	44,908	-2.0
B - Storm	$1.05GD+1.0Q+1.35E_F$	$1.0GD+1.0Q+1.3E_F$	
Total Base Shear	106,314	102,379	+3.8
Overturning Moment	6,401,762	5,903,832	+8.4
Max. Pile Compression	48,457	46,948	+3.2

Note: G_D = dead load, incl. buoyancy
Q = Live load
E_f = 10^{-2} (wave + current + wind)

Table 3.4
Comparison of Member Forces

(compression -ve.)

MEMBER		TOTAL UNFACTORED CSA	BP	% Difference (CSA-BP)	A - OPERATING CONDITION CSA(1.25)	BP	% Difference (CSA-BP)	B - STORM CONDITION CSA(1.05)	BP	% Difference (CSA-BP)
Legs:										
24	Axial	-59071	-58204	1.5	-64683	-66198	-2.3	-66452	-62938	5.6
	Shear	5157	5078	1.6	6122	6294	-2.7	5532	5234	5.7
	Bending	38867	38242	1.6	46408	47716	-2.7	41519	39244	5.8
39	Axial	-79219	-77380	2.4	-80862	-81884	-1.2	-92461	-86735	6.6
	Shear	4103	4011	2.3	4285	4352	-1.5	4741	4449	6.5
	Bending	29066	28369	2.5	30545	30993	-1.4	33467	31357	6.7
58	Axial	-54634	-52992	3.1	-59089	-59835	-1.2	-61881	-57519	7.6
	Shear	526	511	2.9	573	582	-1.4	594	553	7.4
	Bending	6017	5905	1.9	5830	5918	-1.5	7229	6809	6.2
59	Axial	-62898	-62033	1.4	-70089	-71853	-2.5	-70076	-66428	5.5
	Shear	516	503	2.7	593	605	-1.9	566	528	7.1
	Bending	3681	3681	0.0	4601	4786	-3.8	3814	3681	3.6
Top diagonals:										
75	Axial	-11492	-10797	6.4	-11947	-11815	1.1	-13291	-11908	11.6
	Shear	129	129	-0.2	86	85	0.9	177	171	3.6
	Bending	624	606	2.9	558	555	0.6	778	726	7.1
286	Axial	-12295	-12107	1.6	-12472	-12692	-1.7	-14397	-13630	5.6
	Shear	143	143	0.3	108	108	-0.3	189	182	4.1
	Bending	810	807	0.4	695	704	-1.3	1024	982	4.3
625	Axial	-18206	-18158	0.3	-17027	-17382	-2.0	-22145	-21270	4.1
	Shear	222	224	-0.8	151	152	-0.7	303	294	3.1
	Bending	1458	1474	-1.1	994	1003	-0.9	1988	1934	2.8
Mid diagonals:										
61	Axial	6774	6212	9.1	4516	4101	10.1	9271	8198	13.1
	Shear	17	17	0.0	21	22	-3.8	17	17	3.6
	Bending	294	285	3.0	311	315	-1.2	337	314	7.5
263	Axial	-10837	-10581	2.4	-7784	-7623	2.1	-14518	-13647	6.4
	Shear	47	47	1.4	45	46	-1.6	58	55	5.5
	Bending	211	211	0.0	264	275	-3.8	219	211	3.7
524	Axial	-17355	-17262	0.5	-15438	-15672	-1.5	-21564	-20646	4.4
	Shear	29	29	0.0	24	25	-3.8	45	43	3.8
	Bending	394	389	2.2	304	303	0.8	516	491	6.0
607	Axial	-27516	-27398	0.4	-24227	-24595	-1.5	-34314	-32909	4.3
	Shear	55	57	-2.5	26	27	-3.6	90	88	1.9
	Bending	1506	1522	-1.0	1121	1138	-1.5	1996	1942	2.8
Bot. diagonals:										
506	Axial	-21213	-21030	0.9	-18697	-18919	-1.2	-26436	-25240	4.7
	Shear	136	134	2.1	122	122	-0.4	169	159	6.1
	Bending	488	488	0.0	610	635	-3.8	595	573	3.9
602	Axial	-19309	-19195	0.6	-13862	-13814	0.4	-25858	-24765	4.4
	Shear	93	92	0.9	70	70	0.2	122	117	4.6
	Bending	810	812	-0.3	519	516	0.6	1122	1082	3.7
SUMMARY: Average Difference (%)										
	Axial			2.3			-0.1			6.5
	Shear			0.8			-1.6			4.8
	Bending			0.9			-1.5			4.9

3.5 Earthquake Analysis

3.5.1 Analysis Methods

The analysis follows the response spectrum method, taking into account the structural stiffness, topside and jacket mass and added mass effects including marine growth.

The structural model used for the earthquake analysis is essentially the same as the one used for the wave analysis, with the following modifications:

a. The foundation stiffness matrices representing each pile top are replaced by stiffness matrices modelling each pile group, located at the bottom of each jacket leg. The values for each pile matrix are obtained from the information provided by BP.

b. Added mass effects are approximated by point masses applied at all main joints, with horizontal components only. The added mass is calculated using a factor of 1.0; that is, assuming an added mass equal to the displaced volume of each tubular member. BP did not report the details of their added mass calculations.

The project model for the earthquake analysis is similar to the one used by BP, with the following identified differences:

- the modelling of the mass is more detailed in the BP model,

- the BP model refines the representation of the topside modules, approximating the actual stiffness of each as it is connected to the cellar deck which is itself fully modelled.

The response spectrum used for this analysis is the one developed by BP for the 10^{-4} earthquake, as shown on Figure 2.5. It is defined in Table 3.5 in terms of velocities and accelerations.

Table 3.5
10^{-4} Earthquake Response Spectrum Values

Frequency (Hz)	Period (sec)	Velocity PSV (m/s)	Acceleration	
			(m/s^2)	(ref. g)
0.20	5.0	0.046	0.0578	0.006 g
0.57	1.75	0.130	0.04668	0.0047 g
2.84	0.35	0.130	2.3338	0.237 g
10.00	0.10	0.037	2.3248	0.237 g
40.00	0.025	0.006	1.5080	0.153 g

For this analysis, the first ten natural frequencies of the structure are extracted using the subspace iteration method. A response spectra analysis is then executed to calculate the structural response due to the base excitation described by the response spectrum. The complete quadratic formula is used to combine the modal effects.

The response spectrum is applied in the two principal horizontal and the vertical directions, X, Y and Z respectively, using the following factors for both the design to S471 and in accordance with the BP methodology.

Direction	S471	BP Design	
		Major-X	Major-Y
X	1.0	1.0	0.7
Y	1.0	0.7	1.0
Z	0.67	0.5	0.5

3.5.2 Model Evaluation

The accuracy of the project model is assessed by comparing its results to the results reported by BP. The BP information, however, did not directly include global or member forces and so the comparison is performed on the basis of the natural frequency extraction. The first natural period and the dynamic mass in each principal direction are shown in Table 3.6 for both the project and the BP model.

Table 3.6
Earthquake Model Evaluation

Item	Project Model	BP Reported Value
Natural Period	2.3 Secs.	2.72 Secs.
Dynamic Mass (X)	451,701 kN	460,726 kN
Dynamic Mass (Y)	450,917 kN	454,411 kN
Dynamic Mass (Z)	329,685 kN	326,521 kN

The discrepancy in natural period is considered to be mainly due to the differences in the modelling of the topsides. Sensitivity tests performed on the project model indicate that a reduction in topside stiffness, and especially a more accurate modelling of the cellar deck, could account for the majority of the difference noted above. Differences in mass magnitude and distribution are considered to have only a small effect on the results.

On the basis of this comparison, the project model is considered sufficiently accurate to enable a valid comparison of the response spectrum factors and of the load factors.

3.5.3 Comparison of Response Spectrum Factors

Using the results of the project model, the effect of differences in the response spectrum factors are evaluated by considering the earthquake forces alone. The comparison is done on the basis of axial and shear forces for each pile, and the global base shear and overturning moment, as shown in Table 3.7.

Table 3.7
Comparison of Response Spectrum Factors
(Forces in kN, Moment in kN-m)

Pile Group		S471	BP Design		% Difference
			Major-X	Major-Y	S471 - max. BP
A-1	Axial	15930	13540	13080	+17.7
	Shear	3371	2984	2832	+13.0
A-4	Axial	15610	13360	12750	+16.8
	Shear	3289	2925	2747	+12.4
B-1	Axial	15930	13530	13070	+17.7
	Shear	3385	2990	2840	+13.2
B-4	Axial	15570	13300	12760	+17.1
	Shear	3290	2919	2756	+12.1
A 2/3	Axial	10550	7621	9392	+12.3
	Shear	2684	2391	2276	+12.3
B 2/3	Axial	10480	7572	9323	+12.4
	Shear	2716	2353	2295	+15.4
Total Base Shear		18735	16573	15749	+13.0
Total OTM		2401687	2014120	1982372	+19.2

3.5.4 Comparison of Load Factors

The effect of differences in load factors is shown in Table 3.8, in terms of pile forces and global base shear and overturning moment.

Table 3.8
Comparison of Earthquake Load Factors
(Forces in kN, Moment in kN-m)

Pile Group		S471		BP		% Difference
		$1.05G_D+Q+E_r$	$0.9G_D+Q+E_r$	$G_D+Q+E_r(X)$	$G_D+Q+E_r(Y)$	Max. S471 - Max. BP
A-1	Axial	80934	71648	75439	74979	+7.3
	Shear	8745	7979	8104	7945	+7.9
A-4	Axial	75760	67162	70624	70084	+7.3
	Shear	8523	7775	7903	7740	+7.8
B-1	Axial	80436	71221	74974	74514	+7.3
	Shear	8675	7918	8036	7884	+8.0
B-4	Axial	75477	66924	70376	69766	+7.2
	Shear	8686	7915	8065	7888	+7.7
A 2/3	Axial	65153	57394	59299	61050	+6.7
	Shear	11642	10367	10854	10796	+7.3
B 2/3	Axial	64399	56707	58906	60677	+6.1
	Shear	11663	10381	10943	10828	+6.6
Total Base Shear		57934	52334	53905	53081	+7.5
Total OTM		2659319	2626309	2255225	2223853	+17.9

Note: Axial - Only indicates maximum compression
Shear - Indicate the resultant of the X and Y direction shear

The results on Table 3.7 and 3.8 indicate the CSA code is consistently more conservative than the NPD code used by BP in deriving pile forces, base shear and overturning moment by a response spectrum analysis.

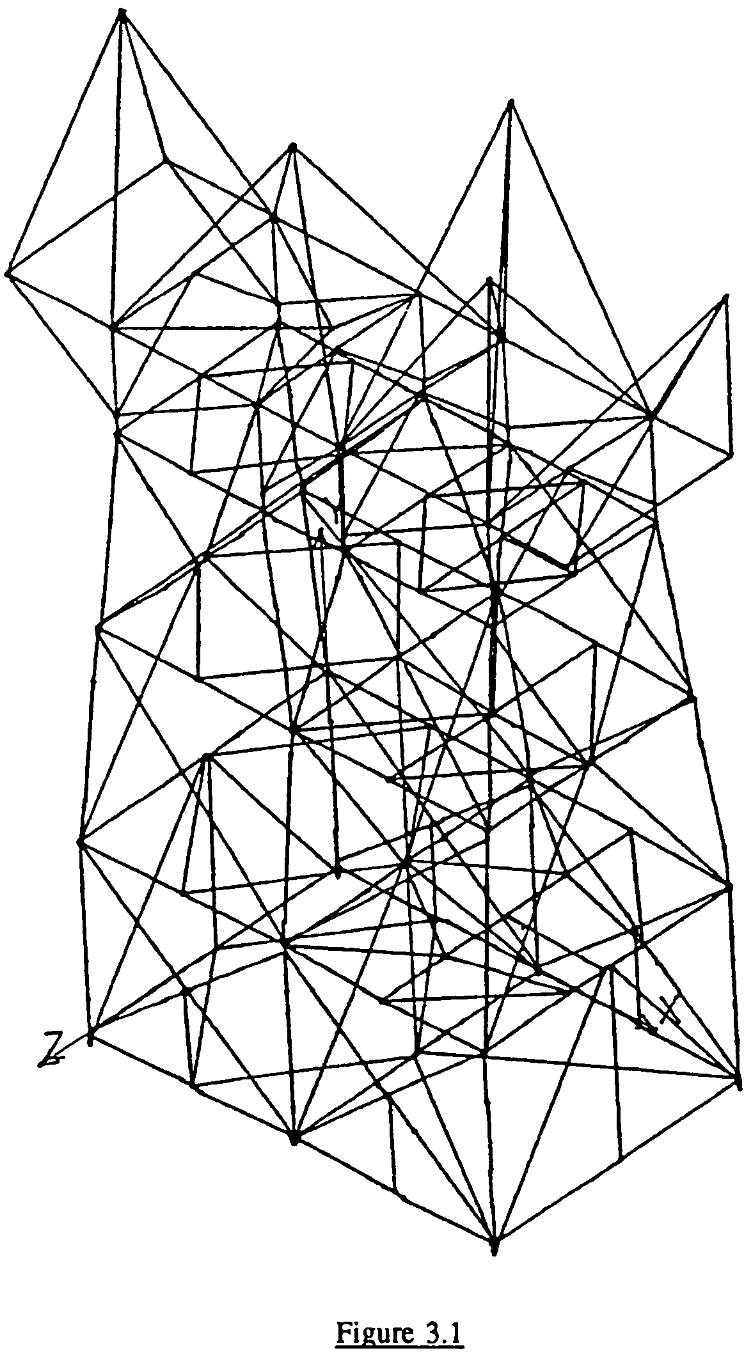


Figure 3.1
Project Model

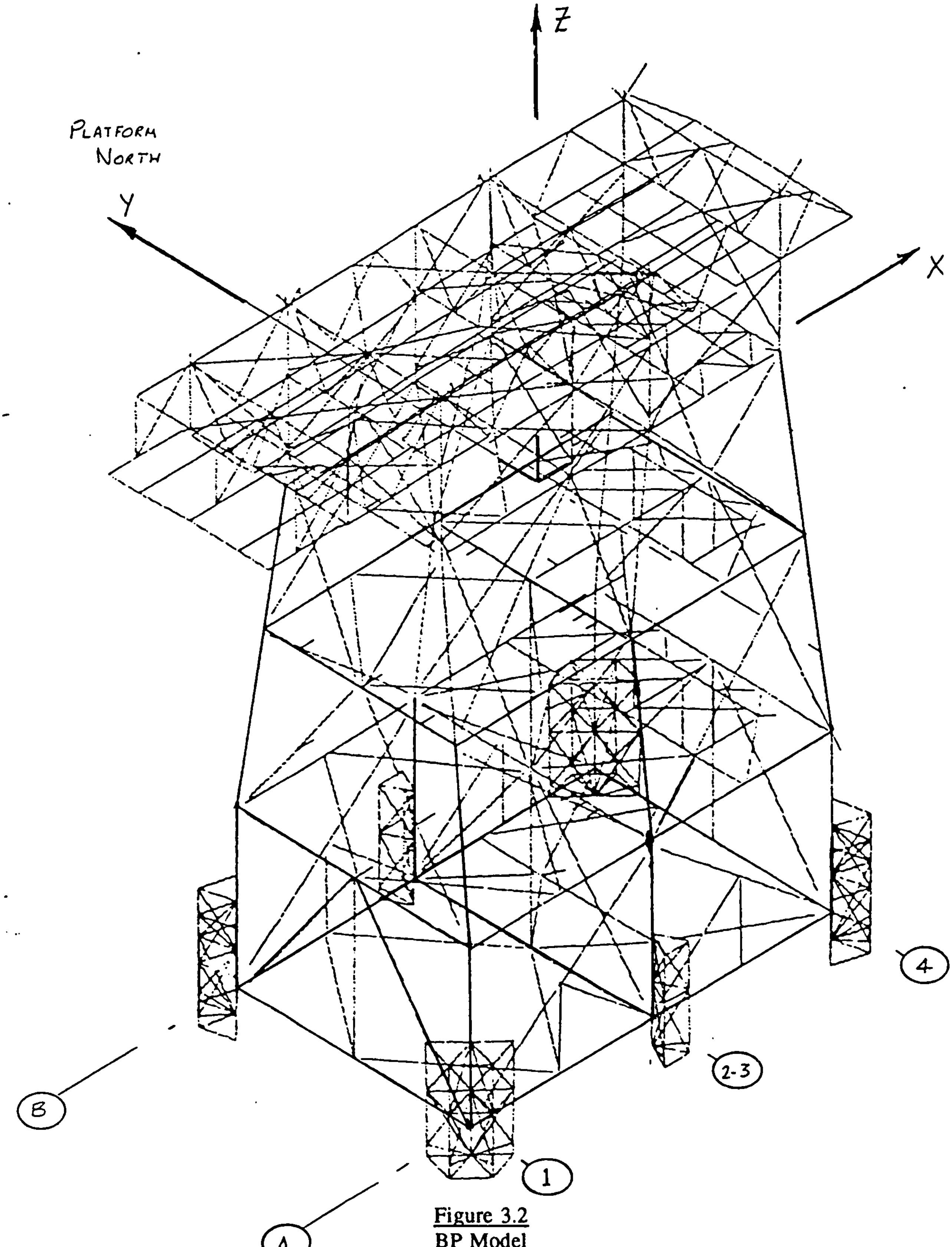


Figure 3.2
BP Model
(Source: BP Design Briefs)

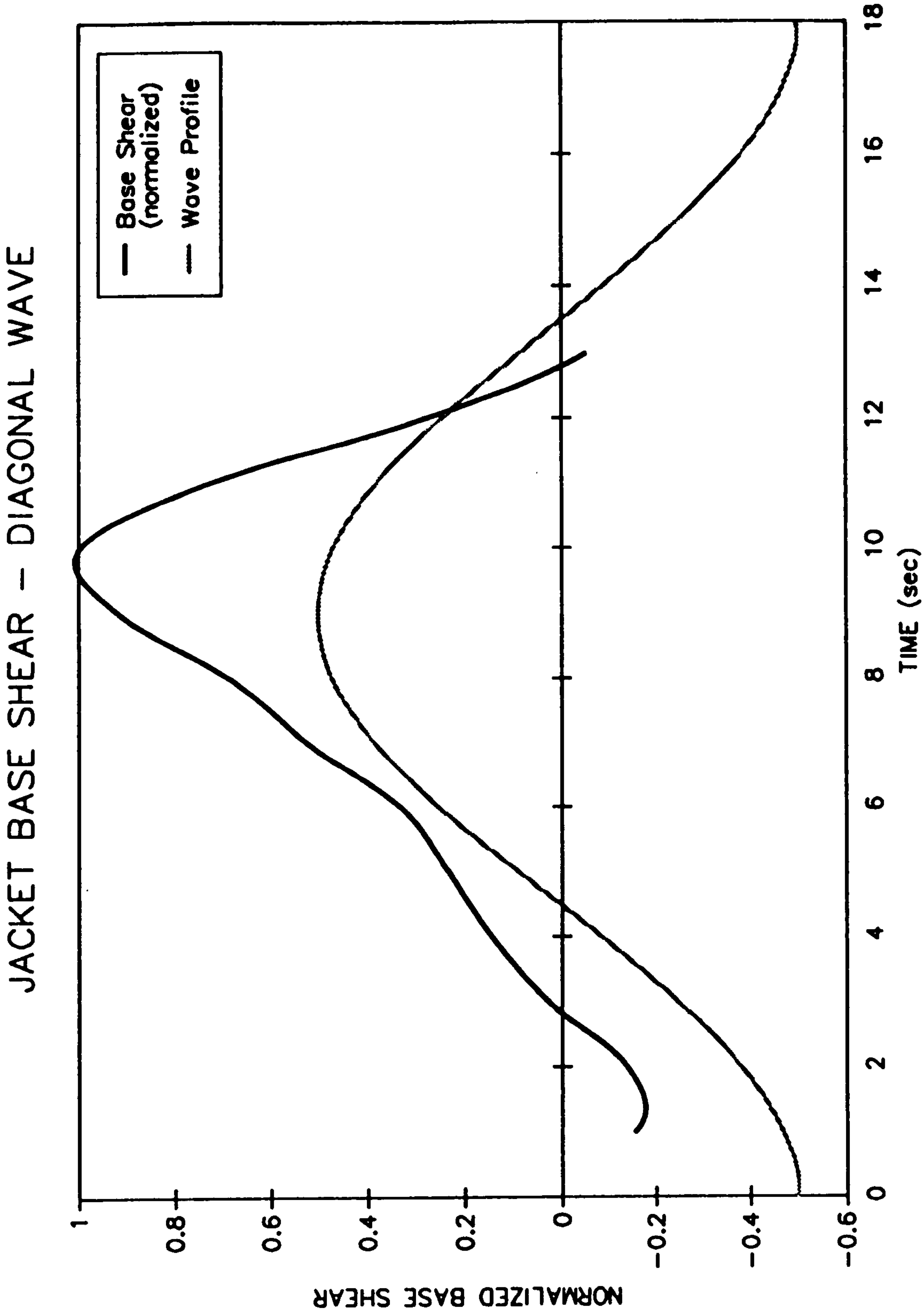


Figure 3.3
Jacket Base Shear - Diagonal Wave

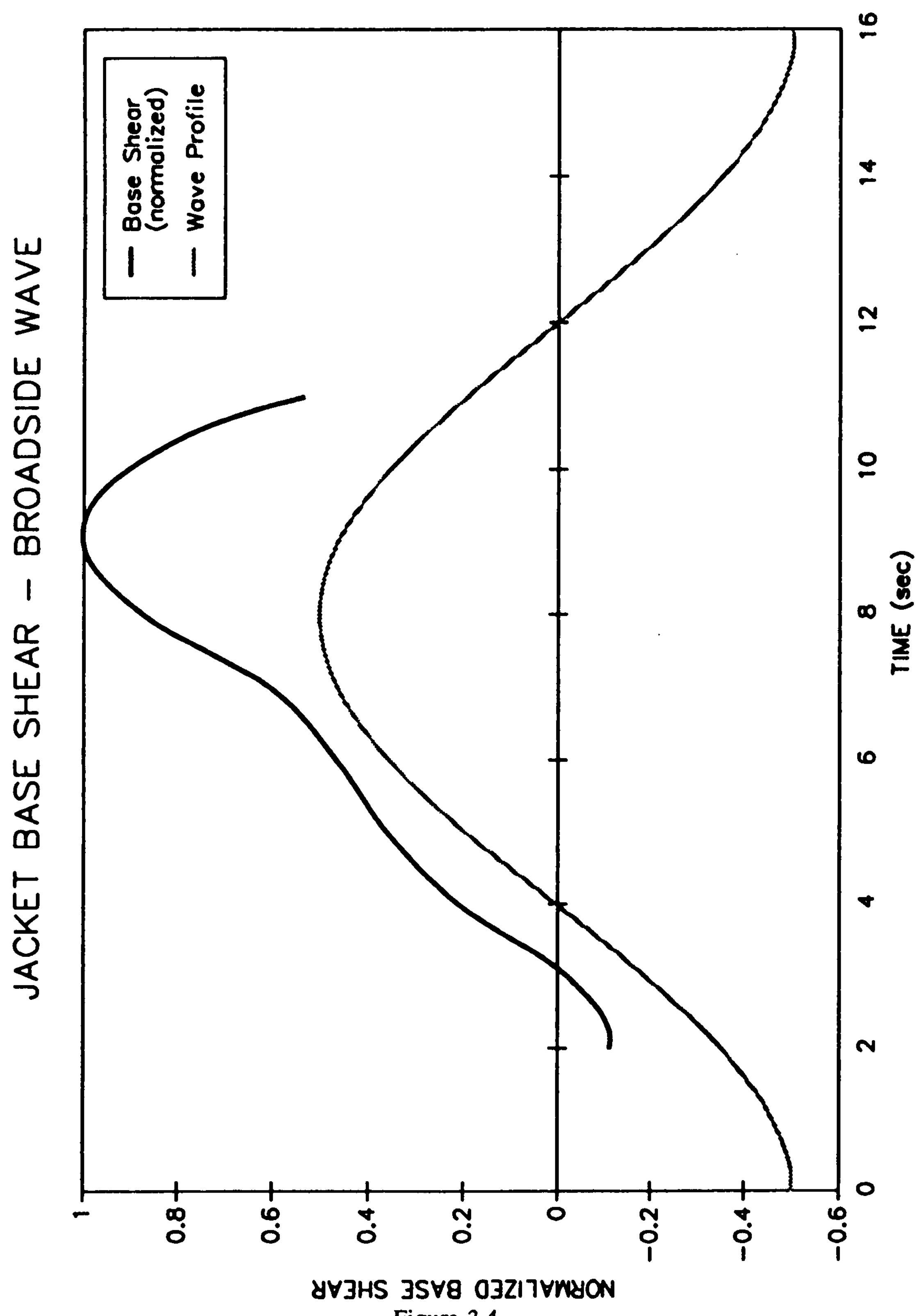


Figure 3.4
Jacket Base Shear - Broadside Wave

4. FOUNDATIONS - S472

4.1 Site Conditions

Foundation conditions at the site were established on the basis of two site investigation programs. The site investigations comprised a total of thirteen boreholes and ten continuous cone penetrometer tests (CPTs). In general, seabed soil conditions consist of a very dense upper sand layer, 10 m to 22 m in thickness, underlain by a stiff to very stiff upper clay layer between 5 m and 19 m in thickness. Beneath the clay is a second very dense sand unit, 10 m to 11 m thick, underlain by a second very stiff clay unit. The lower clay extends below the termination depth of the boreholes at most locations, or to a maximum depth of 95 m below seabed.

Based on the site investigations, four characteristic soil profiles were developed by BP for design purposes; of these, Profile A was selected for the present study as the basis for comparison of the design approaches. Soil Profile A is presented in Figure 4.1, together with design undrained shear strengths (cohesive soils) and effective angles of shearing resistance (cohesionless soils). The submerged unit weight of all soils is taken as 10 kN/m^3.

A water depth of approximately 67 m and a design scour depth of 3 m were assumed.

4.2 Review of BP Pile Design Approach

The design approach used by BP was a limit state method applied in accordance with DnV (1977). The pile foundation was designed to satisfy the requirements of ultimate, fatigue, progressive collapse and serviceability limit states. The design pile resistance, obtained using appropriately factored soil strengths, was compared with the design loading effect under each condition. The present study considers the design pile capacities under the ultimate limit state conditions identified by BP as critical to the design.

The material coefficients used to determine the design pile resistances are listed in Table 4.1.

Table 4.1
Material Coefficients

	Elastic Analysis	Plastic Analysis
Steel	1.15	1.3
Sand, Unit Skin Friction	1.2	
Sand, Coeff of Friction	1.1	1.2
Sand, Limiting Unit End Bearing	1.3	
Clay, Undrained Shear Strength	1.3	1.3

The load combination used by BP for computing pile loads is:

$$1.0\ G_D + 1.0\ Q + 1.3\ E_f$$

where G_D = Permanent Load
Q = Operational Load
E_f = 10^{-2} (wind + wave + current)

The axial (compression and tension) and lateral forces applied to the pile were determined such that the soil/pile/structure interaction is satisfied using P-Y and T-Z data based on non-linear theory and properties of the pile.

The required pile penetration was determined to ensure that it satisfy pile pull-out capacity and compression capacity requirements, based on soil profile A as shown in Figure 4.1. The nominal design pile penetration are:

Corner Piles	=	55	m
Centre Piles	=	60	m
Pile Diameter	=	2,134	mm

4.3 CSA Pile Design Approach

4.3.1 Approach

The CSA S472 Preliminary Standard states that the geotechnical design of foundations shall be based either on an overall factor of safety approach or on a load and resistance factor design approach. The former approach is recommended, since the probabilistic intent of the code is considered to be satisfied empirically, on the basis of conventional practice and experience, by the use of an overall safety factor. Resistance factors have also been specified in the Commentary for use in conjunction with the load factors prescribed in S471. The resistance factors were developed to be consistent with conventional overall safety factors on the basis of selected calibration studies. The factors are somewhat limited, however, in that they apply to specific loading conditions and failure mechanisms.

The principal design approach used in this study was the load and resistance factors design method, in order to accommodate the load combinations prescribed under S471. However, the foundation design was checked with respect to overall safety factor to ensure that conventional stability requirements are met. The foundation was designed to satisfy ultimate limit state requirements on the basis of static equilibrium analysis.

For the load and resistance factor design method, individual axial and lateral pile forces generated under the prescribed load combinations were compared with pile capacities calculated using appropriate resistance factors. The selected resistance factors are tabulated below, as well as the range of recommended values contained in the commentary to S472.

Material	Resistance Factor	Commentary Range
Sand (tan Ø')	1.2	1.2 - 1.5
Clay	1.3	

Under the overall safety factor approach, the total unfactored load was compared with the ultimate resistance, reduced by an overall safety factor of 1.5. The safety factor recommended in the Commentary is in the range of 1.5 to 2.0 for axial pile capacity.

The S471 design load combinations are as follows:

Compression:

$1.05\ G_D + 1.00\ Q + 1.35\ E_f$

Tension:

$0.90\ G_D + 1.00\ Q + 1.35\ E_f$

4.3.2 Results

For the CSA design, the pile diameter was taken as being equal to that for the prototype platform, i.e. 2.134 m. The required pile penetration depth was determined by comparing the design axial and lateral pile capacities, as a function of penetration depth (for Profile A), with the design pile loads. Axial capacity was found to govern penetration depth; lateral capacity was found not to be critical. The required pile penetration depth to satisfy overall safety factor requirements was similarly determined using unfactored loads and the relationship between ultimate capacity and depth.

The magnitudes of the design pile loads are as follows:

Table 4.2
CSA Factored Pile Loads

Maximum Force (kN)	Corner Pile	Centre Pile
Axial Compression	36,004	49,457
Axial Tension	6,547	None
Lateral	6,924	10,553

Table 4.3
CSA Unfactored Pile Loads

Maximum Force (kN)	Corner Pile	Centre Pile
Axial Compression	29,887	42,624
Axial Tension	438	None
Lateral	5,323	8,650

The required pile penetration depths computed using both the load and resistance factor design approach and the total safety factor method are tabulated below.

	Minimum Required Pile Penetration (m)	
Pile Group	Resistance Factor	Total Safety Factor
Corner Piles	51.5	51.0
Centre Piles	63.0	63.0

4.4 Comparison of CSA and BP Designs

As noted previously, the design penetration depths based on the BP design were 55m and 60m for the corner and centre piles respectively. These pile lengths were based on four characteristic soil profiles. In order to compare the CSA and BP designs, the pile penetration depths required to satisfy stability requirements under the BP load combinations were determined for Profile A.

The factored pile resistance as a function of penetration depth is essentially the same in both the CSA and BP designs, the only difference being the end bearing resistance in the sand strata. The resistance factors applied to the sand end bearing resistance are 1.3 and 1.2 under CSA and BP respectively. Since the piles terminate in the lower clay layer, this does not affect the overall pile design. The principal difference between the two designs is therefore in the load combinations used. The magnitudes of the pile loads under the BP load combinations, but derived from the analyses for this project, are as follows:

Table 4.4
BP Factored Loads

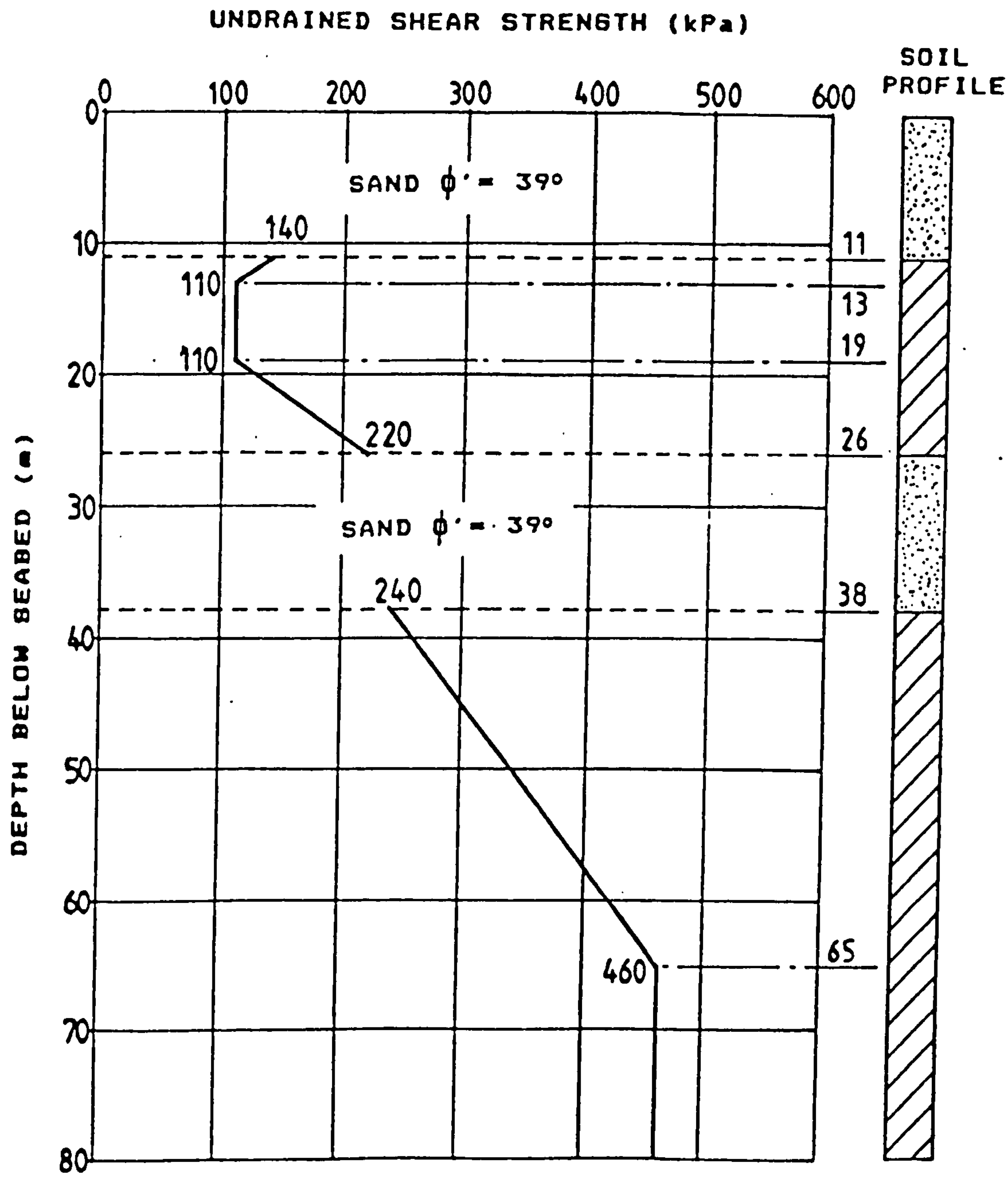
Maximum Force (kN)	Corner Pile	Centre Pile
Axial Compression	33,982	46,948
Axial Tension	3,897	None
Lateral	6,670	10,167

The required pile penetration depths are 49.5 m for the corner piles and 61.0 m for the centre piles.

The BP approach results in a slightly shorter required pile length than the CSA approach, leading to a slightly less conservative design. However, the nominal design pile lengths specified for the GYDA platform would satisfy both the load and resistance factor design and overall safety factor requirements of the CSA approach.

It is noted that the load and resistance factor approach and the overall safety factor approach within CSA are approximately equivalent. This differs from the findings of the G-1A study, in which the load and resistance factor approach was found to be slightly more conservative for the hypothetical sandy soil profile considered in that study. The differences are attributable to the soil profile, and the selection of actual resistance factors from the ranges recommended.

In general, the practices and methodology used in the collection of geotechnical data and the design of the foundation for the Gyda Platform are considered to be equivalent to those that would be carried out were the platform to be designed under CSA.



CHARACTERISTIC SOIL PARAMETERS

SOIL PROFILE A

(FOR PILE STATIC RESISTANCE)

Figure 4.1
Design Soil Profile
(Source: BP Design Resume)

5. STRUCTURAL STEEL DESIGN

5.1 Material Factors

For member strength calculations, CSA S473 uses the following resistance factors:

tubular members: Ø = 0.9 (assumed)
simple joints: Ø = per S473 Table 11.1, see below

Table 5.1
CSA S473 Joint Resistance Factors

Joints	Tension	Compression	In-Place Bending	Out of Plane Bending
K	0.63	0.63	0.72	0.79
T,Y	0.81	0.78	0.72	0.79
X	0.65	0.83	0.72	0.79

The resistance factor for tubular members is assumed to be 0.9 based on CSA S16.1, Steel Structures for Buildings. No value is stated in CSA S473.

The S473 resistance factors are multiplied with the calculated member strength to obtain a reduced design strength. The BP strength calculations use material coefficients following the requirements of NPD and DnV. The values are as follows:

- for operating and storm conditions: $\gamma_m = 1.15$

- for 10,000 year earthquake and accident conditions: $\gamma_m = 1.0$

In the BP calculations, the factor γ_m divides the member strength to obtain a reduced design strength. Taking the inverse enables direct comparison to the S473 value:

$Ø = \gamma_m^{-1} = 0.87$

5.2 Tubular Members

5.2.1 Members Under Investigation

The information provided by BP reported the tubular member design in the form of interaction ratios, for all elements. The design was undertaken for a representative number of members, in order to compare the design methods of S473 and BP. A complete design check of all the tubular members was not undertaken, however, the selected members were chosen to provide a range of member types and tension or compression axial loads.

The waves of 56° and 90° approach are identified as critical storm loading conditions in the BP results. These two load cases have been used to calculate the design check forces in the selected members. These are shown on Figure 5-1, representing the following members:

a. Jacket legs
b. Top diagonal between +10.0 m and -13.0 m
c. Mid-diagonal between -13.0 m and -38.0 m
d. Bottom-diagonal between -38.0 m and -62.0 m

These members represent critical leg sections, and diagonal braces in both tension and compression. The ultimate design forces for each of these members are tabulated in Table 5.2 for both S471 and BP load combinations. It should be noted that the BP design forces are those calculated using the analytical model for this project and a restricted number of load directions, it is not necessarily identical to the original BP design force.

5.2.2 BP Method

The BP design of tubular members, whether stiffened or unstiffened, involves four major stages:

a. Ultimate limit static check
b. Von-Mises stress interaction ratio check
c. Shell buckling usage ratio check for the worst bending axis
d. Shell/column buckling interaction check for the worst bending axis.

These are shown in Figure 5.2. The design procedures used by BP generally follow the requirements of DnV. They require the determination of:

a. Effective length factor, k
b. Column curve factor (ref DnV Figure C1.1)
c. Bending amplification factor (ref DnV Table C1.3)

Table 5.2
Member Design Forces

MEMBERS	CODE	AXIAL (kN)	SHEAR-X (kN)	SHEAR-Y (kN)	MOMENT-X (kN-M)	MOMENT-Y (kN-M)	TORSION (kN-M)
JACKET LEGS							
24	CSA	43980	3334	3367	25527	25634	29
	BP	42400	3220	3250	24600	24700	27
39	CSA	89978	2613	3804	13884	29410	2025
	BP	86735	2518	3668	13378	28360	1953
58	CSA	61881	430	409	5924	4144	225
	BP	57519	395	387	5433	4105	110
59	CSA	52781	317	305	2443	2929	20
	BP	50859	306	294	2359	2826	19
TOP-DIAGONALS							
75	CSA	13291	137	112	139	765	22
	BP	11908	128	113	96	720	21
286	CSA	14397	167	90	36	1024	31
	BP	13630	160	87	50	981	33
625	CSA	22145	154	261	1663	1089	65
	BP	21270	150	252	1613	1068	69
MID-DIAGONALS							
61	CSA	(T) 9271	15	4	65	331	67
	BP	(T) 8198	12	3	55	309	63
263	CSA	14518	40	42	48	67	294
	BP	13647	38	39	44	58	284
524	CSA	21564	25	38	301	514	45
	BP	20646	24	36	284	489	45
607	CSA	34314	16	83	1250	1556	43
	BP	32909	20	83	1227	1506	26
BOT.-DIAGONALS							
506	CSA	26436	86	145	351	481	12
	BP	25240	81	138	342	460	12
602	CSA	25755	21	121	648	862	105
	BP	24765	21	115	652	826	102

To obtain k values, the member end fixity has to be determined. In general, most of the platform members are considered fixed at both ends. The unbraced length, by which k is to be multiplied, was computer generated and BP did not indicate if it was measured from centre-to-centre or face-to-face of intersecting members. A centre-to-centre unbraced length was assumed for this project.

The column curve factor is dependent on the square root of the ratio of yield strength and Euler buckling resistance, known as the reduced slenderness ratio. If this ratio is high, it will significantly reduce the buckling capacity of the member.

The bending amplification factor is dependent on the end fixity condition, the k value and the type of loading on the member. In the BP design, the loading type is based on the following criteria:

CRITERIA	LOADING TYPE
(1) Overall shear stress is less than 1% of yield stress	Uniform Load
(2) Ratio of maximum difference in shear between adjacent section to overall shear is less than 0.25	Uniform Load
(3) If ratio of (2) is greater than 0.25	Point Load

The tubular member design equations for the BP method were prepared on a spreadsheet, and the interaction ratios for the representative members calculated. These interaction ratios are given below, in Table 5.3, comparing them with the most critical interaction values reported in BP's original design.

5.2.3 S473

The representative elements considered are all unstiffened tubular elements, and S473 provides specific sections for stiffened and unstiffened members. Figure 10.1 of the commentary, S473.1, reproduced in Figure 5.3, provides a flowchart to assist in identifying the appropriate clause checks for these two member categories. However, some difficulty was encountered in interpreting whether shell buckling, required within Clause 10.5.3 for stiffened cylinders, was also required to be applied to unstiffened cylinders.

Figure 10.1 (from S473.1) and the heading definitions for Clauses 10.5.2 and 10.5.3 would direct a designer away from undertaking a shell buckling check for unstiffened cylinders. However, Table 10.1 (S473) clearly indicates a shell buckling check (Clause 10.5.3.3) for both stiffened and unstiffened cylinders.

Table 5.3
Interaction Ratios - Model versus BP Original Results

Member	Interaction Ratio	
	BP Method	BP Original[(2)]
Jacket Leg		
24	0.57	0.94
39	0.94	0.93
58	0.73	0.85
59	0.62	0.85
Top Diagonals		
75	0.48	0.88
286	0.56	0.86
625	0.67	0.65
Mid-Diagonals		
61	0.32[(1)]	0.61
263	0.36	0.79
524	0.81	0.81
607	0.72	0.70
Bottom-Diagonals		
506	0.69	0.90
602	0.60	0.78

Notes: (1) Member in tension

(2) All member interaction ratios of BP Original do not necessarily occur at the same wave approach conditions as used for the project model investigation and the BP Method.

It is assumed that it is the intention of S473 that shell buckling be checked in all cases, however the effect of applying an interaction between Clause 10.5.3.3 and Clause 10.5.2 has not been addressed.

The effective unbraced length is defined as the centre-to-centre length while internal forces of the members can be taken from face-to-face of intersecting members. The effective length factor, k, is to be determined using the provisions of CSA S16.1 M84. The results of the member design using S473 are shown in Table 5.4.

Table 5.4
Interaction Ratios - S473 versus BP Method

Member	Interaction Ratio		
	CSA 10.5.2	CSA 10.5.3.3	BP Method
Jacket Leg			
24	0.43	0.46	0.57
39	0.72	0.79	0.94
58	0.59	0.65	0.73
59	0.53	0.52	0.62
Top Diagonals			
75	0.47	0.39	0.48
286	0.52	0.44	0.56
625	0.60	0.53	0.67
Mid-Diagonals			
61	0.30	0.22	0.32
263	0.32	0.22	0.36
524	0.77	0.59	0.81
607	0.67	0.59	0.72
Bottom-Diagonals			
506	0.63	0.55	0.69
602	0.55	0.48	0.60

It can be seen that the BP design yields consistently higher interaction ratios, especially for cases of high compression and high D/t ratios, such as the jacket legs. This is mainly due to the inclusion of shell buckling in the calculation of shell/column buckling interaction effects. For members in compression with low D/t ratios, such as the diagonals, the BP method shows only a marginal increase in the interaction ratio.

Using the BP design as a benchmark, the CSA tubular member design was repeated to obtain the same interaction ratio. Keeping the member outside diameter fixed, the CSA provisions, using S473 Clause 10.5.2, resulted in a plate thickness reduction of approximately 5 mm.

5.3 Joints

5.3.1 Simple Joints

In the BP design all joints are considered simple joints and thus the gap between the loaded braces is assumed to be a minimum of 75 mm.

The flowcharts depicting both the S473 and BP joint design procedures are shown on Figure 5.4.

There is a marked difference in procedure between the two codes for joint design. At every step in computing the punching shear capacity, S473 takes into account the out-of-plane and in-plane bending effects, in addition to compression or tension. The final check for the adequacy of the joint is the interaction of axial compression or tension with the in-plane and out-of-plane bending effects. The spreadsheet used for these calculations and the results for all the members evaluated are reproduced in Appendix E.

For the BP Design, brace out-of-plane bending effects are not added to the axial compression or tension unless the ratio of brace diameter to chord diameter, β, is greater than 0.85. Furthermore, both in-plane and out-of-plane bending effects are only included if the brace acts as a cantilever.

The joints examined all have β less than 0.85 and also the brace does not act as a cantilever. Hence both in-plane and out-of-plane effects are not included. This greatly simplifies the joint design procedure as compared to the S473 method.

Two representative joints are considered, a T or Y joint and an X joint. The characteristics of each joint are described below and the results of the strength calculations are shown in Table 5.5.

T or Y joint:
- located at elev. -13m, leg A-4
- chord, OD = 2000mm, t = 30mm
- brace, OD = 1400mm, t = 30mm

X joint:
- located at lowest jacket bay, between elev. -38 to -62m
- chord, OD = 1800mm, t = 50mm
- brace, OD = 1250mm, t = 35mm

These results indicate that S473 will result in a slightly more conservative joint design. This is because S473 is more complete in its treatment of the joints by accounting for both in-plane and out-of-plane moment effects and also because the CSA factored forces are higher.

Using the BP design as the benchmark, the CSA tubular joint design was repeated to obtain the same interaction ratios. This led to a required increase of approximately 10 mm in the thickness of the joint cans.

Table 5.5
Joint Interaction Ratio

Joint	Factored Forces			Interaction Ratio	
	Component	CSA	BP	CSA	BP
T or Y	Brace Forces:			0.25	0.20
	P(kN)	12,200	11,300		
	M_{op}(kN-m)	1,680	1,610		
	M_{ip}(kN-m)	1,610	1,590		
	Chord Forces				
	P(kN)	47,000	N/A		
	M_{op}(kN-m)	3,300	N/A		
	M_{ip}(kN-m)	1,400	N/A		
X	Brace Forces:			0.11	0.095
	P(kN)	4,263(T)	3,880(T)		
	M_{op}(kN-m)	108	567		
	M_{ip}(kN-m)	614	95		
	Chord Forces				
	P(kN)	19,045	N/A		
	M_{op}(kN-m)	2,415	N/A		
	M_{ip}(kN-m)	3,703	N/A		

Note: (T) indicates axial tension, compression otherwise.

5.3.2 Ring Stiffened Nodes

BP introduced one ring stiffened node in the design in order to satisfy fatigue requirements by reducing the stress concentration factors.

Both S473 and the BP design essentially use the same approach for ring stiffened nodes. BP is more explicit in identifying two methods for their ring design, i.e.:

a. Ultimate Limit State
b. Progressive Limit State

Under the ultimate limit state method, the chord is divided into separate ring segments and analyzed using an elastic closed ring model to determine the stresses in the ring and effective chord wall. The brace member end forces and moments are distributed between the underlying rings based on their relative location and stiffness. Each ring section is to be checked for combined axial and bending stress at each extreme and shear stress in the web. Each interface between the stiffener and an incident brace stub is to be checked for bearing. The local bearing stress is to be evaluated both at the outer fibre of the ring stiffener web and in the brace stub immediately above the toe of the weld.

The progressive limit state method is used to verify the overall capacity of the node for the limit state of progressive collapse under accidental and earthquake conditions. A condensed ring section of equivalent flexural stiffness is developed from the full can length and all stiffeners. The node is analyzed globally using a single closed ring model and the resultant brace end forces and moment.

BP refers to DnV for stiffener design to preclude any local buckling after local yielding.

5.3.3 Conical Transition Design

A conical transition is usually required when enlarged nodes are used to accommodate a congested joint, such that the node can be designed as a simple joint, or when there is a change in member sizes such as jacket or deck legs. S473 does not contain a procedure to guide the designer for conical transition sections. API RP2A provides detailed provisions for the design of conical transition sections, and as part of the exercise of S473, these provisions would be adopted.

The BP design essentially uses the API method for the design of conical transition sections and consequently the design procedure for both CSA and BP follows the same method.

5.4 Fatigue

5.4.1 Introduction

The data provided by BP relating to fatigue design contained the following information:

- Design criteria and design methodology
- Computer output at every joint including:
  - fatigue life
  - stress concentration factor

The information package, however, did not include the intermediate details of the calculations for establishing the fatigue life. Also, the magnitude of the analytical work necessary to undertake the detailed design could not be repeated within the scope of this verification project. Consequently, the investigation of the fatigue aspects of S473, in relation to the BP design, was organized as follows:

- Undertake a step-by-step comparison of both the S473 and BP methodologies.
- Compare the S473 and BP methods by using typical stress range values.
- Compare the actual number of joints that required further investigation in the BP design with that required using S473, and identify possible remedial action.

The BP methodology defines the design life while S473 fatigue calculations are based on satisfying the limiting damage ratio. In order to make a comparison between the two methods, the equivalent damage ratio for the BP design has been calculated.

Both BP and S473 differentiate between joints in air and joints affected by sea water. This study compares:

a. joints in air
b. joints in sea water, with cathodic protection.

S473 has a further differentiation of unprotected joints in sea water, however no such joints exist in the BP structure and therefore they did not form part of this review.

5.4.2 Comparison of BP and S473 Methodology

BP Methodology

The method of fatigue analysis used by BP is summarized below:

1. Determine load cases and loading.

2. Develop a model of the structure (BP allows 10 mm corrosion allowance for in-service conditions when modelling member properties).

3. Analyze the model to determine the stress range and hot-spot positions of all joints (BP uses 8 points around the circumference of each joint).

4. Compute each hot spot stress range, including stress concentration factor (SCF); as a first check, BP recommends a minimum SCF of 2.5; if fatigue design governs at a joint further analysis may be done reducing this value to 2.0.

   BP refers to three references:

   - Wordsworth, A.C., "Stress Concentration Factors at K and KT Tubular Joints, Fatigue in Offshore Structural Steel", Institution of Civil Engineers, London 1981.

   - Kuang J.G., Potvin A.B., Leick R.D., Kahlich J.L., "Stress Concentration in Tubular Joints", Society of Petroleum Engineers Journal, August 1977.

   - Wordsworth, A.C. and Smedley, G.P., "Stress Concentrations at Unstiffened Tubular Joints", Paper 31 at the European Offshore Steel Research Seminar of the Welding Institute, November 1978.

5. Apply a dynamic amplification factor (DAF) to the hot spot stress ranges.

   BP uses the formula:

   $$DAF = 1/([1 - (w/f)^2]^2 + 4(dw/f)^2)^{1/2}$$

   Where
   w = frequency of wave
   f = natural frequency of structure in given direction
   d = damping ratio, 0.02

6. Use the specified S-N curve to obtain N_i, the maximum allowable number of cycles for a stress range S_i. Modify S-N curve values as required if the thickness of the joint material is greater than 32mm.

   Some difficulty was encountered in identifying the S-N curve used in the BP design. Different design briefs referenced different documents, containing different S-N curves:

BP Design Brief	Reference
0903 In-place Fatigue Analysis	NPD, Jan. 1987
0924 Transportation	NPD, 1985
0909 Wave Slam	NS3472E, June 1984
0908 Vortex Shedding	NPD, 1985
Design Report, In-place Fatigue Analysis	NS3472E, June 1984

   For this study, the S-N curve reproduced in the Design Report and based on NS3472E, shown in Figure 5.5 was assumed to be the representative curve. (Note: NPD 1987 was not obtained for comparison, however the S-N curve in NPD 1985 is substantially different as shown in Figure 5.6).

7. Sum the effects of various stress ranges based on their expected frequency over the corresponding N_i values to obtain a damage ratio:

   $$D_i = \Sigma \frac{n_i}{N_i}$$

   Where
   n_i = number of cycles of stress range S_i.
   N_i = number of cycles from S-N curve

8. Determine the fatigue life of each joint where Fatigue Life = $\dfrac{1 - D_t}{D_i + D_{ws} + D_{vs}}$

   In a one year period:

   D_t = damage due to transportation
   D_i = damage due to in-place loading
   D_{ws} = damage due to wave slam
   D_{vs} = damage due to vortex shedding

9. If the calculated fatigue life of a specific joint is less than the required fatigue life then:

   - Check the effect on fatigue life by reducing the SCF from 2.5 to 2.0.
   - Check the effect on fatigue life by including weld fillet effects to reduce peak SCF.
   - Increase the fatigue life by weld grinding (BP recommends factor of 2.0).

S473 Methodology

The following points address the effect of the S473 code on each of the nine steps outlined above.

1. Load Cases

   BP in their analysis included the effects of:

   - in place loading
   - in place wave slam
   - in place vortex shedding effects
   - transportation

   Wind and current loading were omitted.

   S473 recognizes all these loads as important sources of fatigue loading and also notes that loading from mechanical vibration, construction, or installation also be considered. Clause 14.3.2 states:

   > "All stress fluctuations imposed during the intended life of the structure that have a **magnitude** and **number** large enough to cause fatigue effects shall be taken into account in the design against fatigue."

2. Model

   The method of modelling joints of the structure for fatigue analysis is not addressed in this study, since considerable analysis is required to define the stress ranges at a number of hot-spot positions, for a range of load conditions.

   It should be noted that Clause 14.9.2 of the Commentary states that sacrificial steel is to be ignored in the analysis, but provides no guidance regarding the sacrificial thickness. BP has included this item in their model by specifying a 10mm corrosion allowance and reducing member properties accordingly.

3. Analysis

   S473 does not provide commentary or guidance on the type of analysis that should be performed.

4. Stress Concentration Factors

S473 provides little direct guidance on the calculation of stress concentration factors. Section 14.6 of the Commentary discusses SCF, but offers no direct references or values.

Consideration may be given by S473 to specifying minimum SCF based on a given set of reference documents.

5. Dynamic Amplification Factor

Clause 14.3.5 of S473 notes "dynamic amplification shall be included... when considered significant" and the Commentary suggests it be considered only when the structure period is greater than three seconds. No guidance or direct reference on calculating dynamic amplification is provided. The formula used by BP or a specific reference may be useful in the Commentary.

6. S-N Curves

Figure 5.5 shows the S473 S-N curve together with both the NPD85 and the BP design S-N curves.

The BP S-N curve for joints in air is identical to the S473 S-N curve. However, the BP S-N curve for joints in sea water, with cathodic protection, is different from the S473 curve both in values and the fact that it is a single slope curve.

It should be noted that there is a discrepancy between Clause 14.8.2 and Table 14.2 relating to the standard deviation, σ. Clause 14.8.2 refers to the standard deviation as a natural number while Table 14.2 uses the logarithm of the standard deviation.

BP clearly states that the class T S-N curve is valid for thickness greater than 32 mm, and that for values less than 32 mm the reference thickness should be used. A rigid interpretation of Clause 14.9.2 would indicate that a correction for thickness both greater than, and less than 32 mm would be adopted.

7. Damage Ratio

The focus of S473 fatigue design is the limit damage ratio η. The code limits the cumulative damage to a value less than η:

$$\sum \frac{n_i}{N_i} \leq \eta$$

The cumulative damage ratio is calculated in a similar manner to that used by BP, however, BP modifies the ratio to produce a "fatigue life".

S473 produces a matrix of limit values of the damage ratio depending on:

- safety class of structure; 1 or 2
- importance of structural detail; minor or major (damage factor α)
- accessibility for inspection and repair; poor or good (damage factor β).

The structure being evaluated is considered to be Safety Class 1. BP states that all joints are accessible, however no information on whether the access is "good" or "poor" is available.

Thus the following range of limit damage ratios, η are possible:

Structural Detail	α	Access	β	$\eta = \alpha\beta$
Minor	1.0	Good	1.0	1.0
Minor	1.0	Poor	0.6	0.6
Major	0.5	Good	1.0	0.5
Major	0.5	Poor	0.6	0.3

The S473 Commentary states that a major structural detail is one that if failure occurred, it would likely cause progressive collapse of the structure and loss of life. It is assumed all other details are then minor. S473 notes that the major details have 1% of the probability of failure in fatigue compared to minor details.

S473 in Clause 14.3.2 could state:

α = 1.0 except
= 0.5 for those joints/member noted by progressive collapse analysis to be critical for the stability and prevention of progressive collapse of the structure.

In the BP analysis, no differentiation between minor and major details were discussed. However, BP did carry out a progressive collapse analysis noting it did not govern the design. It is considered that some joints in the structure must be defined as major, such as the main leg joints, and for the study all four values of η are assessed.

S473 modifies the design fatigue life of a joint depending on the level of accessibility subjectively assigned by the user. Neither the Code nor Commentary offers guidance on "poor" vs "good" access.

8. Fatigue Life

For joints in air, both BP and S473 have the same design fatigue life, which is one times the planned operating life.

However, for submerged joints (with cathodic protection) there is a major difference in the design fatigue life. Similar to joints in air, S473 recommends a value of one times the planned operating life. BP uses a value of 3 times the planned operating life.

In addition, BP extends the "submerged" zone to include the splash zone. The splash zone is not addressed by S473, and thus all non-submerged joints could be treated as less critical joints in air.

For this structure the planned operating life is 20 years, thus the relative design lives are:

	Joints in Air	Submerged Joints
BP	20 years	60 years
S473	20 years	20 years

As discussed earlier, BP uses the following equation for combining the cumulative effect of all load cases.

$$\text{Fatigue Life} = \frac{1 - D_t}{D_i + D_{WS} + D_{VS}}$$

The effect of putting Dt in the numerator of this equation creates an initial fatigue state prior to the start of in-place fatigue loading. A reduction of the S473 specified limit damage ratio, η, to account for the loads prior to in-place loading may be required if fatigue effects during transportation and installation are significant.

9. Fatigue Life Modification

For those joints not meeting fatigue requirements, the S473 Commentary recommends grinding of the weld toe to increase the damage ratio by a factor of 2.2. BP uses a slightly more conservative value of 2.0. The BP design also includes a weld length correction factor.

5.4.3 Comparison of S473 with the BP Design

The key differences between the BP design and the S473 design are in the structure design life, the S-N curves themselves, and the factors affecting fatigue life such as joint accessibility and joint importance.

Since the effect of transportation is not separable from the BP design notes and computer output, its contribution will be neglected and only the in-place load case effects will be assessed.

Joints in Air

The only effect of S473 on the BP design for joints in air is the determination of the limit damage ratio η. All other factors such as:

- S-N curve
- thickness correction
- required design life

are the same assuming an equivalent analysis.

The S473 limit damage ratio η could vary from 0.3 - 1.0, thus possibly reducing the fatigue life to 30% of that calculated by BP. This would be for joints designated as major. For minor joints the maximum reduction is 60%.

BP has defined all their joints as "accessible," however they do not define the accessibility as either poor or good. An assumption of "good" access is considered appropriate, given the simple joint configuration of the structure. This limits the difference in the damage ratio to either 50 or 100% of the BP design for major and minor joints respectively.

Only two joints in the BP structure above the waterline had fatigue lives less than 600 years, as noted below. The joints would meet S473 requirements with damage ratios well below even the S473 minimum of 0.3.

Joint	BP Life	Effective η
A	220 years	0.091
B	585 years	0.034

Joints in Sea Water - Cathodic Protection

The BP documentation has no data on the stress range of any connections. The computer output merely notes the calculated fatigue life of the joints. Those with a fatigue life greater than 60 years were accepted, and those with less than 60 years were further checked with a reduced SCF and a weld length correction factor.

The number of joints requiring further checking were:

SCF = 2.5	23
SCF = 2.0	14
SCF = 2.0; weld length correction	8

Additionally, if a double slope S-N curve was used, in conjunction with SCF = 2.0 and the weld length correction, only one joint would have to be checked further.

The regulatory body for the GYDA platform required BP to grind eight joints to meet fatigue requirements (thus accepting SCF = 2.0 with the weld length correction).

Performance Comparison - Submerged Joints

The following section compares the S473 requirements to the BP design for a representative set of stress ranges. The comparison is performed by using the relative difference in S473 and BP S-N curves in the calculation of the S473 damage ratio. The selected stress ranges and corresponding relationship between S-N curves are:

$S_1 \geq 53$ N/mm², where BP & S473 curves are parallel, $N_{S473} = 0.5 N_{BP}$
$S_2 \sim 35$ N/mm², where BP & S473 curves intersect, $N_{S473} = N_{BP}$
$S_3 \sim 25$ N/mm², where $N_{S473} \sim 2N_{BP}$

For clarity, and ease of comparison, the damage ratio will be evaluated for one stress range at a time.

Let n_i = number of cycles at stress range S_i in a 20 year period, the CSA operating life.

BP has a requirement of 3 times the operating life, or 60 years. Using the S-N curves to obtain N_i, the BP criteria requires:

$$\frac{N_{iBP}}{3\,n_i} \leq 1.0$$

At the 60 year limit $\frac{N_{iBP}}{3} = n_i$

The S473 damage ratio $\frac{n_i}{N_{iS473}}$ becomes $\frac{N_{iBP}}{3\,N_{iS473}}$

Table 5.6 shows the calculation of the S473 damage ratio for the three selected stress ranges. These ratios are compared to the limit damage ratios.

Table 5.6
S473 Damage Ratios

S_i Stress Range (N/mm²)	$\frac{N_{S473}}{N_{BP}}$	$\frac{n_i}{N_{iS473}}$	Allowable Damage Ratio η_{S473}			
			Minor		Major	
			Good Access	Poor Access	Good Access	Poor Access
$S_1 \geq 53$	0.5	0.67	1.0	.6	.5	.3
$S_2 \sim 35$	1.0	0.33	1.0	.6	.5	.3
$S_3 \sim 25$	2.0	0.16	1.0	.6	.5	.3

For the joint to meet S473 standards:

$$\frac{n_i}{N_{iS473}} \leq \eta_{S473}$$

In the table above, the shaded values in bold print indicate the stress ranges and joint designations that would meet BP requirements but would not meet S473 standards.

The BP computer output was scanned to identify how many joints, if specified accordingly by S473, would require further attention. The results are shown in Table 5.7 and are compared to the BP value of 23.

Table 5.7
No. of Joints Requiring Attention

Stress Range	S473 Joint Designation			
	Minor		Major	
	Good Access	Poor Access	Good Access	Poor Access
≥ 53 N/mm^2	5	28	42	92
~ 35 N/mm^2	0	1	5	28
~ 25 N/mm^2	0	0	0	1

If a good access definition is accepted for the structure, then the number of joints that would require further attention would be in the range of 5 to 42, depending on the number of minor and major joints.

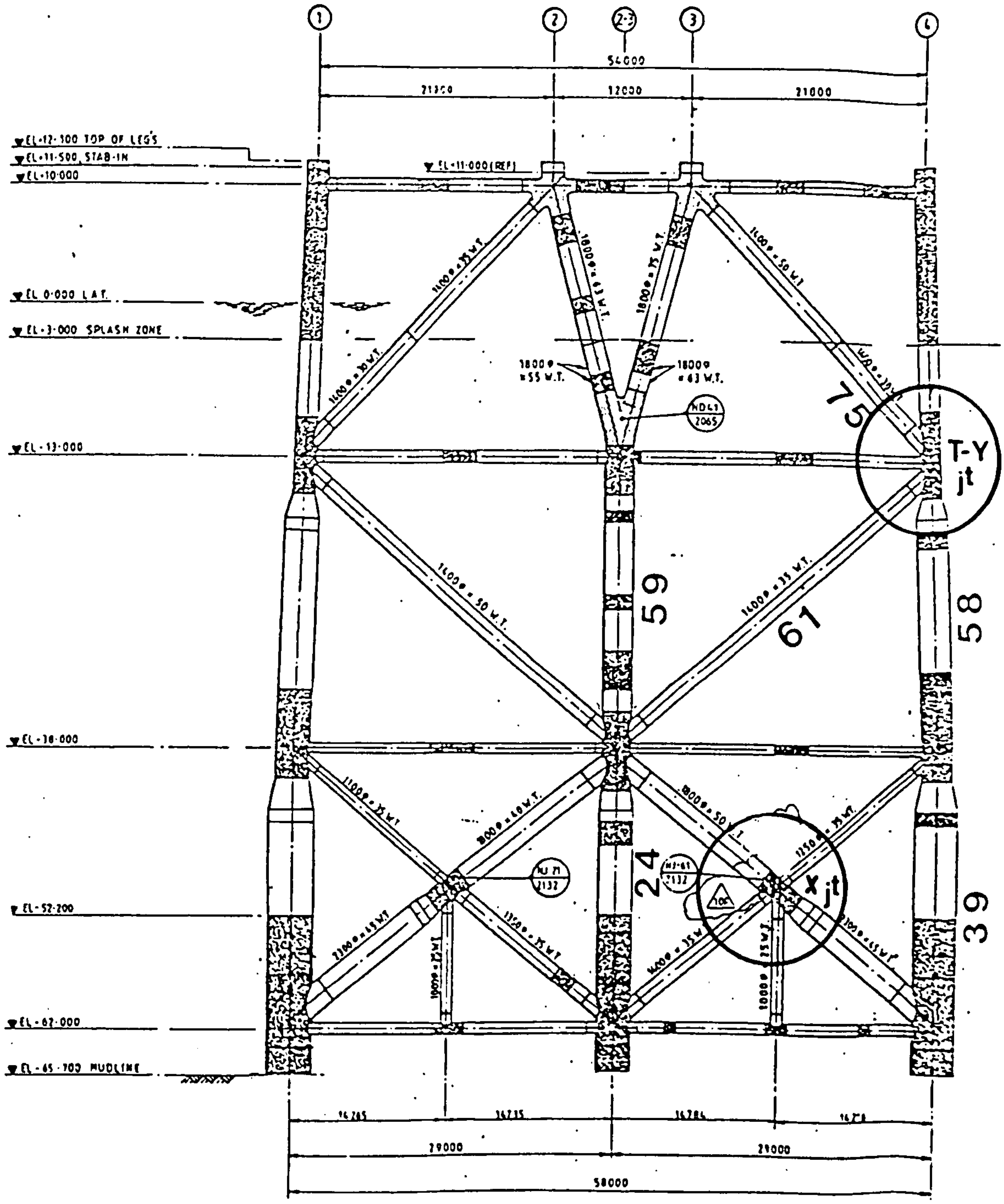


Figure 5.1
Member Locations

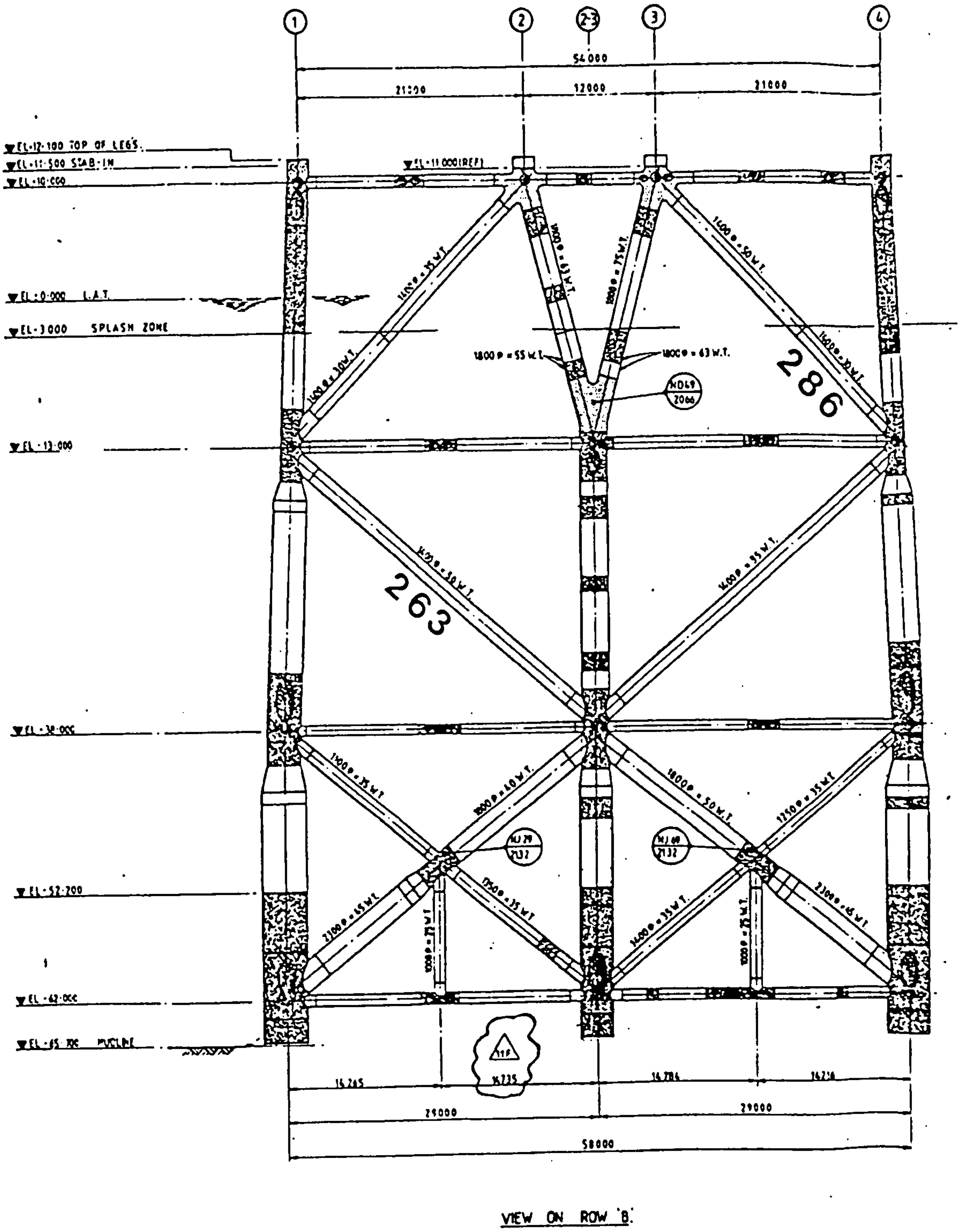
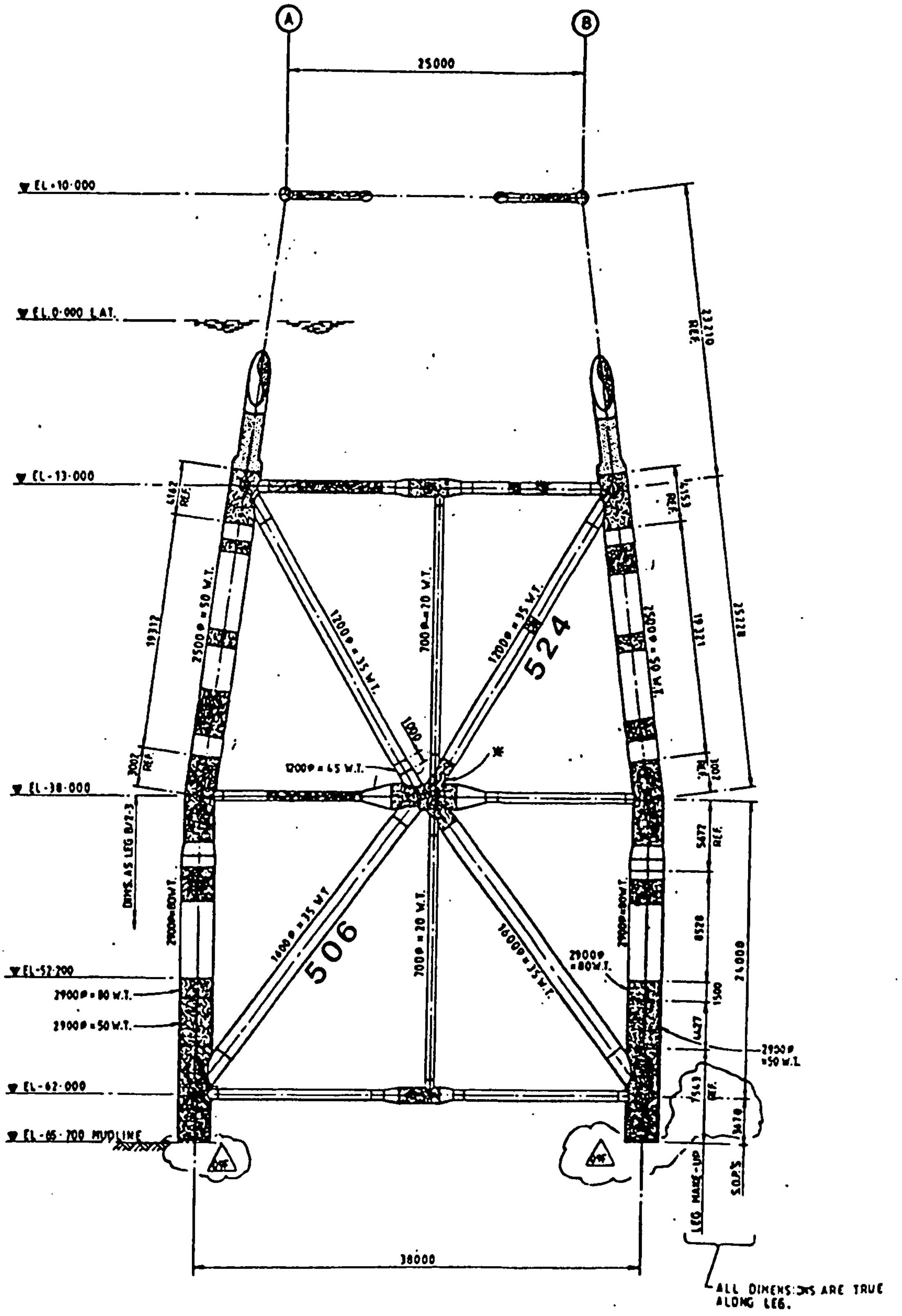
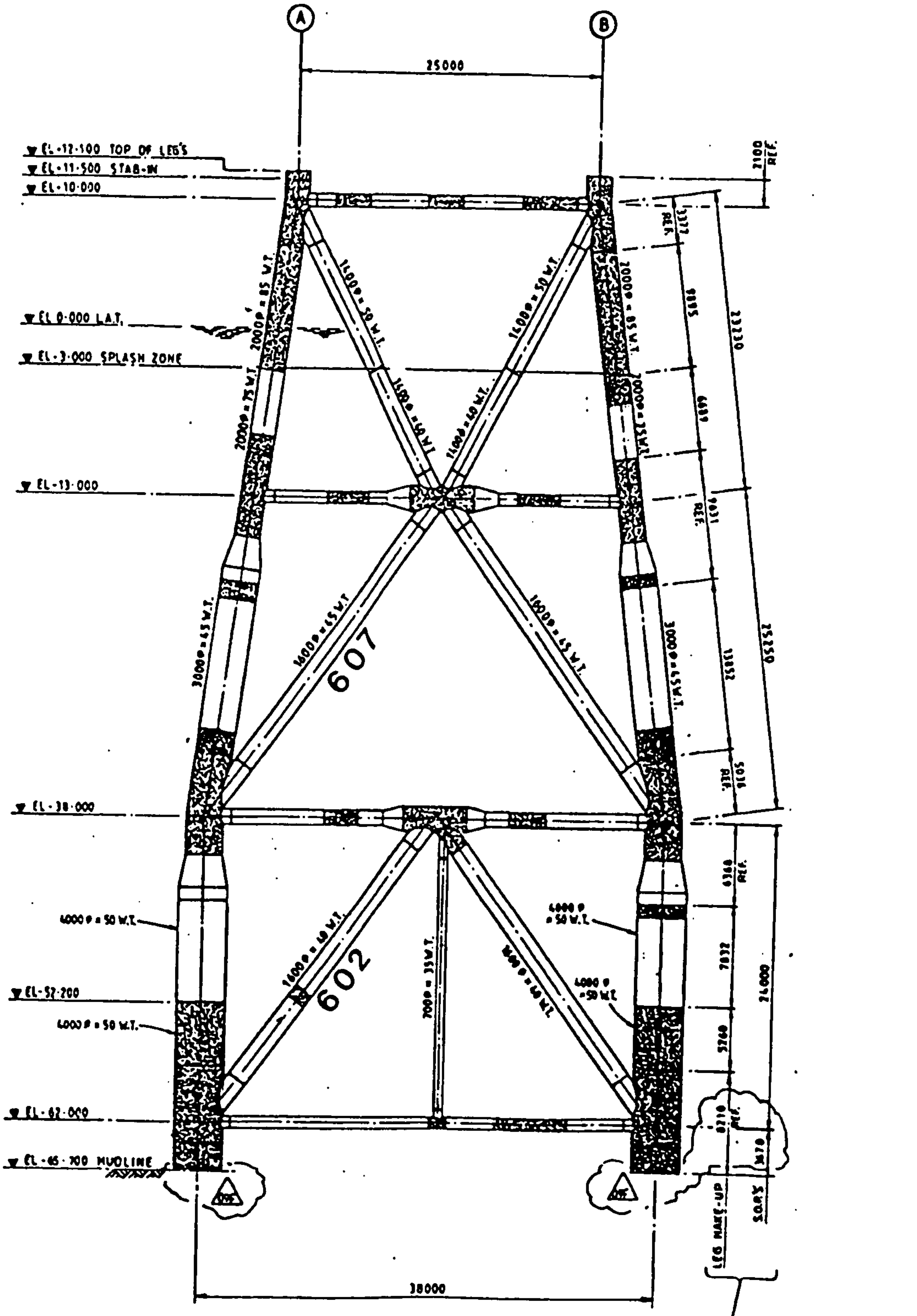


Figure 5.1 (Continued)
Member Locations



VIEW ON ROW 2-3.

Figure 5.1 (Continued)
Member Locations



VIEW ON ROW '4'

Figure 5.1 (Continued)
Member Locations

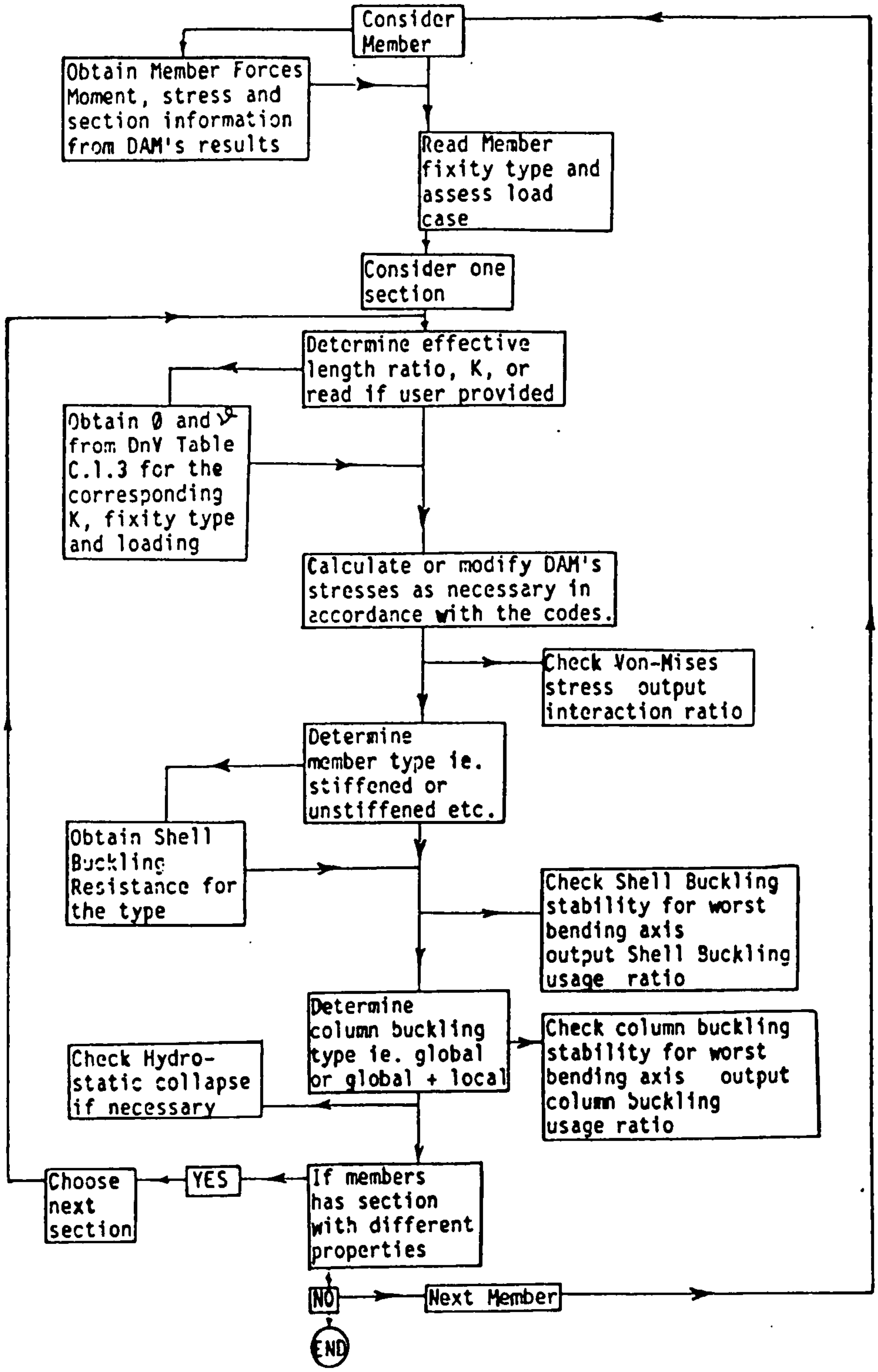


Figure 5.2
Flowchart for BP Member Code Checking Procedure
(Source: BP Design Briefs)

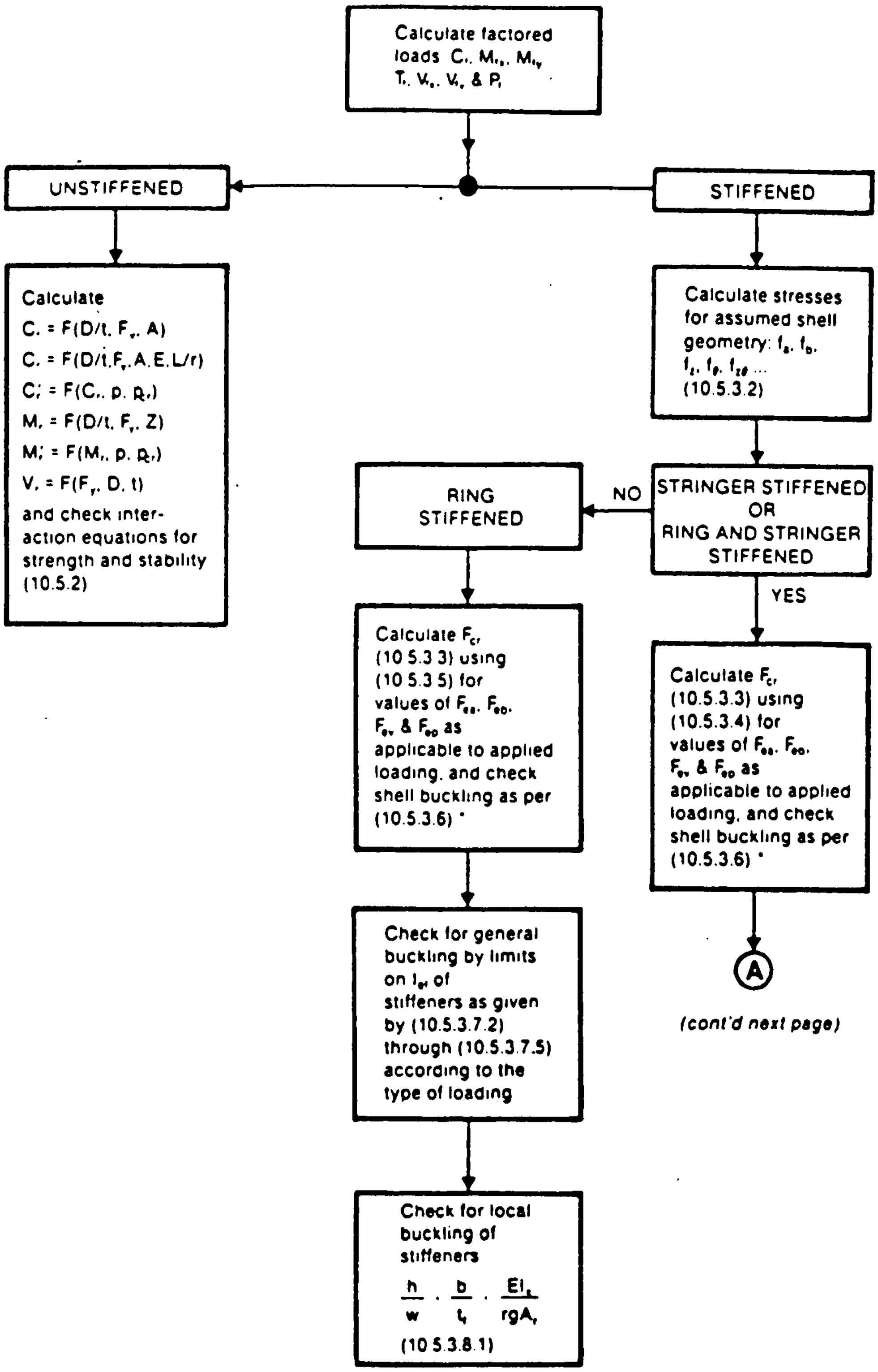


Figure 5.3
Flowchart for Use of S473 Clause 10
(Source: S473.1)

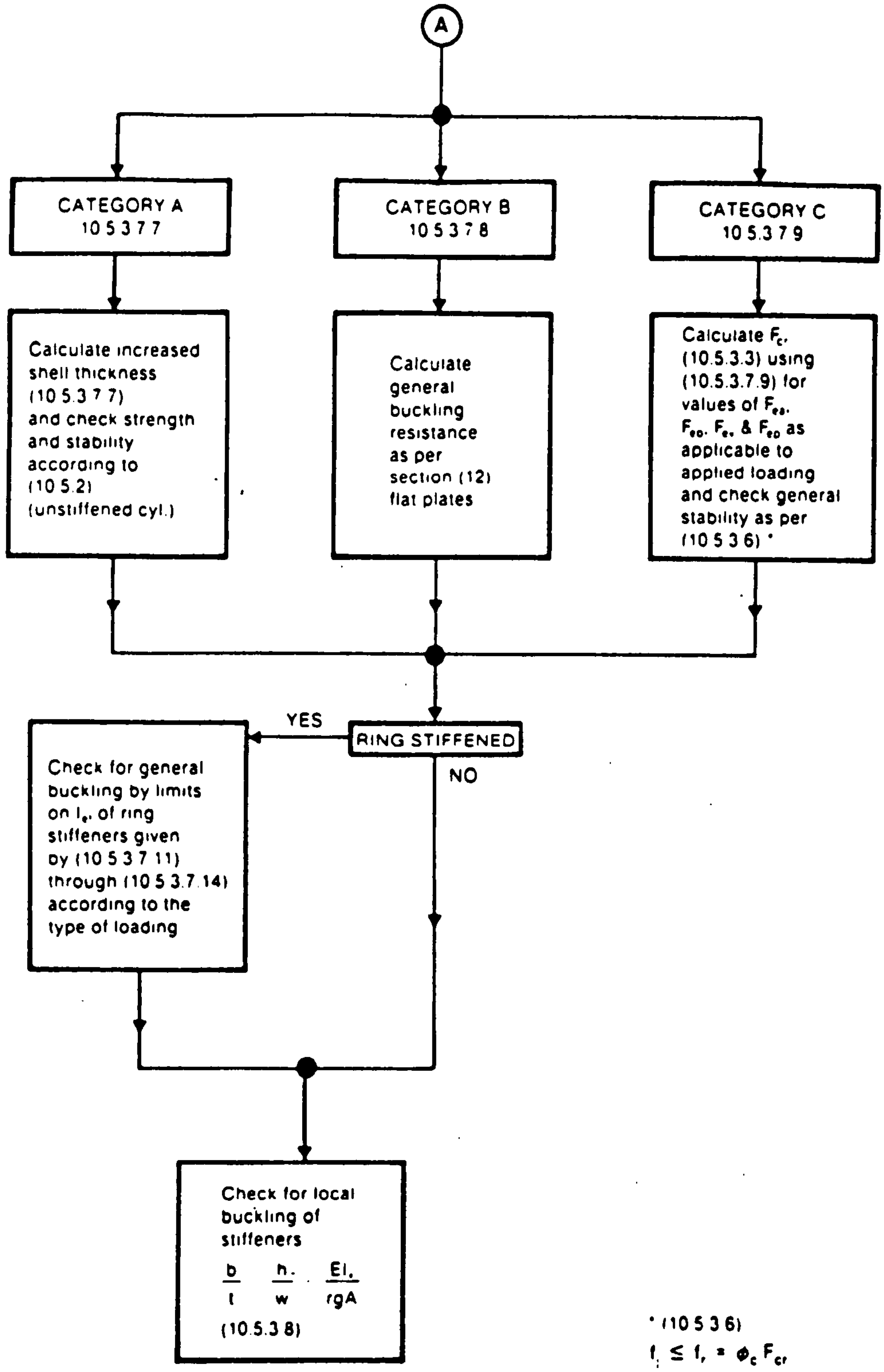


Figure 5.3 (Concluded)
Flowchart for Use of Clause 10
(Source: S473.1)

Figure 5.4
Tubular Joint Design

S473

Determine Joint Resistance Factor $\emptyset_j$ from Table 11.1

Compute the coeff. of tubular joint strength, Q_u from Table 11.2

Compute Q_f from Paragraph 11.1.2.2.1

Compute C_u, T_u, M_u & thus C_R, T_R, M_R

Compute Interaction Ratio:

$$\frac{C_F}{C_R} + \left(\frac{M_f}{M_R}\right)_{op} + \left(\frac{M_F}{M_R}\right)_{ip}^2 \leq 1.0$$

$$\frac{T_F}{T_R} + \left(\frac{M_f}{M_R}\right)_{op} + \left(\frac{M_F}{M_R}\right)_{ip}^2 \leq 1.0$$

BP DESIGN

Compute Actual Punching Shear Force:

$$N_d = \frac{t}{T} \frac{2\sin^2\emptyset}{(1 + \sin\emptyset)} N_{ad}$$

Compute Joint Punching Shear Capacity

$$N_d = \frac{F_y}{\sqrt{3}\ \gamma_m\ K} A_{BRACE} \quad - (i)$$

$$N_d = f_{uK} \frac{A_{BRACE}}{\gamma_m\ K} \quad - (ii)$$

f_{uK} is given in Fig. 3.3.1 of BP Report

Check

$(N_d)_{ACTUAL} < (N_d)_{CAPACITY}$

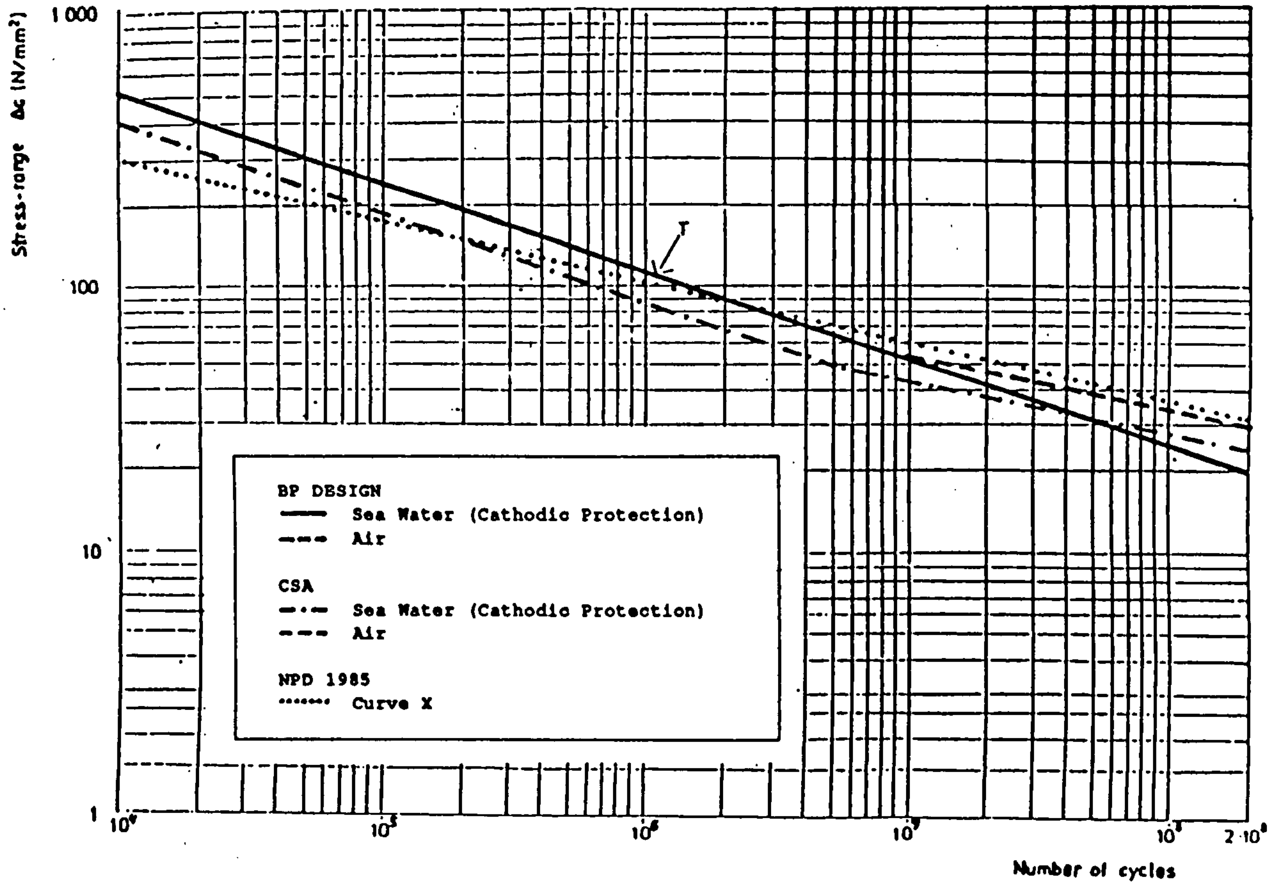


Figure 5.5
S-N Curve for T Tubular Joints

6. MISCELLANEOUS DESIGN REQUIREMENTS

6.1 Material

The steel material specified by BP for the GYDA platform is as follows:

Type	Grade	Thickness (mm)	Yield Strength (N/mm^2)
I,II,III (modified)	50E	Up to 16 17 to 40 41 to 63 64 to 100 100 to 120 121 to 150	355 345 340 325 315 305
IV	Gr.B	All thickness	241
V	43C	Up to 16 17 to 40	245 240

Type I - Primary structural steel to BS 4360 grade 50E (see Table 6.1)
II - As type I, but tested for through thickness properties. (Lamellar Tearing)
III - As type II, but in seamless tubular form, to API 5L (see Table 6.1)
IV - As API 5L Gr B, seamless tubulars
V - Secondary structural steel to BS 4360 Grade 43C.

Steel Design Properties are:

Young Modulus	=	210,000 MPa
Shear Modulus	=	80,000 MPa
Density	=	7,850 Kg/m^3
Poisson Ratio	=	0.3
Thermal Coef.	=	12×10^{-6} m/m^0C

Table 6.1
BS4360 and API 5L Specifications

GRADE	PLATES			HOLLOW SECTION		
	Tensile MP_a	Min. Yield @ 16mm (MP_a)	CVN 27J@	Tensile MP_a	Min. Yield @ 16mm (MP_a)	CVN 27J @
43C	430/510	245	0	430/540	275	0°C
50E	490/620	355	-50°C	490/640	355	-30°C
API 5L GrB				415	240	See Note 1

Note 1: CVN 20J at temperature between 10 - 30°C below lowest anticipated service temperature depending on D/t ratio.

In general, BP used Type I material for the primary braces and parts of the main leg elements. Type II was used at the joint cans and other portions of the leg elements, where attachments were made. Figure 6-1 shows the material specifications for the primary structural elements on Row A.

S473 defines a 3 x 3 matrix for classifying structural materials for fracture control and toughness requirements. This gives good flexibility in identifying the toughness testing requirements throughout the structure.

Applying S473 to the GYDA platform, most primary members will be safety class 1 elements, and will have high susceptibility to fracture initiation. This will require mandatory NDT, CVN, PPT, and optional through thickness ductility testing. However, the BP design, using NPD, required mandatory through thickness testing under the explicit section of "lamellar tearing":

> "Members essential to the safety of the structure which are subjected to applied or heavy residual stresses normal to their surfaces shall have adequate through thickness properties. A program of through thickness testing shall be established. Minimum values for through thickness properties shall be specified. 20% reduction of area is the minimum requirement for any single test specimen."

6.2 Corrosion Protection

BP identified the corrosion protection system for the GYDA platform in the following areas with their respective protection method:

Atmospheric Zone	-	Jacket structure: Protection is by coating alone
Splash Zone	-	Between -3m to +9m: Protection is by coating, 10mm corrosion steel allowance and sacrificial anode
Lower Sections of Legs (Bottle Legs), Pile Sleeves, Diaphragm and Shear Plates	-	Below EL - 3m and bracing member at EL - 66m: Protection by coating and sacrificial anodes
Tie Backs, Conductors	-	Protected by sacrificial anodes throughout entire length
Risers	-	Protected by metallic cladding, epoxy coating and sacrificial anodes
Caissons	-	Protected by epoxy coal tar coating system, and sacrificial anodes

Leg Compartments	-	From EL - 7m, the four corner legs are susceptible to internal corrosion: Inhibitor/biocide chemical is used.

Five types of sacrificial anodes are used, namely:

Type	Location	Net Wt. (Kg)
1	Jacket Structure	222.35
2	Jacket Structure	168.48
3	Jacket Structure	227.40
4	Tie Backs	3.60
5	Riser	30.00

S473 also addresses corrosion protection for atmospheric, splash and submerged zones. It indicates that for the atmospheric zone a coating shall be used. For the splash zone, uncontrolled loss of material is assumed for cases with severe ice abrasion, therefore it recommends a coating, corrosion allowance and/or sheathing to be used. For the submerged zone, a combined system of coating and cathodic protection is recommended.

6.3 Other Design Requirements

6.3.1 Deck Elevation

BP establishes the minimum deck elevation using the following criteria:

a. For the maximum wave with a return period of 1 in 100 years, provide a minimum air gap of 1.5m between the wave crest and the underside of the cellar deck structure.

b. For the maximum wave with a return period of 1 in 10,000 years, ensure the wave crest does not unduly interfere with the underside of the cellar deck structure.

S471 establishes the deck elevation by specifying a minimum air gap of 1.5m between the maximum elevation of the specified extreme wave or ice features. The maximum wave crest elevation and the maximum ice ridge crest elevation are superimposed with the extreme water level.

6.3.2 Marine Growth

Marine Growth increases the drag effect of the wave and current. BP specifies that for the GYDA platform, the marine growth contributing to these forces are:

From EL +3.0m to El -30.0m	= 75mm
Below EL -30.0m	= 25mm

S471 also indicates that possible marine growth on the structure shall be taken into account.

6.3.3 Scour

BP considered the following scour in the pile foundation design:

1m general scour
2m local scour

S471 requires scour, including ice scour, to be evaluated on a site-specific basis and to be included in the design.

6.4 Fabrication, Construction and Installation

BP accounts for the construction phase in the design process by executing a loadout analysis to ensure that the structural joints and members are not unduly stressed or fatigued.

CSA requires that suitable provisions be made to ensure that construction loads can be safely sustained without permanent deformation or damage to any member of the steel frame and other components supported thereby.

BP did extensive analyses for the installation phases, namely transportation, lifting, and on-bottom stability, to ascertain their effects on the structure.

Installation requirements are covered in S475, but not in S473. However, S471 clearly identifies the transportation and installation phases as part of the design process. It specifies environmental loads for phases of short duration as having an annual probability of exceedance of 10^{-2}, calculated from data corresponding to the given time interval. Consequently, the structural design aspects relating to the transportation and installation phases will form part of the use of S473.

The only significant difference between CSA and the BP design is the potential for adopting Safety Class 2 for this phase of the design.

6.5 Decommissioning

BP did not execute any specific analysis for decommissioning while CSA S471 subjects decommissioning to the same safety principles established for other design life phases.

NOTES.

1. FOR DRAWING INDEX, GENERAL NOTES AND FIELD LOCATION DRAWING No. GYDA-J80-70-JS-1900-00 AND 1902-00.
2. ALL STEEL TO BE TYPE I UNLESS NOTED OTHERWISE.
3. TYPE II STEEL SHOWN THUS [pattern].
4. CAST NODES SHOWN THUS [pattern]

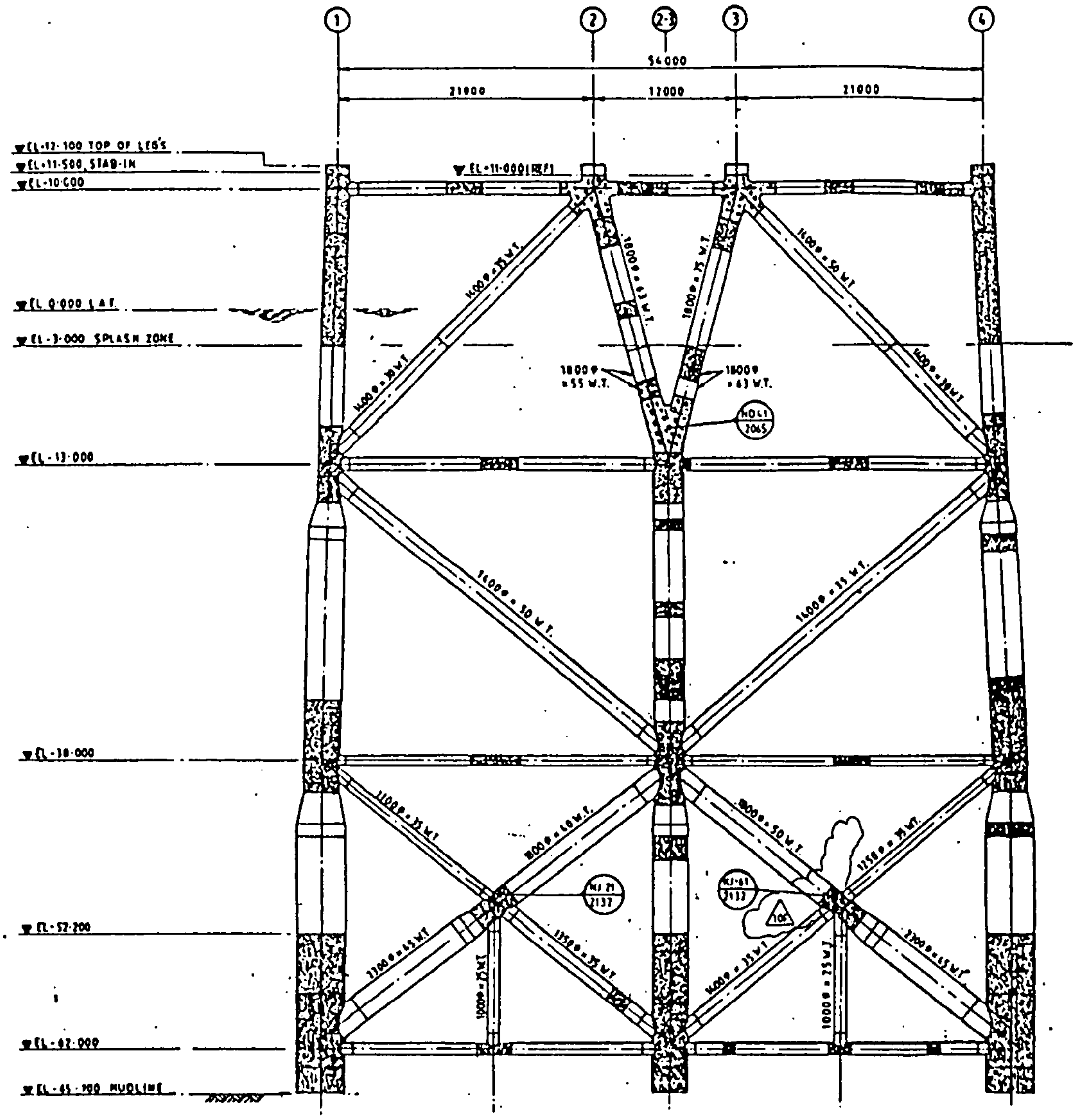


Figure 6.1
Typical Material Specifications
(Source: BP Reference Drawings)

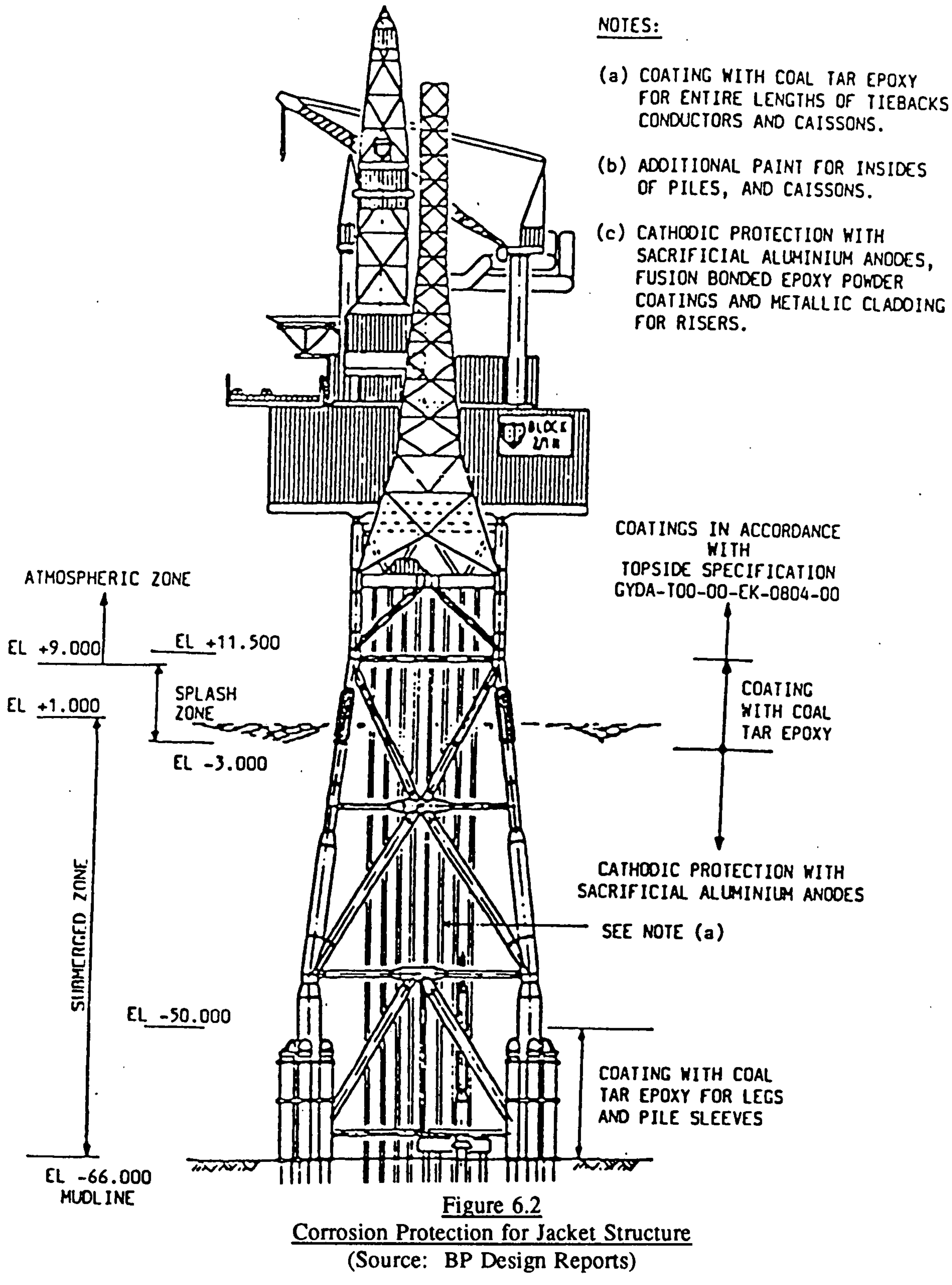


Figure 6.2
Corrosion Protection for Jacket Structure
(Source: BP Design Reports)

7. ASSESSMENT OF CSA STANDARDS S471, S472 AND S473

7.1 Comparison of CSA and BP Designs

The CSA Standards have been exercised using the GYDA platform design as a reference datum, from which both quantitative and qualitative assessments of the effects of adopting the CSA Standards for the design of a jacket structure can be identified. The assessment of the CSA Standards has been based on the following issues:

- The direct effect of the CSA Standards on the structural design of the jacket, including material quantities, detailing complexity and material specifications.

- The ease of use of the CSA Standards in undertaking the design, to identify items of ambiguity in the clause provisions, areas requiring further clause details and also minor typographical errors.

The quantitative assessment of the use of the CSA Standards, compared with the BP design, has been based on the results of the analyses undertaken for this project. In general, BP did not report specific member design forces, from which a direct comparison of CSA with the as-built design could be made. However, a direct comparison between the CSA and BP design methodologies has been made, and it is considered reasonable to assume that any identified differences would directly translate to the as-built structure.

7.2 S471

7.2.1 Safety Class

The GYDA structure was designated as Safety Class 1 for this project, based on the use of the structure as a manned production platform with relatively little structural redundancy (as compared to, say, a gravity based platform). The work concentrated on the operational phase of the platform, where the safety Class 1 designation would more clearly apply.

A Safety Class 2 designation may be appropriate for transportation and installation phases, and the impact on the final design depends on the severity of the loads during these phases. Since the structure was installed by a heavy lift vessel, as opposed to end-launching off a barge, it is considered likely that the installation loads were relatively modest.

However, it is considered that the impact of a safety Class 2 designation for the operational phase should be investigated within one of the verification projects.

7.2.2 System Ductility

The earthquake loads generated by a 10^{-4} event are found to be within the elastic range of the structure; this is consistent with the findings of BP, who also analyzed the structure for a 10^{-4} wave event. This too was within the elastic range of the structure.

The consequence is that the response of the structure in the inelastic range has not been tested, since the location of the structure represents a zone of low seismic activity.

However, for other regions, especially the west coast of Canada, the seismic loading will be considerably higher. This would require a detailed study of the system ductility in order to establish strength design parameters.

7.2.3 Loads

Wind

The wind load on the topside modules was not reported by BP. However, the S471 and NPD (used by BP) wind loads were calculated on the basis of the available module dimensions.

The S471 wind loads were found to be between 33 to 45% greater than the corresponding loads calculated using NPD. This is due to the higher product of basic reference wind pressure and dynamic response factor in S471, as compared to the reference wind pressure in NPD.

Wave and Current

The input parameters for the wave and current loads are identical for both S471 and the BP design. That is, the design wave height, period and wave theory were unaltered between the BP design and the design procedure using S471. Some relatively small differences between the results obtained for this project and the results reported by BP were noted. However, these are considered to be due to differences in modelling procedures, or to the restricted number of wave directions used for this project.

It should be noted that the BP design also includes a 10^{-4} wave event, however this is found to be less critical than the factored 10^{-2} design wave.

Seismic

The ground motion parameters, in the form of the design response spectrum, are identical for both S471 and the BP design. The difference in the calculated base shear between the two designs, is due to the different amplitude factors in the three principal directions. This results in more conservative design forces using S471, for both individual members of the jacket and the foundation piles. The percentage increase in design forces, including all associated load effects, are:

- Base shear 7.5%
- Overturning moment 17.9%

It can be concluded that for a jacket in a more highly active seismic zone, the impact on the structural design, in terms of member sizes, would be of a magnitude similar to the above values.

7.2.4 Load Combinations

Table 7.1 provides a summary of the load factors and combinations to S471 and the BP design.

Table 7.1
Load Factors and Combinations

LOAD / LOAD COMBINATION		G_D	Q	E_f	E_R	A	COMMENTS
In-Place A	CSA	1.25 or 0.9	1.25 or 0.9	0.70			$E_f = 10^{-2}$ (wave + wind + current)
	BP	1.3	1.3	0.70			$E_f = 10^{-2}$ (wave + wind + current)
B	CSA	1.05 or 0.9	1.0	1.35			$E_f = 10^{-2}$ (wave + wind + current)
	BP	1.0	1.0	1.30			$E_f = 10^{-2}$ (wave + wind + current), on $E_f = 10^{-2}$ earthquake
C	CSA	1.05 or 0.9	1.0	-	1.0		$E_R = 10^{-4}$ earthquake
	BP	1.0	1.0	-	1.0		$E_R = 10^{-4}$ earthquake, of $E_R = 10^{-4}$ wave + 10^{-2} wind + 10^{-1} current
D	CSA	1.05 or 0.9	1.0			1.0	A = accidental load
	BP	1.0	1.0			1.0	A = accidental load
	BP post-damage	1.0	1.0	1.0			$E_f = 10^{-2}$ wave + 10^{-1} (wind + current)
Fatigue	CSA	1.0	1.0	1.0			E_f = wave + wind + current
	BP	1.0	1.0	1.0			E_f = wave

The two principal loading conditions that were evaluated are the maximum storm loading (wind, wave and current), and the earthquake loading.

For the storm loading conditions, the factored S471 load combinations result in slightly more conservative design forces, as compared to the BP design. Table 7.2 presents the percentage difference between S471 and the BP load combination results, for the foundation forces and for the average of seventeen representative leg and brace structural elements.

Table 7.2
Differences in Storm Loads

Item	% Difference (S471-BP)
Total Base Shear	+3.8
Overturning Moment	+8.4
Maximum Pile Compression	+3.2
Member: Axial	+6.5
Member: Shear	+4.8
Member: Bending	+4.9

7.3 S472

No significant differences in the pile design were identified between S472 and the BP design. The design approach, using load and resistance factors, for the two designs are similar, although some differences were identified in the resistance factors. However, there is some discretion available in S472 for these factors, and no differences could be identified that are due to reasons other than the definition of these discretionary values.

7.4 S473

7.4.1 Tubular Design

Although the design of tubular elements is relatively straightforward, some difficulty was encountered in applying the clause provisions of S473. The principal difficulty was found in the division of cylindrical shells into separate clauses for stiffened and unstiffened conditions. The majority of the BP design is clearly based on unstiffened tubulars, and it would appear that Section 10.5.2 should apply. However, this does not include the shell buckling check, which is in Section 10.5.3. The only reference to shell buckling, for unstiffened elements, is in Table 10.1. Further, there is no indication whether the shell buckling resistance, F_{CR}, should be applied to the beam/column interaction ratio in Clause 10.5.2.5. It has not been included in this report, as it has been assumed that it is not the intent of S473. However, it is the contributing factor to the significantly lower interaction ratio calculated under S473, compared to the BP design, for members with high compression and a high D/t ratio.

7.4.2 Joint Design

There is a significant difference in the procedure for joint design, with S473 including bending effects while BP considers only axial punching shear forces. The relationship between the interaction ratios calculated using S473 and the BP methodology is shown below.

Joint	Ratio of S473/BP Interaction Ratios
T or Y	1.25
X	1.16

The factored design joint forces are between 8-10% higher for the S473 design, which accounts for part of the above difference. The remainder is due to the more complete punching shear calculations in S473.

7.4.3 Seismic

The seismic design provisions of S473 were not fully excercized since the low seismicity at the GYDA platform location results in member forces generally within the elastic range. Establishing the system ductility is an important requirement for a jacket design in a high seismic zone, and it is recommended that this aspect be examined in more detail.

7.4.4 Fatigue

Some differences in the fatigue design have been identified, and relate primarily to slightly different S-N curves, and to the definition of joint categories. For the S473 design procedures to provide an acceptance level comparable to the BP design, the following joint designations, or a less onerous category, must be assigned:

Stress Range (MPa)	Joint Category
≥ 53	Minor with good access
35	Major with good access
25	All

The assumption of good joint access results in a range of 5 to 42 joints needing further consideration under S473, compared to 23 for the BP design. The actual number depends on the number of joints classified as minor or major in structural importance.

The fatigue design comparison seems to indicate that the application of S473 would not result in major differences in the design of the GYDA platform. It does, however, highlight the large number of parameters to be considered in the joint design, with a correspondingly high degree of flexibility available to the designer. Inherent in this flexibility is the potential for large variations in results, especially since the code does not provide any guidelines for the selection of stress concentration factors, dynamic amplification factors, or for the accessibility of joints.

7.5 **Overall Effect on Design**

There are three primary conclusions that can be drawn for the results of this verification project, in relation to the impact in using the CSA Standards for the GYDA platform:

- The factored loads result in higher individual member and joint forces.

- Using the CSA loads and design provisions for unstiffened tubular members results in a plate thickness reduction of approximately 5 mm, for the same capacity as the BP design.

- The CSA provisions for tubular joints result in a thickness increase of approximately 10 mm in the joint cans, for the same capacity as the BP design.

7.6 **Use of CSA Standards**

During the execution of the verification project, a number of issues were identified relating to the interpretation and application of the codes. These can be summarized as follows;

- In Clause 10.5.2.5.1, the term $\emptyset AF_c$ is defined as including local buckling and hydrostatic effects. However, these are included in the calculation of C_r and C_r' in Clause 10.5.2.2. Therefore, it is assumed that the term $\emptyset AF_c$ should be replaced by the term C_r'. Similarly, it is assumed that the use of C_r in the second half of Clause 10.5.2.5.1 is meant to be C_r' in order to include the reduction for hydrostatic effects.

- Clause 10.5.2 refers to a resistance factor, $\emptyset_c$, which is undefined.

- The provisions of S473 and S473.1 provide mixed guidance on the shell buckling check for unstiffened cylinders.

- Clause 10.5.3.6 refers to a resistance factor, $\emptyset_c$, which is undefined.

- Clause 11.1.2.2.1 refers to the coefficient, U, for tubular joint strength. The terms F_{yo} and M_{ro} are undefined, but have been assumed to be derived from Clause 10.5.2.3 which includes local buckling effects.

APPENDIX A

REQUEST FOR PROPOSAL

Verification Program for the
CSA Code for Fixed Offshore Structures

VERIFICATION PROJECT G-1B
DESIGN STUDIES OF FIXED OFFSHORE STEEL STRUCTURES

Request for Proposal

Introduction

Canada, under the auspices of the Canadian Standards Association (CSA), published in 1989 a series of five Preliminary Standards which comprise a new Code for the Design, Construction and Installation of Fixed Offshore Structures. Associated with the development of this new Code, several state-of-the-art concepts including probabilistic methods, "target" annual reliability levels and the limit states approach were utilized to evolve an enhanced design process for fixed offshore structures. A fundamental assessment of Canada's harsh offshore environment on load effects and materials behaviour also led to the development and recognition of new and innovative technology. As such, the application of this new Design Code, when properly verified, will not only provide for greater consistency in specified and achievable levels of safety and reliability, and increased environmental protection, but will also lead to the design of more economically optimized structures. A program of code verification studies, under the direction of a CSA Subcommittee, has been underway for several years. This verification program has been supported principally through PERD and industry financial contributions. In order to complete certain assessments essential to the design code verification process, additional comparative design studies on both steel and concrete fixed offshore structures are required for a variety of harsh environmental loadings and complex design situations.

Requirement

As part of the verification program for the new CSA Code for the Design, Construction and Installation of Fixed Offshore Structures, a comprehensive series of analyses and design checks are to be undertaken for the existing BP "GYDA" steel production platform, as it exists in its present North Sea location. The checks are to be carried out for the foundation system and the complete primary jacket structure. The main topside facility deck structure and substructures such as the accommodation structure, process module structures, the derrick structure and the helideck structure, etc. should not need to be checked.

Scope of Work

For the existing BP GYDA steel production platform, and in connection with its present site-specific North Sea location, the program of work to be undertaken as part of this verification project is as follows:

1) Load cases, loads and load combinations are to be determined and calculated in accordance with the requirements of CSA Preliminary Standard S471. Loads of a particular nature, such as those that may result from future changes in production capacities, etc., shall be incorporated whenever BP has accounted for them in their existing design.

2) Except where specified in CSA Preliminary Standards S471, S472 or S473, design criteria specified by BP will normally be utilized. Consultation and approval by both the Scientific Authority and the Technical Authority will be required in instances where the choice of alternative design criteria could significantly affect or alter the results of the analyses or design checks.

3) Structural analyses shall be carried out in accordance with the requirements of the CSA S471 and S473 Preliminary Standards. These analyses will include, for the primary jacket structure, static, fatigue and seismic analyses.

4) Design checks, in accordance with the requirements of CSA Standards S472 and S473 and all referenced CSA Standards, shall be carried out for the foundation system and the structural members and joints of the primary jacket structure. In this regard, the sizes of structural elements required to comply with the provisions of the CSA Preliminary Standards shall also be determined.

5) Document for the GYDA platform: the differences in the load cases, loads and load combinations derived from the CSA S471 Standard as opposed to that derived and used by BP; the differences in steel structural element sizes; and the differences in material, fabrication and welding requirements.

6) The design process embodied in the CSA Code shall be carefully scrutinized and commented upon. This evaluation is required to ensure that the designer is being provided with sufficient and non-contradictory information and that an adequate degree of correlation exists between Standards comprising the Code.

7) On the basis of an overall appraisal of the work completed, recommend how CSA Preliminary Standards S471, S472 and S473 may be improved. This appraisal should address:

a) technical correctness - current understanding of loading phenomena and of the design analyses/design strength provisions;

b) allowance for incorporation of new information into Preliminary Standards S471, S472 and S473;

c) suitability of present requirements as a practical tool for the design of typical fixed offshore steel structures; and

d) flexibility for the creative design of new structures.

Information Requirements

In order to undertake this verification project, the following information will be required from BP International, London, England:

1) All basic data and relevant environmental, oceanographic, geotechnical, geological and seismicity information as would be required to develop basic design parameters and design criteria for the GYDA production platform for the site-specific location of the GYDA platform in the North Sea.

2) All pertinent information on topside facility operating requirements or procedures as may affect or alter the results of any of the analyses or design checks to be performed as part of the verification study.

3) Derived from the basic data of (1), all environmental, oceanographic, geotechnical and seismic design criteria used by BP in the analyses and design of the GYDA platform. This information may be used directly or compared with that derived from CSA Standard S471.

4) All pertinent information on steel material design criteria and requirements pertaining to the various welding consumables and welding procedures used in the design and construction of the primary jacket structure and the pile foundation.

5) All pertinent information as would be required on topside facility design requirements, including superimposed dead (e.g. substructure and equipment weights, bulk storage, etc.) and operating (e.g. processing, cranes, helideck, boat mooring, etc.) loads and any other factors associated with the topside facilities as may affect or alter the results of the analyses or design checks to be performed.

6) For the foundation system and the primary jacket structure, all pertinent information including plan and elevation drawings, general arrangements, scantling sizes, material designations, etc. as would be required in connection with the analysis/design verification process.

7) All relevant information on the foundations including the piling, the piling to structure connection system and all assumptions and criteria pertaining to pile/structure interaction and pile/soil interaction.

8) Information is also required on any serviceability requirements such as corrosion allowances, etc. as may be considered an integral part of any analysis/design verification process.

Communications

To monitor the progress of this verification project, appropriate communications plans are to be proposed and implemented by the Contractor to ensure close interaction with both the Scientific Authority and Technical Authority during the study.

Deliverables

A comprehensive technical report detailing the findings of this design verification study.

Four (4) copies of the technical report are required, plus one camera-ready copy.

Level of Effort

The funding for this verification project is proposed at a level of $75,000.00 for calendar year 1991.

Completion

All work must be completed no later than November 30, 1991. A comprehensive draft report, acceptable to both the Technical Authority and the Scientific Authority, must be completed and submitted by August 31, 1991. The invoice for the work completed on this project must be forwarded no later than November 30, 1991.

APPENDIX B

BP ENVIRONMENTAL DATA

APPENDIX B - BP ENVIRONMENTAL DATA

1. **Meteorology**

Wind

One minute mean wind speed at 10m above sea level:

- 10 year return period: 37.6m/s
- 100 year return period: see table B.2

Snow and Ice Accretion

Snow:
- maximum depth = 250mm, on horizontal surfaces
- density = 100kg/m^3

Ice:
- on upward and windward facing surfaces
- thickness = 80mm, elevation +3 to +15m
  = 0mm at elevation +25m
- density = 850kg/m^3 at elevation +3m, to 500 kg/m^3 at elevation +25m

2. **Oceanography**

Wind Generated Wave

Table B.1
Design Omnidirectional Wave Parameters

Return Period	Maximum Wave		
	Height	Period	
	Hmax (m)	Tmax (sec.)	Range of Tmax
10000	29.8	17.5	15.6 - 19.5
100	25.0	16.0	14.3 - 17.8
10	21.5	14.8	13.2 - 16.5
5	20.4	14.4	12.9 - 16.0

Table B.2
100 Year Return Period Wave and Wind Data

Direction relative to Platform North	Wave Height (m)	Wave Period (sec)	Wind Speed (m/s)
N	20.2	15.9	33.9
NE	20.4	16.1	37.6
E	19.9	15.8	36.8
SE	22.2	16.8	38.5
S	20.4	16.1	37.3
SW	24.8	17.8	37.3
W	25.0	17.8	41.4
NW	24.1	17.5	36.1

Spray

Spray zone: elevation -3.0m to +9.0m LAT.

Current

10 year return period surface current: 0.79m/s.

Table B.3
100 Year Return Period Current Profile

Direction relative to Platform North	Height Above Seabed (m)									
	Sur-face	60	55	50	40	30	20	10	1	0.5
N	0.72	0.72	0.64	0.62	0.59	0.57	0.57	0.55	0.43	0.40
NE	0.64	0.64	0.56	0.53	0.49	0.47	0.47	0.45	0.36	0.33
E	0.60	0.60	0.51	0.49	0.45	0.43	0.43	0.42	0.33	0.30
SE	0.65	0.65	0.57	0.54	0.50	0.48	0.48	0.46	0.36	0.34
S	0.64	0.64	0.56	0.53	0.49	0.47	0.47	0.45	0.36	0.33
SW	0.65	0.65	0.65	0.55	0.51	0.49	0.49	0.47	0.37	0.35
W	0.86	0.86	0.86	0.75	0.71	0.69	0.69	0.67	0.52	0.49
NW	0.88	0.88	0.88	0.78	0.75	0.73	0.73	0.70	0.55	0.51

Water Level

Lowest astronomical tide (LAT): elevation 65.7m above sea bed.

Water depth tolerance: ±0.4m.

Highest astronomical tide (HAT) = 100 year tide: 0.92m above LAT.

100 year return period storm surge: maximum = +1.52m
minimum = -1.06m.

100 year return period combined tide and storm surge: +2.25m.

Maximum subsidence due to reservoir settlement: 0.46m.

Water Mass Properties

Sea water density is taken as 1,025 kg/m^3.

Marine Growth

Marine growth thickness = +75mm from +3.0m to -30.0m LAT,
= +25mm below -30.0m LAT.

Submerged density = 375kg/m^3.

3. **Seabed Geology**

The seabed is considered horizontal and level.

APPENDIX C

WIND LOAD CALCULATIONS

WIND LOAD CALCULATIONS

Module Dimensions:

module	b	d	h	Projected Area broadside	long.
L10	15	37	36	540	1332
M20	33	25	25	750	shielded
M30	21	56	18	378	775
M50	11	11	40	260	260
F60	10	10	95	190	190
C40	78	25	8	656	200

Note: for modules M50 and F60, net area = 20% and 30% of the gross area

A) CSA S471, APPENDIX C:

Vt = 41.4 m/s, 1min mean @ 10m
Kzt = 1.11
qref = .000625*(Vt/Ktz)^2 = 0.869
Ce = (Z/10)^.24
Cs = 1

calculate Cd: for broadside wind
h = 39.5 overall avg
Ce = 1.39
Iu = 0.085

for L = 70 , B = 0.77
L/h = 1.77

fo = 0.37 Hz
Vh = 13.85
fo*h/Vh = 1.06
R = 0.53

vT = 104
g = 3.05

Cd = 1.49
Note: for longitudinal wind, results are not significantly different

Force on Modules F = qref*Ce*Cs*Cd*A

Module	z	broadside A	broadside Fy	longitudinal A	longitudinal Fx	diagonal case 80%Fy	diagonal case 80%Fx
L10	52	540	1033	1332	2562	826	2050
M20	45	750	1400	0	0	1120	0
M30	42	378	690	775	1416	552	1133
M50	65	260	527	260	527	422	422
F60	55	190	370	190	370	296	296
C40	26	656	1058	200	322	846	258
TOTAL			5078		5197	4062	4158

B) DnV 1977, Appendix B

V10 = 41.4 m/s
Vh = V10*(h/10)^.11
q = .613*Vh^2

or, q = .613*V10^2*Ch
and Ch = (h/10)^.22

q = 1.05

shape coeffients, C: from table B.5

F = q*Ch*C*A*sin(alpha)

		broadside			Diagonal case			
		alpha = 90			Fx, alpha = 34			Fy, alpha = 56
Module	h	C	A	Fy	C	A	Fx	Fy
L10	52	0.8	540	652	1.1	1332	1211	545
M20	45	0.95	750	1041	0	0	0	871
M30	42	0.75	378	408	1.1	775	673	341
M50	65	1.05	260	433	1.05	260	237	362
F60	55	1.2	190	348	1.2	190	190	291
C40	26	1.1	656	934	0.7	200	99	781
TOTAL				3816			2410	3191

APPENDIX D

ANALYSIS RESULTS

ANALYSIS RESULTS: A) Corner Piles - Load Components

CORNER PILES		DEAD	LIVE	BUOY	DIAGONAL WAVE JACKET	COND-UCTORS	BP WIND	CSA WIND	CSA TOTAL WAVE	BP TOTAL WAVE	BROADSIDE WAVE JACKET	COND-UCTORS	BP WIND	CSA WIND	CSA TOTAL WAVE	BP TOTAL WAVE
1501	Pz	-13273	-4496	1118	2132	1287	233	510	3929	3652	-333	-1456	-549	-728	-2516	-2338
	Px	502	170	-63	1297	691	112	161	2149	2100	1146	961	164	227	2334	2271
	Py	826	280	-76	-1474	-876	-143	-270	-2620	-2493	-189	182	6	-3	-9	-1
1502	Pz	-11171	-3783	895	-440	-190	-23	126	-503	-652	-2436	-3198	-790	-1061	-6695	-6424
	Px	521	176	-65	1194	631	104	148	1973	1929	1093	924	160	220	2237	2176
	Py	754	255	-69	-1055	-638	-111	-217	-1910	-1803	27	333	25	24	385	385
1503	Pz	-11304	-3828	921	-3266	-1822	-343	-384	-5472	-5431	-3920	-4268	-1037	-1407	-9595	-9225
	Px	466	158	-59	1507	808	128	187	2502	2443	1254	1036	174	240	2530	2464
	Py	700	237	-64	-756	-467	-87	-179	-1402	-1309	181	441	39	44	666	661
1504	Pz	-13569	-4596	1177	-4149	-2340	-477	-623	-7112	-6966	-3633	-3832	-1098	-1496	-8961	-8563
	Px	391	132	-52	1923	1044	161	240	3207	3128	1466	1184	192	267	2917	2842
	Py	721	244	-66	-876	-535	-96	-194	-1605	-1507	119	398	33	36	553	551
1505	Pz	-12878	-4362	1440	-6221	-6049	-1327	-1817	-14087	-13597	-3807	-6199	-1057	-1381	-11387	-11063
	Px	349	118	-53	1914	1745	148	159	3818	3807	1595	2173	177	225	3993	3945
	Py	-692	-234	89	-1298	-797	-171	-297	-2392	-2265	-147	95	-52	-78	-130	-104
1506	Pz	-10660	-3610	1160	-7681	-7003	-1371	-1923	-16607	-16055	-4102	-6220	-1010	-1326	-11648	-11332
	Px	420	142	-79	1797	1663	152	176	3636	3612	1368	1904	161	204	3476	3433
	Py	-672	-228	82	-1334	-821	-170	-292	-2448	-2325	-213	17	-57	-84	-281	-253
1507	Pz	-10525	-3565	1137	-6683	-5714	-1311	-1937	-14334	-13708	-2567	-3760	-802	-1066	-7393	-7129
	Px	472	160	-98	1707	1601	154	188	3496	3462	1196	1701	148	189	3086	3045
	Py	-723	-245	101	-1247	-761	-172	-304	-2312	-2180	-48	212	-45	-69	95	119
1508	Pz	-12587	-4263	1389	-4003	-3184	-1193	-1848	-9035	-8380	-395	-733	-593	-804	-1932	-1721
	Px	453	153	-92	1735	1621	153	184	3540	3509	1252	1769	153	194	3215	3174
	Py	-792	-268	126	-1125	-677	-175	-320	-2122	-1977	183	485	-28	-48	619	640

ANALYSIS RESULTS: B) Corner Piles, continued - Load Components

CORNER PILES		DEAD	LIVE	BUOY	DIAGONAL WAVE JACKET	COND-UCTORS	BP WIND	CSA WIND	CSA TOTAL WAVE	BP TOTAL WAVE	BROADSIDE WAVE JACKET	COND-UCTORS	BP WIND	CSA WIND	CSA TOTAL WAVE	BP TOTAL WAVE
1509	Pz	-13488	-4568	1292	5741	4025	1362	2036	11802	11128	3576	3840	1098	1496	8912	8514
	Px	-392	-133	82	1658	907	162	240	2805	2727	1438	1185	192	267	2890	2815
	Py	715	242	-31	-1168	-1236	-151	-222	-2626	-2555	-114	-396	-34	-36	-546	-543
1510	Pz	-11233	-3804	956	7136	5300	1393	2083	14519	13829	3861	4275	1037	1406	9542	9173
	Px	-466	-158	80	1564	899	163	244	2707	2626	1230	1036	174	240	2506	2440
	Py	695	235	-32	-1195	-1239	-151	-221	-2655	-2585	-174	-440	-40	-44	-657	-653
1511	Pz	-11103	-3761	863	6222	5201	1298	1950	13373	12721	2392	3207	790	1060	6659	6389
	Px	-520	-176	78	1494	893	164	246	2633	2550	1074	923	160	220	2217	2157
	Py	747	253	-30	-1127	-1233	-151	-223	-2583	-2511	-23	-331	-25	-24	-378	-379
1512	Pz	-13202	-4472	1086	3709	3806	1151	1740	9255	8666	311	1468	550	727	2506	2329
	Px	-501	-170	79	1519	894	163	245	2658	2577	1128	961	164	227	2316	2253
	Py	819	278	-28	-1031	-1223	-152	-226	-2480	-2406	188	-179	-6	3	12	3
1513	Pz	-12523	-4241	1431	-2356	-1974	-202	-425	-4755	-4532	436	751	593	804	1991	1780
	Px	-456	-154	96	1440	1373	102	96	2909	2915	1242	1768	153	194	3204	3163
	Py	-788	-267	166	-1512	-1543	-128	-190	-3245	-3183	-173	-492	28	48	-617	-637
1514	Pz	-10473	-3547	1187	409	610	29	-154	864	1048	2581	3768	801	1066	7415	7150
	Px	-474	-161	102	1327	1276	93	85	2688	2696	1185	1698	149	189	3072	3032
	Py	-720	-244	144	-1065	-1157	-97	-147	-2369	-2319	53	-212	45	69	-90	-114
1515	Pz	-10604	-3591	1150	3302	3492	317	212	7006	7111	4096	6222	1010	1326	11644	11328
	Px	-423	-143	86	1656	1563	117	117	3336	3336	1352	1906	161	204	3462	3419
	Py	-671	-227	128	-745	-880	-74	-116	-1741	-1699	215	-12	57	84	287	260
1516	Pz	-12813	-4340	1348	4072	4432	437	389	8893	8941	3801	6205	1057	1381	11387	11063
	Px	-354	-120	64	2097	1945	148	160	4202	4190	1575	2182	177	225	3982	3934
	Py	-690	-234	134	-872	-991	-83	-128	-1991	-1946	151	-92	52	78	136	110

ANALYSIS RESULTS: C) Centre Piles - Load Components

	DEAD	LIVE	BUOY	DIAGONAL WAVE				CSA	BP	BROADSIDE WAVE				CSA	BP
					COND-	BP	CSA	TOTAL	TOTAL		COND-	BP	CSA	TOTAL	TOTAL
CENTRE PILES				JACKET	UCTORS	WIND	WIND	WAVE	WAVE	JACKET	UCTORS	WIND	WIND	WAVE	WAVE
1517 Pz	-20938	-7091	2077	-6226	-5179	-1129	-1461	-12866	-12534	-5203	-7245	-1520	-2023	-14471	-13968
Px	2924	990	-322	2223	1793	226	292	4308	4242	1825	2245	288	385	4455	4358
Py	-39	-13	-7	-796	-403	-82	-159	-1359	-1281	21	282	-8	-18	285	296
1518 Pz	-20866	-7067	2158	-8356	-6516	-1415	-1977	-16849	-16287	-5217	-6793	-1537	-2062	-14072	-13547
Px	2948	999	-317	2535	2023	255	343	4901	4813	1833	2229	289	387	4449	4351
Py	-46	-15	-7	-800	-406	-82	-160	-1366	-1289	19	279	-8	-19	278	289
1519 Pz	-20766	-7033	2274	5807	4831	1157	1556	12194	11795	5171	6758	1537	2063	13992	13466
Px	-2943	-997	356	2155	1685	230	303	4143	4070	1820	2190	290	387	4397	4300
Py	-49	-16	65	-819	-901	-68	-96	-1815	-1788	-19	-283	8	19	-283	-294
1520 Pz	-20839	-7058	2137	7849	6987	1412	1944	16780	16248	5148	7208	1520	2024	14380	13876
Px	-2917	-988	338	2424	1943	257	345	4712	4624	1810	2204	288	384	4398	4302
Py	-42	-14	64	-822	-904	-68	-96	-1822	-1794	-21	-286	8	18	-289	-300

ANALYSIS RESULTS: D) Summary - Load Components

	DEAD	LIVE	BUOY	DIAGONAL WAVE				CSA	BP	BROADSIDE WAVE				CSA	BP
					COND-	BP	CSA	TOTAL	TOTAL		COND-	BP	CSA	TOTAL	TOTAL
				JACKET	UCTORS	WIND	WIND	WAVE	WAVE	JACKET	UCTORS	WIND	WIND	WAVE	WAVE
TOTAL BASE SHEAR															
x	-1	-0	162	35166	26998	3193	4156	66320	65357	27882	32179	3814	5074	65135	63875
y	53	18	689	-21116	-17687	-2412	-4058	-42862	-41215	37	0	-2	-0	36	35
SRQT(Px^2+Py^2)	53	18	708	41019	32276	4001	5809	78965	77267	27882	32179	3814	5074	65135	63875
TOTAL OVERTURNING MOMENT															
Mx	-15433	-5227	-5669	-1945230	-1637649	-364388	-493720	-4076600	-3947268	-1418646	-1949895	-435790	-582271	-3950811	-3804330
My	-161080	-54556	-60825	1157725	978021	286706	465257	2601003	2422452	-6931	29	76	-61	-6963	-6826
SQRT(Mx^2+My^2)	161818	54806	61089	2263680	1907465	463659	678397	4835688	4631328	1418663	1949895	435790	582271	3950817	3804336
AXIAL FORCE (-ve = COMPRESSION)															
TOTAL:	-274815	-93076	27196	-3002	0	-2	-2	-3004	-3004	-240	-2	-0	-1	-242	-242
CORNER PILE:															
max compression	-13569	-4596	863	-7681	-7003	-1371	-1937	-16607	-16055	-4102	-6220	-1098	-1496	-11648	-11332
max tension	-10473	-3547	1440	7136	5300	1393	2083	14519	13829	4096	6222	1098	1496	11644	11328
CENTRE PILE:															
max compression	-20938	-7091	2077	-8356	-6516	-1415	-1977	-16849	-16287	-5217	-7245	-1537	-2062	-14471	-13968
max tension	-20766	-7033	2274	7849	6987	1412	1944	16780	16248	5171	7208	1537	2063	14380	13876

ANALYSIS RESULTS: E) Corner Piles - Load Combinations

	TOTAL UNFACTORED				A - OPERATING						B - STORM					
	CSA		BP		DIAGONAL			BROADSIDE			DIAGONAL			BROADSIDE		
CORNER PILES	DIAG.	BROAD.	DIAG.	BROAD.	CSA(1.25)	CSA(0.9)	BP	CSA(1.25)	CSA(0.9)	BP	CSA(1.05)	CSA(0.9)	BP	CSA(1.05)	CSA(0.9)	BP
1501 Pz	-12722	-19167	-12999	-18989	-18063	-12236	-19090	-22575	-16747	-23283	-11955	-10131	-11903	-20656	-18832	-19690
Px	2757	2943	2709	2880	2265	2052	2295	2395	2182	2425	3531	3466	3402	3781	3716	3643
Py	-1590	1021	-1463	1029	-547	-907	-495	1281	920	1332	-2470	-2583	-2377	1055	943	1018
SRQT(Px^2+Py^2)	3183	3115	3078	3058	2330	2244	2348	2716	2368	2767	4310	4322	4150	3926	3833	3782
1502 Pz	-14562	-20754	-14711	-20483	-17926	-13005	-18733	-22260	-17340	-22774	-15252	-13710	-14907	-23611	-22070	-22410
Px	2606	2870	2562	2809	2172	1951	2204	2357	2135	2389	3319	3251	3198	3675	3607	3541
Py	-970	1324	-864	1325	-162	-491	-115	1444	1115	1491	-1604	-1707	-1543	1493	1391	1440
SRQT(Px^2+Py^2)	2780	3161	2704	3106	2178	2011	2207	2764	2409	2816	3686	3671	3550	3967	3866	3822
1503 Pz	-19682	-23806	-19642	-23436	-21593	-16620	-22275	-24480	-19506	-24931	-22116	-20559	-21271	-27683	-26126	-26203
Px	3067	3094	3008	3028	2457	2259	2485	2476	2279	2504	3963	3902	3817	4000	3939	3853
Py	-528	1539	-436	1534	110	-195	154	1557	1252	1601	-987	-1083	-949	1804	1708	1739
SRQT(Px^2+Py^2)	3112	3456	3039	3394	2459	2268	2490	2925	2600	2972	4084	4049	3933	4388	4294	4227
1504 Pz	-24100	-25949	-23954	-25551	-26213	-20268	-26961	-27508	-21562	-28079	-27209	-25350	-26044	-29705	-27846	-28120
Px	3678	3387	3598	3313	2833	2669	2857	2630	2465	2654	4817	4766	4640	4425	4374	4262
Py	-706	1451	-608	1449	-0	-315	45	1510	1196	1555	-1235	-1334	-1188	1678	1579	1617
SRQT(Px^2+Py^2)	3745	3685	3649	3616	2833	2687	2857	3033	2740	3076	4973	4949	4789	4732	4651	4559
1505 Pz	-29887	-27187	-29397	-26863	-29611	-24081	-30058	-27721	-22191	-28284	-35389	-33674	-33476	-31744	-30029	-30182
Px	4232	4407	4221	4359	3190	3045	3211	3312	3167	3333	5583	5539	5378	5819	5775	5605
Py	-3228	-967	-3102	-941	-2720	-2427	-2762	-1137	-844	-1179	-4095	-4005	-3946	-1043	-952	-1006
SRQT(Px^2+Py^2)	5323	4512	5238	4459	4192	3894	4235	3502	3278	3535	6924	6835	6670	5912	5853	5694
1506 Pz	-29717	-24758	-29165	-24442	-28012	-23424	-28282	-24541	-19953	-24975	-36004	-34579	-33982	-29310	-27885	-27842
Px	4119	3959	4095	3916	3148	2979	3173	3037	2868	3061	5408	5357	5209	5193	5142	5002
Py	-3265	-1099	-3143	-1071	-2736	-2449	-2777	-1219	-933	-1260	-4152	-4063	-4000	-1226	-1138	-1183
SRQT(Px^2+Py^2)	5256	4109	5162	4059	4171	3857	4216	3272	3016	3310	6818	6724	6568	5336	5266	5140
1507 Pz	-27287	-20346	-26661	-20082	-26225	-21692	-26435	-21366	-16833	-21829	-32773	-31365	-30773	-23403	-21995	-22221
Px	4029	3619	3995	3578	3114	2927	3140	2827	2640	2853	5272	5215	5078	4718	4662	4545
Py	-3179	-772	-3047	-748	-2702	-2399	-2746	-1017	-714	-1061	-4020	-3926	-3873	-770	-677	-744
SRQT(Px^2+Py^2)	5132	3701	5025	3656	4123	3784	4171	3004	2735	3044	6629	6528	6386	4781	4711	4606
1508 Pz	-24496	-17393	-23841	-17182	-25651	-20239	-25965	-20679	-15267	-21304	-28218	-26538	-26355	-18629	-16949	-17698
Px	4054	3730	4024	3689	3121	2941	3147	2894	2714	2920	5311	5257	5116	4873	4819	4694
Py	-3055	-314	-2910	-294	-2652	-2325	-2699	-734	-407	-780	-3831	-3731	-3692	-131	-31	-129
SRQT(Px^2+Py^2)	5077	3743	4966	3700	4096	3749	4146	2985	2744	3022	6549	6447	6309	4875	4819	4696

ANALYSIS RESULTS: F) Corner Piles,continued - Load Combinations

	TOTAL UNFACTORED				A - OPERATING						B - STORM					
	CSA		BP		DIAGONAL			BROADSIDE			DIAGONAL			BROADSIDE		
CORNER PILES	DIAG.	BROAD.	DIAG.	BROAD.	CSA(1.25)	CSA(0.9)	BP	CSA(1.25)	CSA(0.9)	BP	CSA(1.05)	CSA(0.9)	BP	CSA(1.05)	CSA(0.9)	BP
1509 Pz	-4962	-7852	-5636	-8250	-12694	-6826	-14004	-14717	-8849	-15833	-1441	388	-2298	-5343	-3513	-5696
Px	2363	2448	2285	2373	1411	1566	1389	1470	1625	1448	3329	3376	3205	3444	3490	3315
Py	-1700	380	-1630	382	-681	-1005	-635	775	451	822	-2585	-2687	-2488	223	121	217
SRQT(Px^2+Py^2)	2911	2477	2807	2404	1567	1860	1527	1662	1687	1665	4215	4315	4057	3451	3492	3322
1510 Pz	438	-4539	-252	-4908	-7438	-2510	-8625	-10922	-5994	-11884	5006	6547	3897	-1713	-172	-2156
Px	2163	1963	2083	1896	1216	1406	1188	1075	1265	1048	3092	3149	2976	2821	2878	2715
Py	-1757	241	-1687	245	-736	-1050	-691	662	348	707	-2653	-2753	-2554	44	-56	43
SRQT(Px^2+Py^2)	2787	1977	2681	1912	1421	1755	1375	1263	1312	1264	4074	4183	3921	2821	2879	2715
1511 Pz	-628	-7342	-1280	-7612	-8140	-3240	-9297	-12840	-7940	-13729	3540	5077	2536	-5523	-3987	-5695
Px	2015	1599	1932	1539	1070	1287	1039	780	996	749	2914	2980	2804	2353	2419	2264
Py	-1614	591	-1542	591	-596	-936	-548	947	608	996	-2482	-2590	-2389	495	387	478
SRQT(Px^2+Py^2)	2581	1705	2472	1648	1225	1591	1175	1227	1167	1246	3828	3948	3684	2405	2450	2314
1512 Pz	-7333	-14082	-7922	-14259	-14257	-8451	-15498	-18981	-13175	-19934	-4700	-2882	-5322	-13811	-11993	-13561
Px	2067	1724	1985	1661	1121	1328	1091	881	1088	852	2976	3039	2864	2513	2576	2418
Py	-1411	1081	-1337	1072	-400	-774	-346	1345	970	1398	-2240	-2358	-2155	1125	1006	1084
SRQT(Px^2+Py^2)	2502	2035	2393	1977	1190	1537	1145	1608	1458	1637	3724	3847	3584	2753	2766	2650
1513 Pz	-20088	-13342	-19865	-13553	-22495	-17128	-23105	-17773	-12406	-18687	-22306	-20643	-21225	-13200	-11536	-13019
Px	2394	2690	2401	2649	1393	1573	1367	1600	1780	1574	3394	3448	3267	3793	3847	3651
Py	-4134	-1506	-4072	-1527	-3383	-3072	-3428	-1544	-1232	-1588	-5301	-5208	-5108	-1753	-1660	-1691
SRQT(Px^2+Py^2)	4778	3083	4727	3057	3659	3451	3690	2223	2165	2236	6295	6246	6063	4179	4190	4024
1514 Pz	-11969	-5418	-11785	-5683	-15436	-10945	-15950	-10851	-6359	-11678	-12131	-10738	-11471	-3287	-1894	-3538
Px	2155	2539	2164	2499	1215	1402	1189	1484	1671	1458	3077	3133	2961	3596	3652	3461
Py	-3189	-910	-3139	-934	-2683	-2396	-2724	-1088	-801	-1129	-4047	-3960	-3899	-970	-883	-937
SRQT(Px^2+Py^2)	3849	2697	3812	2668	2946	2776	2972	1840	1853	1844	5084	5049	4896	3724	3757	3585
1515 Pz	-6039	-1401	-5934	-1717	-11402	-6836	-11981	-8155	-3590	-9029	-4059	-2641	-3801	2202	3620	1681
Px	2855	2982	2855	2938	1734	1903	1710	1823	1991	1799	4006	4056	3856	4177	4227	4021
Py	-2511	-483	-2470	-511	-2182	-1912	-2220	-762	-492	-801	-3148	-3066	-3034	-410	-328	-397
SRQT(Px^2+Py^2)	3803	3021	3775	2982	2787	2697	2803	1976	2051	1969	5095	5085	4906	4197	4240	4040
1516 Pz	-6912	-4418	-6864	-4742	-13531	-7999	-14288	-11785	-6254	-12802	-4372	-2653	-4182	-1006	714	-1423
Px	3792	3573	3781	3525	2429	2573	2409	2276	2419	2255	5248	5292	5053	4952	4995	4767
Py	-2780	-653	-2735	-680	-2381	-2104	-2420	-892	-615	-931	-3505	-3422	-3378	-633	-550	-612
SRQT(Px^2+Py^2)	4702	3632	4666	3589	3401	3324	3415	2444	2496	2440	6311	6302	6078	4992	5025	4806

ANALYSIS RESULTS: G) Centre Piles - Load Combinations

	TOTAL UNFACTORED				A - OPERATING						B - STORM					
	CSA		BP		DIAGONAL			BROADSIDE			DIAGONAL			BROADSIDE		
CENTRE PILES	DIAG.	BROAD.	DIAG.	BROAD.	CSA(1.25)	CSA(0.9)	BP	CSA(1.25)	CSA(0.9)	BP	CSA(1.05)	CSA(0.9)	BP	CSA(1.05)	CSA(0.9)	BP
1517 Pz	-38818	-40423	-38486	-39920	-41446	-32363	-42511	-42570	-33487	-43515	-44264	-41435	-42246	-46431	-43602	-44110
Px	7900	8047	7835	7951	7506	6249	7686	7609	6351	7788	9538	9148	9192	9736	9346	9383
Py	-1418	226	-1340	236	-1025	-1005	-1028	125	146	122	-1896	-1889	-1826	323	330	311
SRQT(Px^2+Py^2)	8026	8050	7948	7954	7576	6329	7754	7610	6353	7789	9724	9341	9372	9742	9352	9389
1518 Pz	-42624	-39847	-42062	-39322	-44013	-34992	-44908	-42069	-33048	-42990	-49457	-46650	-46948	-45708	-42901	-43386
Px	8531	8079	8443	7981	7968	6698	8150	7652	6381	7833	10377	9983	10001	9768	9373	9414
Py	-1434	211	-1356	221	-1041	-1018	-1045	110	134	107	-1915	-1907	-1844	305	313	294
SRQT(Px^2+Py^2)	8650	8082	8551	7984	8036	6774	8216	7653	6383	7834	10553	10163	10169	9773	9378	9418
1519 Pz	-13331	-11533	-13730	-12059	-23370	-14437	-24926	-22112	-13178	-23756	-9988	-7214	-10191	-7560	-4787	-8019
Px	559	813	486	716	-1580	-326	-1759	-1402	-148	-1581	1879	2267	1802	2223	2611	2132
Py	-1815	-283	-1788	-294	-1271	-1271	-1271	-198	-198	-198	-2450	-2452	-2360	-381	-383	-367
SRQT(Px^2+Py^2)	1899	861	1853	774	2028	1312	2170	1416	247	1593	3088	3340	2969	2255	2639	2164
1520 Pz	-8980	-11380	-9512	-11884	-20454	-11438	-22114	-22134	-13118	-23775	-4042	-1237	-4638	-7282	-4477	-7721
Px	1145	831	1057	735	-1160	88	-1339	-1380	-132	-1559	2666	3052	2559	2241	2628	2150
Py	-1813	-281	-1785	-291	-1265	-1268	-1264	-192	-195	-192	-2450	-2453	-2360	-381	-385	-368
SRQT(Px^2+Py^2)	2145	877	2075	791	1716	1271	1841	1393	235	1570	3620	3916	3481	2274	2656	2182

ANALYSIS RESULTS: H) Summary - Load Combinations

	TOTAL UNFACTORED				A - OPERATING						B - STORM					
	CSA		BP		DIAGONAL			BROADSIDE			DIAGONAL			BROADSIDE		
	DIAG.	BROAD.	DIAG.	BROAD.	CSA(1.25)	CSA(0.9)	BP	CSA(1.25)	CSA(0.9)	BP	CSA(1.05)	CSA(0.9)	BP	CSA(1.05)	CSA(0.9)	BP
TOTAL BASE SHEAR																
x	66481	65296	65517	64035	46625	46569	46633	45795	45739	45803	89701	89677	86377	88101	88077	84836
y	-42101	797	-40455	795	-29053	-29319	-29015	976	710	1014	-57066	-57177	-54960	846	735	807
SRQT(Px^2+Py^2)	78691	65300	77001	64040	54936	55029	54922	45805	45744	45814	106314	106354	102379	88105	88080	84840
TOTAL OVERTURNING MOMENT																
Mx	-4102929	-3977140	-3973597	-3830659	-2886532	-2877316	-2797316	-2798479	-2789264	-2697259	-5530794	-5527629	-5157778	-5360979	-5357814	-4971958
My	2324542	-283423	2145992	-283287	1475126	1571887	1336318	-350450	-253689	-364177	3223798	3257084	2872727	-296956	-263670	-285334
SQRT(Mx^2+My^2)	4715668	3987226	4516055	3841120	3241614	3278685	3100116	2820337	2800777	2721733	6401762	6415861	5903832	5369197	5364298	4980139
AXIAL FORCE (-ve = COMPRESSION)																
TOTAL:	-343699	-340937	-343699	-340937	-427971	-308728	-445006	-426038	-306795	-443073	-357131	-319988	-344600	-353403	-316260	-341010
CORNER PILE:																
max compression	-29887	-27187	-29397	-26863	-29611	-24081	-30058	-27721	-22191	-28284	-36004	-34579	-33982	-31744	-30029	-30182
max tension	438	-1401	-252	-1717	-7438	-2510	-8625	-8155	-3590	-9029	5006	6547	3897	2202	3620	1681
CENTRE PILE:																
max compression	-42624	-40423	-42062	-39920	-44013	-34992	-44908	-42570	-33487	-43515	-49457	-46650	-46948	-46431	-43602	-44110
max tension	-8980	-11380	-9512	-11884	-20454	-11438	-22114	-22112	-13118	-23756	-4042	-1237	-4638	-7282	-4477	-7721

ANALYSIS RESULTS - A) Member Forces - Load Components

MEMBER		DEAD	LIVE	BUOY	DIAGONAL WAVE JACKET	COND-UCTORS	BP WIND	CSA WIND	BP TOTAL WAVE	CSA TOTAL WAVE	BROADSIDE WAVE JACKET	COND-UCTORS	BP WIND	CSA WIND	BP TOTAL WAVE	CSA TOTAL WAVE
39	Pz	-36939	-12511	3253	-14389	-12636	-4158	-5997	-31183	-33022						
	Px	765	259	-66	591	475	134	213	1200	1279						
	Py	-1972	-668	218	-190	-560	-209	-268	-958	-1017						
	Mx	3505	1187	-269	3165	3039	684	1054	6888	7258						
	My	14835	5025	-1655	753	5193	1866	2465	7812	8411						
	Mz	-24	-8	-311	248	1506	12	-58	1766	1696						
61	Pz	-196	-66	-149	3468	2601	554	1116	6623	7185						
	Px	-10	-3	2	11	5	1	3	17	19						
	Py	11	4	-1	-3	-5	0	1	-8	-7						
	Mx	6	2	-15	-30	-2	-6	-11	-38	-43						
	My	-140	-47	-5	-50	-31	-8	-16	-89	-97						
	Mz	105	36	-17	-40	-8	1	2	-47	-46						
75	Pz	-5576	-1888	368	-2710	-117	-874	-1569	-3702	-4396						
	Px	34	11	-37	76	11	6	9	92	95						
	Py	-63	-21	58	114	-3	-4	-9	107	103						
	My	-99	-34	-39	-55	153	-40	-69	58	29						
	Mx	-53	-18	-108	-294	-114	-8	-20	-416	-428						
	Mz	46	16	8	-20	-24	7	6	-38	-38						
602	Pz	-1216	-412	999	-8774	-9166	-626	-664	-18566	-18604	-6935	-10812	-746	-933	-18493	-18680
	Px	-32	-11	39	12	6	1	0	19	18	8	14	2	2	24	24
	Py	28	9	-27	34	44	3	4	81	82	27	46	3	3	76	76
	Mx	-251	-85	269	219	324	10	-14	553	529	239	404	16	14	659	657
	My	-95	-32	184	-372	-294	-13	-18	-679	-684	-259	-338	-16	-15	-613	-612
	Mz	111	38	-169	58	41	-5	-4	94	95	59	89	1	0	149	148
607	Pz	-7358	-2492	822	-7664	-9813	-893	-1011	-18370	-18488	-5511	-11322	-729	-895	-17562	-17728
	Px	-34	-11	31	19	6	1	-3	26	22	19	37	4	3	60	59
	Py	-32	-11	-16	42	64	3	1	109	107	31	57	4	3	92	91
	Mx	-124	-42	214	427	446	34	14	907	887	295	545	35	32	875	872
	My	-200	-68	152	-457	-560	-52	-48	-1069	-1065	-361	-635	-60	-64	-1056	-1060
	Mz	84	29	-117	-37	29	-9	-20	-17	-28	44	96	0	-1	140	139
24	Pz	-33446	-11328	2349							-5688	-7525	-2566	-3433	-15779	-16646
	Px	2612	884	-279							22	-94	169	233	97	161
	Py	2618	887	-256							62	373	164	213	599	648
	Mx	-20105	-6809	2278							872	-1186	-1287	-1738	-1601	-2052
	My	20058	6793	-2106							-727	2499	1305	1739	3077	3511
	Mz	9	3	-39							29	1264	-30	-71	1263	1222
263	Pz	-240	-81	-40	-4165	-5527	-528	-784	-10220	-10476						
	Px	19	7	-2	9	1	1	1	11	11						
	Py	4	1	-1	3	23	1	2	27	28						
	Mx	141	48	5	-40	-135	-8	-10	-183	-185						
	My	77	26	-19	33	-57	4	9	-20	-15						
	Mz	169	57	-14	51	3	1	1	55	55						

ANALYSIS RESULTS - B) Member Forces - Load Components

MEMBER		DEAD	LIVE	BUOY	DIAGONAL WAVE JACKET	COND-UCTORS	BP WIND	CSA WIND	BP TOTAL WAVE	CSA TOTAL WAVE	BROADSIDE WAVE JACKET	COND-UCTORS	BP WIND	CSA WIND	BP TOTAL WAVE	CSA TOTAL WAVE
625	Pz	-5765	-1952	-69	-6052	-3284	-1036	-1084	-10372	-10420						
	Px	-39	-13	58	48	59	4	2	111	109						
	Py	17	6	-10	-160	-40	-4	-3	-204	-203						
	Mx	-208	-70	322	579	561	67	55	1207	1195						
	My	75	25	-279	428	447	84	72	959	947						
	Mz	-42	-14	76	28	12	-2	-8	38	32						
524	Pz	-4167	-1411	-403							-3485	-7513	-283	-376	-11281	-11374
	Px	-6	-2	-6							7	21	1	1	29	29
	Py	10	3	0							-10	-27	-1	-1	-38	-38
	Mx	55	18	-31							100	71	15	20	186	191
	My	51	17	-17							140	179	18	23	337	342
	Mz	1	0	-7							3	36	0	-1	39	38
58	Pz	-29809	-10096	2004	-7521	-4186	-3384	-5026	-15091	-16733						
	Px	-235	-80	70	-71	-11	-33	-49	-115	-131						
	Py	179	61	42	68	-11	24	29	81	86						
	Mx	-1231	-417	92	-1610	-1095	-277	-488	-2982	-3193						
	My	-2155	-730	197	-369	-706	-15	69	-1090	-1006						
	Mz	-192	-65	1	-167	327	-48	-130	112	30						
59	Pz	-36693	-12428	1738							-4759	-7318	-2573	-3438	-14650	-15515
	Px	-226	-77	-3							-81	110	-28	-37	1	-8
	Py	239	81	-26							113	-39	32	42	106	116
	Mx	-2003	-679	323							469	-424	50	62	95	107
	My	-2256	-764	194							525	-233	53	58	345	350
	Mz	-8	-3	-8							-29	538	-26	-51	483	458
286	Pz	-5491	-1860	322	-2119	-2565	-394	-582	-5078	-5266						
	Px	48	16	-42	95	7	4	5	106	107						
	Py	52	18	-53	-91	8	3	4	-80	-79						
	Mx	20	7	91	-62	-91	24	35	-129	-118						
	My	-109	-37	-81	-311	-262	-7	-10	-580	-583						
	Mz	-45	-15	-8	-2	19	10	12	27	29						
506	Pz	-6028	-2041	1072							-5643	-7844	-546	-729	-14033	-14216
	Px	29	10	-13							16	23	3	5	42	44
	Py	33	11	-4							24	47	4	6	75	77
	Mx	-201	-68	-47							204	304	-2	-5	506	503
	My	303	103	-34							-300	-338	-2	-4	-640	-642
	Mz	-15	-5	22							-7	17	-2	-3	8	7

ANALYSIS RESULTS - C) Member Forces - Load Combinations

MEMBER		TOTAL UNFACTORED				A - OPERATING						B - STORM					
		CSA		BP		DIAGONAL			BROADSIDE			DIAGONAL			BROADSIDE		
		DIAG.	BROAD.	DIAG.	BROAD.	CSA(1.25)	CSA(0.9)	BP	CSA(1.25)	CSA(0.9)	BP	CSA(1.25)	CSA(0.9)	BP	CSA(1.25)	CSA(0.9)	BP
39	Pz	-79219		-77380		-80862	-64693	-81884				-92461	-87408	-86735			
	Px	2237		2158		2092	1757	2085				2719	2614	2518			
	Py	-3440		-3381		-3740	-2892	-3820				-3883	-3620	-3668			
	Mx	11681		11311		10609	9061	10571				14383	13897	13377			
	My	26616		26017		28644	22272	29135				30218	28241	28360			
	Mz	1354		1423		759	879	791				1931	1981	1953			
61	Pz	6774		6212		4516	4660	4101				9271	9323	8198			
	Px	8		7		-0	4	-2				15	16	12			
	Py	6		5		11	7	11				4	2	3			
	Mx	-49		-44		-38	-36	-34				-65	-63	-55			
	My	-290		-282		-309	-241	-313				-331	-309	-309			
	Mz	79		77		123	80	129				67	54	63			
75	Pz	-11492		-10797		-11947	-9463	-11815				-13291	-12510	-11908			
	Px	103		100		77	74	75				137	137	128			
	Py	76		81		39	48	41				112	113	113			
	My	-142		-113		-194	-134	-182				-139	-118	-96			
	Mx	-607		-595		-523	-461	-524				-765	-741	-720			
	Mz	32		32		61	36	65				22	13	21			
602	Pz	-19233	-19309	-19195	-19122	-13809	-13589	-13814	-13862	-13642	-13763	-25755	-25723	-24765	-25858	-25825	-24670
	Px	14	20	15	20	8	9	8	12	13	12	21	20	21	29	28	27
	Py	92	86	91	86	70	66	70	66	62	66	121	121	115	113	113	109
	Mx	462	590	486	592	287	310	300	376	400	374	648	645	652	821	818	790
	My	-627	-555	-622	-556	-408	-427	-401	-357	-377	-355	-862	-875	-826	-765	-778	-740
	Mz	75	128	74	129	41	48	40	79	86	78	105	114	102	177	186	174
607	Pz	-27516	-26756	-27398	-26590	-24227	-21067	-24595	-23695	-20535	-24030	-34314	-33333	-32909	-33288	-32307	-31859
	Px	8	45	12	46	-2	3	-0	24	29	24	16	16	20	66	66	64
	Py	48	32	50	33	1	22	-0	-10	11	-12	83	90	83	61	69	61
	Mx	935	920	955	923	681	664	697	670	654	675	1250	1236	1227	1230	1216	1186
	My	-1181	-1176	-1185	-1172	-891	-850	-899	-887	-846	-890	-1556	-1549	-1506	-1549	-1542	-1489
	Mz	-32	135	-21	136	-25	-23	-17	92	94	93	-43	-39	-26	182	187	178
24	Pz		-59071		-58204				-64683	-49835	-66198				-66452	-61787	-62938
	Px		3378		3314				4134	3008	4250				3551	3201	3343
	Py		3897		3848				4515	3378	4643				4242	3888	4028
	Mx		-26688		-26237				-32231	-23609	-33148				-28298	-25624	-26717
	My		28256		27822				33389	24728	34322				30382	27690	28745
	Mz		1195		1236				822	831	849				1621	1626	1615
263	Pz	-10837		-10581		-7784	-7658	-7623				-14518	-14476	-13647			
	Px	35		35		38	29	39				40	37	38			
	Py	32		31		25	23	24				42	42	39			
	Mx	9		11		113	45	124				-48	-70	-44			
	My	69		64		95	65	95				67	58	58			
	Mz	267		267		304	229	314				294	271	284			

ANALYSIS RESULTS - D) Member Forces - Load Combinations

MEMBER		TOTAL UNFACTORED				A - OPERATING						B - STORM					
		CSA		BP		DIAGONAL			BROADSIDE			DIAGONAL			BROADSIDE		
		DIAG.	BROAD.	DIAG.	BROAD.	CSA(1.25)	CSA(0.9)	BP	CSA(1.25)	CSA(0.9)	BP	CSA(1.25)	CSA(0.9)	BP	CSA(1.25)	CSA(0.9)	BP
625	Pz	-18206		-18158		-17027	-14301	-17382				-22145	-21270	-21270			
	Px	115		117		84	82	86				154	151	150			
	Py	-190		-191		-126	-130	-126				-261	-262	-252			
	Mx	1239		1251		892	876	902				1663	1646	1613			
	My	768		780		439	502	439				1089	1120	1068			
	Mz	52		58		47	40	53				65	60	69			
524	Pz		-17355		-17262				-15438	-13345	-15672				-21564	-20879	-20646
	Px		15		15				3	8	2				25	26	24
	Py		-25		-25				-10	-15	-10				-38	-39	-36
	Mx		233		228				186	172	185				301	297	284
	My		393		388				303	285	302				514	509	489
	Mz		32		33				19	21	19				45	46	45
58	Pz	-54634		-52992		-59089	-45824	-59835				-61881	-57710	-57519			
	Px	-376		-360		-398	-312	-399				-430	-405	-395			
	Py	368		363		413	314	423				409	376	387			
	Mx	-4749		-4538		-4180	-3636	-4110				-5924	-5753	-5433			
	My	-3694		-3778		-4064	-3123	-4257				-4144	-3850	-4105			
	Mz	-226		-144		-299	-209	-254				-225	-196	-110			
59	Pz		-62898		-62033				-70089	-53505	-71853				-70076	-64833	-66428
	Px		-314		-305				-388	-281	-397				-328	-294	-305
	Py		410		400				449	346	456				461	429	432
	Mx		-2252		-2264				-2874	-2048	-3000				-2299	-2047	-2236
	My		-2476		-2481				-3288	-2298	-3432				-2457	-2147	-2378
	Mz		439		464				297	304	313				598	601	609
286	Pz	-12295		-12107		-12472	-10012	-12692				-14397	-13621	-13630			
	Px	129		128		102	95	103				167	166	160			
	Py	-62		-63		-34	-40	-34				-90	-90	-87			
	Mx	0		-11		65	24	63				-36	-52	-50			
	My	-810		-807		-692	-612	-701				-1024	-995	-981			
	Mz	-39		-41		-65	-41	-70				-31	-24	-33			
506	Pz		-21213		-21030				-18697	-16249	-18919				-26436	-25693	-25240
	Px		70		68				63	54	63				86	84	81
	Py		117		115				104	90	105				145	141	138
	Mx		187		190				-43	68	-57				351	388	342
	My		-270		-268				16	-115	36				-481	-522	-460
	Mz		9		10				7	7	8				12	11	12

APPENDIX E

TUBULAR MEMBER CALCULATIONS (CSA & BP)

TUBULAR MEMBER CAPACITY — Dec 6/91
CSA S473-M1989 - SECTION 10, MEMBER RESISTANCES — by MG
(for unstiffened members) — FILE: MEMBER.WK1

MEMBER NO: 24

INPUT:

D =	outside diameter	2900	mm
t =	thickness	80	mm
L =	length	24000	mm
K =	effective length factor	1	
Fy =	yield strength	325	MPa
phi =	resistance factor	0.9	
E =	modulus	210000	MPa
Cf =	factored axial load	43980	kN
Mfx =	bending moment, x	25527	kN-m
Mfy =	bending moment, y	25643	kN-m
Mf =	sqrt(Mfx^2 + Mfy^2)	36183	kN-m
P =	UNFACTORED hydrostatic pressure	0.503	MPa
omega =	bending factor, from S16.1 - 13.8.4	1	

OUTPUT:

Cr =	compressive resistance	197767	kN
Mr =	bending resistance	186136	kN-m
Vr =	shear resistance	58465	kN
(Tr =	tension r. - S16.1-13.2	207307	kN, not in S471)
Interactive strength < 1.0 :			
	A) axial & bending	0.36	
	B) bending	0.20	
	C) int. buckling & bending	0.43	

CALCULATIONS:

D/t =	(<= 360)	36	
A =	@PI/4*(D^2-(D-2*T)^2)	708743	mm^2
r =	@SQRT(F6^2+(D-2*T)^2)/4	997	mm
ka =	0.18+109000/(D/t)^3.65	0.40	
km =	0.15+43000/(D/t)^3.65	0.24	
Z =	(D^3-(D-2*t)^3)/6	6.4E+08	mm^3
Ce =	1970000*A/(K*L/r)^2	2411516.	kN, Euler buckling
I =	@PI/64*(D^4-(D-2*T)^4)	7.05E+11	mm^4
Pcr =	440000/(D/t)^3	9.24	MPa

10.5.2.1 FACTORED AXIAL COMPRESSIVE RESISTANCE (Local Buckling)

Fc =		325	MPa
Cr_a = phi*Fc*A		207307	kN

a) Fy	=	325	for D/t < 25000/Fy
b) Fy(.75+6200/(Fy*D/t)) =		414.7844	for D/t < 80000/Fy
c) 66000/(D/t)	=	1820.689	for D/t <= 360

10.5.2.2 FACTORED AXIAL COMPRESSIVE RESISTANCE (Primary & Interactive Local Buckling, S16.1-13.3.1)

Fc =	(from 10.5.2.1)	325	MPa
lambda =	K*L/r*@sqrt(Fc/@PI^2/E)	0.30	
Cr_b =	phi*A*Fc*...	197767	kN
	(S16.1-13.3.1)		

a) phi*A*Fc	=	207307	for lambda <= 0.15
b) phi*A*Fc*(1.035-.202*lambda-.222*lambda^2)	=	197767	for lambda <= 1.0
c) phi*A*Fc*(-0.111+0.636/lambda+0.087/lambda^2)	=	613226	for lambda <= 2.0
d) phi*A*Fc*(0.009+0.877/lambda^2)	=	2004424	for lambda <= 3.6
e) phi*A*Fc/lambda^2	=	2283419	for 3.6 < lambda

Cr_b' =	Cr_b*(1-ka*(P/Pcr)^1.2)	195349	kN

10.5.2.3 BENDING RESISTANCE

Mu =		206818	kN-m	a) FyZ	=	206818	for D/t <= 14200/Fy
				b) FyZ(0.775+3200/(Fy*D/t))	=	216459	for D/t <= 62000/Fy
				c) FyZ(51000/(Fy*D/t))	=	895296	for D/t <= 360
Mr =	phi*Mu	186136	kN-m				
Mr' =	Mr*(1-km*(P/Pcr))	183729	kN-m				

10.5.2.4 TRANSVERSE SHEAR RESISTANCE

Vr =	0.95*phi*@PI*D*t/2*Fy/@sqrt(3)	58465	kN	for D/t <= 360

10.5.2.5 INTERACTION

zeta =	slenderness parameter	0.7		a) 1.0	=	1	for Fy(D/t) > 35000
				b) (1.4-14000/(Fy*D/t)) =		0.2	for Fy(D/t) >= 20000
				c) 0.7	=	0.7	for Fy(D/t) < 20000

A) Cf/Cr_b' + zeta*Mf/Mr' <= 1.0	0.36	*
B) Mf/Mr' <= 1.0	0.20	
C) Cf/Cr_b' + omega*Mf/(Mr'*(1-Cf/Ce)) <= 1.0	0.43	

* : note change from code, using Cr_b' for phi*A*Fc

CLAUSE 5.3.3 - SHELL BUCKLING

v =	poisson's ratio	0.3		
additional forces:				
Vfx =	shear force, x	3334	kN (input)	
Vfy =	shear force,y	3367	kN (input)	
Tf =	torsion	29	kN-M(input)	
theta =		45	deg.	(rads = 0.785398)
cl = cylinder length		24000	mm (input)	
r' =	D/2	1450		
Z' =	cl^2/r'/t*@sqrt(1-v^2)	4737		
stress calculation:				
fa =	-Cf/A	-62.05	MPa	undefined in S473
fb =	-Mf*D/2/I	-74.41	MPa	undefined in S473
fp =	1.2*-P*D/2/t	-10.94	MPa	undefined in S473, factor of 1.2 used for P
fzt =	Tf/(2*@pi*r'^2*t)+Vfx/(@pi*r'*t)*@cos(theta)+Vfy/(@pi*r'*t)*@sin(theta)			
		0.01	MPa	from 10.5.3.2.2
A) for fb:				
fao =		62.1	MPa	
fbo =		74.4	MPa	compression (-), enter 1 1
fpo =		10.9	MPa	

fj =	@sqrt((fa+fb)^2-(fa+fb)*fp+fp^2+3*(fzt)^2)	131.3	MPa

from 10.5.3.5:

Fe =	@pi^2*E/12/(1-v^2)*(t/cl)^2		2.11	
Ka =	0.36/@sqrt(1+r'/t/150)		0.34	
ka =	@sqrt(1+(Ka*Z')^2)		1610.71	
Fea =	Fe*ka		3396.81	
Kb =	0.36/@sqrt(1+r'/t/300)		0.35	
kb =	@sqrt(1+(Kb*Z')^2)		1655.96	
Feb =	Fe*kb		3492.23	
for cl/r' =	16.6	>3.85*@sqrt(r'/t)= 16.4		
	Fev =	0.225*E*(t/r')^(3/2)	612.33	
else				
	ks =	5.34*@sqrt(1+.009*Z'^(3/2))	289.30	
	Fev =	Fe*ks	610.10	
Fev =	612.3			
for cl/r'=	16.6	>2.25*@sqrt(r'/t)= 9.6		
	Fep =	0.25*E*(t/r')^2	159.8	
else				
	kp =	4*@sqrt(1+0.025*Z')	43.7	
	Fep =	Fe*kp	92.2	
Fep =	159.8			
lamb^2 =	Fy/fj*(fao/Fea+fbo/Feb+fpo/Fep+fzt/Fev)		0.27	MPa
Fcr =	Fy/@sqrt(1+(lamb^2)^2)		314.0	MPa
check fj <= phi_c*Fcr				
phi_c =			0.9	
interaction:		fj/(phi_c*Fcr)	0.46	

TUBULAR MEMBER CAPACITY

CSA S473-M1989 - SECTION 10, MEMBER RESISTANCES

(for unstiffened members)

Dec 6/91

by MG

FILE: MEMBER.WK1

MEMBER NO: 39

INPUT:				OUTPUT:			
D =	outside diameter	4000	mm	Cr =	compressive resistance	182057	kN
t =	thickness	50	mm	Mr =	bending resistance	213103	kN-m
L =	length	24000	mm	Vr =	shear resistance	52727	kN
K =	effective length factor	1		(Tr =	tension r. - S16.1-13.2	189862	kN, not in S471)
Fy =	yield strength	340	MPa	Interactive strength < 1.0 :			
phi =	resistance factor	0.9			A) axial & bending	0.70	
E =	modulus	210000	MPa		B) bending	0.17	
Cf =	factored axial load	89978	kN		C) int. buckling & bending	0.72	
Mfx =	bending moment, x	13884	kN-m				
Mfy =	bending moment, y	29410	kN-m				
Mf =	sqrt(Mfx^2 + Mfy^2)	32523	kN-m				
P =	UNFACTORED hydrostatic pressure	0.503	MPa				
omega =	bending factor, from S16.1 - 13.8.4	1					

CALCULATIONS:

D/t =	(<= 360)	80		Z =	(D^3-(D-2*t)^3)/6	7.8E+08	mm^3
A =	@PI/4*(D^2-(D-2*T)^2)	620465	mm^2	Ce =	1970000*A/(K*L/r)^2	4139372.	kN, Euler buckling
r =	@SQRT(F6^2+(D-2*T)^2)/4	1397	mm	I =	@PI/64*(D^4-(D-2*T)^4)	1.21E+12	mm^4
ka =	0.18+109000/(D/t)^3.65	0.19		Pcr =	440000/(D/t)^3	0.86	MPa
km =	0.15+43000/(D/t)^3.65	0.15					

10.5.2.1 FACTORED AXIAL COMPRESSIVE RESISTANCE (Local Buckling)

Fc =	332.5	MPa	a) Fy	=	340	for D/t < 25000/Fy
			b) Fy(.75+6200/(Fy*D/t)) =		332.5	for D/t < 80000/Fy
			c) 66000/(D/t)	=	825	for D/t <= 360
Cr_a = phi*Fc*A	185674	kN				

10.5.2.2 FACTORED AXIAL COMPRESSIVE RESISTANCE (Primary & Interactive Local Buckling, S16.1-13.3.1)

Fc =	(from 10.5.2.1)	332.5	MPa				
lambda =	K*L/r*@sqrt(Fc/@PI^2/E)	0.22					
Cr_b =	phi*A*Fc*...	182057	kN				
	(S16.1-13.3.1)			a) phi*A*Fc	=	185674	for lambda <= 0.15
				b) phi*A*Fc*(1.035-.202*lambda-.222*lambda^2)	=	182057	for lambda <= 1.0
				c) phi*A*Fc*(-0.111+0.636/lambda+0.087/lambda^2)	=	862946	for lambda <= 2.0
				d) phi*A*Fc*(0.009+0.877/lambda^2)	=	3439066	for lambda <= 3.6
				e) phi*A*Fc/lambda^2	=	3919492	for 3.6 < lambda
Cr_b' =	Cr_b*(1-ka*(P/Pcr)^1.2)	163644	kN				

10.5.2.3 BENDING RESISTANCE

Mu =		236781	kN-m	a) FyZ	=	265257	for D/t <= 14200/Fy
				b) FyZ(0.775+3200/(Fy*D/t))	=	236781	for D/t <= 62000/Fy
				c) FyZ(51000/(Fy*D/t))	=	497356	for D/t <= 360
Mr =	phi*Mu	213103	kN-m				
Mr' =	Mr*(1-km*(P/Pcr))	193786	kN-m				

10.5.2.4 TRANSVERSE SHEAR RESISTANCE

Vr =	0.95*phi*@PI*D*t/2*Fy/@sqrt(3)	52727	kN	for D/t <= 360

10.5.2.5 INTERACTION

zeta =	slenderness parameter	0.885294		a) 1.0	=	1	for Fy(D/t) > 35000
				b) (1.4-14000/(Fy*D/t)) =		0.9	for Fy(D/t) >= 20000
				c) 0.7	=	0.7	for Fy(D/t) < 20000

A) Cf/Cr_b' + zeta*Mf/Mr' <= 1.0	0.70	*
B) Mf/Mr' <= 1.0	0.17	
C) Cf/Cr_b' + omega*Mf/(Mr'*(1-Cf/Ce)) <= 1.0	0.72	

* : note change from code, using Cr_b' for phi*A*Fc

CLAUSE 5.3.3 - SHELL BUCKLING

v =	poisson's ratio	0.3			
additional forces:					
Vfx =	shear force, x	2613	kN		
Vfy =	shear force,y	3804	kN		
Tf =	torsion	2025	kN		
theta =		45	deg.	(rads = 0.785398)	
cl = cylinder length		12000	mm (input)		
r' =	D/2	2000			
Z' =	cl^2/r'/t*@sqrt(1-v^2)	1374			
stress calculation:					
fa =	-Cf/A	-145.02	MPa	undefined in S473	
fb =	-Mf*D/2/I	-53.74	MPa	undefined in S473	
fp =	1.2*-P*D/2/t	-24.14	MPa	undefined in S473, factor of 1.2 used for P	
fzt =	Tf/(2*@pi*r'^2*t)+Vfx/(@pi*r'*t)*@cos(theta)+Vfy/(@pi*r'*t)*@sin(theta)				
		0.01	MPa	from 10.5.3.2.2	
A) for fb:					
fao =		145.0	MPa		
fbo =		53.7	MPa	compression (-), enter 1	1
fpo =		24.1	MPa		

fj = @sqrt((fa+fb)^2-(fa+fb)*fp+fp^2+3*(fzt)^2) 187.9 MPa

from 10.5.3.5:					
Fe =	@pi^2*E/12/(1-v^2)*(t/cl)^2			3.30	
Ka =	0.36/@sqrt(1+r'/t/150)			0.32	
ka =	@sqrt(1+(Ka*Z')^2)			439.40	
Fea =	Fe*ka			1447.87	
Kb =	0.36/@sqrt(1+r'/t/300)			0.34	
kb =	@sqrt(1+(Kb*Z')^2)			464.52	
Feb =	Fe*kb			1530.67	
for cl/r' =	6.0	>3.85*@sqrt(r'/t)=	24.3		
	Fev =	0.225*E*(t/r')^(3/2)		186.77	
else					
	ks =	5.34*@sqrt(1+.009*Z'^(3/2))		114.43	
	Fev =	Fe*ks		377.07	
Fev =	377.1				
for cl/r'=	6.0	>2.25*@sqrt(r'/t)=	14.2		
	Fep =	0.25*E*(t/r')^2		32.8	
else					
	kp =	4*@sqrt(1+0.025*Z')		23.8	
	Fep =	Fe*kp		78.4	
Fep =	78.4				
lamb^2 =	Fy/fj*(fao/Fea+fbo/Feb+fpo/Fep+fzt/Fev)			0.80	MPa
Fcr =	Fy/@sqrt(1+(lamb^2)^2)			265.2	MPa
check fj <= phi_c*Fcr					
phi_c =				0.9	
interaction:		fj/(phi_c*Fcr)		0.79	

TUBULAR MEMBER CAPACITY
CSA S473-M1989 - SECTION 10, MEMBER RESISTANCES
(for unstiffened members)

Dec 6/91
by MG
FILE: MEMBER.WK1

MEMBER NO: 58

INPUT:

D =	outside diameter	3000	mm
t =	thickness	45	mm
L =	length	24000	mm
K =	effective length factor	1	
Fy =	yield strength	340	MPa
phi =	resistance factor	0.9	
E =	modulus	210000	MPa
Cf =	factored axial load	61881	kN
Mfx =	bending moment, x	5924	kN-m
Mfy =	bending moment, y	4144	kN-m
Mf =	sqrt(Mfx^2 + Mfy^2)	7230	kN-m
P =	UNFACTORED hydrostatic pressure	0.251	MPa
omega =	bending factor, from S16.1 - 13.8.4	1	

OUTPUT:

Cr =	compressive resistance	122254	kN
Mr =	bending resistance	110170	kN-m
Vr =	shear resistance	35591	kN
(Tr =	tension r. - S16.1-13.2	127833	kN, not in S471)

Interactive strength < 1.0 :

A) axial & bending	0.57
B) bending	0.07
C) int. buckling & bending	0.59

CALCULATIONS:

D/t =	(<= 360)	67	
A =	@PI/4*(D^2-(D-2*T)^2)	417753	mm^2
r =	@SQRT(F6^2+(D-2*T)^2)/4	1045	mm
ka =	0.18+109000/(D/t)^3.65	0.20	
km =	0.15+43000/(D/t)^3.65	0.16	

Z =	(D^3-(D-2*t)^3)/6	3.9E+08	mm^3
Ce =	1970000*A/(K*L/r)^2	1559873.	kN, Euler buckling
I =	@PI/64*(D^4-(D-2*T)^4)	4.56E+11	mm^4
Pcr =	440000/(D/t)^3	1.48	MPa

10.5.2.1 FACTORED AXIAL COMPRESSIVE RESISTANCE (Local Buckling)

Fc = 340 MPa

a) Fy	=	340	for D/t < 25000/Fy
b) Fy(.75+6200/(Fy*D/t)) =		348	for D/t < 80000/Fy
c) 66000/(D/t)	=	990	for D/t <= 360

Cr_a = phi*Fc*A 127833 kN

10.5.2.2 FACTORED AXIAL COMPRESSIVE RESISTANCE (Primary & Interactive Local Buckling, S16.1-13.3.1)

Fc =	(from 10.5.2.1)	340	MPa
lambda =	K*L/r*@sqrt(Fc/@PI^2/E)	0.29	
Cr_b =	phi*A*Fc*...	122254	kN
	(S16.1-13.3.1)		

a) phi*A*Fc	=	127833	for lambda <= 0.15
b) phi*A*Fc*(1.035-.202*lambda-.222*lambda^2)	=	122254	for lambda <= 1.0
c) phi*A*Fc*(-0.111+0.636/lambda+0.087/lambda^2)	=	390668	for lambda <= 2.0
d) phi*A*Fc*(0.009+0.877/lambda^2)	=	1296492	for lambda <= 3.6
e) phi*A*Fc/lambda^2	=	1477014	for 3.6 < lambda

Cr_b' = Cr_b*(1-ka*(P/Pcr)^1.2) 119300 kN

10.5.2.3 BENDING RESISTANCE

Mu =		122411	kN-m	a) FyZ	=	133610	for D/t <= 14200/Fy
				b) FyZ(0.775+3200/(Fy*D/t))	=	122411	for D/t <= 62000/Fy
				c) FyZ(51000/(Fy*D/t))	=	300623	for D/t <= 360
Mr =	phi*Mu	110170	kN-m				
Mr' =	Mr*(1-km*(P/Pcr))	107200	kN-m				

10.5.2.4 TRANSVERSE SHEAR RESISTANCE

Vr =	0.95*phi*@PI*D*t/2*Fy/@sqrt(3)	35591	kN	for D/t <= 360

10.5.2.5 INTERACTION

zeta =	slenderness parameter	0.782352		a) 1.0	=	1	for Fy(D/t) > 35000
				b) (1.4-14000/(Fy*D/t))	=	0.8	for Fy(D/t) >= 20000
				c) 0.7	=	0.7	for Fy(D/t) < 20000

A) Cf/Cr_b' + zeta*Mf/Mr' <= 1.0	0.57	*
B) Mf/Mr' <= 1.0	0.07	
C) Cf/Cr_b' + omega*Mf/(Mr'*(1-Cf/Ce)) <= 1.0	0.59	

* : note change from code, using Cr_b' for phi*A*Fc

CLAUSE 5.3.3 - SHELL BUCKLING

v =	poisson's ratio	0.3			
additional forces:					
Vfx =	shear force, x	430	kN (input)		
Vfy =	shear force,y	409	kN (input)		
Tf =	torsion	225	kN-M(input)		
theta =		45	deg.	(rads = 0.785398)	
cl = cylinder length		24000	mm (input)		
r' =	D/2	1500			
Z' =	cl^2/r'/t*@sqrt(1-v^2)	8140			
stress calculation:					
fa =	-Cf/A	-148.13	MPa	undefined in S473	
fb =	-Mf*D/2/I	-23.78	MPa	undefined in S473	
fp =	1.2*-P*D/2/t	-10.04	MPa	undefined in S473, factor of 1.2 used for P	
fzt =	Tf/(2*@pi*r'^2*t)+Vfx/(@pi*r'*t)*@cos(theta)+Vfy/(@pi*r'*t)*@sin(theta)				
		0.00	MPa	from 10.5.3.2.2	
A) for fb:					
fao =		148.1	MPa		
fbo =		23.8	MPa	compression (-), enter 1	1
fpo =		10.0	MPa		

fj =	@sqrt((fa+fb)^2-(fa+fb)*fp+fp^2+3*(fzt)^2)	167.1	MPa

from 10.5.3.5:

Fe =	@pi^2*E/12/(1-v^2)*(t/cl)^2		0.67	
Ka =	0.36/@sqrt(1+r'/t/150)		0.33	
ka =	@sqrt(1+(Ka*Z')^2)		2650.74	
Fea =	Fe*ka		1768.75	
Kb =	0.36/@sqrt(1+r'/t/300)		0.34	
kb =	@sqrt(1+(Kb*Z')^2)		2780.12	
Feb =	Fe*kb		1855.08	
for cl/r' =	16.0 >3.85*@sqrt(r'/t)=	22.2		
	Fev = 0.225*E*(t/r')^(3/2)		245.52	
else				
	ks = 5.34*@sqrt(1+.009*Z'^(3/2))		434.19	
	Fev = Fe*ks		289.72	
Fev =	289.7			
for cl/r'=	16.0 >2.25*@sqrt(r'/t)=	13.0		
	Fep = 0.25*E*(t/r')^2		47.3	
else				
	kp = 4*@sqrt(1+0.025*Z')		57.2	
	Fep = Fe*kp		38.2	
Fep =	47.3			
lamb^2 =	Fy/fj*(fao/Fea+fbo/Feb+fpo/Fep+fzt/Fev)		0.63	MPa
Fcr =	Fy/@sqrt(1+(lamb^2)^2)		287.8	MPa
check fj <= phi_c*Fcr				
phi_c =			0.9	
interaction:	fj/(phi_c*Fcr)		0.65	

TUBULAR MEMBER CAPACITY
CSA S473-M1989 - SECTION 10, MEMBER RESISTANCES
(for unstiffened members)

Dec 6/91
by MG
FILE: MEMBER.WK1

MEMBER NO: 59

INPUT:

D =	outside diameter	2500	mm
t =	thickness	50	mm
L =	length	25500	mm
K =	effective length factor	1	
Fy =	yield strength	340	MPa
phi =	resistance factor	0.9	
E =	modulus	210000	MPa
Cf =	factored axial load	52781	kN
Mfx =	bending moment, x	2443	kN-m
Mfy =	bending moment, y	2929	kN-m
Mf =	sqrt(Mfx^2 + Mfy^2)	3814	kN-m
P =	UNFACTORED hydrostatic pressure	0.251	MPa
omega =	bending factor, from S16.1 - 13.8.4	1	

OUTPUT:

Cr =	compressive resistance	109202	kN
Mr =	bending resistance	88474	kN-m
Vr =	shear resistance	32954	kN
(Tr =	tension r. - S16.1-13.2	117763	kN, not in S471)
Interactive strength < 1.0 :			
	A) axial & bending	0.52	
	B) bending	0.04	
	C) int. buckling & bending	0.53	

CALCULATIONS:

D/t =	(<= 360)	50	
A =	@PI/4*(D^2-(D-2*T)^2)	384845	mm^2
r =	@SQRT(F6^2+(D-2*T)^2)/4	866	mm
ka =	0.18+109000/(D/t)^3.65	0.25	
km =	0.15+43000/(D/t)^3.65	0.18	
Z =	(D^3-(D-2*t)^3)/6	3.0E+08	mm^3
Ce =	1970000*A/(K*L/r)^2	875174.8	kN, Euler buckling
I =	@PI/64*(D^4-(D-2*T)^4)	2.89E+11	mm^4
Pcr =	440000/(D/t)^3	3.52	MPa

10.5.2.1 FACTORED AXIAL COMPRESSIVE RESISTANCE (Local Buckling)

Fc = 340 MPa

a) Fy	=	340	for D/t < 25000/Fy
b) Fy(.75+6200/(Fy*D/t)) =		379	for D/t < 80000/Fy
c) 66000/(D/t)	=	1320	for D/t <= 360

Cr_a = phi*Fc*A 117763 kN

10.5.2.2 FACTORED AXIAL COMPRESSIVE RESISTANCE (Primary & Interactive Local Buckling, S16.1-13.3.1)

Fc =	(from 10.5.2.1)	340	MPa
lambda =	K*L/r*@sqrt(Fc/@PI^2/E)	0.38	
Cr_b =	phi*A*Fc*...	109202	kN
	(S16.1-13.3.1)		

a) phi*A*Fc	=	117763	for lambda <= 0.15
b) phi*A*Fc*(1.035-.202*lambda-.222*lambda^2)	=	109202	for lambda <= 1.0
c) phi*A*Fc*(-0.111+0.636/lambda+0.087/lambda^2)	=	257705	for lambda <= 2.0
d) phi*A*Fc*(0.009+0.877/lambda^2)	=	727818	for lambda <= 3.6
e) phi*A*Fc/lambda^2	=	828686	for 3.6 < lambda

Cr_b' = Cr_b*(1-ka*(P/Pcr)^1.2) 108060 kN

10.5.2.3 BENDING RESISTANCE

Mu =		98305	kN-m	a) FyZ	=	102057	for D/t <= 14200/Fy
				b) FyZ(0.775+3200/(Fy*D/t))	=	98305	for D/t <= 62000/Fy
				c) FyZ(51000/(Fy*D/t))	=	306170	for D/t <= 360
Mr =	phi*Mu	88474	kN-m				
Mr' =	Mr*(1-km*(P/Pcr))	87357	kN-m				

10.5.2.4 TRANSVERSE SHEAR RESISTANCE

Vr =	0.95*phi*@PI*D*t/2*Fy/@sqrt(3)	32954	kN	for D/t <= 360

10.5.2.5 INTERACTION

zeta =	slenderness parameter	0.7	a) 1.0	=	1	for Fy(D/t) > 35000
			b) (1.4-14000/(Fy*D/t))	=	0.6	for Fy(D/t) >= 20000
			c) 0.7	=	0.7	for Fy(D/t) < 20000

A) Cf/Cr_b' + zeta*Mf/Mr' <= 1.0	0.52	*
B) Mf/Mr' <= 1.0	0.04	
C) Cf/Cr_b' + omega*Mf/(Mr'*(1-Cf/Ce)) <= 1.0	0.53	

* : note change from code, using Cr_b' for phi*A*Fc

CLAUSE 5.3.3 - SHELL BUCKLING

v =	poisson's ratio	0.3		
additional forces:				
Vfx =	shear force, x	317	kN (input)	
Vfy =	shear force,y	305	kN (input)	
Tf =	torsion	20	kN-M(input)	
theta =		45	deg.	(rads = 0.785398)
cl = cylinder length		25500	mm (input)	
r' =	D/2	1250		
Z' =	cl^2/r'/t*@sqrt(1-v^2)	9925		
stress calculation:				
fa =	-Cf/A	-137.15	MPa	undefined in S473
fb =	-Mf*D/2/I	-16.50	MPa	undefined in S473
fp =	1.2*-P*D/2/t	-7.53	MPa	undefined in S473, factor of 1.2 used for P
fzt =	Tf/(2*@pi*r'^2*t)+Vfx/(@pi*r'*t)*@cos(theta)+Vfy/(@pi*r'*t)*@sin(theta)			
		0.00	MPa	from 10.5.3.2.2
A) for fb:				
fao =		137.1	MPa	
fbo =		16.5	MPa	compression (-), enter 1 1
fpo =		7.5	MPa	

fj =	@sqrt((fa+fb)^2-(fa+fb)*fp+fp^2+3*(fzt)^2)	150.0	MPa

from 10.5.3.5:					
Fe =	@pi^2*E/12/(1-v^2)*(t/cl)^2			0.73	
Ka =	0.36/@sqrt(1+r'/t/150)			0.33	
ka =	@sqrt(1+(Ka*Z')^2)			3307.88	
Fea =	Fe*ka			2413.83	
Kb =	0.36/@sqrt(1+r'/t/300)			0.35	
kb =	@sqrt(1+(Kb*Z')^2)			3432.75	
Feb =	Fe*kb			2504.95	
for cl/r' =	20.4	>3.85*@sqrt(r'/t)=	19.3		
	Fev =	0.225*E*(t/r')^(3/2)		378.00	
else					
	ks =	5.34*@sqrt(1+.009*Z'^(3/2))		503.76	
	Fev =	Fe*ks		367.61	
Fev =	378.0				
for cl/r'=	20.4	>2.25*@sqrt(r'/t)=	11.3		
	Fep =	0.25*E*(t/r')^2		84.0	
else					
	kp =	4*@sqrt(1+0.025*Z')		63.1	
	Fep =	Fe*kp		46.1	
Fep =	84.0				
lamb^2 =	Fy/fj*(fao/Fea+fbo/Feb+fpo/Fep+fzt/Fev)			0.35	MPa
Fcr =	Fy/@sqrt(1+(lamb^2)^2)			321.2	MPa
check fj <= phi_c*Fcr					
phi_c =				0.9	
interaction:		fj/(phi_c*Fcr)		0.52	

TUBULAR MEMBER DESIGN USING BP DESIGN METHOD NOV/91

MEMBER NO: = 24 BY:GK

INPUT:

D =	DIAMETER	=	2.90E+00	m
t =	THICKNESS	=	8.00E-02	m
L =	LENGTH	=	2.40E+01	m
k =	EFF.LENGTH RATI	=	1.00E+00	
Fy =	YIELD STRENGTH	=	3.25E+02	MPa
phi =	RESIST. FACTOR	=	9.00E-01	
E =	MODULUS	=	2.10E+05	MPa
Cf =	FACT.AXIAL FORC	=	4.24E+04	kN
Py =	FACT. SHEAR-Y	=	3.22E+03	kN
Pz =	FACT. SHEAR-Z	=	3.25E+03	kN
Mfy =	FACT. BEND-Y	=	2.46E+04	kN-M
Mfz =	FACT. BEND-Z	=	2.47E+04	kN-M
T =	FACT.TORSION	=	2.70E+01	kN-M
UMfy =	UNFACT.BEND-Y	=	2.62E+04	kN-M
UMfz =	UNFACT.BEND-Z	=	2.78E+04	kN-M
Dpth =	DEPTH OF MEMB LOCATION		5.00E+01	M
Water=	DENS OF WATER	=	1.03E+03	kg

COMPUTATION:

RADIUS (R)		=	1.45E+00	M
INNER DIAMETER (DI)		=	2.74E+00	M
X-SECTION AREA (A)		=	7.09E-01	M2
INERTIA (I)		=	7.05E-01	M4
kL/r (LAMDA)		=	2.41E+01	
P =	HYDRO. PRESS.	=	5.03E-01	MPa

MEMBER STRESSES:

Sa (AXIAL STRESS)	=	5.99E+04	kPa
Sby (BENDING STRESS)	=	5.07E+04	kPa
Sbz (BENDING STRESS)	=	5.09E+04	kPa
Sb <SQRT(Sby^2+Sbz^2)>	=	7.18E+04	kPa
Ty (SHEAR STRESS)	=	8.83E+03	kPa
Tz (SHEAR STRESS)	=	8.92E+03	kPa
Tyz (TORSION STRESS)	=	2.55E+01	kPa
Sh (HOOP STRESS)	=	9.11E+03	kPa
USby (UNFACT BEND STRESS	=	5.40E+04	kPa
USbz (UNFACT BEND STRESS	=	5.72E+04	kPa

CHARACTERISTIC COMPRESSIVE RESISTANCE:

Eb (ELASTIC BUCK RESIST)	=	3.58E+03	MPa
ALPHA1	=	2.00E-03	(INPUT)
ALPHA2	=	4.80E+02	(INPUT)
APLHA	=	2.45E-03	
Bd	=	7.7E+00	
BA	=	3.96E+03	MPa

BUCKLING RESIST:

LD1 (REDUCED SLENDER)	=	2.94E-01	
Bkc or Bkt(BUCK RESIST)	=	3.03E+02	MPa

OVERALL STRESS UTILSN:

ULS:
====

H	=	1.00E+00			
Gm (MAT'L FACTOR)	=	1.15E+00	(INPUT)		
Sp1	=	1.32E+05	kPa	USE:	
Sp2	=	-1.2E+04	kPa	1.32E+05	kPa

UNITY CHECK = 5.01E-01 OK
========

VON MISES STRESSES:

VMb (DESIGN BEND STRESS)	=	6.53E+04	kPa	
UVMb (UNFACT. BEND STRE	=	7.86E+04	kPa	
VMx1 (BEND TENSILE AXIAL	=	1.39E+05	kPa	
VMx2 (BEND COMPRESS AXI	=	-1.9E+04	kPa	
BENDING TENSILE:				
VMj1	=	1.34E+05	kPa	MAX.CHECK:
BENDING COMPRESSIVE:				1.34E+05
				BTW VMj1&VMj2
VMj2	=	2.46E+04	kPa	5.99E+04
NO BENDING:				BTW VMj2&VMj3
				1.34E+05
VMj3	=	5.99E+04	kPa	BTW VMb&VMj1-3
VMmax (MAX. V-M STRESS)	=	1.34E+05	kPa	

VON MISES STRESS CHECK:

UNITY CHECK = 4.75E-01 OK
========

SHELL BUCKLING RESISTANCE:

LL (CYCL LGTH OR SPC BETW RINGS)		1.20E+01	M (INPUT)
Z	=	1.18E+03	
SHB	=	8.44E+00	

COMPRESSION:

Kac	=	3.40E-01	
Sea	=	3.40E+03	MPa

BENDING:

Kab	=	3.50E-01	
Seb	=	3.49E+03	MPa

TORSION OR SHEAR:

CHECK MAX

Set1	=	8.64E+02	MPa	
LONG SHELL SUBJECT TO SH				8.64E+02
Set2	=	0.00E+00	MPa	

SHELL SUBJ TO LATR PRESS:

Sep1	=	1.87E+02	MPa	
LONG SHELL SUBJ LATR PRE				1.87E+02
Sep2	=	0.00E+00	MPa	

SHELL BUCKLING UTILSN:

				INPUT:
Sao (INPUT 1 IF COMPRESS)	=	5.99E+04	kPa	1
Sbo (INPUT 1 IF COMPRESS)	=	7.18E+04	kPa	1
Spo (INPUT 1 IF COMPRESS)	=	9.11E+03	kPa	1
Td	=	1.25E+04	kPa	
LD2 (REDUCED SLENDER)	=	2.35E-01		
Sek (CHRC. BUCKLING RESIS	=	3.01E+02	MPa	

INTERACTN SHELL/COLUMN

CHECK FOR LONG CYCLIND = YES

Mu	=	1.67E-02	
Bmp (MEMB MID PT)	=	1.02E+00	
Bep (MEMB END PT)	=	0.00E+00	(INPUT k, p=infinity)
BDD	=	1.02E+00	
LD3	=	2.94E-01	
dSbd (INCR COMPRESS)	=	2.62E+00	MPa
LDnew (NEW REDUCED SLEN	=	2.34E-01	

STABILITY REQUIREMENT:

H1	=	1.00E+00		
Gm1	=	1.15E+00	(INPUT)	
SI	=	9.00E-01	(INPUT)	
UNITY CHECK	=	5.70E-01	OK	

TUBULAR BEAM COLUMN:

CHECK D/t RATIO

D/t	=	3.63E+01		CHECK GLOBAL/LOCAL INTERACTION:
0.5*SQRT(E/FY)	=	1.27E+01		INTERACTION OCCURS
0.1*E/FY	=	6.46E+01		N.A.
YES-INTERACTION INPUT 1	=	1.00E+00	(INPUT)	(IF NOT 0)
SBR (BUCKLING RESIST)	=	3.01E+02	MPa	(SAME AS Sek)
MUo	=	1.86E-02		
Bphi	=	1.00E+00	(INPUT FROM DNV TABLE C1.3)	
Nu	=	1.13E+00	(INPUT FROM DNV TABLE C1.3)	
Bdb	=	1.02E+00		
SaC	=	6.65E+04	kPa	
a,b or c factor (FACT)	=	9.90E-01	(INPUT FROM DNV FIGURE C1.1)	
SSby	=	6.27E-01		
UNITY CHECK	=	5.38E-01	OK	

TUBULAR MEMBER DESIGN USING BP DESIGN METHOD

MEMBER NO: = 39

INPUT:

D =	DIAMETER	=	4.00E+00	m
t =	THICKNESS	=	5.00E-02	m
L =	LENGTH	=	2.40E+01	m
k =	EFF.LENGTH RATI	=	1.00E+00	
Fy =	YIELD STRENGTH	=	3.40E+02	MPa
phi =	RESIST. FACTOR	=	9.00E-01	
E =	MODULUS	=	2.10E+05	MPa
Cf =	FACT.AXIAL FORC	=	8.67E+04	kN
Py =	FACT. SHEAR-Y	=	2.52E+03	kN
Pz =	FACT. SHEAR-Z	=	3.67E+03	kN
Mfy =	FACT. BEND-Y	=	1.34E+04	kN-M
Mfz =	FACT. BEND-Z	=	2.84E+04	kN-M
T =	FACT.TORSION	=	1.95E+03	kN-M
UMfy =	UNFACT.BEND-Y	=	1.13E+04	kN-M
UMfz =	UNFACT.BEND-Z	=	2.60E+04	kN-M
Dpth =	DEPTH OF MEMB LOCATION		5.00E+01	M
Water=	DENSITY OF WATE	=	1.03E+03	kg

COMPUTATION:

RADIUS (R)		=	2.00E+00	M
INNER DIAMETER (DI)		=	3.90E+00	M
X-SECTION AREA (A)		=	6.20E-01	M2
INERTIA (I)		=	1.21E+00	M4
kL/r (LAMDA)		=	1.72E+01	
P =	HYDRO. PRESS.	=	5.03E-01	MPa

MEMBER STRESSES:

Sa (AXIAL STRESS)	=	1.40E+05	kPa
Sby (BENDING STRESS)	=	2.21E+04	kPa
Sbz (BENDING STRESS)	=	4.69E+04	kPa
Sb <SQRT(Sby^2+Sbz^2)>	=	5.18E+04	kPa
Ty (SHEAR STRESS)	=	8.02E+03	kPa
Tz (SHEAR STRESS)	=	1.17E+04	kPa
Tyz (TORSION STRESS)	=	1.55E+03	kPa
Sh (HOOP STRESS)	=	2.01E+04	kPa
USby (UNFACT BEND STRESS	=	1.87E+04	kPa
USbz (UNFACT BEND STRESS	=	4.30E+04	kPa

CHARACTERISTIC COMPRESSIVE RESISTANCE:

Eb (ELASTIC BUCK RESIST)	=	7.02E+03	MPa
ALPHA1	=	2.00E-03	(INPUT)
ALPHA2	=	4.80E+02	(INPUT)
APLHA	=	2.51E-03	
Bd	=	1.2E+00	
BA	=	7.36E+03	MPa

BUCKLING RESIST:

LD1 (REDUCED SLENDER)	=	2.15E-01	
Bkc or Bkt(BUCK RESIST)	=	3.22E+02	MPa

OVERALL STRESS UTILSN:

ULS:

H	=	1.00E+00			
Gm (MAT'L FACTOR)	=	1.15E+00	(INPUT)		
Sp1	=	1.93E+05	kPa	USE:	
Sp2	=	8.64E+04	kPa	1.93E+05	kPa

UNITY CHECK	=	6.90E-01	OK

VON MISES STRESSES:

VMb (DESIGN BEND STRESS)	=	4.71E+04	kPa	
UVMb (UNFACT. BEND STRE	=	4.69E+04	kPa	
VMx1 (BEND TENSILE AXIAL	=	1.87E+05	kPa	
VMx2 (BEND COMPRESS AXI	=	9.29E+04	kPa	
BENDING TENSILE:				
VMj1	=	1.77E+05	kPa	MAX.CHECK:
BENDING COMPRESSIVE:				1.77E+05
				BTW VMj1&VMj2
VMj2	=	8.47E+04	kPa	1.33E+05
NO BENDING:				BTW VMj2&VMj3
				1.77E+05
VMj3	=	1.33E+05	kPa	BTW VMb&VMj1-3
VMmax (MAX. V-M STRESS)	=	1.77E+05	kPa	

VON MISES STRESS CHECK:

UNITY CHECK	=	6.00E-01	OK

SHELL BUCKLING RESISTANCE:

LL (CYCL LGTH OR SPC BETW RINGS)		1.20E+01	M (INPUT)
Z	=	1.37E+03	
SHB	=	3.30E+00	
COMPRESSION:			
Kac	=	3.20E-01	
Sea	=	1.45E+03	MPa
BENDING:			
Kab	=	3.38E-01	
Seb	=	1.53E+03	MPa

				CHECK MAX
TORSION OR SHEAR:				
Set1	=	3.77E+02	MPa	
LONG SHELL SUBJECT TO SH				3.77E+02
Set2	=	0.00E+00	MPa	
SHELL SUBJ TO LATR PRESS:				
Sep1	=	7.84E+01	MPa	
LONG SHELL SUBJ LATR PRE				7.84E+01
Sep2	=	0.00E+00	MPa	

SHELL BUCKLING UTILSN:				INPUT:
Sao (INPUT 1 IF COMPRESS)	=	1.40E+05	kPa	1
Sbo (INPUT 1 IF COMPRESS)	=	5.18E+04	kPa	1
Spo (INPUT 1 IF COMPRESS)	=	2.01E+04	kPa	1
Td	=	1.42E+04	kPa	
LD2 (REDUCED SLENDER)	=	7.75E-01		
Sek (CHRC. BUCKLING RESIS	=	2.55E+02	MPa	

INTERACTN SHELL/COLUMN

CHECK FOR LONG CYCLIND	=	YES	
Mu	=	1.99E-02	
Bmp (MEMB MID PT)	=	1.02E+00	
Bep (MEMB END PT)	=	0.00E+00	(INPUT k, p=infinity)
BDD	=	1.02E+00	
LD3	=	2.15E-01	
dSbd (INCR COMPRESS)	=	1.69E+00	MPa
LDnew (NEW REDUCED SLEN	=	7.73E-01	

STABILITY REQUIREMENT:

H1	=	1.00E+00		
Gm1	=	1.15E+00	(INPUT)	
SI	=	9.00E-01	(INPUT)	
UNITY CHECK	=	8.88E-01	OK	

TUBULAR BEAM COLUMN:

CHECK D/t RATIO				
D/t	=	8.00E+01		CHECK GLOBAL/LOCAL INTERACTION:
0.5*SQRT(E/FY)	=	1.24E+01		INTERACTION OCCURS
0.1*E/FY	=	6.18E+01		INTERACTION OCCURS
YES-INTERACTION INPUT 1	=	1.00E+00	(INPUT)	(IF NOT 0)
SBR (BUCKLING RESIST)	=	2.55E+02	MPa	(SAME AS Sek)
MUo	=	2.21E-02		
Bphi	=	1.00E+00	(INPUT FROM DNV TABLE C1.3)	
Nu	=	1.13E+00	(INPUT FROM DNV TABLE C1.3)	
Bdb	=	1.03E+00		
SaC	=	1.55E+05	kPa	
a,b or c factor (FACT)	=	9.90E-01	(INPUT FROM DNV FIGURE C1.1)	
SSby	=	1.51E+00		
UNITY CHECK	=	9.46E-01	OK	

TUBULAR MEMBER DESIGN USING BP DESIGN METHOD

MEMBER NO:		=	58	
INPUT:				
D =	DIAMETER	=	3.00E+00	m
t =	THICKNESS	=	4.50E-02	m
L =	LENGTH	=	2.40E+01	m
k =	EFF.LENGTH RATI	=	1.00E+00	
Fy =	YIELD STRENGTH	=	3.40E+02	MPa
phi =	RESIST. FACTOR	=	9.00E-01	
E =	MODULUS	=	2.10E+05	MPa
Cf =	FACT.AXIAL FORC	=	5.75E+04	kN
Py =	FACT. SHEAR-Y	=	3.95E+02	kN
Pz =	FACT. SHEAR-Z	=	3.87E+02	kN
Mfy =	FACT. BEND-Y	=	5.43E+03	kN-M
Mfz =	FACT. BEND-Z	=	4.11E+03	kN-M
T =	FACT.TORSION	=	1.10E+02	kN-M
UMfy =	UNFACT.BEND-Y	=	4.54E+03	kN-M
UMfz =	UNFACT.BEND-Z	=	3.78E+03	kN-M
Dpth =	DEPTH OF MEMB LOCATION		2.50E+01	M
Water=	DENSITY OF WATE	=	1.03E+03	kg
COMPUTATION:				
RADIUS (R)		=	1.50E+00	M
INNER DIAMETER (DI)		=	2.91E+00	M
X-SECTION AREA (A)		=	4.18E-01	M2
INERTIA (I)		=	4.56E-01	M4
kL/r (LAMDA)		=	2.30E+01	
P =	HYDRO. PRESS.	=	2.51E-01	MPa

MEMBER STRESSES:

Sa (AXIAL STRESS)	=	1.38E+05	kPa
Sby (BENDING STRESS)	=	1.79E+04	kPa
Sbz (BENDING STRESS)	=	1.35E+04	kPa
Sb <SQRT(Sby^2+Sbz^2)>	=	2.24E+04	kPa
Ty (SHEAR STRESS)	=	1.86E+03	kPa
Tz (SHEAR STRESS)	=	1.82E+03	kPa
Tyz (TORSION STRESS)	=	1.73E+02	kPa
Sh (HOOP STRESS)	=	8.38E+03	kPa
USby (UNFACT BEND STRESS	=	1.49E+04	kPa
USbz (UNFACT BEND STRESS	=	1.24E+04	kPa

CHARACTERISTIC COMPRESSIVE RESISTANCE:

Eb (ELASTIC BUCK RESIST)	=	3.93E+03	MPa
ALPHA1	=	2.00E-03	(INPUT)
ALPHA2	=	4.80E+02	(INPUT)
APLHA	=	2.51E-03	
Bd	=	6.9E+00	
BA	=	4.32E+03	MPa

BUCKLING RESIST:

LD1 (REDUCED SLENDER)	=	2.87E-01	
Bkc or Bkt(BUCK RESIST)	=	3.17E+02	MPa

OVERALL STRESS UTILSN:

ULS:

H	=	1.00E+00		
Gm (MAT'L FACTOR)	=	1.15E+00	(INPUT)	
Sp1	=	1.60E+05	kPa	USE:
Sp2	=	1.15E+05	kPa	1.60E+05 kPa

UNITY CHECK = 5.81E-01 OK

VON MISES STRESSES:

VMb (DESIGN BEND STRESS)	=	2.04E+04	kPa	
UVMb (UNFACT. BEND STRE	=	1.94E+04	kPa	
VMx1 (BEND TENSILE AXIAL	=	1.57E+05	kPa	
VMx2 (BEND COMPRESS AXI	=	1.18E+05	kPa	
BENDING TENSILE:				
VMj1	=	1.53E+05	kPa	MAX.CHECK:
BENDING COMPRESSIVE:				1.53E+05
				BTW VMj1&VMj2
VMj2	=	1.14E+05	kPa	1.34E+05
NO BENDING:				BTW VMj2&VMj3
				1.53E+05
VMj3	=	1.34E+05	kPa	BTW VMb&VMj1-3
VMmax (MAX. V-M STRESS)	=	1.53E+05	kPa	

VON MISES STRESS CHECK:

UNITY CHECK = 5.18E-01 OK

SHELL BUCKLING RESISTANCE:

LL (CYCL LGTH OR SPC BETW RINGS)		2.40E+01	M (INPUT)
Z	=	8.14E+03	
SHB	=	6.67E-01	
COMPRESSION:			
Kac	=	3.26E-01	
Sea	=	1.77E+03	MPa
BENDING:			
Kab	=	3.42E-01	
Seb	=	1.86E+03	MPa

				CHECK MAX
TORSION OR SHEAR:				
Set1	=	2.90E+02	MPa	
LONG SHELL SUBJECT TO SH				2.90E+02
Set2	=	0.00E+00	MPa	
SHELL SUBJ TO LATR PRESS:				
Sep1	=	3.82E+01	MPa	
LONG SHELL SUBJ LATR PRE N				4.73E+01
Sep2	=	4.73E+01	MPa	

SHELL BUCKLING UTILSN:

				INPUT:
Sao (INPUT 1 IF COMPRESS)	=	1.38E+05	kPa	1
Sbo (INPUT 1 IF COMPRESS)	=	2.24E+04	kPa	1
Spo (INPUT 1 IF COMPRESS)	=	8.38E+03	kPa	1
Td	=	2.61E+03	kPa	
LD2 (REDUCED SLENDER)	=	5.87E-01		
Sek (CHRC. BUCKLING RESIS	=	2.79E+02	MPa	

INTERACTN SHELL/COLUMN

CHECK FOR LONG CYCLIND	=	YES	
Mu	=	3.50E-02	
Bmp (MEMB MID PT)	=	1.04E+00	
Bep (MEMB END PT)	=	0.00E+00	(INPUT k, p=infinity)
BDD	=	1.04E+00	
LD3	=	2.87E-01	
dSbd (INCR COMPRESS)	=	3.47E+00	MPa
LDnew (NEW REDUCED SLEN	=	6.72E-01	

STABILITY REQUIREMENT:

H1	=	1.00E+00	
Gm1	=	1.15E+00	(INPUT)
SI	=	9.00E-01	(INPUT)
UNITY CHECK	=	7.02E-01	OK

TUBULAR BEAM COLUMN:

CHECK D/t RATIO

D/t	=	6.67E+01		CHECK GLOBAL/LOCAL INTERACTION:
0.5*SQRT(E/FY)	=	1.24E+01		INTERACTION OCCURS
0.1*E/FY	=	6.18E+01		INTERACTION OCCURS
YES-INTERACTION INPUT 1	=	1.00E+00	(INPUT)	(IF NOT 0)
SBR (BUCKLING RESIST)	=	2.79E+02	MPa	(SAME AS Sek)

MUo	=	3.89E-02	
Bphi	=	1.00E+00	(INPUT FROM DNV TABLE C1.3)
Nu	=	1.13E+00	(INPUT FROM DNV TABLE C1.3)
Bdb	=	1.05E+00	
SaC	=	1.53E+05	kPa
a,b or c factor (FACT)	=	9.90E-01	(INPUT FROM DNV FIGURE C1.1)
SSby	=	1.45E+00	
UNITY CHECK	=	7.34E-01	OK

TUBULAR MEMBER DESIGN USING BP DESIGN METHOD

MEMBER NO: = 59

INPUT:

D	=	DIAMETER	=	2.50E+00	m
t	=	THICKNESS	=	5.00E-02	m
L	=	LENGTH	=	2.55E+01	m
k	=	EFF.LENGTH RATI	=	1.00E+00	
Fy	=	YIELD STRENGTH	=	3.40E+02	MPa
phi	=	RESIST. FACTOR	=	9.00E-01	
E	=	MODULUS	=	2.10E+05	MPa
Cf	=	FACT.AXIAL FORC	=	5.09E+04	kN
Py	=	FACT. SHEAR-Y	=	3.06E+02	kN
Pz	=	FACT. SHEAR-Z	=	2.94E+02	kN
Mfy	=	FACT. BEND-Y	=	2.36E+03	kN-M
Mfz	=	FACT. BEND-Z	=	2.83E+03	kN-M
T	=	FACT.TORSION	=	1.90E+01	kN-M
UMfy	=	UNFACT.BEND-Y	=	2.36E+03	kN-M
UMfz	=	UNFACT.BEND-Z	=	2.83E+03	kN-M
Dpth	=	DEPTH OF MEMB LOCATION		2.50E+01	M
Water	=	DENSITY OF WATE	=	1.03E+03	kg

COMPUTATION:

RADIUS (R)		=	1.25E+00	M
INNER DIAMETER (DI)		=	2.40E+00	M
X-SECTION AREA (A)		=	3.85E-01	M2
INERTIA (I)		=	2.89E-01	M4
kL/r (LAMDA)		=	2.94E+01	
P =	HYDRO. PRESS.	=	2.51E-01	MPa

MEMBER STRESSES:

Sa (AXIAL STRESS)	=	1.32E+05	kPa
Sby (BENDING STRESS)	=	1.02E+04	kPa
Sbz (BENDING STRESS)	=	1.22E+04	kPa
Sb <SQRT(Sby^2+Sbz^2)>	=	1.59E+04	kPa
Ty (SHEAR STRESS)	=	1.56E+03	kPa
Tz (SHEAR STRESS)	=	1.50E+03	kPa
Tyz (TORSION STRESS)	=	3.87E+01	kPa
Sh (HOOP STRESS)	=	6.28E+03	kPa
USby (UNFACT BEND STRESS	=	1.02E+04	kPa
USbz (UNFACT BEND STRESS	=	1.22E+04	kPa

CHARACTERISTIC COMPRESSIVE RESISTANCE:

Eb (ELASTIC BUCK RESIST)	=	2.39E+03	MPa
ALPHA1	=	2.00E-03	(INPUT)
ALPHA2	=	4.80E+02	(INPUT)
APLHA	=	2.51E-03	
Bd	=	1.3E+01	
BA	=	2.80E+03	MPa

BUCKLING RESIST:

LD1 (REDUCED SLENDER)	=	3.67E-01	
Bkc or Bkt(BUCK RESIST)	=	3.11E+02	MPa

OVERALL STRESS UTILSN:

ULS:

H	=	1.00E+00			
Gm (MAT'L FACTOR)	=	1.15E+00	(INPUT)		
Sp1	=	1.48E+05	kPa	USE:	
Sp2	=	1.16E+05	kPa	1.48E+05	kPa

UNITY CHECK = 5.48E-01 OK

VON MISES STRESSES:

VMb (DESIGN BEND STRESS)	=	1.45E+04	kPa	
UVMb (UNFACT. BEND STRE	=	1.59E+04	kPa	
VMx1 (BEND TENSILE AXIAL	=	1.48E+05	kPa	
VMx2 (BEND COMPRESS AXI	=	1.16E+05	kPa	
BENDING TENSILE:				
VMj1	=	1.45E+05	kPa	MAX.CHECK:
BENDING COMPRESSIVE:				1.45E+05
				BTW VMj1&VMj2
VMj2	=	1.13E+05	kPa	1.29E+05
NO BENDING:				BTW VMj2&VMj3
				1.45E+05
VMj3	=	1.29E+05	kPa	BTW VMb&VMj1-3
VMmax (MAX. V-M STRESS)	=	1.45E+05	kPa	

VON MISES STRESS CHECK:

UNITY CHECK = 4.91E-01 OK

SHELL BUCKLING RESISTANCE:

LL (CYCL LGTH OR SPC BETW RINGS)		2.55E+01	M (INPUT)
Z	=	9.92E+03	
SHB	=	7.30E-01	

COMPRESSION:

Kac	=	3.33E-01	
Sea	=	2.41E+03	MPa

BENDING:

Kab	=	3.46E-01	
Seb	=	2.50E+03	MPa

TORSION OR SHEAR:

CHECK MAX

Set1	=	3.68E+02	MPa	
LONG SHELL SUBJECT TO SH				3.78E+02
Set2	=	3.78E+02	MPa	

SHELL SUBJ TO LATR PRESS:

Sep1	=	4.61E+01	MPa	
LONG SHELL SUBJ LATR PRE				8.40E+01
Sep2	=	8.40E+01	MPa	

SHELL BUCKLING UTILSN:

				INPUT:
Sao (INPUT 1 IF COMPRESS)	=	1.32E+05	kPa	1
Sbo (INPUT 1 IF COMPRESS)	=	1.59E+04	kPa	1
Spo (INPUT 1 IF COMPRESS)	=	6.28E+03	kPa	1
Td	=	2.16E+03	kPa	
LD2 (REDUCED SLENDER)	=	3.21E-01		
Sek (CHRC. BUCKLING RESIS	=	3.08E+02	MPa	

INTERACTN SHELL/COLUMN

CHECK FOR LONG CYCL	=	YES	
Mu	=	5.52E-02	
Bmp (MEMB MID PT)	=	1.06E+00	
Bep (MEMB END PT)	=	0.00E+00	(INPUT k, p=infinity)
BDD	=	1.07E+00	
LD3	=	3.67E-01	
dSbd (INCR COMPRESS)	=	5.84E+00	MPa
LDnew (NEW REDUCED SLEN	=	4.53E-01	

STABILITY REQUIREMENT:

H1	=	1.00E+00		
Gm1	=	1.15E+00	(INPUT)	
SI	=	9.00E-01	(INPUT)	
UNITY CHECK	=	6.03E-01	OK	

TUBULAR BEAM COLUMN:

CHECK D/t RATIO				
D/t	=	5.00E+01		CHECK GLOBAL/LOCAL INTERACTION:
0.5*SQRT(E/FY)	=	1.24E+01		INTERACTION OCCURS
0.1*E/FY	=	6.18E+01		N.A.
YES-INTERACTION INPUT 1	=	1.00E+00	(INPUT)	(IF NOT 0)
SBR (BUCKLING RESIST)	=	3.08E+02	MPa	(SAME AS Sek)
MUo	=	6.14E-02		
Bphi	=	1.00E+00	(INPUT FROM DNV TABLE C1.3)	
Nu	=	1.13E+00	(INPUT FROM DNV TABLE C1.3)	
Bdb	=	1.07E+00		
SaC	=	1.47E+05	kPa	
a,b or c factor (FACT)	=	9.90E-01	(INPUT FROM DNV FIGURE C1.1)	
SSby	=	1.33E+00		
UNITY CHECK	=	6.18E-01	OK	

APPENDIX F

JOINT DESIGN CALCULATIONS (CSA & BP)

TUBULAR JOINT CAPACITY Oct. 22/90 FILE:JOINT.WK1

CSA S471-M1989 - SECTION 11; simple & overlap joints, unstiffened

BRACE NO: 75

JOINT NO: 256

INPUT:

brace information:

d =	brace diameter	1400	mm			
theta =	brace angle	41.76	degrees (	0.73	rad.)	
g =	K joint gap width	75	mm (use one of g or q)			
q =	K joint overlap	0	mm (<=0.4do =		800)	
factored loads;	JOINT TYPE:	K	T&Y	X		
Tf =	tension	0	0	0	kN	
Cf =	compression	0	13195	0	kN	
Mfip =	in-plane bending	0	1610	0	kN-m	
Mfop =	out-of-plane bending	0	1668	0	kN-m	

chord information:

do =	diameter	2000	mm
to =	thickness	100	mm
phi =	resistance factor	0.9	
Fyo =	yield stress	315	MPa
Mroip =	in-plane bending resist.	113820	kN-m
Mroop =	out-of-plane bend. resist.	113820	kN-m
Cfo =	max. factored comp.	46693	kN
Mfoip =	in-plane factored bending	10445	kN-m
Mfoop =	out-of-plane fact. bending	3271	kN-m

CALCULATIONS:

Ao =	chord area	596903	mm^2	
beta =	d/do	0.70		
U =	from 11.1.2.2.1	0.29		
Qk =	tbl 11.2, >= 0.77	1.73	a) for do/2to<=20	1.73
			b) for do/2to>20	1.65
Qxt =	from table 11.2	1.00		
Qxc =	from table 11.2	1.03		

FROM 11.1.2.2.1:

		AXIAL		BENDING		
		TENSION	COMP.	-PLANE	F-PLANE	
lambda =		0.03	0.03	0.045	0.021	
Qf =	1.0 - lambda*do/2to*U^2	0.97	0.97	0.96	0.98	
TYPE K JOINT:						
Qu =	(from tbl. 11.2)	39.76	39.76	13.28	8.22	
Ultimate resistance =		183232	183232	84565	53464	kN,kN-m
phi_j =	(from tbl. 11.1)	0.63	0.63	0.72	0.79	
Factored resistance =		115436	115436	60887	42237	kN,kN-m
TYPE T&Y JOINT:						
Qu =	(from tbl. 11.2)	26.91	17.73	13.28	8.22	
Ultimate resistance =		124025	81709	84565	53464	kN,kN-m
phi_j =	(from tbl. 11.1)	0.81	0.78	0.72	0.79	
Factored resistance =		100460	63733	60887	42237	kN,kN-m
TYPE X JOINT:						
Qu =	(from tbl. 11.2)	25.20	14.71	13.28	8.22	
Ultimate resistance =		116134	67794	84565	53464	kN,kN-m
phi_j =	(from tbl. 11.1)	0.65	0.83	0.72	0.79	
Factored resistance =		75487	56269	60887	42237	kN,kN-m

11.1.2.2.2 LOAD COMBINATIONS: (<=1.0)

	K	T&Y	X	K+T	K+X	T+X	K+T+X
Tension + Bending =	0.00	0.04	0.00	0.04	0.00	0.04	0.04
Compression + Bending =	0.00	0.25	0.00	0.25	0.00	0.25	0.25

TUBULAR JOINT CAPACITY Oct. 22/90 FILE:JOINT.WK1

CSA S471-M1989 - SECTION 11; simple & overlap joints, unstiffened

BRACE NO: 45

JOINT NO: 146a

INPUT:

brace information:

d =	brace diameter	1250	mm		
theta =	brace angle	77.3	degrees (	1.35	rad.)
g =	K joint gap width	75	mm (use one of g or q)		
q =	K joint overlap	0	mm (<=0.4do =	720	)

factored loads;	JOINT TYPE:	K	T&Y	X	
Tf =	tension	0	0	4263	kN
Cf =	compression	0	0	0	kN
Mfip =	in-plane bending	0	0	614	kN-m
Mfop =	out-of-plane bending	0	0	108	kN-m

chord information:

do =	diameter	1800	mm
to =	thickness	100	mm
phi =	resistance factor	0.9	
Fyo =	yield stress	315	MPa
Mroip =	in-plane bending resist.	80604	kN-m
Mroop =	out-of-plane bend. resist.	80604	kN-m
Cfo =	max. factored comp.	19045	kN
Mfoip =	in-plane factored bending	3703	kN-m
Mfoop =	out-of-plane fact. bending	2415	kN-m

CALCULATIONS:

Ao =	chord area	534071	mm^2	
beta =	d/do	0.69		
U =	from 11.1.2.2.1	0.14		
Qk =	tbl 11.2, >= 0.77	1.73	a) for do/2to<=20	1.73
			b) for do/2to>20	1.63
Qxt =	from table 11.2	1.00		
Qxc =	from table 11.2	1.02		

FROM 11.1.2.2.1:		AXIAL		BENDING		
		TENSION	COMP.	-PLANE	F-PLANE	
lambda =		0.03	0.03	0.045	0.021	
Qf =	1.0 - lambda*do/2to*U^2	0.99	0.99	0.99	1.00	
TYPE K JOINT:						
Qu =	(from tbl. 11.2)	39.50	39.50	12.50	8.14	
Ultimate resistance =		126894	126894	50068	32727	kN,kN-m
phi_j =	(from tbl. 11.1)	0.63	0.63	0.72	0.79	
Factored resistance =		79943	79943	36049	25854	kN,kN-m
TYPE T&Y JOINT:						
Qu =	(from tbl. 11.2)	25.36	17.61	12.50	8.14	
Ultimate resistance =		81484	56586	50068	32727	kN,kN-m
phi_j =	(from tbl. 11.1)	0.81	0.78	0.72	0.79	
Factored resistance =		66002	44137	36049	25854	kN,kN-m
TYPE X JOINT:						
Qu =	(from tbl. 11.2)	25.00	14.57	12.50	8.14	
Ultimate resistance =		80315	46798	50068	32727	kN,kN-m
phi_j =	(from tbl. 11.1)	0.65	0.83	0.72	0.79	
Factored resistance =		52204	38842	36049	25854	kN,kN-m

11.1.2.2.2 LOAD COMBINATIONS: (<=1.0)

	K	T&Y	X	K+T	K+X	T+X	K+T+X
Tension + Bending =	0.00	0.00	0.09	0.00	0.09	0.09	0.09
Compression + Bending =	0.00	0.00	0.00	0.00	0.00	0.00	0.00

TUBULAR JOINT CAPACITY   Oct. 22/90   FILE:JOINT.WK1

CSA S471-M1989 - SECTION 11; simple & overlap joints, unstiffened

BRACE NO: 45

JOINT NO: 146b

INPUT:

brace information:

d =	brace diameter	1400	mm			
theta =	brace angle	77.3	degrees (	1.35	rad.)	
g =	K joint gap width	75	mm (use one of g or q)			
q =	K joint overlap	0	mm (<=0.4do =		720	)
factored loads;	JOINT TYPE:	K	T&Y	X		
Tf =	tension	0	0	4143	kN	
Cf =	compression	0	0	0	kN	
Mfip =	in-plane bending	0	0	560	kN-m	
Mfop =	out-of-plane bending	0	0	482	kN-m	

chord information:

do =	diameter	1800	mm
to =	thickness	100	mm
phi =	resistance factor	0.9	
Fyo =	yield stress	315	MPa
Mroip =	in-plane bending resist.	80604	kN-m
Mroop =	out-of-plane bend. resist.	80604	kN-m
Cfo =	max. factored comp.	19045	kN
Mfoip =	in-plane factored bending	3703	kN-m
Mfoop =	out-of-plane fact. bending	2415	kN-m

CALCULATIONS:

Ao =	chord area	534071	mm^2	
beta =	d/do	0.78		
U =	from 11.1.2.2.1	0.14		
Qk =	tbl 11.2, >= 0.77	1.73	a) for do/2to<=20	1.73
			b) for do/2to>20	1.63
Qxt =	from table 11.2	1.00		
Qxc =	from table 11.2	1.10		

FROM 11.1.2.2.1:

		AXIAL		BENDING		
		TENSION	COMP.	-PLANE	F-PLANE	
lambda =		0.03	0.03	0.045	0.021	
Qf =	1.0 - lambda*do/2to*U^2	0.99	0.99	0.99	1.00	
TYPE K JOINT:						
Qu =	(from tbl. 11.2)	43.40	43.40	14.00	9.62	
Ultimate resistance =		139442	139442	62806	43341	kN,kN-m
phi_j =	(from tbl. 11.1)	0.63	0.63	0.72	0.79	
Factored resistance =		87848	87848	45220	34239	kN,kN-m
TYPE T&Y JOINT:						
Qu =	(from tbl. 11.2)	27.87	19.36	14.00	9.62	
Ultimate resistance =		89541	62181	62806	43341	kN,kN-m
phi_j =	(from tbl. 11.1)	0.81	0.78	0.72	0.79	
Factored resistance =		72528	48501	45220	34239	kN,kN-m
TYPE X JOINT:						
Qu =	(from tbl. 11.2)	28.00	17.15	14.00	9.62	
Ultimate resistance =		89952	55095	62806	43341	kN,kN-m
phi_j =	(from tbl. 11.1)	0.65	0.83	0.72	0.79	
Factored resistance =		58469	45728	45220	34239	kN,kN-m

11.1.2.2.2 LOAD COMBINATIONS: (<=1.0)

	K	T&Y	X	K+T	K+X	T+X	K+T+X
Tension + Bending =	0.00	0.00	0.09	0.00	0.09	0.09	0.09
Compression + Bending =	0.00	0.00	0.01	0.00	0.01	0.01	0.01

SIMPLE JOINT DESIGN - BP METHOD

DEC/91
BY:GK

JOINT NO: 256

INPUT:

BRACE/CHORD DIMENSION:

Bd (brce diameter)	=	1.40E+03	mm		
Bt (brce thick)	=	3.00E+01	mm		
Cd (chd diameter)	=	2.00E+03	mm		
Ct (chd thick)	=	1.00E+02	mm		
theta (chd/brc angle)	=	4.18E+01	deg	0.73	rad
a (gap betw considered braces)	=	7.50E+01	mm		
fy (yield strength)	=	3.14E+02	MPa		
Gm (material coeff)	=	1.15E+00			
k (kappa)	=	1.15E+00			

FORCE INPUT:

Nad (factored brace axial force)	=	1.18E+04	kN
Mbop (factored out of plane bending)	=	1.61E+03	kN-M
Mbip (factored in-plane bending)	=	1.59E+03	kN-M

COMPUTATION:

g (a/D)	=	3.75E-02				
beta (r/R)	=	7.00E-01				
gamma (R/T)	=	1.00E+01				
tau (t/T)	=	3.00E-01				
Rb (brace radius)	=	7.00E+02	mm			
Rc (chord radius)	=	1.00E+03	mm			
Ba (brace x-section area)	=	1.29E+05	mm^2			
Ndp (punching shear force)	=	1.89E+03	kN			
Nad1 (check to include Mbop effect)	=	1.89E+03	kN	input:		
Nad2 (check if brace is cantilever)	=	1.89E+03	kN		0	(1=cantilever)

PUNCHING SHEAR CAPACITY:

Nd	=	1.77E+04	kN
JOINT TYPE:	=	10	
fuk	=	9.53E+01	MPa
Nd1	=	9.30E+03	kN

PUNCHING SHEAR CHECK:

Ndc(critical puching shear capacity)	=	9.30E+03	kN	
CHOOSE BRACE TYPE	=	1.00E+00		1= AXIAL CONTROL
Nadc (crtical punching shear force)	=	1.89E+03	kN	2=AXIAL+Mbop
				3=AXIAL+Mbop+Mbip
Nadc/Ndc	=	2.03E-01	OK	

JOINT TYPE COMPUTATION:

INPUT NO:

Ja (10)	=	95.27	MPa
Jb (20)	=	147.81	MPa
Jc (30)	=	147.54	MPa
Jd1 (40)	=	219.74	MPa
Jd2 (41)	=	1481.21	MPa
Je (50)	=	147.54	MPa
Jf (60)	=	219.74	MPa
Jg (70)	=	416.89	MPa

SIMPLE JOINT DESIGN - BP METHOD

JOINT NO: 146A

INPUT:

BRACE/CHORD DIMENSION:

Bd (brce diameter)	=	1.25E+03	mm		
Bt (brce thick)	=	3.50E+01	mm		
Cd (chd diameter)	=	1.80E+03	mm		
Ct (chd thick)	=	9.00E+01	mm		
theta (chd/brc angle)	=	7.73E+01	deg	1.35	rad
a (gap betw considered braces)	=	7.50E+01	mm		
fy (yield strength)	=	3.25E+02	MPa		
Gm (material coeff)	=	1.15E+00			
k (kappa)	=	1.15E+00			

FORCE INPUT:

Nad (factored brace axial force)	=	3.88E+03	kN
Mbop (factored out of plane bending)	=	5.67E+02	kN-M
Mbip (factored in-plane bending)	=	9.50E+01	kN-M

COMPUTATION:

g (a/D)	=	4.17E-02			
beta (r/R)	=	6.94E-01			
gamma (R/T)	=	1.00E+01			
tau (t/T)	=	3.89E-01			
Rb (brace radius)	=	6.25E+02	mm		
Rc (chord radius)	=	9.00E+02	mm		
Ba (brace x-section area)	=	1.34E+05	mm^2		
Ndp (punching shear force)	=	1.46E+03	kN		
Nad1 (check to include Mbop effect)	=	1.46E+03	kN	input:	
Nad2 (check if brace is cantilever)	=	1.46E+03	kN	0	(1=cantilever)

PUNCHING SHEAR CAPACITY:

Nd	=	1.90E+04	kN
JOINT TYPE:	=	20	
fuk	=	1.53E+02	MPa
Nd1	=	1.55E+04	kN

PUNCHING SHEAR CHECK:

Ndc(critical puching shear capacity)	=	1.55E+04	kN	
CHOOSE BRACE TYPE	=	1.00E+00		1= AXIAL CONTROL
Nadc (crtical punching shear force)	=	1.46E+03	kN	2=AXIAL+Mbop
				3=AXIAL+Mbip+Mbip
Nadc/Ndc	=	9.39E-02	OK	

JOINT TYPE COMPUTATION:

INPUT NO:

Ja (10)	=	121.80	MPa
Jb (20)	=	153.42	MPa
Jc (30)	=	168.38	MPa
Jd1 (40)	=	250.78	MPa
Jd2 (41)	=	1893.75	MPa
Je (50)	=	168.38	MPa
Jf (60)	=	250.78	MPa
Jg (70)	=	628.03	MPa

SIMPLE JOINT DESIGN - BP METHOD

JOINT NO: 146B

INPUT:

BRACE/CHORD DIMENSION:

Bd (brce diameter)	=	1.40E+03	mm		
Bt (brce thick)	=	3.50E+01	mm		
Cd (chd diameter)	=	1.80E+03	mm		
Ct (chd thick)	=	9.00E+01	mm		
theta (chd/brc angle)	=	7.73E+01	deg	1.35	rad
a (gap betw considered braces)	=	7.50E+01	mm		
fy (yield strength)	=	3.25E+02	MPa		
Gm (material coeff)	=	1.15E+00			
k (kappa)	=	1.15E+00			

FORCE INPUT:

Nad (factored brace axial force)	=	3.77E+03	kN
Mbop (factored out of plane bending)	=	5.09E+02	kN-M
Mbip (factored in-plane bending)	=	4.83E+02	kN-M

COMPUTATION:

g (a/D)	=	4.17E-02			
beta (r/R)	=	7.78E-01			
gamma (R/T)	=	1.00E+01			
tau (t/T)	=	3.89E-01			
Rb (brace radius)	=	7.00E+02	mm		
Rc (chord radius)	=	9.00E+02	mm		
Ba (brace x-section area)	=	1.50E+05	mm^2		
Ndp (punching shear force)	=	1.41E+03	kN		
Nad1 (check to include Mbop effect)	=	1.41E+03	kN	input:	
Nad2 (check if brace is cantilever)	=	1.41E+03	kN	0	(1=cantilever)

PUNCHING SHEAR CAPACITY:

Nd	=	2.13E+04	kN	
JOINT TYPE:	=	20		
fuk	=	1.48E+02	MPa	
Nd1	=	1.67E+04	kN	

PUNCHING SHEAR CHECK:

Ndc(critical puching shear capacity)	=	1.67E+04	kN	
CHOOSE BRACE TYPE	=	1.00E+00		1= AXIAL CONTROL
Nadc (crtical punching shear force)	=	1.41E+03	kN	2=AXIAL+Mbop
				3=AXIAL+Mbop+Mbip
Nadc/Ndc	=	8.42E-02	OK	

JOINT TYPE COMPUTATION:

INPUT NO:

Ja (10)	=	121.80	MPa
Jb (20)	=	147.55	MPa
Jc (30)	=	177.24	MPa
Jd1 (40)	=	263.98	MPa
Jd2 (41)	=	1893.75	MPa
Je (50)	=	177.24	MPa
Jf (60)	=	263.98	MPa
Jg (70)	=	615.18	MPa

APPENDIX G

REFERENCES

APPENDIX G - REFERENCES

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