FINITE ELEMENT ANALYSIS OF THE RISER COLUMN CHAINTABLE AND CHAINHAWSE STRUCTURES FOR A FLOATING PRODUCTION STORAGE AND OFFLOADING FACILITY USING MSC/NASTRAN

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ABSTRACT

An overview is given of a recently completed finite element stress analysis of the Riser Column Chaintable and Chainhawse Structures for an offshore Floating Production Storage and Offloading (FPSO) oil and gas facility.

The project involved finite element modelling of a symmetric half model of the chaintable and analysis of the model under a series of Unit Load Cases and Load Combinations. The primary objective of the analysis was to quantify stress levels and stress combinations throughout the structure to enable strength and fatigue capacity of the chaintable and chainhawse structures to be confirmed.

The model involved approximately 60,000 DOF and analysis was carried out using a CRAY-YMP Supercomputer.

The paper will present a summary description of the problem and objectives of the analysis, finite element discretisation of the structure, analysis approach, and quality assurance checking procedures applied to verify the results.

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1.0 INTRODUCTION

BHP Engineering has recently completed a finite element stress analysis of the Riser Column Chaintable and Chainhawse structures for an offshore Floating Production Storage and Offloading oil and gas facility. The oil and gas field underlies approximately 120m of water and is located almost 70km offshore.

An FPSO facility involves flowlines from several seabed wellheads feeding into a riser column (in this case approximately 90m long) which is attached to a tanker via a rigid arm protruding from the bow. The tanker serves as both a platform for some product processing, and as a storage facility from which oil and gas is unloaded to tankers which moor nearby and thereby despatched directly to markets around the globe.

The riser column is moored or anchored to the seabed via a series of pretensioned chains which attach to a level in the column known as the chaintable deck located approximately halfway up the riser column. The riser attaches to the tanker rigid arm via a universal joint connection, and for stability, has buoyancy chambers in the upper areas and ballast compartments near the base. Product flowlines feed into spigots protruding from the riser just below the chaintable level. Figure 1 presents a schematic arrangement of the riser column in relation to the bow of the tanker. The riser can be disconnected from the tanker at any time.

2.0 PROBLEM DEFINITION AND SCOPE OF ANALYSIS

The chaintable and chainhawse structures are critical components of the riser column system's structural and operational integrity. Accordingly, a comprehensive finite element stress analysis was carried out to quantify stress levels throughout this area of the structure to enable confirmation, or modification, of the strength and fatigue capacity of the chaintable and chainhawse structures.

Modelling and analysis were carried out using MSC/XL (Version 3.0) and MSC/NASTRAN (Version 67) respectively.

The chaintable and chainhawse structures are located at Deck I of the riser column shown in Figures 1 and 2. Six (6) chainhawse structures are equally spaced around the circumference of the column at Deck I. Mooring/anchorage of the riser column is achieved by radially attached chains to the chainhawse journal bearing "hooks" via pivoting chainstoppers mounted in the hooks.

Whilst geometry of the chaintable is axisymmetric in 60 degree segments, loading is not strictly axisymmetric. However, it was considered that for analysis and design purposes, global design loads are such that they could generally be considered to be symmetrical about the plane of the lead chain meaning that it was only necessary to model one half of the structure.

It was also considered that because the effects of out-of-plane, non-symmetrical loading on the chainhawses are primarily of local interest in the chainhawses and close vicinity of the riser shell, these effects would be modelled by applying out-of-plane loads (as a unit load case) to a single chainhawse.

The finite element model is presented in Figures 3, 4 and 5.

Analysis of the model was performed on the BHP CRAY-YMP supercomputer.

3.0 MODELLING PHILOSOPHY AND DESCRIPTION

3.1 Extension of Model to Decks H and J

As stated already, the primary objective of the analysis was to determine stress levels in the vicinity of the chaintable at Deck I. In analyses of this type where only a part of the structure is modelled, it is often difficult to accurately determine appropriate boundary constraints which are truly representative and which will not have a detrimental effect on the accuracy of results in the area of interest. For this reason, it was decided to extend the model above and below Deck I to Decks J and H respectively, and apply global boundary constraints (including global loads) at Decks J and H only, thus invoking Saint Venant's Principle for the area of interest. Global loads were therefore applied at Deck H and boundary constraints applied at Deck J. No benefit was to be gained by modelling Decks H and J, hence they were not included in the model.

Saint Venant's Principle states that localised restraints or loads, or geometric discontinuities, cause stresses and strains only in the immediate vicinity of the restraint, load or discontinuity. Therefore, according to Saint Venant, any effects ensuing from poor choice of restraint positioning or from imprecise estimation of restraint rigidity, are local and are dissipated within a characteristic attenuation length in the vicinity of the restraint or loads.

In this case, Decks J and H are 7.25m away from the chaintable, Deck I, and with a riser column diameter of approximately 6.0m, and even though boundary constraints applied are considered to be representative, results in the area of particular interest would be insensitive to any localised effects of the particular restraints and loading applied to Deck J and H.

3.2 Mesh Refinement

A relatively fine mesh has been used in the column shell between EL55.5 and EL59.5 in the chaintable (with typical element dimensions of 100mm x 250mm) and in the chainhawses, with the greatest refinement (elements, 35mm x 55mm) under the points of chain load application in the webs of the chainhawses where some of the highest stress gradients are to be expected.

Above EL59.5 and below EL55.5 the shell mesh becomes coarser, although it is still relatively fine. In these areas the mesh provides a boundary to the area of interest and is only required to adequately model structural stiffness. To ensure accurate representation of structural stiffness (hoop, axial, and bending) in these boundary areas, it was decided to model the radial ring girders in detail using plate (QUAD4) elements rather than attempting to approximate the stiffening effect of the ring girders using beam elements or an equivalent increased shell plate thickness.

3.3 Structural Details

All details of structural platework have been meshed into the model with a level of mesh refinement and limits on element skew and distortion such as to avoid the need to estimate stress concentration factors (SCF's) in any area.

The level of detail in the model is such that small cope holes at the intersection of plates for fabrication purposes (commonly called "ratholes") have not been included. (Refer Figure 2)

3.4 Lateral Loads

The number of permutations of lateral loading on a chainhawse structure is significant. Lateral loads vary according to the chain off-lead angle (refer Figure 2) relative to the centreline of the chainhawses. The off-lead angle varies due to excursion of the chaintable, chaintable rotation to overcome main bearing (in the rigid arm) friction torque, and installation position tolerances.

Rather than attempting to model lateral load effects explicitly for each chainhawse (given that each chainhawse has a different chain load and a different maximum off-lead angle), it was decided to rationalise lateral loading effects by reducing the problem to a single unit load case in which the worst effects of lateral loading could be represented. Lateral load effects are primarily of local interest in the chainhawses and close vicinity of the riser shell.

Chain 1 (the lead chain) and Chain 2 have the highest loads by a significant margin for any of the possible load combinations on the riser. Similarly lateral effects will be greatest for these chainhawses. However, although the off-lead angle for Chain 2 can be approximately double that for Chain 1, the Chain 1 load is sufficiently higher such as to impose the greater lateral, or out-of-plane load, on the structure. Hence, the worst lateral load is due to the lead chain, Chain 1.

Accordingly, it was decided to analyse lateral loading with a unit loading acting on the chainhawse. Lateral loading on the chainhawse is transmitted fully to the journal bearing hook on one side only, hence the unit lateral load has been applied totally to one journal bearing hook, (i.e, half of a chainhawse).

By virtue of the funnel housing of the chain passing through the chainhawse, the lateral loading due to an inclined chain simultaneously includes a twisting moment, or couple, in the journal bearing hooks of the same magnitude as the lateral force. Accordingly, the unit lateral load case (Load Case 5, refer Section 4.0) models out-of-plane lateral loading effects with a unit lateral load on one hook and opposing unit vertical forces (parallel to the axis of the riser column) on the two journal bearing hooks.

Although the maximum lateral loading (as noted above) occurs on the lead chain, it was necessary to model this non-symmetric unit load condition on Chainhawse 2 (adjacent to the lead chain) as the symmetric half model of the chaintable used for the analysis (in which the symmetry plane passes through the centreline of the lead chainhawse) precluded modelling of non-symmetric lateral loading effects on the lead chainhawse. This modelling approach is reasonable as the effects of the lateral loads on the chainhawses are primarily of local interest in the chainhawse "hooks" and the close vicinity of the connecting riser shell.

3.5 Boundary Constraints

Symmetric boundary constraints have been applied to the geometric symmetry plane of the half model.

Vertical, radial and circumferential restraint was applied to all nodes of the outer shell of the column at the top of the model, EL.65.500m (Deck J).

These constraints are depicted in Figure 5.

4.0 LOADINGS

The following load cases and load combinations were specified for analysis.

Load Cases

Load Case	Loading Type	Description/Comment
1	Static/Dynamic Water Pressure	Applied to the outer shell from Deck H-J as a uniform unit pressure acting radially inwards
2	Global Axial Load	Applied as a unit load acting upwards at Deck H, distributed uniformly around shell (using rigid body element)
3	Global Shear Load	Applied as a unit load uniformly distributed over at Deck H (using rigid body element)
4	Global Bending Moment	Applied as a unit load at Deck H. Moment applied using rigid body element
5	Lateral and Twisting Load on Chainhawse 2	Unit lateral load applied over 30° of bearing block. Twisting couple applied with opposing unit vertical loads on each bearing
6	Load on Lead Chainhawse	Applied as unit load acting over 120° at γ = 30°. Cosine loading distribution. Refer Figure 6 for definition of γ angle.
7	Structure Self-Weight	Applied with gravity acceleration in - Z direction. (riser column assumed to be vertical)

Load Combinations (Refer Figure 6)

In addition to the above load cases, several load combinations variously including both the above unit load cases and extreme chain load sets (on each of the four chainhawses of the half model), were specified for the riser column "connected" and "disconnected" to the tanker. Chain loads have generally been applied as cosine loading distributions over 120° of the journal bearing (60° each side of the line of action, γ angle).

5.0 MODEL AND ANALYSIS STATISTICS

Key statistics of the model and analysis are as follows:

No. of Node Points	:	10,974
No. of QUAD4 Elements	:	10,620
No. of Degrees of Freedom	:	59,238
CPU (CRAY-YMP Supercomputer)	:	85min

6.0 ANALYSIS FINDINGS AND DISCUSSION

Analysis results for each load case and load combination were reviewed in terms of both Major and Minor Principal stresses, and Von Mises Stresses. Typical stress plots for various locations throughout the model are presented in Figures 7, 8, and 9.

Stress results were examined in order to:-

- Confirm structural strength capacity (for example in terms of plate thickness) throughout the chaintable and chainhawse structures
- Identify any potentially serious stress concentrations
- Quantify ranges in Principal Stresses as a basis for checking fatigue capacity of the structure at critical locations.

6.1 Design Review

The following design checks were carried out on the stress results of the analysis:

- Unit load case results factored for fatigue analysis of cumulative damage
- Check on Von Mises Stresses throughout
- Check on localised plate buckling and combined stress states

It was found that stress levels throughout the model were generally well within acceptable limits, therefore negating any need for design modifications or adjustments to plate thicknesses except in the top and bottom flanges of the chainhawses. In these areas, structural strengthening was designed to relieve high stress levels (due to both in-plane and out-of-plane bending effects) through the addition of vertical side plates to the flanges.

6.2 Locking Beams

It was assumed in the analysis that the chainhawse locking beams (depicted in Figure 2), do not provide any restraint against opening up of the journal bearing "hook". This was the intention of the design as the outside hole of the locking beam has been elongated to facilitate some opening of the hook under load.

Deflection results showed that the design-allowed hole elongation is almost totally consumed under the "worst" loading combinations. It was therefore recommended that elongation of the outside pin hole be increased to ensure a greater tolerance against the locking beam restricting the opening of the journal bearing under load.

7.0 QUALITY ASSURANCE

In addition to independent colleague review of the analytical philosophy, modelling procedures, and all input data, several checking procedures have been carried out to verify modelling accuracy and the quality of the results obtained. Brief descriptions of the primary checks are listed below.

The checks carried out are considered to comprise an appropriate degree of verification to confirm the accuracy of the modelling. Most checking has been carried out on the unit load cases as the relatively simpler loading in these cases generally means that hand calculations can more readily approximate model behaviour. If the model integrity and accuracy of results can be confirmed for the simple unit cases (as has been done here) it is reasonable to conclude that results from the more complex load cases and load combinations are no less accurate.

Manual Stress Calculations

Manual stress calculations have been carried out at numerous sections through the chainhawses (particularly between the journal bearing and the riser shell) and the main riser column as a whole. In some cases resultant stresses could be manually estimated very accurately, whereas in other cases the local complexity of the geometry was such as to preclude hand calculations from being anything more than a rough estimate. For example, manual stress calculations at a section through the chainhawse approximately midway between the journal bearing and the riser shell show that increased stress levels can be expected in this area because the ratio of bending moment to effective section modulus reaches a maximum in this region. This finding was totally consistent with computed results. In all cases, correlation between manual and computed results was considered to be good.

External Force Checks

External force checks between reaction forces and applied loads on the model indicate an equilibrium discrepancy of less than 1% as well as showing good correlation between reactions and expected loads in the coordinate directions. Of the three physical laws governing elastic structural behaviour (Equilibrium, Compatibility and Material Laws) finite element analyses usually guarantee that two of them, Compatibility and the Material Law, are satisfied exactly.

As the FE method involves the solution of a large number of simultaneous equations by numerical methods, equilibrium conditions are only ever approximately satisfied and therefore an equilibrium discrepancy of less than 1% is seen to be reasonable and acceptable for a model of the size and complexity of that developed for this study.

Mass Confirmation/Material Completeness Check

The model was "hung" from Deck J (Load Case 7) and a gravity load only applied.

A detailed manual calculation of the model mass was also carried out as a check on model completeness. Comparison of the computed and manually calculated masses was considered to be excellent, with a discrepancy of less than1.7%.

Free Edges/Free Faces

Internal MSC/XL facilities were used to identify any free edges and free faces to ensure there were no "cracks" in the model. None were found.

Cross-Referencing of Graphical and Data file Results

Random checks were made between graphical and data file results for stresses, displacements and boundary constraints. Excellent consistency was found.

Displacement - Boundary Constraint Consistency

Random checks on the displacement profiles for the model have been done to confirm that displacement characteristics were consistent with the BC's applied (or intended).

8.0 CONCLUSION

A finite element stress analysis has been carried out using MSC/NASTRAN on a symmetric half model of the FPSO Riser Column between EL51.0m and EL65.5m to determine stress levels throughout the chaintable and associated chainhawse structures.

Several unit load cases and load combinations have been investigated.

A description of the problem and objectives of the analysis, finite element discretisation of the structure and analysis approach have been summarised herein and a sample of typical graphical stress results is also presented. Quality Assurance checking of results has shown good comparison with independent hand calculations, thus confirming the adequacy of the finite element idealisation of the structure.

The analysis has provided a sound knowledge of structural behaviour of the chaintable under the load combinations specified.

9.0 ACKNOWLEDGEMENTS

The authors would like to acknowledge and thank the management of BHP Engineering Pty Ltd for providing financial support in the presentation of this paper.

10.0 REFERENCES

[1]. MacNeal Schwendler Corporation
MSC/NASTRAN (Version 67)
User's Manual and Handbook for Linear Analysis

[2]. Cook, R D
Concepts and Applications of Finite Element Analysis
John Wiley & Sons, 1981

[3]. Roark, R J; Young, W C;
Formulas for Stress and Strain, 5th ed.,
McGraw-Hill, 1975

[4]. Twine, D J; "FEA on PC-based Systems and Quality Control",
The Institution of Engineers Australia, National Structural Engineering
Conference, Adelaide, 3-5 October 1990. Proceedings pp. 150-155

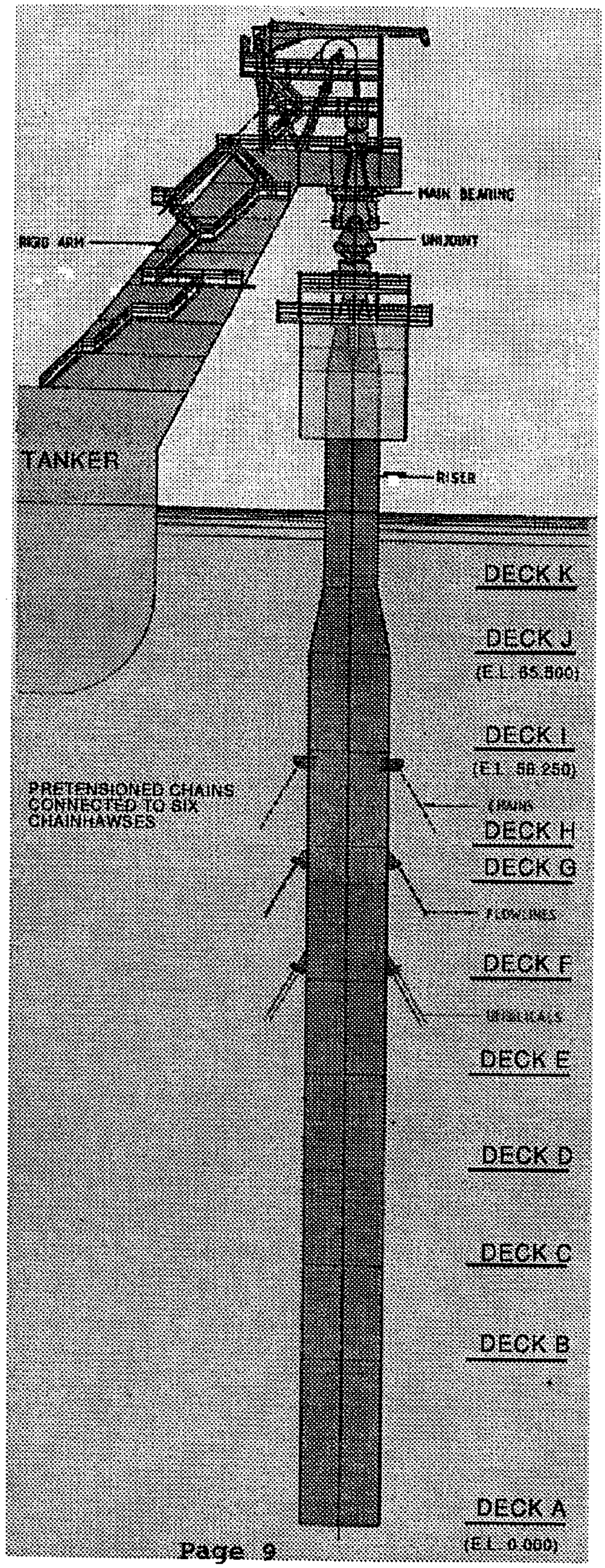
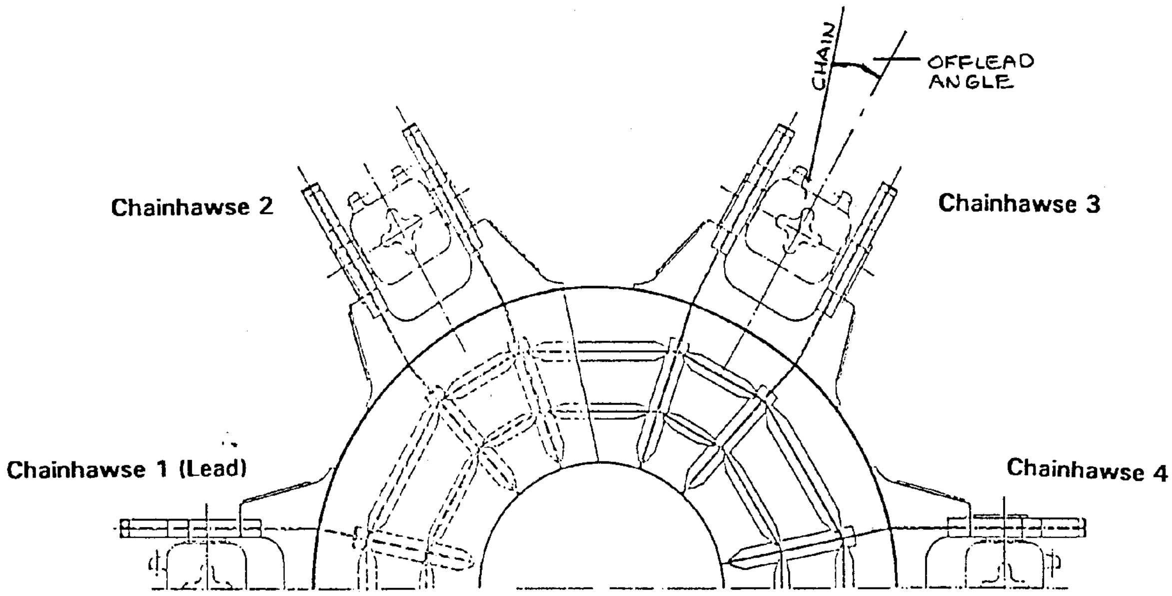
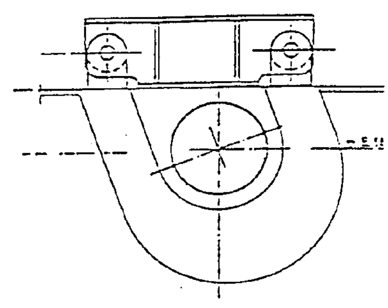

MAIN BEARING
UNIJOINT
RIGID ARM
TANKER
RISER
DECK K
DECK J
(E.L. 65.500)
DECK I
(E.L. 58.250)
PRETENSIONED CHAINS
CONNECTED TO SIX
CHAINHAWSES
DECK H
DECK G
DECK F
DECK E
DECK D
DECK C
DECK B
DECK A
(E.L. 0.000)

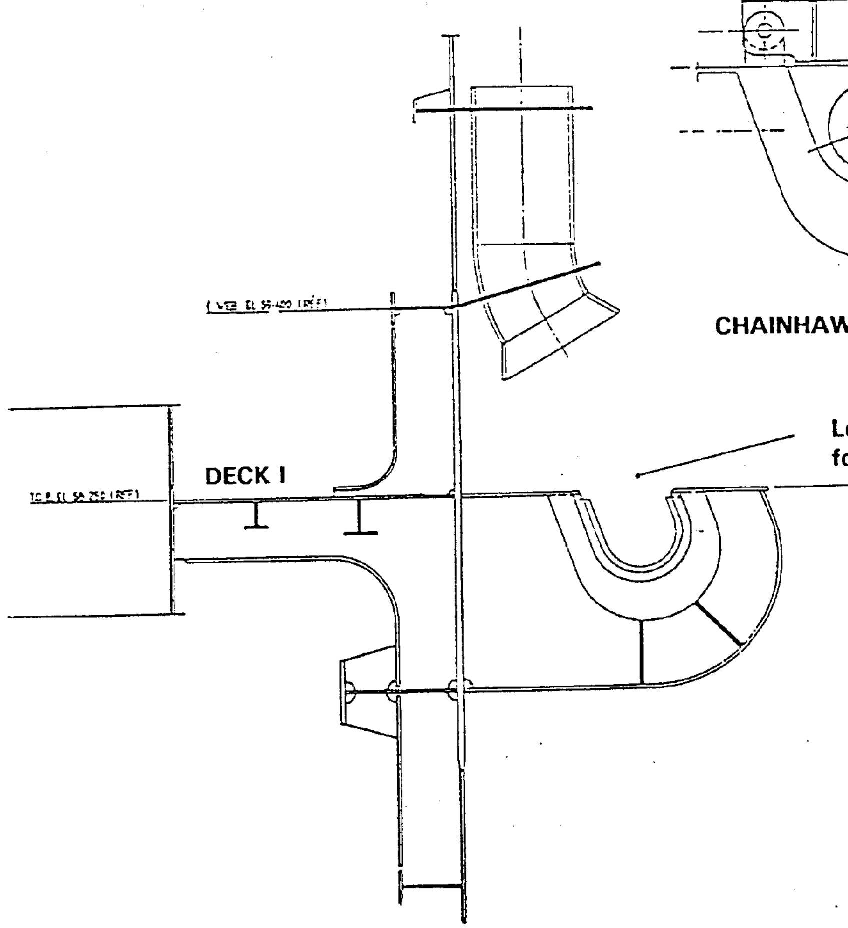
FIGURE 1



HALF PLAN OF CHAINTABLE (DECK I)



CHAINHAWSE LOCKING BEAM



**CHAINHAWSE DETAIL
(SECTION THROUGH CHAINTABLE)**

FIGURE 2

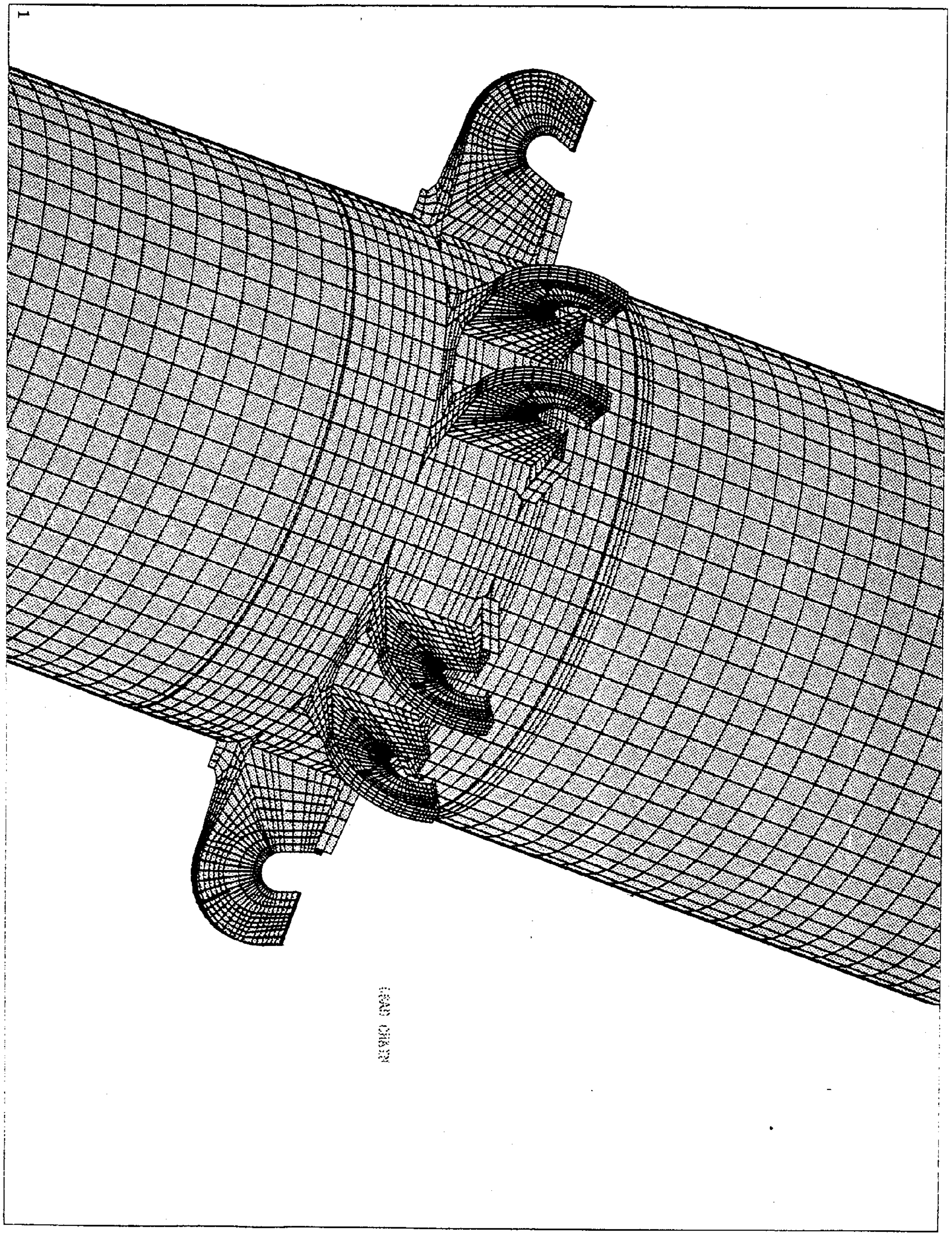


FIGURE 3 - EXTERNAL VIEW OF CHAINTABLE FE MESH

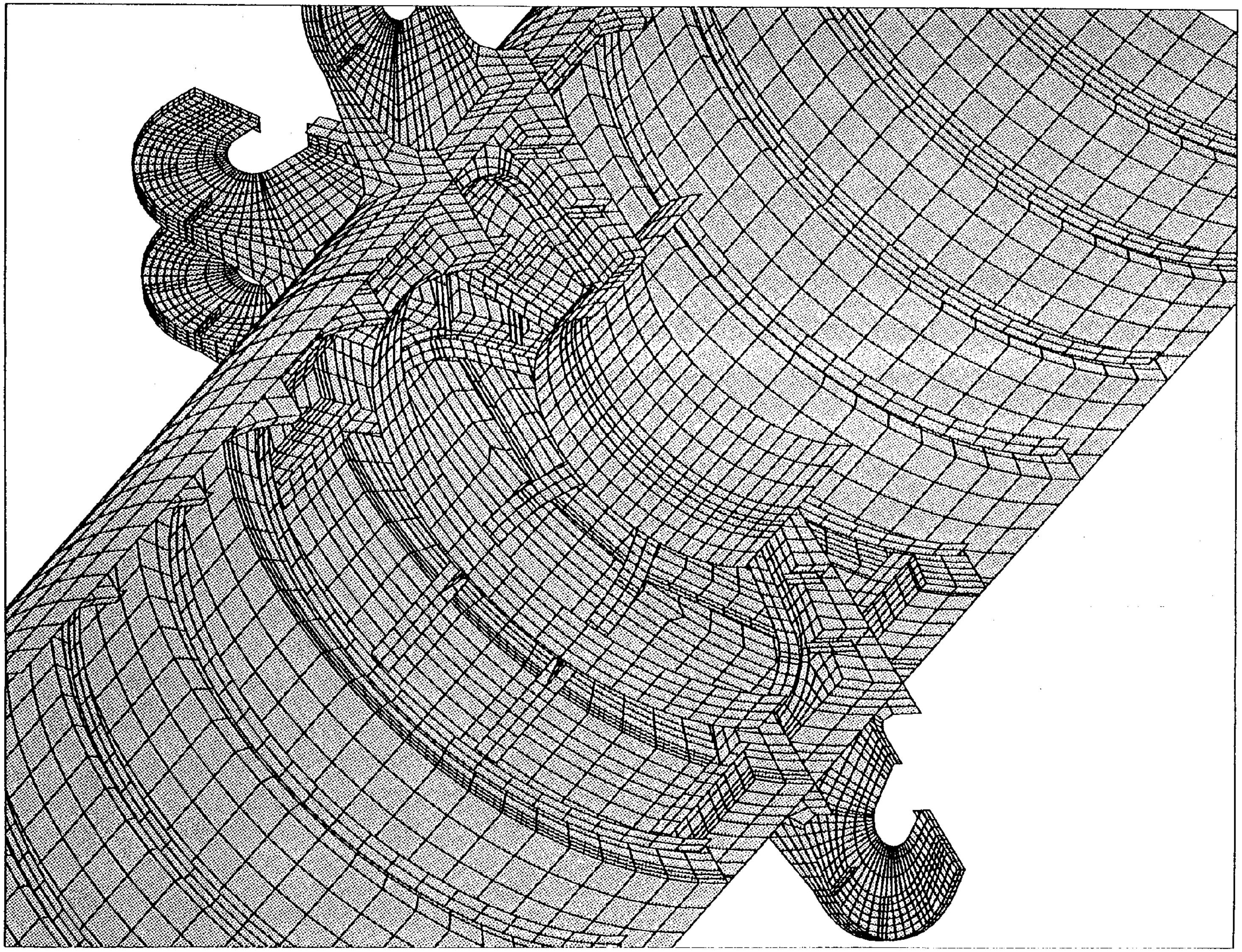
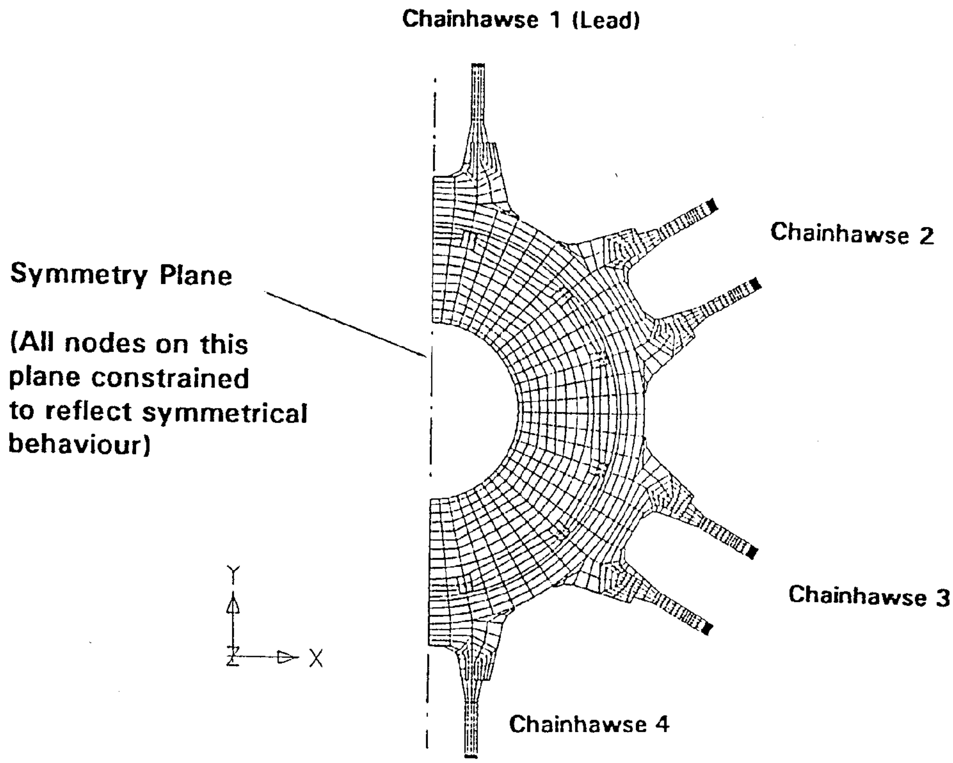


FIGURE 4 - UNDERSIDE INTERNAL VIEW OF FE MESH



PLAN VIEW OF CHAINTABLE MESH

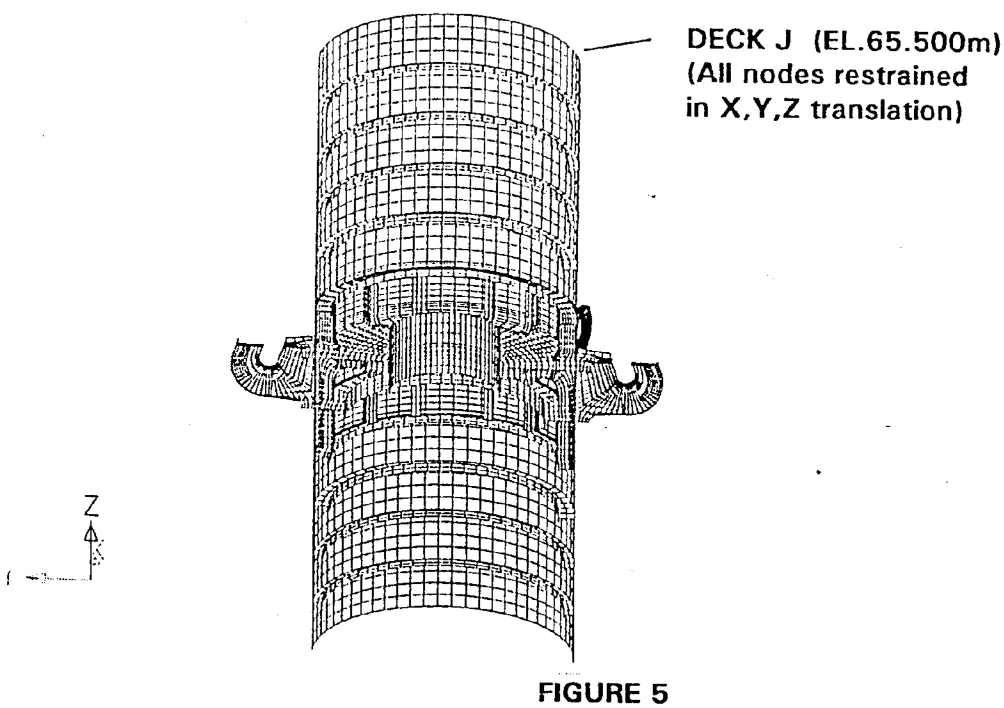


FIGURE 5
INTERNAL AND PLAN VIEWS OF FE MESH AND BOUNDARY CONSTRAINTS

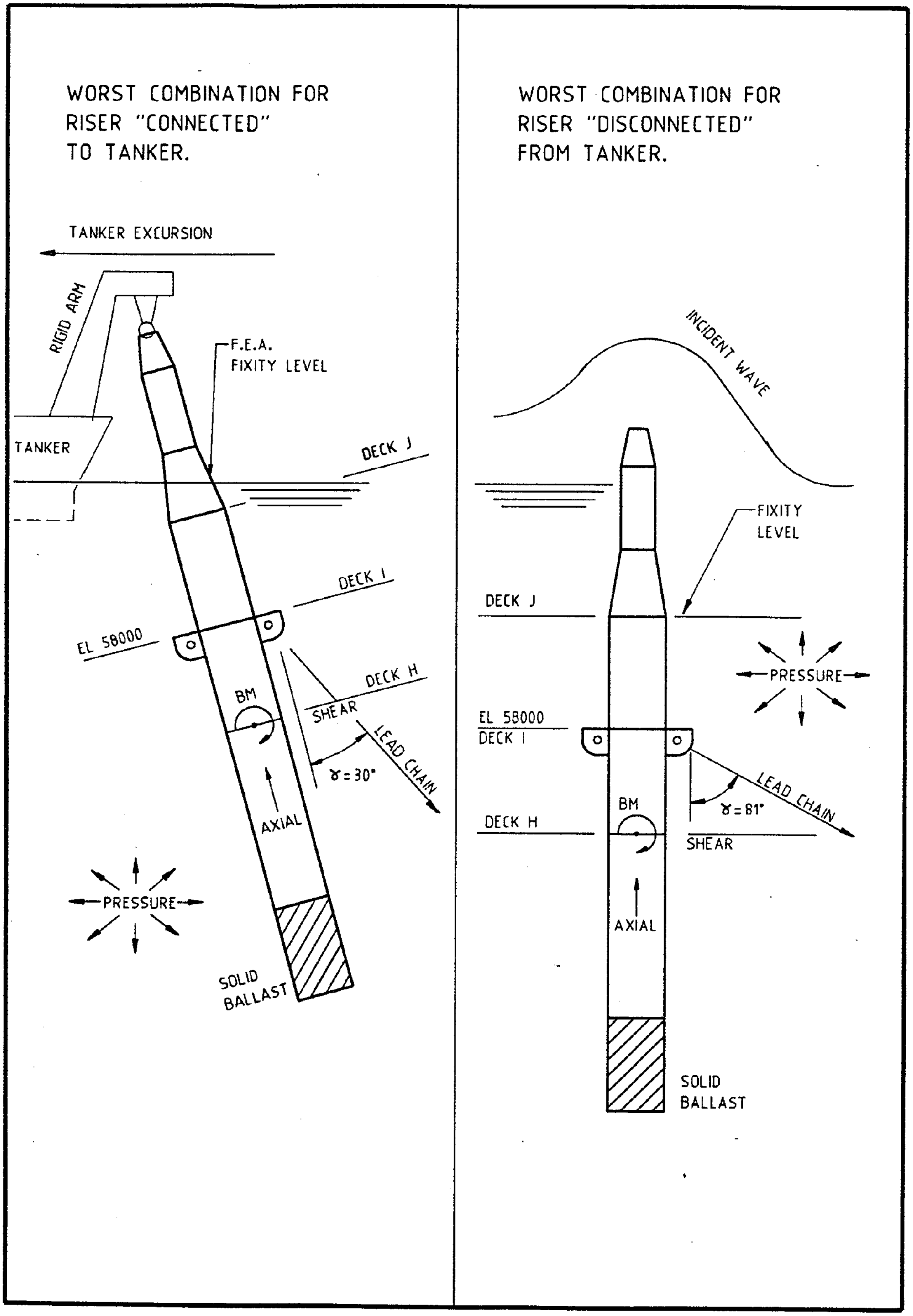

WORST COMBINATION FOR
RISER "CONNECTED"
TO TANKER.
TANKER EXCURSION
RIGID ARM
F.E.A.
FIXITY LEVEL
TANKER
DECK J
DECK I
EL 58000
DECK H
BM
SHEAR
LEAD CHAIN
ɤ=30°
AXIAL
PRESSURE
SOLID
BALLAST
WORST COMBINATION FOR
RISER "DISCONNECTED"
FROM TANKER.
INCIDENT WAVE
FIXITY
LEVEL
DECK J
PRESSURE
EL 58000
DECK I
LEAD CHAIN
ɤ=81°
DECK H
BM
SHEAR
AXIAL
SOLID
BALLAST

FIGURE 6

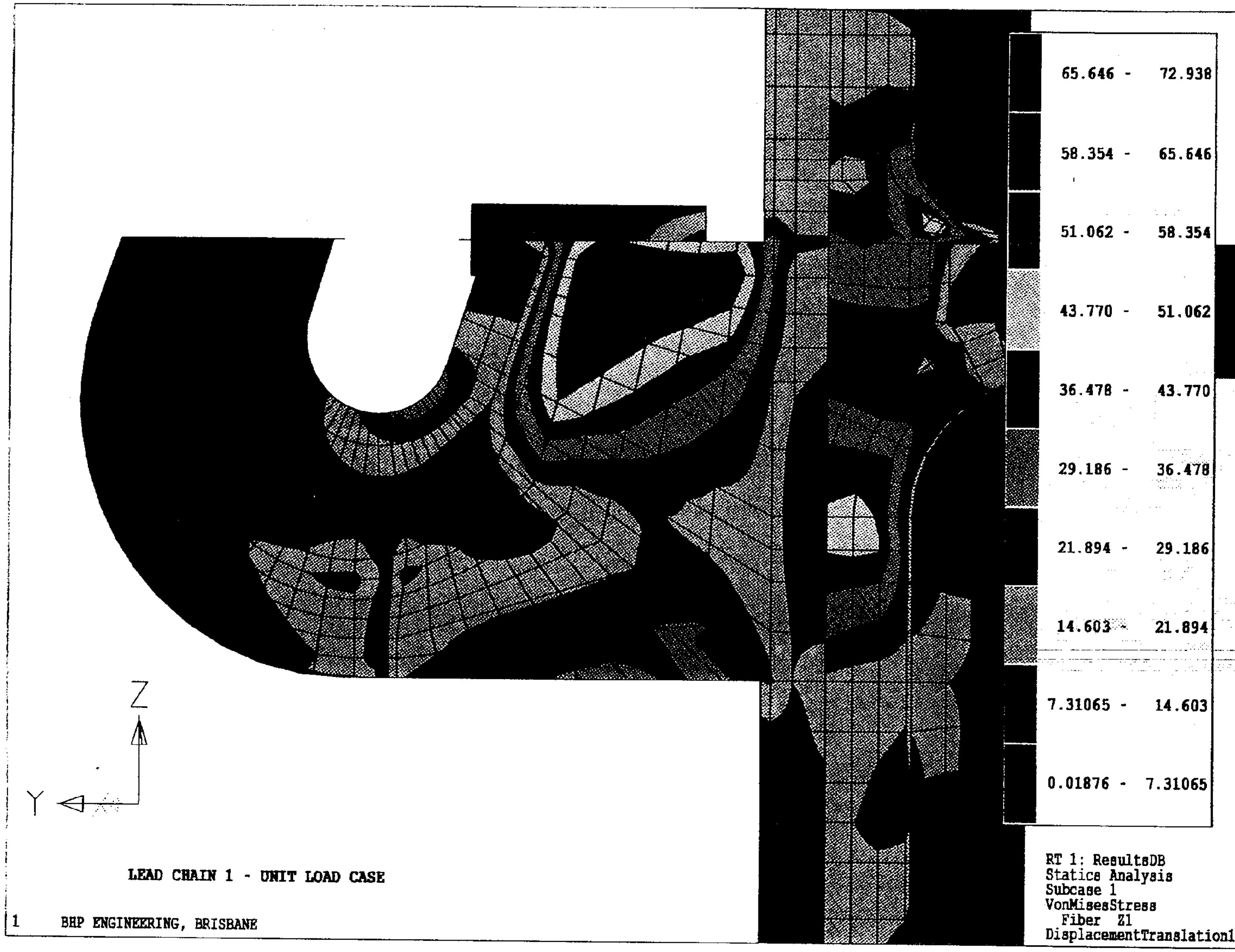

Z
Y
65.646 - 72.938
58.354 - 65.646
51.062 - 58.354
43.770 - 51.062
36.478 - 43.770
29.186 - 36.478
21.894 - 29.186
14.603 - 21.894
7.31065 - 14.603
0.01876 - 7.31065
LEAD CHAIN 1 - UNIT LOAD CASE
1 BHP ENGINEERING, BRISBANE
RT 1: ResultsDB
Statics Analysis
Subcase 1
VonMisesStress
Fiber Z1
DisplacementTranslation1

FIGURE 7


1
LEAD CHAIN
16.051 - 23.116
8.98506 - 16.051
1.91948 - 8.98506
-5.14611 - 1.91948
-12.212 - -5.14611
-19.277 - -12.212
-26.343 - -19.277
-33.408 - -26.343
-40.474 - -33.408
-47.540 - -40.474

FIGURE 8

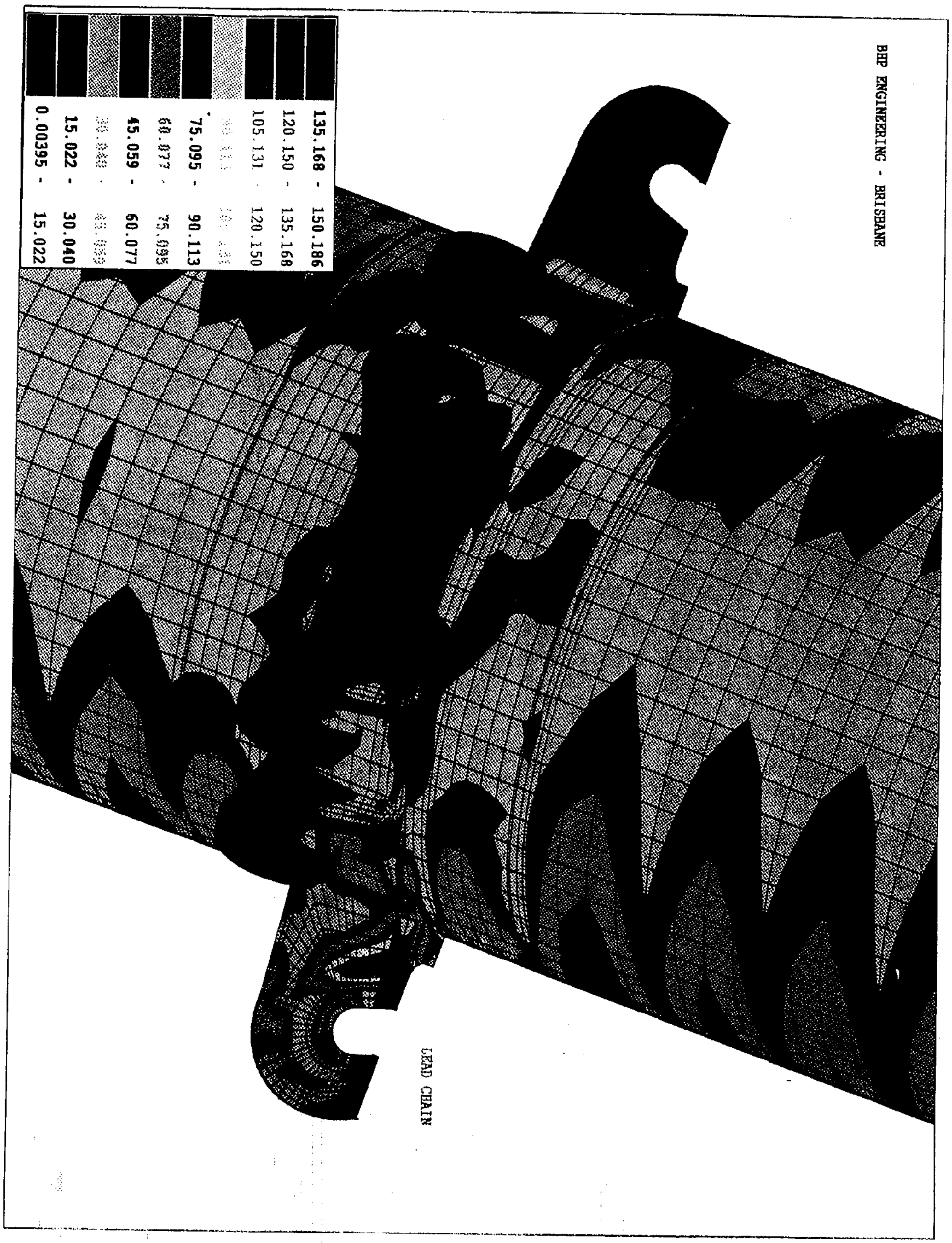

BHP ENGINEERING - BRISBANE
135.168 - 150.186
120.150 - 135.168
105.131 - 120.150
75.095 - 90.113
60.077 - 75.095
45.059 - 60.077
30.040 - 45.059
15.022 - 30.040
0.00395 - 15.022
LEAD CHAIN

FIGURE 9