# ANALYSIS OF HYPERBOLIC SHELL NATURAL DRAUGHT COOLING TOWERS USING MSC/NASTRAN

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## ABSTRACT

Natural Draught Cooling Towers are very common in modern day thermal and nuclear power stations. These towers with very small shell thickness are exceptional structures by their sheer size and sensitivity to horizontal loads. This paper discusses the analysis of R.C.C. hyperbolic shell of a Natural Draught Cooling Tower using Quad8/Quad4 elements of MSC/NASTRAN. Analysis has been carried out for different cases by varying the mesh size and aspect ratio of Quad8/Quad4 elements and the results have been compared.Not much variation in results has been found for these cases except at the base of the shell. At the base of the shell the Quad8 results are much at variance from quad4 and SAPIV results.

## INTRODUCTION

A natural draught cooling tower is an enclosed device where hot water gets cooled under direct contact with air. Natural draught cooling towers are prominent features in many thermal and Nuclear Power Stations in view of their large size. Natural draught cooling towers rank among the largest reinforced concrete thin shell structures. The thin outer shell of the tall natural draught cooling towers can be said to be one of the greatest structural innovations of all times. With thickness as little as 170 mm for a height of over 150 m, the shell is a remarkable structure and its analysis and design demands considerable precision and care.

## PROBLEM DEFINITION

The problem taken for analysis is the cooling tower under construction for Stage I 2x210 MW Units of Rayalaseema Thermal Power Project, Muddanur, Andhra Pradesh State Electricity Board. The cooling tower consists of a hyperbolic RCC shell and supporting structure on the out side. An inside supporting structure for the hot water distribution system at the top and the recooled water distribution system at the bottom, is completely isolated from the outer shell structure and thus it is not taken into account in the analysis.

**Salient features of the Cooling Tower**

| | | | |
|---|---|---|---|
| 1. | Type of tower | : | Counter flow natural draught cooling tower |
| 2. | Quantity of circulating water per tower | : | 35,000 Cum./Hr |
| 3. | Duty | : | To cool condenser hot water for 1 No. of 210MW Unit |
| 4. | Period of operation | : | 24 Hours continuous |
| 5. | Hot water inlet temperature | : | 43 Degrees Celsius |
| 6. | Re-Cooled water outlet temp. | : | 33 Degrees Celsius |
| 7. | Design relative humidity | : | 40.0% |
| 8. | Design ambient wet bulb temp. | : | 27.2 Degrees Celsius |
| 9. | Design wind speed for thermal performance | : | 0 to 18 KMPH |

**Important Centreline dimensions:**

| | | | |
|---|---|---|---|
| i) | Elevation of pond sill level | : | P + 0.00M |
| ii) | Elevation of ground level | : | P - 0.3 M |
| iii) | Level of basin floor below sill at periphery | : | P - 3.0 M |
| iv) | Nominal working level of water in basin below sill level | : | P - 0.3 M |
| v) | Founding level of tower foundations | : | P - 4.5 M |
| vi) | Height of top of tower above sill | : | P + 125.0 M |
| vii) | Height of throat of tower above sill | : | P + 106.25 M |
| viii) | Height of top of air inlet above sill | : | P + 6.0 M |
| ix) | General height of top of fill above sill | : | P + 10.0 M |
| x) | General height of bottom of fill above sill | : | P + 3.55 M |
| xi) | Height of hot water riser centre line above sill | : | P + 10.0 M |
| xii) | Diameter at sill level | : | 104.000 M |
| xiii) | Diameter at top of air opening | : | 100.104 M |
| xiv) | Diameter at throat level | : | 55.200 M |

The shell has a thickness of 720mm at base, 350 mm at top and a throat level thickness of 230mm with the thickening at the top and bottom effected gradually. The shell is supported on 44 pairs of diagonal columns which are racked in the vertical plane, being tangential to the meridional plane of the shell at its bottom. The diagonal columns rest on pedestals which have the same inclination with respect to the vertical as the tangent to the meridional profile of the shell at its bottom. The pedestals are also integral with the pond wall. At the bottom, a ring spread footing is provided below pond wall with its bottom plane normal to the inclined centerline of pond wall.

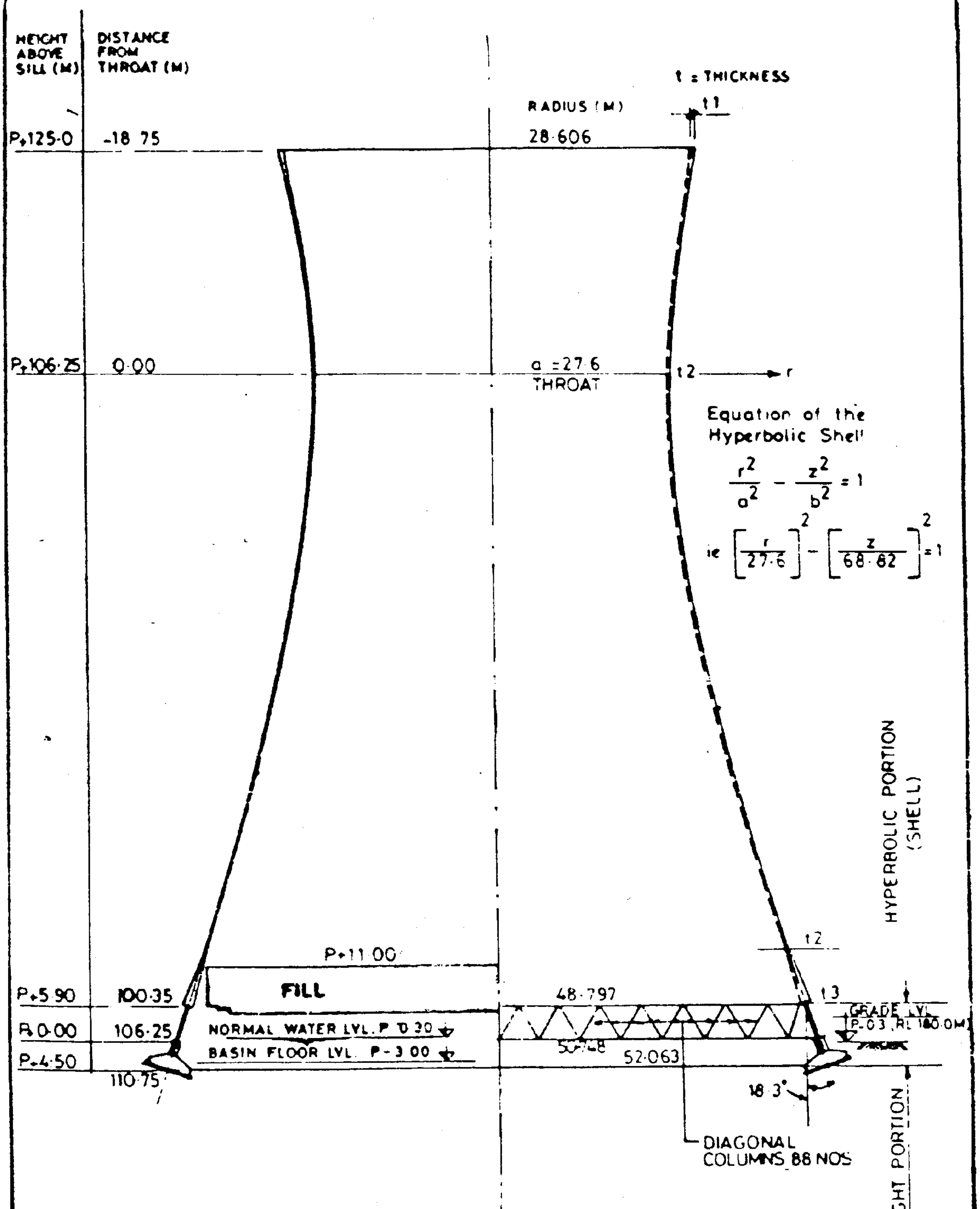



FIG. 1 - GEOMETRY OF THE COOLING TOWER MUDDANUR N·D C T UNIT NO. 1 & 2

NOTE ALL DIMENSIONS AND LEVELS ARE IN METRES.

## ANALYSIS

The analysis of these cooling towers is an interesting challenge to any structural engineer in view of their shape and large size combined with the non-axisymmetic horizontal wind loads:

The complete tower i.e., outer shell, raker columns, pond wall and ring foundation, has been considered for analysis. The outer shell and pond wall are meshed with Quad8/Quad4 elements, raker columns and foundation with bar elements of MSC/NASTRAN. Analysis has been carried out for the following cases by varying the mesh size and aspect ratio of Quad8/Quad4 elements.The divisions along the height are so chosen as to have finer mesh in the areas of possible steep stress variations i.e., near the top and bottom of the shell. Care has also been taken to have nodes at the 44 pairs of diagonal columns.

| S.No. | Element Used | Total No. of Elements Used | No. of Divisions along with Horizontal Plane | No. of Divisions along Meridional Plane | CPU Time |
|---|---|---|---|---|---|
| CASE 1 | Quad 8 | 880 | 44 | 20 | *5100 sec |
| CASE 2 | Quad 8 | 1760 | 88 | 20 | **2400 sec |
| CASE 3 | Quad 8 | 440 | 22 | 20 | 1500 sec |
| CASE 4 | Quad 4 | 880 | 44 | 20 | *660 sec |
| CASE 5 | Quad 4 | 1760 | 88 | 20 | 1320 sec |
| CASE 6 | Quad 4 | 3520 | 176 | 40 | 4920 sec |

* Analysis for both gravity & windloads

** Analysis for half the cooling tower for gravity load

FINITE ELEMENT MODEL
OF COOLING TOWER

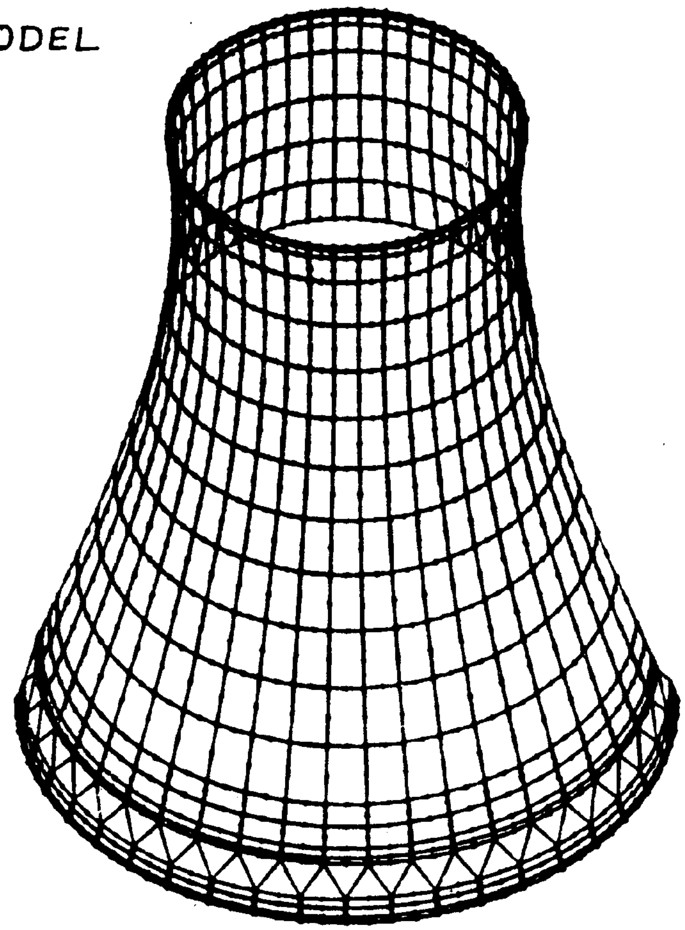


FIG-2

## DISCUSSIONS

An attempt has been made to compare the results of Quad8 elements with Quad4 elements by using equal number of elements for meshing cooling tower. The results of Quad8/Quad4 elements are also compared with SAP IV (four noded shell element) results. These results are as shown in Table - 1 and Table - 2.

It is seen from Table - 1 and Table - 2 that the results from Quad8 elements, Quad4 elements and SAP IV four noded shell elements closely match each other. However, at the base of the tower (at the junction of the shell with the raker columns) the Quad8 results are at large variation from the Quad4 and SAP IV results. This variation may be due to the fact that Quad8 results are at the corners whereas Quad4 and SAP IV results are at the element centres.The corner stresses may be picking up a stress concentration at the racker column junction.

It is also observed that the Quad8/Quad4 results are at variance with the SAP IV results at the top of tower for wind load case as seen from the Table-2.

Table-3 shows the comparision of results of Quad8 elements for various mesh sizes. It is observed from these results that there is no significant variation in results for these cases except at the bottom of the shell. As explained above, this variation at the bottom of the shell may be due to stressconcentration at the junction of racker column & shell. It is also quite interesting to see that the maximum compressive force at the bottom of shell is 82.388 tonns/metre when one element is used in between the racker column for the bottom ring. Maximum compressive force is 70.71 tonns/metre when two elements are used in between the raker columns. Thus, the stress concentration effects may be reduced when more elements are used for bottom ring portion.

Table-4 shows the comparision of results of Quad4 elements for various mesh sizes. It is seen from the Table-4 that there is no variation of forces from top to bottom of the shell for all the mesh sizes.

It is also observed from the above analysis that the results of Quad4 elements agree very well with SAP IV (four noded shell element) results. The results of Quad8 elements are differ somewhat from the Quad4 and SAP IV results. This deviation may be due to curved surface of Quad8 elements in contrast to plane surface of Quad4/SAP IV ( four noded shell) elements.

Graphs are developed for the variation of forces along the height of and circumference of the tower for the above cases and these are shown in Graph 1 to Graph 12.

## TABLE-I

**COMPARISION OF RESULTS FOR DEAD LOAD**

| | RESULTS OF QUAD-8 ELEMENTS | | RESULTS OF QUAD-4 ELEMENTS | | SAP-IV RESULTS | |
|---|---|---|---|---|---|---|
| ELEVATION | FX | FY | FX | FY | FX | FY |
| 124.500 ML | -0.41 | 2.442 | -0.41 | 2.54 | -0.42 | 2.53 |
| 123.000 ML | -1.485 | 1.743 | -1.494 | 1.763 | -1.52 | 1.78 |
| 119.125 ML | -3.827 | -1.943 | -3.82 | 0.76 | -3.89 | 0.75 |
| 111.250 ML | -8.4 | -1.22 | -8.33 | -0.89 | -8.5 | -0.93 |
| 101.250 ML | -14.06 | -3.39 | -13.96 | -2.95 | -14.24 | -2.98 |
| 91.250 ML | -19.41 | -5.30 | -19.32 | -4.68 | -19.72 | -4.76 |
| 81.250 ML | -24.35 | -6.837 | -24.25 | -6.12 | -24.79 | -6.23 |
| 71.250 ML | -28.88 | -8.021 | -28.76 | -7.26 | -29.42 | -7.41 |
| 61.250 ML | -33.0 | -8.941 | -32.85 | -8.206 | -33.58 | -8.37 |
| 51.250 ML | -36.74 | -9.681 | -36.58 | -8.94 | -37.35 | -9.15 |
| 41.250 ML | -40.19 | -10.24 | -40.06 | -9.83 | -40.80 | -10.01 |
| 31.250 ML | -43.41 | -10.17 | -43.34 | -9.97 | -44.0 | -10.15 |
| 21.250 ML | -46.96 | -10.70 | -46.96 | -10.33 | -47.51 | -10.72 |
| 14.350 ML | -49.97 | -13.79 | -49.90 | -11.89 | -50.45 | -12.71 |
| 10.550 ML | -52.20 | -13.60 | -52.15 | -11.71 | -52.56 | -12.89 |
| 7.825 ML | -57.21 | -9.047 | -54.05 | -10.03 | -54.45 | -10.72 |
| 6.500 ML | -82.388 | -4.30 | -55.53 | -7.31 | -55.92 | -6.11 |

FX = MERIDIONAL FORCES IN SHELL ELEMENTS IN tonns/metre
FY = TANGENTIAL FORCES IN SHELL ELEMENTS IN tonns/metre.

## TABLE - 2

**COMPARISION OF RESULTS FOR WIND LOAD**

| | RESULTS OF QUAD-8 ELEMENTS | | RESULTS OF QUAD-4 ELEMENTS | | SAP-IV RESULTS | |
|---|---|---|---|---|---|---|
| ELEVATION | FX | FY | FX | FY | FX | FY |
| 124.500 ML | .34 | -49.14 | 0.023 | -61.65 | 0.03 | -14.37 |
| 123.000 ML | 2.664 | -18.00 | 2.01 | -13.95 | 0.29 | -10.93 |
| 119.125 ML | 8.73 | -6.05 | 5.7 | -0.985 | 1.58 | -9.40 |
| 111.250 ML | 14.76 | -6.07 | 10.74 | -7.83 | 6.29 | -8.74 |
| 101.250 ML | 20.12 | -3.778 | 17.19 | -6.15 | 15.17 | -6.54 |
| 91.250 ML | 25.67 | -2.36 | 25.47 | -4.48 | 25.60 | -4.83 |
| 81.250 ML | 31.589 | -2.137 | 34.0 | -3.93 | 35.35 | -3.97 |
| 71.250 ML | 37.05 | -2.90 | 41.3 | -4.1 | 43.24 | -4.04 |
| 61.250 ML | 41.65 | -4.25 | 47.0 | -5.0 | 49.01 | -4.77 |
| 51.250 ML | 45.54 | -5.73 | 51.3 | -6.05 | 53.06 | -5.77 |
| 41.250 ML | 49.165 | -6.93 | 54.7 | -6.76 | 55.96 | -6.55 |
| 31.250 ML | 53.0 | -7.824 | 57.85 | -8.13 | 58.19 | -7.44 |
| 21.250 ML | 56.60 | -8.70 | 60.76 | -7.57 | 60.22 | -10.00 |
| 14.350 ML | 58.45 | -8.72 | 62.19 | -6.08 | 62.39 | -11.19 |
| 10.550 ML | 58.91 | -11.97 | 62.22 | -10.00 | 63.27 | -12.08 |
| 7.825 ML | 63.51 | -25.56 | 62.21 | -25.817 | 63.84 | -22.50 |
| 6.500 ML | 81.62 | -53.35 | 62.1 | -51.6 | 63.98 | -37.08 |

## TABLE-3

**COMPARISION RESULTS OF QUAD8 ELEMENTS FOR DIFFERENT MESH SIZES**
**DEAD LOAD CASE**

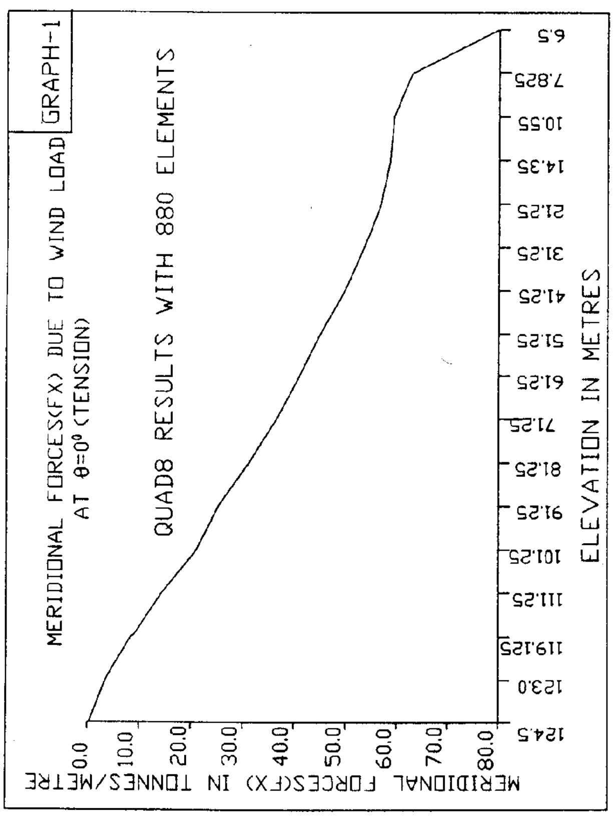
| | RESULTS OF 880 ELEMENTS | | RESULTS OF 1760 ELEMENTS | | RESULTS OF 440 ELEMENTS | |
|---|---|---|---|---|---|---|
| ELEVATION | FX | FY | FX | FY | FX | FY |
| 124.500 ML | -0.41 | 2.442 | -0.41 | 2.34 | -.41 | 2.574 |
| 123.000 ML | -1.485 | 1.743 | -1.5 | 1.7 | -1.49 | 1.687 |
| 119.125 ML | -3.827 | -1.943 | -3.825 | .2 | -3.778 | -.26 |
| 111.250 ML | -8.4 | -1.22 | -8.4 | -1.208 | -8.28 | -1.2 |
| 101.250 ML | -14.06 | -3.39 | -14.1 | -3.38 | -14.011 | -3.39 |
| 91.250 ML | -19.41 | -5.30 | -19.5 | -5.29 | -19.56 | -5.33 |
| 81.250 ML | -24.35 | -6.837 | -24.4 | -6.82 | -24.65 | -6.93 |
| 71.250 ML | -28.88 | -8.021 | -28.87 | -8.0 | -29.06 | -8.12 |
| 61.250 ML | -33.0 | -8.941 | -32.95 | -8.89 | -33.016 | -8.73 |
| 51.250 ML | -36.74 | -9.681 | -36.7 | -9.62 | -36.97 | -9.51 |
| 41.250 ML | -40.19 | -10.24 | -40.14 | -10.18 | -40.87 | -10.65 |
| 31.250 ML | -43.41 | -10.17 | -43.4 | -10.12 | -44.24 | -10.63 |
| 21.250 ML | -46.96 | -10.70 | -46.9 | -10.82 | -47.56 | -10.89 |
| 14.350 ML | -49.97 | -13.79 | -49.82 | -13.36 | -50.22 | -14.65 |
| 10.550 ML | -52.20 | -13.60 | -52.03 | -13.52 | -52.64 | -12.56 |
| 7.825 ML | -57.21 | -9.047 | -53.65 | -8.33 | -56.61 | -8.28 |
| 6.500 ML | -82.388 | -4.30 | -70.71 | -2.16 | -62.67 | -2.53 |

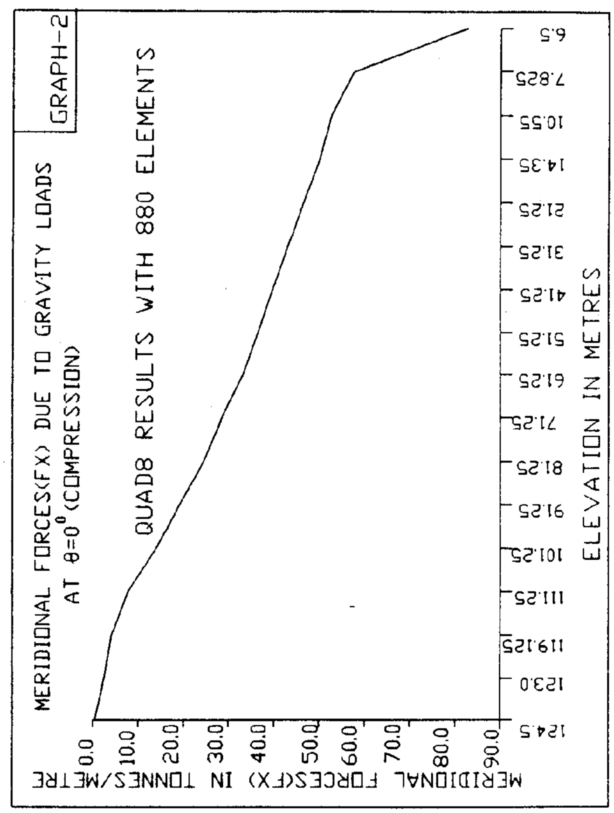
FX = MERIDIONAL FORCES IN SHELL ELEMENTS IN tonns/metre.
FY = TANGENTIAL FORCES IN SHELL ELEMENTS IN tonns/metre.

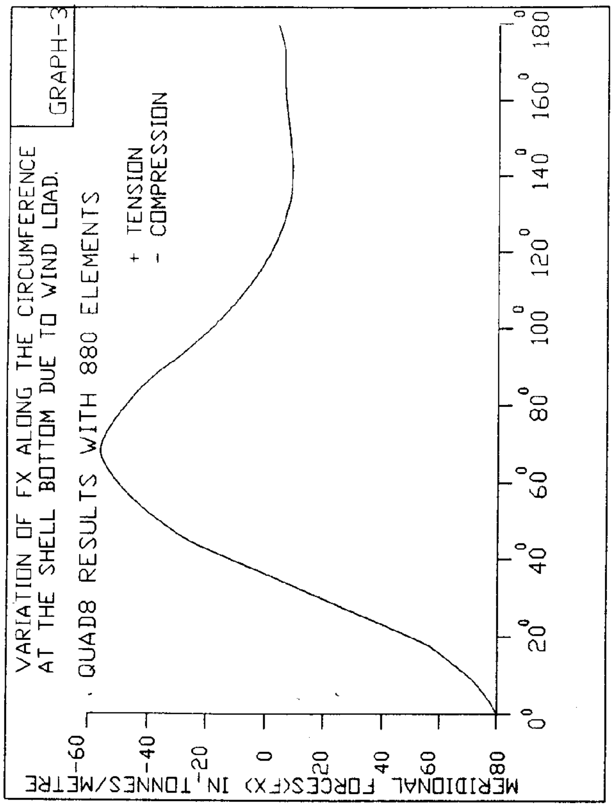
## TABLE-4

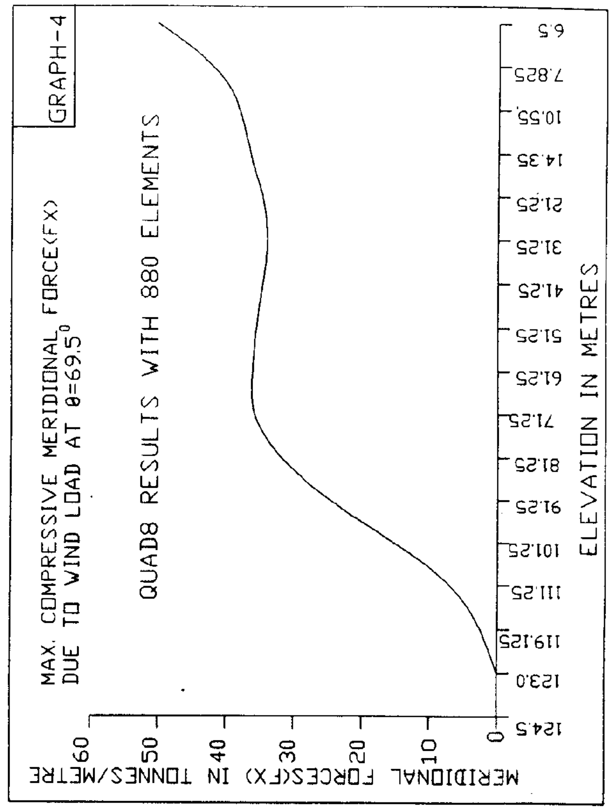
**COMPARISION OF RESULTS OF QUAD4 ELEMENTS FOR DIFFERENT MESH SIZES**
**DEAD LOAD CASE**

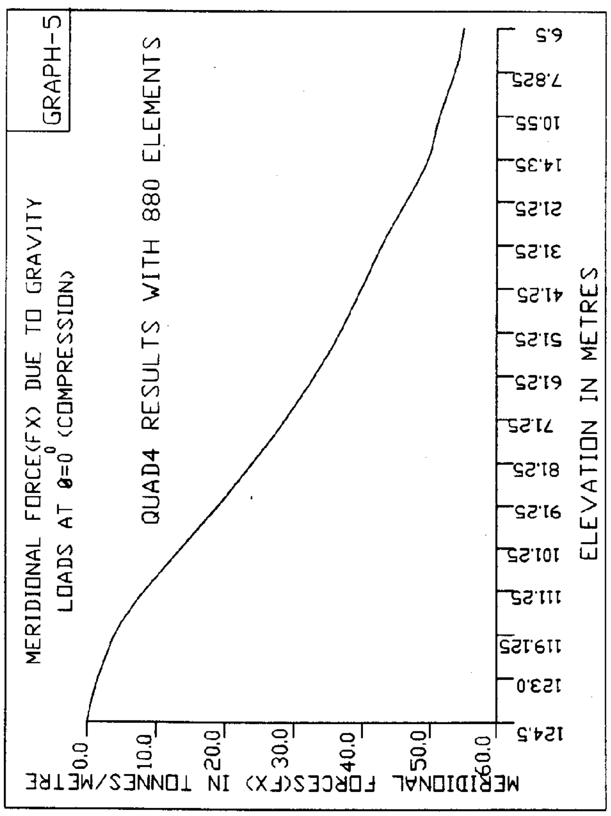
| | RESULTS OF 880 ELEMENTS | | RESULTS OF 1760 ELEMENTS | | RESULTS OF 3520 ELEMENTS | |
|---|---|---|---|---|---|---|
| ELEVATION | FX | FY | FX | FY | FX | FY |
| 124.500 ML | -0.41 | 2.54 | -.41 | 2.56 | -.41 | 2.46 |
| 123.000 ML | -1.494 | 1.763 | -1.494 | 1.764 | -1.494 | 1.71 |
| 119.125 ML | -3.82 | 0.76 | -3.82 | .76 | -3.82 | .43 |
| 111.250 ML | -8.33 | -0.89 | -8.328 | -.894 | -8.35 | -.94 |
| 101.250 ML | -13.96 | -2.95 | -13.95 | -2.952 | -13.98 | -2.9 |
| 91.250 ML | -19.32 | -4.68 | -19.3 | -4.68 | -19.315 | -4.64 |
| 81.250 ML | -24.25 | -6.12 | -24.29 | -6.125 | -24.26 | -6.08 |
| 71.250 ML | -28.76 | -7.26 | -28.79 | -7.27 | -28.77 | -7.24 |
| 61.250 ML | -32.85 | -8.206 | - 32.88 | -8.218 | -32.87 | -8.18 |
| 51.250 ML | -36.58 | -8.94 | -36.661 | -8.949 | -36.61 | -8.98 |
| 41.250 ML | -40.06 | -9.83 | -40.05 | -9.88 | -40.065 | -9.75 |
| 31.250 ML | -43.34 | -9.97 | -43.28 | -9.91 | -43.3 | -9.87 |
| 21.250 ML | -46.96 | -10.33 | -46.86 | -10.42 | -46.87 | -10.00 |
| 14.350 ML | -49.90 | -11.89 | -49.90 | -11.77 | -49.93 | -15.8 |
| 10.550 ML | -52.15 | -11.71 | -52.17 | -11.3 | -52.23 | -10.5 |
| 7.825 ML | -54.05 | -10.03 | -53.85 | -10.73 | -55.525 | -10.783 |
| 6.500 ML | -55.53 | -7.31 | -55.0 | -11.42 | -55.96 | -12.26 |

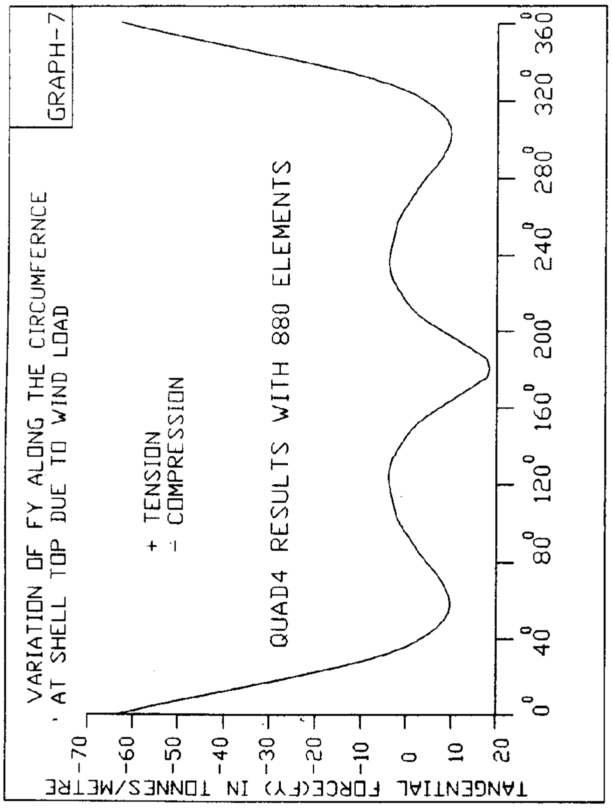

GRAPH-1
MERIDIONAL FORCE(FX) DUE TO WIND LOAD
AT θ=0° (TENSION)
QUAD8 RESULTS WITH 880 ELEMENTS
MERIDIONAL FORCES(FX) IN TONNES/METRE
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
ELEVATION IN METRES
124.5
123.0
119.125
111.25
101.25
91.25
81.25
71.25
61.25
51.25
41.25
31.25
21.25
14.35
10.55
7.825
6.5

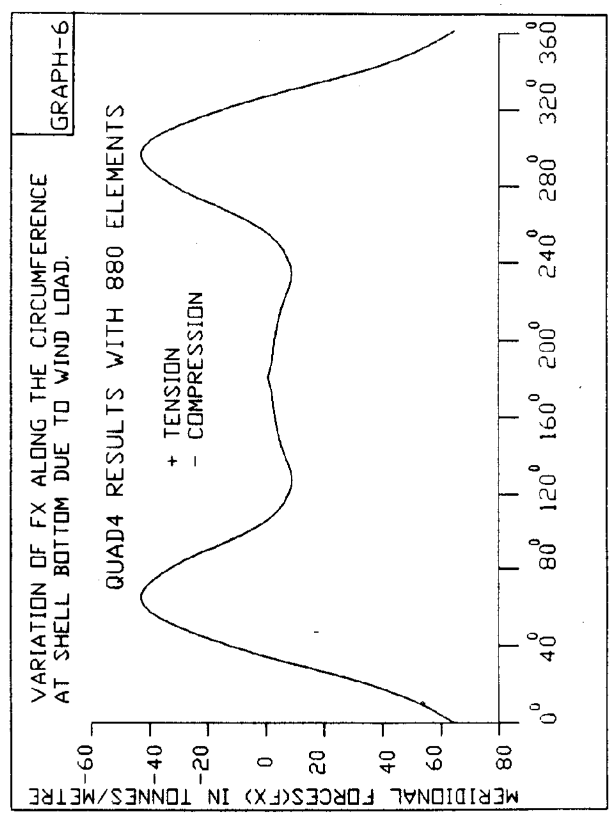

GRAPH-2
MERIDIONAL FORCES(FX) DUE TO GRAVITY LOADS
AT θ=0° (COMPRESSION)
QUAD8 RESULTS WITH 880 ELEMENTS
MERIDIONAL FORCES(FX) IN TONNES/METRE
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
ELEVATION IN METRES
124.5
123.0
119.125
111.25
101.25
91.25
81.25
71.25
61.25
51.25
41.25
31.25
21.25
14.35
10.55
7.825
6.5

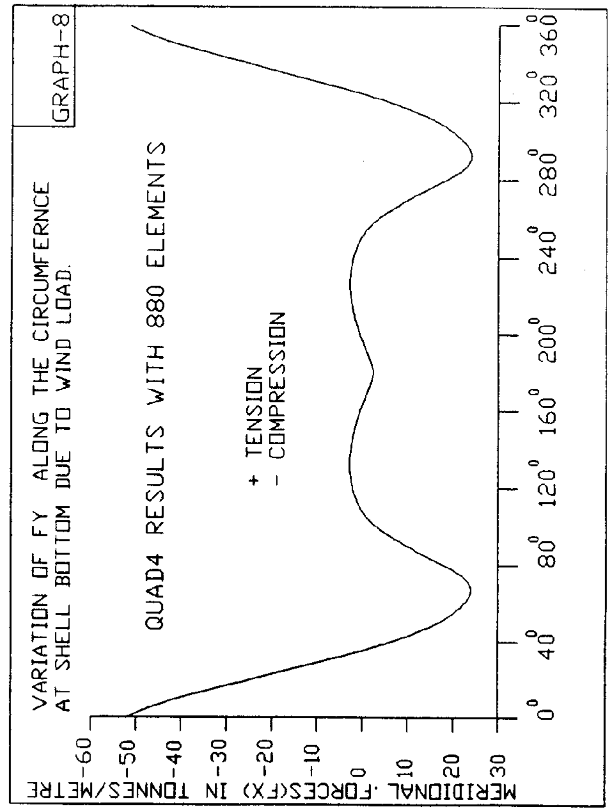

GRAPH-3
VARIATION OF FX ALONG THE CIRCUMFERENCE
AT THE SHELL BOTTOM DUE TO WIND LOAD.
QUAD8 RESULTS WITH 880 ELEMENTS
+ TENSION
- COMPRESSION
MERIDIONAL FORCES(FX) IN TONNES/METRE
-60
-40
-20
0
20
40
60
80
0°
20°
40°
60°
80°
100°
120°
140°
160°
180°

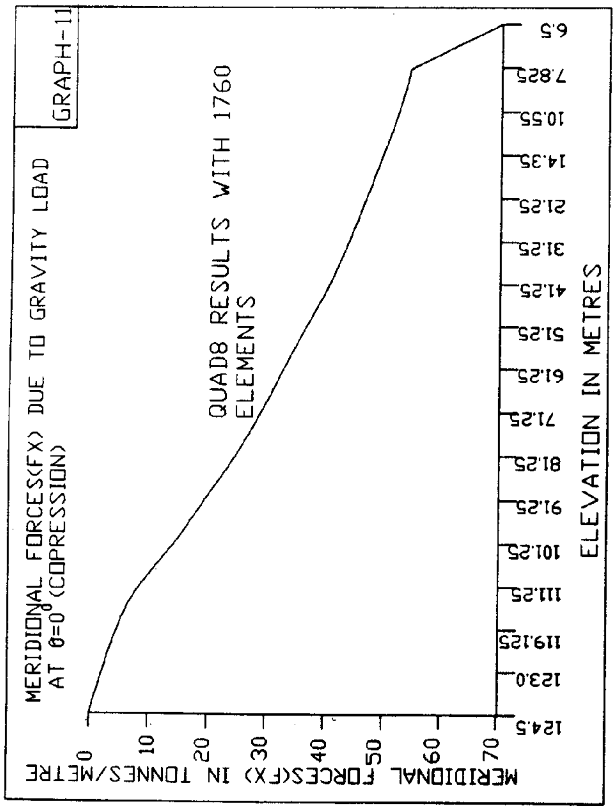

GRAPH-4
MAX. COMPRESSIVE MERIDIONAL FORCE(FX)
DUE TO WIND LOAD AT θ=69.5°
QUAD8 RESULTS WITH 880 ELEMENTS
MERIDIONAL FORCES(FX) IN TONNES/METRE
60
50
40
30
20
10
0
ELEVATION IN METRES
124.5
123.0
119.125
111.25
101.25
91.25
81.25
71.25
61.25
51.25
41.25
31.25
21.25
14.35
10.55
7.825
6.5

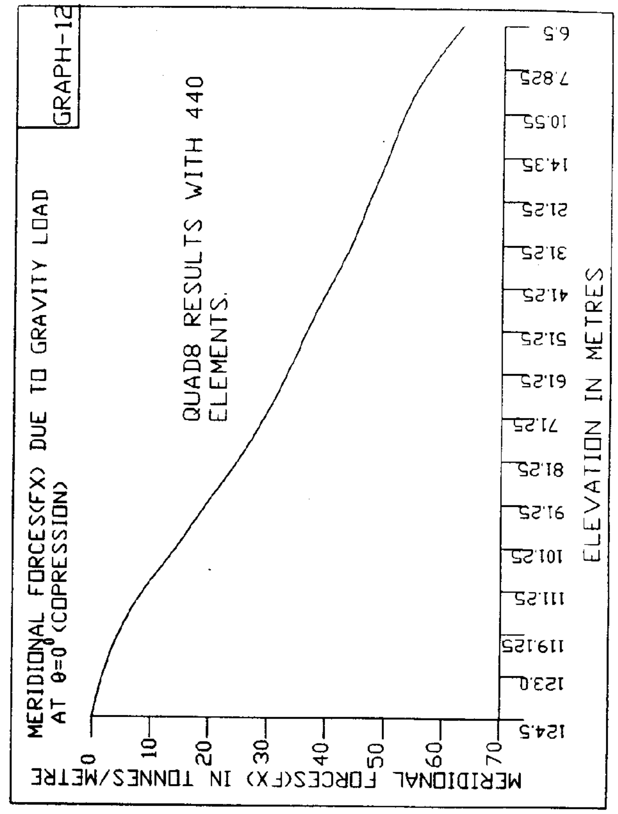

GRAPH-5
MERIDIONAL FORCE(FX) DUE TO GRAVITY
LOADS AT Ø=0° (COMPRESSION)
QUAD4 RESULTS WITH 880 ELEMENTS
MERIDIONAL FORCES(FX) IN TONNES/METRE
ELEVATION IN METRES
0.0
10.0
20.0
30.0
40.0
50.0
60.0
124.5
123.0
119.125
111.25
101.25
91.25
81.25
71.25
61.25
51.25
41.25
31.25
21.25
14.35
10.55
7.825
6.5

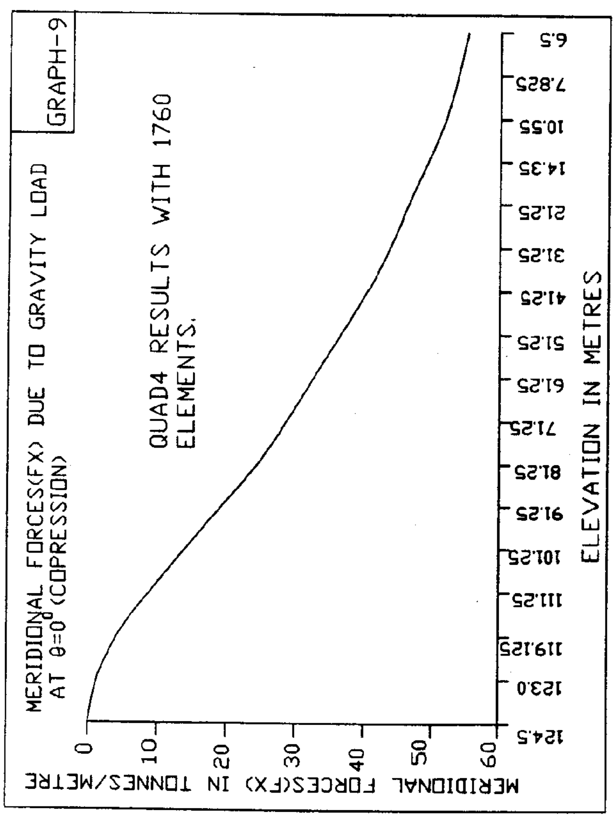

GRAPH-7
VARIATION OF FY ALONG THE CIRCUMFERNCE
AT SHELL TOP DUE TO WIND LOAD
+ TENSION
- COMPRESSION
QUAD4 RESULTS WITH 880 ELEMENTS
TANGENTIAL FORCE(FY) IN TONNES/METRE
-70
-60
-50
-40
-30
-20
-10
0
10
20
0°
40°
80°
120°
160°
200°
240°
280°
320°
360°

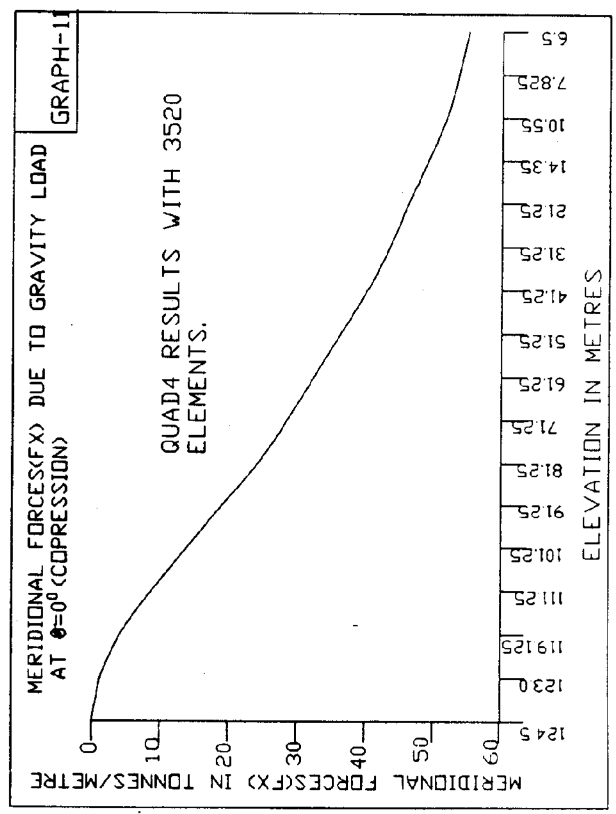

GRAPH-6
VARIATION OF FX ALONG THE CIRCUMFERENCE
AT SHELL BOTTOM DUE TO WIND LOAD.
QUAD4 RESULTS WITH 880 ELEMENTS
+ TENSION
- COMPRESSION
MERIDIONAL FORCES(FX) IN TONNES/METRE
-60
-40
-20
0
20
40
60
80
0°
40°
80°
120°
160°
200°
240°
280°
320°
360°


GRAPH-8
VARIATION OF FY ALONG THE CIRCUMFERNCE
AT SHELL BOTTOM DUE TO WIND LOAD.
+ TENSION
- COMPRESSION
QUAD4 RESULTS WITH 880 ELEMENTS
MERIDIONAL FORCES(FX) IN TONNES/METRE
-60
-50
-40
-30
-20
-10
0
10
20
30
0°
40°
80°
120°
160°
200°
240°
280°
320°
360°


GRAPH-11
MERIDIONAL FORCES(FX) DUE TO GRAVITY LOAD
AT θ=0° (COPRESSION)
QUAD8 RESULTS WITH 1760
ELEMENTS
MERIDIONAL FORCES(FX) IN TONNES/METRE
0 10 20 30 40 50 60 70
ELEVATION IN METRES
124.5 123.0 119.125 111.25 101.25 91.25 81.25 71.25 61.25 51.25 41.25 31.25 21.25 14.35 10.55 7.825 6.5


GRAPH-12
MERIDIONAL FORCES(FX) DUE TO GRAVITY LOAD
AT θ=0° (COPRESSION)
QUAD8 RESULTS WITH 440
ELEMENTS.
MERIDIONAL FORCES(FX) IN TONNES/METRE
0 10 20 30 40 50 60 70
ELEVATION IN METRES
124.5 123.0 119.125 111.25 101.25 91.25 81.25 71.25 61.25 51.25 41.25 31.25 21.25 14.35 10.55 7.825 6.5


GRAPH-9
MERIDIONAL FORCES(FX) DUE TO GRAVITY LOAD
AT θ=0° (COPRESSION)
QUAD4 RESULTS WITH 1760
ELEMENTS.
MERIDIONAL FORCES(FX) IN TONNES/METRE
0 10 20 30 40 50 60
ELEVATION IN METRES
124.5 123.0 119.125 111.25 101.25 91.25 81.25 71.25 61.25 51.25 41.25 31.25 21.25 14.35 10.55 7.825 6.5


GRAPH-1
MERIDIONAL FORCES(FX) DUE TO GRAVITY LOAD
AT θ=0° (COPRESSION)
QUAD4 RESULTS WITH 3520
ELEMENTS.
MERIDIONAL FORCES(FX) IN TONNES/METRE
0 10 20 30 40 50 60
ELEVATION IN METRES
124.5 123.0 119.125 111.25 101.25 91.25 81.25 71.25 61.25 51.25 41.25 31.25 21.25 14.35 10.55 7.825 6.5

## CONCLUSIONS

The analysis of a cooling tower is a challenging job for a structural engineer. It requires great care in view of its large size and shape. Very few agencies are competent to analyse and design these cooling towers. MSC/NASTRAN can conveniently be used for the analysis of cooling towers,because it accounts for the curvature of the surface by using Quad8 elements. This is not true for SAP IV where only plane surfaces are considered. The results of the MSC/NASTRAN with Quad8 elements are quite reliable for cooling towers as compared to other packages (SAP IV etc.) particularly at the base of tower where raker columns are joining, as the Quad8 elements give the forces at the four corners and at the C.G. of the element. It covers the possible stress concentration at the base of the towers.

Not much variation in the results has been found for different mesh sizes of Quad8/Quad4 elements from top to bottom of the tower except at thee base. At the base of the tower the results of Quad8 elements are varying for different mesh sizes due to stress concentration effects at the junction of racker column & shell. It is desirable to use more number of Quads8 elements for bottom ring portion to get more reliable results.

Another advantage of MSC/NASTRAN compared to other packages for analysis of cooling towers comes from its preprocessor MSC/XL. Modelling and meshing of cooling tower can be done quickly by using MSC/XL. The complete analysis of cooling tower could be done within one day by using MSC/NASTRAN with its preprocessor MSC/XL, whereas other packages without a preprocessor require a lot of data entry to tackle a problem of this magnitude.

## ACKNOWLEDGMENTS

The author would like to thank the ANDHRA PRADESH STATE ELECTRICITY BOARD for its kind permission and encouragement to submit this paper.

## REFERENCES


1) MSC/NASTRAN User's Manual,Version 67. The MacNeal-Schwendler Corporation,Los Angles,CA.

2) G.S.Ramaswamy "Design and construction of concrete shell roof structures" CBS Publishers and distributors,New Delhi,India.

3) IS 875 (part3)-1983, "Indian standard code of practice for design loads for Buildings and structures-part3, wind loads",Bureau of Indian standards,New Delhi,India.

4) IS 11504-1985,"Criteria for structural design of RCC Natural Draught cooling towers", Bureau of Indian standards,New Delhi,India.

5) Raghavan,N. "Recent developments in structural design aspects of Natural Draught cooling towers" National seminar on cooling towers Jan 1820,1990,New Delhi,India.

6) SAPIV Manual "A structural analysis programme for static and dynamic response of linear systems", K.J.BATHE,E.L.WILSON & F.E.PETERSON.

7) Report on "Analysis and design calculations for cooling towers of Rayalaseema Thermal Power Project".