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SHIP STRUCTURAL ANALYSIS
USING
FINITE ELEMENT ANALYSIS
AND
ONBOARD STRESS MONITORING METHODS

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towards the degree of Master of Science in Engineering,
at the University of Cape Town

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DECLARATION

I, DAVID ANDREW KETLEY
Hereby declare that this thesis is my own
work and has not been submitted for a degree
at another University

Signed by candidate

September 1991

ABSTRACT

Ship's, predominantly constructed from steel, but also aluminium and glass reinforced plastic (GRP), are complex structures, which are subjected to complex loading, both static and dynamic.

In order to overcome the arduous task of identifying all applicable static and dynamic loads which a ship or section thereof, would be subjected to, and then designing each and every component to withstand the load identified, most new commercial ships are designed according to the rules of one of the more prominent classification societies. The rules thus serve as a sound and conservative basis for the design of ship structure, and tend to "standardize" methods and techniques in ship construction, which then also aids the marine surveyor in assessing the condition of structure after extended periods of exposure to the operational environment.

Rules have thus been developed over time, and are an amalgamation of manual calculations, good structural principles, good ship building techniques, and have evolved to address the shortcomings that have been identified due to observed failures.

However, most Classification Societies recognized that there are situations where the structure being designed is not covered by a specific set of rules, or where optimization is required for reasons of weight / cost or other factors. In such situations, Classification Societies accept that structure may be designed with the aid of analysis tools such as finite element analysis or hull stress monitoring/ measurements. In such cases the analysis report, together with all relevant supporting documentation and drawings, is normally submitted to the Classification Society, or other controlling authority, for their approval. With the ever increasing availability of PC based finite element packages which have the capabilities to analyse large and complex models, more and more ship structures are being analysed over the traditional rule based methods. However applications where the loads can be accurately identified, are better suited to analysis, whereas in ship structures the difficulty in identifying the applicable loads still leads to rule based designs being a popular and accepted practice, and will still be the case for some time to come. Some of the classification societies are now bringing out customized, rule based, analysis software, which amounts to a combination of traditional rule methods coupled to specific and customized finite element analysis tools.

One area where rules are not normally applicable, and finite element analysis is often employed, is in the design of mining plants and the associated equipment and supporting structure, and the stiffening of existing ship's structure and decks, onboard offshore mining vessels or oil drill ships/rigs.

Other areas where specific analysis is utilized, is in the design of helicopter decks, winch foundations, crane pedestals and cranes in general, and other such areas where the loads are specific to the application and easily quantified.

This dissertation covers the application of finite element analysis and hull stress monitoring and measuring methods, in the current day design of, and/or the analysis of ship structures.

ACKNOWLEDGEMENTS

My earlier grounding in Naval Architecture was largely thanks to the lecturing and course work of Prof K.G. Hoppe, of the University of Stellenbosch. This tuition coupled to the experience of working as a Naval Architect, in the local commercial marine industry, has been of significant value in the process of completing this dissertation.

Both case studies were based on actual commercial projects, conducted by myself, under the employ of Triton Naval Architects. My appreciation must go to Triton for providing the material, the funding and the backing in terms of provision of software, hardware, and drawing office resources, where applicable.

The owners of the Diamond Vessel, which was used in the hull stress monitoring exercise, chose to remain un-named, and requested that the vessel not be named, but gave their permission for the material to be used for academic purposes.

Prof Nic Marais is thanked for his continued guidance throughout this period, and for his understanding and forbearance through the process of an evolving topic and case study.

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INTRODUCTION

The original objective of this project was to establish a comparison and correlation between actual measured stresses onboard ships, with those predicted by the finite element method. Due to circumstances as described below, this developed into a more general topic of “Ship Structural Analysis”, using finite element analysis and physical stress measuring methods.

The project evolved into a study of ship structural analysis, focussing on the use of finite element analysis with specific application to ship structures. In so doing certain applications were identified where finite element analysis was better substituted by physical stress measuring/monitoring, due to the difficulties that come about in distinguishing between the influences of various simultaneous loading.

Introductory chapters cover an overview of ship structures, with particular reference to bulkcarriers, loads and responses, and general techniques and procedures in the analysis of ship structures. Hull girder and hull module analysis is covered as specific method advocated by Hughes[1], culminating in a case study involving detailed hull module analysis, presented in *Chapter 7*.

Some background into the development stages of this project.

Originally the Bulk Carrier ¹“FEROSA” was identified for this project due to having an onboard stress measuring system installed. This device had been in operation since soon after the vessel was launched in 1992. This project would look at the interpretation and calibration of results obtained from this device.

The proposed method of calibration is by means of comparing measurements taken from the onboard system, relating them to those predicted by a detailed finite element structural analysis model.

For reasons outlined below, a diamond mining vessel was eventually used as the principle case study, as presented in *Chapter 8*. The Ferosa FE model, which had been completed by this time, was then rather used in discussion with reference to modelling techniques applicable to ship structures, as presented in the earlier chapters. A bulkcarrier “Decurion” was used as a secondary case study, presented in *Chapter 7*, which illustrates the practical application of detailed hull module analysis.

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“Ferosa” is a bulk carrier belonging to Safmarine (now Mearsk), was built in 1992 and fitted with hull stress monitoring instrumentation soon afterwards.

The hull stress monitoring project of the diamond mining vessel, which is detailed in the case study, was a project conducted, under the supervision of the author, by ²Triton Naval Architects (TNA), with ³Labratorium vir Gevorderde Meganika (LGI) as a subcontractor. The owners of the diamond mining vessel gave permission for the project to be used as a case study for academic purposes, with the proviso that neither the company name nor the ship name be mentioned. As one can appreciate, the company concerned would not specifically want to draw the attention of their competitors, to any shortcoming of their vessels. The mining vessel will be referred to as ⁴M.V. "DBG".

The change of vessels, for the main case study, came about for a combination of reasons, briefly listed as follows:

Reasons against using the M.V. Ferosa as the primary case study were;

- In the case of the bulk carrier "Ferosa" it was found that actual hull stress data, was limited, and when available was not related to any loading, or environmental conditions. Thus the data was of very limited use, especially in a project involving the comparison and calibration of results.
- It was also found during an onboard visit, which involved witnessing the loading of iron ore, that not only was the instrumentation's calibration out, but also the stress deviations being recorded during loading were not within expectations. This indicated possible malfunction or other problems within the system.

Reasons for using mining vessel M.V. "DGB" as the primary case study were;

- An actual hull stress monitoring project was being undertaken by the author's company under his personal supervision. Such a project would lead to quality assured relevant data.
- Structural deformation (damage) had been observed at certain locations on the vessel, indicating that the vessel was either experiencing some kind of operational or environmental overloading, and/or indicating shortcomings in structural strength.

The detailed structural analysis is based on modelling of vessels using the finite element method, and modelling strategies for ships advocated by Hughes[1]. It will also be shown that some of the approaches developed from experience, differ in some aspects from those advocated by Hughes.

² Triton Naval Architects (TNA) is the company at which the author is employed as a partner.

³ Labratorium vir Gevorderde Ingenieurswese (LGI) is a commercial branch of the Department of Mechanical Engineering of the University of Pretoria.

⁴ *MV* when used as a prefix to a ship's name, means either a Mining Vessel or Motor Vessel. Other examples would be *M.F.V.* indicating a Motor Fishing Vessel, or *MODU* indicating Mobile Offshore Drilling Unit, which are similar to Mining Vessels, but normally non self propelled vessels or Rigs.

The initial principle case study took the form of the following principle steps; not all of which are documented here, due to a later change in principle case study, and thus had reduced relevance.

1. A study into ship structural analysis by the finite element method, and stress monitoring systems.
2. In the case of the “Ferosa”, establishing the ships weight distribution by modelling the hull, tanks and holds on GHS™ ‘ship stability’ software [12], and creating loading conditions according to the actual distribution of weight, and buoyancy. Determining the lightship weight distribution by derivation from the shipyard supplied bending moment and shear force diagrams for know loading conditions.
3. Creating a hull girder finite element model of the Ferosa primary structure to which hydrostatic pressure loads, selfweight and other loads (as obtained from the loading conditions) could be applied.
4. Creating a hull module finite element model, defined to incorporate three holds in the midship region. Boundary condition loads as obtained from the primary structure is then be applied to the hull module, to produce a higher level of detail regarding stress distributions.
5. Correlating the analytical hull module stresses with the onboard stress recordings, for the case Bulk Carrier “Ferosa”.

As already mentioned, the recorded stress data from the Ferosa was not sufficiently calibrated nor specific to conditions of operational or environmental loading, thus this step was not fulfilled as initially intended, and the Mining Vessel project was adopted as the case study. The finite element modelling of the Ferosa is however used to illustrate modelling techniques, adopted in later sections.

With the identification of the new and more applicable case study, the principle case study took on the following form, as documented in Chapter 8:

1. Building a detailed hull module model of the midship region of the Mining Vessel, along with the moonpool, and base structure supporting the drill tower.
2. Applying operational and environmental loads to obtain displacements and distortions that reflect actual / observed responses.

3. Apply stress monitoring techniques to the tower support structure and affected bulkheads of the Mining Vessel, in collaboration with LGI[13]. Measure stresses over a period of 7 to 10 days, whilst fully operational, in typical sea conditions. Taking stress samples at specific operational occurrences, for eg. shifting the vessel on her mooring chains, drill string blow offs.
4. The post processing of data into stress and acceleration curves would be undertaken by LGI. Analysing the processed data, in identifying the most probable causes of the observed problems.
5. Proposing counter measures, and designing the “class approved” structure to be retrofitted, which would rectify the structural shortcomings, and enhance structural integrity for future operation.
6. Conducting a post retrofit stress monitoring exercise, now also including monitoring stresses in the deck and new structure, to establish whether the modifications were successful.

Secondary Case Study - Hull Module Analysis

The secondary case study, as documented in Chapter 7, illustrates the practical application of hull module analysis, as prescribed by Hughes[1], as being the secondary step in ship structural analysis.

In this case the initial hull girder analysis was performed, in terms of simple beam theory, using dedicated ship stability and longitudinal strength software GHSTM[12], due to its ability to calculate the corrected weight vs buoyancy distribution of various scenarios of loading and flooding.

CHAPTER 1 OVERVIEW OF SHIP STRUCTURES

This section will give a general overview for ship structure, along with the associated ship structure terminology, which will be individually accentuated by means of footnotes. This section does however not attempt to specify design parameters, for example, typical frame spacing, plate thickness or section properties and span limits. These parameters are either obtained from ¹Classification Society Rules, or as a result of detailed analysis, as they are dependent on the application and size of the vessel.

1.1 KEELS

The keel is seen a primary strength member contributing to the overall longitudinal strength of the ship. The keel of smaller vessels is often more pronounced in comparison, as larger vessels normally have a heavy double bottom structure, of which the keel forms only a part.

Typically keels are of three principal types, namely, plate keels, bar keel, and duct keels or box keels.

The plate and duct keels are found in double bottom structures, the former being a centreline ²girder plate, running the full height of the ³double bottom, whereas the latter is typically two girders separated by a distance similar to the height of the double bottom, thus forming a duct or box, often used for piping and cabling. In both of these cases the ⁴scantling or thickness of the plate is similar to all other ⁵longitudinal girders, only the keel girders will generally not have cutouts or ⁶lightening holes, as whole side girders. The keel, whether plate or duct, will in most cases also form the boundary between port and starboard double bottom tanks.

Bar keels are typically found on single bottom ships, and smaller ships, like fishing boats, ferries and small cargo vessels. The keel is normally made up of a heavy plate on edge (50mm to 100mm thick).

Box keels are similar in application to bar keels, but are generally a construction that

¹ Ship's Classification Societies, for eg. Lloyds of London, American Bureau of Shipping, of USA, Bureau Veritas of France, Germanischer Lloyd of Germany, amongst other have over the years, developed rule books which specify design parameters for ships that are to be classed (registered) with their society.

² Girder's refer to the secondary or larger member, whether transverse or longitudinal. Refer to the sections on longitudinal and transverse framing.

³ Double Bottom is the space (and structure) between the bottom of the holds, often referred to as the tank top, and the bottom of the hull. This space is normally used as tanks, either for fuel or ballast.

⁴ Scantling or Scantlings is an all encompassing term which refers to the sizes of the structural members, in terms of thickness of plate, or sectional properties of a beam section. Reference is often made to the midship scantlings, which will include the sectional properties of all longitudinals, along with the plate thickness of all strakes, side and bottom and deck, which considered in unison can be used to calculate the midship sectional modulus.

⁵ Longitudinal Girders, normally plate girders which extend between the bottom shell and the tank top (ie. the full height of the double bottom), or in the base of single bottom ships, they are deeper beams, typically deep bulb sections, or T sections, spaced at large intervals, with smaller longitudinal stiffeners (often angle or bulb section) spaced at close intervals.

⁶ Lightening Holes refer to the cutouts in the deep girders, or floors, to reduce weight, and to allow access.

extends below the bottom the of the hull, and often filled with concrete.

1.2 SINGLE BOTTOM STRUCTURES

Smaller ships generally having single bottoms throughout, or in certain areas, for example before and beyond the hold spaces.

Single bottom structures generally comprise of a single centre line girder, with either one side girder or two side girders on either side, with full depth open plate ⁷ floors at every frame space, which are stiffened on the top edge.

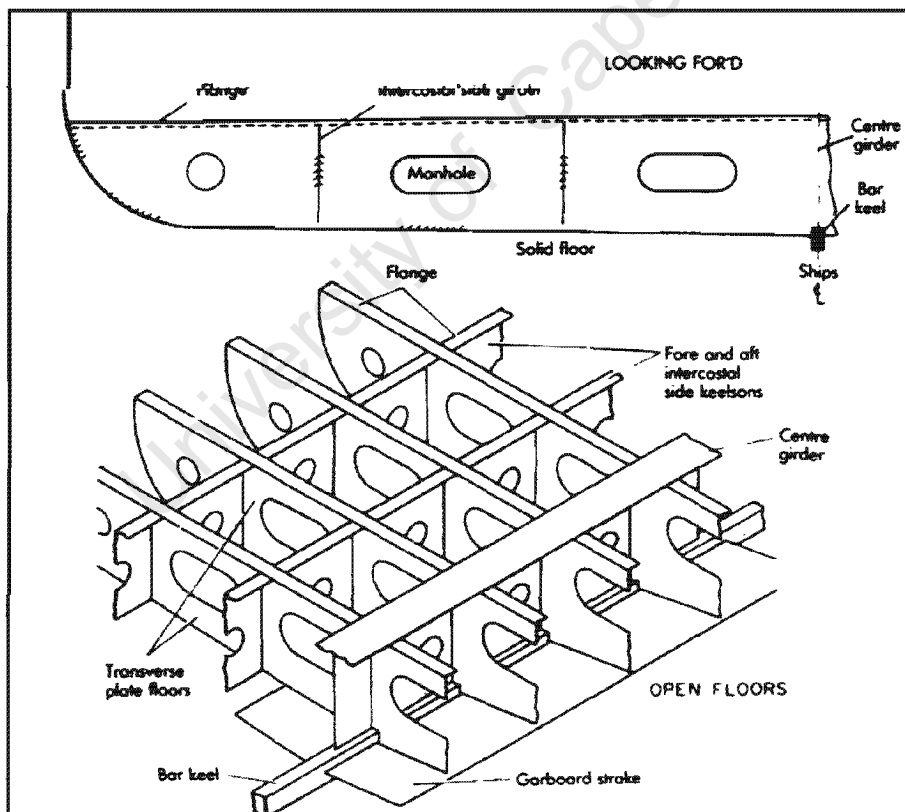


Figure 1.1 - Single Bottom construction (illustration by Eyres[2])

1.3 DOUBLE BOTTOM STRUCTURE

A double bottom structure comprises of a tank top, or inner bottom, which is watertight from the bilges. Advantages of this structure are three fold;

- Strength is considerably increased as a enclosed box structure is very strong relative to its weight.
- Useful watertight space for the use of ballast tanks, or fuel tanks
- Safeguard against damage, as rupturing of the double bottom spaces not necessarily mean flooding of the hold above, or in the case of a tanker, flooding of the cargo fuel holds.

Double bottoms may be framed transversely or longitudinally. Ships of length exceeding 120m are generally longitudinally framed, but not necessarily. Even on longitudinally framed vessels, there may be areas which are transversely framed, for eg. on a bulkcarrier the areas between the bottom hopper side tanks and the upper hopper side tanks are often transversely framed. This will be illustrated in the case of the modelling of the bulk carrier "Ferosa". Machinery spaces are often transversely framed, even on otherwise longitudinally framed vessels.

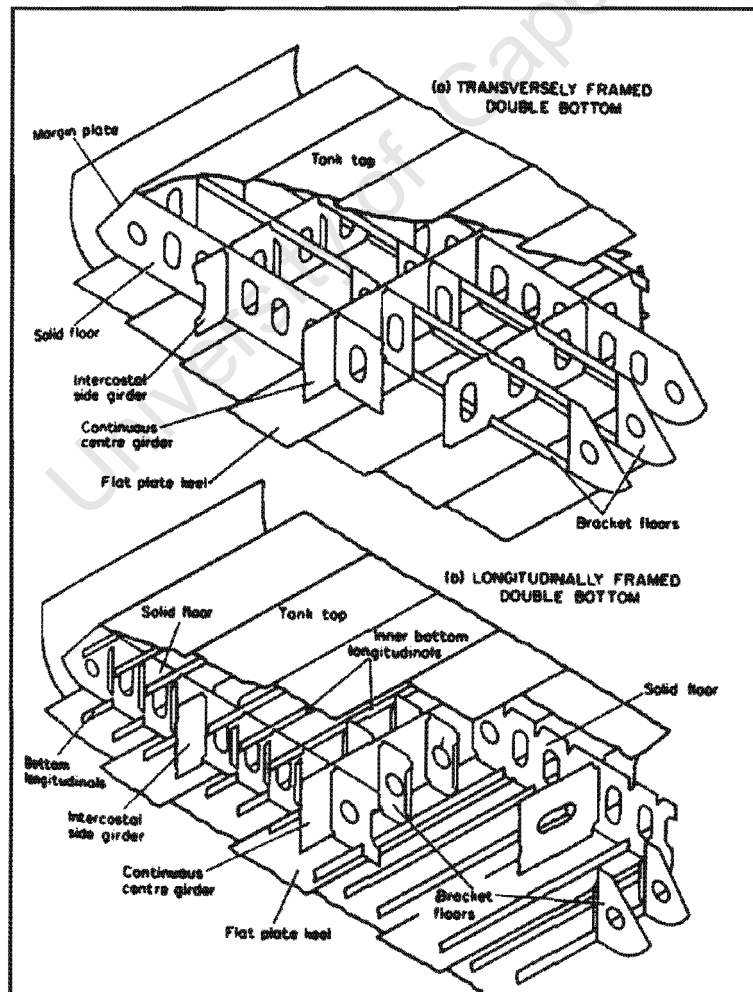


Figure 1.2 - Double bottom construction (illustration by Eyres[2])

1.3.1 Transversely Framed Double Bottoms

In the case of transversely framed double bottoms, solid plate floors with bracket floors located at every frame space, provide the strength. Some areas requiring additional strength, for example, in way of the machinery spaces, may have solid floors at every frame. Under general cargo holds, or cargo oil tanks, bracket floors are typically located at every frame, with every fifth or sixth frame space, being a solid floor, or in way of tank bulkheads.

Depending on the beam of the vessel, either one or two⁸ intercostal side girder would be provided on either side of the centreline girder, to reduce the effective span of the transverse floors.

1.3.2 Longitudinally Framed Double Bottoms

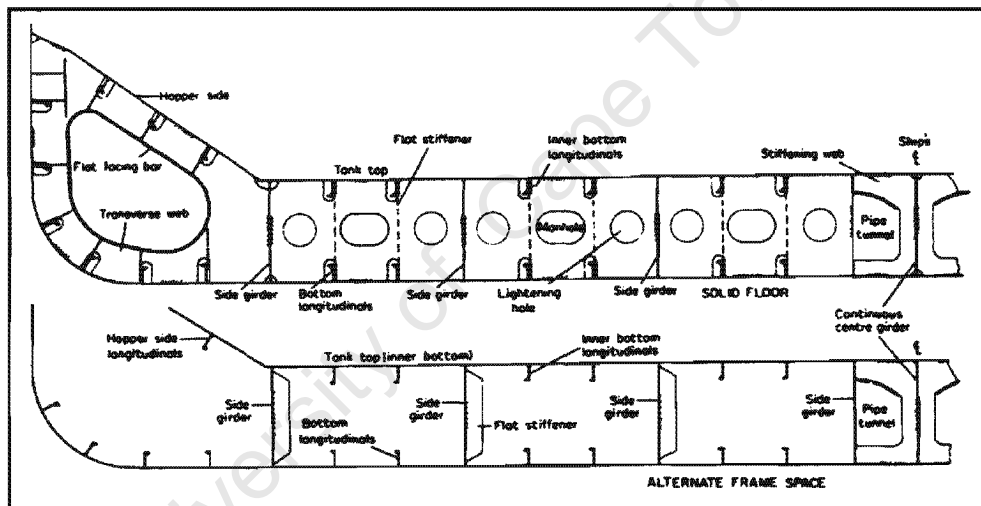


Figure 1.3 - Typical double bottom structure of a bulk carrier. (illustration by Eyres[2]).

In the case of longitudinally framed double bottoms, solid floors are located at larger intervals, in the longitudinal direction, but not exceeding 3.8m, with continuous longitudinal stiffeners, spaced at closer intervals (typically in the order of 0.6m in the transverse direction), intersecting the transverse floors. These longitudinal members would be continuously welded to both the bottom shell and to the underside of the tank top. The transverse floors would have cutouts to allow the longitudinal members to be continuous.

To reduce the span of the longitudinal stiffeners, vertical angles or channel bar struts may be provided at each bracket floor.

1.4 FRAMING

1.4.1 Transverse Framing

In general cargo ships, including bulk carriers, the hold sides are generally transversely framed, even if the double bottom and deck is longitudinally framed. This is due to the vertical span between the bottom hopper tanks and the upper hopper tanks being much less than the longitudinal span between bulkheads. The vertical transverse frames can thus be unsupported, whereas if they were running longitudinally, deeper transverse frames would be necessary to break their effective span. Such deep frames would interfere with the grabs during discharge, and would become damaged. Secondly any horizontal frame or section located in a hold, would tend to trap cargo, whereas vertical frames, or even vertical corrugated bulkheads do not tend to trap cargo.

Transverse framing may be used in the case of general purpose vessels, like the Mining Vessel in the case study. The Mining Vessel has transverse framing throughout, ie bottom sides and decks. This type of design utilizes longitudinal bulkheads, longitudinal girders, and side stringers, to support the transverse frames, thus reduce their effect span. The longitudinal (deep) girders, whether on the bottom or deck, would normally be aligned above each other, viz bottom girder - 1st deck girder, main deck girder etc., so as to facilitate the use of pillars between decks. The pillars along with transverse bulkheads, would then reduce the unsupported span of the girders.

Where the ⁹deckhead is higher than 2 to 2.5m from the deck, side stringers are used, which are typically up to 3 times the section depth of the intersecting transverse (vertical) frames. Class rules specify the scantlings (depth, section modulus etc) of the side stringers relative to the intersecting transverse frames.

1.4.2 Longitudinal Framing

Longitudinal framing was explained under the previous section covering longitudinal framing of the bottom structure.

In cases where longitudinal framing is employed for the side framing, the longitudinal members, often bulb sections or large angle sections are closely spaced in the vertical direction, just as the bottom and deck stiffeners are closely framed in the transverse direction (typically 550 to 750mm). Larger transverse frames or girders spaced at wider intervals, then support these bottom side and deck stiffeners. A typical spacing of transverse frames on a longitudinally framed ship would be 2 to 3m.

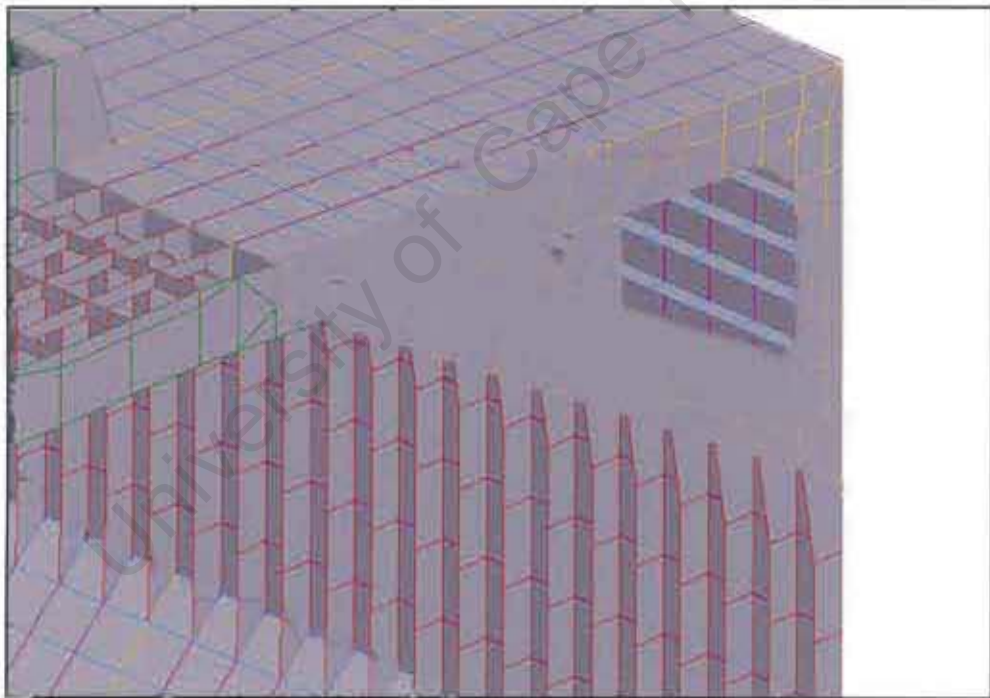


Figure 1.4 - Transverse side frames (red) clearly indicated in this Finite Element plot, of the bulk carrier Ferosa. The longitudinal side frames or stiffeners (light blue) of the upper hopper tank are visible through the cutout of the deep transverse frame (yellow). The yellow line on the deck indicated the position of the next deep transverse frame.

CHAPTER 2 SHIP STRUCTURAL ANALYSIS

This chapter deals broadly with inception stages of analysing typical ship structures as described in the previous chapter.

The structural response of most ship types, but bulkcarriers in particular, would be addressed;

- firstly on a global level, where the primary structure, along with the relevant primary loads are considered to give a overall global response, and then
- secondly on a modular or module level, where secondary structure, which is typically a division of uniform structure, is loaded according to the response of the primary structure, coupled to any secondary loading not already considered.

2.1 HULL GIRDER ANALYSIS (Primary Structure)

The overall structure of a ship is generally considered to be essentially a floating beam that is internally stiffened and subdivided.

An overall response analysis considers the effects of the environmental loads on the overall structure in terms of bending moment, deflection and bending stress and shear stress. The outcome of the overall response analysis constitutes the loads and the boundary conditions at substructure level.

Hull girder analysis deals only with longitudinally integrated forces and moments as dealt with in simple beam theory. Of shear forces, longitudinal bending moment in vertical and horizontal planes, and longitudinal twisting moments, the most important and significant is the vertical bending moment. The load being principally made up of the difference in longitudinal load distribution and the longitudinal hydrostatic pressure distribution accentuated by waves.

Vertical bending occurs along the length of the ship, being zero in magnitude at the ends and a maximum in the vicinity of midships. The maximum value of the vertical bending moment being considered as the most important load effect in the design of ships.

Horizontal bending loads (typically 20% or less than that of vertical bending loads, but up to 50% in certain large tankers) arises out of the ship being at an inclined attitude due to rolling and in quartering seas where a crest of a wave on the one side of the ship is in phase with a trough on the other side, causing a horizontal pressure difference.

In using simple beam theory (Bernoulli-Euler) the following assumptions are assumed to be implied:

- i. Plane cross section remain plane.
- ii. The beam is essentially prismatic (no openings or discontinuities)
- iii. Other modes of response eg. transverse deflection and distortion, caused by shear and torsion do not effect the hull girder bending and can be treated separately
- iv. The material is homogeneous and elastic.

The hull girder stress σ_x is given by:

$$\sigma_x = M_z \cdot y / I_{xx} = M_z / Z$$

where M_z = the longitudinal bending moment
 y = the distance from the neutral axis to the outer most surface of the beam
 I_{xx} = the second moment of area about the neutral axis, in the vertical direction (in the case of a ship)
 Z = the section modulus = I_{xx}/y

In the calculation of the hull girder stress σ_x is greatest when y is greatest, thus at the upper and lower edges of the section. Since the neutral axis does not usually pass through the geometric centre of the beam (hull), there are two values for y , y_D for the deck and y_K for the keel. There are thus two values of section modulus Z , $Z_D = I/y_D$ and $Z_K = I/y_K$. Due to the bottom structure typically being more sturdy than the deck, y_D is usually larger than y_K resulting in larger stresses in the deck than the bottom.

Departure From Simple Beam Theory

Simple beam theory states that the stress is constant across horizontal decks and varies linearly in the sides. Several factors cause actual stress patterns to differ from this idealized distribution.

- i. Due to transverse shear there is longitudinal distortion of the cross section known as "warping", thus plane cross sections do not necessary remain plane.
- ii. The hull girder is not prismatic and has large openings, discontinuities, and transverse bulkheads.
- iii. Shear lag

For ships where no major changes in cross section occur, other than hatch openings, the longitudinal stress due to hull girder bending generally corresponds well to that predicted by idealized beam theory, excluding local effects such as the stress concentration around openings. For these cases the effects of shear, transverse structures and openings can be calculated separately.

For ships with significant changes in cross section, the load effects can only be assessed at hull module level. The boundary conditions for the module being obtained from a non-prismatic hull girder analysis using methods such as finite elements.

Shear forces can be quite significant in certain vessels such as bulk carriers where alternative holds are loaded, and in vessels with large and numerous deck openings resulting in low torsional rigidity, such as container ships.

Hughes clearly states that the ideal is to model a structure as a single unit. He would go on to say that "present day computational means are not yet adequate for the complete procedure to be applied to a structure as large and as complex as a ship." This was stated in 1983, and as the report of this study continues, it will appear that the findings were fairly conclusive as to just how ideal a complete model is, and that by the year 2000's computational means, it can be argued that they are adequate, although still very large.

The most time consuming exercise is the human input into modelling. It could be argued

that the same, or possibly more time is required to model a hull girder (crude model) plus a detailed hull module, than to model one detailed model. This comparison would be very much dependant on the hull geometry, ie. how much of the hull is parallel, and thus generally of uniform structure, which can be duplicated, when modelling.

The advantages of one model will be illustrated later in this report, but briefly entails the transfer of loads from a global model to a detailed model. The disadvantage of one complete model, other than the exhaustive run times, is the checking time, ie. every time a correction or change is made the model has to be re-run.

2.2 HULL MODULE ANALYSIS (Secondary Structure)

In order to account for all of a structures interactions, the structure should be designed and analysed as a whole. This however involves extremely complex computational modules, thus it becomes necessary to subdivide the overall structure into fairly uniform substructures. Even at this level, not all the interactions between sub-substructures can be accounted for, thus these will be analysed individually as local structures.

In order to prevent inaccuracies regarding interactions between substructures: in response, limit states and optimality, the divisions must be made in such a way that these interactions are most accurately portrayed. ie.

- i The substructures must be sufficiently small, cohesive, and regular as to make its rationally-based design both feasible and practical.
- ii It must be sufficiently large and sufficiently autonomous in response, its limit states, and its effect on the overall structure, such that no significant characteristic of the overall structure is lost, and such that all significant interactions which do exist can be fully accounted for.
- iii By locating the hull module boundaries at transverse bulkheads, the structural interaction between hull modules can be minimized. Hughes emphasised that each hull module must be defined such that a complete set of boundary conditions can be established for it from the hull girder analysis.

It will be shown in this report, that particularly from the Ferosa Study, just how important it is to be able to extract boundary conditions directly related to the geometry of the hull girder module, which without discussing it in detail at this stage, can mean that the mesh geometry and density at the boundary of the hull module has to be the same as the mesh geometry and density of that part of the hull girder, causing the girder to have a much finer mesh than otherwise necessary, further supporting the argument for one model of the entire structure.

CHAPTER 3 LOADS & RESPONSES

In order to run an analysis on ship structure, whether it be for the purpose of determining the strength of existing structure, or for the purpose of designing new structure, the applicable loads have to be identified and quantified. In referring back to the previous chapter, with reference to hull girders and hull modules, loads also have to be categorized, as being global or local.

The principal loads on ships can be classified as follows:

- i. Static Loads
- ii. Slowly Varying Loads
- iii. Rapidly Varying Loads

3.1 STATIC LOADS

3.1.1 The buoyancy or hydrostatic loads, are a function of the displaced shape of the partially submerged hull, at a specific draft, trim and heel, are equivalent in magnitude to the combination of the self weight of the structure, and the static cargo loads. By integrating the ¹weight distribution against the ²buoyancy distribution, the shear forces along the length of the vessel are obtained, when integrated, result in a shear forces distribution, and integrated again, result in a bending moment distribution.

The calculation of weight distributions, buoyancy distributions, leading to shear force and bending moments calculations, are generally termed by Naval Architectural publications and computer programs, as “a static longitudinal strength calculation”, and will be often be referred to as such in this text.

3.1.2 Dry docking loads play less of a role in the design phase, as vessels are normally docked with minimum cargo, and are supported throughout their length. Thus a design that can withstand operational load requirements, should be able to withstand normal dry docking loads. However care must be taken when docking vessels to minimize trim so as to reduce the bearing pressure on the section of the keel which first comes into contact with the docking blocks.

In certain rare occasions large cargo ships have to be docked whilst heavily loaded. In such case specific docking calculations are undertaken to ascertain that the bearing pressure from any one docking block does not exceed what the local structure in way of that block can withstand. Note, every block takes a different load, depending on the weight distribution, and the deflection of the hull bottom.

¹ The weight distribution, as a weight unit function of length (eg. tonne/m), is the sum of the self weight of the structure per unit length, combined with the sum of all other static loads, eg. cargo, fuel, water, ballast etc, tallied as a function of length. The distribution of the latter being calculated from the shape of the spaces in which they are contained, or the distance over which they are spread, in the case of cargo.

² The buoyancy distribution, as a weight unit function of length (eg. tonne/m) is calculated from the changing displaced shape of the hull, over length. Most methods consider the ship divided into number of finite sections, each of which have a submerged area. By summing the areas over length, the buoyancy distribution is obtained.

A case study of such an analysis, on a damaged grain cargo bulk carrier, is presented in chapter 7.

3.1.3 **Thermal loads** are not considered in most ship structural analyses.

3.2. SLOWLY VARYING LOADS (PSEUDO STATIC)

3.2.1 Pseudo static loads are primarily due to **wave induced dynamic pressure**, the effect being a wave induced hull girder bending moment, meaning the difference between the still-water pressure distribution and that of the wave-induced pressure distribution. The total load on the hull girder being the sum of the two.

Typically the wave-induced pressure distribution is calculated from the ship motion analysis, but methods exist whereby the value of the extreme wave-induced (vertical) bending moment can be calculated by approximate, yet reasonably accurate expressions.

Such methods normally consider a longitudinal strength calculation, as already described for a still-water buoyancy distribution, but now considering the vessel afloat in ³equilibrium, on a static wave of trochoidal, or sinusoidal shape, of specified wave height, specified wave length, specified position (or phase) of the crest relative to the vessel, and specified angle of encounter.

In static hull module analysis these wave-induced hull girder stresses, combined with the still-water hull girder stresses, constitute the loads at the ends of the module.

3.2.2 **Sloshing of liquid cargoes, shipping of green seas, wave slap on sides, inertia loads** are all calculated by ship motion analysis. The magnitude and duration of these effects are that they are not usually included in the analysis, but may, on occasion, be investigated as part of a damage enquiry.

3.2.3 Methods and expressions exist for the calculation of **launching, berthing and ice-breaking loads**, but these are also less general in their use in structural analysis.

3.3. RAPIDLY VARYING LOADS

3.3.1 Slamming

Bottom slamming occurs when the ship's bottom emerges from the water and subsequently undergoes severe hydrodynamic impact on re-entry, due to the pitching motion combined with a wave trough. The impact is often of sufficient intensity and short duration to cause a high intensity pressure pulse, felt as a whipping effect on the bottom plating, and accompanied by a loud slamming sound.

3

Afloat in equilibrium - means the method of calculation or computer program, balances the weight distribution of the vessel against either a still water, or static wave, buoyancy distribution, in order to determine the depth (draft) and attitude (trim and heel) of submersion. One can appreciate varying the phase (or position of crest) of the wave, would significantly influence the trim of the vessel, for a wave encountered on the bow or stern.

Bow flare slamming differs due to the geometry of the flare and is less intense and of longer duration. No or little slamming sound is heard, although fairly severe forces are imparted to the forward part of the ship. They are independent phenomena and can occur one without the other.

Slamming has important effects at two levels of the structure.

a. *Hull Girder Level*

Slamming causes sudden vertical acceleration and deflection of the bow, resulting in vibration of the hull girder, principally in the two-node mode, but also at higher modes. The hull girder flexural vibration is known as whipping.

The case study involving stress monitoring onboard a mining vessel, as included in this report, includes stress recordings measured whilst the vessel was underway, clearly illustrating the effects of whipping, seen as higher frequency, small amplitude stress fluctuations.

b. *Principal Member Level*

The principal member level refers to the shell plating and its related stiffeners, frames and webs etc, all of which are subjected to high impact pressures. These impact pressures cause deflection of the principal members setting up vibration, particularly in the plating. The calculation of slamming response requires detail information on pressure distribution in terms of time and space, and are related to the bottom shape and forward speed of the vessel.

3.3.2 Forced Vibration

Forced vibration comes about as a result of engine, shaft and propeller vibration, and although not considered severe loads, need careful consideration in designing to avoid resonance, and to reduce fatigue.

3.3.3 Springing

In the case of flexible ships, like the Great Lakes Bulk Carriers, the period of two-node vibration can be sufficiently long that it can be excited by the shorter period components of encountered waves. This form of vibration is termed "springing". Normally the period of the waves encountered are longer than the longest natural period of the ships hull girder. When springing occurs it generally does not last for more than a few cycles as it is dependant on so many coincident factors. It is characterized by large deformations of the hull girder and contributes to the overall hull girder fatigue, rather than excessive stresses that lead to failure of the hull.

3.4. LOADS APPLIED TO THE HULL GIRDER MODEL

For the purpose of this study with relation to results obtained from linear static finite element methods, only static and pseudo static loads are applicable. The dynamic effects correspond to variations of stresses recorded, which are of small magnitude and duration,

which would appear as “noise” on the graphs, and are not considered in detail.

If an analysis specifically requires the calculation of dynamic responses, which would include the effects of inertia, resonance etc, or the loading to be applied includes dynamic (time based) considerations, then a non linear analysis should be performed. Non linear analysis of large models are normally heavier on resources than an equivalent size linear static analysis, with significantly longer run times.

3.5. LOADS APPLICABLE TO RECORDED STRESSES

For the purpose of results obtained from the hull stress monitoring, and with particular reference to the Mining Vessel Case Study of chapter 8, all load types as described in the previous section are applicable, but not necessarily discernable from one another. This being due to the data being recorded whilst the vessel was being subjected to all dynamic factors influencing the vessels response at the time.

Certainly the static “still water” contribution towards the recorded stresses is calculable, based on the known condition of loading of the vessel, offset against the known depth and attitude of submersion, of a known hull shape. The pseudo static effects are clearly seen as cyclic stresses due to the wave / swell action.

i. Static Loads

- i. External and internal loads resulting from buoyancy and cargo. (Still-water loads)
- ii. Dry-docking loads
- iii. Thermal loads

Slowly Varying Loads

- i. The wave induced dynamic pressure distribution on the hull due to the combination of wave encounter and the resulting ship response.
- ii. Sloshing of liquid cargoes.
- iii. Green seas on deck.
- iv. Wave slap on the side plating and foredeck.
- v. Inertia loads, primarily on tall structures, but also on decks and frames.
- vi. Launching and berthing loads.
- vii. Ice-breaking loads.

Rapidly Varying Loads

- i. Slamming
- ii. Forced vibration; pressure pulses from the propeller.
- iii. Springing.

CHAPTER 4 PRACTICAL FE MODELLING OF SHIP STRUCTURES

This chapter deals with practical aspects of FE modelling of ships structures, generally pertaining to:

- the selection of mesh densities,
- element selection,
- modelling of local structures for local loads. An example being, the underdeck structure to support specific deck loads, which includes the modelling of underdeck beams and girders, pillars, bulkheads etc.
- detailed plate analysis, for example helicopter deck analysis for crash landing

4.1 FRAMING VS MESH DENSITY

With properly designed ship structures being framed according to a rational and uniform system, the following considerations were established from experience with respect to FE modelling:

- It is important to always design the finite element mesh in accordance with the framing of the structure concerned.
- When modelling a hull girder, where the emphasis may only be on the plate and not the associated stiffening, there would be a tendency to create a mesh which not only does not tie in with the location of the framing, but may also be coarser than the geometry of the actual frames.
- Coarser meshes are normally due to limitations of the program with regard to the size of the problem, in terms of number of elements and number of nodes.
- A major short coming of mismatching the FE mesh to the actual framing of the structure may come in at a later stage when it is too late to change the mesh design. Typically all applied local loads bear down on frames, girders, bulkheads or longitudinal stiffeners, thus the nodes will already be in position, and local elements will not have to be split in order to create nodes in the correct positions.
- Should the hull girder model not be able to support itself, rather than fictitiously increase the plate thickness or increase the stiffness of the material, it is more efficient and far more accurate to include actual stiffeners at those points of concern.
- In cases where the hull girder model cannot support itself, (gravitational loads) or cannot support the static loads applied, due to insufficient stiffening, or no stiffening being included at the early stages, the displacement of local unsupported plates are often so exaggerated that it clouds the more subtle overall displacement, i.e. ¹hogging or sagging, to the extent that it renders the result useless.
- When trying to use the outcome of one model, as input into a smaller more detailed model, mismatch of node positions from the coarser model to the detailed model can lead to excessive complexities.
- It is often more effective and efficient to increase the mesh density, where required, in the coarse model, so that loads are transferred from the coarser region to the detailed region automatically, and more accurately.
- With the more recent developments in PC hardware technology, from the mid 90's, with ever increasing capacities of memory storage, coupled in quantum leaps in

¹

Hogging or Sagging, refers to the overall deflection of the hull girder. Sagging being the convex longitudinal deflection of the ship's bottom, and hogging being the concave longitudinal of the ship's bottom.

terms of processor performance, PC based FE programs have largely done away with implicit limitations on the problem size. It is left at the discretion of the user as to how much run time he can afford. Some problems tend to be one off runs, in which case longer run times are affordable, whereas projects that require many iterative steps of analysis for optimization, generally favour faster running models, to reduce waiting time.

4.2 COURSE MESH MODELLING OF STIFFENED PLATES

The following figures illustrate a finite element mesh which is based entirely on the actual frame spacing of the structure. By modelling the deck plate (blue) according to the frame spacing of the structure, the girders and secondary stiffeners automatically tie in with the deck nodes. Note the webs of the girders are modelled using 3D plate elements, of a certain plate thickness, while the flanges are modelled using plate elements of a different plate thickness, shown in a different colour. In the model below, the secondary (smaller) longitudinal deck stiffeners, 150x90x10² Angle (L) are modelled using offset beam elements, so as to reduce the mesh complexity at intersection points between the longitudinal stiffeners and the transverse girders.

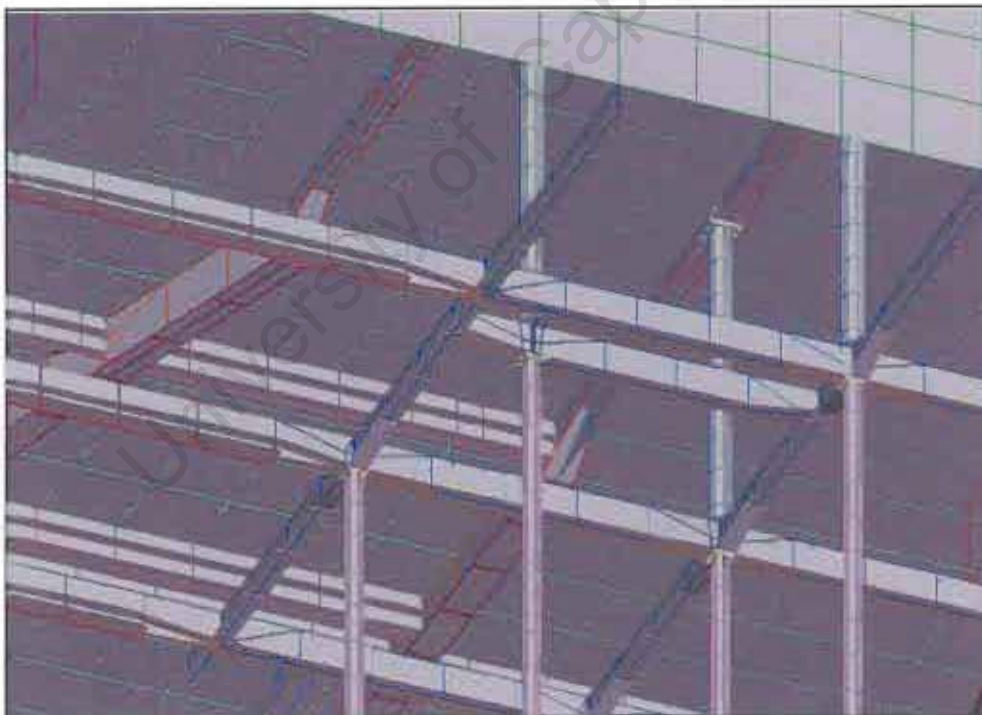


Figure 4.1 - Underdeck stiffening of a mining vessel, illustrating the modelling of deep girders as plate elements, while the smaller section transverse frames are modelled as beam elements, coinciding with the deck plate nodes.

4.3 COLUMNS

The columns are either modelled using 3D Beam elements, or by 3D Plate elements as shown above. In the above figure, a 12 sided column was modelled using plate elements, as they enable better presentation of stresses, although the same results should be achieved.

The intersection of the columns and the beams they support, require additional consideration. When using 3D Beam elements attached to a plate element underdeck girder, artificially high stress concentrations are often displayed at the intersection node. This is due to the load being applied to an infinitely small area of the plate. Using brick elements as a ³doubler, is often a good method to distribute the load into the adjoining plate, however, brick elements do not have rotational degrees of freedom, thus the (beam element) column will be considered pinned at the intersection. A method to overcome this shortcoming is to add one or two spokes off the intersection point, to another node on the brick element, thereby ensuring efficient transferral of rotations.

Although the columns depicted in *Figure 4.1* above, were modelled using plate elements, the brick element doubler technique was still employed, as can be seen by the yellow elements at the head of each pillar/column. A close up of the brick element doubler is illustrated below in *Figure 4.2*.

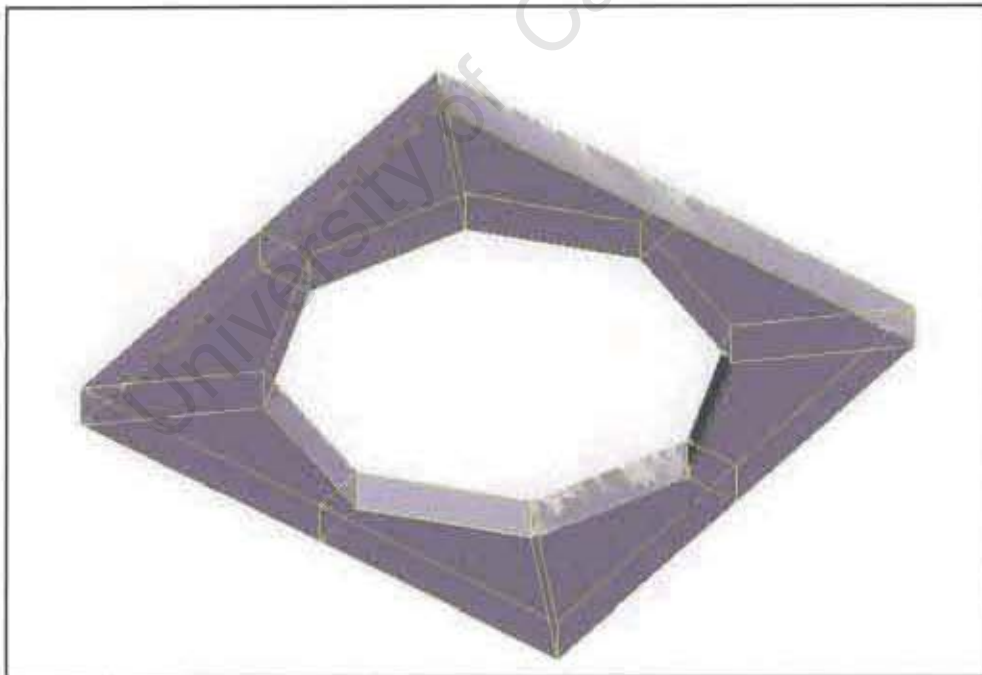


Figure 4.2 - A plate doubler made up of 6 brick elements, used at the top or bottom of a 6 sided plate element pillar (pillar not shown), in order to better distribute the forces into the adjoining structure.

³

A doubler is a piece of plate (generally thicker than the original plate) welded onto the original plate, to better distribute loads into the primary structure, and to add local stiffening. This could be at the base of a pillar, ie. a doubler on the deck, or it could be used at the head of a pillar, ie. a doubler under the flange of the associated beam to which the pillar is being attached.

4.4 ILLUSTRATION OF MODELLING METHODS FOR UNDERDECK STIFFENING

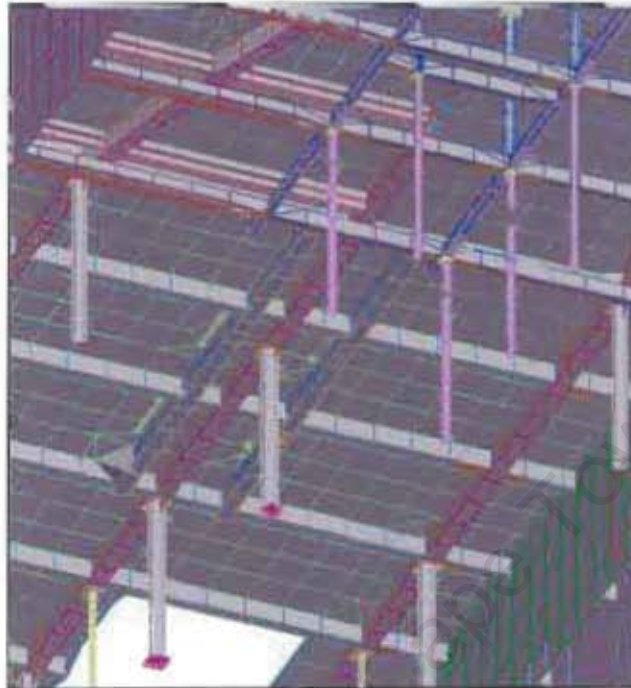


Figure 4.3 - Underdeck stiffening of the shelterdeck of a mining vessel, illustrating typical modelling techniques in course meshing of ship structures. Fine meshing would only be undertaken at problem areas.



Figure 4.4 - In this case the pillars were modelled in more detail as their intersection with the girders, indicated higher stress areas. This vessel was transversely framed, with deep transverse girders spaced every 4 frame spaces.

Further examples of typical meshing methods which correspond to the framing system of the physical structure will be illustrated in chapters 5 & 6, on Hull Girder and Hull Module Analysis.

4.5 HIGHER MESH DENSITIES FOR DETAILED PLATE ANALYSIS OR SPECIFIC CONCENTRATED LOADING.

Where detailed stress and displacement results are required for a specific region, of a larger model, or due to specific loading in one region, the mesh density would be increased well beyond the frame spacing, but would still tie in with the global framing. An example of such a detailed analysis, is illustrated in the following figure, which was extracted from a helicopter deck analysis, recently undertaken by the author, where crashing landing on one wheel had to be investigated in terms of plate failure.

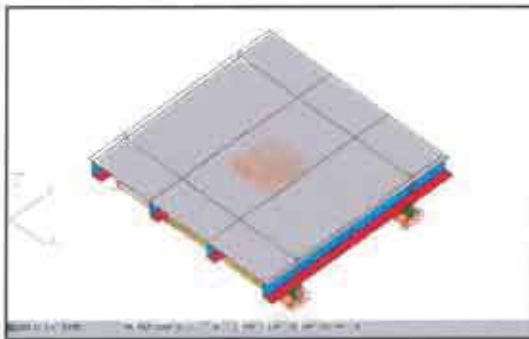


Figure 4.5 - Top view of three bays of the helideck. Note the applied pressure (orange arrows) over an area equivalent to one footprint of a wheel.

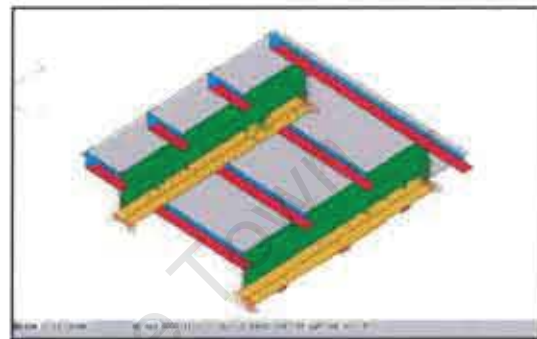


Figure 4.6 - Bottom view of the same three bays of the helideck. Note different thickness plates are denoted by different colours.

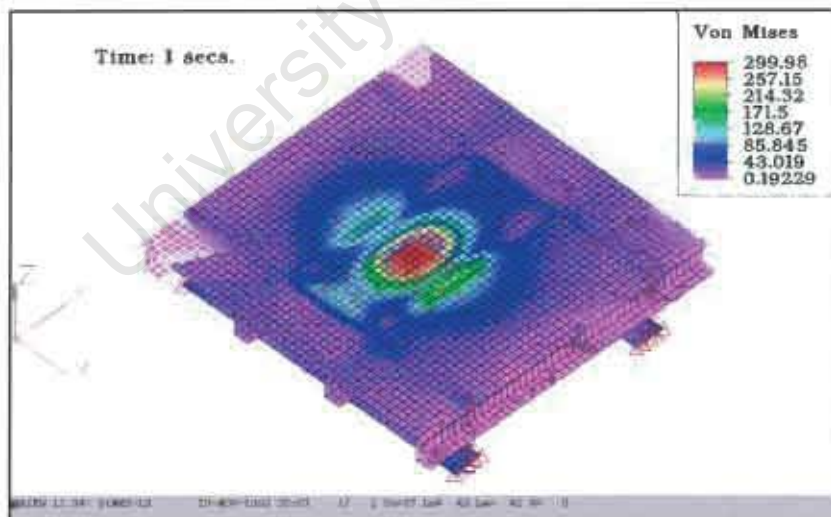


Figure 4.7 - Stresses in the deck plate, viewed from above. Stresses shown to be at yield stress for 300WA steel.

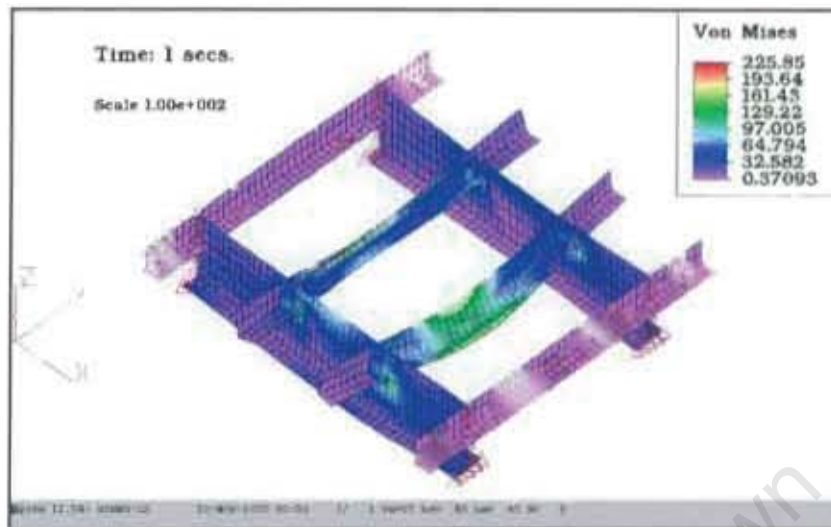


Figure 4.8 - Displaced beams, indicating high stresses at midspan as expected, but also at the intersection with the girders.

Due to the above analysis involving stresses and displacement bordering on the elasto-plastic limits of the material, ALGOR™'s Non Linear (Mechanical Event Simulation) module, using non linear materials was used.

Other than selecting non-linear plastic model, the load could also be subjected over time, and reduced over time. In this manner, any displacement showing up, once the load had been removed, would be permanent set, as a result of the plastic yielding.

The classification society, Lloyds Register of Shipping, allows plastic deformation of the deck plate, in the case of crash landing, as long as total destruction of the helideck does not take place. In other words the beams should be able to withstand the load, thereby keeping the helicopter from falling through/off the deck. In the event of crash landing, the affected plate would be replaced.

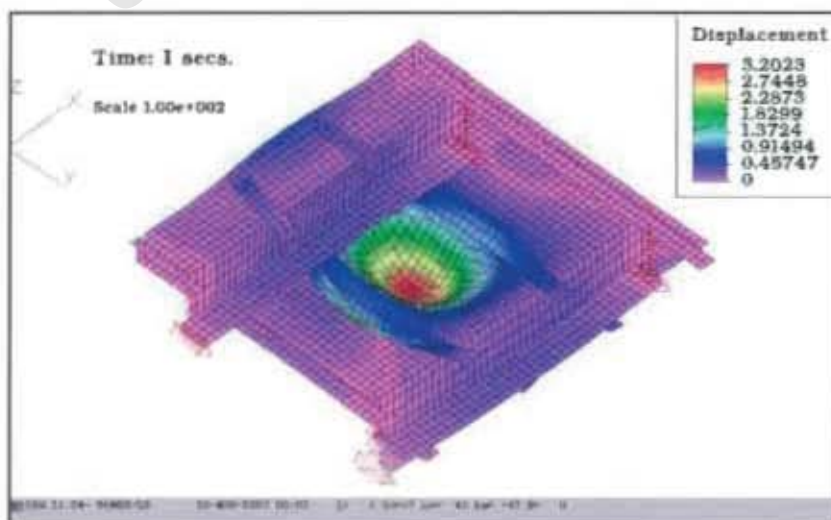


Figure 4.9 - Displacement Plot indicating a deflection of 3.2mm, which by reference to the plate stresses would be on the point of experiencing permanent set.

1.4.2 Longitudinal Framing

Longitudinal framing was explained under the previous section covering longitudinal framing of the bottom structure.

In cases where longitudinal framing is employed for the side framing, the longitudinal members, often bulb sections or large angle sections are closely spaced in the vertical direction, just as the bottom and deck stiffeners are closely framed in the transverse direction (typically 550 to 750mm). Larger transverse frames or girders spaced at wider intervals, then support these bottom side and deck stiffeners. A typical spacing of transverse frames on a longitudinally framed ship would be 2 to 3m.

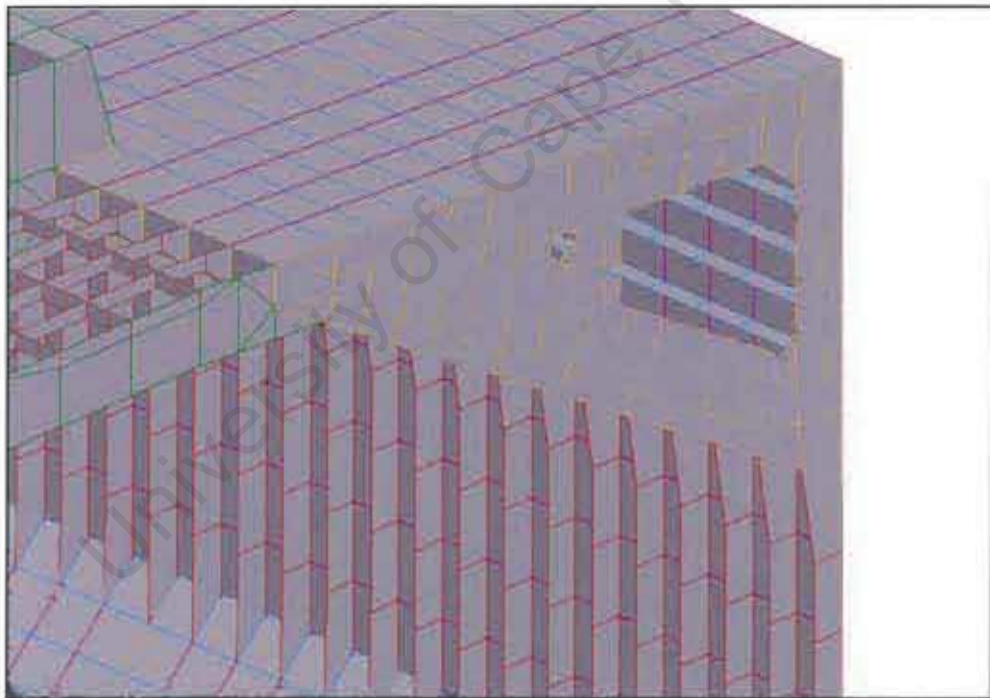


Figure 1.4 - Transverse side frames (red) clearly indicated in this Finite Element plot, of the bulk carrier *Ferosa*. The longitudinal side frames or stiffeners (light blue) of the upper hopper tank are visible through the cutout of the deep transverse frame (yellow). The yellow line on the deck indicated the position of the next deep transverse frame.

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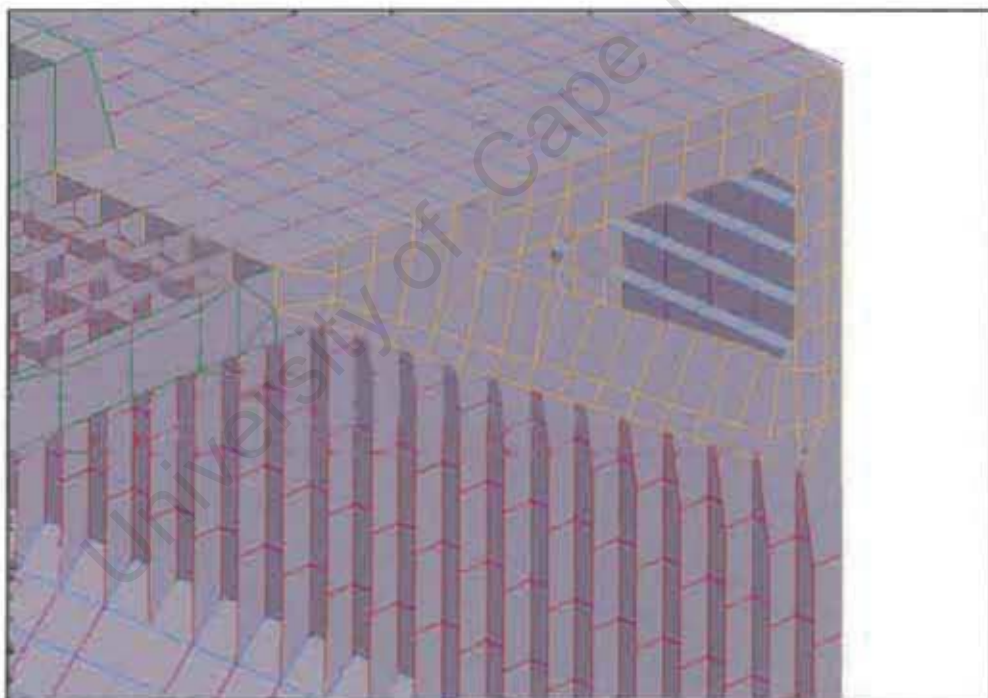


Figure 1.4 - Transverse side frames (red) clearly indicated in this Finite Element plot, of the bulk carrier Ferosa. The longitudinal side frames or stiffeners (light blue) of the upper hopper tank are visible through the cutout of the deep transverse frame (yellow). The yellow line on the deck indicated the position of the next deep transverse frame.

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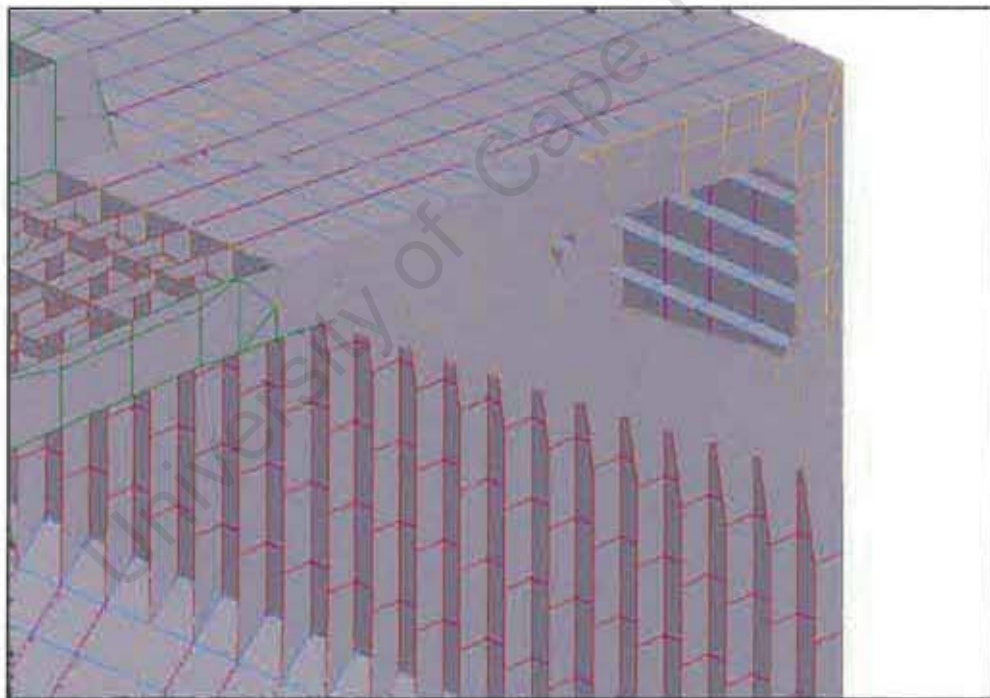


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CHAPTER 5 FE MODELLING OF HULL GIRDERS

Where the previous chapter dealt with general aspects of finite element analysis on general ship structures, this chapter and the next will look in more detail at the Hull Girder / Hull Module method of analysis, strongly advocated by Hughes' [1]. While it can be applied to any ship type, it is particularly well suited to bulk carriers and oil tanks, where a significant portion of the midship region of the ship is parallel and uniform.

5.1 HULL GIRDER MODELLING

The following figures illustrate a hull girder modelled according to Hughes[1] proposed methods for hull girders. The mesh density was restricted by the total number of nodes, to be within the limits of the software, whilst ignoring or largely disregarding the actual frame spacing, both longitudinal and transverse. This was in accordance with Hughes's [1] proposed methods for modelling hull girders.

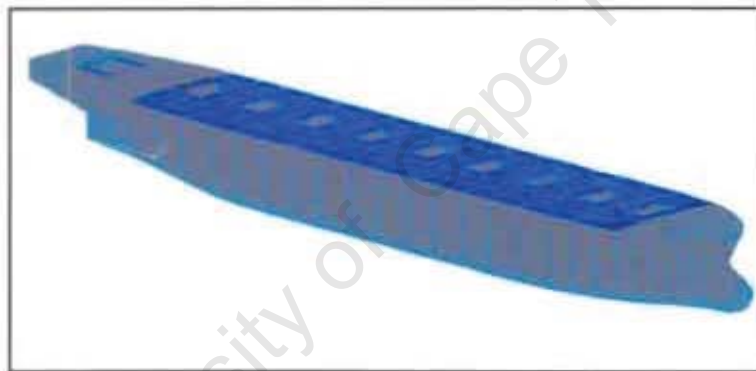


Figure 5.1 - Element Plot (hidden elements removed) of the complete Hull Girder Model

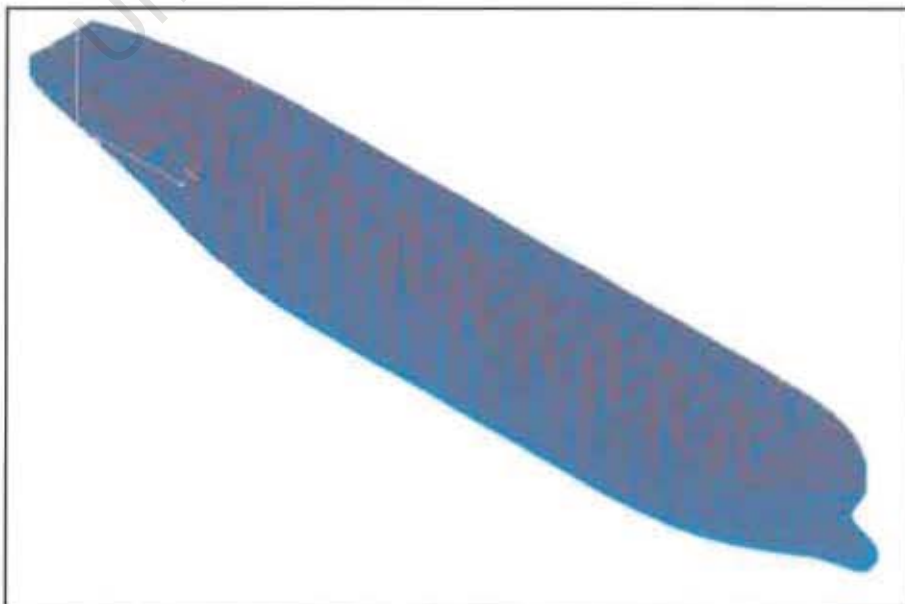


Figure 5.2 - Element Plot of the complete model with the deck and hatch elements removed. The transverse bulkheads clearly shown.

If one takes a closer look at a section of the double bottom structure of the FE model depicted in *Figures 5.1 and 5.2*, it is clear that the mesh is not matched to the framing of the structure, but was selected in order to form a realistic representation of the shape of the structure, while limiting the ¹aspect ratio of the elements to reasonable levels, albeit slightly greater than desired. In some cases a limited number of high aspect ratio elements are inevitable, which is acceptable as long as they are not in the region of concern, and are not considered to be in the load path, but merely to complete the geometry.

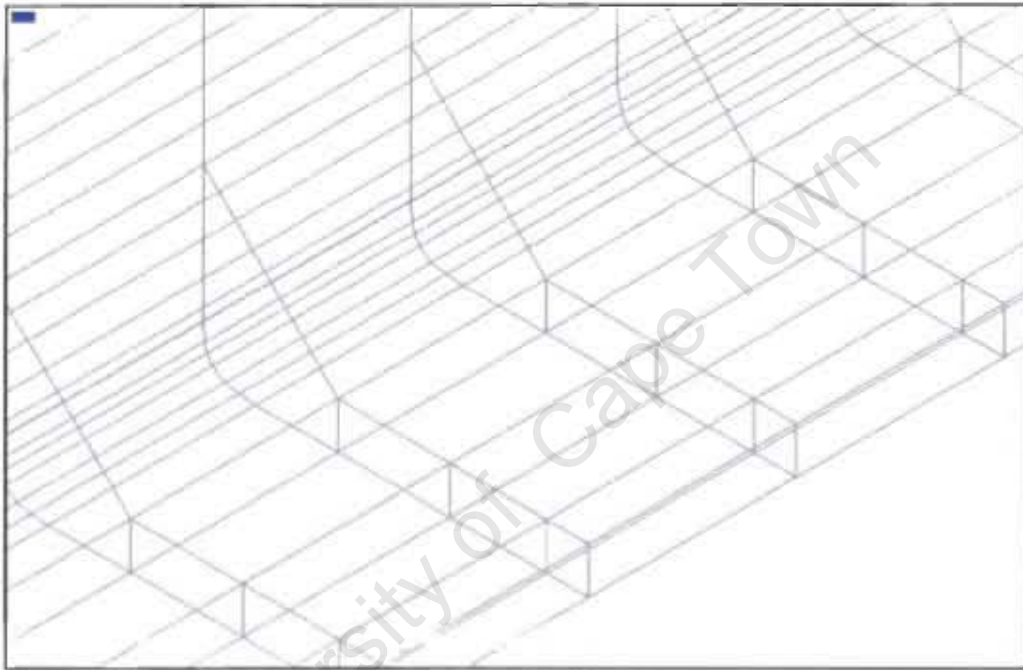


Figure 5.3 - Double Bottom Structure of the Hull Girder - This should be compared with the detailed double bottom structure of the Module model, which follows in the next chapter.

In *Figure 5.3*, above, the double bottom structure is modelled using 3D plate elements. The mesh was selected so as to create a meshed geometry of the complete bottom plate, the tank top plate, the longitudinal inner tank bulkheads (or floors), the centreline girder, and the sloping hopper tank top. These plate regions were made up of single large elements, which extend from the bottom shell to the tank top, and from one bulkhead to the next. This method should be compared with *Figure's 6.3 & 6.4* of the following chapter in which the meshing density of the module, for the same structure, will be discussed.

Note: No local stiffening of the plate is considered, neither in the transverse or longitudinal direction. Nor would it be possible to include stiffening, without re-meshing the entire region concerned.

¹

Aspect Ratio of plate elements is the ratio of the length to the breadth of the individual element. It is generally considered that aspect ratio of a 3D plate elements should not exceed 5. Excessive aspect ratios lead to inaccuracies in the calculation of nodal displacements and subsequently element stresses

5.2 APPLYING LOADS TO THE HULL GIRDER

The primary loads being subjected to the hull girder, when disregarding dynamic effects, are the weight of the vessel, being supported by the hydrostatic pressures on the bottom and side shell.

5.2.1 Vessel's Own Weight

The vessel's own weight should ideally be applied in such a way so that its distribution would result in the vessel floating at the applicable draft and trim, such that when applying hydrostatic forces according to those drafts and trim, the resultant would be zero (i.e. the vessel would be in equilibrium).

As the hull model does not include any internal stiffening, nor does it include the mass of the systems, piping, outfitting, machinery and superstructure, thus additional weight, according to the correct distribution, has to be included in some way or other, in order to result in equilibrium between the weight and buoyancy.

The correct hydrostatic pressures could simply be applied to the vessel, up to a level (depth) predetermined by a stability and loading program. If the hydrostatic pressures (or buoyancy forces) are in excess of the model's own weight (including additional superimposed weights of non-modelled items, and cargo) then the model will have to be restrained from moving. These restraints would tend to be extremely large in magnitude, which in turn will result in excessive stresses and distortion of the structure in way of the points of restraint, which nullifies the whole exercise.

5.2.2 Supporting Hydrostatic Forces

Depending on the software capabilities, the hydrostatic pressure on the bottom and side shell, can be applied to the model in either of two methods.

Where the software supports hydrostatic pressures, these can be applied directly to the submerged elements according to their respective depths below the waterplane.

Where the software only allows for manual application of element pressures the following procedure can be followed, as was the case for the "Ferosa".

- i. Determine the drafts and trim of the vessel, by using a dedicated hydrostatic and stability program, which balances the weight distribution of the vessel, against the buoyancy distribution.
- ii. Develop a simple program which reads in the element geometry, and based on the average depth of all the nodes associated with a particular element, applies an individual pressure to that element based on its depth below the waterplane.
- iii. This procedure is only applicable where the software allows for element and node data to be input via a run file, where pressures can be applied to individual elements, and the numbering of nodes and elements remain unchanged for subsequent runs, or even with the addition of additional individual elements, by number, as is the case for Cosmos/M™.

Figure 5.4 below depicts the pressure loading applied to the “Ferosa” model, using the Cosmos/M program, based on the method of using an external program to calculate the pressure per element based on its location below the waterplane.

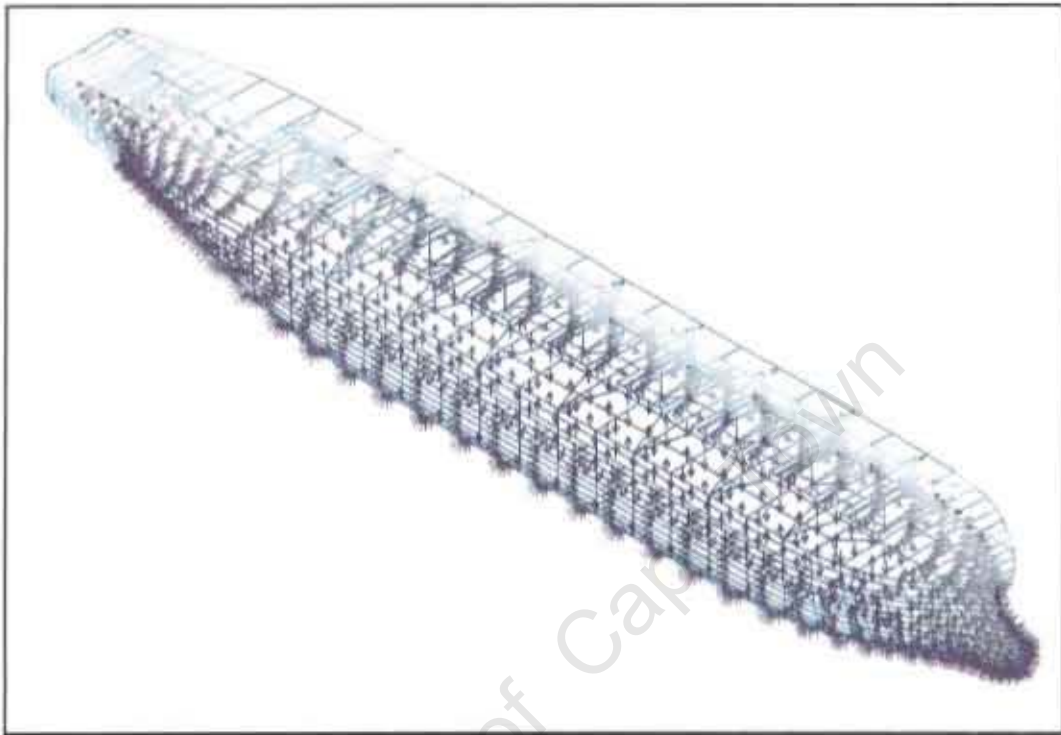


Figure 5.4 - Pressure plot, showing individual element pressures applied according to their location with respect to the waterplane. Notice in this pressure plot, internal pressures applicable to the internal loading of the holds are also applied by the same method, resulting pressure in the counter direction to the external pressure.

Algor™, on the other hand, performs automatic element generation based on geometry of line segments, in which case manual application of pressures per element is not possible. Surfaces have to be defined, for which pressure parameters may be specified, but only on one surface. It is thus impossible to apply an external pressure to the side or bottom plate, and an internal pressure from cargo loading on the inside of the same 3D plate element, as was done in Cosmos/M in Figure 5.4 above.

At this stage Algor's Linear Static Module only allows hydrostatic pressure loading to be applied to brick elements, while uniform pressure loading can be applied to 3D plate elements. In the case of hydrostatic pressure loading, the program calculates the pressure per element internally, based on its location relative to the waterplane.

Algor's Non Linear, Event Simulation Module, does however allow hydrostatic pressures to be applied to 3D plate elements, but for some reason, it is a global setting, and not a regional setting, thus the hydrostatic pressures can only be applied to all plate elements within a model, which is totally impractical. They have indicated that further development will take place in rectifying this for future modules.

5.2.3 Additional Weight Distributions resulting from fluid and cargo contained in Holds and Tanks

The calculation and application of individual loading as a result of pressure distributions applicable to tanks and holds containing fluids or homogeneous cargos, can be arduous if performed manually.

If the bending response of the hull girder is to be realistic, then all sub loading has to be applied as per the actual loading of the vessel. There are however hydrostatic and stability programs which calculate the weight distribution of filled or partially filled tanks. However in applying these loads to the model, individual element pressure have to be applied, thus the same method as used for the outer shell element pressure would have to be used for each tank and holds containing fluids or homogeneous cargos.

If the local stress distribution is of less importance than the overall longitudinal weight distribution, for a hull girder model, then the load per region, (ie. load per hold), can be calculated separately and then applied as a uniform pressure to each of the affected components, namely, the tank top plate elements, the sloping hopper tank top plate elements, and transverse bulkheads etc.

This method was used to perform an analysis which would investigate the effects of docking the damaged bulkcarrier "Decurion", which is discussed in more detail in Chapter 7, as a case study on module analysis.

²

The bulkcarrier, "Decurion" fully loaded with 60 000 tonnes of grain, was damaged when a Container Vessel collided with her, just outside the port of Cape Town, in Feb 2000. The Container Vessel struck approximately midships, opening a hole some 13m in height, flooding Hold 4, and partially flooding Hold 5.

CHAPTER 6

FE MODELLING OF MODULE STRUCTURES

This chapter in the 2nd stage or progression of analysing a ship structure in terms of the Hull Girder / Hull Module procedure, and follows on from Chapter 5.

6.1 GENERAL MODELLING OF HULL MODULES

In the case of the modelling of the module, it is not only preferable but imperative to create the mesh according to the framing system of the ship structure concerned. Stiffeners, particularly deep girders, are often modelled in detail using plate elements, so as to see the detailed stress patterns within the stiffener concerned.

In order to simplify the intersection between perpendicular stiffeners, and to avoid excessively high aspect ratios on the narrower flanges, the flange is often not modelled in detail with plate elements, but replaced by beam elements of similar sectional properties. In cases where the size relation between the smaller stiffener, vs the larger girder is excessive, or where the frame spacing is such that the aspect ratio on the flange and web would be excessive, it is was found that the stiffeners should be modelled as beam elements.

Beam elements are preferred to truss elements for the flange of or stiffener, in substitution to using long narrow plate elements. Truss elements modelled as the flange of a stiffener or girder, can only contribute to the axial strength, and not to any bending strength. Admittedly the flange is predominantly under tension or compression, but using a beam element for this purpose provides for the axial contribution just as effectively as the truss element. If modelled with the correct orientation, the beam element's contribution to the bending strength will be equivalent to that of the substituted plate, thus is considered a more accurate option.

Figures 6.1 to 6.4 below, illustrate a detailed module model for the vessel "Ferosa", where in Figure 6.4, the longitudinal method of framing is well illustrated. All stiffeners, both transverse and longitudinal are modelled using plate elements, while the bulb flanges of the "smaller" longitudinal stiffeners are modelled using beam elements.

6.2 "THREE HOLD" HULL MODULE FOR THE "FEROSA"

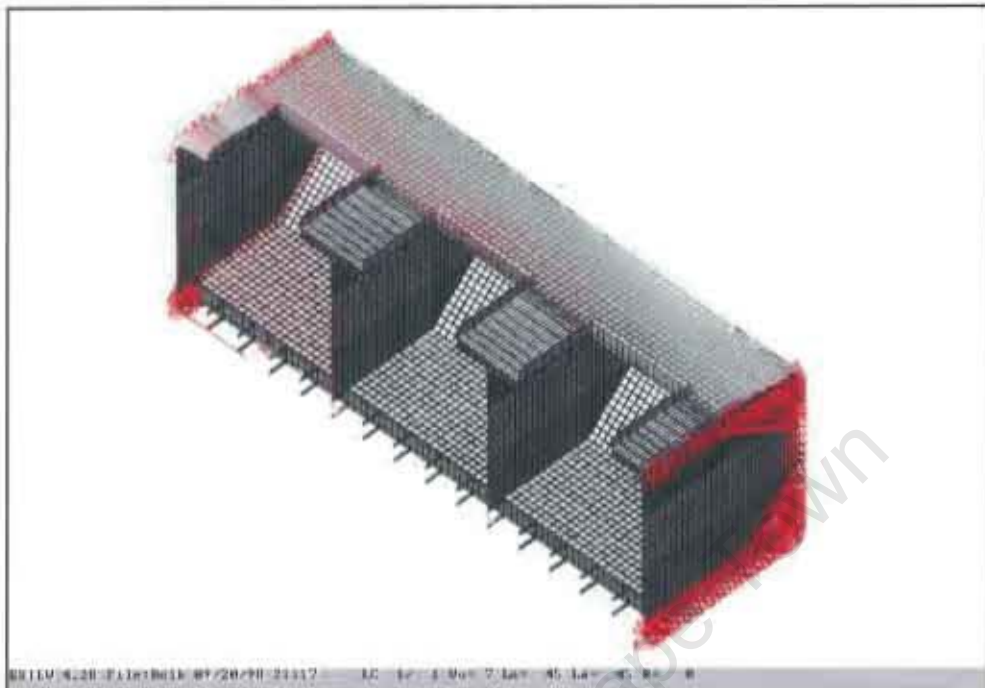


Figure 6.1 - 3 Hold Module for the Bulk Carrier "Ferosa" One side shown only due to symmetry.

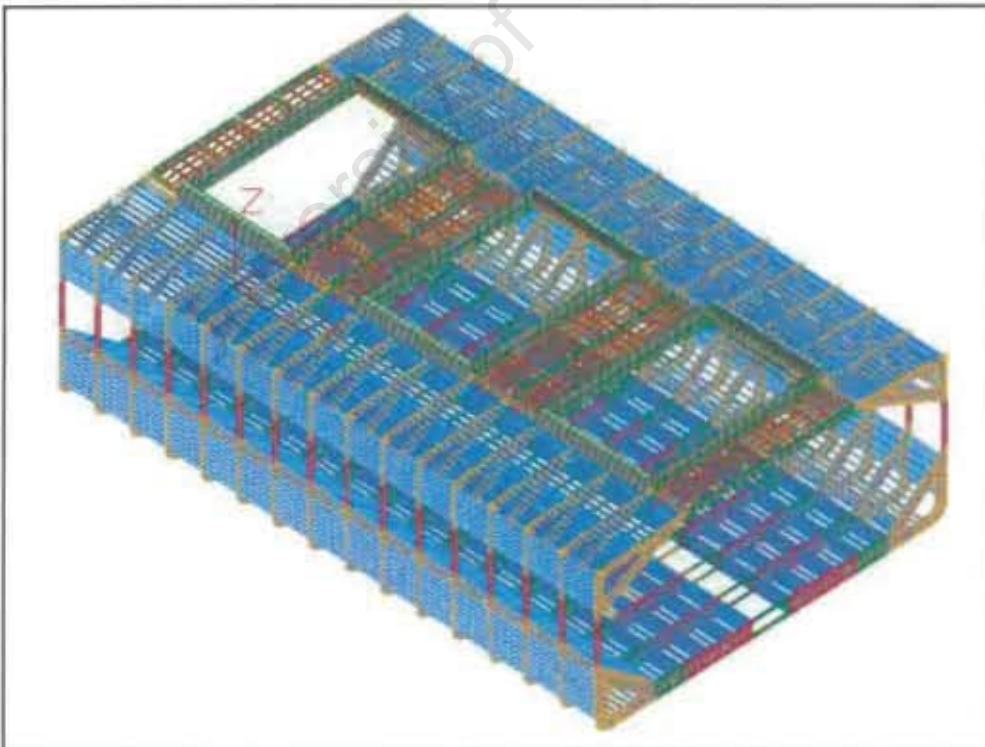


Figure 6.2 - Internal Stiffening of the 3 Hold Module. Longitudinal Framing with deep Transverse Frames widely spaced. The longitudinal members are bulb stiffeners, modelled here using plate element for the deep web, with beam elements used for the bulb flanges.

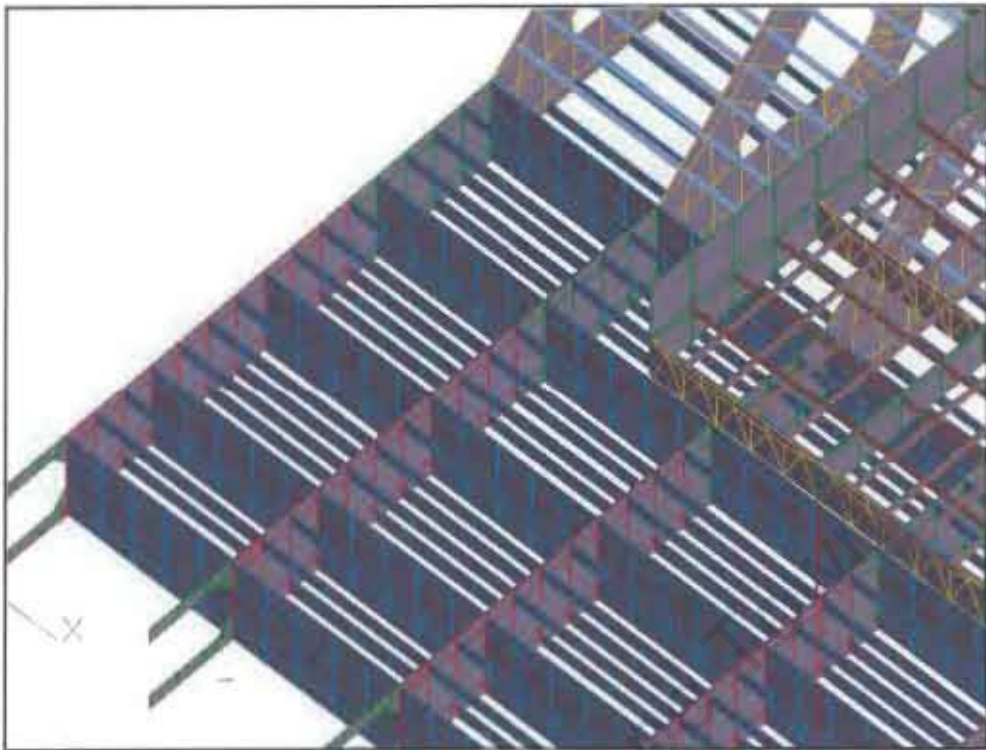


Figure 6.3 - Double Bottom Structure of the 3 Hold Module of the Bulk Carrier "Ferosa"

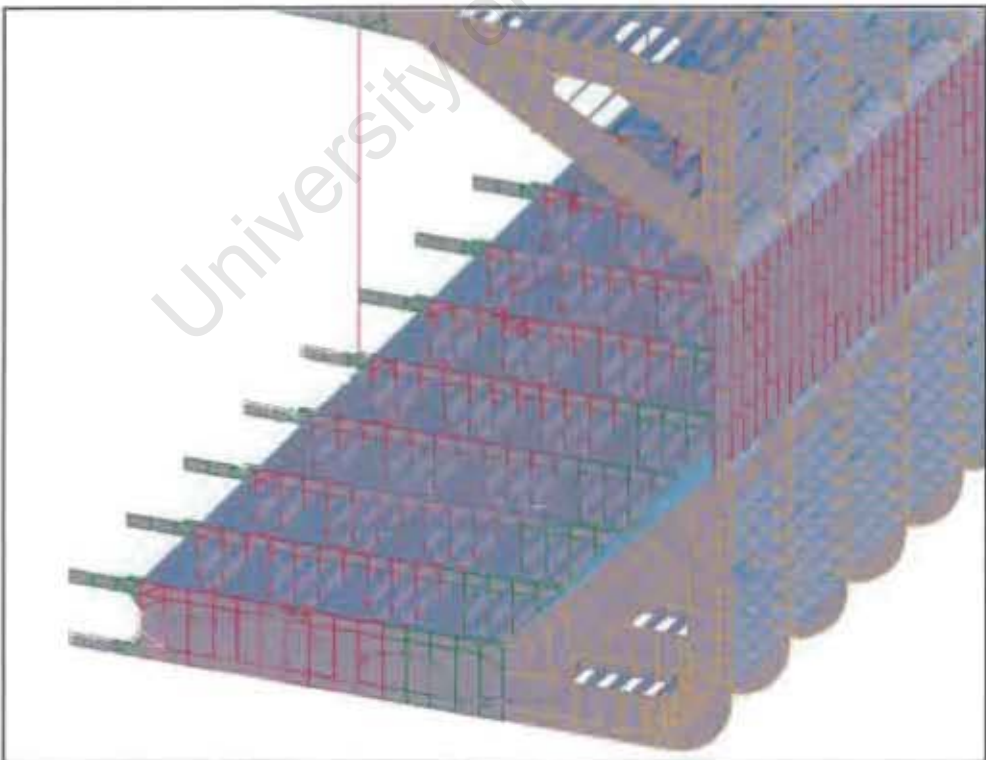


Figure 6.4 - 3 Hold Module of the Bulk Carrier - A combination of transverse and longitudinal framing. Notice the side shell supported by transverse frames, while the double bottom, turn of the bilges, upper wing tanks and deck are all supported by longitudinal framing, modelled as described in the previous figure.

6.3 TRANSFERAL OF LOADS FROM THE HULL GIRDER TO THE HULL MODULE

In theory, the hull girder can be loaded according to weight and buoyancy distributions as described, with the resultant bending moments and nodal forces being used for input loads on the hull girder.

This was attempted with very limited success in the case of the “Ferosa”’s Cosmos model. The shortcomings being:

- limited success in achieving the desired overall bending of the girder, due to excessive local deformation of “un-stiffened” plate structure in way of the wing tanks, both bottom and top, and the deck plate, due to own weight and applied pressures.
- the mismatch of nodal locations and structural non continuity between the girder and the module. Even after interpolating boundary condition nodal forces from the girder and attempting to apply it to the module, it was found that local deformation at the boundary was excessive relative to the deformation at mid span, where the results were sought.

As a secondary method of applying loads to the module, bending moment and shear forces were calculated at the boundary conditions using traditional beam theory using the Hydrostatic and Stability Program GHS™. Incidentally both Hughes and Lloyds Register of Shipping, advocate this method of attaining realistic input data into the hull module model.

The advantage of this approach is that the weight and buoyancy distribution can be accurately attained for the overall hull, but more importantly for sub elements, like holds, tanks etc.

The hull module would then be “bent” by applying bending moments to the boundaries of the model, whilst restraining it in such a way so as to limit restraint against bending, ie longitudinal and transverse translational restraint being applied in the plane of maximum bending, with vertical translation being restrained on the lower edge of the boundaries.

6.3.1 Application of Bending Moments to a Hull Module

The bending moments can be applied to the boundary of the hull module model in two ways.

- From the bending moment, calculate longitudinal nodal forces on the exposed boundary, which when summed relative to the neutral axis would result in that bending moment.
- Apply a “global” bending moment to the boundary “plane”, if the software system allows it.

Shortcomings of the first method:

- The elements in the immediate vicinity of the boundary where the nodal forces are applied tend to experience exaggerated deformation, and exaggerated stresses, relative to the elements in the region of interest.
- The model does not tend to “bend” as expected, but rather just experienced high compressive or tensile stresses in the deck and bottom shell plate.

Shortcoming of the second method:

- If the software system being used allowed a boundary plane to be “locked” together and a single bending moment to be applied at the neutral axis, this would almost certainly have resulted in the better outcome, as the model would have been forced to “bend” and the compressive and tensile stresses recorded in the mid section would have been as a result of the bending, and not as a result of directly applied forces.
- It may have been necessary to increase the stiffness of all elements in the region of the boundary, in excess of just the boundary elements, so as to limit deformation near the applied loads, and in that way achieve a realistic distribution of exaggerated deformation for the model as a whole.
- Unfortunately the software system being used did not allow for a bending moment to be applied to a plane.

6.3.2 Conclusion on the Transferal of Loads between the Hull Girder and Hull Module

As is apparent from the various shortcomings stated above, and as will be illustrated in the 2nd case study (Chapter 8), it was found that stresses in ship structure resulting from global environmental loading, both static and dynamic, are best determined by methods of hull stress measurements.

Experience has shown that methods of finite element analysis on ship structures are particularly useful at design, or modification stage, where loads are known, or closely approximated, and the capability of the structure to withstand those loads needs to be determined and / or documented. Examples of such applications include designing or analysing the underdeck structure of a mining vessel to determine whether the mining plant, winches, A Frames etc. will be adequately supported, and whether there is sufficient continuity of structure between the plant and the ship's to avoid local areas of high stress occurring.

Various criteria exist for determining load factors to account for the inertial effects of accelerations of the ship motion due to wind waves and mooring, or loads may be calculated using ship motion prediction methods, but these does not form part of this study, thus are not addressed in any detail.

CHAPTER 7 HULL MODULE - CASE STUDY

M.V. DECURION INVESTIGATION INTO DOCKING WITH LIMITED CARGO

7.1 INTRODUCTION

The bulkcarrier, "Decurion" fully loaded with 60 000 tonnes of grain, was damaged when a Container Vessel collided with her, just outside the port of Cape Town, in April 2000. The Container Vessel struck approximately midships, opening a hole some 13m in height, flooding Hold 4, and partially flooding Hold 5.

Triton Naval Architects were requested to investigate the implications of docking the vessel with limited cargo, including determining the maximum amount of cargo that may remain onboard for the docking.

This case study deals with the calculation of bottom stresses and block loads for the parallel section of the vessel, by assuming certain worst case weight distributions, as described in the following sections. The block arrangement and calculation of block loads for the bow and stern are dealt with separately and are described at the end of the report.

7.2 ASSUMPTIONS AND LIMITATIONS

The Cape Town Dock Master informed us that the maximum number of blocks available were 300, and that the maximum allowable load per block is 100 tonnes.

Based on 300 blocks at 100 tonnes/block, it was initially assumed that the maximum displacement that could be docked would be 30 000 tonnes, pending the outcome of an investigation / calculation into the affect of such loads on the ships bottom structure. This displacement was in good agreement with the "Solberg" which was docked at 33000 tonnes on 328 blocks.

30 000 tonnes assumes (incorrectly) that it is possible to arrange the blocks in such a way, so that all blocks contribute equally towards supporting the load. The following paragraphs will illustrate that the limiting factor is not over stressing the hull, but keeping the maximum load on any one block close to, or under the 100 tonne limit.

7.3 PROCEDURE

Conditions of loading applicable to docking the vessel at a displacement of +/- 30 000 tonnes were first prepared using GHS™ loading and stability software (of Creative Systems, Seattle, WA, USA). The conditions include calculation of general stability parameters. eg, trim, heel, drafts, GMT, and also longitudinal strengths, by taking the lightship weight distribution, as obtained from ship's loading program manuals, and combining it to actual weight distributions of liquid and grain, calculated from the shapes of the compartments in question, also taking flooded spaces into account.

In accepting an initial value of 30 000 tonnes as being the maximum weight, conditions of loading were drawn up which resulted in no trim and heel, and minimum deflection (hog/sag), taking the damaged hold and No.3 Double Bottom Ballast Tank into account.

Two alternatives arose from drawing up these conditions, namely:

- ii Distribute the cargo evenly between the holds, in such a way as to limit the trim to a minimum (slightly by the stern). This distribution results in the most even weight distribution on the blocks, but due the flooded No.4 Hold result is a deflection of the hull (HOGGING). See Annex A, Condition 1.
- ii Distribute the cargo in such a manner so as minimize the trim, and at the same time reduce the hog, by leaving more cargo in the holds adjacent to the damaged holds and discharging more cargo out of the extreme holds, namely 1 & 7. See Annex A, Condition 2.

The disadvantage of Condition 2 is that the weight distribution in way of the higher loaded adjacent holds, is in the order of 50% greater than the maximum weight distribution of Condition 1. Thus it is suggested that allowing an acceptable amount of deflection (HOG) but distributing the cargo more evenly, thus a more even distribution of loads on the blocks is a better approach.

With the likely weight distribution known, a Finite Element Model of a section of the double bottom structure (2 holds long) was developed from the structural drawings made available by the owners. The weight distribution curve, or sections thereof, could be applied to the finite element model as a pressure load, applied over the hold bottom and sloping hopper sides. The model would then be supported (restrained) underneath in the same way as the docking blocks would support the vessel. From this analysis the stresses induced in the bottom structure as a result of bearing on the blocks could be quantified, as well as determining the load on each and every block.

Once it is established that certain blocks are being overloaded, or if areas of high stress are being identified, either the layout of the blocks could be changed, or the loading of the vessel could be changed.

The idea of only using a two hold section of the vessel as the model, is to limit the size of the model, in order to save modelling time, but more importantly to reduce computer run time, (or waiting time) between runs.

The main transverse frames and longitudinal stiffeners were modelled using plate elements, as were the tank top, bottom shell, and sloping hopper sides. All plate was modelled according to its actual and varying thickness, as depicted by different colours on the model. In some cases where there is a lot of differing plate thickness, worst case thicknesses were used. All longitudinal beams, namely the bottom beams, tank top beams, side beams, hopper tank beams, and small vertical tripper plates, were modelled as beam elements, and are depicted as lines. Different colour depict different sectional properties. The beam element are orientated according to the actual orientation, and the neutral axis offset from the ends nodes by the distance of that beams neutral axis from bottom / top edge.

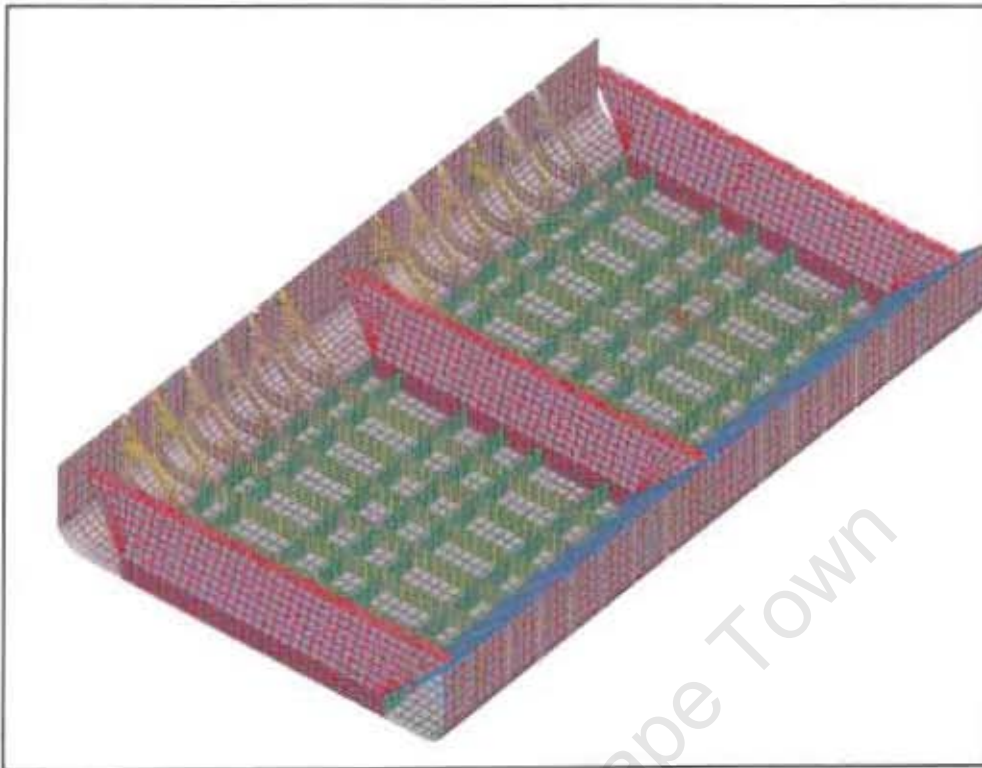


Figure 7.1 - Initial Model with Alternative Transverses modelled. Tank Top and other elements removed for clarity.

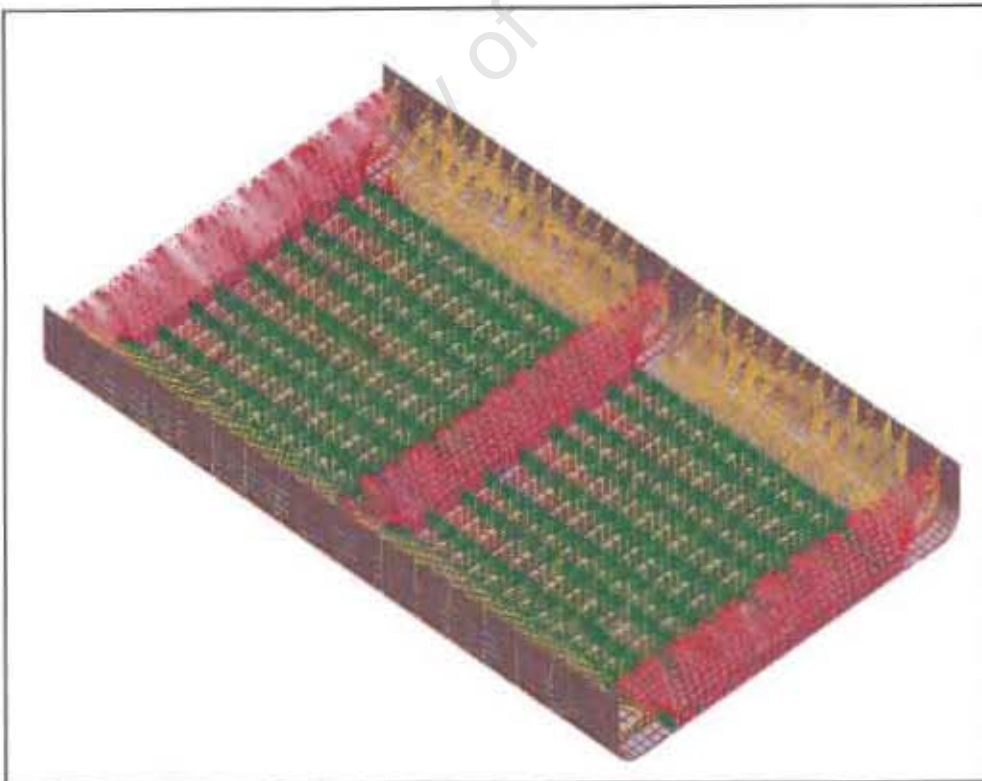


Figure 7.2 - Final Model. Tank top, hopper plate, and beam elements removed for illustration purposes. Note structure in Red, are the bulkhead pedestals.

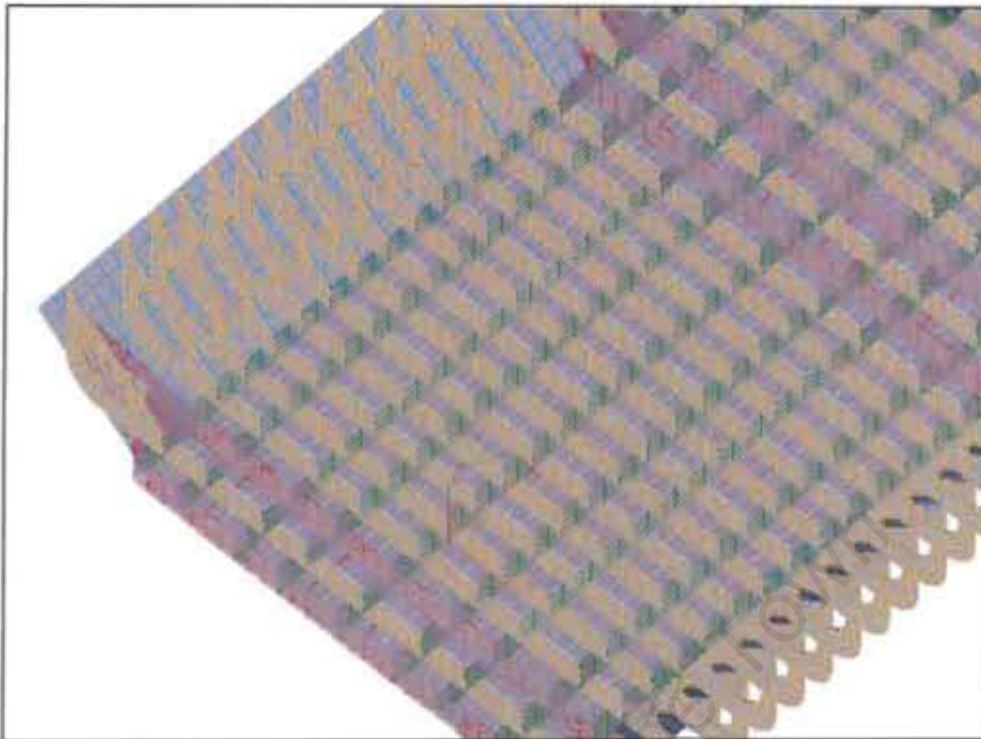


Figure 7.3 - Final model seen from underneath, with bottom plate and beam elements removed for illustration purposes.

Finite Element Statistics

The analysis was performed on the Linear Static Stress Module of the FE package Algor™, of Pittsburgh, Pennsylvania, USA.

The final model comprises of some 28800 elements, 18124 nodes, 107 855 DOF's (or equations), and for any given condition of loading, takes 6½ hours to solve on a Pentium II 233 MHz, and requires 1.35 Giga Bytes of free space in order to execute the solution. The initial model, some of who's plots are depicted in this report, excluded every second main transverse, and excluded 1 set of bottom longitudinals. This model took 3½ hours to solve, and was used to get initial estimates of block positions, and loading per block. It is possible for the analysis to solve for more than one loadcase at a time, but not for more than one condition of restraint (ie. position of blocks)

7.4 INITIAL RESULTS

The following figure illustrated an initial block layout, where it can be seen that the load per block varies from 50 tonnes to 230 tonnes, in spite of an even pressure distribution on a symmetrical block layout. This variation comes about due the very slight deflections in some places, effectively “unloading” that block to a large degree, whereas blocks that are placed under stiffer structure, have to take up the difference, and thus become higher loaded. The longitudinal bulkhead at the edge of the bottom hopper tanks (10.92m offset) is a very stiff area, due to the configuration of the hopper tank structure above. The centreline girder, as part of the double bottom structure, can deflect as a whole, albeit very slightly, and thus unload itself slightly.

The most pronounced effect of this tendency is apparent on Figure 7.5, where blocks were placed on every frame. Although the longitudinal centreline girder is bearing on all the blocks, the blocks that are under the main transverses are taking 10 times the load, of those between. This points clearly to the “in between” blocks being superfluous and could better used elsewhere.



Figure 7.4 - In this case, blocks were placed every second main transverse (initial model), on longitudinals as indicated. The block loads vary from 45t to 236t, with most of the blocks exceeding the 100t limit. Not all the blocks are labelled, but the loading is symmetrical.

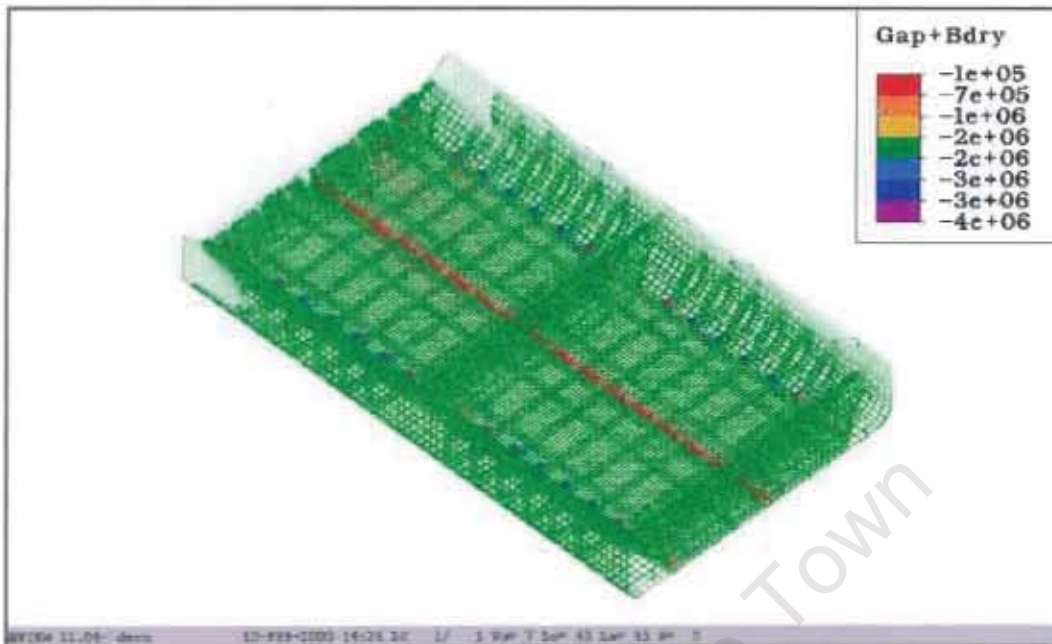


Figure 7.5 - A very early block arrangement. Included in the report, merely to illustrate the variation of block loads on the centreline girder. Not very clear in this plot, due to the scale, but the blocks on the transverse were loaded in the order of 100t, whilst those on frames between transverse, were only loaded 10 tonnes. Those on the extreme outside, under the hopper, are loaded up to 400t in this case.

During initial calculations, with only every second transverse modelled, the stresses experienced by those transverses, for the blocks arranged as per Figure 7.4, were found to be high but acceptable. The limiting factor was thus identified as block loads, especially when taking into account that the final model, with every transverse included is going to be stiffer. At this stage the blocks were only being placed at every second transverse due to a limit in the number of blocks, thus every frame was not necessary from the point of view of calculating block loads, and run time (as explained earlier) was significantly reduced. The maximum stresses are found to be in the order of 180 MPa, for the blocks arranged as per Figure 7.4.

It will be shown later, that for the final results, these maximum stresses were also significantly reduced to less than 100MPa, due to alternative block arrangements, where the outside blocks were placed on every transverse frame, ie 1.6m apart, and the remaining three rows of blocks were placed at alternate transverse frames, ie 3.2m apart.

7.5 FINAL BLOCK ARRANGEMENT

The block arrangements differ from Hold to Hold, as the total weight per hold differs from one to the next, obtained by summation of the weight distribution curve, over the length of the hold.

For the final analysis the vessel was loaded as per Annexure 1 Condition 3, Hold 7 is

discharged to 1000 tonnes, to reduce weight in this area, due to a lack of space to arrange sufficient blocks. Hold 1 is considered to contain about half the grain that Holds 2,3 & 6 contain. Holds 4 and 5 are considered empty, with Hold 4 considered partially flooded. No.3 Double Bottom Ballast Tanks, Stbd is considered flooded, with the Portside filled to counter the heeling effect.

The results of the analysis are divided into different holds which have different block arrangements. They are depicted as follows:

- Holds 2 & 3, modelled together, as per the Final Model illustrated in Figure's 7.2 & 7.3.
- Block arrangements for Holds 4 and 5 were determined by using single hold models, and were run individually, in order to determine how many blocks could be relocated from this area, to be placed at the bow and stern.
- Hold 6 corresponds to the same loading and same block arrangements as Holds 2 & 3, but was repeated on a "single hold" model.
- Holds 1 & 7, and the area aft of Hold 7, and the Forepeak, were not modelled per se, due to shape considerations, as separate detailed models would be required, and there was not sufficient time to develop them. The blocks were however arranged according to the weight per region, as calculated from the weight distribution curve, and a conservative margin was allowed on the average load per block.

Weight per Region determined by summation of the weight distribution curve over the distance concerned. The layout should be seen on the attached Drawing TNA 1110/01.

Region	Description	Total Weight per Region	No of Blocks per Region
1	Forepeak	543 t	9
2	Hold 1	3553 t	37
3	Hold 2	5420 t	54
4	Hold 3	5612 t	55
5	Hold 4	2348 t	24
6	Hold 5	1904 t	23
7	Hold 6	5245 t	55
8	Hold 7	2396 t	29
9	Aft of Frame 45	2526 t	30

The weight calculated per region, as listed in the last column in the table above, was used to determine a uniform pressure in N/mm^2 , to be applied to each Finite Element Model / loadcase. This assumes that the weight distribution over each region is fairly uniform. In the case of the Holds 2 to 6, this assumption is realistic, as the structure, and the cargo load is basically constant over the length of each hold. In the case of the Hold 1 and 7, this is not as realistic, but these holds were not modelled, and the blocks were arranged, as far as possible, to simulate the “expected” distribution of each of those two holds. In the case of the aftpeak and forepeak, there was no option but to place the required amount of blocks on the keel, as there was no other possibility of support positions.

7.5.1 Results for Holds 2 & 3

The following figure illustrates the block layout as well as the load per block. Note not all of the blocks are labelled due to symmetry.

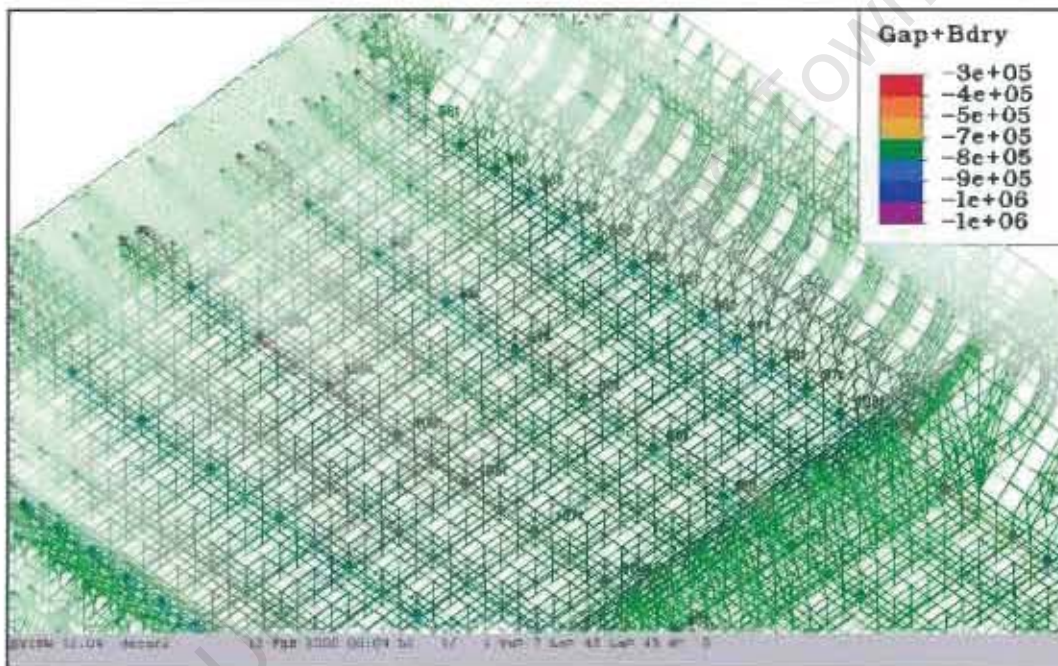


Figure 7.6 - Block Positions, and loads per block, in tonnes. Note the units of the legend on the top right corner is Newton. [negative = down].

The following figure is a stress plot, zoomed in, to see the stress patterns, and magnitudes in the transverse frames. Note: that while these were the areas of highest stress, the magnitude is at a very acceptable level.

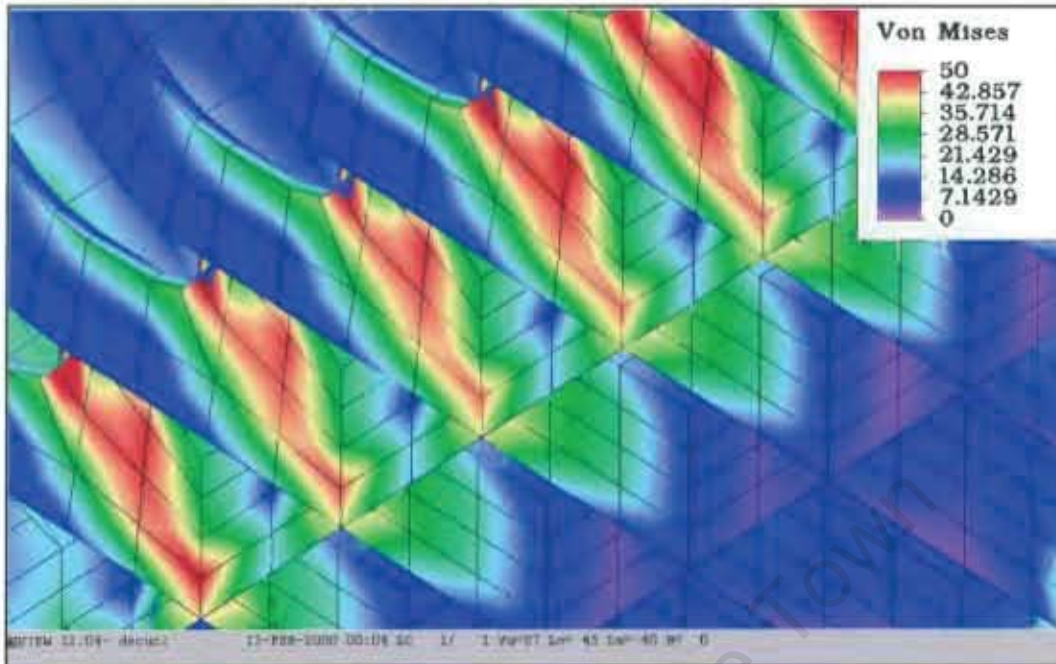


Figure 7.7 - Close up view of the stress patterns in the transverse frames (floors). Higher stress areas shown in red. This view is from underneath, with the bottom plate removed for clarity. The vessel side is just off the left edge, and the centreline off the right edge of the picture.

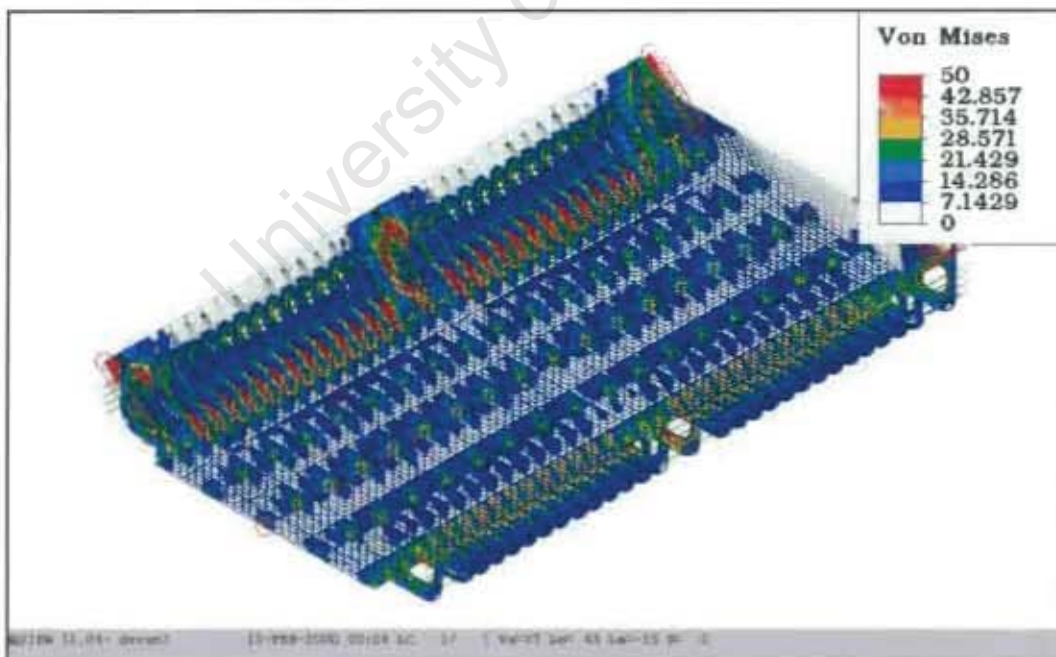


Figure 7.8 - Overall Plot of the bottom stresses (Bottom Shell plate removed for clarity). The positions of the docking blocks can be made out from the stress patterns. Note the green lines on the outboard extreme. There are the side stiffeners, modelled using 3D Beam elements, rather than Plate elements, as their contribution to stiffness was required, while their graphic stress patterns were of less importance for the load cases considered.

7.5.2 Results for Hold 4

The following figure illustrates the block positions and loads per block for Hold 4, after a number of iterations. Note the blocks saved under Hold 4, vs those used under Holds 2,3 & 6, would be relocated to the bow and stern.

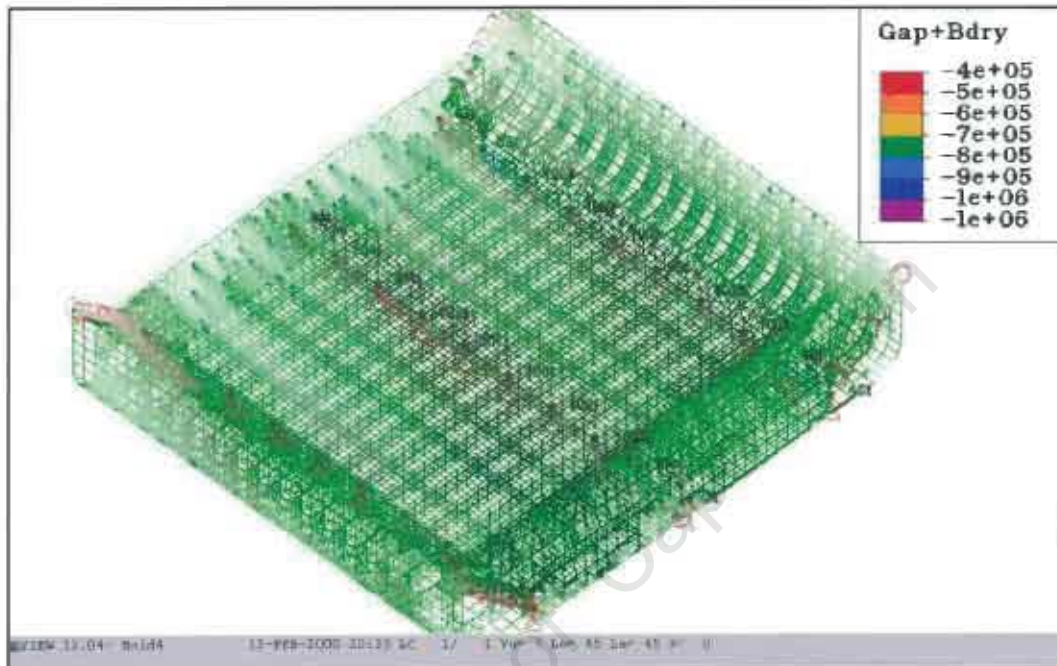


Figure 7.9 - Block Positions and loads for Hold 4.

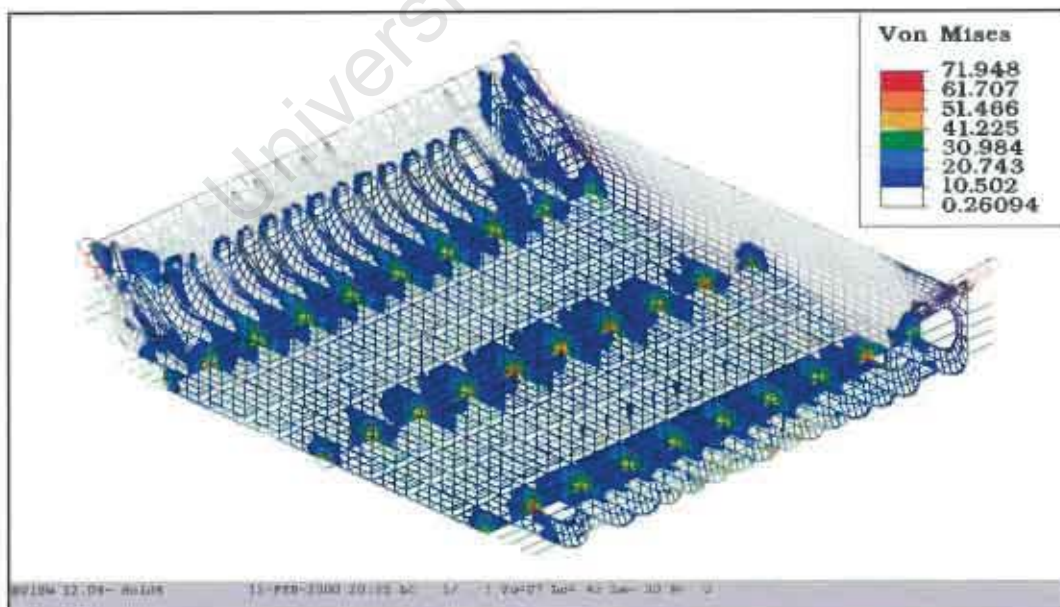


Figure 7.10 - Bottom Stresses in way of Hold 4. Maximum shown to be 72MPa.

7.5.3 Results for Hold 5

The following figure illustrates the block positions and loads per block for Hold 5, after reducing the blocks even further from those used for Hold 4.

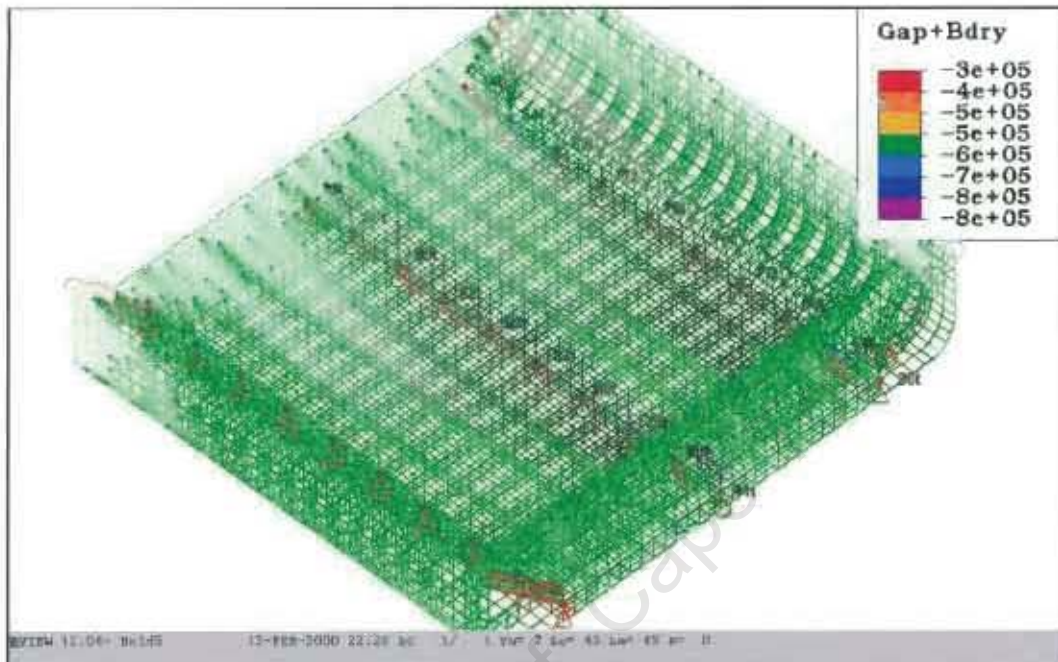


Figure 7.11 - Block positions and block loads for the region of Hold 5

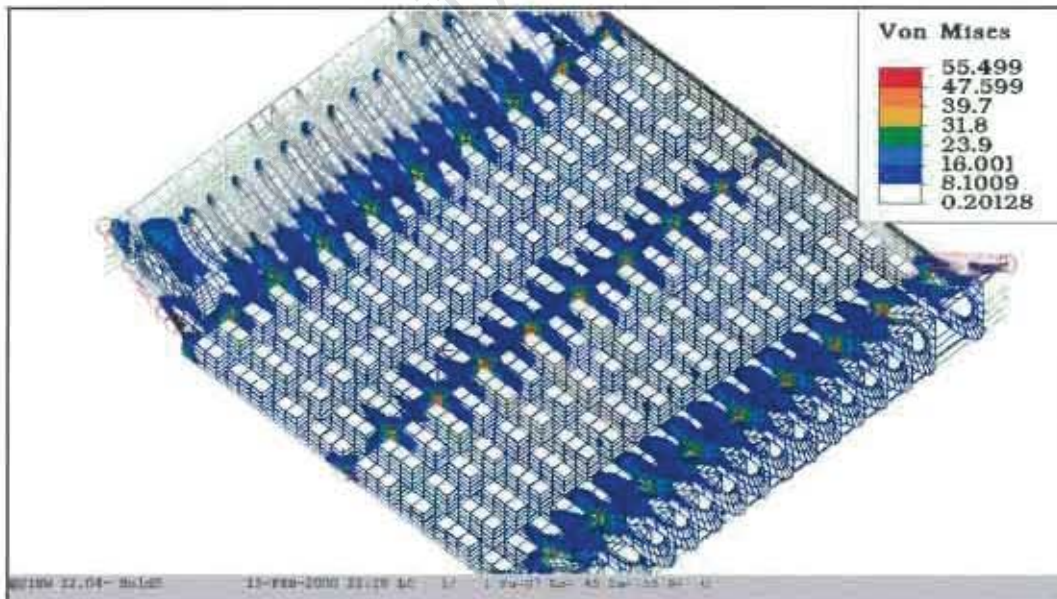


Figure 7.12 - Bottom Stresses in the region of Hold 5. Bottom shell plate and longitudinal beam elements removed for clarity. The maximum stress shown to be 55MPa.

7.5.4 Results for Hold 6

The block arrangement for Hold 6 is taken as per Holds 2 & 3, due to similar weight distributions. The total weight for Hold 6 is 5245 tonnes vs 5420 and 5612 for Holds 2 & 3 respectively. There was not sufficient time to run an analysis specific to Hold 6, and it was not envisaged that the ± 400 tonnes would have resulted in significant savings in blocks over Holds 2 & 3, as the symmetry of the layout would have to be maintained.

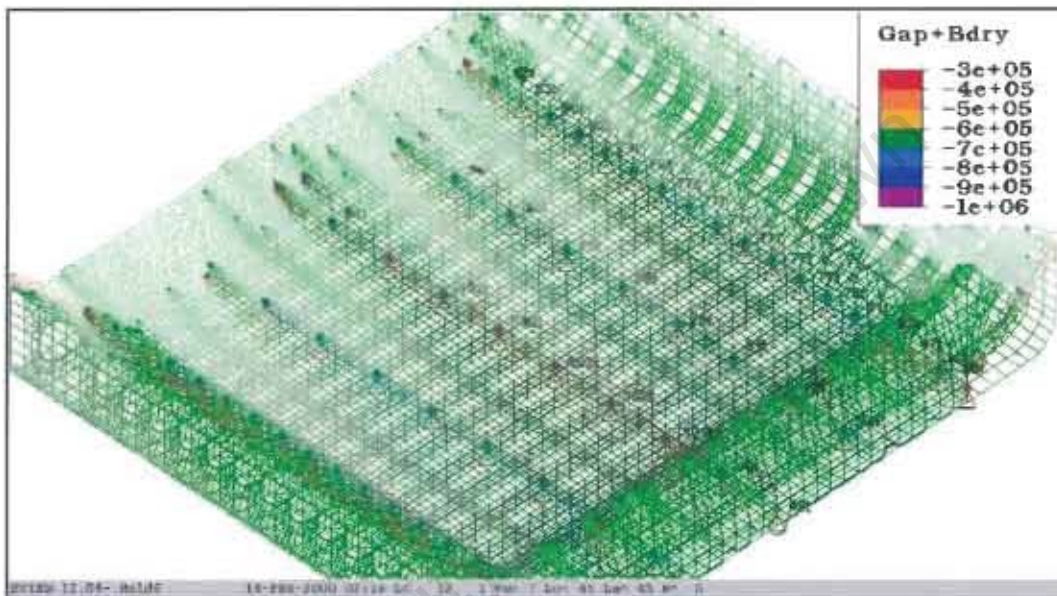


Figure 7.13 - Block Positions and block loads for the region of Hold 6.

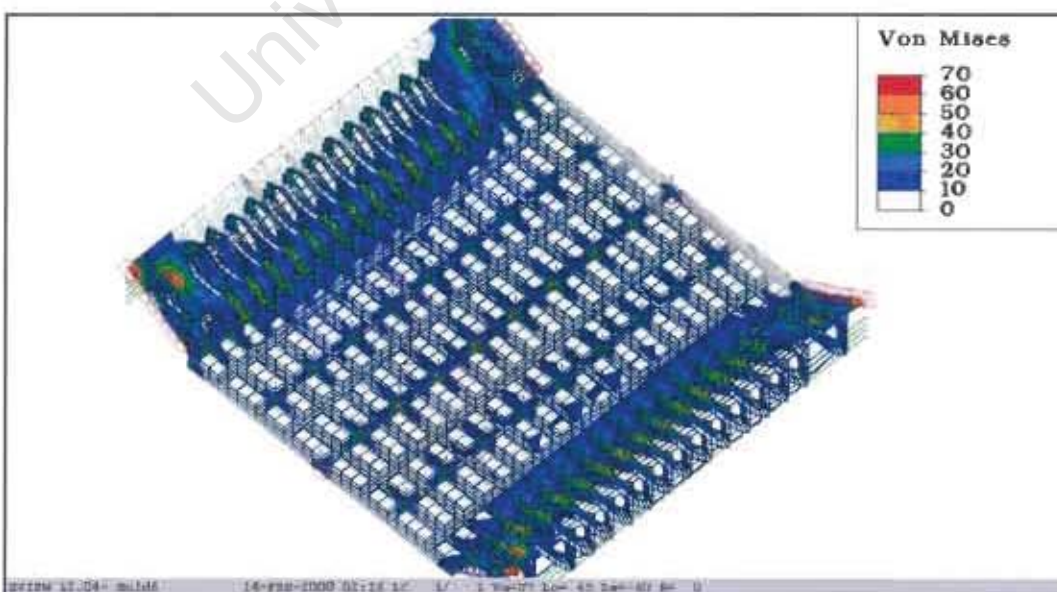


Figure 7.14 - Bottom stresses in the region of Hold 6. Bottom plate and longitudinals removed for clarity.

7.5.5 Results for Hold 7

As was mentioned earlier in this report, Holds 1 and 7 were not analysed due to shape factors. There was not sufficient time to generate specific models for these two holds which accurately portray their shape.

The loading for Hold 7 was reduced significantly, by leaving only 1000 tonnes of grain, as there is not sufficient space to locate more blocks (had they been available).

28 blocks are arranged as per the drawing TNA 1110/01 to support the 2396 tonnes of Hold 7. It is assumed that the loading of the blocks will be "reasonably" uniform, at an average block load of 85.6 tonnes, by arranging the blocks in such a manner so as to agree with the trends found in the detailed analysis of the mid holds.

7.5.6 Results for Hold 1

The same rationale applies to Hold 1 as for Hold 7, w.r.t to the shape of the flat of bottom tapering off, but in the case of Hold 1, which was not entirely discharged, mainly for trim reasons, the layout of the blocks is slightly more tricky, and the weight to be supported is also higher. Here 44 blocks are allocated to support the 3553 tonnes at an average block load of 80.29 tonnes per block. Due to the tapering off of the flat of bottom of the vessel, beyond frame 247, blocks can only be located on the centreline girder. In order to support the proportion of the hold from frame 247 to 262, it is proposed to locate blocks on every frame, ie at 800mm intervals.

The finer shape at the fore end of this region (Hold 1) is a very strong structure, in the vertical direction, thus the fact that only one row of blocks is available, can still be acceptable. The block spacing is increased significantly in order to cater for the single row taking a much higher load than elsewhere.

7.5.7 Results for Forepeak Region

The forepeak region, with the forepeak ballast tank empty, amounts to 542 tonnes being supported on the centreline (keel) by 14 blocks, at an average block loading of 38.7 tonnes per block. It is expected that the load per block will be very uniform in this region due to the structure not being able to deflect, one block to the next.

Some blocks may however have to be removed from this (lighter loaded) region, as the total number of blocks in the above table exceeds the 300 blocks, but 34, although it is assumed from the Solberg docking that at least 317 blocks are in fact available.

7.5.8 Results for Region Aft of Frame 45

Only a single row of blocks on the keel is possible in this region. It is therefore proposed to place blocks on every frame (800mm apart) from frame 45 - aft. This amounts to 30 blocks supporting 2526 tonnes at an average of 84.2 tonnes per

block. Due to the shape of the hull, in this region, ie the fine “run” to the stern, with its associated internal structure, makes this section of the hull very stiff on the centreline (keel). It can be realistically assumed that, in spite of a significant overhand over the last block, these blocks would bear load fairly uniformly.

The loading on the blocks in this region is virtually independent of the loading of the vessel, except for some small tanks. Thus the load on the structure and on the blocks would be the same for this region of the ship, even if the docked in a lightship condition.

7.6 CONCLUSION

The Condition of Loading as depicted in Condition 3 of Annexure A, should be seen as the MAXIMUM possible condition for docking with the limit of 300 blocks. This condition amounts to a displacement of 30 000 tonnes, of which 16 000 tonnes is cargo.

If the blocks per region are added up, it will be apparent that the total is actually 313 blocks. This is based on the Solberg, which was docked on 317 blocks.

The stresses in the ship structure, for all areas modelled were found to be quite low, and very acceptable.

The limiting factor is definitely the 100 tonnes per block limit. The highest block load, resulting from the analysis was 109 tonnes, which is still acceptable.

On referencing the drawing TNA 1110/01, it will be apparent that Hold 6 and Hold 3 have four additional blocks, which are not reflected in the models of those two holds. These were placed, where the actual geometry differed slightly from the model, in that the bulkhead fell just before or just after a row of blocks.

CHAPTER 7 - ANNEXURE A

**CALCULATION OF CONDITIONS OF LOADING FOR DOCKING,
TAKING ACCOUNT OF FLOODING OF AFFECTED SPACES/HOLDS**

University of Cape Town

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M.V. "DECURION"

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CONDITION 1 - INITIAL CONDITION FOR EVEN DISTRIBUTION OF HOLDS

WEIGHT and DISPLACEMENT STATUS							
BPL draft: 6.293 @ 215.44f, 6.237 @ 0.00							
Trim: Fwd 0.06/215.44, Heel: Port 0.04 deg.							
Part			Weight (MT)	LCG	TCG	VCG	
LIGHT SHIP+			11,829.23	97.646f	0.000	10.073	
Sundry Small HFO Tks			28.05	20.000f	0.000	1.250	
Sundry Small DO Tks			8.80	20.000f	0.000	1.250	
Total Fixed			11,866.08	97.405f	0.000	10.046	
	Load	SpGr	Weight (MT)	LCG	TCG	VCG	RefHt
HOLD1.C	0.497	0.746	3,800.53	189.552f	0.028s	5.897	FROZEN
HOLD2.C	0.426	0.830	3,800.09	165.691f	0.046s	5.335	FROZEN
HOLD3.C	0.436	0.808	3,800.00	141.750f	0.045s	5.413	FROZEN
HOLD6.C	0.392	0.806	3,400.09	69.756f	0.050s	5.076	FROZEN
HOLD7.C	0.265	0.775	2,200.21	45.320f	0.045s	4.074	FROZEN
FO6.C	0.622	0.935	269.43	45.003f	0.006p	0.530	-1.050
DO_1.S	0.713	0.850	56.10	24.353f	3.276s	1.010	-1.739
FW_1.P	0.805	1.000	130.01	10.267f	7.659p	15.613	-17.451
FW_1.S	0.283	1.000	45.71	10.292f	7.249s	14.323	-15.089
FW_2.P	0.930	1.000	56.39	5.588f	7.007p	16.639	-18.096
FW_2.S	0.911	1.000	55.29	5.588f	6.999s	16.611	-18.053
WB_FPEAK.C	0.001	1.025	2.21	207.200f	0.015p	0.091	-0.087
WB_DB1.P	0.010	1.025	4.96	188.950f	2.455p	0.050	-0.028
WB_DB1.S	0.012	1.025	5.94	189.053f	2.386s	0.056	-0.042
WB_DB2.S	0.007	1.025	10.54	153.093f	9.659s	0.014	0.007
WB_DB3.P	1.000	1.025	1,414.28	105.720f	12.177p	1.882	
WB_DB4.S	0.010	1.025	6.74	72.254f	8.951s	0.029	-0.037
WB_DB5.P	0.011	1.025	3.62	48.961f	6.784p	0.047	-0.060
WB_DB5.S	0.030	1.025	10.02	48.876f	7.226s	0.099	-0.156
WB_TS2.P	0.025	1.025	36.81	153.787f	15.448p	12.940	-13.150
WB_TS5.P	0.011	1.025	7.86	44.978f	15.594p	12.769	-12.890
WB_TS5.S	0.006	1.025	4.52	45.006f	15.648s	12.705	-12.796
WB_AP.C	0.043	1.025	22.74	6.119f	0.125s	5.490	-7.271
Total Tanks			19,144.08	125.504f	0.909p	5.100	
Total Weight			31,010.16	114.752f	0.561p	6.993	
			Displ (MT)	LCB	TCB	VCB	
HULL		1.025	35,342.82	114.637f	0.008p	3.207	-6.237
HOLD4 B.C	Flooded	1.025	-2,920.17	117.723f	0.014p	4.115	-6.237
WB_DB3.S	Flooded	1.025	-1,412.94	105.720f	12.174s	1.878	-6.237
WB_TS3.S	Flooded	1.025	0.00				
Total Displacement			31,009.72	114.753f	0.563p	3.182	
Righting Arms:				0.000	0.001s		
Distances in METERS.							

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Page 2

CONDITION 1 - INITIAL CONDITION FOR EVEN DISTRIBUTION OF HOLDS

HYDROSTATIC PROPERTIES with FLOODING

Trim: Fwd 0.06/215.44, Heel: Port 0.04 deg., VCG = 6.993

LCF Draft	Displacement Weight (MT)	Buoyancy-Ctr. LCB	Weight/Ctr. VCB	Weight/CM	Moment/ LCF	Moment/ CM trim	GML	GMT	
6.266	31,009.72	114.753f	3.182	51.19	112.595f	745.18	517.71	8.308	
Distances in METERS.		Specific Gravity = 1.025.			Moment in M.-MT.				
Draft is from BPL.				Trim is per 215.44M.				True Free Surface included.	

LONGITUDINAL STRENGTH with FLOODING at Heel = Port 0.04 deg.

LOCATION M.	WEIGHT MT/M.	BUOYANCY MT/M.	SHEAR MT	MOMENT MT-M.
220.000f	0.00		0.0	0.0
219.000f	1.50	0.86	-0.9	0.5
217.040f	2.98	12.80	6.9	-2.1
217.040f	46.35	12.80	6.9	-2.1
214.600f	43.97	31.51	-50.3	61.2
213.284f	42.61	38.51	-61.1	135.7
211.331f	40.67	48.89	-57.1	255.1
209.378f	38.77	59.27	-29.1	343.1
207.426f	36.90	70.50	23.3	352.9
205.473f	35.04	82.58	102.6	234.4
203.600f	33.31	94.16	204.1	-48.8
203.520f	58.15	94.65	206.9	-65.2
203.520f	154.24	94.65	206.9	-65.2
202.524f	160.40	100.81	147.6	-241.9
202.120f	162.93	103.31	123.5	-296.6
201.528f	165.15	106.58	88.5	-359.3
200.532f	169.78	112.08	30.6	-418.6
199.420f	174.96	118.22	-33.0	-417.2
199.420f	171.61	118.22	-33.0	-417.1
198.539f	175.56	123.09	-79.6	-367.5
198.020f	177.91	125.96	-106.7	-319.1
198.020f	165.35	125.96	-106.7	-319.1
197.543f	167.24	128.59	-125.3	-263.7
196.547f	171.29	134.09	-163.1	-119.9
195.551f	175.58	139.59	-199.6	60.8
194.554f	177.38	144.44	-234.1	277.1
193.120f	179.54	150.71	-278.4	645.4
193.120f	178.24	150.71	-278.4	645.4
192.562f	180.06	153.15	-293.6	804.9
191.566f	183.34	157.50	-319.8	1,110.5
190.570f	186.65	161.85	-345.1	1,441.7
189.574f	190.08	166.21	-369.3	1,797.7
188.578f	193.99	170.56	-392.9	2,177.3
187.582f	195.25	173.95	-415.6	2,580.2
186.585f	196.76	176.53	-436.2	3,004.5

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CONDITION 1 - INITIAL CONDITION FOR EVEN DISTRIBUTION OF HOLDS

LOCATION M.	WEIGHT MT/M.	BUOYANCY MT/M.	SHEAR MT	MOMENT MT-M.
185.589f	198.16	179.12	-455.8	3,449.0
184.593f	199.57	181.70	-474.2	3,912.3
183.597f	201.03	184.28	-491.4	4,393.3
182.800f	202.32	186.34	-504.5	4,790.2
182.601f	207.71	186.86	-508.7	4,891.1
181.120f	210.29	190.69	-538.6	5,666.7
180.608f	208.59	191.43	-548.0	5,944.8
179.120f	208.96	193.57	-572.2	6,778.7
179.120f	213.95	193.57	-572.2	6,778.8
177.720f	214.33	195.59	-599.6	7,599.3
177.620f	216.08	195.73	-601.6	7,659.3
177.620f	207.71	195.73	-601.6	7,659.3
173.720f	208.53	201.34	-638.6	10,084.0
169.300f	208.38	204.54	-663.0	12,966.2
168.120f	208.41	205.39	-667.1	13,751.0
162.520f	207.90	206.60	-679.1	17,524.9
161.200f	207.79	206.59	-680.8	18,422.5
161.100f	210.09	206.59	-681.0	18,490.6
160.720f	215.51	206.59	-684.4	18,749.9
157.720f	214.58	206.56	-709.9	20,842.2
153.720f	213.35	206.52	-739.6	23,742.6
153.720f	214.94	206.52	-739.6	23,742.7
152.140f	214.45	206.51	-752.5	24,921.6
149.720f	213.72	206.49	-770.9	26,765.3
144.860f	212.24	206.45	-802.5	30,591.5
143.560f	211.84	206.43	-809.8	31,639.6
139.600f	210.64	206.40	-828.9	34,885.6
139.600f	214.04	206.40	-828.9	34,885.7
134.980f	213.10	206.36	-862.1	38,793.4
130.520f	212.18	206.32	-890.2	42,702.4
129.720f	215.69	206.32	-897.7	43,417.4
129.720f	87.06	55.11	-897.7	43,417.5
128.120f	86.89	55.11	-948.7	44,894.8
128.120f	83.22	55.11	-948.7	44,894.8
126.400f	83.04	55.11	-996.9	46,568.1
125.000f	82.88	55.11	-1,035.9	47,991.1
120.000f	82.34	55.10	-1,173.5	53,515.6
117.820f	82.14	55.10	-1,232.6	56,138.2
115.000f	82.39	55.10	-1,309.2	59,721.9
109.240f	82.91	55.10	-1,467.9	67,718.5
105.000f	83.29	176.67	-1,499.1	74,162.0
100.000f	83.74	176.62	-1,033.4	80,492.0
96.400f	84.06	176.59	-699.6	83,611.1
96.400f	79.05	176.59	-699.6	83,611.2
95.000f	79.35	176.58	-563.3	84,495.1
92.080f	79.97	176.56	-280.3	85,726.3

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CONDITION 1 - INITIAL CONDITION FOR EVEN DISTRIBUTION OF HOLDS

LOCATION M.	WEIGHT MT/M.	BUOYANCY MT/M.	SHEAR MT	MOMENT MT-M.
90.000f	80.42	176.54	-79.9	86,100.8
82.520f	82.02	176.47	632.8	84,025.1
81.720f	85.82	176.47	705.4	83,489.8
81.720f	199.75	205.90	705.4	83,489.7
80.120f	199.93	205.78	715.0	82,353.4
80.120f	196.30	205.78	715.0	82,353.3
77.720f	196.57	205.59	737.2	80,610.4
74.800f	196.62	204.73	762.3	78,420.5
74.800f	189.58	204.73	762.3	78,420.4
69.720f	191.29	203.23	831.1	74,366.3
66.340f	191.84	201.16	867.0	71,494.1
61.720f	193.56	198.32	899.5	67,405.2
57.720f	193.98	193.34	907.9	63,783.4
57.720f	155.30	193.34	907.9	63,783.3
56.120f	156.33	191.35	966.3	62,283.4
56.120f	151.12	191.35	966.3	62,283.4
53.200f	152.71	187.27	1,075.7	59,298.2
53.200f	146.89	187.27	1,075.7	59,298.1
49.180f	143.07	178.79	1,228.6	54,660.3
45.720f	140.84	171.48	1,343.4	50,205.5
40.600f	134.08	156.50	1,479.3	42,961.3
37.720f	128.83	148.07	1,539.3	38,612.3
36.920f	126.18	144.90	1,554.4	37,374.9
35.286f	121.34	138.41	1,583.6	34,810.7
33.770f	116.91	132.39	1,608.3	32,391.2
33.770f	162.10	132.39	1,608.3	32,391.1
32.120f	155.56	125.84	1,559.2	29,778.2
32.120f	74.42	125.84	1,559.2	29,778.0
32.120f	129.60	125.84	1,559.2	29,777.9
30.520f	123.91	119.49	1,552.7	27,288.2
30.520f	129.59	119.49	1,552.7	27,288.1
29.720f	127.09	116.31	1,544.4	26,049.6
28.920f	124.09	112.46	1,535.4	24,817.6
28.920f	122.18	112.46	1,535.4	24,817.5
27.320f	116.35	104.76	1,518.3	22,374.2
27.320f	153.85	104.76	1,518.3	22,374.1
26.520f	150.94	100.91	1,478.7	21,175.4
26.520f	152.82	100.91	1,478.7	21,175.3
24.920f	146.48	93.21	1,394.6	18,876.4
24.920f	144.41	93.21	1,394.6	18,876.3
21.720f	131.66	77.81	1,226.5	14,680.5
20.000f		69.68	1,132.7	12,651.3
20.000f	36.85*	69.68	1,095.9	12,651.2
18.520f	118.97	62.69	1,013.4	11,090.2
18.520f	115.15	62.68	1,013.4	11,090.1
17.720f	111.94	58.90	971.2	10,296.3

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CONDITION 1 - INITIAL CONDITION FOR EVEN DISTRIBUTION OF HOLDS

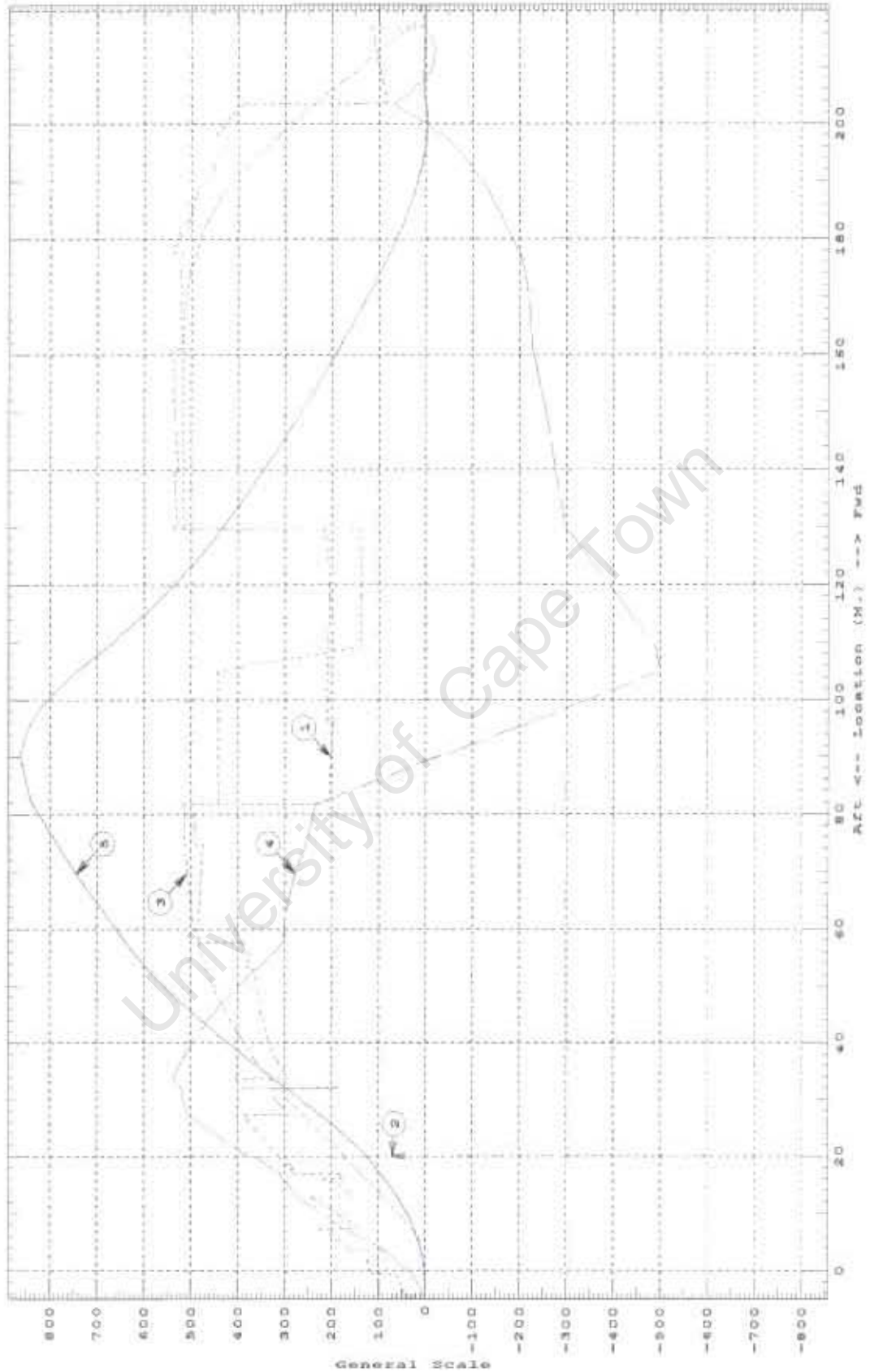
LOCATION M.	WEIGHT MT/M.	BUOYANCY MT/M.	SHEAR MT	MOMENT MT-M.
17.720f	115.05	58.90	971.2	10,296.3
16.920f	111.57	55.12	926.2	9,537.4
16.920f	73.39	55.12	926.2	9,537.3
16.120f	70.23	51.34	911.3	8,802.3
16.120f	87.73	51.34	911.3	8,802.3
15.320f	82.63	47.56	882.7	8,084.8
15.320f	75.12	47.56	882.7	8,084.6
13.720f	65.69	39.99	840.1	6,706.9
12.920f	60.97	36.30	820.0	6,042.8
12.920f	97.06	36.30	820.0	6,042.8
9.720f	73.26	21.54	640.0	3,714.7
8.920f	66.69	18.21	599.9	3,218.8
7.320f	57.45	11.54	524.4	2,319.9
7.320f	79.88	11.54	524.4	2,319.9
7.320f	90.78	11.54	524.4	2,319.9
4.228f	66.84	0.00	298.6	1,057.5
3.660f	62.64		261.9	898.4
3.660f	37.04		261.9	898.3
1.830f	34.19		196.7	479.6
1.830f	50.32		196.7	479.6
0.610a	45.58		79.7	144.7
0.610a	24.27		79.7	144.7
4.500a	16.71		0.0	-0.8
4.500a	0.00			
* Point weight in METRIC TON				
S U M M A R Y				
Largest Shear:		1,608.3 MT	at	33.770f
Largest Bending Moment:		86,101 MT-M.	at	90.000f (Hogging)

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CONDITION 1 - INITIAL CONDITION FOR EVEN DISTRIBUTION OF HOLDS

LONGITUDINAL STRENGTH at 0.04 degrees PORT HEEL
WITH FLOODING



(5) Bending Mom. 1=100 MT-M.

(3) Buoyancy 1=.4 MT/M.

(4) Shear 1=3 MT

(1) Weight 1=.4 MT/M.

(2) Point Weight 1=.5 MT

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CONDITION 2 - INITIAL DISTRIBUTION FOR MINIMUM HOG

WEIGHT and DISPLACEMENT STATUS							
BPL draft: 6.149 @ 215.44f, 6.204 @ 0.00							
Trim: Aft 0.05/215.44, Heel: Port 0.07 deg.							
Part			Weight (MT)	LCG	TCG	VCG	
LIGHT SHIP+			11,829.23	97.646f	0.000	10.073	
Sundry Small HFO Tks			28.05	20.000f	0.000	1.250	
Sundry Small DO Tks			8.80	20.000f	0.000	1.250	
Total Fixed	→		11,866.08	97.405f	0.000	10.046	
	Load	SpGr	Weight (MT)	LCG	TCG	VCG	RefHt
HOLD1.C	0.293	0.746	2,238.05	189.644f	0.045s	4.273	FROZEN
HOLD2.C	0.372	0.830	3,320.16	165.698f	0.053s	4.928	FROZEN
HOLD3.C	0.677	0.808	5,898.40	141.739f	0.029s	7.185	FROZEN
HOLD6.C	0.585	0.806	5,077.80	69.747f	0.034s	6.510	FROZEN
FO6.C	0.622	0.935	269.43	44.975f	0.012p	0.530	-1.050
DO_1.S	0.713	0.850	56.10	24.346f	3.275s	1.010	-1.754
FW_1.P	0.805	1.000	130.01	10.267f	7.660p	15.613	-17.251
FW_1.S	0.283	1.000	45.71	10.291f	7.248s	14.323	-15.099
FW_2.P	0.930	1.000	56.39	5.588f	7.008p	16.639	-18.094
FW_2.S	0.911	1.000	55.29	5.588f	6.999s	16.611	-18.061
WB_FPEAK.C	0.001	1.025	2.20	207.141f	0.031p	0.090	-0.294
WB_DB1.P	0.010	1.025	4.92	188.365f	2.582p	0.050	-0.224
WB_DB1.S	0.012	1.025	5.95	188.662f	2.366s	0.056	-0.241
WB_DB2.S	0.008	1.025	11.19	150.008f	9.543s	0.015	-0.080
WB_DB3.P	1.000	1.025	1,414.28	105.720f	12.177p	1.882	
WB_DB4.S	0.011	1.025	7.18	71.564f	8.687s	0.031	-0.083
WB_DB5.P	0.011	1.025	3.50	48.716f	6.744p	0.045	-0.078
WB_DB5.S	0.030	1.025	10.00	48.675f	7.183s	0.100	-0.186
WB_TS2.P	0.025	1.025	36.81	153.557f	15.449p	12.940	-13.220
WB_TS5.P	0.011	1.025	7.86	44.864f	15.594p	12.769	-12.903
WB_TS5.S	0.006	1.025	4.52	44.837f	15.648s	12.705	-12.829
WB_AP.C	0.043	1.025	22.74	6.119f	0.125s	5.490	-7.273
Total Tanks	→		18,678.49	125.380f	0.937p	5.864	
Total Weight	→		30,544.57	114.512f	0.573p	7.488	
			Displ (MT)	LCB	TCB	VCB	
HULL		1.025	34,804.27	114.417f	0.017p	3.160	-6.204
HOLD4 B.C	Flooded	1.025	-2,849.65	117.717f	0.028p	4.063	-6.204
WB_DB3.S	Flooded	1.025	-1,411.53	105.719f	12.170s	1.873	-6.204
WB_TS3.S	Flooded	1.025	0.00				
Total Displacement	→		30,543.09	114.511f	0.579p	3.135	
Righting Arms:				0.000	-0.000s		
Distances in METERS.							

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CONDITION 2 - INITIAL DISTRIBUTION FOR MINIMUM HOG

HYDROSTATIC PROPERTIES with FLOODING

Trim: Aft 0.05/215.44, Heel: Port 0.07 deg., VCG = 7.488

Draft@	Displacement	Buoyancy-Ctr.		Weight/		Moment/			
107.720f	Weight (MT)	LCB	VCB	CM	LCF	CM trim	GML	GMT	
6.176	30,543.09	114.511f	3.135	51.17	112.643f	744.19	524.93	7.938	
Distances in METERS.		Specific Gravity = 1.025.				Moment in M.-MT.			
Draft is from BPL.				Trim is per 215.44M.					True Free Surface included.

LONGITUDINAL STRENGTH with FLOODING at Heel = Port 0.07 deg.

LOCATION	WEIGHT	BUOYANCY	SHEAR	MOMENT
M.	MT/M.	MT/M.	MT	MT-M.
220.000f	0.00		0.0	0.0
219.000f	1.50	0.86	-0.9	0.2
217.040f	2.98	12.63	6.9	-2.9
217.040f	46.35	12.64	6.9	-2.9
214.600f	43.96	30.91	-51.3	60.8
213.284f	42.60	37.70	-63.0	136.8
211.331f	40.67	47.76	-60.9	261.1
209.378f	38.77	57.83	-35.4	358.4
207.426f	36.89	68.75	13.9	382.9
205.473f	35.05	80.52	89.4	285.8
203.600f	33.31	91.81	186.8	30.5
203.520f	58.16	92.29	189.5	15.5
203.520f	115.52	92.29	189.5	15.5
202.524f	118.86	98.30	167.7	-162.5
201.528f	121.29	103.94	148.7	-320.0
200.532f	123.89	109.32	132.8	-460.2
199.420f	126.79	115.34	118.3	-599.8
199.420f	123.43	115.34	118.3	-599.8
198.539f	125.58	120.10	112.3	-701.4
198.020f	126.87	122.91	109.9	-759.2
197.543f	115.22	125.49	114.4	-812.8
196.547f	117.22	130.88	126.3	-932.6
194.554f	119.70	141.03	160.4	-1,216.2
192.562f	119.83	149.60	211.4	-1,584.0
191.566f	121.83	153.89	242.2	-1,810.0
190.570f	123.87	158.18	275.2	-2,067.8
189.574f	126.03	162.47	310.5	-2,359.7
187.582f	128.97	170.10	386.7	-3,053.3
186.460f	129.91	172.98	433.9	-3,513.6
184.593f	131.26	177.77	517.5	-4,401.3
182.800f	132.82	182.37	603.7	-5,406.1
182.601f	138.08	182.88	612.6	-5,527.3
181.120f	139.69	186.68	680.6	-6,484.7
180.608f	137.79	187.41	705.3	-6,839.5
179.120f	137.82	189.55	780.7	-7,945.3

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CONDITION 2 - INITIAL DISTRIBUTION FOR MINIMUM HOG

LOCATION M.	WEIGHT MT/M.	BUOYANCY MT/M.	SHEAR MT	MOMENT MT-M.
179.120f	142.80	189.55	780.8	-7,945.4
177.720f	142.86	191.57	847.6	-9,085.2
177.620f	144.59	191.71	852.3	-9,170.2
177.620f	187.93	191.71	852.3	-9,170.2
173.720f	188.42	197.32	877.3	-12,537.2
169.300f	188.19	200.56	924.3	-16,514.3
168.120f	188.19	201.43	939.4	-17,614.0
162.520f	187.72	202.74	1,018.5	-23,093.0
161.200f	187.61	202.75	1,038.4	-24,450.9
161.100f	189.91	202.75	1,039.8	-24,554.9
160.720f	195.33	202.76	1,042.6	-24,950.5
157.720f	194.43	202.78	1,066.3	-28,114.2
153.720f	193.22	202.81	1,102.2	-32,450.3
153.720f	302.37	202.81	1,102.2	-32,450.4
152.140f	301.90	202.83	945.2	-34,068.2
149.720f	301.17	202.85	706.4	-36,067.1
144.860f	299.72	202.89	232.1	-38,346.1
143.560f	299.34	202.90	106.5	-38,566.5
139.600f	298.15	202.94	-272.9	-38,236.5
139.600f	301.56	202.94	-272.9	-38,236.4
134.980f	300.64	202.97	-726.4	-35,927.6
130.520f	299.75	203.01	-1,159.9	-31,720.9
129.720f	303.26	203.02	-1,240.1	-30,761.2
129.720f	87.06	54.97	-1,240.1	-30,761.2
128.120f	86.89	54.97	-1,291.4	-28,736.2
128.120f	83.22	54.97	-1,291.4	-28,736.2
126.400f	83.04	54.97	-1,339.8	-26,473.8
125.000f	82.88	54.97	-1,379.0	-24,571.1
120.000f	82.34	54.97	-1,517.2	-17,330.9
117.820f	82.14	54.97	-1,576.6	-13,959.3
115.000f	82.39	54.97	-1,653.6	-9,405.7
109.240f	82.91	54.98	-1,813.0	575.2
105.000f	83.29	173.82	-1,846.7	8,482.7
100.000f	83.74	173.86	-1,395.0	16,584.6
96.400f	84.06	173.89	-1,071.1	21,022.4
96.400f	79.05	173.89	-1,071.1	21,022.4
95.000f	79.35	173.90	-938.5	22,428.7
92.080f	79.97	173.92	-663.3	24,766.2
90.000f	80.42	173.94	-468.4	25,942.5
82.520f	82.02	174.00	225.5	26,841.8
81.720f	85.82	174.01	296.1	26,632.9
81.720f	269.72	203.42	296.1	26,632.9
80.120f	269.91	203.33	189.8	26,243.8
80.120f	266.28	203.33	189.8	26,243.7
77.720f	266.56	203.18	38.2	25,969.3
74.800f	266.48	202.37	-147.9	26,128.3

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CONDITION 2 - INITIAL DISTRIBUTION FOR MINIMUM HOG

LOCATION M.	WEIGHT MT/M.	BUOYANCY MT/M.	SHEAR MT	MOMENT MT-M.
74.800f	259.45	202.37	-147.9	26,128.3
69.720f	261.32	200.96	-446.2	27,629.0
66.340f	261.67	198.94	-654.3	29,485.6
61.720f	263.61	196.18	-954.9	33,193.5
57.720f	263.41	191.30	-1,234.0	37,563.9
57.720f	65.10	191.30	-1,234.0	37,564.0
56.120f	66.18	189.34	-1,034.5	39,377.7
56.120f	60.97	189.34	-1,034.5	39,377.8
53.200f	62.67	185.33	-667.8	41,858.4
53.200f	56.85	185.32	-667.8	41,858.4
49.180f	53.37	176.96	-161.2	43,517.1
45.720f	51.72	169.76	256.8	43,345.1
40.600f	47.87	154.96	833.2	40,529.4
36.920f	45.11	143.49	1,211.7	36,756.1
35.059f	43.59	136.18	1,389.4	34,333.2
33.770f	42.58	131.12	1,506.1	32,466.7
33.770f	87.77	131.12	1,506.1	32,466.6
32.120f	84.76	124.64	1,574.8	29,923.8
32.120f	74.42	124.64	1,574.8	29,923.7
32.120f	129.60	124.64	1,574.8	29,923.6
30.520f	123.91	118.36	1,566.4	27,410.1
30.520f	129.58	118.36	1,566.4	27,410.0
29.720f	127.08	115.21	1,557.1	26,160.7
28.920f	124.08	111.40	1,547.3	24,918.6
28.920f	122.17	111.40	1,547.3	24,918.5
27.320f	116.35	103.78	1,528.7	22,456.9
27.320f	153.85	103.78	1,528.7	22,456.8
26.520f	150.94	99.97	1,488.2	21,249.9
26.520f	152.81	99.97	1,488.2	21,249.9
24.920f	146.48	92.35	1,402.7	18,936.5
24.920f	144.41	92.35	1,402.7	18,936.4
21.720f	131.66	77.10	1,232.1	14,717.9
20.000f		69.05	1,137.2	12,679.6
20.000f	36.85*	69.05	1,100.3	12,679.6
18.520f	118.97	62.13	1,017.0	11,112.3
18.520f	115.16	62.13	1,017.0	11,112.2
17.720f	111.94	58.38	974.3	10,315.5
17.720f	115.05	58.38	974.3	10,315.4
16.920f	111.58	54.64	928.9	9,554.0
16.920f	73.40	54.64	928.9	9,553.9
16.120f	70.24	50.89	913.6	8,816.7
16.120f	87.74	50.89	913.6	8,816.7
15.320f	82.63	47.15	884.7	8,097.2
15.320f	75.12	47.15	884.7	8,097.1
13.720f	65.69	39.66	841.5	6,716.2
12.920f	60.97	36.01	821.1	6,051.0

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Triton Naval Architects
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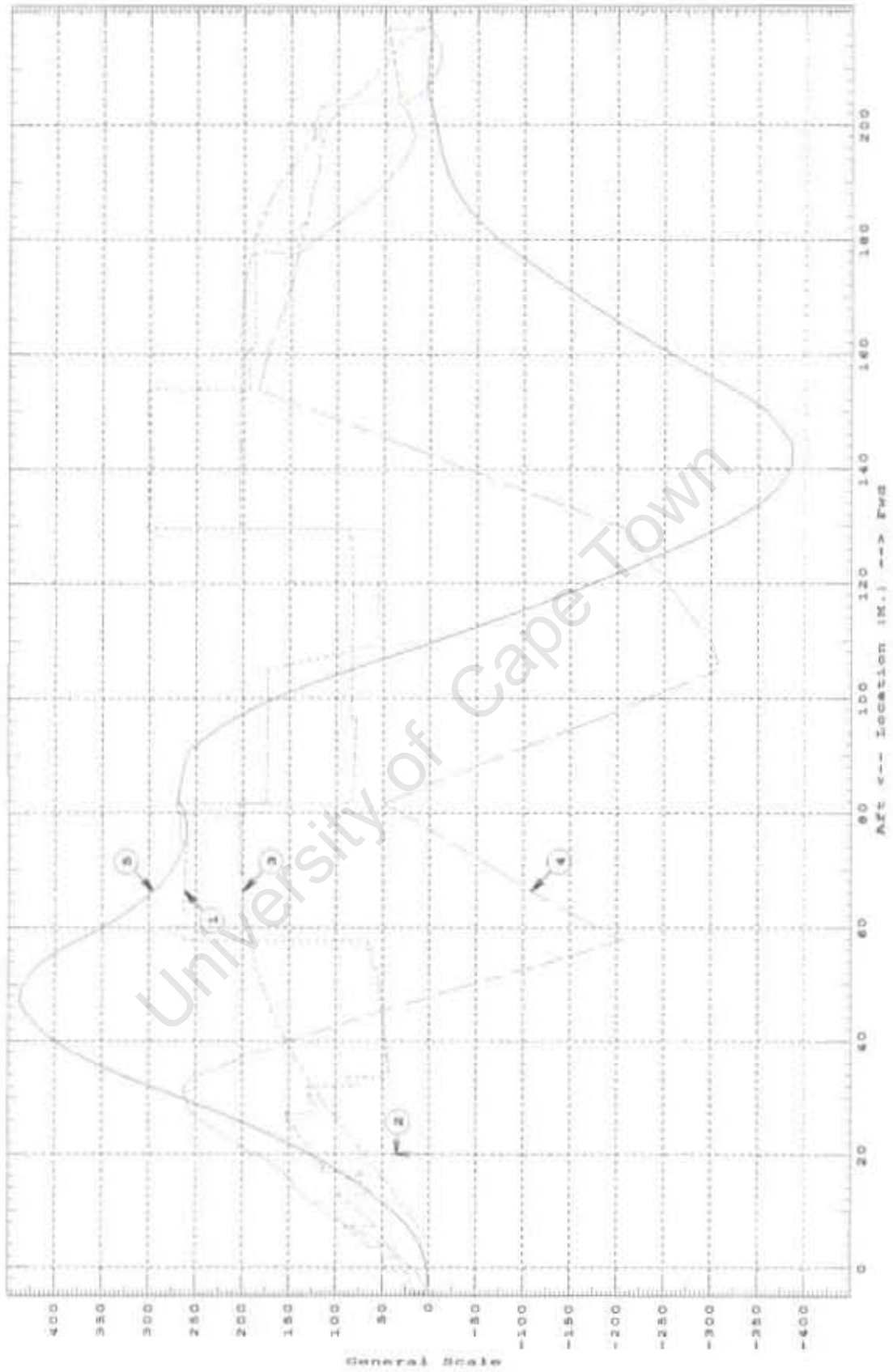
CONDITION 2 - INITIAL DISTRIBUTION FOR MINIMUM HOG

LOCATION M.	WEIGHT MT/M.	BUOYANCY MT/M.	SHEAR MT	MOMENT MT-M.
12.920f	97.04	36.01	821.1	6,050.9
9.720f	73.26	21.39	640.5	3,719.5
8.920f	66.70	18.09	600.3	3,223.2
7.320f	57.46	11.49	524.6	2,323.5
7.320f	79.87	11.49	524.6	2,323.4
7.320f	90.77	11.49	524.6	2,323.4
4.246f	66.98	0.00	299.8	1,065.2
3.660f	62.65		261.9	900.6
3.660f	37.04		261.9	900.6
1.830f	34.19		196.7	481.3
1.830f	50.32		196.7	481.3
0.610a	45.58		79.7	145.9
0.610a	24.27		79.7	145.9
4.500a	16.71		0.0	-0.7
4.500a	0.00			
* Point weight in METRIC TON				
S U M M A R Y				
Largest Shear:		-1,911.9 MT	at 105.720f	
Largest Bending Moment:		43,517 MT-M.	at 49.180f (Hogging)	

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M.V. "DECURION"
CONDITION 2 - INITIAL DISTRIBUTION FOR MINIMUM HOG

LONGITUDINAL STRENGTH at 0.07 degrees PORT HEEL
with FLOODING



- ① Weight 1=1 MT/M.
- ② Point Weight 1=1 MT
- ③ Buoyancy 1=1 MT/M.
- ④ Shear 1=5 MT
- ⑤ Bending Mom. 1=100 MT-M.

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CONDITION 3 - CARGO REDUCED IN HOLDS 1 & 7, DUE TO BLOCK LOCATIONS

WEIGHT and DISPLACEMENT STATUS							
BPL draft: 6.039 @ 215.44f, 6.106 @ 0.00							
Trim: Aft 0.07/215.44, Heel: Port 0.06 deg.							
Part			Weight (MT)	LCG	TCG	VCG	
LIGHT SHIP+			11,829.23	97.646f	0.000	10.073	
Sundry Small HFO Tks			28.05	20.000f	0.000	1.250	
Sundry Small DO Tks			8.80	20.000f	0.000	1.250	
Total Fixed	→		11,866.08	97.405f	0.000	10.046	
	Load	SpGr	Weight (MT)	LCG	TCG	VCG	FSM
HOLD1.C	0.327	0.746	2,500.03	189.617f	0.041s	4.550	FROZEN
HOLD2.C	0.470	0.830	4,200.06	165.687f	0.042s	5.669	FROZEN
HOLD3.C	0.493	0.808	4,300.00	141.747f	0.040s	5.840	FROZEN
HOLD6.C	0.461	0.806	4,000.03	69.752f	0.043s	5.594	FROZEN
HOLD7.C	0.121	0.775	1,000.03	45.214f	0.069s	2.837	FROZEN
FO6.C	0.622	0.935	269.43	44.972f	0.009p	0.530	2615.1
DO_1.S	0.713	0.850	56.10	24.346f	3.275s	1.010	58.4
FW_1.P	0.805	1.000	130.01	10.267f	7.659p	15.613	176.6
FW_1.S	0.283	1.000	45.71	10.291f	7.249s	14.323	100.6
FW_2.P	0.930	1.000	56.39	5.588f	7.008p	16.639	57.5
FW_2.S	0.911	1.000	55.29	5.588f	6.999s	16.611	56.8
WB_FPEAK.C	0.001	1.025	2.20	207.135f	0.023p	0.090	53.2
WB_DB1.P	0.010	1.025	5.08	188.354f	2.558p	0.051	599.9
WB_DB1.S	0.012	1.025	5.94	188.582f	2.401s	0.056	597.2
WB_DB2.S	0.008	1.025	11.03	149.621f	9.615s	0.015	2586.0
WB_DB3.P	1.000	1.025	1,414.28	105.720f	12.177p	1.882	0.0
WB_DB4.S	0.011	1.025	6.95	71.532f	8.697s	0.030	920.4
WB_DB5.P	0.011	1.025	3.62	48.664f	6.749p	0.047	60.2
WB_DB5.S	0.030	1.025	10.00	48.669f	7.187s	0.100	199.5
WB_TS2.P	0.025	1.025	36.81	153.531f	15.449p	12.940	22.8
WB_TS5.P	0.011	1.025	7.86	44.851f	15.594p	12.769	4.4
WB_TS5.S	0.006	1.025	4.52	44.818f	15.648s	12.705	2.7
WB_AP.C	0.043	1.025	22.74	6.119f	0.125s	5.490	0.6
Total Tanks	→		18,144.10	125.705f	0.960p	5.163	8112.1
Total Weight	→		30,010.18	114.515f	0.581p	7.094	
			Displ (MT)	LCB	TCB	VCB	RefHt
HULL		1.025	34,191.20	114.410f	0.013p	3.107	-6.106
HOLD4 B.C	Flooded	1.025	-2,771.66	117.716f	0.021p	4.005	-6.106
WB_DB3.S	Flooded	1.025	-1,409.61	105.719f	12.165s	1.868	-6.106
WB_TS3.S	Flooded	1.025	0.00				
Total Displacement	-->		30,009.92	114.513f	0.584p	3.082	
Righting Arms:				0.000	0.001s		
Distances in METERS.				Moments in M.-MT.			

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CONDITION 3 - CARGO REDUCED IN HOLDS 1 & 7, DUE TO BLOCK LOCATIONS

HYDROSTATIC PROPERTIES with FLOODING

Trim: Aft 0.07/215.44, Heel: Port 0.06 deg., VCG = 7.094

Draft@	Displacement	Buoyancy-Ctr.		Weight/		Moment/		
107.720f	Weight(MT)	LCB	VCB	CM	LCF	CM trim	GML	GMT
6.072	30,009.92	114.513f	3.082	51.14	112.725f	743.57	533.81	8.482
Distances in METERS.		Specific Gravity = 1.025.				Moment in M.-MT.		
				Trim is per 215.44M.				
Draft is from BPL.				True Free Surface included.				

LONGITUDINAL STRENGTH with FLOODING at Heel = Port 0.06 deg.

LOCATION	WEIGHT	BUOYANCY	SHEAR	MOMENT
M.	MT/M.	MT/M.	MT	MT-M.
220.000f	0.00		0.0	0.0
219.000f	1.50	0.86	-0.9	0.2
217.040f	2.98	12.49	6.8	-2.8
217.040f	46.35	12.49	6.8	-2.8
214.600f	43.96	30.44	-52.1	61.9
213.284f	42.60	37.06	-64.6	139.5
211.331f	40.67	46.88	-63.9	268.3
209.378f	38.77	56.70	-40.3	373.3
207.426f	36.89	67.37	6.5	409.9
205.473f	35.05	78.89	79.1	330.2
203.600f	33.31	89.95	173.1	97.4
203.520f	58.16	90.42	175.7	83.4
203.520f	121.96	90.42	175.7	83.4
202.524f	125.75	96.30	145.3	-76.5
202.120f	127.32	98.68	133.6	-132.9
201.528f	128.58	101.82	117.2	-207.3
200.532f	131.52	107.11	91.7	-311.3
199.420f	134.81	113.01	66.0	-399.0
199.420f	131.45	113.01	66.0	-399.0
198.539f	133.90	117.69	50.8	-450.5
198.020f	135.37	120.45	42.7	-474.8
197.543f	123.88	122.98	41.9	-495.1
196.547f	126.23	128.27	42.5	-537.1
194.554f	129.33	138.24	52.5	-630.0
193.120f	129.98	144.32	69.2	-716.7
193.120f	128.67	144.32	69.2	-716.7
192.562f	129.91	146.69	78.2	-757.9
191.566f	132.13	150.91	96.0	-844.7
190.570f	134.39	155.13	115.6	-950.1
189.574f	136.78	159.36	137.2	-1,076.2
187.582f	140.11	166.88	185.3	-1,396.7
186.460f	141.18	169.72	216.3	-1,621.9
184.593f	142.76	174.45	272.5	-2,077.7
182.800f	144.54	178.99	331.9	-2,619.2
182.601f	149.82	179.49	337.7	-2,685.9

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CONDITION 3 - CARGO REDUCED IN HOLDS 1 & 7, DUE TO BLOCK LOCATIONS

LOCATION M.	WEIGHT MT/M.	BUOYANCY MT/M.	SHEAR MT	MOMENT MT-M.
181.120f	151.62	183.24	383.2	-3,219.6
180.608f	149.72	183.97	400.0	-3,420.1
179.120f	149.82	186.09	452.5	-4,054.4
179.120f	154.81	186.09	452.5	-4,054.5
177.720f	154.93	188.08	497.6	-4,719.5
177.620f	156.67	188.22	500.7	-4,769.4
177.620f	224.17	188.22	500.7	-4,769.5
173.720f	225.10	193.77	369.8	-6,461.9
169.300f	225.05	197.01	238.6	-7,802.3
168.120f	225.10	197.87	206.0	-8,064.8
162.520f	224.63	199.20	58.6	-8,802.3
161.200f	224.52	199.21	25.1	-8,857.8
161.100f	226.82	199.21	22.5	-8,860.2
160.720f	232.24	199.22	9.9	-8,866.4
157.720f	231.34	199.25	-87.8	-8,749.5
153.720f	230.13	199.29	-213.7	-8,145.9
153.720f	235.77	199.29	-213.7	-8,145.9
152.140f	235.30	199.30	-270.9	-7,763.3
149.720f	234.58	199.33	-357.1	-7,003.5
144.860f	233.13	199.38	-524.8	-4,858.5
143.560f	232.74	199.39	-568.4	-4,148.1
139.600f	231.56	199.44	-698.1	-1,639.9
139.600f	234.96	199.44	-698.1	-1,639.9
134.980f	234.05	199.48	-860.0	1,959.8
130.520f	233.16	199.53	-1,012.1	6,135.0
129.720f	236.67	199.54	-1,041.8	6,956.2
129.720f	87.06	54.80	-1,041.8	6,956.2
128.120f	86.89	54.81	-1,093.3	8,664.1
128.120f	83.22	54.81	-1,093.3	8,664.2
126.400f	83.04	54.81	-1,142.0	10,586.2
125.000f	82.88	54.81	-1,181.4	12,212.3
120.000f	82.34	54.81	-1,320.5	18,467.0
117.820f	82.14	54.81	-1,380.2	21,410.2
115.000f	82.39	54.81	-1,457.7	25,410.9
109.240f	82.91	54.81	-1,618.0	34,266.2
105.000f	83.29	170.42	-1,654.7	41,349.3
100.000f	83.74	170.48	-1,220.0	48,534.0
96.400f	84.06	170.51	-908.3	52,363.7
96.400f	79.05	170.51	-908.3	52,363.7
95.000f	79.35	170.53	-780.4	53,545.4
92.080f	79.97	170.56	-515.0	55,435.6
90.000f	80.42	170.58	-327.1	56,310.8
82.520f	82.02	170.65	341.6	56,247.5
81.720f	85.82	170.66	409.6	55,946.8
81.720f	224.74	200.03	409.6	55,946.8
80.120f	224.93	199.94	369.8	55,322.9

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CONDITION 3 - CARGO REDUCED IN HOLDS 1 & 7, DUE TO BLOCK LOCATIONS

LOCATION M.	WEIGHT MT/M.	BUOYANCY MT/M.	SHEAR MT	MOMENT MT-M.
80.120f	221.30	199.94	369.8	55,322.9
77.720f	221.59	199.80	318.0	54,496.8
74.800f	221.59	198.99	253.2	53,661.5
74.800f	214.56	198.99	253.2	53,661.5
69.720f	216.35	197.59	166.1	52,588.4
66.340f	216.82	195.58	98.4	52,138.2
61.720f	218.64	192.83	-10.3	51,925.3
57.720f	218.79	187.99	-123.5	52,185.2
57.720f	105.37	187.99	-123.5	52,185.2
56.120f	106.43	186.05	6.3	52,277.9
56.120f	101.23	186.05	6.3	52,277.9
53.200f	102.90	182.07	246.0	51,905.0
53.200f	97.07	182.07	246.0	51,905.0
49.180f	93.55	173.81	578.1	50,241.3
45.720f	91.87	166.69	846.4	47,770.6
40.600f	87.86	152.09	1,202.4	42,501.4
37.720f	84.71	143.88	1,380.1	38,778.4
36.920f	82.89	140.78	1,426.8	37,655.5
34.948f	79.11	133.16	1,537.2	34,730.7
33.770f	76.90	128.61	1,599.5	32,883.3
33.770f	122.09	128.61	1,599.5	32,883.2
32.120f	117.27	122.23	1,608.9	30,235.8
32.120f	74.42	122.23	1,608.9	30,235.6
32.120f	129.60	122.23	1,608.9	30,235.6
30.520f	123.91	116.04	1,596.8	27,670.5
30.520f	129.58	116.04	1,596.8	27,670.4
29.720f	127.08	112.95	1,585.7	26,397.6
28.920f	124.08	109.21	1,574.1	25,133.3
28.920f	122.17	109.21	1,574.1	25,133.2
27.320f	116.35	101.72	1,552.0	22,631.7
27.320f	153.85	101.72	1,552.0	22,631.6
26.520f	150.94	97.98	1,510.0	21,406.7
26.520f	152.81	97.98	1,510.0	21,406.6
24.920f	146.47	90.49	1,421.3	19,061.0
24.920f	144.41	90.49	1,421.3	19,060.9
21.720f	131.67	75.51	1,245.2	14,791.9
20.000f		67.63	1,147.7	12,733.3
20.000f	36.85*	67.63	1,110.9	12,733.3
18.520f	118.97	60.85	1,025.5	11,151.9
18.520f	115.16	60.85	1,025.5	11,151.8
17.720f	111.94	57.18	981.9	10,348.7
17.720f	115.05	57.18	981.9	10,348.7
16.920f	111.58	53.51	935.5	9,581.6
16.920f	73.40	53.51	935.5	9,581.5
16.120f	70.24	49.85	919.4	8,839.4
16.120f	87.74	49.85	919.4	8,839.4

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CONDITION 3 - CARGO REDUCED IN HOLDS 1 & 7, DUE TO BLOCK LOCATIONS

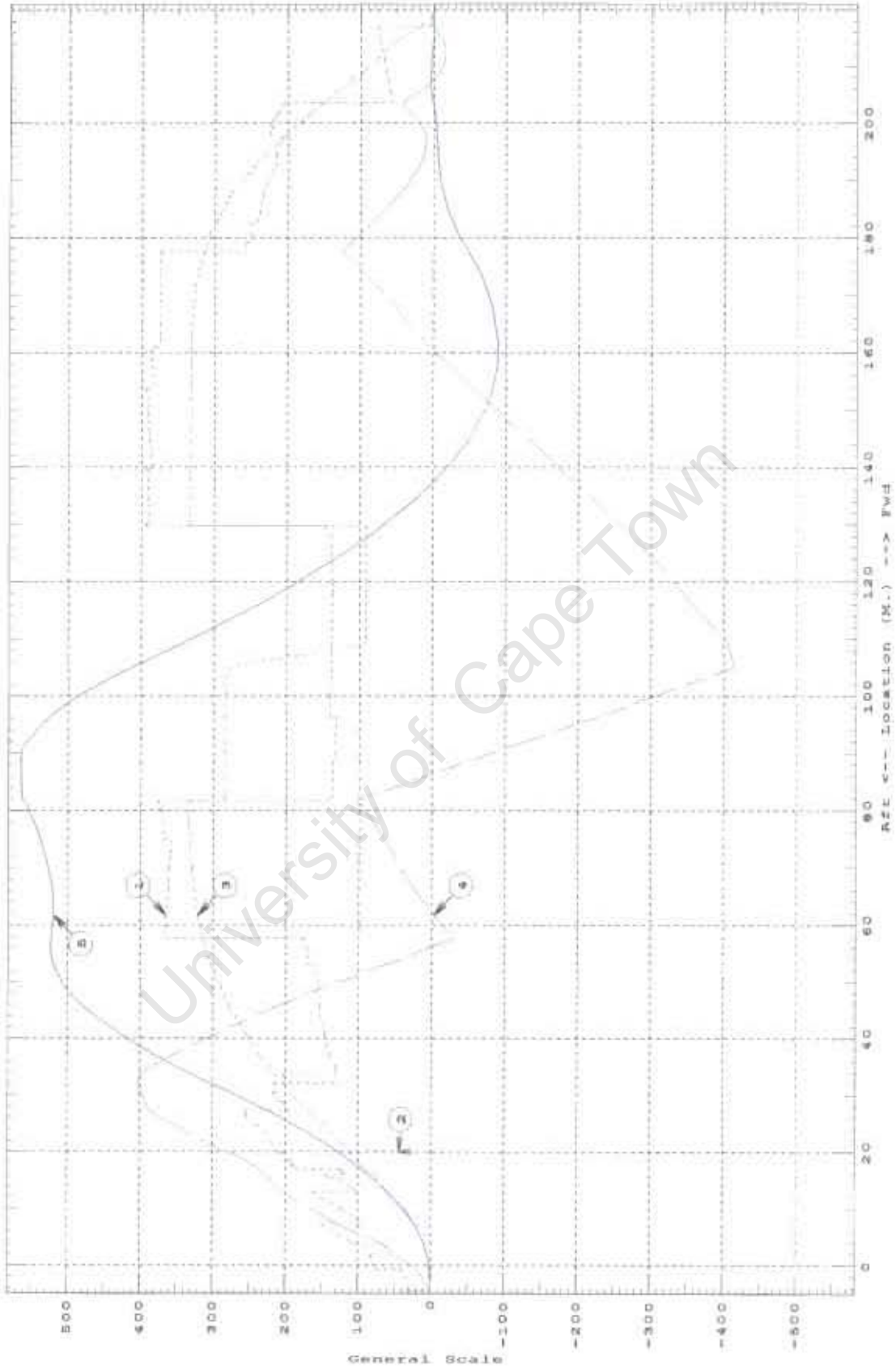
LOCATION	WEIGHT	BUOYANCY	SHEAR	MOMENT
M.	MT/M.	MT/M.	MT	MT-M.
15.320f	82.63	46.18	889.7	8,115.7
15.320f	75.12	46.18	889.6	8,115.6
13.720f	65.69	38.85	845.0	6,728.0
12.920f	60.97	35.28	824.0	6,060.2
12.920f	97.04	35.28	824.0	6,060.1
9.720f	73.26	20.99	641.6	3,722.7
8.920f	66.70	17.78	601.1	3,225.6
7.320f	57.46	11.36	525.1	2,325.0
7.320f	79.87	11.36	525.1	2,324.9
7.320f	90.76	11.36	525.1	2,324.9
4.295f	67.36	0.00	303.1	1,080.9
3.660f	62.65		261.9	901.5
3.660f	37.04		261.9	901.5
1.830f	34.19		196.7	482.3
1.830f	50.32		196.7	482.3
0.610a	45.58		79.7	146.9
0.610a	24.27		79.7	146.9
4.500a	16.71		-0.0	0.6
4.500a	0.00			
* Point weight in METRIC TON				
S U M M A R Y				
Largest Shear:		-1,717.4 MT	at 105.720f	
Largest Bending Moment:		56,540 MT-M.	at 83.500f (Hogging)	

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GHS 7.14

M.V. "DECURION"

CONDITION 3 - CARGO REDUCED IN HOLDS 1 & 7, DUE TO BLOCK LOCATIONS

LONGITUDINAL STRENGTH at 0.06 degrees PORT HEEL
WITH FLOODING



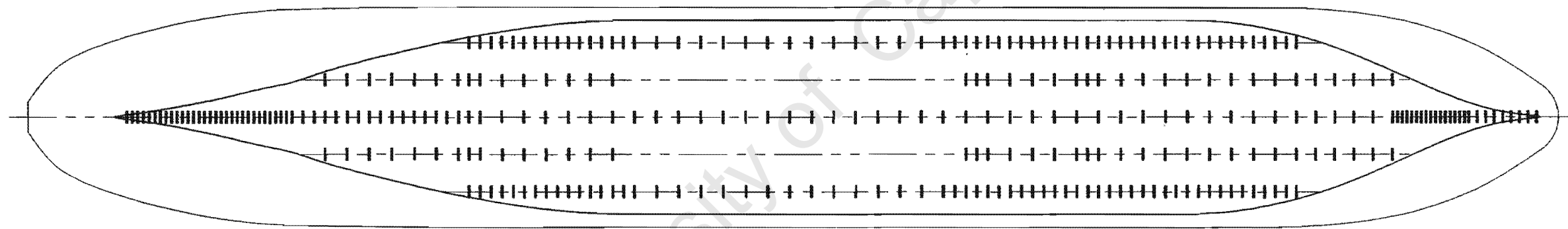
- 1 Weight 1 = .6 MT/M.
- 2 Point Weight 1 = .8 MT
- 3 Buoyancy 1 = .6 MT/M.
- 4 Shear 1 = 4 MT
- 5 Bending Mom. 1 = 100 MT-M.

CHAPTER 7 - ANNEXURE B

DRAWING OF THE PROPOSED ARRANGEMENT OF DOCKING BLOCKS

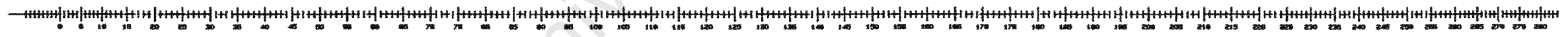
University of Cape Town

M.V. DECURION
 L.O.A. 224.55 m
 L.R.P. 215.44 m
 BEAM 32.20 m



ROW P2 No of BLOCKS 62
 ROW P1 No of BLOCKS 38
 CENTRE ROW No of BLOCKS 114
 ROW S1 No of BLOCKS 38
 ROW S2 No of BLOCKS 62
 TOTAL No OF BLOCKS EMPLOYED 334

AFT PEAK HOLD No. 7 HOLD No. 6 HOLD No. 5 HOLD No. 4 HOLD No. 3 HOLD No. 2 HOLD No. 1 FOREPEAK
 MASS- 2020 T BLOCKS- 28 MASS- 2580 T BLOCKS- 28 MASS- 6246 T BLOCKS- 68 MASS- 1804 T BLOCKS- 23 MASS- 2340 T BLOCKS- 24 MASS- 8152 T BLOCKS- 68 MASS- 5420 T BLOCKS- 64 MASS- 3820 T BLOCKS- 37 MASS- 643 T BLOCKS- 6



FRAME SPACING 610mm FRAME SPACING 800mm FRAME SPACING 700mm FRAME SPACING 610mm

REV	DATE	DESCRIPTION
<small>This drawing is the property of TRITON SHIP DESIGNERS and may not be copied or used for purposes other than those for which it is supplied without the express written consent of TRITON SHIP DESIGNERS.</small>		
Triton Naval Architects CAPE TOWN		
M.V. DECURION HULLING PLAN		
SCALE	AS SHOWN	DATE
DRAWN		Feb 2000
CHECKED	<i>AK</i>	
APPROVED		

CHAPTER 8
DIAMOND MINING SHIP - ANALYSIS AND RETROFIT SOLUTION
on the ¹M.V. "DGB"

INVESTIGATION INTO THE CAUSE OF CRACKING OF THE HULL GIRDER, AND
BUCKLING OF TRANSVERSE BULKHEADS, AND THE PROPOSAL OF
SOLUTIONS.

This case study reports on an investigation, into the cracking of the ship's structure and buckling of main transverse bulkheads.

The study first investigates the causes, with the aid of finite element analysis and onboard hull stress monitoring methods. Solutions are then proposed, with the aid of structural drawings, prepared by Triton Naval Architects, which were submitted to the controlling classification society for approval, and then implemented as a retrofit. After the completion of the retrofit, a further session of "in-port" and "operational" stress monitoring was undertaken, to quantify the success of the exercise.

8.1 CRACKING AND BUCKLING OF THE HULL STRUCTURE IN WAY OF THE MIDSHIP REGION OF THE VESSEL

8.1.1 INSPECTION

In June of 1998, Christo Smit of Triton Naval Architects visited the vessel to inspect alleged cracking of the ship structure in way of the tank top of No. 8 Port and Stbd Wash Water Tanks, on Frame 91 and 110. During this inspection he observed significant buckling of the transverse bulkheads at Frames 91 and 110, between tanktop and tweendeck level, and also between tweendeck and maindeck level. These bulkheads are the main transverse bulkheads on either side of the moonpool. The longitudinal bulkheads at 6.286m outboard running from the transverse bulkheads at frame 91 to 110 where also buckled to a lesser extent, between the tweendeck and the main deck. The outcome of this inspection was described in detail in his report "Structural Inspection Report for M.V. Grand Banks" - TNA 796, dated 9th June 1998. [10]

8.1.2 IDENTIFICATION OF CAUSES

The buckling of the transverse bulkheads, were ascribed to the possible high transferal of loads from the bottom longitudinal girders (running off the corners of the moonpool) and from the deck longitudinal girders, into the respective bulkheads, at frame 91 and 110. The buckling of the bulkheads could also possibly be ascribed to high transverse loads being transferred from the drill tower base legs into the ship structure, as these drill floor legs penetrate the main deck on Frame 91 and 110.

¹

M.V. "DGB" is an alias given to the actual diamond vessel, considered in this case study, due to the owners requesting that the company name and vessel name not specifically be mentioned.

Such transverse loads, which would come about due to the dynamic effects of the ship rolling, would justify the manner in which the bulkheads were buckling, ie isotropic buckling between vertical stiffeners, as a result of high in-plane compressive loading.

A less likely cause was identified as;

- possible excessive global bending moments as a result of inadequate section modulus for the static, and dynamic (wave and drill/mooring) induced loads.

In other words the entire vessel in the midships region would be flexing too much, due to wave and drilling induced loads. This was initially seen as a less likely cause, as the transverse bulkheads would have been less affected, unless the vessels was also twisting excessively.

The drill floor structure (which is a very stiff structure, at a significant offset from the overall neutral axis of the hull girder) would tend to resist any global bending of the hull girder, and in so doing, would result in higher loads being transmitted through the drill tower base legs into the ship structure in way of the affected bulkheads.

With the most likely cause initially being identified as the effect of loads being transferred from the drill tower into the ship's structure, it was proposed to perform a finite element analysis of the midship area of the vessel, including the drill floor structure.

8.2 FINITE ELEMENT ANALYSIS TO DETERMINE THE EFFECT OF LOADS TRANSMITTED THROUGH THE DRILL TOWER LEGS INTO THE SHIP'S STRUCTURE

With the first cause being identified as the more likely, a finite element analysis was undertaken by Triton Naval Architects, in order to endeavour to establish the magnitude and effect of the forces that were being transmitted from the drill floor and drill tower through the drill tower base into the ship's structure, particularly in way of bulkheads at frame 91 and 110, as a result of static tower loads.

The following section should not be seen as a full report on the Finite Element Analysis, but merely a description, together with some sample plots.

The model included all structure from tank top level up to and including main deck, the moonpool, the longitudinal bulkheads and sections of the drill floor base.

The model was restrained at tank top level at all degree's of freedom, and at the ship's edge (port and stbd) in vertical plane for the deck and tweendeck structure, and in the longitudinal plane for the transverse bulkheads.

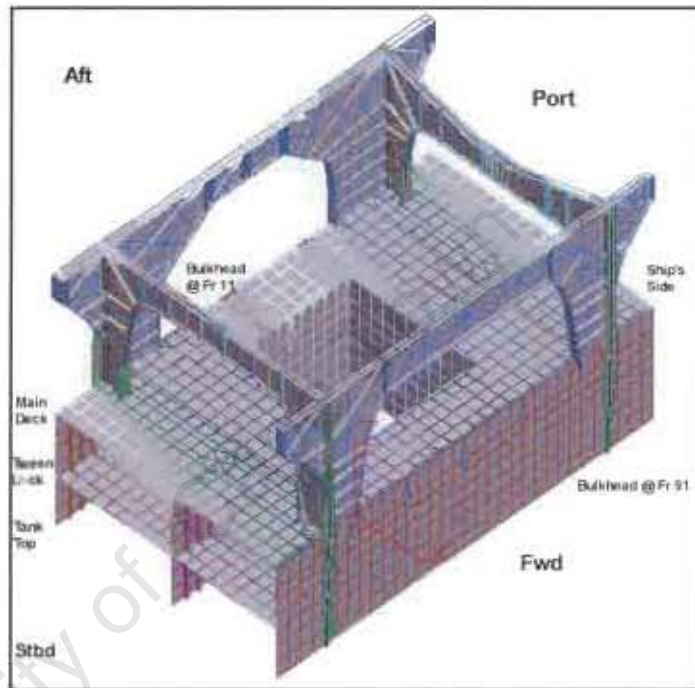


Figure 8.1 - Initial FE Model

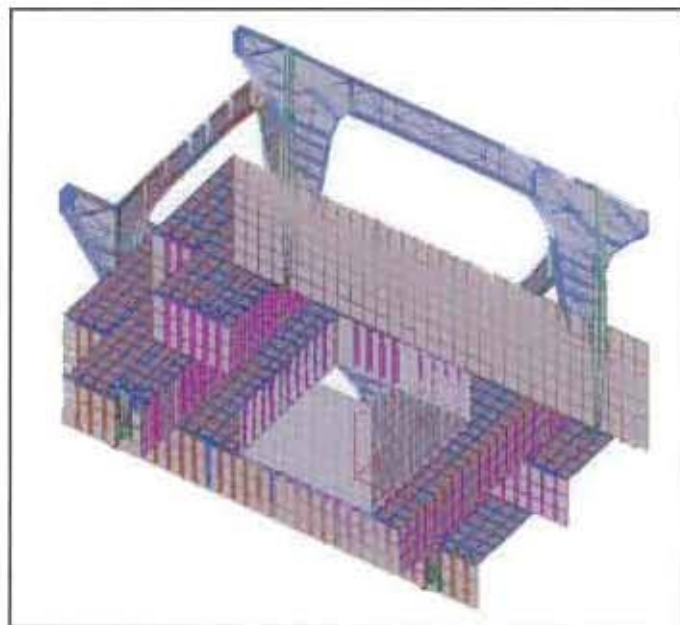


Figure 8.2 - Initial FE Model view from Underneath

The model was loaded according to loads obtained from Debeers Marine applicable to the tower base on frames 91 and 110. The loads had been calculated in 1993 when the tower was designed. Exact references of what the various forces were referring to, was not entirely clear, but additional load cases were also analysed for the travelling gear plus tower mass being subjected to a transverse acceleration of 2 g's, and a vertical acceleration of 1g.

As can be seen in the sample stress plots attached, none of these load cases indicated significant loading of the bulkheads, although very local higher stress areas were observed in the immediate vicinity of the tower legs.



Figure 8.3 - Restraints marked in Red, Triangles are rigid restraints, while Circles are limited restraints. Applied Nodal Forces are marked in Yellow. Distributed Loads are not shown, but are applied.



Figure 8.4 - Von Mises Stresses, under the combined Debeers Marine Loads (both bulkheads loaded simultaneously, and both directions loaded simultaneously)

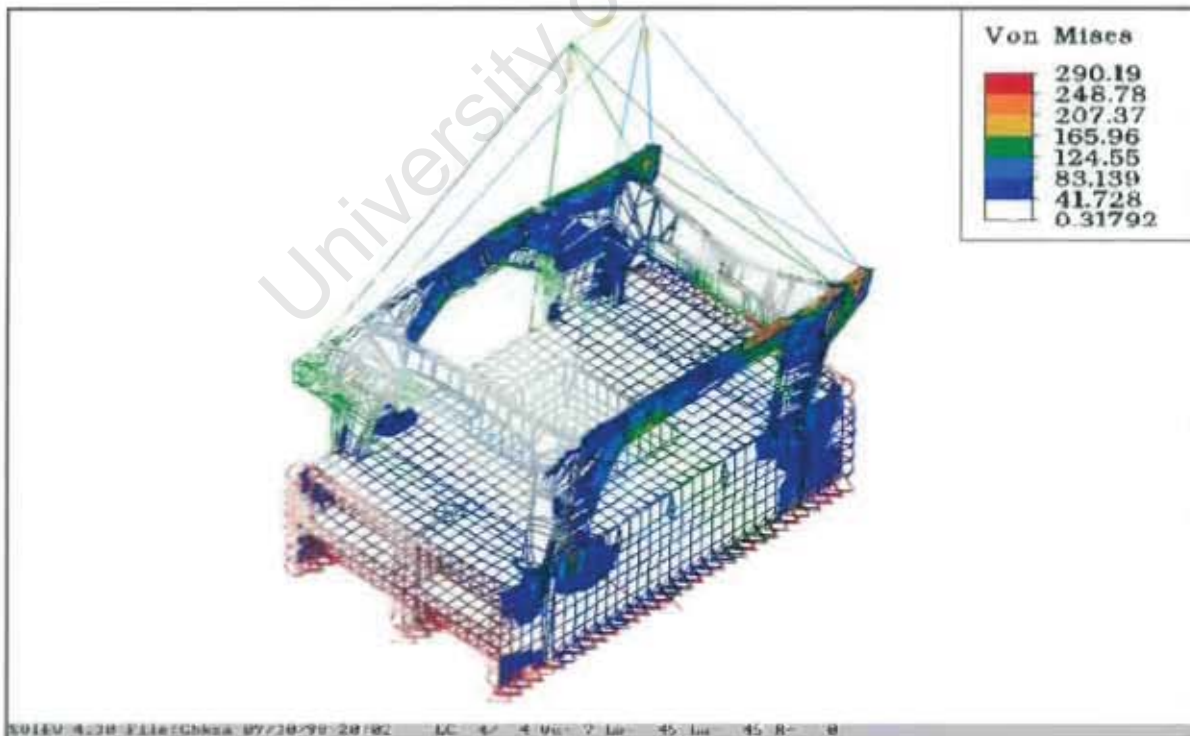


Figure 8.5 - Von Mises Stresses for the Drill Tower and associated weights being subjected to a 2g transverse acceleration. The modelled structure is also being subjected to a 2g transverse acceleration.

8.3 **GLOBAL LONGITUDINAL HULL STRENGTH CALCULATION**

It was then decided to look at the global bending of the vessel, and possibly apply the calculated global bending moments to the model (or an extended model) to establish the effects of the fairly stiff drill floor structure resisting global bending, and global torsion. This extension of the model would involve significant additional modelling in terms of extending the existing model well beyond the bulkheads in question, and the entire drill floor structure would also have to be modelled in order to predict the torsional resistance that such a structure would offer. A traditional longitudinal bending moment calculation would have to be undertaken, whereby the buoyancy distribution vs the weight distribution is integrated along the ship's length to give the shear force and again integrated to give the bending moments along the length of the vessel. In order to perform a traditional bending moment calculation, the lightship weight distribution would have to be established or obtained, as well as the section modulus along the length of the vessel, or at least in the midship region, (if one was to ignore the stresses in other areas).

The section modulus at the midship region could easily be calculated from the available structural drawings, but the lightship weight distribution was not readily available.

In 1993 a detailed longitudinal strength calculation was calculated for the sister ship. In that calculation it was established that the bottom structure in way of the No.7 Port and Stbd Tanks had to be reinforced through additional longitudinal girders, which were subsequently installed on both vessels, running from Frame 76 to Frame 126. In view of that calculation and the remedial steps that were taken, it was decided that to repeat the exercise was fruitless, especially without a reasonably accurate lightship weight distribution.

8.4 **PROPOSED MEASURES TO COUNTER THE EFFECTS OF THE DAMAGE**

Without having any conclusive evidence as to the cause of the failing structure, only the effect could be addressed and not the cause. Measures to address the effect would include adding stringers to all the affected bulkheads, thus reducing their vertical span, thus significantly improving their isotropic buckling characteristics. In way of the cracking that was taking place at the interface between the longitudinal deep girder at tank top level, coming off the corners of the moonpool, large softnose brackets on either side of the bulkheads at frame 91 and 110 were proposed. These brackets would more effectively transmit any loads in the longitudinal girder in way of the moonpool region, back into the double bottom structure beyond the region between Frame 91 and 110, without loading the transverse bulkheads excessively.

It was however decided that treating the effect without establishing the cause was an unacceptable approach.

8.5 PROPOSED HULL STRESS MONITORING

It was then suggested by Triton Naval Architects to install a hull stress monitoring device, so as to establish not only the measurable stresses in the applicable structure, but also to link these stresses with operational conditions, ie mining operations, wave and wind conditions, and mooring winch operations. With such information the cause of the failing structure could be more accurately determined, and efficient and effective counter measures could then be undertaken.

It was proposed that Triton Naval Architects, together with ²LGI of the University of Pretoria, undertake a project to install and monitor the stresses in the affected areas for a period of time, which should include all conditions of weather and mining operations. It would possibly be even more beneficial if hull stress monitoring equipment were installed on both sister vessels so as to collaborate the combined data. Areas identified for stress monitoring would typically be on the affected bulkheads, the drill tower base leg structure, the underdeck girders where accessible etc.

Strain gauges along with the associated electronic monitoring and recording equipment would be installed onboard the vessels. A procedure for the recording of weather, wind, estimated wave conditions and mining operation conditions, as well as the ³“current loading conditions” of the ship, would have to be drawn up. The current loading conditions could merely be extracted from the onboard stability program recently installed onboard both vessels. An electronic log book system, or spreadsheet, could be established for the recording of weather and mining conditions. The electronic hull stress monitoring equipment would record strain on a time basis. This strain data would later be processed into applicable stress data.

² LGI is the “Laboratorium vir Gevorderde Ingenieurswese”, translated to “Laboratory for Advanced Engineering”, which is a commercial consulting branch of the University of Pretoria.

³ The “current loading condition” of the ship, refers to the manner in which the ship is loaded at any given time. For example, the status of the tanks (fluids) and the weight and location of all other weight items not associated with the vessels own weight.

8.5.1 **PROPOSED POSITIONS OF STRESS MONITORING**

It was initially proposed to measure stresses at locations as depicted on the following two figures. Some of these locations, marked with the letter Y, would not be possible due to them being inside fuel tanks.

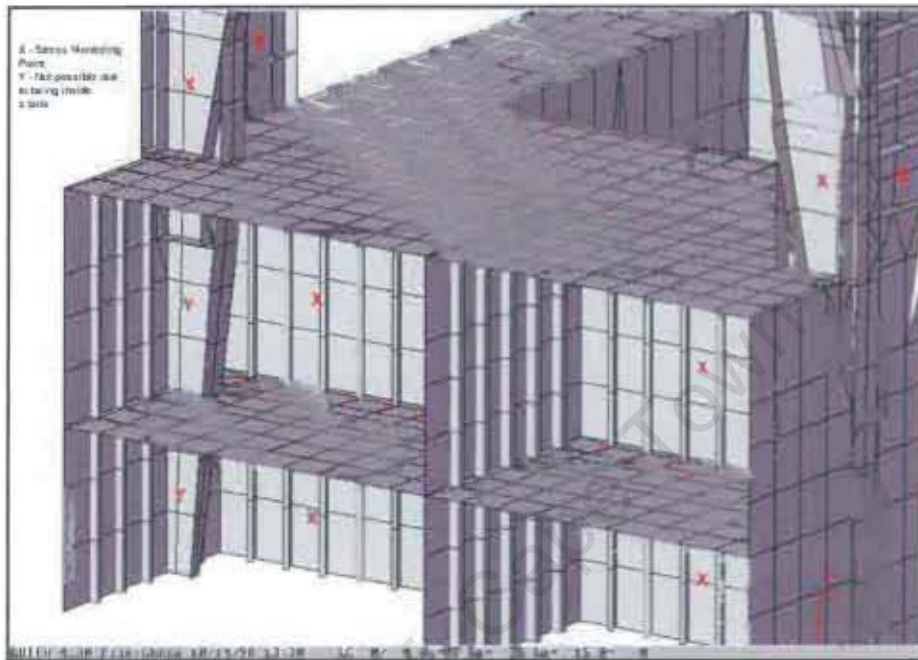


Figure 8.6 - Initial proposal of locations for strain gauges. Viewed from the side.

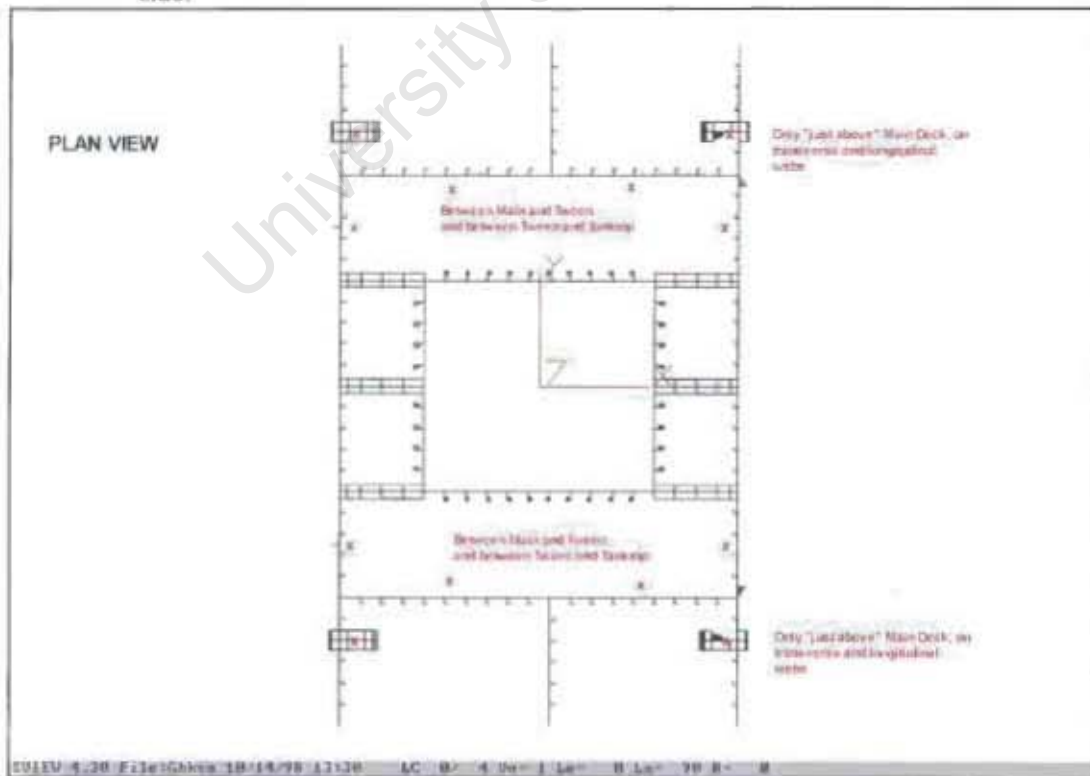


Figure 8.7 - Plan view of possible strain gauge locations

8.6 **INSTRUMENTATION FOR STRESS MONITORING**

Once onboard the vessel at sea, the locations for attaching strain gauges was re-assessed and finalized according to practical considerations.

8.6.1 **Hull Stress Monitoring of Bulkheads**

Location of Gauges:

9 channels of strain gauges were located on the Bulkhead of Frame 91 between the tweendeck and tanktop.

4 Channels were located on the Bulkhead of Frame 110 between the Tweendeck and Maindeck.

As these bulkheads were already buckled or tripped, it was not envisaged to obtain good stress deflections on these bulkheads. The vertical stiffeners of these bulkheads were not bent/ buckled or tripped, thus the structural integrity of these bulkheads from the position of being able to withstand hydrostatic pressure from liquids in tanks should not be adversely affected.

As has been said before, the buckling of these bulkheads were most likely symptoms of a wider problem, and less likely a local problem. The bulkheads are not expected to have strength in the direction in which they have buckled. The fact that they had buckled, gave the indication that forces had been imposed on them in a adverse direction. The bulkheads can withstand forces in two directions, namely limited vertical loading, and pressure loading perpendicular to the bulkheads.

The buckling of the bulkheads indicated (in all likelihood) a *couple* type load between the drill floor legs, where they extend below main deck. In other words, the effect of one leg pushing down harder than the other leg, or one leg pushing down while the other leg is pulling up. This effect could be caused by inertia effects of the drill tower and all associated equipment, when the vessel rolls, and /or the actual twisting of the ship as a global member (beam).

The web and flanges of the drill floor legs extend through to the tank top level, to the ship's bottom shell. If one had to consider the loading as described, there would be shear forces in the bulkhead between the legs. The solution to this problem, would be to "unload" the bulkheads. A closed loop structure would have to be created, which would be very effective in transmitting torsional loads. A dramatic simplification of this concept is to compare a pipe used as a torsional shaft, and then to cut the bottom section out of the pipe, leaving an inverted U shaped cross section, and then to apply the same torsional load. The torsional strengths of the two are not even in the same order. One could then place a rib, or two ribs at a central location in the pipe to simulate the transverse bulkheads. If one had to apply the torsional load to the pipe, the two ribs (torsional bulkheads) would buckle, whilst the torsional stiffness of the pipe would still be nowhere near the original strength.

One can argue at this point that the ship is a closed loop structure, ie bottom sides and deck, which is fairly effective at resisting torsion. While that is certainly true, it is counter argued that if the torsional loading is being transmitted through the drill floor legs, the torsional flow from one leg to the other (ie to close the loop) is not effective through a relatively weak, vertically stiffened bulkhead.

In applying large fictitious transverse loads to the drill floor, the finite element model shows high stresses in the bulkheads immediately inboard of the drill floor legs. This confirms to a certain extent, what has just been discussed.

It is further maintained that a drill floor structure, with legs that extend down and through the ship's structure, in line with the ship's side, would be more effective, than the configuration of the ship under consideration. Had the legs tied in directly with the side shell, torsional loads could be effectively transmitted through the side shell and transverse stiffening, (which is a strong structure, acting in the correct direction), around the bilge, across the bottom structure, around the other side bilge up the ship side and back into the far side drill floor leg.

A proposed solution was to incorporate structure, either at maindeck, tweendeck or tanktop level, which would "close" the torsional loop, and at the same time "unload" the bulkheads in question.

The existing bulkheads (being buckled in places), would require local stiffening in way of ⁴stringers, which would tie the vertical stiffeners together. It was not envisaged to replace any bulkhead plating.

It was initially envisaged to mirror the actual response of the structure, as measured by the strain gauges and accelerometers, against the response obtained from Finite Element Analysis.

It must however be mentioned that the vessel was not rolling significantly at the time the data was recorded, due to the prevailing weather at the time, thus the inertia effects of the drill tower and associated equipment, could not be determined with any degree of accuracy. Longer term data acquisition would be necessary to track all conditions of operation and weather.

8.6.2 Longitudinal Strength

The original objective had been to ascertain only drill floor related stresses and effects on the ship structure, but with a channel or two spare, a strain gauge was placed on the maindeck, in the region of midships, to determine the strain deflections, due to wave loads and other influences. Whilst being present onboard, it was quite clear that the recordings from this gauge were perfectly in phase with the prevailing swell, and the vertical accelerations being recorded midships.

⁴

Stringers are horizontal deep stiffeners, longitudinal or transverse, designed to reduce the effective span of the smaller, but closer spaced vertical stiffening.

The primary mode of failure for a vessel such as this, is a global failure through midships, ie through the moonpool. This was confirmed by the failure of a sister vessel in the 1970's when she floundered during a severe storm. In being transversely framed, with basically no significant longitudinal structure other than the longitudinal bulkheads, the likelihood of this mode of failure is further exaggerated over a longitudinally framed vessel.

Due to the questionable longitudinal strength of these vessels, additional longitudinal girders have already been placed in the ships' bottom outboard of the longitudinal bulkheads, during a previous retrofit.

Recordings from the deck strain gauge, coupled to the recorded accelerations, would give an indication of the longitudinal strength integrity of the vessel. It must be said, that if longitudinal failure was likely, the longitudinal bulkheads in way of the moonpool, should have shown signs of buckling or tripping, although this would be a late symptom, as it would require large global deflections of the hull to cause non elastic deflection of the bulkheads. The same applies to buckled deck plating, which would also be a symptom of excessive global bending, but again it would be a late symptom, as once the deck is permanently buckled/tripped, the longitudinal strength of the vessel would be severely impeded, and failure would be imminent.

The cracking of the bulwark in many places in the midship region, where it is attached to the maindeck at side, although appearing to be a local failure, possibly due to seas coming over the portside deck (which is commonplace), could also be due to excessive global bending. In this case, the former appears more likely though, as there was one place where the bulwark was non continuous, and yet there were cracks in the immediate vicinity of the non continuity. Also there were far more cracks on the portside than the starboard side. The portside is generally being exposed to more wave loading. A further study into the cracking of the ⁵bulwark ⁶stations, indicated fatigue failure, and incorrect repair procedures. This study will not be addressed in this thesis, but is included as a reference. [11]

8.7 INITIAL RESULTS FROM STRAIN RECORDINGS

Initial indications from the recordings were that virtually all the strain deflections were very much in phase with the wave action, indicating that the loading of the structure was more affected by the global influences, viz wave action, than the local influences, viz. mining operations. Within the clear wave period fluctuations, higher frequency mining induced vibrations, were clear on all drill floor structure, and transverse bulkhead gauges, but to a very much lesser extent on the deck gauge.

Recordings were also taken for specific modes of operation, namely whilst lifting the drill

⁵ Bulwarks are the section of supported plate that extends beyond the upper deck, forming a handrail and safety barrier.

⁶ The stations are the supports for the bulwark plate, and are located opposite underdeck frames.

bit, lowering the drill bit, drilling, moving to a new block, and during a blow off.

Indications were that the problem may be more global than local, in which case further longitudinal strengthening would have to be considered, if these stresses were found to be excessive.

8.8 **FINITE ELEMENT CORRELATION**

The original finite element model was extended, and fictitious forces were applied in order to ascertain their effects on certain structure. These fictitious loads would later be replaced by more realistic loads in order to attempt to obtain a reasonable correlation between the stresses that were being measured, and those predicted by finite element methods.

8.8.1 **ASCERTAINING REALISTIC LOADS TO APPLY TO A FE MODEL**

Text Book Approach

Text book methods, more specifically those proposed by Hughes [1], are as follows:

Start with a global, but crude finite element model of the entire hull. This model should only include the global structure, ie all shell plating bottom plating, deck plating, bulkheads, double bottom plating, if applicable, but exclude all local stiffening.

The self weight of this structure would then reproduce the lightship weight distribution. Additional local loading, or nodal forces may be necessary to adjust/add to the self weight, in order to take account of lightship items not considered in the model, such as the superstructure, heavy machinery etc.

Additional loading in way of fluid or cargo loads must be applied to the model in the applicable locations and on the applicable structure, either by means of nodal forces, or element pressures, in a way which would best simulate the actual loading of the vessel.

The hydrostatic pressure distribution of the surrounding water, must be applied to the outside shell of the model in such a way so as to take account of the current draft and trim of the vessel for the loading condition in consideration.

In an ideal situation the model of the vessel, once analysed, would then “bend” according to the current hog or sag produced by a loading combination as applied.

The theory then dictates that the responses of this analysis, in the form of either bending moments and/or nodal forces are then applied to a detailed “module” model, which only encompasses the area in question. In this case the “module” model would be similar to the model shown here, incorporating the moonpool area, drill floor structure and surrounding hull structure. It would extend far enough beyond the area of immediate concern, as applied loading from the global structure

will result in some exaggerated local distortion in the immediate area of application. Such a model would include all principle structure and local stiffening to best simulate the actual structure. It would generally exclude secondary structure, like minor brackets etc. These can be modelled individually should a particular area show up problems.

The “module” model would then, in an ideal situation, give a good representation of the stresses experienced by the structure in that area.

Shortcoming in this Approach

Shortcomings to this approach, as experienced first hand, are the following:

Modelling and loading of the global model generally do not pose problems, although the loading can be arduous. Unless the Finite Element program provides otherwise, the pressure loading for the outer shell, has to be pre-computed according to each element’s individual water depth for a known draft and trim of the ship, and applied individually element by element. If the program provides for a run file input, a simple program can be written to calculate applicable pressures relative to the mean of the nodal coordinates for each submerged element. These pressures can then be inputted into the FE program via a run file. The same method of applying hydrostatic pressures would have to be applied to all tanks or holds that contain liquids.

Once analysed the combined vertical reaction force should equal the combined weight of the model and applied loads (cargo, tank and other), for the vessel to be in equilibrium.

One real shortcoming, is that without the detailed stiffening, the shell plate alone cannot withstand the loading. One finds exaggerated local displacements, due to hydrostatic pressures, applied loading and even self weight. Although one is generally looking at the overall bending of the global structure these local deformities obstruct and /or overshadow the global deflections. One way to overcome this is to artificially adjust plate thicknesses, material densities and modulus of elasticity, as one is looking for nodal forces as input into the “module” model, and not so much interested in the stress result of the global model.

Shortcoming in the transfer of Loads between the Global Model and the Module Model.

The second shortcoming occurs in the process of transferring the results from the global model to be used as input on the “module” model.

The output of the global model will generally be a combination of nodal forces and nodal moments.

Generally the module model will have extents that correspond to specific locations on the global model, such as transverse bulkheads. The idea being to obtain nodal

forces and/or moments at those locations and apply them to the “module” model at its extents, which in terms of the ship’s coordinates, are at the same position. In order to successfully perform this transferal, the nodal positions of the two models must be identical. If they are identical it means (in all likelihood) that the global model has the same mesh density as the module model, which goes a long way to defeating the purpose of the global model. The locations of the nodes on the “module” model would generally be dictated by the locations of the stiffeners. ie in the longitudinal direction, nodes would always fall on the frames, as they would in the transverse direction, so that any longitudinal stiffeners or girders automatically tie in with the general mesh pattern. If the transferal of loads from the global model to the module model is to be successful, the global model should have a similar mesh pattern. In my opinion, this together with the lack of stiffeners of the un-stiffened global model as described above, negates the necessity for global model. The “module” model should be modeled in sufficient detail to accurately portray the response of the structure concerned, and it should extend as far beyond the immediate area of concern, as is necessary to transfer the applicable loads to that area, without causing excessive local deformation in that area due to the application of loads.

A more efficient method of determining global bending moments and shear forces for a ship structure is using a dedicated hydrostatic program, which by the nature of its use, balances the vessel in equilibrium between the buoyancy forces and weight forces. It also calculated weight distributions of filled or partially filled tanks, also taking heel and trim into account. Thus it can be used as output to a *simple beam theory* type of solution of bending moments and shear forces along the length of the ship. This data can then be used an input into the module model at its extents. Strictly speaking the module model, should still be loaded according to buoyancy forces and distributed weight forces between those extents, but at least the boundary conditions would have been established, and in a more efficient manner than using a global model as described.

One drawback of this approach, is that one still experiences exaggerated distortions and high stresses at the boundaries at which the loads are being applied, as one is applying high nodal forces or bending moments to a discontinuous structure, whereas in reality that structure is continuous, and although experiencing the same loads, it relies on the continuity of the structure in being able to handle those loads without exaggerated distortion.

In summary it must be said that correlating the response of the FE model to the stresses recorded by the strain gauges met with limited success, certainly with not enough accuracy to make any predictions using the FE results.

8.9 RECORDED STRESS DATA

The instrumentation for strain gauging and measuring of accelerations were performed onboard the vessel, whilst at sea, by LGI, under our supervision.

A total of 33 strain gauge channels and 8 accelerometers were installed, with 24 channels being measured at any one time.

8.9.1 MEASUREMENT PROCEDURE

Measurements were performed for various operational conditions. The signal conditioning of the data was performed by four Spider 8 amplifiers coupled to a PC. The data was recorded with a sampling frequency of 300Hz for typical samples of 40 seconds. A 40 second sample proved to be sufficiently long to incorporate at least 2 full wave periods, which were typically in the order of 13 seconds.

The first readings were performed to obtain information regarding the effect on the bulkheads when No.7 Water Ballast Tanks were empty. Thus a reference reading was obtained for No.7 Water Ballast Tank empty, and later compared with those read when the No.7 Water Ballast Tanks were refilled (See Figure A.2. - Annexure A). The objective of this exercise being to determine the effect of the hydrostatic pressure of the fluid within the tank. A secondary spinoff of this comparison, came about once it became apparent from the deck gauge that the longitudinal strength may be more of a problem, as the difference in deck stress between empty No7 Water Ballast Tanks and full No7 Water Ballast tanks proved to be significant. (See Figure A.1. - Annexure A).

8.9.2 MEASUREMENT RESULTS

As there is no absolute zero reference, all stresses, with the exception of those described above w.r.t. the filling and emptying of the No.7 Water Ballast Tanks, were plotted with reference to their own mean. Thus only the dynamic stress fluctuations are depicted.

Only specific results will be depicted in this report, which were extracted from the three bound volumes of ⁷stress plots prepared by LGI.

Due to the bulkheads on Frames 91 and 110 already being buckled, and thus considered unstable, measurements from these gauges were treated with circumspect. If one had to re-measure stresses on these bulkheads once they were repaired, valuable insight would be gained as to the cause of the original failure.

Acceleration measurements yielded values in the order of 0.05g's in the vertical and longitudinal direction, and roughly half of that in the transverse direction. The

7

The stress plots illustrated in Annexure A, were extracted from the full set of graphs supplied by LGI. As this initial data was not available in magnetic format, and had to be copied, from copies, the quality of the graphs is somewhat lacking.

accelerometers were all placed on the drill floor. The prevailing swell was approximately 20 to 30 degrees off the portside bow, resulting in very little roll, but a more pronounced pitch and heave.

Investigation of the acceleration data furthermore yielded small higher frequency fluctuations, depicting vibrations caused by the mining plant.

It was initially envisaged to use the acceleration data as input into the finite element model, but due to the values obtained, all being of very low magnitude, it would have been fruitless.

8.10 **BENDING STRESSES**

8.10.1 MOVING THE SHIP ON HER ANCHOR CHAINS

Although the average bending stress fluctuations, as recorded on the deck gauge were between 20 and 30MPa in most cases, one notable reading of fluctuations in the order of 60MPa was recorded whilst moving the ship on her anchor chains. (See Figure A.6 - Annexure A)

8.10.2 No.7 WATER BALLAST TANK EMPTY AND FULL

As can be seen from Figure A.1. - Annexure A, The direct stress offset due to the No.7 Water Ballast Tanks being empty versus the same tanks being filled, was in the order of 80MPa. This is the offset which took place between readings 01 and 10/11. For this pair of ballast tanks to have such a marked effect on deck stresses, pointed to questionable longitudinal strength, which is also quite apparent from the structural configuration of the vessel, which is a transversely framed structure, with no longitudinal girders passing the midship region. The three longitudinal underdeck girders, run up to the corners and centreline of the moonpool. The filling of the No.7 Water Ballast Tanks increased the deck compression or decreased the deck tension to the order of 80MPa, which is in accordance with what one would expect, ie. increased sagging or decreased hogging. The magnitude is however higher than one would expect.

8.10.3 FREAK DECK STRESS RECORDING

One "freak" high deck stress reading was recorded which took place during a blowoff. There are however other "blow off" recordings which did not show exceptionally high stress fluctuations.

In this isolated case, a stress fluctuation of 225MPa was recorded, which was initially dismissed as being either a faulty recording or an error in post processing, as it appeared to be in the order of 10 too high. Unfortunately only one deck gauge was employed thus no direct means of correlation was possible.

The manner used to check gauges for faultiness is by correlating them to the accelerations recorded at the same instant. In this case the accelerations as

recorded by eight accelerometers were much the same as those recorded for other conditions, and showed the same trends as those recorded for other conditions, namely the normal harmonic motion induced by the passing waves. The stresses recorded for this instant, namely S21A, depicted in *Figure A.8. - Annexure A*, does not show a normal harmonic trend, which although hard to explain, is possible, as the bending stresses in the deck are not all directly related to accelerations, but are also influenced by buoyancy distributions, weight distributions, and any other force influences. The only way to conclusively correlate this stress recording would have been via a second deck gauge. It was then decided that for all future recording, gauges would be arranged in pairs.

The data recorded by the deck gauge, both before and after this event, gave normal results, thus also giving reason to believe that the gauge was not faulty at any time.

8.10.4 GENERAL BENDING STRESS RECORDINGS

General bending stress recordings due to drill action, namely lifting and lowering the drill bit, and actual drilling, had very little influence on the bending stresses recorded by the deck gauge, as can be seen by the domination of the wave (sea swell) influence on the stress plots. See *Figure A.5. - Annexure A*.

8.10.5 STRESS DATA RECORDED ON THE DRILL TOWER

General drill tower stress fluctuations were recorded to be in the order of 0.5 to 2MPa, with some isolated instances of higher values up to 7 to 8 MPa. The drill tower stress fluctuations, unlike the deck gauge stresses, are directly related to the dynamic effect, or accelerations experienced by the structure in the particular direction of the gauge. In view of vertical accelerations (or heave accelerations) averaging 0.05g's, one can immediately establish that the dynamic effect being recorded is a very small component of the static load (which is unknown), and it would be imprudent to extrapolate (across the board) the dynamic effect back to the static load, using the small accelerations recorded. What could be established however was that the drill tower (in the conditions recorded) was probably not significantly stressing the hull structure, much in accordance of its static load.

8.11 STRUCTURAL MODIFICATIONS

A proposal was then drawn up by Triton Naval Architects, for the design and drawing of additional structure which would strengthen the vessel in a manner adequate to overcome the shortcomings identified in the stress monitoring exercise.

8.11.1 LONGITUDINAL BEAMS

In order to overcome the requirement for additional longitudinal strength in way of the deck structure, additional deep girders were proposed. By tying these girders in with the existing drill floor legs, ie. between Fr 91 and 110, and utilizing the same offset from centerline, namely 24', as do the web plates of the drill floor legs, this

would lend itself to the added advantage of creating a strong “closed loop” structure, between the new girder at underdeck level, the vertical fwd and aft drill floor legs, and the horizontal drill floor longitudinal side beam.

The proposed beam would extend well beyond the midship area, by a similar distance on either side. It would thus run from Frame 75 to 125, with the midship region being from Frame 91 to 110. The girders would have dimensions of 1200x16mm Web, and a 400x25mm flange. The flange of these girders would tie in exactly with an existing 32mm flange plate which is 1200mm below deck level. The web of the girders would obviously tie in with the 20mm web of the drill floor legs.



Figure 8.8

At the extremes, the girder would taper off significantly, ie. short of the extreme bulkheads, then extend up to the bulkhead and be bracketed on the far side. See Drawing TNA 945/02.

8.11.2 TRANSVERSE STRUCTURE

Although the stress fluctuations as recorded on the drill floor legs were very low, as were the recordings on the bulkheads, it must be noted that due to the heading of the moored vessel, together with the prevailing weather, the vessel had no notable roll during the time the recordings were taken. The vertical and longitudinal accelerations as measured on the drill floor were in the order of 0.01 to 0.05g's or 0.1 to 0.5m/s², while the transverse accelerations were typically less than half of that.

The buckling of the bulkheads at frame 91 and frame 110 still however indicate an inplane shear resulting from the drill floor being subjected to a significant transverse moment, as would be expected at higher angles of roll, or a high degree of “twist” in the hull structure due to global hull responses. We were still of the opinion that the “torsional loop” of this structure should be closed, to counter the effect of such loading.

Due to the nature of the structure at tank top level, ie. the ⁸split level between

⁸

The levels are split inboard and outboard of the longitudinal bulkhead, in that the outer wing tanks are full depth (bottom shell to main deck), whilst the compartments inboard of the bulkhead, (located aft and fwd of the No.7 ballast tank), extend from tank top level to tweendeck level.

inboard and outboard of the longitudinal bulkhead, it was decided to locate the bridging structure at tweendeck level. It would also be more effective at this level, as the applicable forces dissipate with distance from main deck, thus the lower down the structure, the less effective it would be.

The modification would involve, cutting out the bulkhead plate on frames 91 and 110 from tweendeck level to 1200mm above tweendeck, and from the existing portside 2" thick, vertical bar flange stiffener to the same on the starboard side. These two 2" thick vertical bar stiffeners are the flanges of the transverse section of the drill floor legs, where they continue below main deck, down through the tweendeck and tanktop, culminating on the bottom shell.

A new 1200 x 16mm web plate with a 250 x 25mm flange would replace this section of bulkhead plating, but would be radiused up to the vertical bar stiffeners, at the two extremes, to effectively form two large softnose brackets. The existing vertical bulkhead stiffeners would then be cut off at flange level and would run onto the new flange. See Drawing TNA 945/03 in Annexure C.

It was noticed on the sister ship, that the stiffener brackets immediately under tweendeck on the transverse bulkheads in the No.7 Water Ballast Tank were merely small rectangular plates welded between the web of the angle stiffener, where it stops short of the deck, and the deck above, and were severely corroded. This in contrast to the brackets located immediately above the tweendeck in the central store, which were normal triangular stiffeners with bent over flanges. It was then suggested on that vessel, that the brackets below the tweendeck (in the tank) should be replaced with matching brackets to those above. This was again proposed for this vessel, especially in light of the new proposed bridging structure as depicted in the drawing.

As the bulkheads on Frame 91 and Frame 110 were buckled in places, it was also proposed to install one transverse stringer, to be located midway between tank top and tweendeck, to support the buckled plate. Such a stringer would typically be 250mm x 16mm. It would have to be wide enough to span the largest vertical stiffener, which was a 200x100x20 angle. See Drawing TNA 945/03 in Annexure C.

8.11.3 LARGE SOFTNOSE BRACKETS IN WAY OF NO7 WATER BALLAST TANKS, TO FORM AN EXTENSION OF PREVIOUS MODIFICATION.

⁹DSA Drawing No. 350 depicts details on a previous proposal for large softnose brackets that were installed on this vessel (but not the sistership). These brackets were in-line with the longitudinal bulkheads of the moonpool, where the bottom longitudinal ties in with bulkheads on Frame 91 and 110. These brackets, although alleviating the cracking problem, tend to overstress the bulkheads, thus it was

⁹

DSA (Daggitt Smit and Associates) was the name of Triton Naval Architects, prior to the departure of the partner, Richard Daggitt.

proposed to mirror them with identical but opposite brackets on the other side of the bulkhead. In this way the forces would be transmitted back into the double bottom structure, and unload the bulkhead at that point. The following photograph shows the location at tanktop level, and also a transverse "ship's heeling system" pipe which would have to be accommodated by the proposed brackets.



Figure 8.9

8.11.4 MODIFICATION IN WAY OF THE LUFFING CYLINDER FOUNDATION

The underdeck foundation of the luffing cylinder of the A-Frame, was attached to the transverse bulkhead, on Frame 110. The structure of the foundation is typically 32mm plate, which was attached to an 11mm bulkhead, but without additional bracketing on the far side, thus was due to cause the bulkhead to buckle. The repair solution was to free the bulkhead of the load. See Figure 8.10, below.

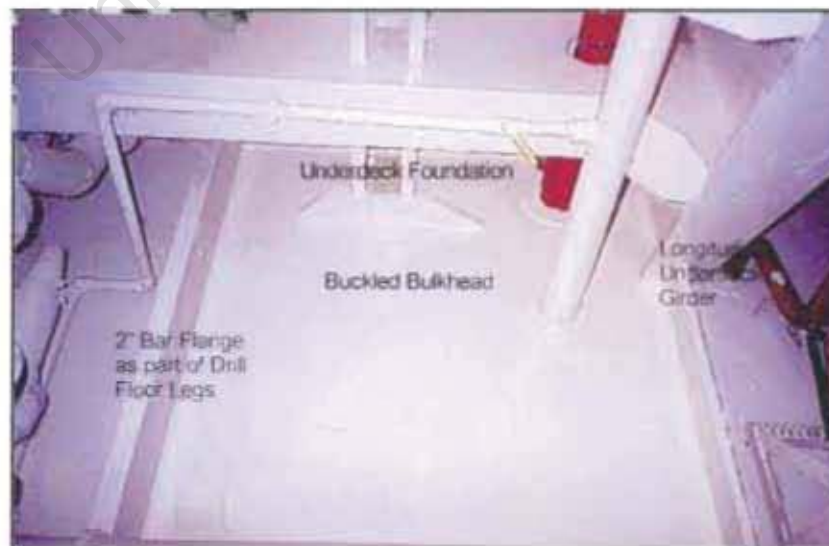


Figure 8.10

A drawing was prepared for the modification of the structure. The underdeck foundation plates are shown to be cut short of the affected bulkhead, thus “unloading” the bulkhead, and alternative stiffening has been proposed. See TNA Drawing No. 945/01 in Annexure C.



Figure 8.11 - Figure 8.10 seen from the left.

8.12 FABRICATION

All works were completed in accordance with the drawings as proposed. Minor variations were necessary in way of the following:

8.12.1 HYDRAULIC DOOR AT FRAME 110

The portside longitudinal beam had to be modified to accommodate the hydraulic watertight door at frame 110, which was not apparent on the original drawings referenced.

This significant notch or cutout in the main girder was of concern from a stress concentration point of view, especially in light of its position. It is quite conceivable that the highest loads in the new girders may occur at frames 91 and 110 and not necessarily at midspan between these bulkheads. This being due to the significant stiff structure of the drill floor, well above main deck, significantly increasing the midships section modulus. Any bending load that the drill floor structure absorbs would have to be transmitted through the drill floor legs into the ship structure. Part of this load would be transmitted from the drill floor legs into the new girder, thus a stress concentration or significant narrowing of the beam at this point would be disadvantageous.

Due to their being no other choice but to accommodate the hydraulic door, it was

decided that during the post retrofitting stress monitoring phase, the stresses would be recorded at this stress concentration and be compared those recorded at the same location on the starboard girder.

8.12.2 MODIFICATION IN WAY OF THE LUFFING CYLINDER FOUNDATION (STBD SIDE ONLY)

Due to a large vent trunk passing through the path of the proposed new longitudinal bracket which would have tied the three deep transverse sections, as seen in Figure 8.11 above, back onto the 2" flange of the drill floor leg (also visible on the photographs), an alternative solution had to be proposed for the starboard side.

It was then proposed that the bulkhead attached to the existing foundation be cut out, and a new stiffer insert plate with an associated "table" be fabricated which would tie back to the 2" flange. This arrangement can be seen on *Drawing TNA 945/01 in Annexure C*.

8.12.3 RELOCATION OF THE STORES HATCH

Not shown on any of the reference drawings, was a small stores hatch (approx 1.2m x 1.2m) directly in line with the proposed new portside girder. This hatch was located directly fwd of the drill floor leg at frame 110.

It was proposed to relocate this hatch outboard of the side girder, as it was imperative that the side girders remain continuous, and that they tie in directly with the drill floor legs, where they protrude through main deck.

A drawing was prepared, indicating the position of the hatch, details of doubler plates to be removed, and to be replaced.

The new position of the hatch would be directly in way of the walkway, thus a simple two step "climb over" arrangement was proposed, whereby a person would step onto the hatch cover and down the other side. The hatch cover opens in the fwd/aft direction, and stands almost vertical when open, thus obstructs a person from climbing over (or into) the hatch when open.

See Drawing TNA 945/05 in Annexure C.

8.13 **POST RETROFIT STRESS MONITORING**

A second stress monitoring exercise was undertaken, on completion of the retrofit, in order to correlate the effect of the additional strengthening against the situation before.

Once again LGI were contracted for the instrumentation and data capturing. This information was then sent through to Triton Naval Architects for post processing, implementation, and reporting.

Due to the emphasis on improving longitudinal strength, as identified from the initial stress

recording, the final stress measuring exercise centred around bending stresses in the deck and bottom structure, with no interest in the drill floor structure.

The instrumentation would take place while the ship was still in drydock, so as to calibrate the gauges for a zero reference, which would be as close to a realistic zero as is ever likely to occur. With the ship fully supported under her keel at very close intervals along her entire length, it is argued that both the deck and bottom structure would be experiencing very little static longitudinal bending stress. Any stresses recorded later, once the vessel is afloat, as referenced to a zero taken in drydock, would be very close to the actual static stress experienced by the structure concerned. With this approach, actual stresses could be recorded, whilst during the previous stress measurement exercise, only the dynamic effects could be obtained, as the instrumentation was performed with the ship afloat, at sea, being subjected to constantly changing loads.

Immediately after un-docking the still water bending stresses measured by all the gauges would be recorded, against a fixed "static" loading condition. The condition of the ship, viz trim and drafts and thus displacement or buoyancy distribution, and the status of all the tanks, fixed weights not part of the lightship, and the lightship weight would all be known quantities.

It was then proposed to perform certain ballasting operations, whilst still in port, in still water conditions, which would result in "bending" the vessel in a sagged condition, and then again in a "hogged" condition. By recording stresses against known static loading conditions, a much more accurate conclusion of ship strength could be attained.

8.13.1 LOCATION OF STRAIN GAUGES

10 linear strain gauges and one (vertical) accelerometer were employed in the midship region of the vessel to quantify the hull bending stress scenario for different operating conditions.

Gauges attached to the bottom structure

Immersed strain gauges were attached to the bottom shell inside the No.7 Water Ballast Tanks.

The No.7 Water Ballast Tanks are located around the moonpool, extending from frame 91 to 110, and between the bottom plating and tweendeck. The port and stbd tanks are separated by a centreline bulkhead. The tanks thus extend from the centreline to a longitudinal bulkhead located at 20' (6.096m) to port or stbd.

The location of the gauges for the port tank described below, were mirrored for the starboard tank.

One gauge was attached near the side longitudinal bulkhead, one frame from midships, with a second gauge at midspan between the moonpool longitudinal bulkhead (10' or 3.048m off centre) and the side longitudinal bulkhead of the tank. A third gauge was located halfway up the web of the longitudinal girder, which runs

off the corner of the moonpool to the bulkheads at frame 91 (fwd of the moonpool) and 110 (aft of the moonpool). This is the same location where the large softnose brackets (previously described) are located. It is also the location where cracks had been identified before the softnose brackets were incorporated.

Gauges attached to the deck structure

One gauge was located on top of the deck, at side, ie. just inboard of the sheer strake rounding, close to midships. The moonpool was located with its centre at midships, thus this gauge would measure stresses in the region of "reduced" section modulus, of the vessel.

A second gauge was attached to the underside of the flange of the new side girder. In the case of the portside girder, the gauge was located on the flange of the section of beam with a reduced depth, so as to record the concentrated stresses. The gauge on the starboard side was located at the same longitudinal location as the portside gauge so as to obtain a realistic comparison between the two.

Accelerometer to Record Vertical Accelerations

One accelerometer was located on the centreline of the vessel, in the central store. The central store was located around the moonpool between the tweendeck and the maindeck, directly above the No.7 water ballast tanks, and was used to locate the stress measuring equipment, amplifiers, computer etc.

The recording of heave accelerations were proposed as a means to compare the sea conditions experienced by the vessel during the post retrofit phase, and those measured prior to the modifications. If similar heave accelerations were encountered during both periods of measurements, it could be stated that the sea conditions were similar. The heave acceleration data could also be used to expose any operational accelerations, bumps or shudders experienced by the vessel as a result of mining, moving the ship on her chain moorings, and blow-offs. In this way any sudden variations in the stress data could be correlated back to the accelerations recorded at the same instant.

8.14 **RESULTS**

8.14.1 IN-PORT RESULTS

The still water bending stresses recorded immediately after un-docking indicated an average stress offset in the order of 30MPa in the deck and bottom structure, relative to the docked condition. Unfortunately we were not permitted the opportunity to perform a ballasting scenario as planned, due to apparent time constraints for the ship to leave port.

It was planned to fill and empty the No.7 Water Ballast Tanks, situated amidships, in order to cause an increased sagging deflection, and then to fill and empty the No.2 and No.27 Water Ballast Tanks, which are situated extreme fwd and extreme

aft respectively, in order to cause an increased hogging deflection.

In the days that followed, certain events led to the crew filling and empty the No.7 Water Ballast Tanks, for other reasons, and without our knowledge. The stress monitoring equipment had been set up to record samples every hour, whilst in port, thus the effect of these ballasting and de-ballasting events were recorded, but the exact loading was not logged against time. At some stage during this time, either one of the No.7 tanks were filled, or both of them filled, or both emptied, thus the stresses recorded cannot be directly correlated to a specific loading condition. Never-the-less, the peak to trough fluctuations that occurred during this time, are in the order of 27 to 42MPa in the case of the Port Deck Gauge, and it is assumed this corresponds to full and empty No.7 Water Ballast Tanks, as these tanks were definitely full and empty during this time. The No.7 Fuel Oil Tanks, which are wing tanks outboard of the ballast tanks, were also partially filled with water during this time, adding further uncertainty to the exact loading of the vessel corresponding to these recordings.

The following graph was compiled by combining the peak values from a number of samples recording during this period.

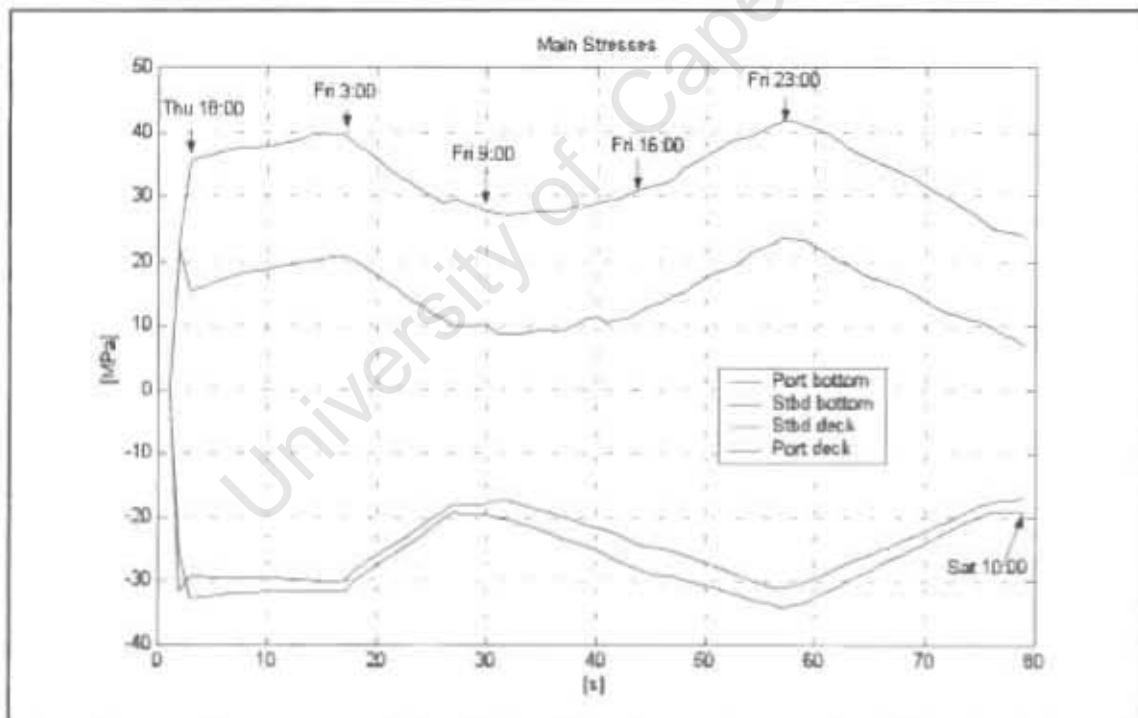


Figure 8.12 - In port recording taken immediately after undocking. Note the static offset of ± 30 MPa (on average) from the zero taken whilst docked.

8.14.2 RESULTS RECORDED DURING SEA TRIALS

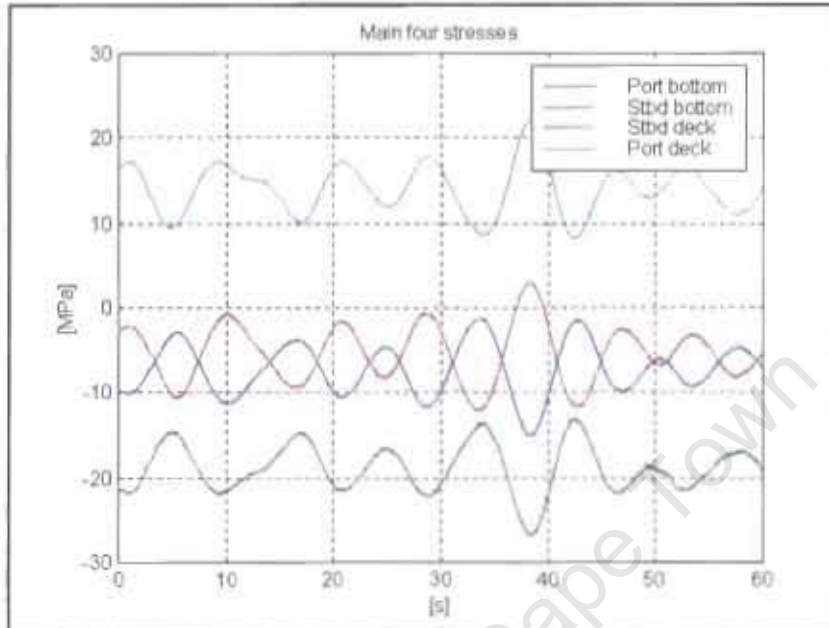


Figure 8.13 - Typical Stress Plot recorded during sea trials, whilst anchored. Only the main deck and bottom gauge results are displayed here.

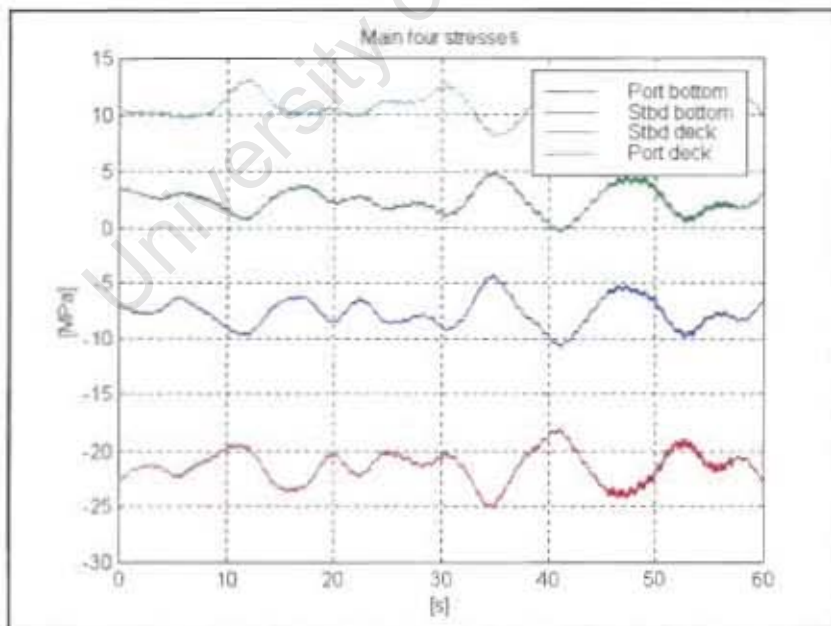


Figure 8.14 - Typical stresses recorded whilst underway during sea trials. Note the higher frequency fluctuations, indicating the whipping effect of oncoming waves against the bow. This is a typical effect seen on most "underway" recordings.

8.14.3 RESULTS RECORDED WHILST UNDERWAY TO THE MINING GROUNDS

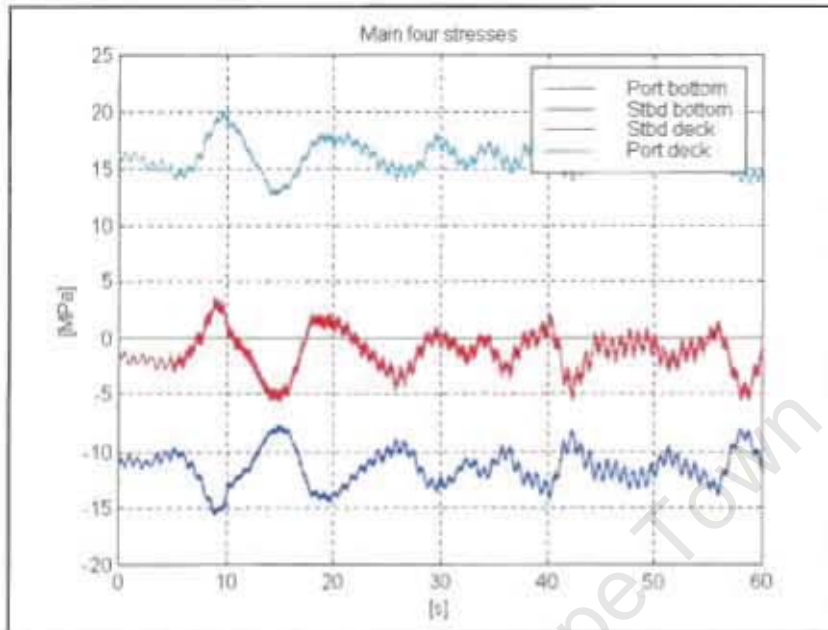


Figure 8.15 - Typical stress plot of a sample taken whilst underway to the mining grounds. Notice the same whipping effect as recorded on trials. Here they are more significant, probably indicating higher swells. Note the Stbd Bottom channel was disconnected due to losing its connection.

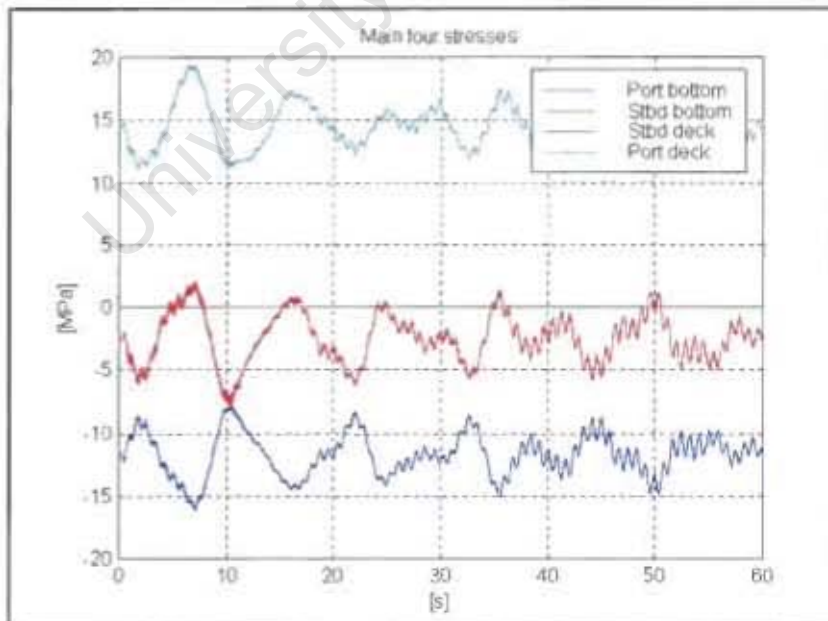


Figure 8.16 - Another typical stress plot, of a sample taken 2½ hours later than that depicted in the previous figure.

8.14.4 RESULTS OBTAINED WHILST MINING

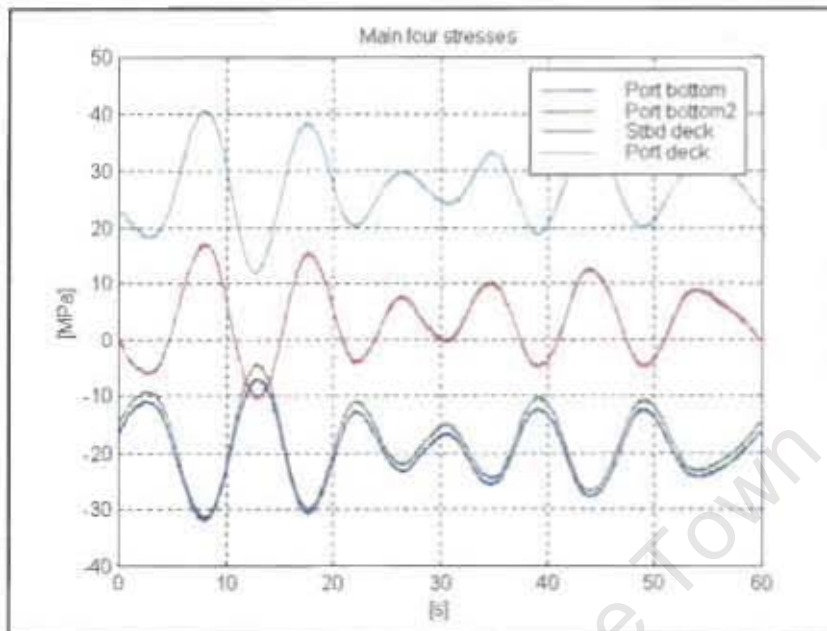


Figure 8.17 - One of the highest stress fluctuations, recorded whilst normal drilling. Notice the smoothness of the fluctuations, vs those recorded whilst underway.

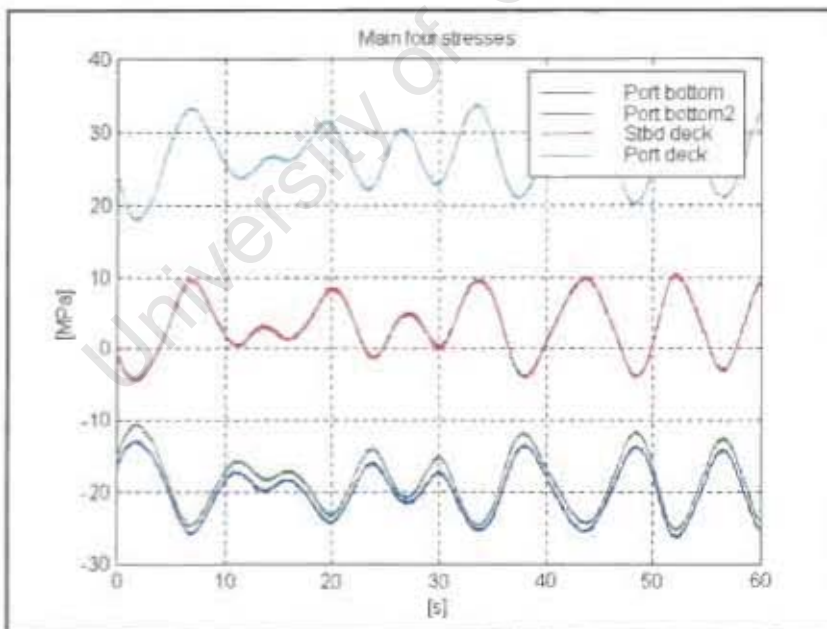


Figure 8.18 - The very next sample to that depicted in the previous figure, as recorded a ½ hour later. This stress plot compares well as a typical mining sample in terms of stress fluctuation amplitudes.

8.15 CONCLUSION OF POST RETROFIT STRESS RECORDINGS

Still Water Results

Although the 30MPa to 35MPa hogging stress as recorded in the deck and bottom gauges, once the vessel was undocked, appeared fairly significant, the later recordings taken whilst filling and empty the No.7 Water Ballast Tanks (in an uncontrolled environment), only reduced the stresses by ± 14 MPa, versus the 80 MPa offset measured at sea for the same procedure prior to the refit. Unfortunately a proposed ballasting scenario could not be implemented, thus the static stresses could not be further correlated or investigated, as planned.

The loading condition of the vessel as applicable to the still water recordings as extracted from the Onboard Stability Program, is as attached on Annexure C.

Dynamic Effects of Wave Action

From the recordings taken during trials, and on the voyage back to the mining grounds, the stress plots exhibited similar patterns. Those recorded during trails had smaller peak to peak amplitudes, to those recorded whilst underway, which suggests more sheltered conditions during trails. However when the ship was underway, whether during trials or on route to the mining grounds, the whipping effect of the due to wave action on the bow is clearly visible as higher frequency low amplitude fluctuations.

All results recorded whilst moored showed very much smoother fluctuations, to those recorded at the mining grounds, indicating greater peak to peak fluctuations, indicative of higher swells. The magnitude of these results are however well within reason, indicating a successful refit in terms of reducing longitudinal bending stresses in the deck and bottom structure.

It can be expected that the change in configuration of the hull structure, may well result in changed vibration responses of the vessel, as a result of mining induced vibrations. This change should however be limited to the response of the hull itself, and not the mining plant.

8.16 ABS APPROVAL OF DRAWINGS

All Drawings, with one exception were received back from ABS, indicating their approval of the design of the modifications.

One drawing, namely TNA 945/03 had certain comments, which when challenged, ABS admitted that they were technicalities in that ABS had to consider the new structure on Bulkheads 91 and 110, as a stringer on a watertight bulkhead, irrespective of

- i. whether it is stronger than before, or
- ii. whether it was designed to support the drill floor, or any other structure external to the hull, or
- iii. whether it was actually intended to be a stringer.

Whilst they accepted our design rational, they maintained that in order for it to be accepted as a stringer, 3 additional “stantion” type brackets would have to be incorporated, as well as other small brackets. In light of ABS’s acceptance that the required changes were of an academic nature, in fulfilling certain rule requirement, irrespective of their actual loading, they accepted that the minor modifications could be done when next the vessel returned to port. A copy of their “marked up” drawing showing these additional brackets will be attached to this report, in a separate sleeve.

University of Cape Town

CHAPTER 8 - ANNEXURE A

INITIAL STRESSES AND ACCELERATIONS RECORDED AT SEA

University of Cape Town

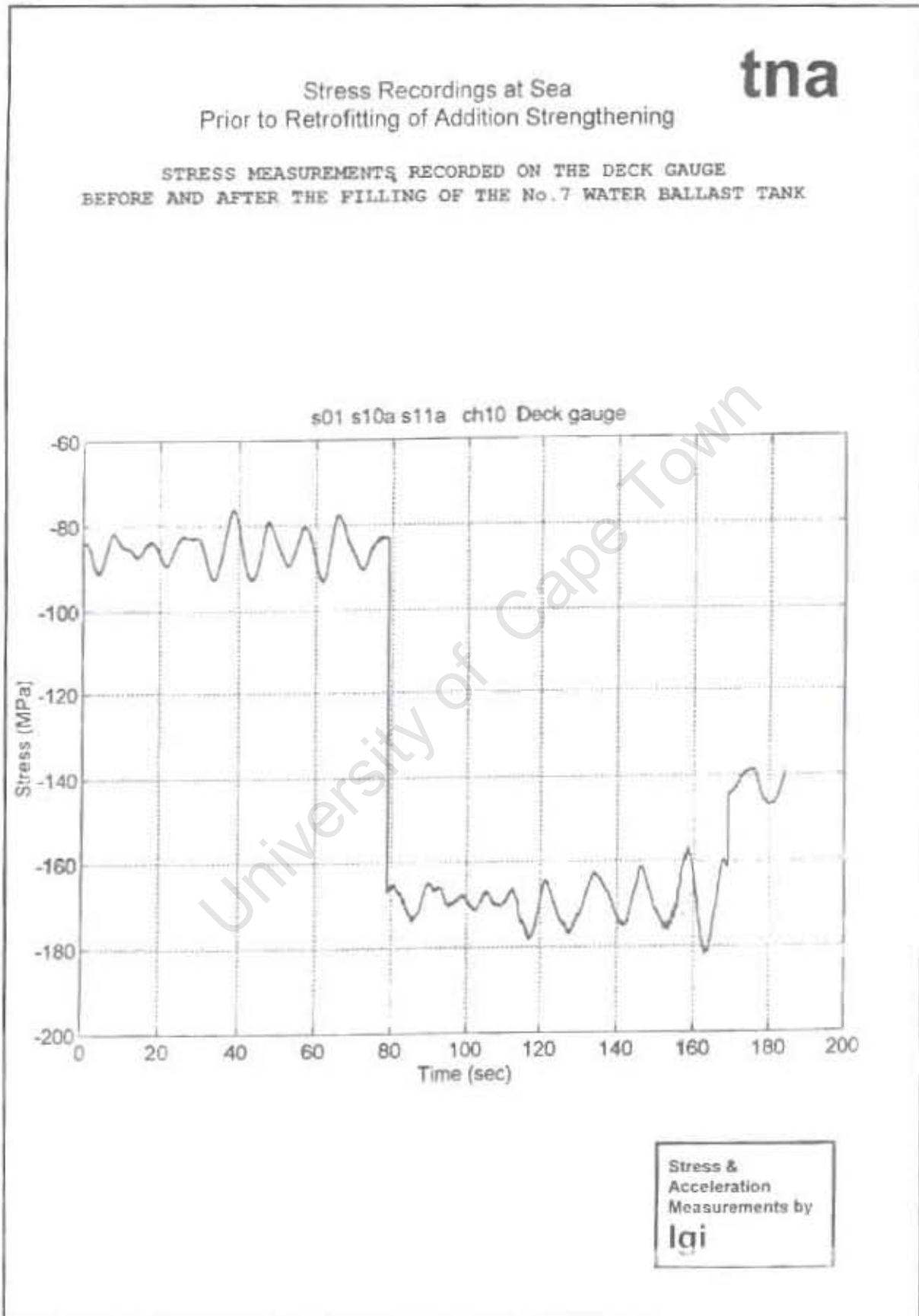
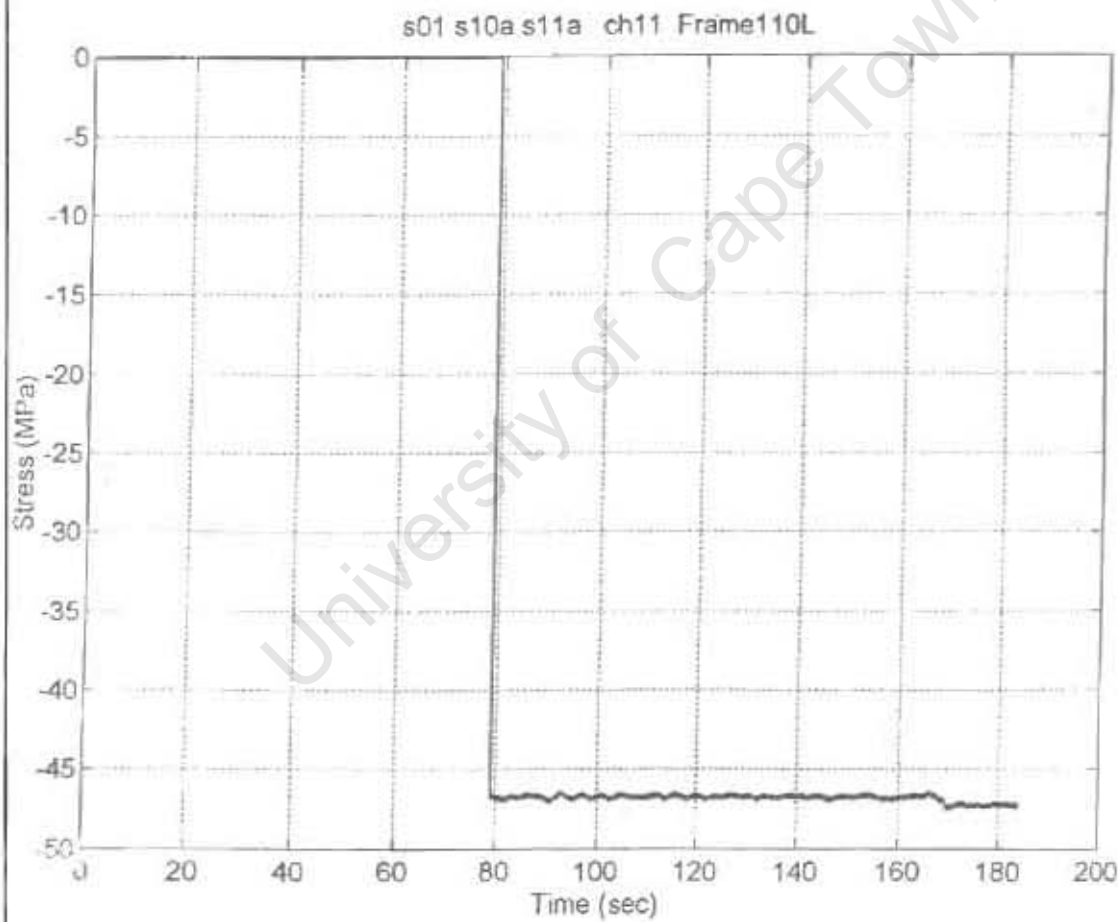


Figure A.1.

tna

Stress Recordings at Sea
Prior to Retrofitting of Addition Strengthening

STRESS MEASUREMENTS RECORDED ON
THE BULKHEAD AT FRAME 110
BEFORE AND AFTER THE FILLING OF THE No.7 WATER BALLAST TANK



Stress &
Acceleration
Measurements by
lgi

Figure A.2.

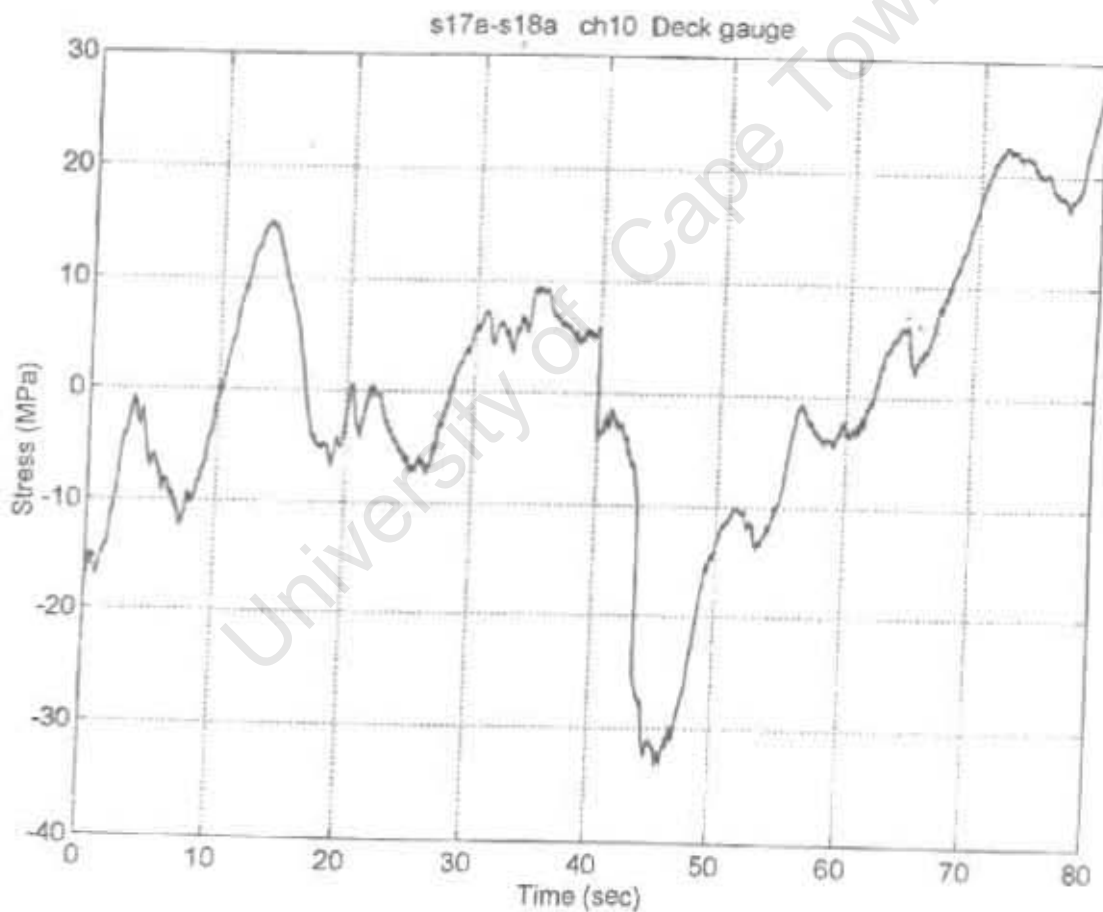
tna

Stress Recordings at Sea
Prior to Retrofitting of Addition Strengthening

STRESS RECORDINGS ON
THE DECK GAUGE

COMBINED PLOT RECORDED DURING NORMAL DRILLING
Time Scale (0-40)

AND
NORMAL DRILLING AT A DIFFERENT TIME
Time Scale (40-80)



ESTIMATED SWELL HEIGHT (4.0m)

Stress &
Acceleration
Measurements by
Igi

Figure A.3.

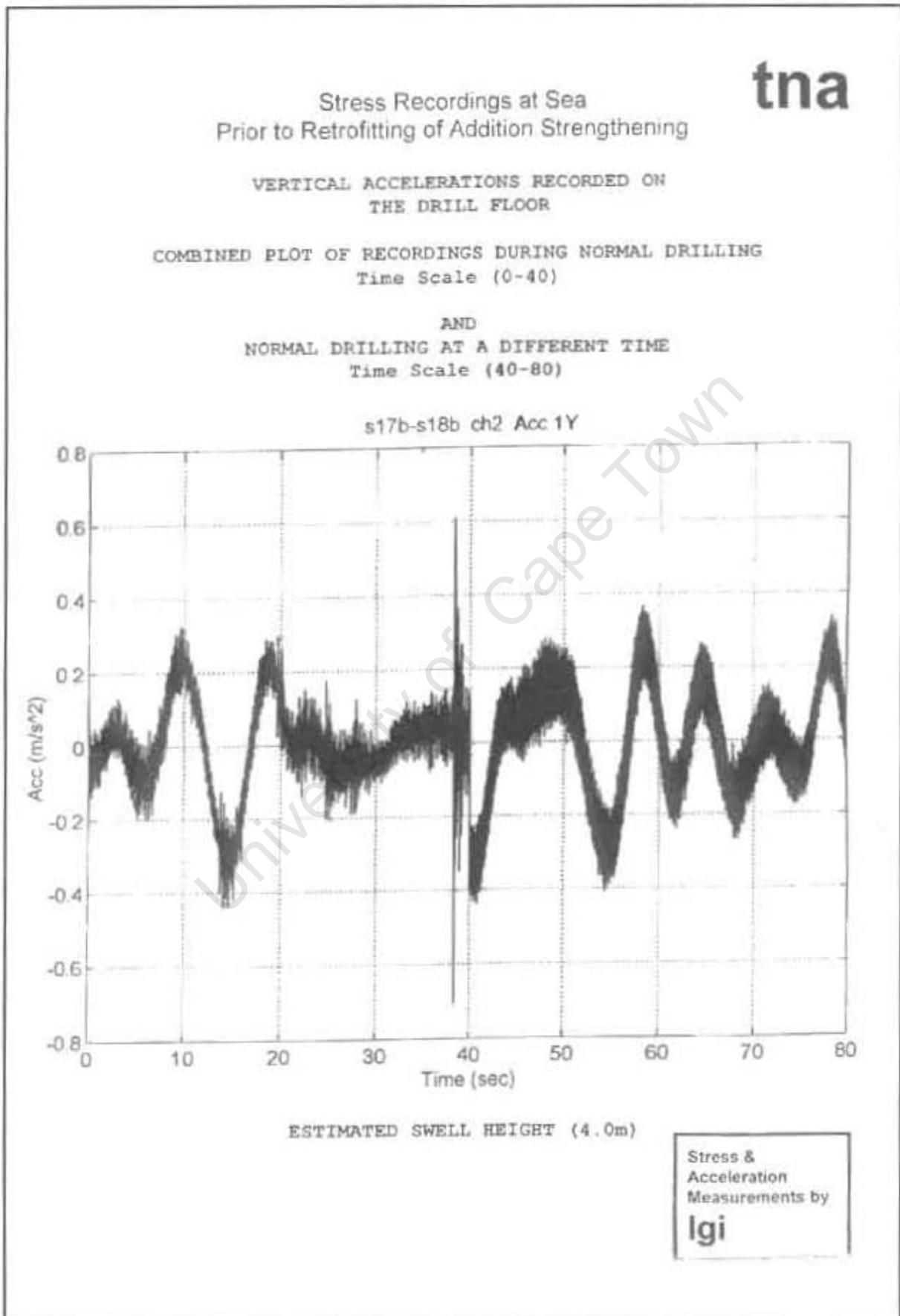


Figure A.4.

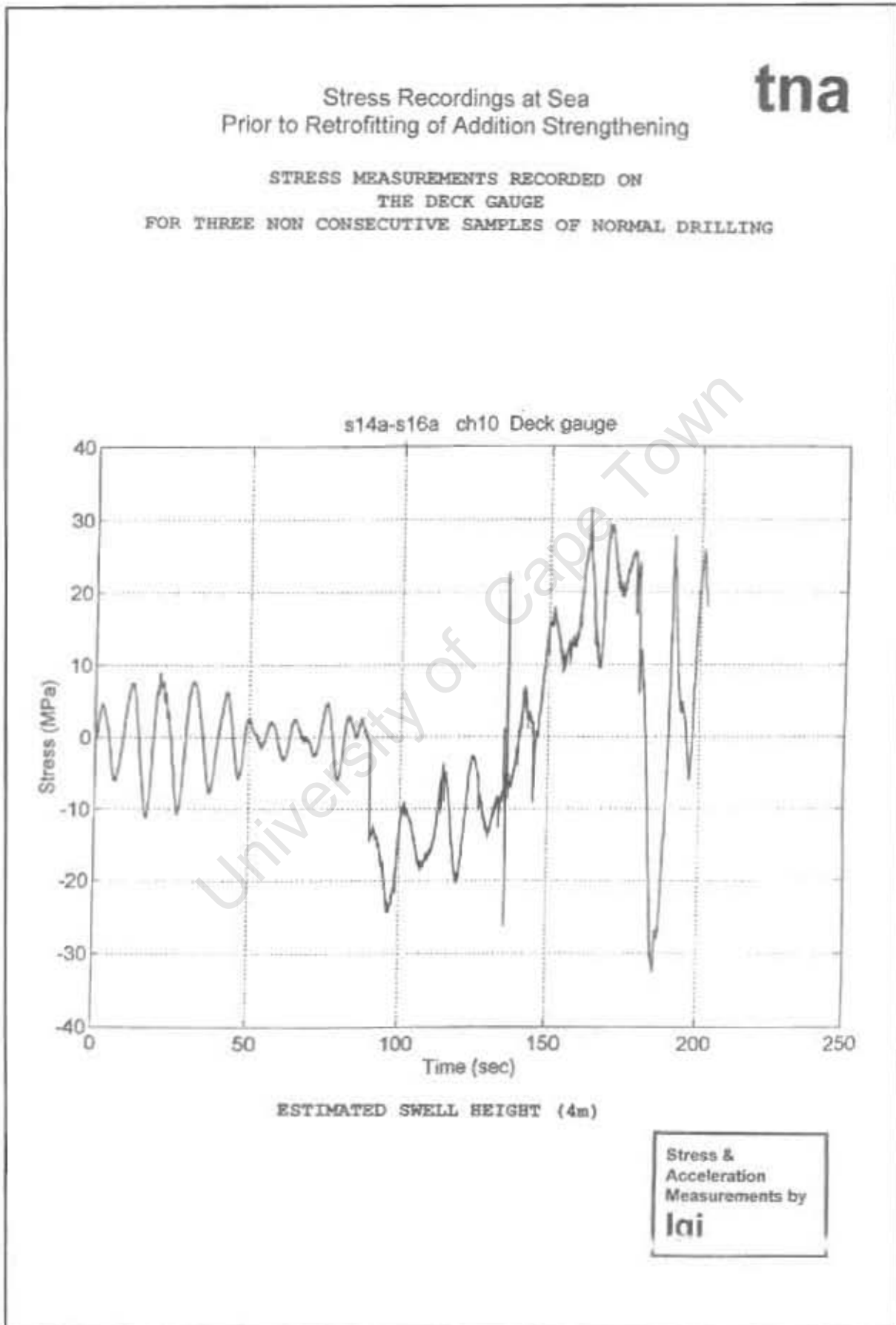


Figure A.5.

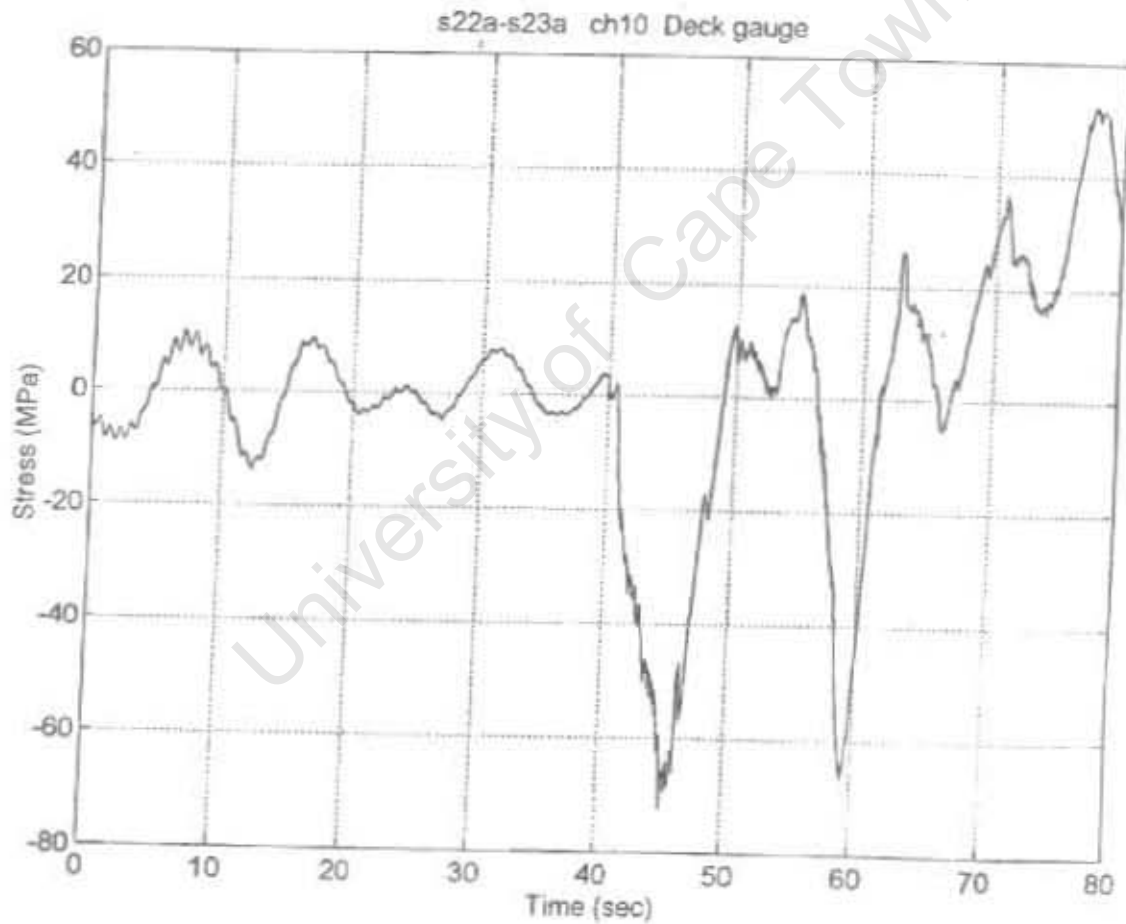
tna

Stress Recordings at Sea
Prior to Retrofitting of Addition Strengthening

STRESS MEASUREMENTS RECORDED ON
THE DECK GAUGE

COMBINED PLOT OF STRESS RECORDED WHILE LOWERING THE DRILL STRING
Time Scale (0-40)

AND
MOVING THE SHIP WITH ANCHOR CHAINS
Time Scale (40-80)



ESTIMATED SWELL HEIGHT (4.5m)

Stress
Measurements by
lai

Figure A.6.

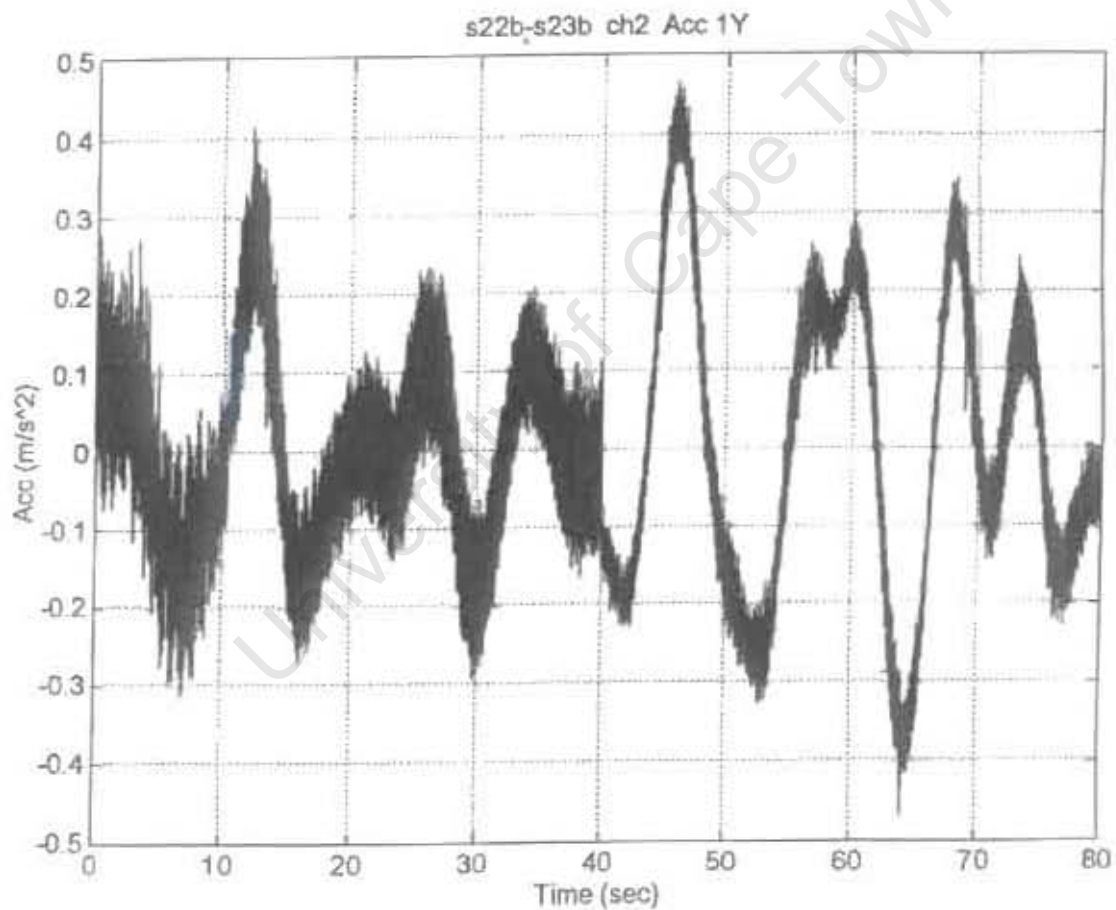
tna

Stress Recordings at Sea
Prior to Retrofitting of Addition Strengthening

VERTICAL ACCELERATIONS RECORDED ON
THE DRILL FLOOR

COMBINED PLOT RECORDED WHILE LOWERING THE DRILL STRING
Time Scale (0-40)

AND
MOVING THE SHIP WITH ANCHOR CHAINS
Time Scale (40-80)



ESTIMATED SWELL HEIGHT (4.5m)

Stress &
Acceleration
Measurements by
lgi

Figure A.7.

tna

Stress Recordings at Sea
Prior to Retrofitting of Addition Strengthening

STRESS RECORDINGS ON
THE DECK GAUGE

STRESSES RECORDED DURING A BLOW OFF



ESTIMATED SWELL HEIGHT (5.0m)

Stress &
Acceleration
Measurements by
lai

Figure A.8.

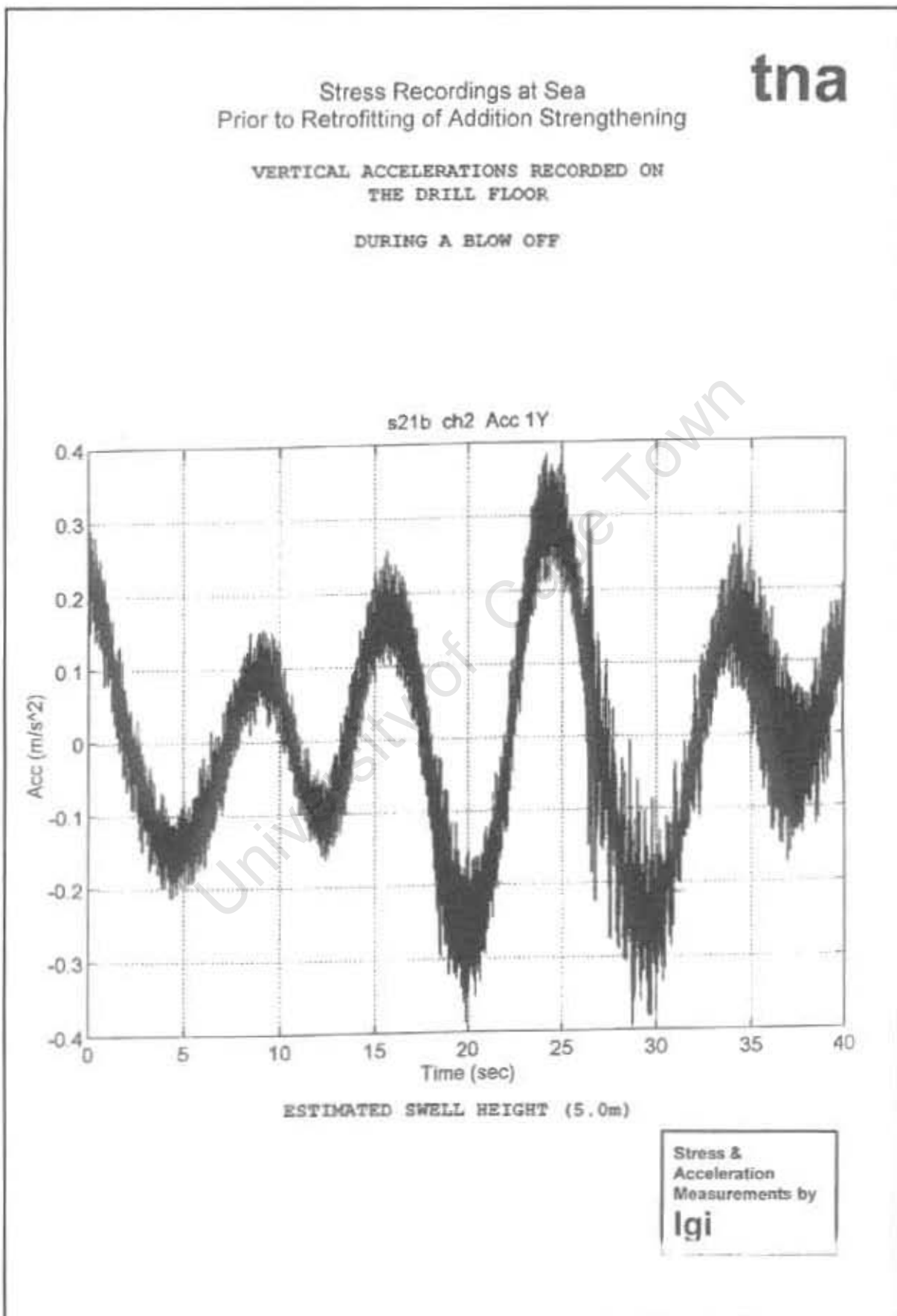


Figure A.9.

CHAPTER 8 - ANNEXURE B

SAMPLE PLOTS OF THE REVISED FINITE ELEMENT MODEL

University of Cape Town

M.V. "DGB"
Revised Finite Element Model

tna

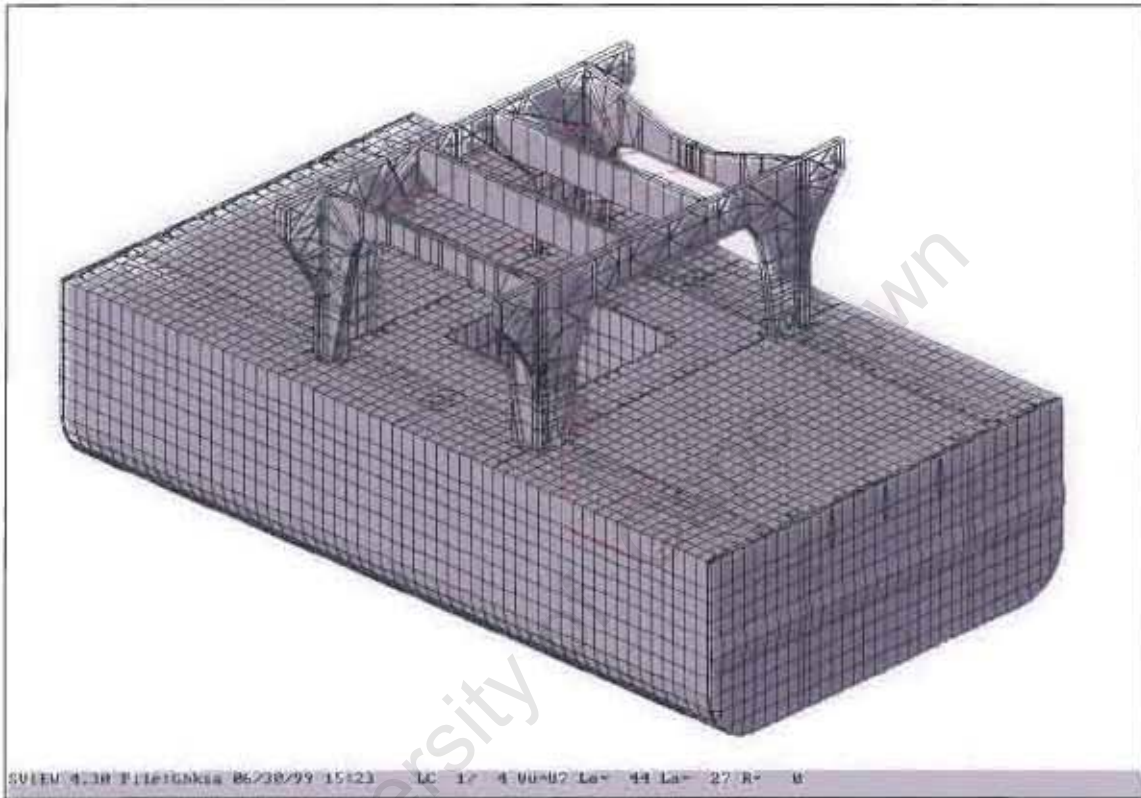


Figure B.1.

M.V. "DGB"
Finite Element Model
Cutaway through Moonpool

tna

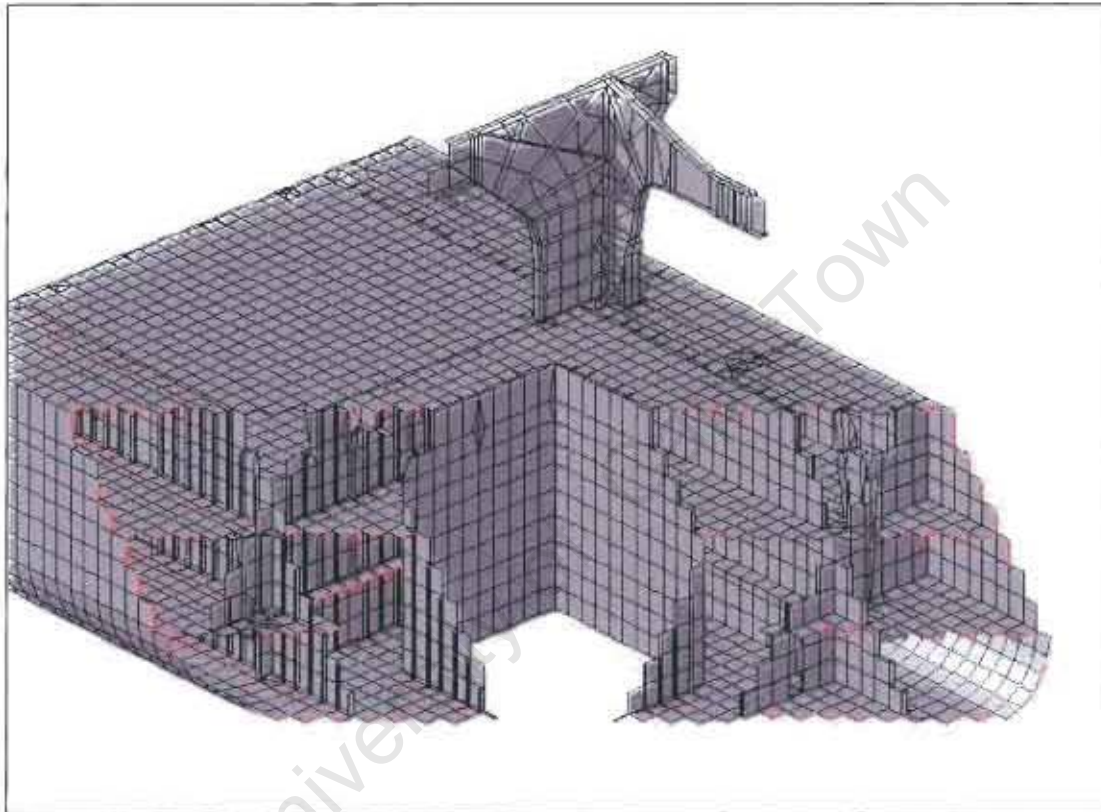


Figure B.2.

M.V. "DGB"
Finite Element Model
Stress Plot of Debeers Load Case

tna

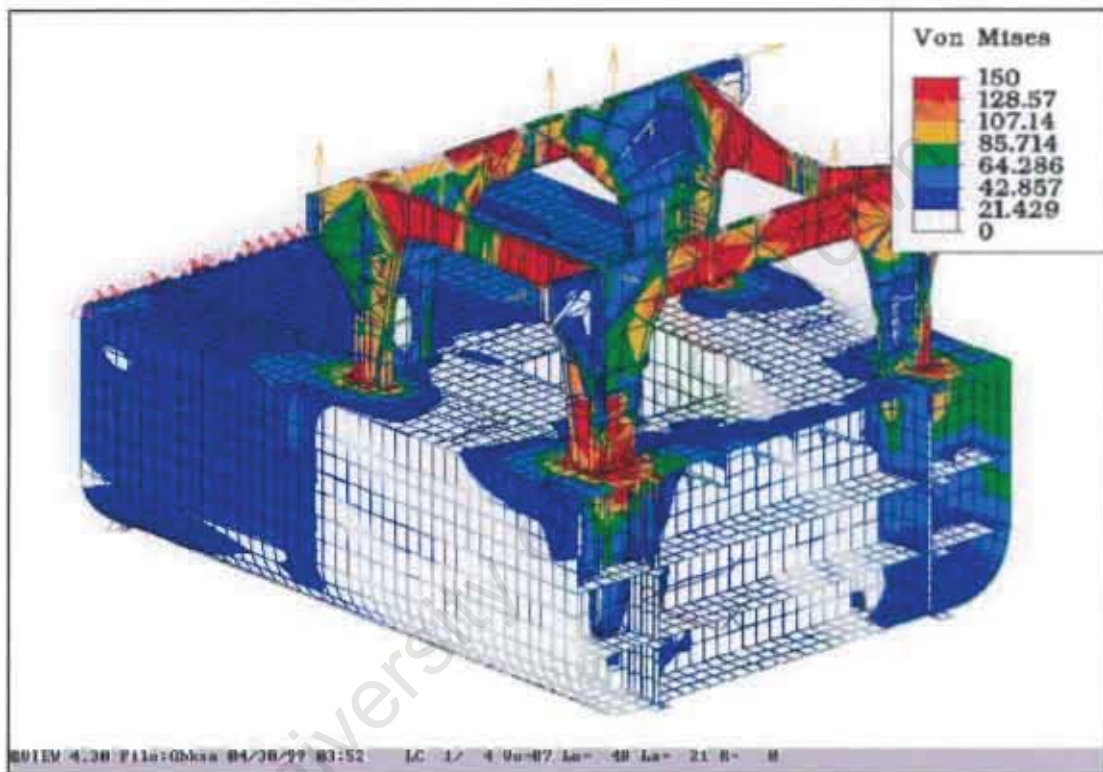
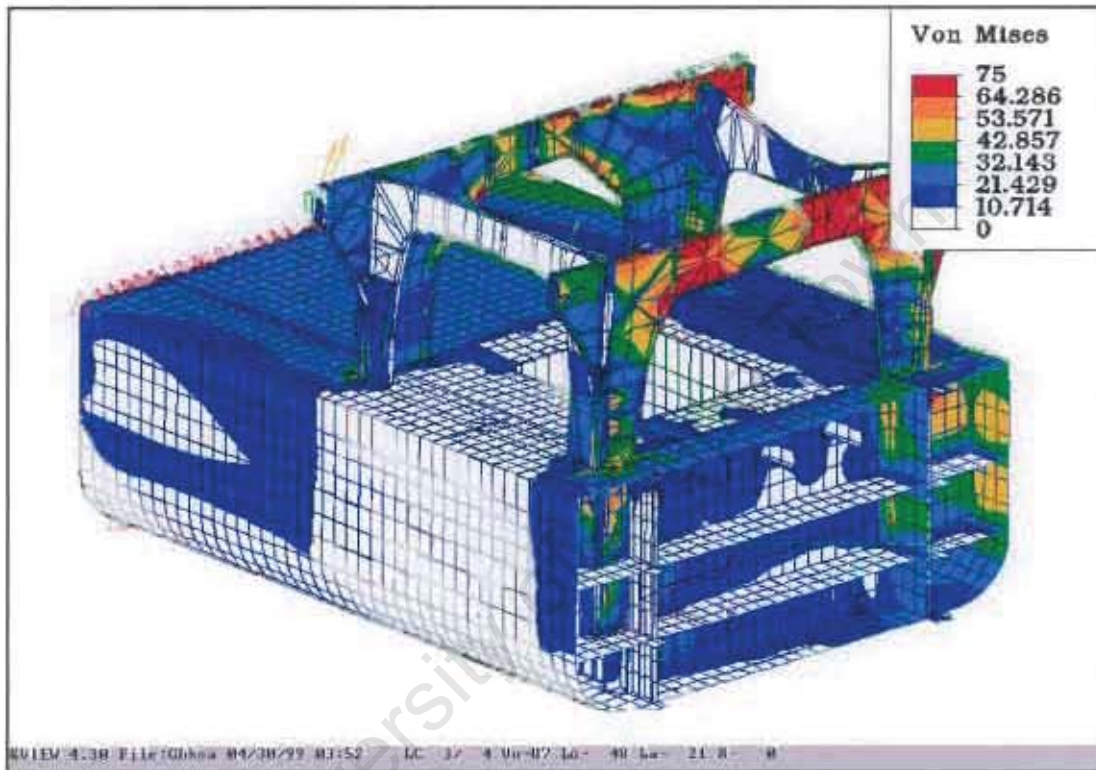


Figure B.3.

M.V. "DGB"
Finite Element Model
Stress Plot
Fictitious Load causing torsional moment

tna



CHAPTER 8 - ANNEXURE C

STRUCTURAL DRAWINGS FOR THE PROPOSED RETROFIT

(The retrofit was implemented according to the drawings with minor comments by Class, as stated in the report)

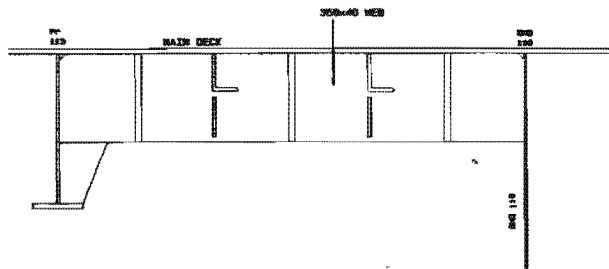
(The drawings included were reduced from A0 to A3 for reporting purposes)

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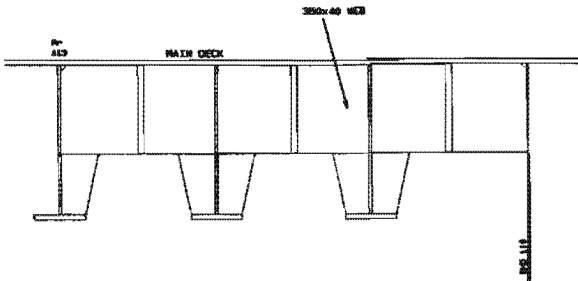
9. REFERENCES

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- 2 Eyres, D.J. "Ship Construction", 4th edition, Heinemann 1994.
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- 7 B. Kingwill, "Report on the Finite Element Analysis of the Underdeck Stiffening of the M.V. 'Kovambo'" Triton Naval Architects Report - TNA 1002, 1999.
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- 13 LGI - Laboratory for Advanced Engineering, University of Pretoria.
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- 16 COSMOS/MTM (Student Edition) Finite Element Analysis Software, by Structural Research and Analysis Corporation (SRAC) Santa Monica CA USA.

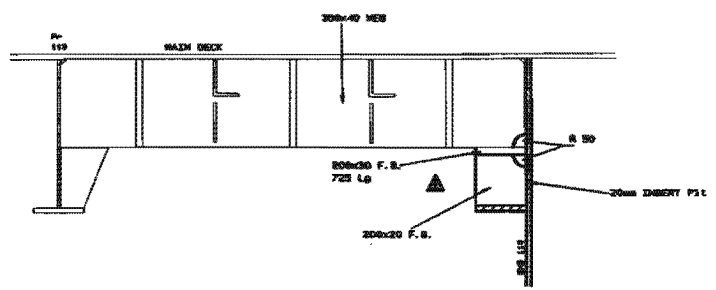
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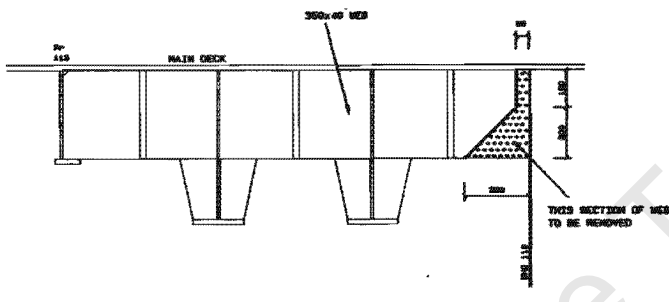
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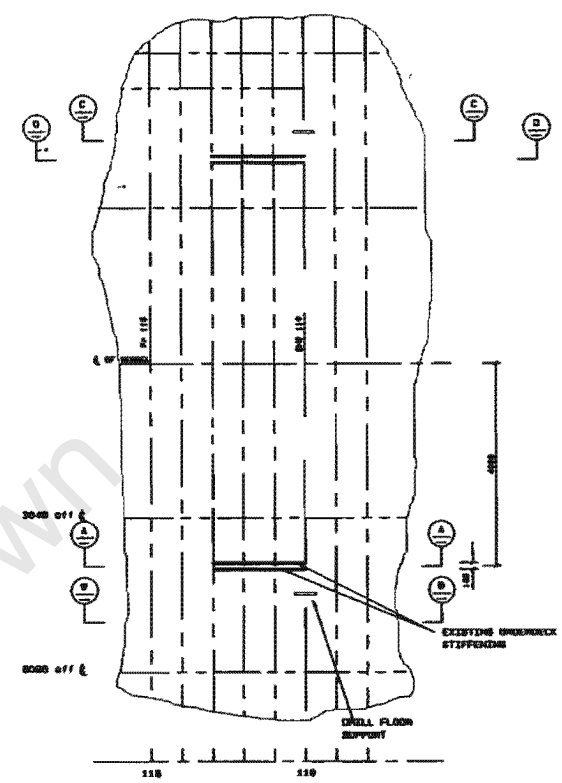
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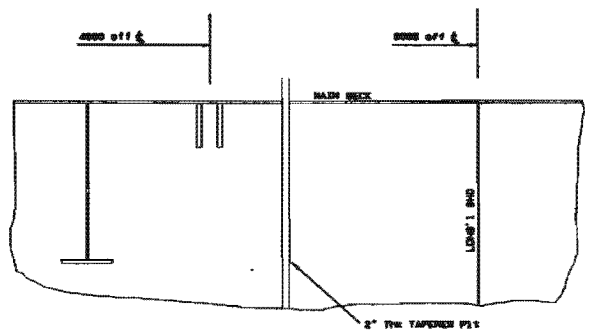
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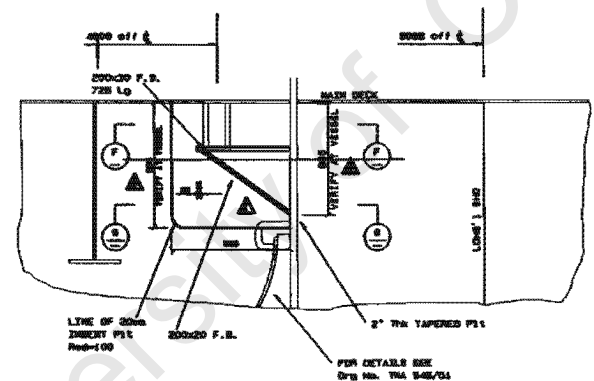
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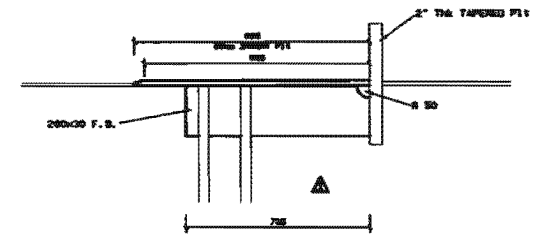
1:10 PART PLAN ON MAIN DECK IN WAY OF AIRLIFT LIFTING CYLINDER STRUCTURE



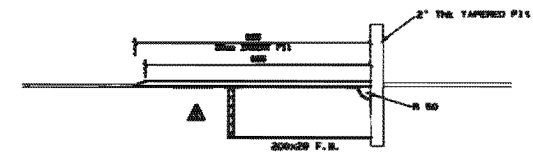
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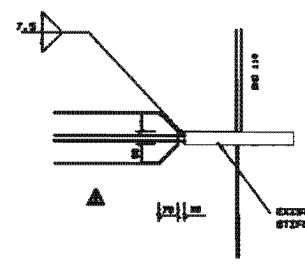
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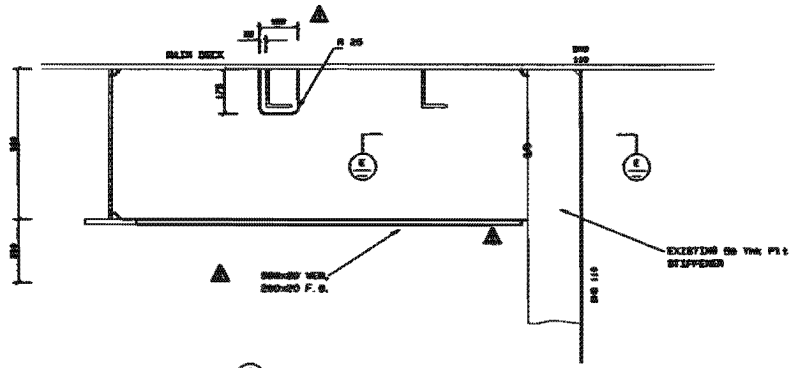
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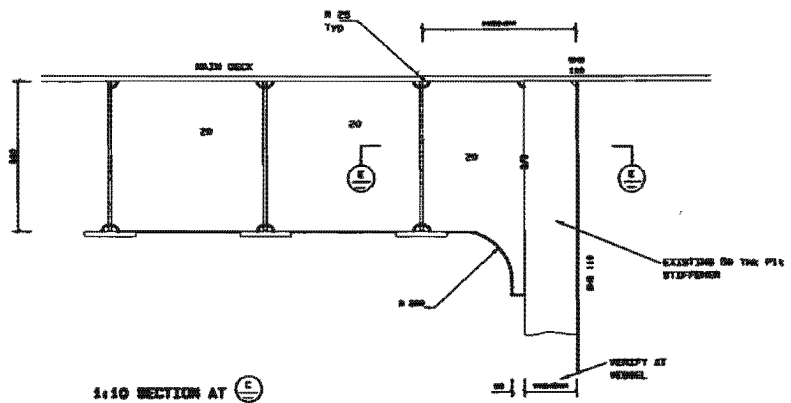
1:10 PLAN AT F-F



1:10 PLAN AT G-G



1:10 SECTION AT H-H INDICATING MODIFIED STRUCTURE



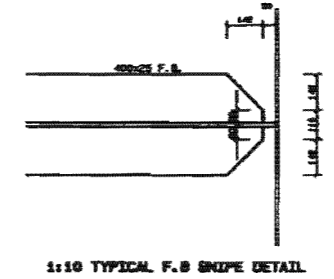
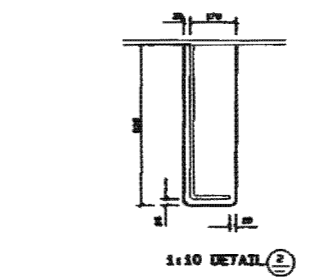
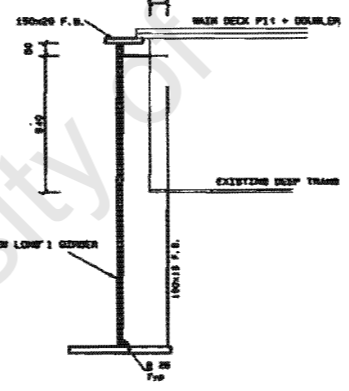
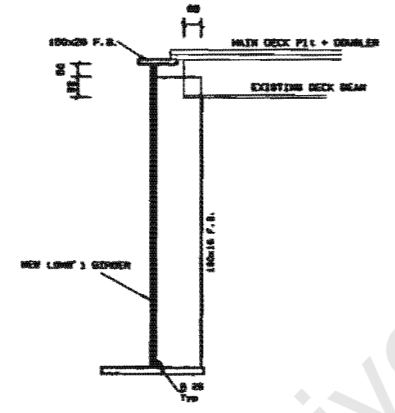
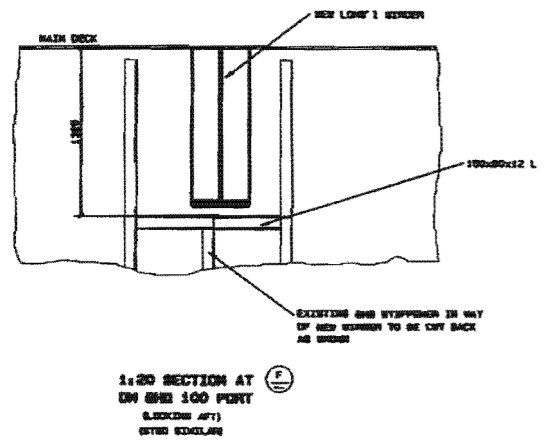
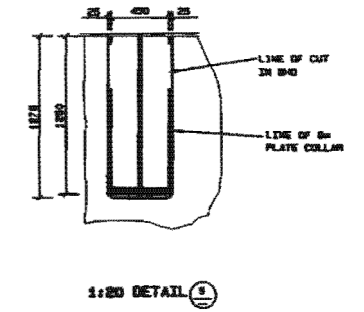
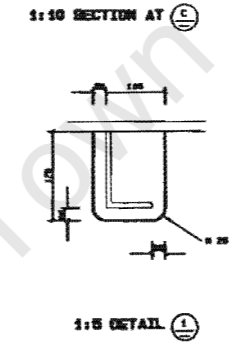
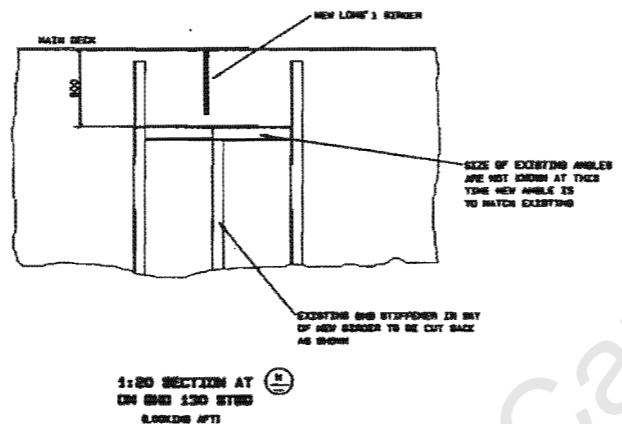
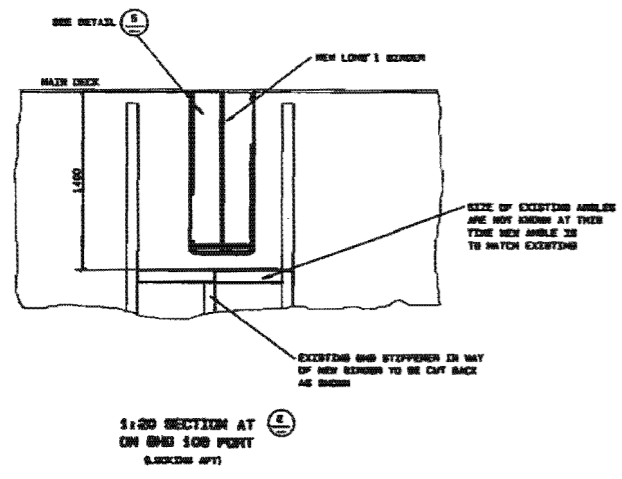
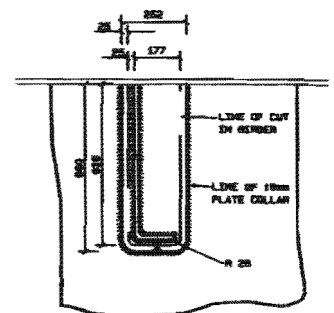
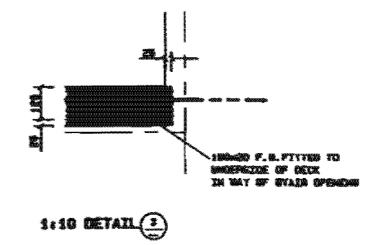
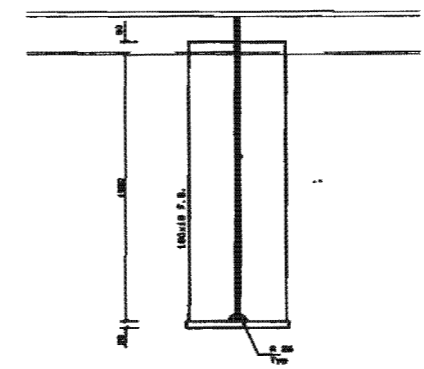
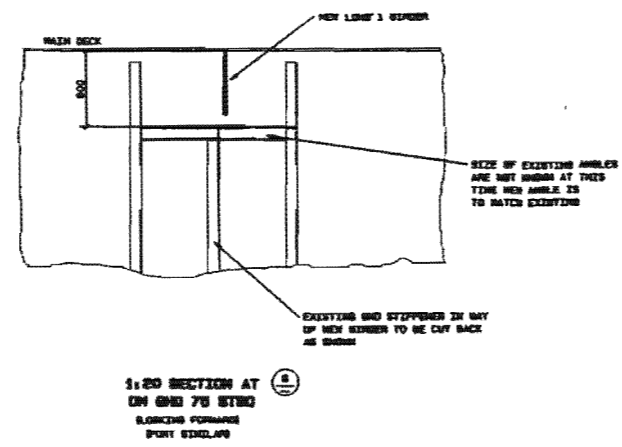
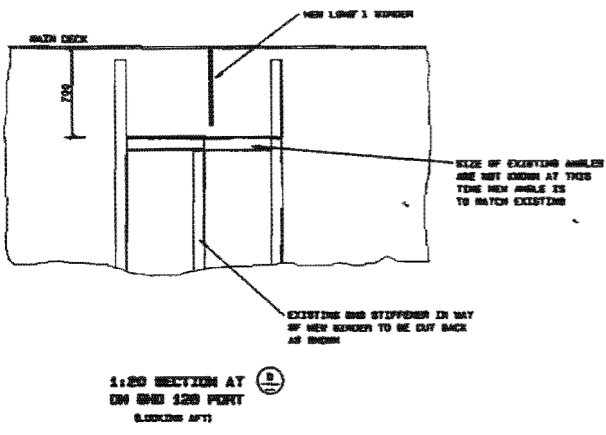
1:10 SECTION AT I-I INDICATING MODIFIED STRUCTURE

- GENERAL NOTES UNLESS OTHERWISE NOTED
- 1) THIS DRAWING IS TO BE READ IN CONJUNCTION WITH THE APPLICABLE DE DESIGN DRAWING SPECIFICATIONS ISSUED WITH THE CONTRACT DOCUMENTS.
 - 2) ALL STRUCTURAL STEEL USED IS TO BE IN ACCORDANCE WITH THE SAWS 1-05 GRADE SUPPLY.
 - 3) ALL WELD SYMBOLS TO BE CLASSIFIED BY THE APPLICABLE SOCIETY, TO BE GRADE A OR EQUIVALENT SPECIFICATION, WHERE APPLICABLE STEELWORK TO COMPLY WITH THE LATEST ISSUE OF SAWS 1-05, 1-06 & 1-08.
 - 4) CONTRACTOR TO VERIFY ALL WELD DIMENSIONS ON SITE PRIOR TO MANUFACTURE.
 - 5) ALL STRUCTURAL WELDS TO COMPLY WITH THE AWS D1.1-05 SPECIFICATIONS.
 - 6) ALL WELD SYMBOLS TO COMPLY WITH THE APPLICABLE SOCIETY RULES AND REGULATIONS FOR THE CLASSIFICATION OF SHOPS.
 - 7) ALL WELDS TO BE 6mm CONTINUOUS FILLET WELDS.
 - 8) ALL BOLTS TO BE 20mm DIA.
 - 9) ALL BOLTS TO BE 700, GRADE 8.8, IN ACCORDANCE WITH SAWS 1-05.
 - 10) ALL SURVEY SLAB, SHARP EDGES AND CORNERS TO BE REMOVED.
 - 11) THIS DRAWING IS NOT TO BE SCALED.

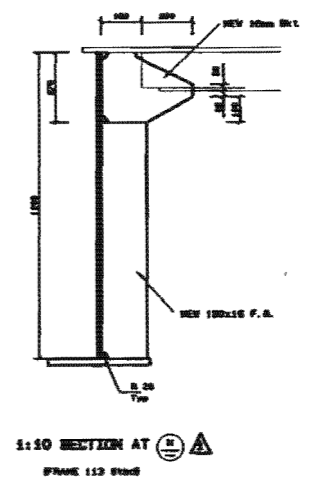
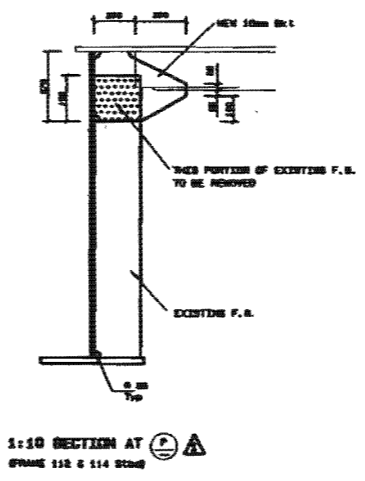
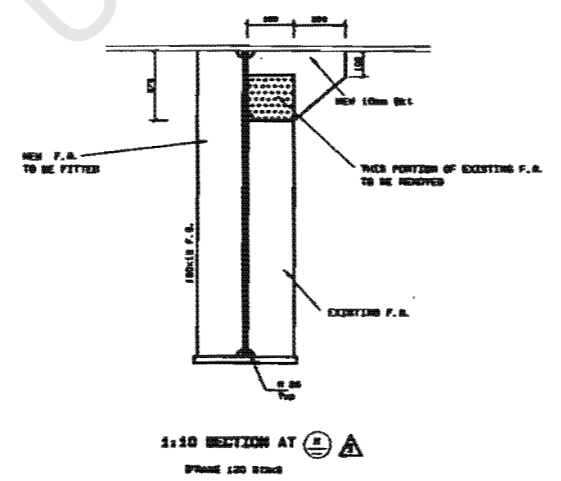
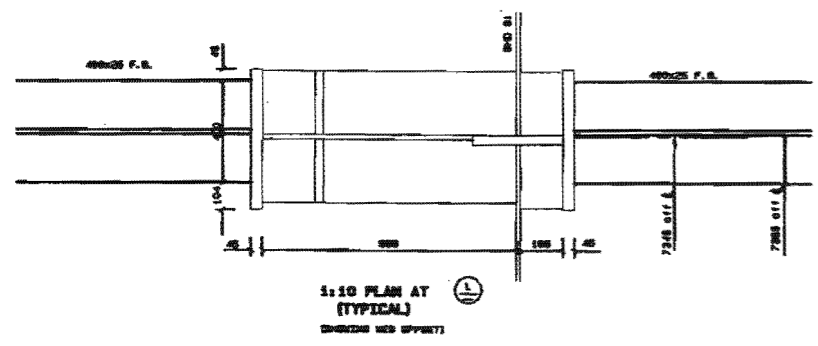
- Notes:-
1. WELD SYMBOLS INDICATE THROAT THICKENERS.
 2. ALL PLATE TO BE LLOYD GRADE A OR APPROVED EQUIVALENT. ALL SECTIONS TO BE 75 TO 4300 GRADE 43A.

2	MAY 1988	SECTION AT BND 110 INDICATING MODIFIED STRUCTURE, ALL SECS
1	MAY 1988	SECTIONS AT FRAMES 111 & 112 REMOVED SECTION AT BND 110 ADDED, SECTIONS AT A, B, AND DIMENSIONS TO NEW WELDS.
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 - (2) ALL WELD STEELWORK IS TO BE CLASSIFIED BY THE APPLICABLE SOCIETY, TO BE MADE A OR EQUIVALENT SPECIFICATION.
 - c) WHERE APPLICABLE STEELWORK TO COMPLY WITH THE LATEST ISSUE OF BRIDGE CODE, SECTION 6.10000.
 - d) CONTRACTOR TO VERIFY ALL MAJOR CONNECTIONS ON SITE PRIOR TO MANUFACTURE.
 - e (1) ALL STRUCTURAL WELDS TO COMPLY WITH THE AWS D1.1-88 SPECIFICATIONS.
 - (2) ALL WELD STEELWORK WELDING TO COMPLY WITH THE APPLICABLE SOCIETY RULES AND REGULATIONS FOR THE CLASSIFICATION OF WELDS.
 - f) ALL WELDS TO BE FULL CONTINUOUS FILLET WELD.
 - g) ALL HOLES TO 20mm DIA.
 - h) ALL BOLTS TO BE M10, BRIDGE S.S. IN ACCORDANCE WITH BRIDGE 130.
 - i) ALL BURRS, SLAG, SHARP EDGES AND CORNERS TO BE REMOVED.
 - j) THESE DRAWINGS IS NOT TO BE SCALED.

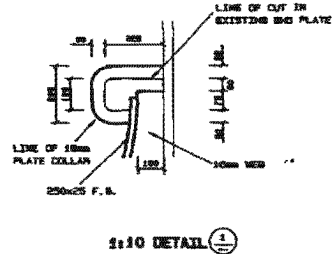
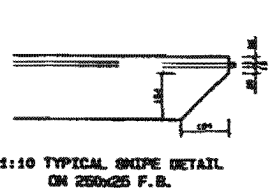
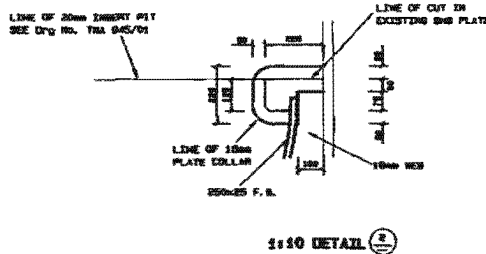


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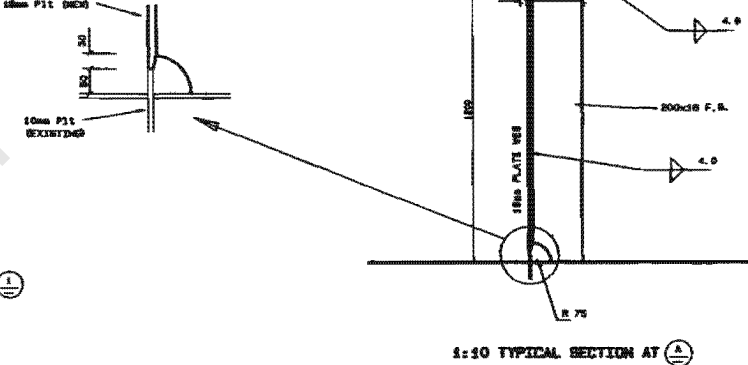
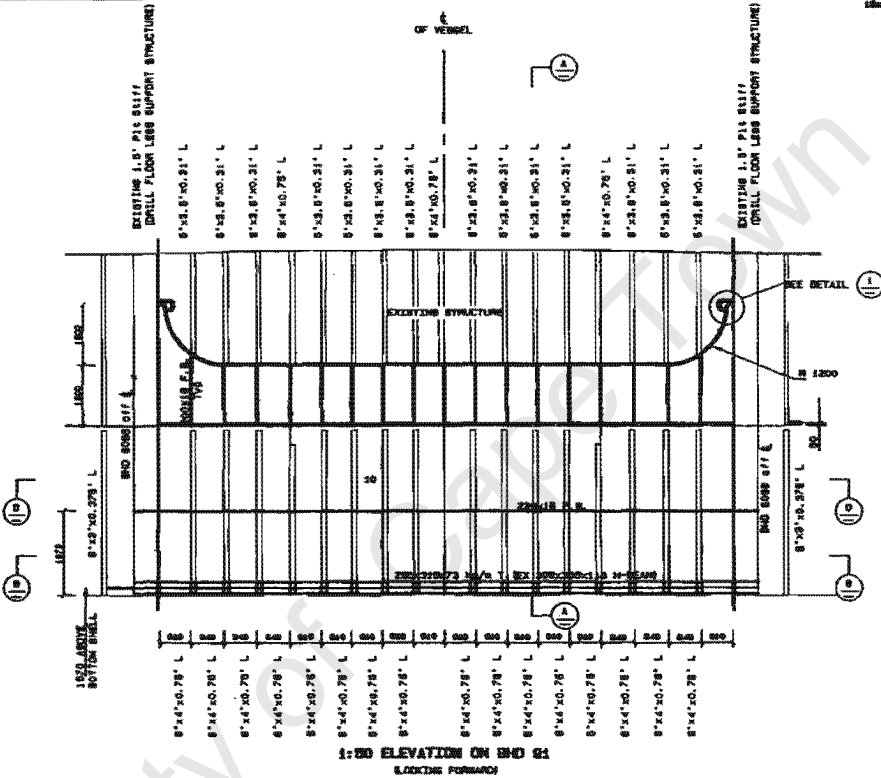
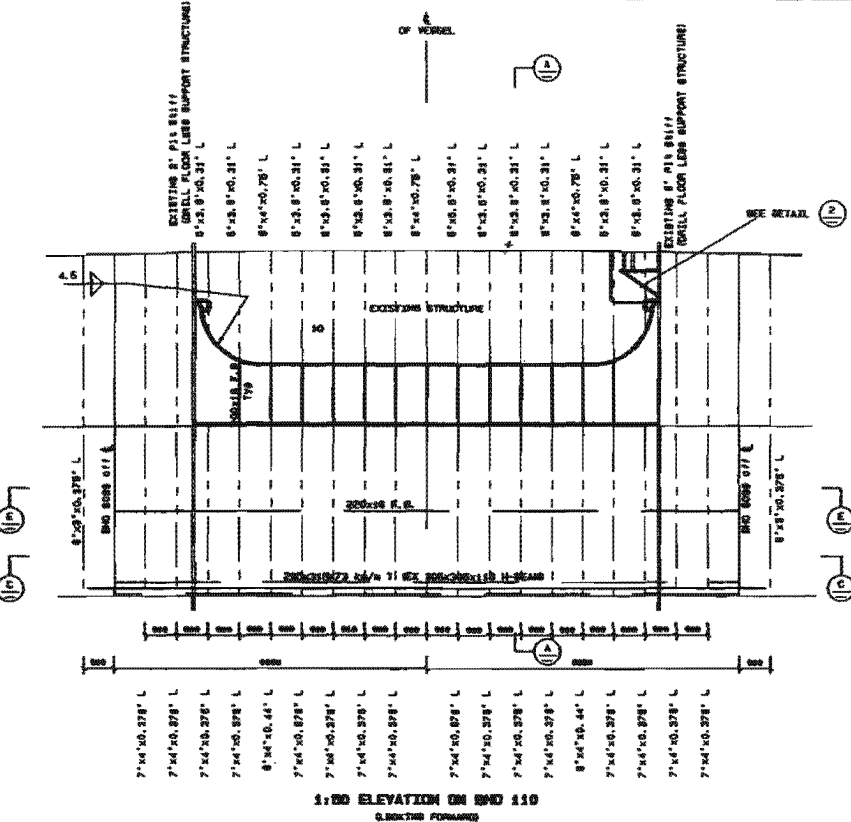
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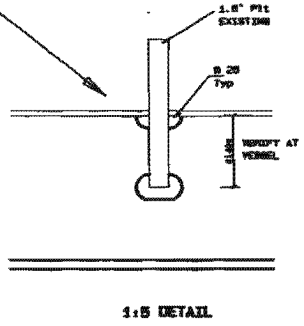
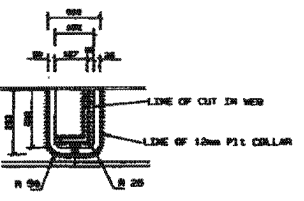
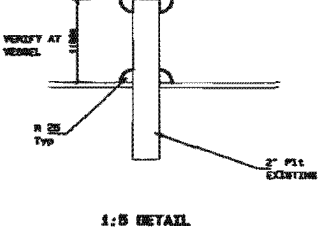
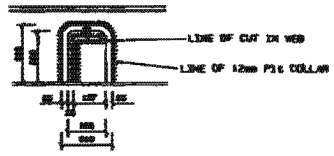
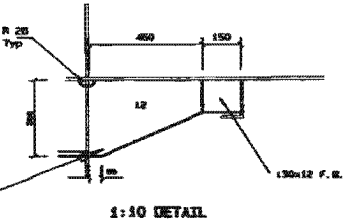
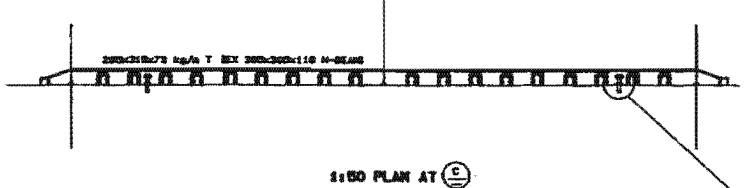
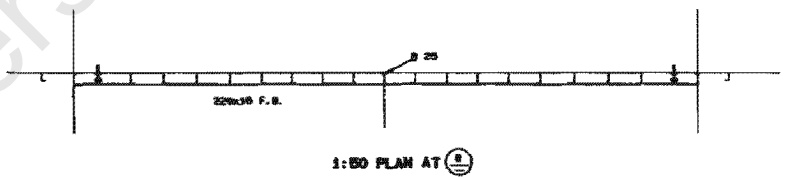
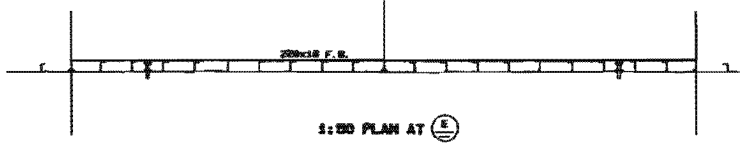
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GREAT CARE IS TO BE TAKEN TO ENSURE CORRECT ALIGNMENT BETWEEN NEW 200x18 F.B. AND LEG OF EXISTING BULKHEAD ANGLE STIFFENER



- GENERAL NOTES UNLESS OTHERWISE NOTED**
- 1) THIS DRAWING IS TO BE READ IN CONJUNCTION WITH THE APPLICABLE REVISIONS AND SPECIFICATIONS ISSUED WITH THE CONTRACT DOCUMENTS.
 - 2) ALL STRUCTURAL STEEL USED IS TO BE IN ACCORDANCE WITH THE BSAFE 1.235 GRADE 300MA.
 - 3) ALL WELD STEELWORK IS TO BE CLASSIFIED BY THE APPLICABLE SOCIETY, TO BE GRADE A OR EQUIVALENT SPECIFICATION. WHERE APPLICABLE STEELWORK TO COMPLY WITH THE LATEST ISSUE OF BSAFE 0482, 1200N & 1200NA.
 - 4) CONTRACTOR TO VERIFY ALL MAJOR DIMENSIONS ON SITE PRIOR TO MANUFACTURE.
 - 5) ALL STRUCTURAL WELDS TO COMPLY WITH THE AWS D5.1-08 SPECIFICATIONS.
 - 6) ALL WELD STEELWORK WELDING TO COMPLY WITH THE APPLICABLE SOCIETY P111 AND REGULATIONS FOR THE CLASSIFICATION OF SHIP.
 - 7) ALL WELDS TO BE 5mm CONTINUOUS FILLET WELDS.
 - 8) ALL BOLTS TO BE 8.8, GRADE 8.8, IN ACCORDANCE WITH BSAFE 130.
 - 9) ALL SURF, SLAG, SWAMP SLACK AND CORROSION TO BE REMOVED.
 - 10) THIS DRAWING IS NOT TO BE SCALED.

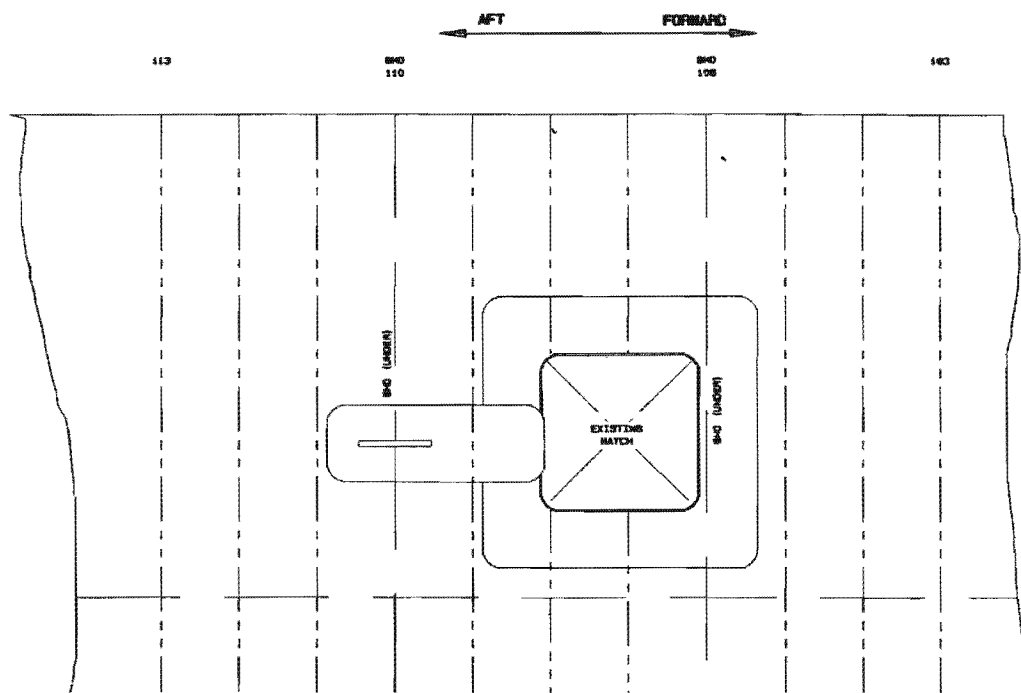


- Notes 1-**
1. ALL PLATING IS TO BE LOWER GRADE A OR APPROVED EQUIVALENT.
 2. ALL SECTIONS ARE TO BE TO BS 4360 GRADE 43A.
 3. ALL WELDING IS TO CONTINUOUS FILLET WELD. THROAT DIMENSIONS ARE INDICATED.

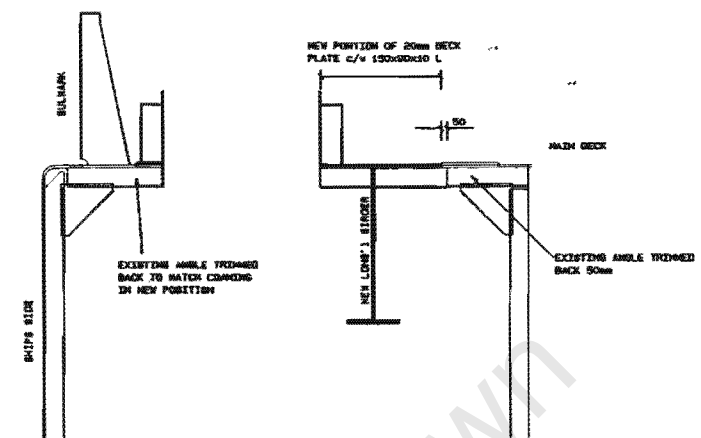
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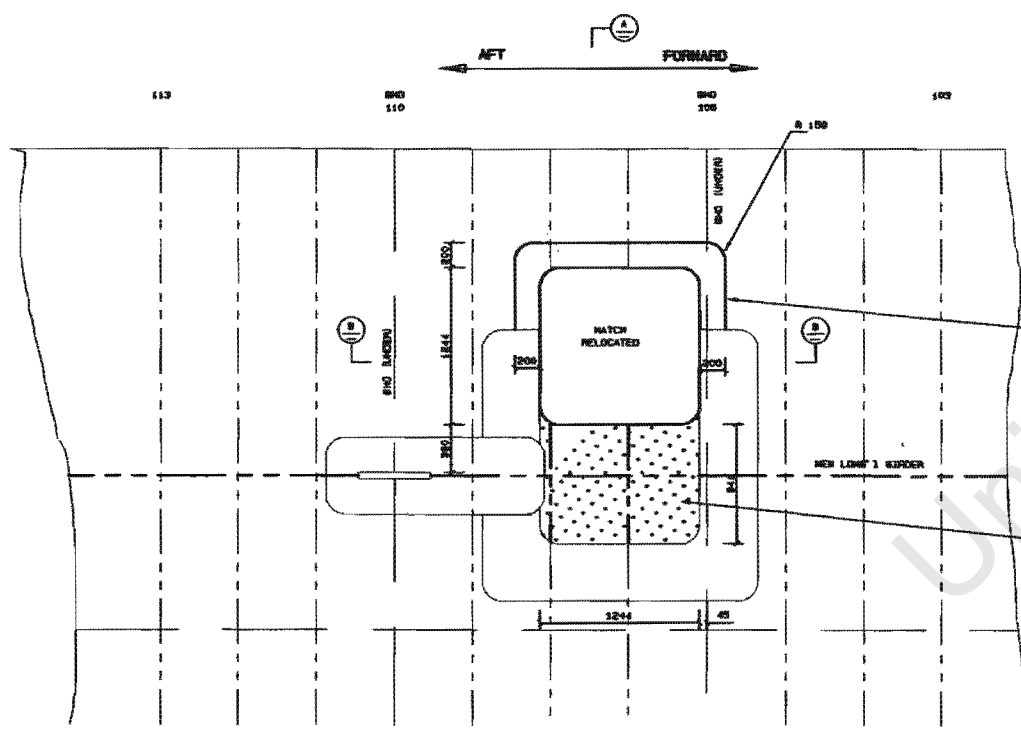


1:20 PART PLAN ON MAIN DECK AT EXISTING STORES MATCH

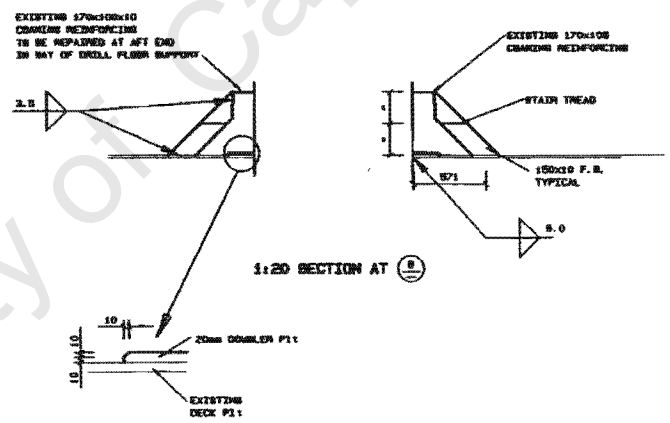


1:20 SECTION AT A

ACCESS STAIRS ARE TO BE FITTED TO THE FORE AND AFT END THE MATCH AS INDICATED STAIRS TO BE 600mm WIDE AND POSITIONED AFTER MATCH HAS BEEN RELOCATED



1:20 PART PLAN ON MAIN DECK AT RELOCATED STORES MATCH



1:20 SECTION AT B

- GENERAL NOTES (EXCEPT OTHERWISE NOTED)**
- 01) THIS DRAWING IS TO BE READ IN CONJUNCTION WITH THE APPLICABLE DE WEISS HANDBOOK SPECIFICATIONS ISSUED WITH THE CONTRACT DOCUMENTS.
 - 02) ALL STRUCTURAL STEEL USED IS TO BE IN ACCORDANCE WITH THE SAME LATEST ISSUE 2000A.
 - 03) ALL WALL STEELWORK IS TO BE CLASSIFIED BY THE APPLICABLE SOCIETY, TO BE GRADE A OR UNGRADED SPECIFICATION.
 - 04) WHERE APPLICABLE STEELWORK TO COMPLY WITH THE LATEST ISSUE OF SAME CODE, ISSUE A 12000A.
 - 05) CONTRACTOR TO VERIFY ALL MAJOR DIMENSIONS ON SITE PRIOR TO MANUFACTURE.
 - 06) ALL STRUCTURAL WELDS TO COMPLY WITH THE AWS D1.1-98 SPECIFICATIONS.
 - 07) ALL WALL STEELWORK WELDS TO COMPLY WITH THE APPLICABLE SOCIETY RULES AND REGULATIONS FOR THE CLASSIFICATION OF SHIPS.
 - 08) ALL WELDS TO BE 6mm CONTIGUOUS FILLET WELDS U.S.R.
 - 09) ALL BOLTS TO BE 20mm DIA.
 - 10) ALL BOLTS TO BE HDG, GRADE 8.8, IN ACCORDANCE WITH SABS 126.
 - 11) ALL DRILLS, SLITS, SHARP EDGES AND CORNERS TO BE ROUNDED.
 - 12) THIS DRAWING IS NOT TO BE SCALED.

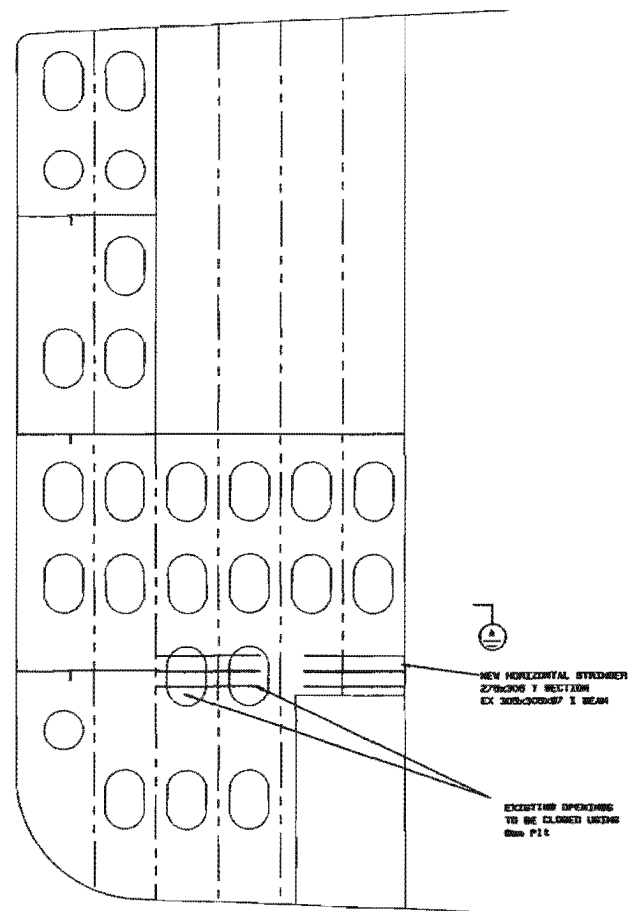
- Notes:-**
1. WELDS TO BE CONTIGUOUS FILLET WELDS THROAT DIMENSIONS ARE INDICATED.
 2. MATCH COVER IS TO OPEN THIS APPROXIMATELY 120 DEGREES. STOPPER IS TO BE SHOWN AT VESSEL IF NECESSARY. MATCH COVER IS NOT TO BE REMOVED NOR IS IT TO OPEN FLAT 1.0 THRU 180 DEGREES.

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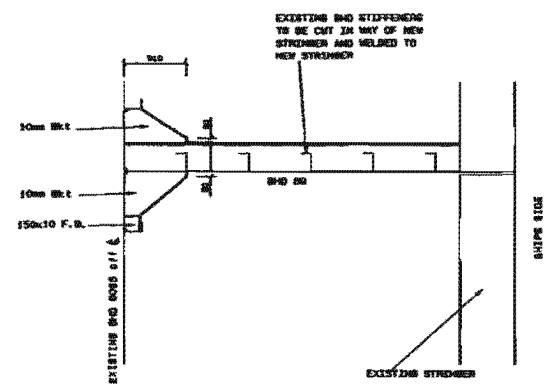
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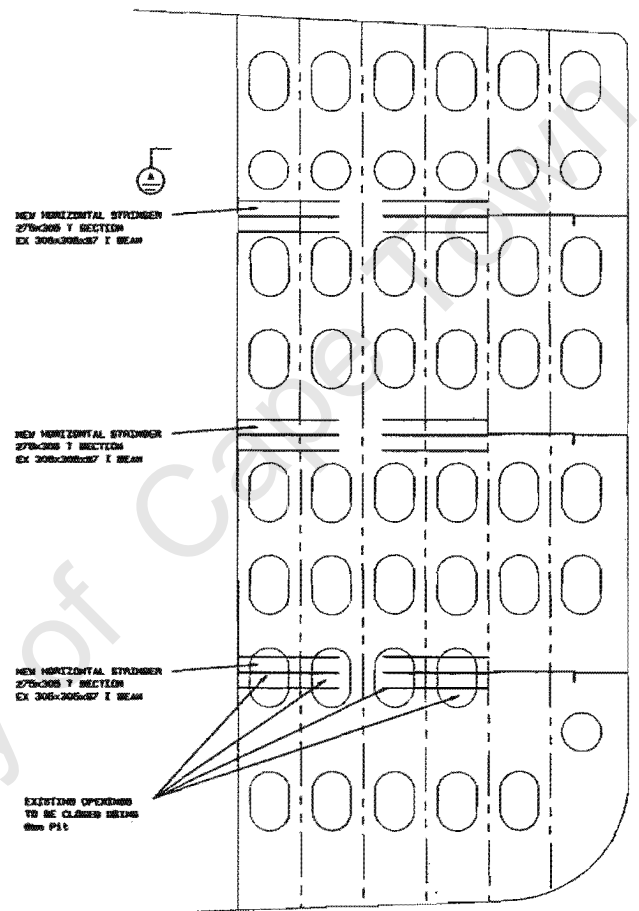
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APPROVED			



BHD 08 PORT



TYPICAL SECTION AT



BHD 08 STARBOARD

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- a) THIS DRAWING IS TO BE READ IN CONJUNCTION WITH THE APPLICABLE BE BOPNS DRAWING SPECIFICATIONS ISSUED WITH THE CONTRACT DOCUMENTS.
 - b (1) ALL STRUCTURAL STEEL USED IS TO BE IN ACCORDANCE WITH THE SAAS 1-424 GRADE 3000A.
 - (1.1) ALL HULL STEELWORK IS TO BE CLASSIFIED BY THE APPLICABLE SOCIETY, TO BE GRADE A OR EQUIVALENT SPECIFICATION.
 - c) WHERE APPLICABLE STEELWORK TO COMPLY WITH THE LATEST ISSUE OF SAAS 0306, 12000 & 12000A.
 - d) CONTRACTOR TO VERIFY ALL MAJOR DIMENSIONS ON SITE PRIOR TO MANUFACTURE.
 - e (1) ALL STRUCTURAL WELDS TO COMPLY WITH THE AWS D1.1-08 SPECIFICATIONS.
 - (1.1) ALL HULL STEELWORK WELDS TO COMPLY WITH THE APPLICABLE SOCIETY RULES AND REGULATIONS FOR THE CLASSIFICATION OF SHIPS.
 - f) ALL WELDS TO BE 6mm CONTINUOUS FILLET WELDS
 - g) ALL HOLES TO BE 20mm DIA.
 - h) ALL BOLTS TO BE HDG, GRADE 8.8, IN ACCORDANCE WITH SAAS 1306.
 - i) ALL SURF. SLAB, SHARP EDGES AND CORNERS TO BE REMOVED.
 - j) THIS OPENING IS NOT TO BE SEALED.

Notes:-
 1. WELD SYMBOLS INDICATE THROAT THICKNESSES.
 2. ALL PLATE TO BE L45198 GRADE A OR APPROVED EQUIVALENT.
 ALL SECTIONS TO BE TO BS 4360 GRADE 43A.

REV	DATE	DESCRIPTION
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