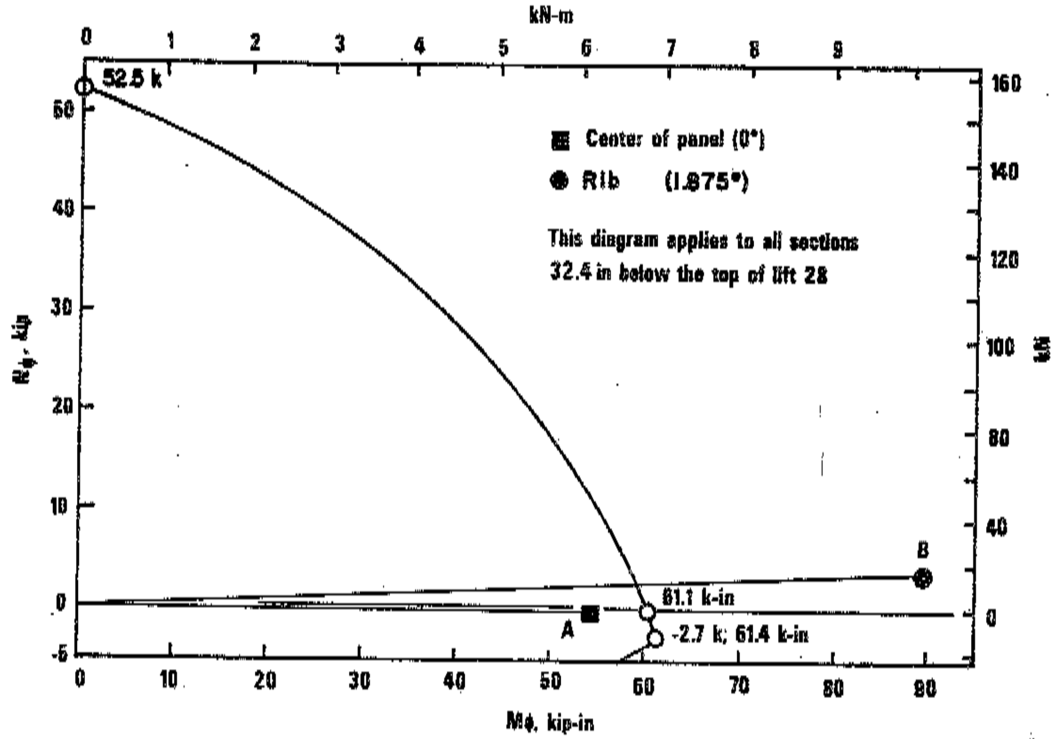

Figure 7.5 Combined Effect of Axial Force and Bending Moment at Locations A and B

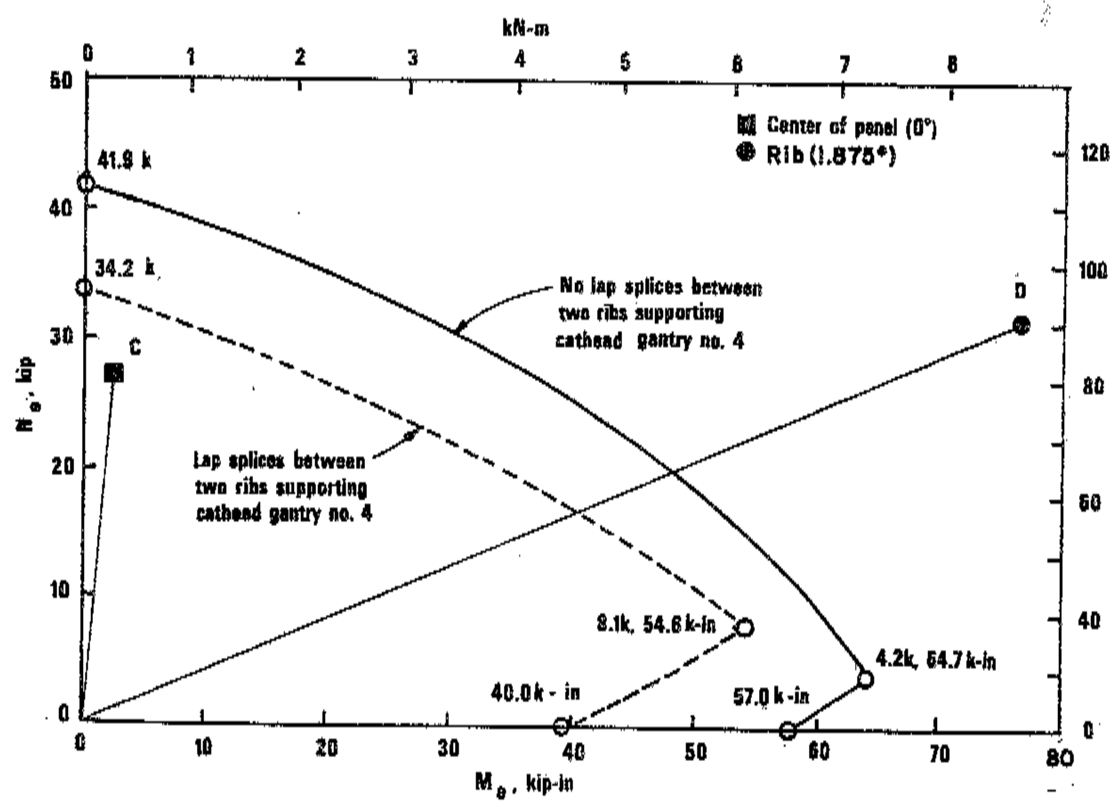

Figure 7.6 Combined Effect of Axial Force and Bending Moment at Locations C and D

APPENDIX A

Patent of Wall Construction System

Appendix A

Patent of Wall Construction System

United States Patent [19]
Scheller

[11] **4,040,774**
[45] **Aug. 9, 1977**

[54] **APPARATUS FOR CONSTRUCTING CONCRETE WALLS**

[75] Inventor: **Herman Scheller**, Eaton, Colo.

[73] Assignee: **Research-Cottrel, Inc.**, Bound Brook, N.J.

[21] Appl. No.: **681,723**

[22] Filed: **Apr. 29, 1976**

[51] **Int. Cl.**[2] **E04G 11/04; E04G 11/28**
[52] **U.S. Cl.** **425/65**; 249/20; 254/139
[58] **Field of Search** 425/63-65; 249/20-22; 264/33-34; 254/139, 142

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Primary Examiner—Francis S. Husar
Assistant Examiner—John McQuade
Attorney, Agent, or Firm—Harold L. Stowell

[57] **ABSTRACT**

In an apparatus for constructing high-rising, poured concrete walls, pairs of spaced-apart, upright supports are preliminarily mounted on a foundation and then detachably attached to both sides of at least a partially hardened level of concrete wall and at intervals along the length of the wall for repeated, upward, step-wise use as the wall is being formed; a plurality of carriages are mounted on adjacent supports along both sides of the wall for continuous upward movement as the wall is being cast, and adjustable concrete shaping assemblies are mounted on the carriages. Each assembly opposing a similar assembly to define a continuous mold into which new concrete is poured on top of previously poured concrete to form the wall.

3 Claims, 10 Drawing Figures

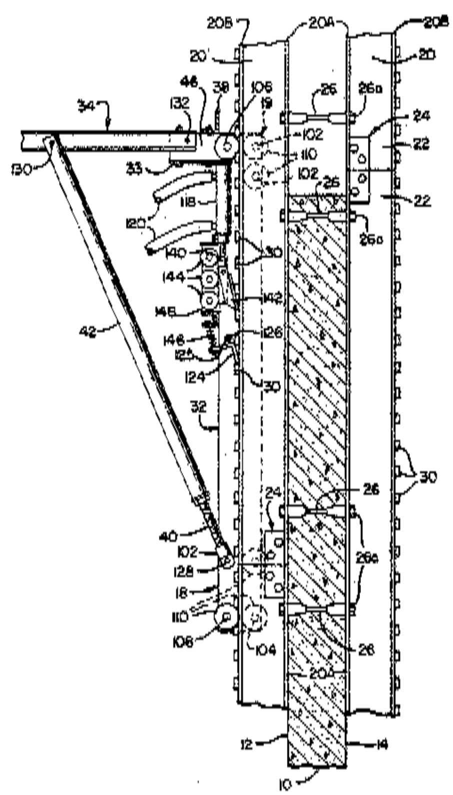


FIG. 1.

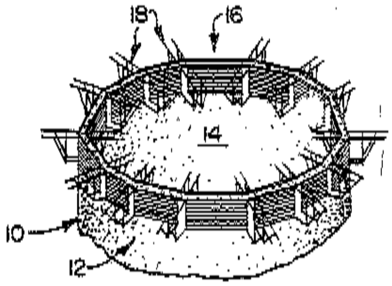

18
16
14
10
12

FIG. 2.

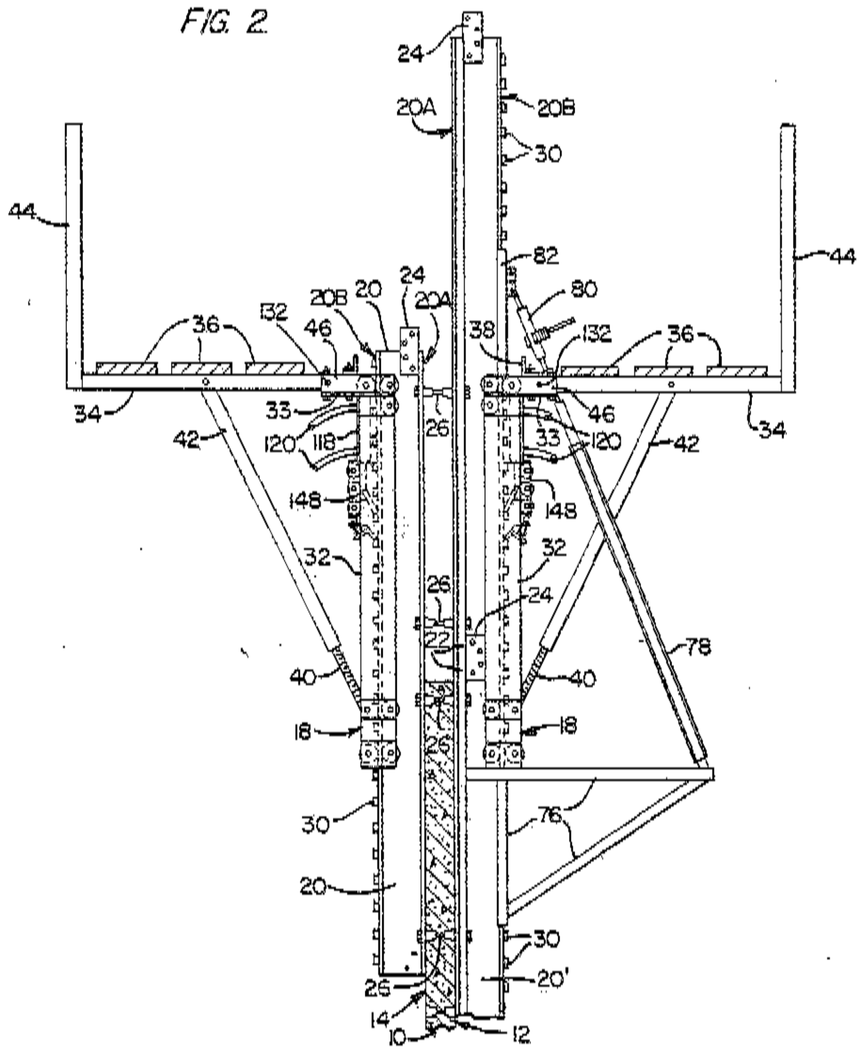

24
20A
20B
30
44
82
80
44
24
20B
20
20A
36
132
46
38
132
36
34
33
26
46
34
42
120
118
33
120
42
148
148
32
32
26
24
22
78
40
40
18
18
26
30
76
20
30
26
20'
14
10
12

FIG. 3.

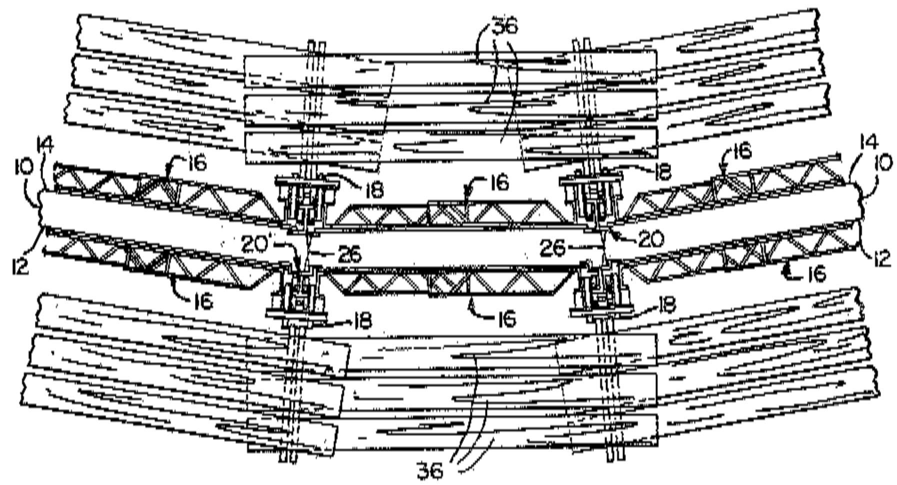
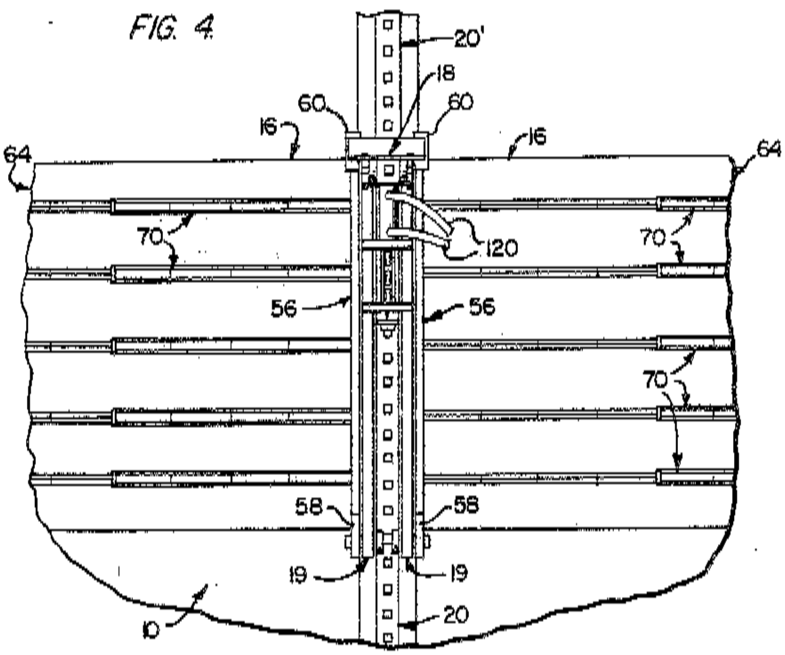

36
14
10
16
18
16
18
14
10
16
20'
26
26
20
12
12
16
16
18
16
18
36

FIG. 4.


20'
18
60
60
16
16
64
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70
70
120
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56
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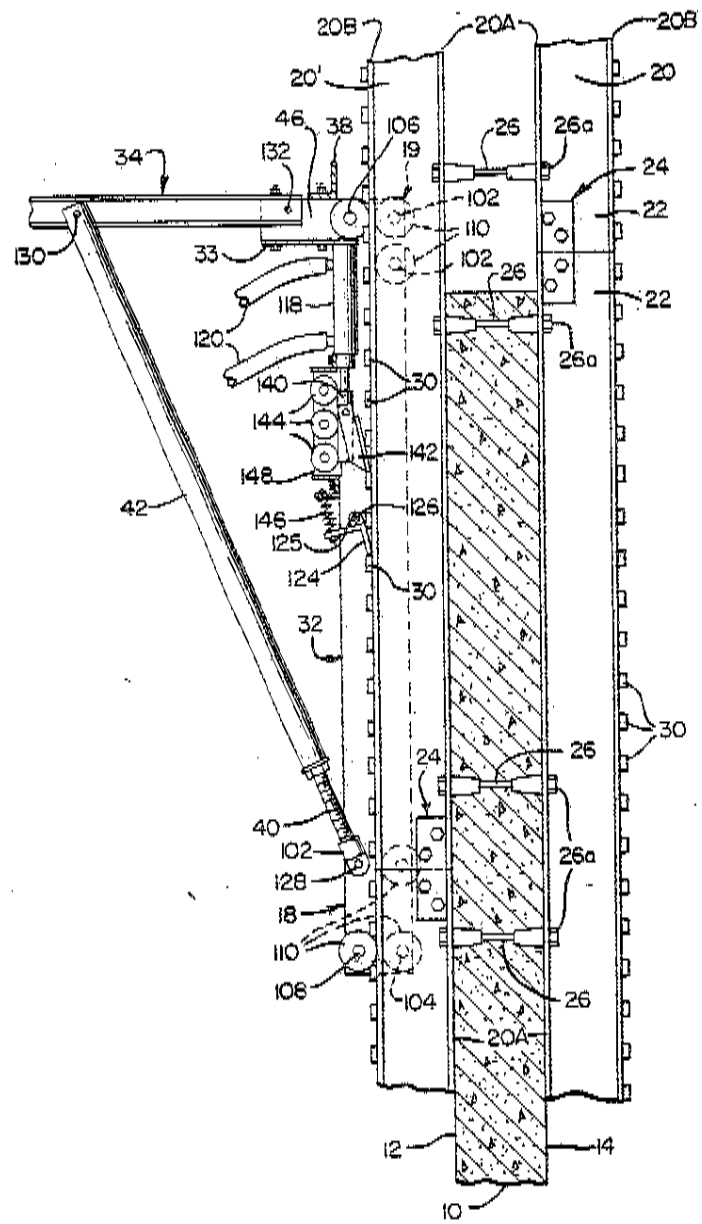
FIG. 5.


20B
20A
20B
20'
20
46
38
106
19
26
26a
24
34
132
102
22
110
130
33
102
26
22
118
120
26a
140
30
144
142
148
42
146
126
125
124
30
32
30
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24
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26a
102
128
18
110
108
104
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20A
12
14
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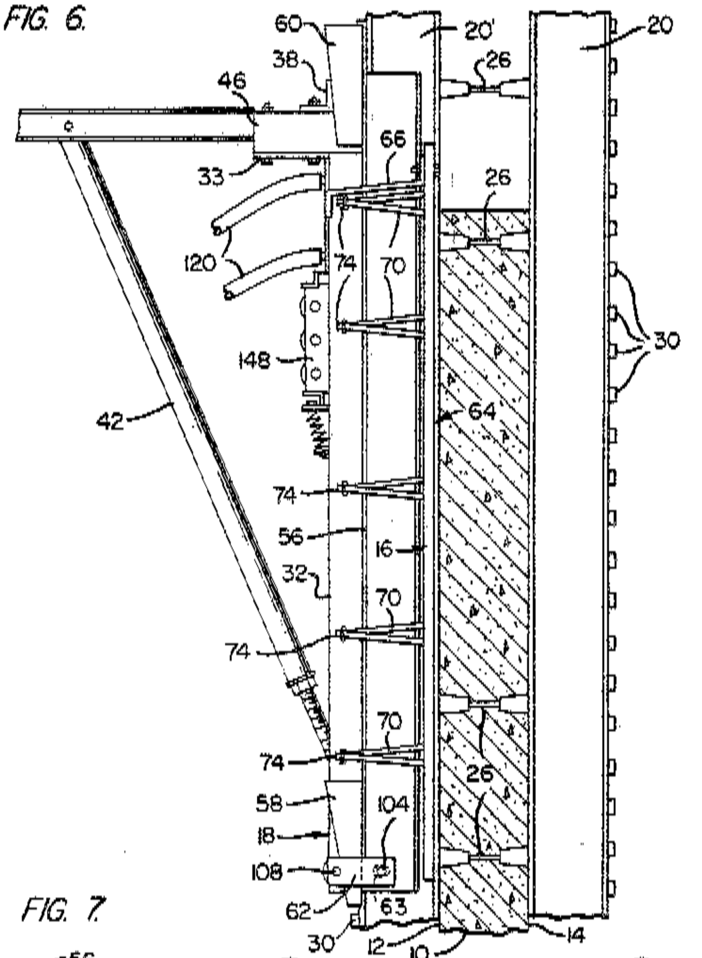
FIG. 6.


60
38
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120
148
42
20'
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66
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74
70
30
64
74
56
16
32
70
74
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18
108
104
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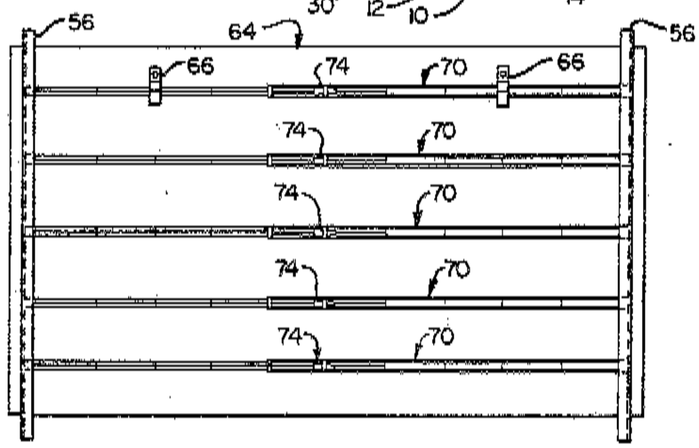
62
63
30
12
10
14

FIG. 7.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70

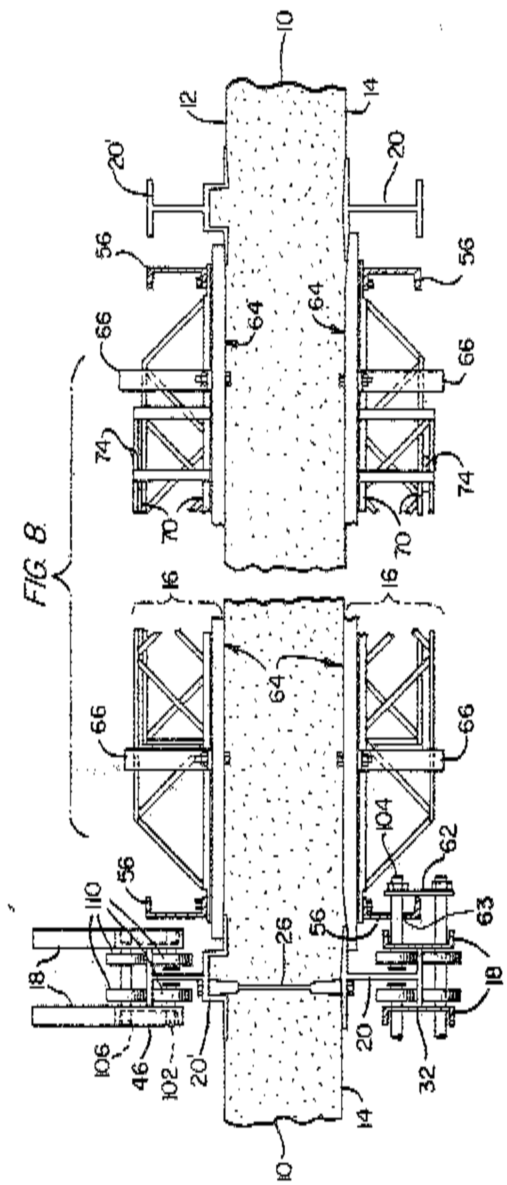
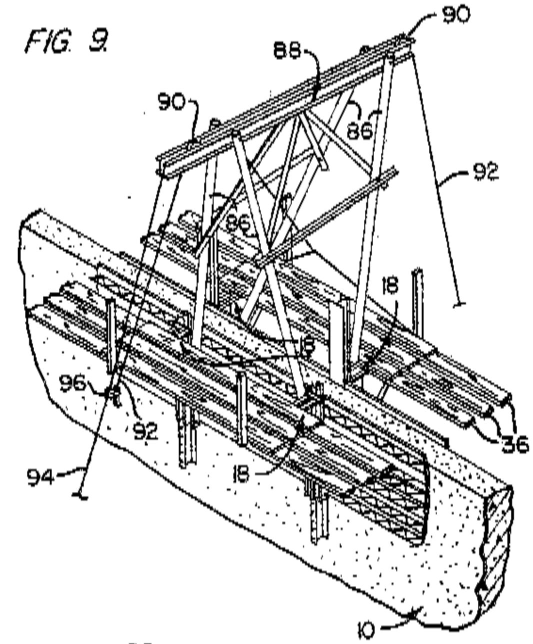


FIG 8

FIG. 9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88
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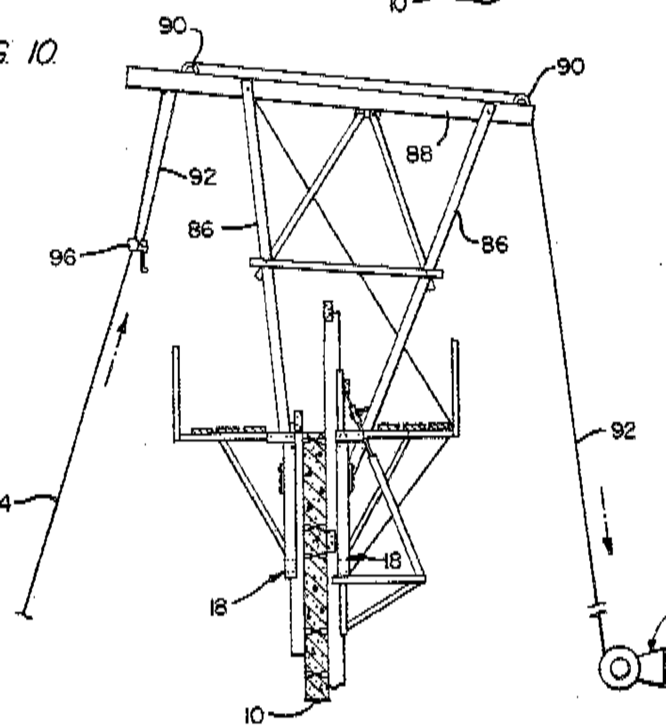
FIG. 10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94
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18
93
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1

APPARATUS FOR CONSTRUCTING CONCRETE WALLS

CROSS-REFERENCE TO RELATED SUBJECT MATTER

Related subject matter is disclosed and claimed in my U.S. Pat. No. 3,779,678 granted Dec. 18, 1973.

BACKGROUND OF THE INVENTION

Modern concrete wall casting techniques frequently utilize pairs of spaced-apart, shaping forms held in position by various types of movable supports. the concrete being poured between te forms and on top of the section of wall poured earlier and partially set. After the last poured concrete has at least partially set, the forms are removed and relocated above the former position and then the procedure is repeated until the wall is completed.

SUMMARY OF THE INVENTION

This invention provides a new and improved apparatus for efficient casting of shaped concrete walls and, in the exemplary embodiment, includes a plurality of pairs of spaced-apart, upright supports extending from the foundation initially and then attached to opposing sides of the wall being formed along the entire length of the wall, sections of each support being detachable at the bottom of the support and from the wall at intervals and re-attached at the upper end of the support to form a continuously advancing support as the wall is formed.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective, stylized view of the base portion of a cooling tower veil being formed by the casting apparatus of this invention;

FIG. 2 is a vertical section of the apparatus showing the preferred form of supports and carriage;

FIG. 3 is a top view of the apparatus shown in FIG. 2;

FIG. 4 is an enlarged, fragmentary side elevation of a form or shaping assembly;

FIG. 5 is an enlarged, vertical section showing the carriage elevating and retaining mechanism;

FIG. 6 is an enlarged, vertical section showing the intermediate form in relation to the carriage;

FIG. 7 is a rear elevation of the sheet portion of the form assembly;

FIG. 8 is a fragmentary horizontal sectional view of the form assembly and related apparatus;

FIG. 9 is a perspective view of the hoisting apparatus; and

FIG. 10 is a side elevation of the hoisting apparatus.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The preferred embodiment of the apparatus is set forth herein, for illustrative purposes, in connection with the construction of a concrete veil or outside wall of a nature draft cooling tower, which frequently rises 450 feet above the ground and has a diameter of 350 feet at ground level. In such construction, the round concrete wall decreases in diameter as it rises until narrow section or throat is reached, and then increases in diameter toward the top to form the hyperbolic shape. As illustrated in FIG. 1, the tower veil or wall 10 has an outer surface 12 and an inner surface 14, and a series of carriages 18 located entirely around the top of the wall.

2

During the initial construction of a cooling tower and after the ground foundation has been laid, pairs of opposed, spaced-apart, generally vertical supports or H-beams, designated 20 for the inside 14 and 20' for the outside 12, are anchored on the foundation. Each support 20 and 20', not shown in FIG. 1 burt located at each carriage 18, is 20–30 feet long and is composed of several sections 22 of extruded aluminum, generally H-shaped beams, jointed at their ends by bolted plates 24 as shown in FIGS. 2 and 5. The beams of each pair are separeated from each other by a distance while will generally be the thickness of the wall 10 being formed, which at the base of a tower is about 30 inches. The beams are spaced apart, as desired, as best shown in FIG. 5, by a plurality of horizontal spacers or internally threaded inserts 26 attached to the beam flanges 20A by bolts 26a before concrete is poured between the beams. Each pair of beams are separated by about 10 feet from similar pairs around the wall so that the beams are located at spaced intervals completely along both the inner and outer wall surfaces 12, 14. As the concrete is poured between the beams and the wall increases in height, a lower section of each beam is detached from the side of the wall 10 by removing bolts 26a from the spacers 26, leaving the spacers in the wall. Then the section is attached to the top of the same beam. As the concrete cures, the lower sections of each support held tightly against the wall surfaces easily support the carriages 18 and other structures mounted on them. The beam sections 22 may be lifted into new position by a simple block and tackle or other lifting means mounted on the carriages 18. The beams 20–20' are also provided with spaced apart lugs 30 (FIG. 2) permanently affixed to the outer flange 20B of each beam for a purpose later described.

A plurality of carriages 18, shown in FIGS. 1, 2, 3, 4, 5 and 6, are separately mounted for vertical movement on beams 20–20' and adjacent carriages support there between concrete form assemblies 16 which shape the surfaces of the wall being formed. Additionally, as shown on FIG. 2, the carriages provide a working platform for men and equipment which extends entirely around the wall being formed.

Each carriage 18, reference being made to FIGS. 2, 4, 5 and 6, includes a pair of similar frames 19 composed of several common structural beams welded and bolted together to form a strong, unitary structure. In detail and as shown in FIG. 2, each frame includes a vertical channel 32, which is welded to a horizontal tubing 46, which in turn is bolted with bolt 132, to channel 34, which is welded to channel 44. Two adjacent frames 19, one being constructed opposite hand, are jointed together to form each carriage 18 mounted on a beam 20 by bolted connector plates 33 (FIG. 5), angle 38, roller frame 148, and machine bolts 108, 126, 128, 130 and 132, which also serve as axles to other components. A pipe 42 and a thread rod assembly 40 are bolted between adjacent frames 19, and serve as an adjustable support to channel 34. Wheels 110 are attached to channel 32 and tube 46 of each frame by axles 102, 104, 106 and 108, and ride against opposing sides of the two outer flanges 20B of the beam holding the carriage against the beam.

A hydraulic jack 118 (FIG. 5) is attached to plate 33 and roller frame 148 in each carriage by bolts and mounts and exerts upward thrust against the carriage when hydraulic pressure is supplied through flexible hose 120. A reciprocating bar 140 is attached to the ram of the hydraulic jack 118, which in turn has a pivoted pawl 142 which is spring loaded (spring not shown) to insure positive engagement between pawl 142 and lug 30 on beam 20-20'.

Further, wheels 144 are mounted on roller frame 148 which extends between adjacent beams 32, and are in rolling contact with reciprocating bar 140 to resist lateral forces on bar 140 and prevent disengagement between pawl 142 and lugs 30. In addition, a follower pawl 124 welded to a short pipe 125, which in turn is mounted for rotation on a shaft 126 extending between beams 32, engages lugs 30 and is held in engagement by spring 146.

Normally, the carriages progress in an upward direction by extension of pawl 142 until tooth 124 engages a higher lug, 30 followed by withdrawal of pawl 142 for relocation against a higher lug 30, and repeating. However, if necessary, a carriage can be lowered by extending hydraulic jack 118 so that the load carried by follower pawl 124 is now transferred to extendable pawl 142 and engaged cleat 30. When the load is thus transferred, pawl 124 can be pivoted so that by slowly retracting the jack will allow the carriage to settle and follower pawl 124 to engage in the next lower cleat 30.

A working scaffold is formed by planks 36 resting on beams 34 of adjacent carriages and an outer rail 44 between which ropes or planks may be placed.

Concrete shaping form assemblies 16, generally shown in FIGS. 4, 6 and 7 span the distance between adjacent carriages 18 on both sides of the wall being formed and form and sides of the mold into which fresh concrete is poured. Each form assembly 16 includes a forming sheet 64, two end stiffback channels 56, to which lateral, telescoping steel trusses 70 are bolted, with incorporated wedges 74, that strengthen the trusses 70 when in the proper position. Forming sheet 64 may be 3/4" plywood for example, or any ridgid material that can be easily cut, or added to, to provide a smooth casting surface, telescoping trusses 70 provide lateral support for sheet 64, throughout their effective length, once the incorporated wedges 74 are wedged firmly.

The stiffback channels 56 are structural channels that are vertically supported at the bottom by axle 104 which extend beyond beam 32, thru slotted holes 63 (FIGS. 6 and 8) to a retainer plate 62. Further, axle 108 also extends beyond beam 32 to the retainer plate 62. The form panel 64 is held firmly against the extruded flange 20A of beams 20—20'. This is accomplished by wedging the opposite side of the stiffback channel 56 (FIG. 6) with a steel wedge 58 against the extended axle 108.

Similarly the top of channel 56 forces form panel 64 tightly against the extruded flange 20A of beams 20-20', with a hardwood wedge 60, driven between its opposing side and angle 38. With reference the FIGS. 6 and 7, the forming sheet 64 is held vertically by a bracket 66 which merely serves to keep the sheet 64 from falling out when the entire form assembly is unwedged as required while "jacking".

As in the case of cooling tower construction, as the tower moves upward in height the diameter decreases to the throat or neck of the tower, requiring the carriages 18 to become closer together. With reference made to FIG. 8 it can be seen that as the carriages 18 move upward and wedges 74 of the steel trusses 70 being loosened, they are forced together, or can open freely as required. FIG. 8 also illustrates that while the form assembly 16 has its wedges loosened, the form panel 64 is only supported from falling by bracket 66 and can easily be pulled out be sliding it upward from between the support beams 20-20' and the steel trusses 70 for cutting.

The nature of the extruded aluminum beams 22 that make up the support beams 20-20' permits that they can be repeatedly bent or flexed approximately 3 inches over each length without permanent damage.

Using this characteristic, (FIG. 2) a frame 76, comprising two opposite hand weldments are attached to either half 19 of the carriage 18 on one side of the wall 10. The frame 76 encases the outer flange 20B of a portion of beams 20-20' which is adjacent to firm concrete. Similarly a frame 82 is mounted on the top of either half 19 of the carriage 18 which encases the outer flange 20B of beams 20-20' above the form enclosure. An arm 78 is bolted to the lower frame 76, and in turn a stream-bolt ratchet 80 connects to the top frame 82. By extending or contracting the steam-bolt ratchet 80, lateral pressure is applied sufficient to bend the support beam 20 and properly align the wall 10 being cast.

The vertical strength afforded by such a forming system is also used to best advantage by eliminating excessively high mobile cranes or tower cranes required in high rise construction, as used in previous forming systems. Gantries are erected at selected points around the top of the tower as illustrated in FIGS. 9 and 10. Each gantry is comprised of a beam 88, which is bolted to four pipe legs 86, which in turn are attached to four separate carriages 18. On the upper side of beam 88, two sheaves 90 are attached. A commercial hoisting engine 93 on the ground is used with these gantries so that the load line 92, originating from the hoisting engine on one side of wall 10, is supported over the wall on sheaves 90 so that materials can be hoisted on the opposite side of wall 10 as the arrows indicated in FIG. 10. Also, a stationary static line 94, which extends from beam 88 to a strategic point or concrete hopper on the ground, is used as a guide for the load line 92, which is attached to a small block 96 so that its sheave wheel rolls on static line 94. The static line 94 serves to make the ground loading point (not shown) central, which expedites concrete handling from a concrete truck or hopper, as well as keeping the workmen from working beneath the scaffolding along the perimeter of the tower.

The two variations in the form surface, or flanges 20A of jack beams 20 and 20', are shown as in cooling tower construction, the outer wall surface 12 is generally ridged and the inner wall surface 14 is generally smooth. The plurality of vertical ribs thus formed on the outside surface 12 of the completed tower serve to induce air turbulance, thus enhancing heat transfer.

In casting the initial courses of the wall, an ordinary general crane is used to raise the plastic concrete from the ground to the working scaffold where it is distributed by wheeled carts to the forms around the periphery of the structure. It will be appreciated that several cranes may be used simultaneously so that such a large structure can be cast at a reasonable rate. When the structure height exceeds reach of the cranes, a number of gantries are attached to selected carriages spaced around the wall. These gantries now provide the means to transport plastic concrete and other materials to the work area. The concrete is raised in buckets (approximately ½ cu. yd. capacity) by cables running over the gantries and returning to hoisting engines on the ground. Thus, the necessity for using a large tower crane is avoided and the work can progress much more quickly and safely than with such a crane.

I claim:

1. Apparatus for forming a concrete wall comprising

a. a plurality of generally vertical supports spaced apart along both sides of the wall being formed, each support being located opposite to another support on the other side of the wall and detachably connected to said opposing support by a plurality of spacers some of which are contained in the wall previously formed, each support consisting of separate segments detachably joined together at their ends, and the lower portion of each support being held contiguous the surface of the wall previously formed by said spacers while the upper portion extends above the portion of the wall previously formed.

b. a carriage mounted on each support with means for advancing the carriage upwardly along the supports as the wall is formed,

c. a plurality of concrete casting assemblies located along and on both sides of the wall being formed adjacent its top, each assembly supported at its ends by two carriages on adjacent supports and each assembly having a generally vertical casting surface extending between the adjacent supports so that the assemblies and the supports together define a continuous mold extending on top of the wall into which concrete is poured, whereby as the concrete hardens the carriages and assemblies are moved upwardly on the supports to form a new level of wall and, at intervals, support segments are detached from the bottom of each support and attached to the top to provide a continuous track for the carriages,

d. each casting surface comprises the inner surfaces of generally horizontal, plywood sheets which combine to form a continuous casting surface,

e. each casting assembly comprising a plurality of generally horizontal braces positioned contiguous the outer surface of the plywood sheets to support the sheets while the concrete is setting against the inner surface of said sheets, and

f. each casting assembly comprising at least a pair of slotted beams movably carried by adjacent carriages, said plurality of horizontal braces mounted between said slotted beams which are adapted to be wedged against said adjacent carriages, so that by wedging the slotted beams against the carriages the inner surface of the sheets are drawn into contact against the adjacent supports thereby providing said continuous mold.

2. The apparatus defined in claim 1 further including hoisting means attached to said carriages, a ground supported hoisting engine, and a hoisting cable connecting said hoisting engine and said hoisting means.

3. The apparatus defined in claim 2 further including a stationary cable connecting the hoisting means to a central loading point below on which the hoisting cable is guided.

* * * * *

APPENDIX B

Computer Programs for Shell Analysis

Appendix B

Computer Programs for Shell Analysis

B.1 Introduction

Failure of the cooling tower shell under the imposed construction loads at the location of cathead gantry no. 4 was believed to be a plausible cause for the initiation of the total collapse of lift 28. Thus, an analysis of the shell structure as it existed at the time of the collapse was made using the construction loads. The complexity of the loading conditions as well as the variation in shell thickness and material properties required that the finite element method be employed as the means of analysis. A survey of finite element programs available for the analysis of this type of shell structure with the constraints mentioned previously indicated that SHORE-III[6.2] satisfied these requirements and has been used previously [B.1, B.2] to analyze this type of structure.

As a means of verifying the results obtained in the SHORE-III analysis, a second finite element program, SAP IV [6.3], was selected. SAP IV is a general finite element program which provides an alternate method for load input and an alternate shell model from those used in the SHORE-III analysis.

This appendix will present a discussion of the pertinent features of the two finite element programs used in the analysis of the shell and a comparison of the results obtained from each analysis, for selected loading conditions.

B.2 Discussion of SHORE-III and SAP IV

SHORE-III (SHORE) is a finite element program for the linear elastic static and dynamic analysis of arbitrarily loaded axisymmetric plates and shells. SAP IV (SAP) on the other hand is a general finite element structural analysis program for the linear elastic analysis of three dimensional structural systems. Although both programs are capable of performing either a static or dynamic analysis, this discussion will be limited to the static analysis since all construction loads used in the analysis were treated as being static. Furthermore, since SAP has a rather large element library (truss, beam, plane stress or strain, three-dimensional solid, pipe, etc.) only the plate/shell element which was used in the SAP analysis will be discussed.

The capacity of SAP is primarily dependent upon the total number of nodal points needed to model the shell while SHORE is restricted to a model comprised of no more than fifty (50) elements. This element restriction for SHORE is not serious for this analysis since the stress distributions at the lower elevations of the shell do not have a significant effect on the results obtained for lift 28. Thus, the number of elements used to model the lower portion of the shell can be reduced.

The shell model is developed for SHORE by discretizing the meridian curve of the shell with a series of curved rotational ring elements. SAP requires a discretization along the meridian and around the circumference of the shell in order to develop its model. Thus, the SHORE model is composed of a series of continuous ring elements along the meridian of the shell while the SAP model is a three-dimensional assemblage of flat plates.

Only a brief description of the elements used in the SHORE and SAP analysis will be presented. References which present the details on the formulation of the individual elements are given in the description. The curved rotational ring element [B.3] used in SHORE has an element stiffness matrix which is derived from displacement fields that may vary from linear to sixth order and includes the exact geometry of the shell as well as the effect of transverse shear deformation. The extra coefficients in the higher order displacement fields are eliminated by kinematic condensation at the element level. Sixth order displacement fields were used throughout in this analysis. The element used in the SAP analysis is a quadrilateral of arbitrary geometry formed from four compatible triangles. A constant strain triangle [B.4] and a linear curvature compatible triangle with nine (9) degrees of freedom [B.5] are used to represent the membrane and bending behavior, respectively, of the SAP element. A central node is located at the average of the coordinates of the four corner nodes and has six degrees of freedom which are also eliminated by condensation at the element level.

Each element in both SHORE and SAP have constant material properties (moduli of elasticity) although the properties may vary as required from element to element in the respective models. The thickness of a particular element in SAP must be constant, but may change as required throughout the SAP shell model. The thickness of the SHORE element can vary linearly along the meridian as dictated by the shell geometry.

Various loads including thermal effects may be used as input for both the SHORE and SAP analysis with distributed loads (gravity, pressure, etc.) and thermal loads being treated as consistent equivalent nodal loads in both analyses. However, a major difference exists in the manner in which other loads are input for analysis. SAP requires that all external loads including moments applied to the shell structure be input as concentrated loads at nodal points while for the SHORE analysis all loads are expanded in Fourier harmonics with respect to an element nodal point and the final result is obtained by superimposing the results of each harmonic.

Finally, both finite element programs solve the resulting set of linear simultaneous equations for the structural model by a modification of the Gaussian elimination scheme which takes advantage of the symmetric narrow banded nature of the global matrices used.

B.3 Comparison of Results

Several of the most significant differences between the two finite element models are considered and comparisons of results are made. The differences include the effect of element discretization, boundary conditions, the method of applying the loads, the precision of calculations and the type of elements used.

One of the biggest differences between the two analyses lies in the initial scheme for discretizing the shell. While SHORE uses continuous ring elements as shown in figure B.1, SAP requires that the rings be broken into numerous elements. The radial grid adopted is shown in figure B.2. The changes in radial increment were chosen to reduce the number of nodes required for the model in hopes of making the program manageable on the computer while preserving resolution at cathead gantry no. 4 and providing loading points at the other catheads. As it was, the SAP analysis required more than eight hours of computer time. The effect of having varying radial increments was to introduce some variations in the solution which could be attributed directly to the variations in the size of the elements. This can be best illustrated by considering the gravity loads which should be identical at any angle. Figures B.3 and B.4 illustrate the radial variation of hoop stress, N_θ, and the meridional stress, N_ϕ, respectively, 1.5 ft (.457 m) below the top of lift 28. The radial variations in the stresses as predicted by SAP are due to the changes in size of adjacent elements and to the poor aspect ratio of the larger elements. The smallest elements at cathead no. 4 (elements 126 and 127) are 2.18 ft (0.66 m) long by approximately 0.6 ft (0.18 m) high for an aspect ratio of 3.63 while the largest elements near the top (elements 112 and 120) have an aspect ratio of approximately 58. As can be seen in figure B.3 and B.4 element size change has more of an effect on N_ϕ (fig. B.3) than the aspect ratio, while the aspect ratio has more of an influence on N_θ (fig. B.4). However, figure B.3 and B.4 do illustrate that the stress distribution becomes more uniform near cathead no. 4 where the mesh is finer and the aspect ratio of the elements is more favorable to obtaining a good solution. In the SHORE analysis, the radial stress distribution is dependent only upon the equations used to develop the ring elements. The SHORE and SAP analyses for the gravity load showed good agreement between N_ϕ and N_θ along the meridian at cathead no. 4. The largest difference was less than 5 percent.

Different boundary conditions are used in the two models. The SHORE model uses an open type element developed specifically to represent the columns at the base of the shell. The effect on the model is to smear the stiffness of the columns into a ring. In the SAP model the shell at the top of the ring beam tying the columns together was fixed by prescribing zero displacements. This was done to reduce the number of nodes in the SAP model. Consequently, the stress distributions within the bottom ring of the shell are quite different for the two models. However, in element 17 of the SHORE model (see fig. B.1) and the corresponding elements in the SAP model, the stress distributions are similar. The same results are presented in reference B.1 where the effect of different boundary conditions on a hyperboloidal shell were studied. Consequently, the effects of the boundary conditions at the base seem to be far enough away from the area of interest, the top two lifts, so that none of the differences in results are due to the differences between boundary conditions used in the two models.

The method of applying the loads seems to have a great impact upon the results. SHORE requires that the loads be applied as line loads acting over some finite length. The length is chosen to allow a reasonably rapid convergence of the fourier series used to generate the load. SAP requires that the loads be point loads applied at nodes. For this problem where the loads are essentially applied to the shell by bolts, the point load approach is more realistic. The effect of using the distributed line loads is to cause the stress distribution to be more uniform near the point of application and the maximum stress predicted should be lower than the real stress experienced by the shell.

The loading function used in the SHORE analysis is developed by first distributing the concentrated loads about the centerline of the jumpform beam. The loads are distributed over 0.358 degrees (10 in or 254 mm at lift 28) for the scaffold loads (load cases 2 and 3) and 0.859 degrees (24 in or 610 mm at lift 28) for the cathead gantry and hoist loads (load cases 4 and 5). The 10 in (254 mm) distribution width is the surface contact length between the shell and jumpform beam. This distributed load is then expanded in a Fourier Series which applies the load at the required points around the circumference of the tower for that particular construction load. The larger distribution angle used in load cases 4 and 5 was chosen because it reduces the number of Fourier series harmonics required to adequately define the loads. Ideally, a 0.358 degree distribution angle should have been used for all cases. However, when the distribution angle was reduced from 0.859 to 0.358 degrees, the number of harmonics required to produce a load function with an acceptable shape increased from 56 to 150 and computer time and costs almost tripled. A sample analysis was conducted using both the 0.358 and 0.859 degree distribution angles and the maximum stresses differed by only a few percent. The stress distributions were also essentially the same. Consequently, it would appear that the compromise between distribution angle and computer analysis time is justified. Figure B.5 illustrates this distributed line loading for the normal, meridion and tangential forces F_x, F_y, and F_z, respectively and for the meridion moment M_y, applied to the shell by the jumpform beams. The bold vectors represent the points loads used in the SAP analysis.

The development of a convergent Fourier series with only a few harmonics was found to be a difficult task for load cases 4 and 5 which are applied only at cathead 4. This is because as the number of application points decreases (two points or ribs for cases 4 and 5), the number of harmonics required for a convergent series increases rapidly. In addition, the required computer time to analyze a load case using SHORE is related to the number of harmonics. An investigation of the stress distributions that occurred around the circumference of the shell in load case 4 where the six cathead gantry loads are applied, for both the SHORE and SAP analysis, indicated that the internal shell forces decayed rapidly to a small value at approximately 20° from the cathead as shown in figures B.6 and B.7. Thus, it was concluded that since the catheads are 60° apart, the loads applied at a cathead have little influence on the internal forces at the catheads on either side. Consequently, in order to reduce the number of harmonics necessary to obtain convergence, the loads for load cases 4 and 5 were applied, in the SHORE analysis, at all six cathead locations instead of just at cathead no. 4. Figure B.8 illustrates the loading function for a normal force applied to the shell by the jumpform beams at a cathead. This load would then be repeated at all six cathead locations in load case 4 to produce a symmetric loading condition.

The loading functions were developed for each construction load (cases 2 through 5) and a separate analysis was made for each case, including the gravity load which was internally generated by both programs. Since both SHORE and SAP are linear elastic finite element programs, the principle of superposition applies and the results for each load case may be combined algebraically to find the resultant stresses for any combination of the construction loads.

Comparison between values of membrane stress, N_θ , and bending moment, M_θ , obtained for solutions to load case 4 using SHORE and SAP are illustrated in figures B.6 and B.7. The comparisons are illustrated for selected elevations in lift 28 and are typical of results from other load cases. It is interesting to note that although the loads are distributed over an arc length in the SHORE analysis, the stress magnitudes predicted compare well with those obtained using SAP. However, because loads are applied at points in the SAP analysis, the stresses would be expected to be larger than those obtained using the SHORE analysis. Several features of the SAP model and solution process may contribute to the apparent inconsistency. A major feature is that SAP calculates stresses at the center of the element which essentially represent the average stress in the whole element. Since even the smallest elements are over two feet wide and the stress distribution is sharp the peak stress may be missed by a significant amount. A second feature involves the precision of the calculations. SHORE carries out all calculations in double precision on a 32-bit word machine while the version of SAP used carries out single precision calculations on a 36-bit word machine. Consequently, roundoff errors may have occurred in the SAP solution process, especially since there were over 6400 equations to be solved and the band width of the stiffness matrix was 612. Another reason the SAP program calculates smaller stresses may be the poor aspect ratio of the elements and the relative size of adjacent elements. Finally, there are differences in the types of elements used in the two models. SAP uses a plate/shell element which provides only for membrane stresses and bending moments. SHORE on the other hand uses a shell element which accounts for transverse shear and thus provides for a better estimate of bending moments since the elements are relatively thick (0.667

ft, 0.2 m) in lift 28. This appears to be corroborated by the fact that the comparison between membrane stresses in figure B.6 is better than the comparison between bending moments in figure B.7.

B.4 Conclusion

Despite the differences in the values of the stresses there are several encouraging points which arise from the comparison of the two solutions. Both models gave stress distributions of similar shape for corresponding stress components. Also, the fact that such different models could lead to the prediction of stresses and moments for which the peak values agreed within a few percent for membrane stresses is encouraging, especially since insufficient time was available to refine the SAP model. Consequently, the SAP model is considered to be a first cut at verification of the SHORE results, while the SHORE program is designed specifically for the solution of problems involving shells of revolution.

Based primarily on the difference between the SHORE closed ring element, which included transverse shear deformation, and the SAP plate/shell approximation which does not, it is believed that the stress resultant and moments obtained in the SHORE analysis are a better approximation of the stress levels experienced by the shell in lift 28 for the specified construction loads. The actual stress levels may be higher since the distributed loads used by SHORE to represent the loads applied to the shell at the jumpform beam bolts tend to smear the loads over a larger surface area of the shell than actually occurs and the shell model is not sufficiently able to model the stress distributions that occur at the bolt locations.

Both the SAP and SHORE models give stress distribution that agree reasonably well for the type of loads applied in each analysis. Thus, the areas of high stresses in lift 28 could be predicted from the results of either model.

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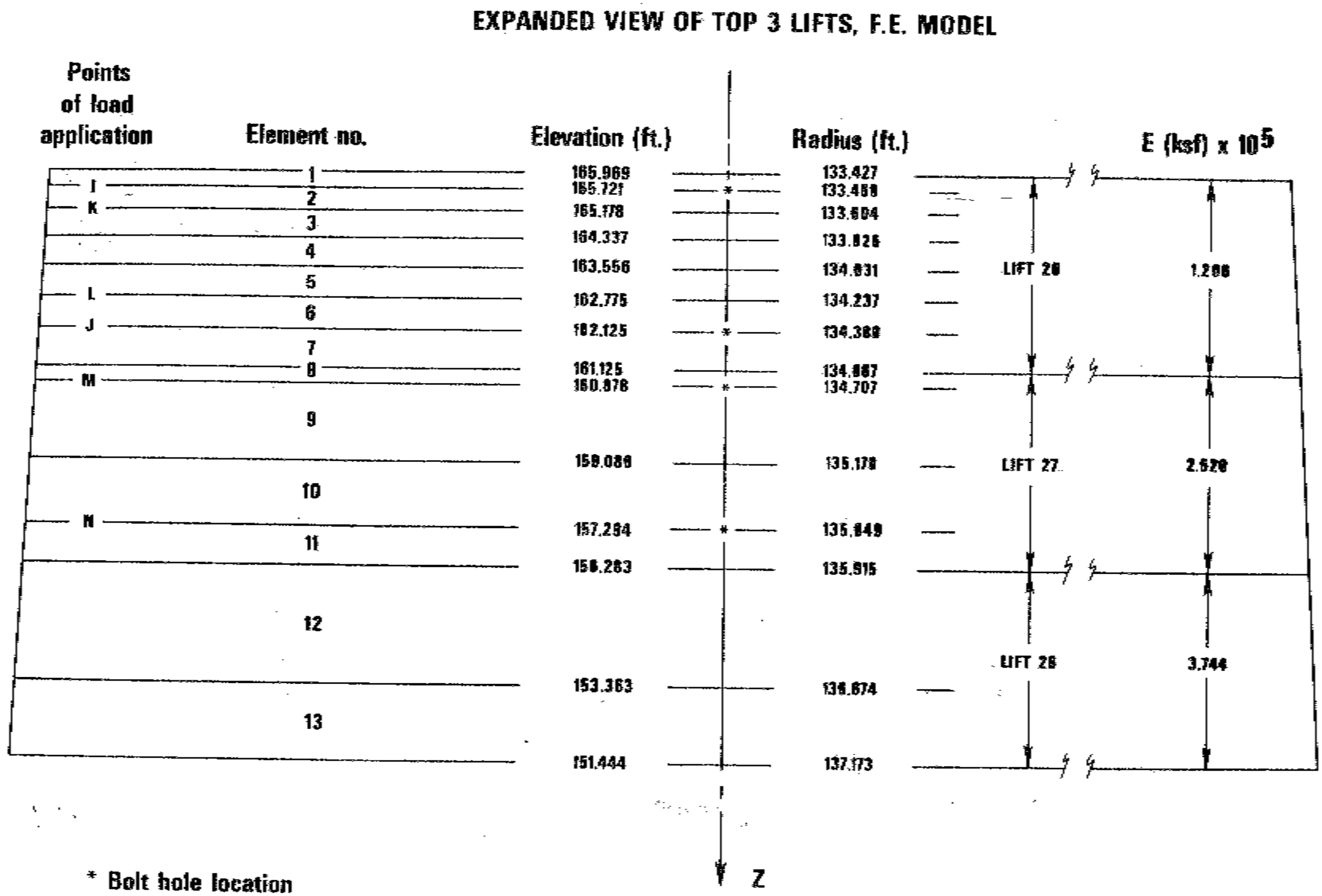

Figure B.1 SHORE-III Finite Element Model for Lifts 26,27 and 28

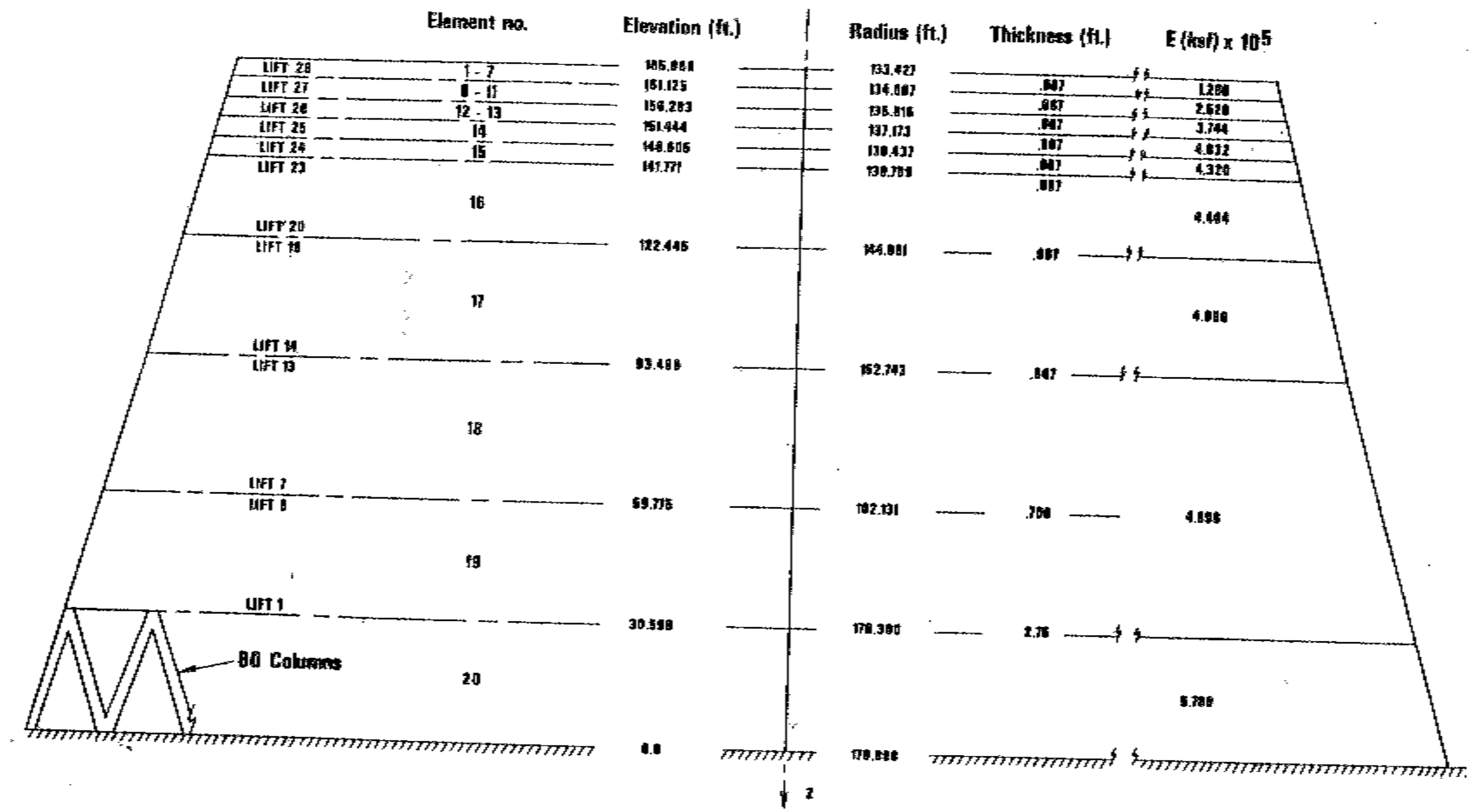

Figure B.1 SHORE III Finite Element Model for Tower Unit No. 2

NODE	THICKNESS (ft)	LIFT NO.	ELEVATION (ft)	RADIUS (ft)	E (Ksf) x 10^5	POINT OF LOAD APPLICATION
1			165.810	133.468		1
	.667	28			1.296	
52			165.277	133.604		K
	.667	28			1.296	
103			164.660	133.762		
	.667	28			1.296	
154			164.042	133.921		
	.667	28			1.296	
205			163.424	134.079		
	.667	28			1.296	
256			162.807	134.237		L
	.667	28			1.296	
307			162.177	134.398		J
	.667	27			2.520	
358			160.966	134.707		N
	.667	27			2.520	
409			159.756	135.020		
	.667	27			2.520	
460			158.546	135.332		
	.667	27			2.520	
511			157.335	135.644		H
	.667	27			2.520	
562			156.125	135.957		
	.667	26			3.744	
613			153.765	136.565		
	.667	26			3.744	
664			151.444	137.173		
	.667	25			4.032	
715			146.605	138.437		
	.667	24			4.320	
766			141.771	139.709		
	.667	23 22			4.392	
817			132.104	142.273		
	.667	21 20			4.464	
868			122.445	144.851		
	.667	19 to 16			4.608	
919			103.143	150.099		
	.667	15 to 11			5.184	
970			79.040	156.738		
	.738	10 to 6			5.760	
1021			54.913	163.457		
	1.900	5 to 1			5.760	
1072			30.599	170.300		

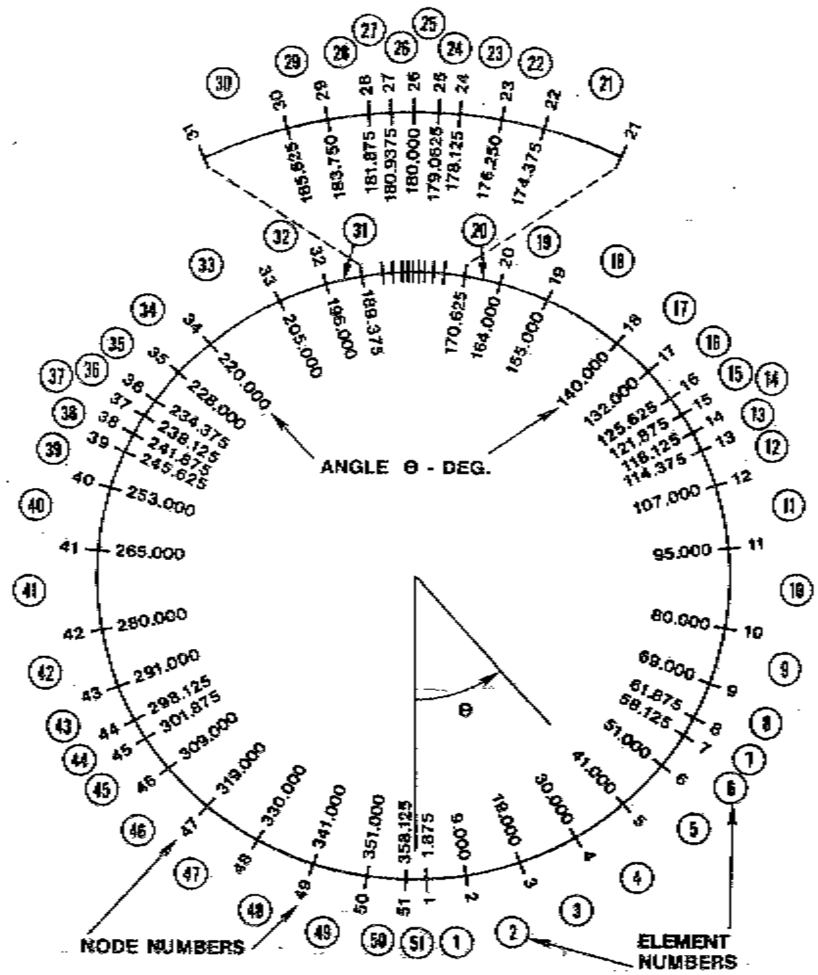

Figure B.2 SAP-IV Finite Element Model for Tower Unit No.2

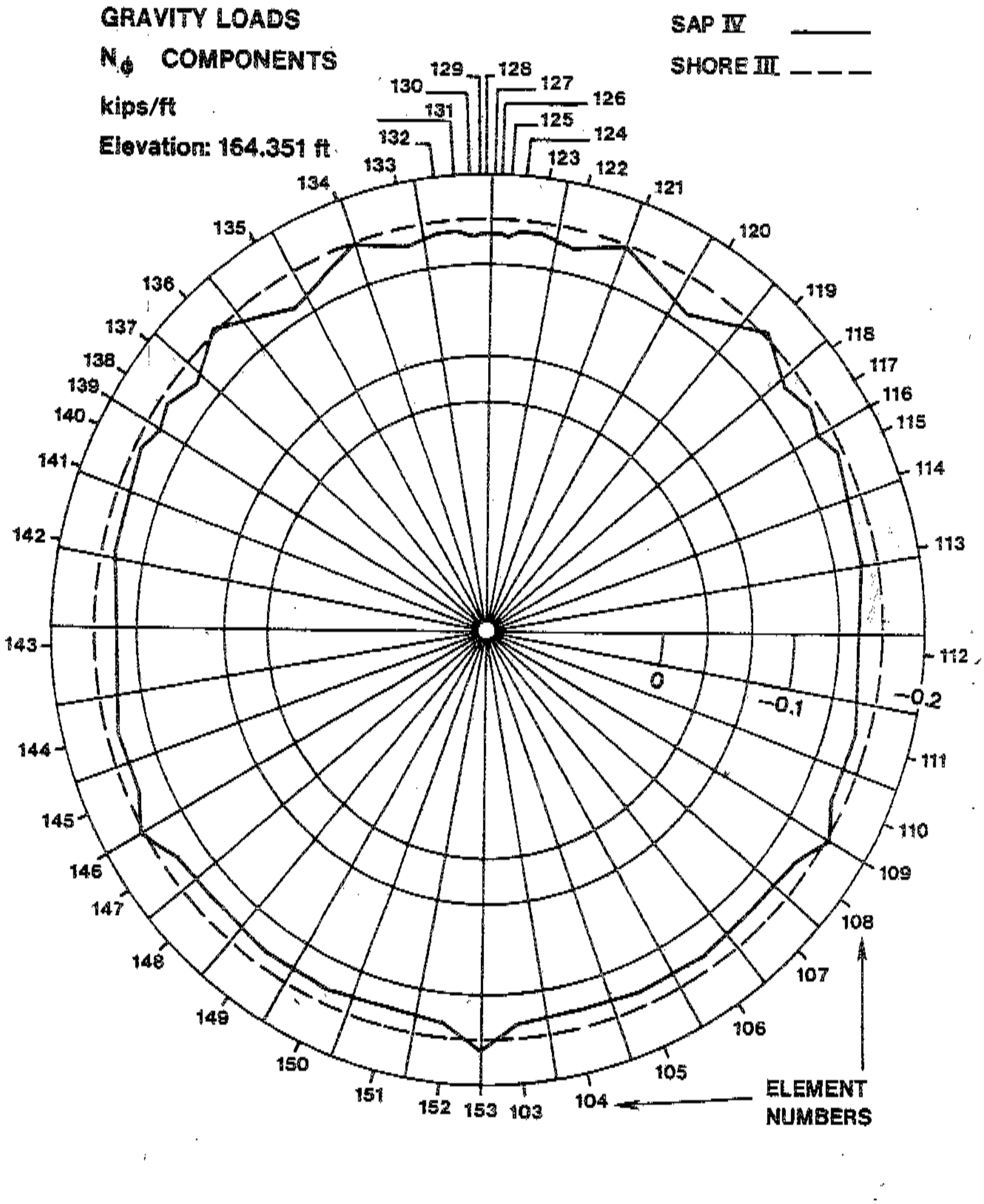

Figure B.3 Comparison of N_ϕ from Gravity Load, Load Case 1

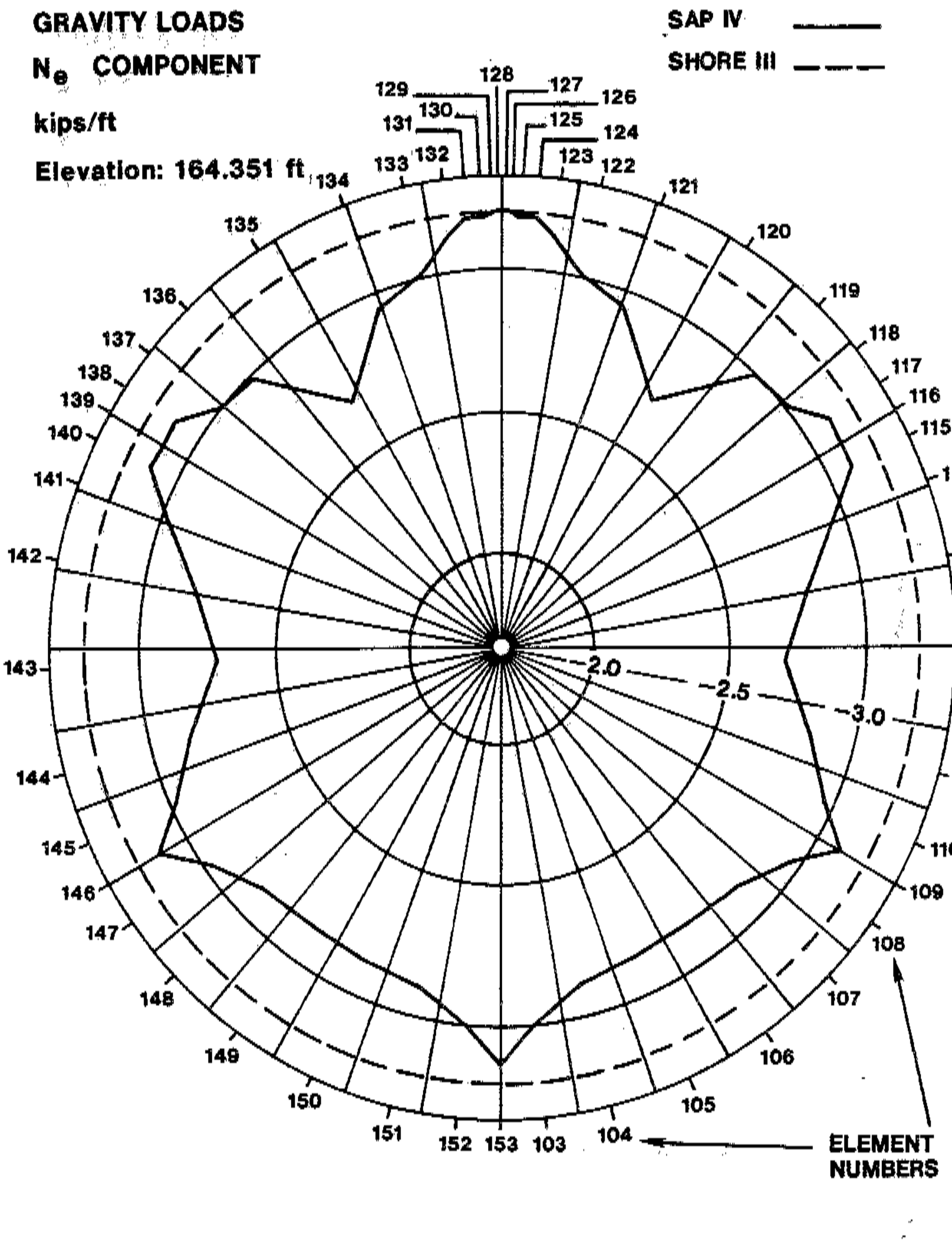

Figure B.4 Comparison of N_θ from Gravity Load

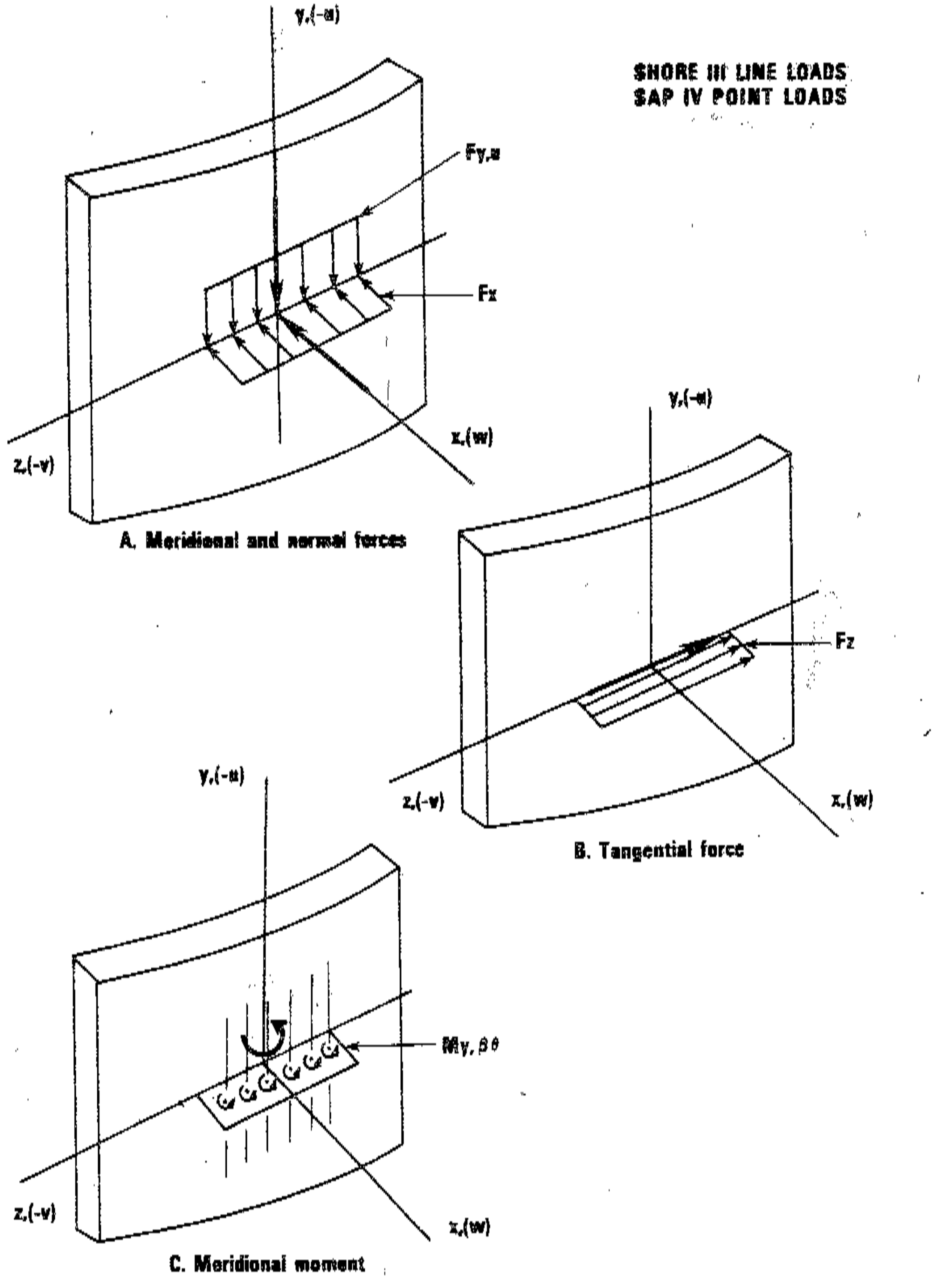

Figure B.5 Load Functions for SHORE-III and SAP-IV Programs

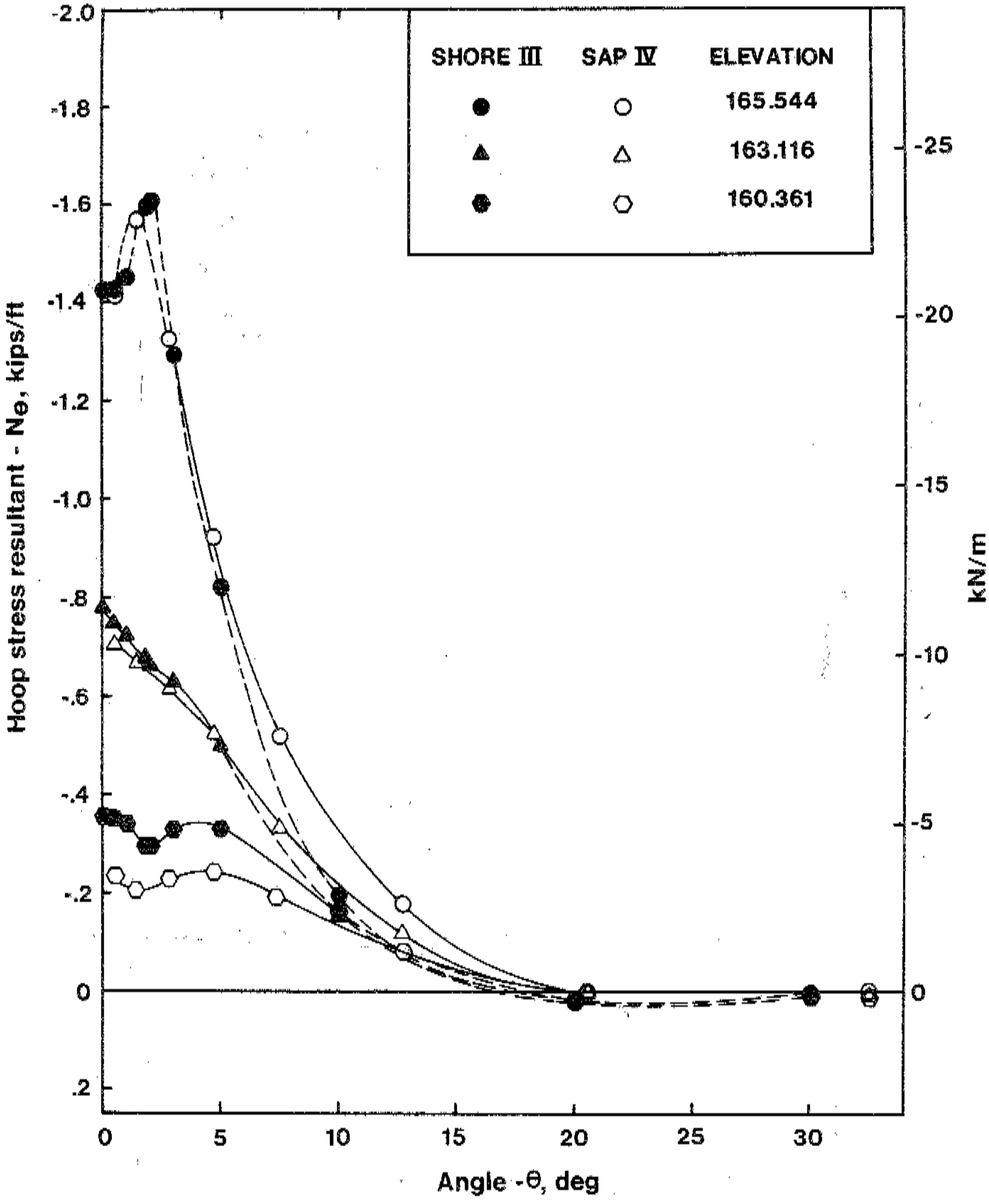

Figure B.6 Comparison of Hoop Stress Resultant for Load Case 4

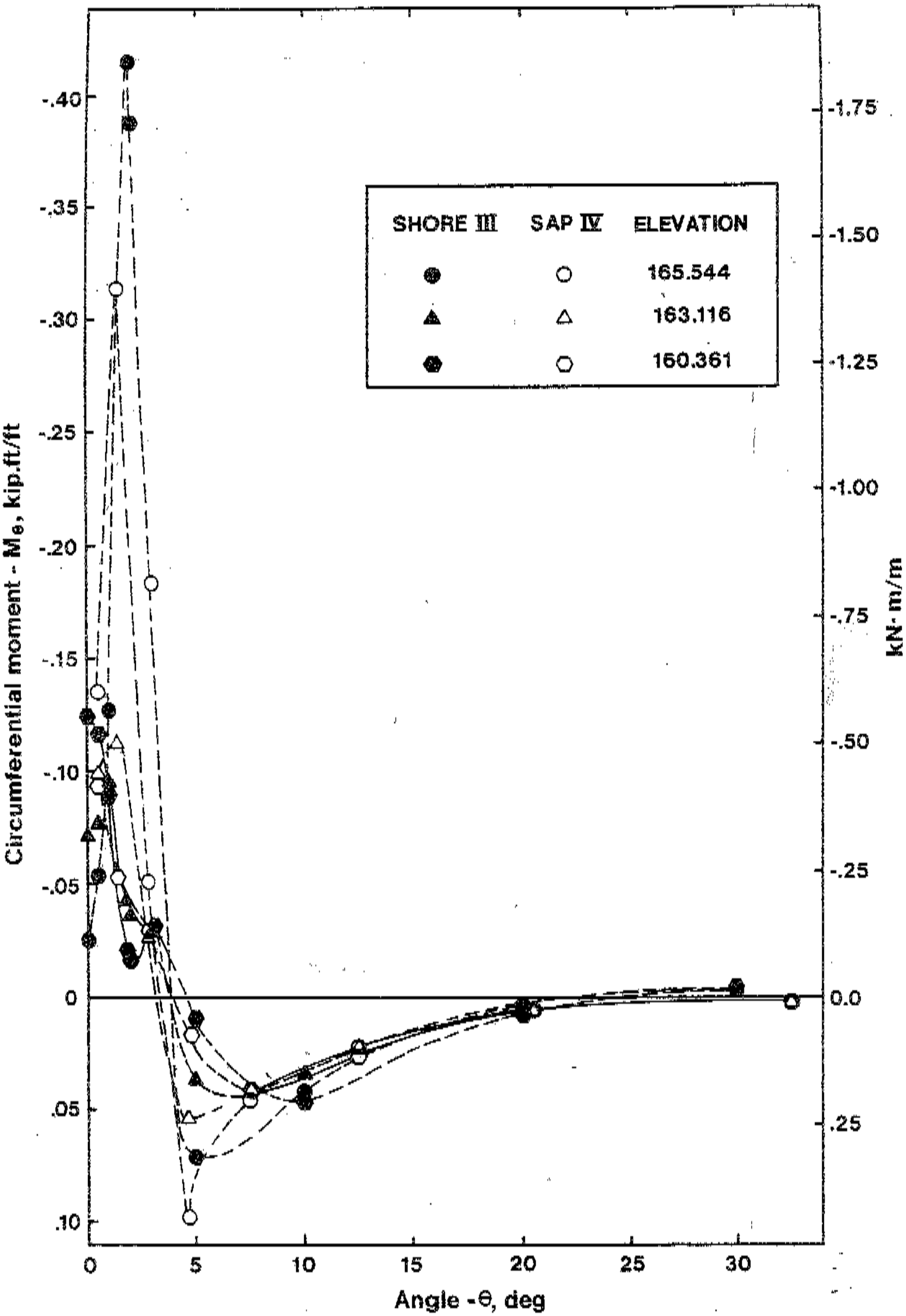

Figure 8.7 Comparison of Circumferential Momemt for Load Case 4

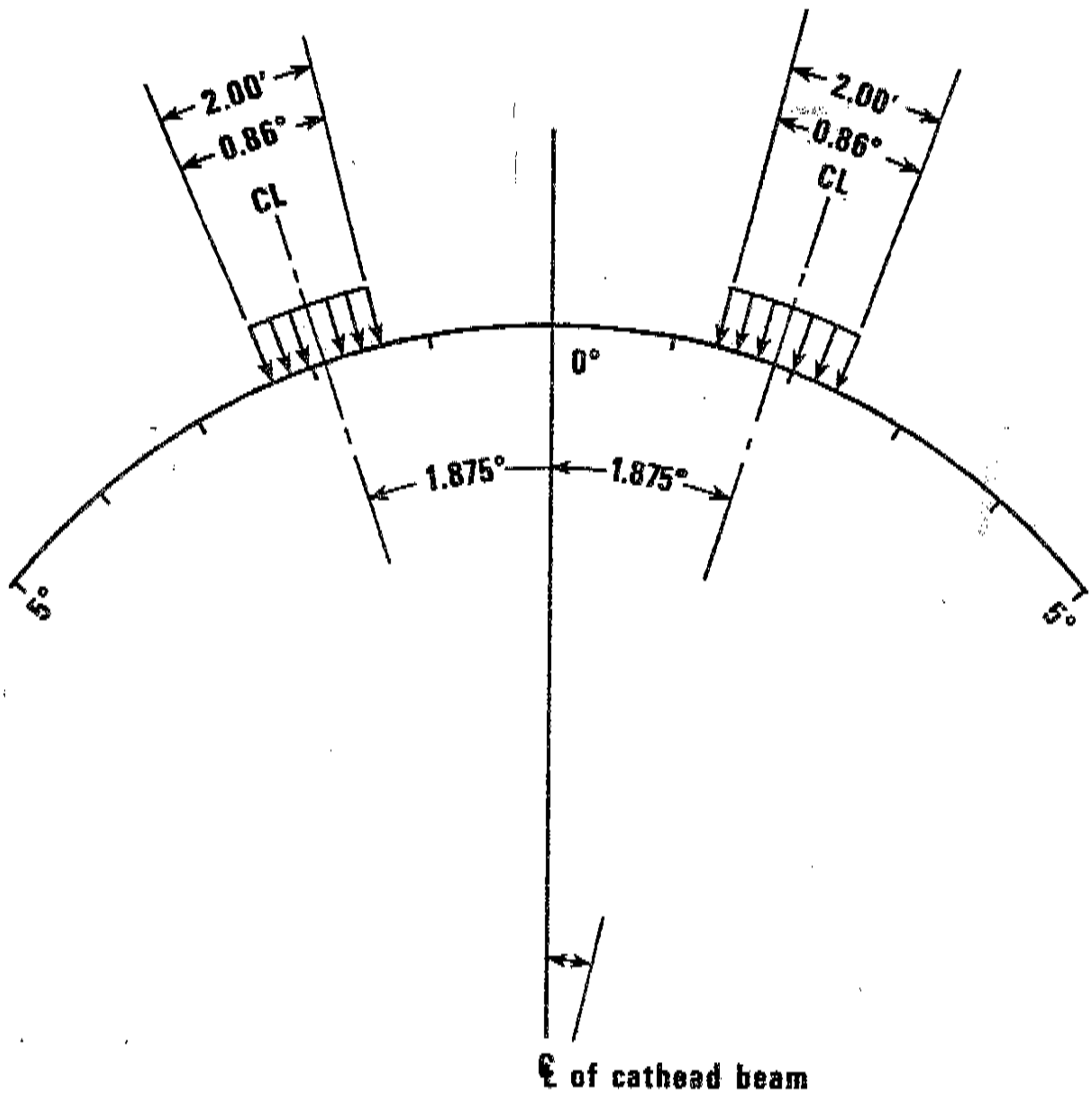

Figure B.8 Loading Function for Normal Force, Load Case 4

APPENDIX C

Results of Chemical Analysis of Cemet

LAW ENGINEERING TESTING COMPANY
MATERIALS TESTING ENGINEERS
SOIL AND FOUNDATION INVESTIGATIONS
412 Plasters Ave., N. E. • P. O. Box 13815, Sta. K
ATLANTA, GEORGIA 30324

REPORT OF CEMENT ANALYSIS

Client: LETCO MC LEAN
Office: Atlanta, Georgia
Project: NBS SAMPLE #45
Date: August 9, 1978
LETCO JOB NO. M- 110
Lab. No. 21531B

BRAND OF CEMENT ? PLANT ? SAMPLE RECEIVED 7-15-78

PHYSICAL DATA

SETTING TIME (Gillmore)	HOURS	MINUTES
Initial Set:	3	10
Final Set:	4	50

SOUNDNESS (Expansion) 0.00 %

FINENESS (Surface Area, Blaine) 3720 Sq. Cm./Gm.

COMPRESSIVE STRENGTH, PSI	
1 Day Break	---
3 Days Break	1680
7 Days Break	1900
28 Days Break	---

AIR CONTENT (Percent by Volume) 7.2

CHEMICAL ANALYSIS

Silicon Dioxide (SiO_2)	20.0
Aluminim Oxide (Al_2O_3)	5.2
Ferric Oxide (Fe_2O_3)	3.9
Calcium Oxide (CaO)	63.5
Magnesium Oxide (MgO)	2.1
Sulphur Trioxide (SO_3)	2.0
Alkalies (Na_2O & 0.658 K_2O)	0.44
Loss on Ignition	1.6
Insoluble Residue	0.25
Tricalcium Silicate ($3CaO.SiO_2$)	60
Dicalcium Silicate ($2CaO.SiO_2$)	12
Tricalcium Aluminate ($3CaO.Al_2O_3$)	7.1
Tetracalcium Aluminoferrite ($4CaO.Al_2O_3.Fe_2O_3$)	12

NOTE: The Type of this cement is not known.

cc: H.S. Lew Washington, D.C.

Respectfully submitted,
LAW ENGINEERING TESTING CO.
Dan Welch
DAN WELCH

LAW ENGINEERING TESTING COMPANY

MATERIALS TESTING ENGINEERS
SOIL AND FOUNDATION INVESTIGATIONS
412 Plasters Ave., N. E. • P. O. Box 13815, Sta K
ATLANTA, GEORGIA 30324

REPORT OF CEMENT ANALYSIS

Client: LETCO MC LEAN

Office: Atlanta, Georgia

Project: NBS SAMPLE #29

Date: August 9, 1978

LETCO JOB NO. M- 110

Lab. No. 21531-A

BRAND OF CEMENT ? PLANT ? SAMPLE RECEIVED 7-15-78

PHYSICAL DATA

SETTING TIME (Gillmore)	HOURS	MINUTES
Initial Set:	2	49
Final Set:	4	45

SOUNDNESS (Expansion) 0.00 %

FINENESS (Surface Area, Blaine) 3710 Sq. Cm./Gm.

COMPRESSIVE STRENGTH, PSI	
1 Day Break	---
3 Days Break	2140
7 Days Break	2200
28 Days Break	---

AIR CONTENT (Percent by Volume) 7.4

CHEMICAL ANALYSIS

Silicon Dioxide (SiO_2)	20.6
Aluminim Oxide (Al_2O_3)	5.3
Ferric Oxide (Fe_2O_3)	3.0
Calcium Oxide (CaO)	64.1
Magnesium Oxide (MgO)	2.4
Sulphur Trioxide (SO_3)	2.1
Alkalies (Na_2O & 0.658 K_2O)	0.38
Loss on Ignition	1.2
Insoluble Residue	0.22
Tricalcium Silicate ($3CaO.SiO_2$)	60
Dicalcium Silicate ($2CaO.SiO_2$)	14
Tricalcium Aluminate ($3CaO.Al_2O_3$)	7.1
Tetracalcium Aluminoferrite ($4CaO.Al_2O_3.Fe_2O_3$)	9

NOTE: The Type of this cement is not known.

cc: H. S. Lew

Respectfully submitted,
LAW ENGINEERING TESTING CO.

DAN WELCH

APPENDIX D

Results of Analysis of Concrete

Technical Service Report

Project: Slow Setting Concrete Wall Section

Project No.: CT-0477 Date: November 7, 1978

Customer: National Bureau of Standards (Washington, D.C.)

Objective

Determine if Pozzolith 200-N, a water-reducing admixture, was present in concrete placed in a wall section of a thin wall structure at a concentration sufficient to account for an unusually slow setting behavior.

Conclusion

The concrete in question contained a water-reducing admixture, similar in composition to Pozzolith 200-N, at a level not exceeding that normally recommended by the admixture manufacturer (3 to 5 fl. oz./100 lbs. of cement).

Sample Identification and Background Information

A piece of hardened concrete, weighing about 11 lbs., and three small bottles of various liquid substances, identified as Pozzolith 200-N, Starch Hydrozylate, and Amine Derivatives Mixture, respectively, were received from Dr. H. S. Lew, Structures and Materials Division, Center for Building Technology, on 9/5/78.

Methods of Test

The concrete sample was subjected to chemical analyses to determine the presence and addition level of a water-reducing admixture (ASTM C-494, Type A). The liquid sample identified as Pozzolith 200-N was characterized to obtain its chemical composition and certain physical properties. The two remaining liquid samples, identified as Starch Hydrozylate and Amine Derivatives Mixture, were subjected to infrared analysis to determine the principal ingredients present.

Results and Discussion

The liquid sample identified as Pozzolith 200-N consisted principally of a mixture of corn syrup (Starch Hydrozylate) and triethanolamine (Amine Derivatives Mixture). The latter comprised 11% of the admixture formulation as received. Chloride ion (Cl^-) in the amount of 0.24% also was detected. A comparison of this sample with one analyzed previously by us in October 1975 suggested they were quite similar.

Chemical analysis revealed the concrete sample most likely contained no more than a normal dose of a water-reducing admixture similar in composition to Pozzolith 200-N (ASTM C-494, Type A). In this case, a normal dose is an addition rate of 3 to 5 fluid ounces per 100 lbs. of cement, as recommended by the admixture manufacturer (Master Builders).

A more precise determination of admixture concentration is not possible at this time, unless a calibration curve was to be prepared employing actual job materials at the levels specified in the mix design.

L. Michael Meyer

L. M. Meyer, Manager
Technical Services Section

lg
CT-0477

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NBS-114A (REV. 7-73)

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WASHINGTON, D.C. 20234

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Occupational Safety and Health Administration
U.S. Department of Labor
Washington, D.C. 20001

13. Type of Report & Period Covered

Fianl

14. Sponsoring Agency Code

15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

The coolapse of the natural-draft hyperbolic concrete cooling tower unit no. 2 at the Pleasants Power Station at Willow Island, West Virginia has been investigated. This investigation included onsite inspections, laboratory tests of construction assembly components and concrete specimens, and analytical studies.

Based on the results of these field, laboratory and analytical investigations, it was concluded that the most probable cause of the collapse was due to the imposition of construction loads on the shell before the concrete of lift 28 had gained adequate strength to support these loads. The analysis of the shell indicates that the collapse initiated at the part of the shell in lift 28 where cathead no. 4 was located. It further showed that calculated stress resultants at several points in that part equaled or exceeded the strength of the shell in compression, bending and shear. The failure of these points in that part of the shell would have propagated to cause the collpase of the entire lift 28.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Collapse; concrete; concrete strength; construction; cooling tower; failure; hyperbolic shell; shell.

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