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PRESSURE TEST ANALYSIS 200-INCH MULTICELL TEST TANK

Prepared under Contract No. NAS8-20073 by

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Methods and Research Section
Strength Analysis Branch
Structures Department

For

NASA-GEORGE C. MARSHALL SPACE FLIGHT CENTER
Huntsville, Alabama

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PRESSURE TEST ANALYSIS
200-INCH MULTICELL TEST TANK

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This report is a result of the work conducted under Technical Directive C1-SSP-020C, Item 03. The intent of this report is a qualitative analysis of the test results with recommendations and conclusions for possible future tests.

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BROWN ENGINEERING, A TELEDYNE COMPANY
Methods and Research Section
Strength Analysis Branch
Structures Department

(Original work completed in September 1965)

For

Structural Engineering Branch
Propulsion and Vehicle Engineering Laboratory

NASA-GEORGE C. MARSHALL SPACE FLIGHT CENTER

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TABLE OF CONTENTS

LIST OF FIGURES

INTRODUCTION

The actual test procedure is described in a report for Structures Division, P&VE Laboratory, George C. Marshall Space Flight Center entitled

200-INCH MULTICELL
(PRESSURE TEST)
September 15, 1965

Prepared By

Jon J. Spano

BROWN ENGINEERING COMPANY, INC.
NAS8-20073
T. D. C1-SER-030B

This report should be read in conjunection with the above report.

The principal objectives of the pressure test were to provide basic stress information and check manufacturing processes. Following is a detailed discussion of the first of these objectives and results of the test.

OBJECTIVES

The major specific objective was the determination of discontinuity effects. Other objectives were the clarification of (1) liquid weight effects in the waffle skins and radial webs, (2) the elastic distribution of stresses through the radial webs, and (3) the basic load paths in cylinder walls and bottom bulkheads for liquid load.

The discussion of these objectives will consist of two parts:

(1) List "A" - Stress patterns normally expected in the pressurized multicell tank.

(2) List "B" - Stress patterns actually indicated by the test measurements and compared with List "A".

List A

A-1. At junctures of the waffle skin sections, extrusions, and radial webs at approximately mid-depth of the tank, the discontinuity principal stresses should be at right angles and parallel to the extrusion (waffle skin rib effects are essentially symmetrical). This statement must be qualified in that possible fluid weight lag effects could interrupt this pattern (see A-5, page 3).

Since the radial web acts basically as an elastic foundation to the waffle skin sections, a shear is developed along the longitudinal edge approximately as shown in Figure 1, page 9. This shear should be distributed equally to both waffle skins, thus indicating opposite and equal theta angles for principal stresses on either side of the radial web except in the low shear area of the middle portions.

A-2. At sphere-cone and sphere-cylinder junctures in the area around the centerline of a cell (Fig. 2, page10), the principal stresses should be parallel and perpendicular to the joints.

A-3. The sphere-sphere and cone-cone junctures are very similar to the cylinder-cylinder junctures. The elastic foundation effect of the radial web should again come into play, thus distributing a shear equally to both elements. The theta angles should again be opposite and equal on each side of the radial web.

A-4. At a juncture of three elements (Fig. 2, page 10), the principal stresses should be at some undetermined angle due to crosscoupling effects.

The extent of this crosscoupling should be indicated by a change in the stress pattern at varying distances from the three juncture area. At points near the centers of the sphere-cone or sphere-waffle skin junctures the principal stresses should become perpendicular and parallel to the juncture. This indicates that the crosscoupling effect is no longer predominant.

Along the radial web juncture, the extent of this effect would probably be indicated by a non-linear change of theta angles.

A-5. Liquid weight effects in the radial webs and waffle skin segments will be determined from the tank in the full condition with no applied pressure. Thus these stresses should be separable from membrane and discontinuity effects as the tank is pressurized.

A-6. The elastic distributions of stresses through the radial web are expected to indicate the effects of the pressure reactions of the waffle skins as well as the support of the vertical liquid loads.

A-7. The distribution of the liquid load transferred directly through the spherical head-skirt juncture or through the radial web-waffle skin-skirt junctures should be determined by the tank in the full condition (Fig. 3).

List B

(All references listed as "SER report" indicate report mentioned in the introduction.)

B-1. It appears that as anticipated in "A-1" the principal stresses are approximately parallel and perpendicular to the waffle skin extrusion at the mid-depth of the tank (Fig. 28, "SER report", page 45 and gages 726, 729, 720 and 723, Table VIII, "SER report", pages 96-108). There also appears in general to be a definite trend from a high theta angle (~45°) reading at the full loading to a low angle at the higher pressure readings; this indicates that the liquid weight effects (vertical shear) are of a negligible effect in this portion of the tank at high pressures. Note also that the biaxial gages on the extrusion are not effective as a check on A-1.

Also as indicated in A-1, the principal stresses near the top and near the bottom of the tank are at appreciable theta angles to the horizontal and vertical (Fig. 28, "SER report", page 45). However, there are no gages opposite gages 618, 621, 666 and 669 to check the supposition of equal and opposite theta angles.

Condition A-1 also indicates an expected symmetrical stress condition on each side of the extrusion; i. e. , the bending effects should be equal in Cell 3 and Cell 4. Figure 29 of "SER report", page 46, indicates that in the extrusion area this is not true. There appears to be a much heavier bending stress on the Cell 4 side.

This same condition exists when the bending stresses are compared for gages 416-418, 420-422 against 428-430, 424-426 near the top of the tank. This condition is also shown by gages 450-542, 454-456 against 462-464, 458-460 at the bottom (see Table XV, "SER report," pages 153-159).

In connection with this unsymmetrical bending condition the signs of the single gage readings on the outstanding legs of the radial web horizontal stiffeners are found to be of great significance. Gages 140, 141, 142 and 143 at the exterior ends of the stiffener and gages 123, 124, 125, 126, 127 and 128 at the interior ends all indicate compressive stress while the radial web is basically a tension member.

The compressive stresses in the outstanding flanges of the horizontal Z-stiffeners indicate that the pull applied through the radial web plate was eccentric with respect to the centroid of the plate-stiffener combination. This eccentricity of loading resulted in a bending moment in the plate-stiffener combination which produced rotation and consequent bending of the unstiffened portion of the plate adjacent to the extrusion. The stress distribution in the plate-stiffener combination is shown in Figure 4A, page 12. The resulting eccentric loading is shown in Figure 4B and the resulting moments at the joint in Figure 4C.

Discontinuity bending stresses at the extrusions are caused by the outward deflection of the skin relative to the extrusion. The corresponding stresses would be symmetrical as indicated qualitatively in Figure 4D, page 13. Such stresses will have superimposed upon them the stresses resulting from the bending of the plate-stiffener combinations.

The resulting stresses of such a superposition are consistent with the measured stresses in Cell 3 and Cell 4.

B-2. In the top and bottom bulkheads, the presence of cross welds on the centerline precluded getting reliable rosette readings at sphere-cone junctures (Fig. 42 and Fig. 55 "SER report," pages 59 and 72). However, at the sphere-cylinder junctures (Fig. 28 "SER report," page 45) this condition appears to be fairly accurate for both the top and bottom where no cross welds occur.

B-3. The discontinuity stresses adjacent to the extrusion at the top and bottom of the tank are not symmetrical but indicate the presence of a bending moment similar to and in the same direction as that in the walls of the tank. Since the vertical stiffeners are on the opposite side of the web from the horizontal stiffeners it might appear that the superimposed bending would be opposite to that in the vertical section. The fact that the web tensions are greatest in the horizontal directions gives rise to very low stresses in the vertical stiffeners and consequently no significant bending rotation at their ends.

The extrusion being appreciably heavier than the attached sheet continues to preserve the rotation developed in the vertical section. Of course, the web plate, vertical stiffeners and end connections at the central tube dissipate this rotation and consequently the imposed asymmetrical bending in the conical shell walls near the stiffener.

B-4. At junctures of three elements, the data obtained are not conclusive but not at variance with what was expected.

B-5. The magnitude of the stresses under liquid load alone were so small compared with unavoidable noise levels that a reliable stress pattern could not be separated from the total stress.

B-6. As in B-5, the stresses due to liquid weight are exceedingly low; but a definite pattern can be observed from enlarged scale plots in Figure 15 of "SER report," page 32. As would be expected, the top of the web is practically unstressed; but noticeable shear effects can be observed from the presence of ten.-comp. vectors along the inner edge of the radial web.

With respect to Figure 16 of "SER report," page 33, the stress patterns at 30 psi are symmetrical. An interesting phenomenon is the low stress area of the radial web at the mid-depth of the tank adjacent to the center tube. This phenomenon is caused by the stiffer load paths of the upper and the lower end assemblies compared to the radial stiffness of the center tube.

B-7. Similar to B-5, no definite load paths could be determined because of the low magnitude of stresses at the full condition only.

GENERAL COMMENTS

Following is a list of general comments:

1. The stresses under full liquid load were so low that extraneous effects obscured the detailed trends. For example the gage readings for stresses in the radial web are generally less than 1500 psi for the full condition. As any reading may vary ±300 psi, a very large error is introduced.

2. In some instances, manufacturing deviations caused by the experimental nature of the manufacturing processes tended to disrupt local normal stress patterns and general symmetry. As stresses are very sensitive to radii changes and local material thicknesses, unusual results are obtained in some locations. A prime example is gages 708 and 711 on the waffle skins.

3. Photostress measurements were not made because of a number of factors including the very low stress level.

4. In general the changes in stress with pressure were linear within the limits of accuracy obtained (see data graphs, "SER report"). Even in cases where large offsets occur between individual pressure readings, the remaining differential trends are quite consistent.

5. While it is possible to use Mohr's circle to compare biaxial gages with rosettes in symmetrical stress patterns, the use of additional rosettes is highly desirable.

6. The ribs on the waffle skin are basically provided to prevent premature buckling, but they also tend to disturb the stresses in the skin and should be taken into account in any general analysis.

7. The determination of the basic liquid load paths and the elastic distributions of the stresses through the radial web will be very sensitive to design changes in the radial webs, the waffle skins, and the center tube.

8. For additional information on manufacturing deviations mentioned in No. 2, see "Contour Comparison Study, Multicell Test Tank," May 24, 1965, prepared for Structures Division, P&VE Laboratory, George C. Marshall Space Flight Center, prepared by P. M. Crossfield, M. S. Morgan, G. W. Kinney, Brown Engineering Company, Inc., NAS8-20073.

RECOMMENDATIONS AND CONCLUSIONS

It is recommended that another pressure test be made with the following revisions to test procedure:

1. The liquid used for this additional test should have a specific gravity of about five to simulate a five-g acceleration (general water soluble compounds appear to be available for this purpose).

2. Appreciable higher uniform pressures should be applied to the tank until some preset stress level is reached by a "prime" gage (those gages not monitoring manufacturing defects).

3. Relief of the eccentric stiffener effect as described in List B-1 could possibly be obtained by releasing the end fasteners at the extrusion.

4. In general, additional channels of stress will be needed to more adequately define the true stress picture. The most obvious of these added gage locations are defined as follows:

   a. Short length gages on the extrusion stem at the outer end of the horizontal stiffeners on the radial webs.

   b. Short length gages on the fillets of the abrupt ends of the waffle pattern ribs next to the extrusion.

   c. Rosettes on the extrusion in every case to more adequately check the discontinuity effect.

d. Horizontal gages on the center tube web.

e. Additional rosettes on the cylinder wall and/or spherical bulkhead for indicating load path of the liquid.

f. Rosettes located so as to clarify condition described in List A-4.

g. Additional single gages on eccentric Z-stiffeners and waffle skin ribs.

h. Rosettes opposite gages 618 and 666 with one more intermediate row between the existing gages.

The following final conclusions may be drawn from the foregoing study.

The discontinuity stresses resulting from unavoidable geometric differential deflections are not the governing stresses in this test tank. It appears that the controlling stresses are caused by avoidable stress concentrations and eccentricities.

Thus there is no evidence from this test that a properly designed and constructed multicell tank cannot be both light-weight and safe.

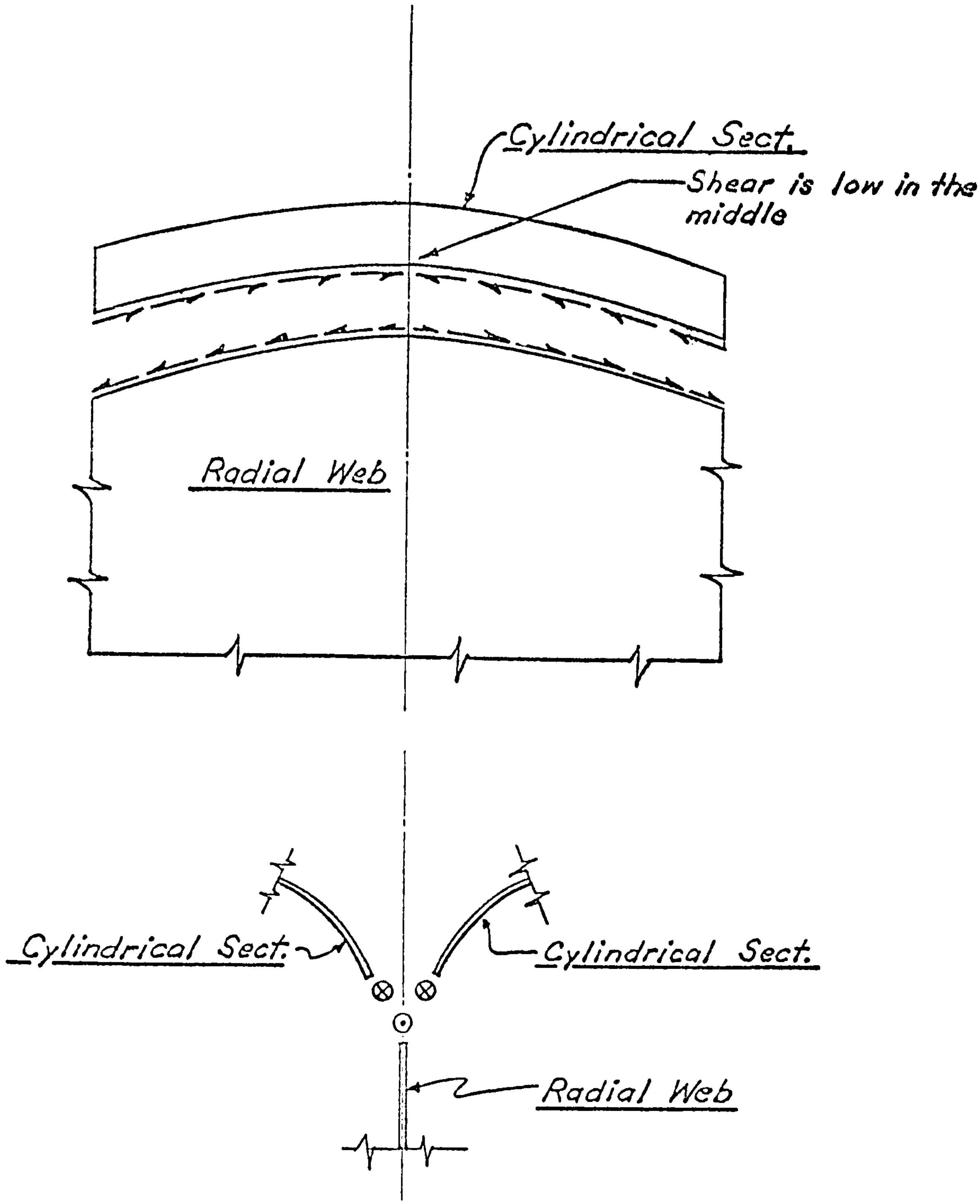


FIGURE 1. EXPECTED CONTINUITY EFFECT OF THE RADIAL WEB

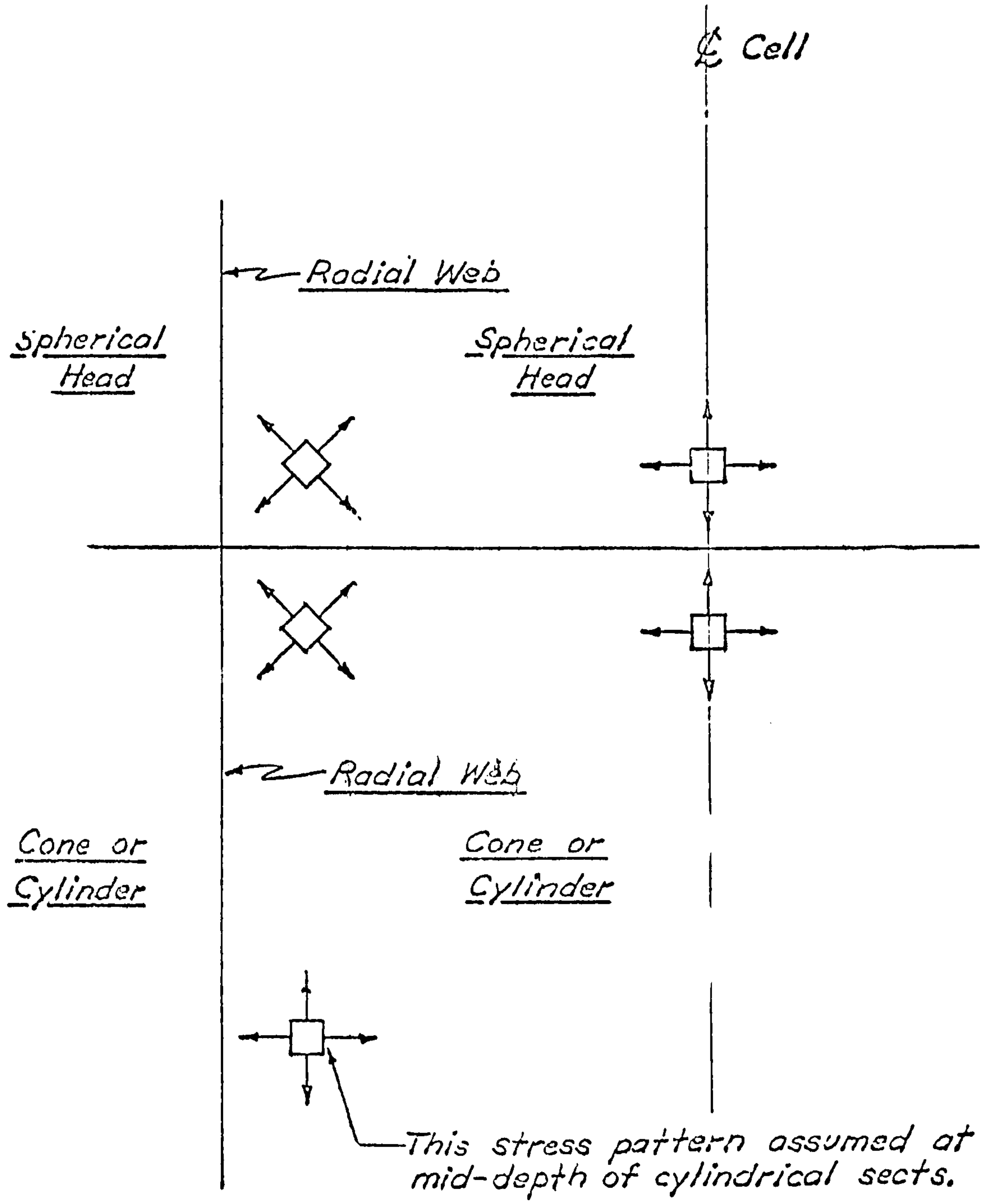


FIGURE 2. ASSUMED PRINCIPAL STRESS DIRECTION AT VARIOUS JUNCTURES

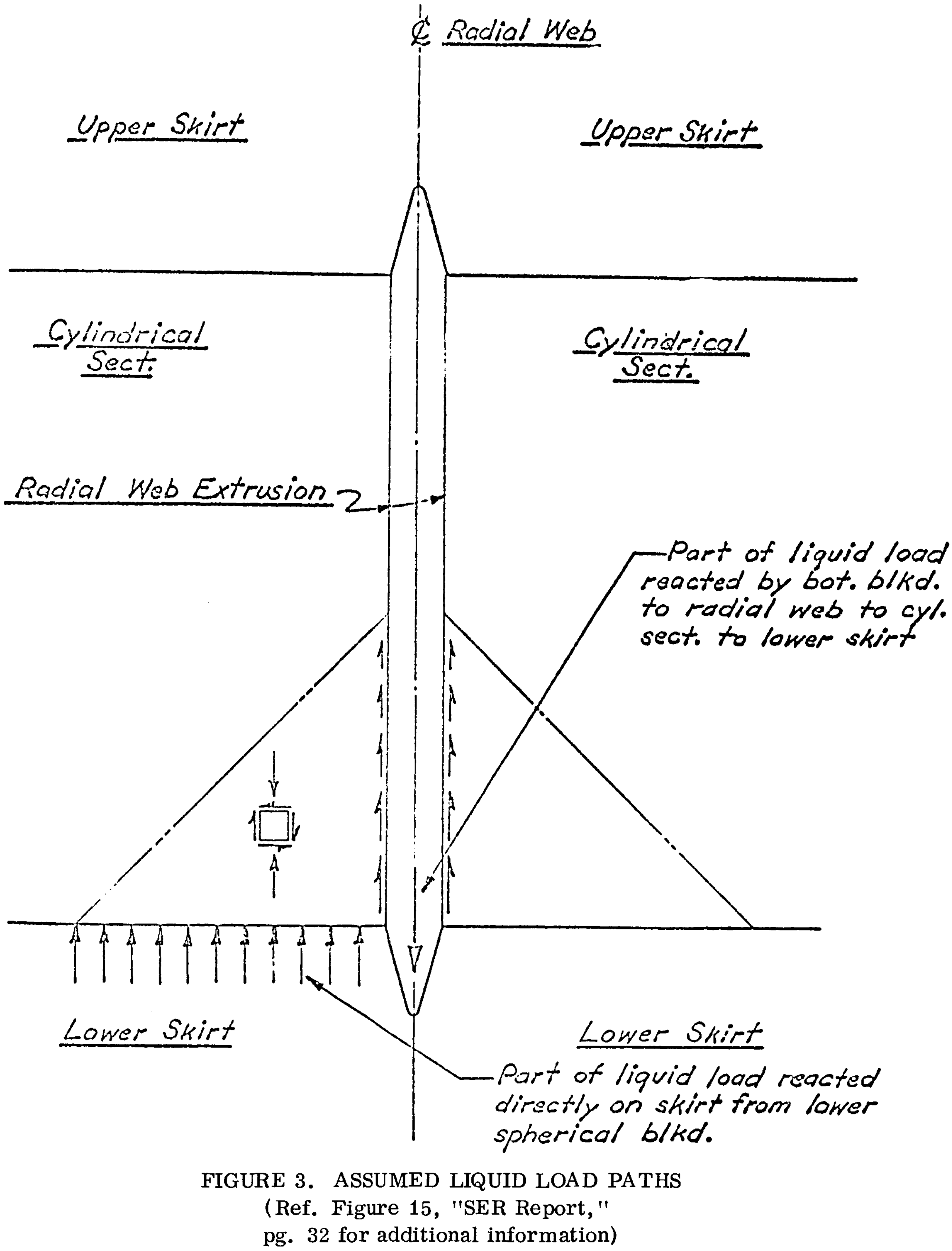
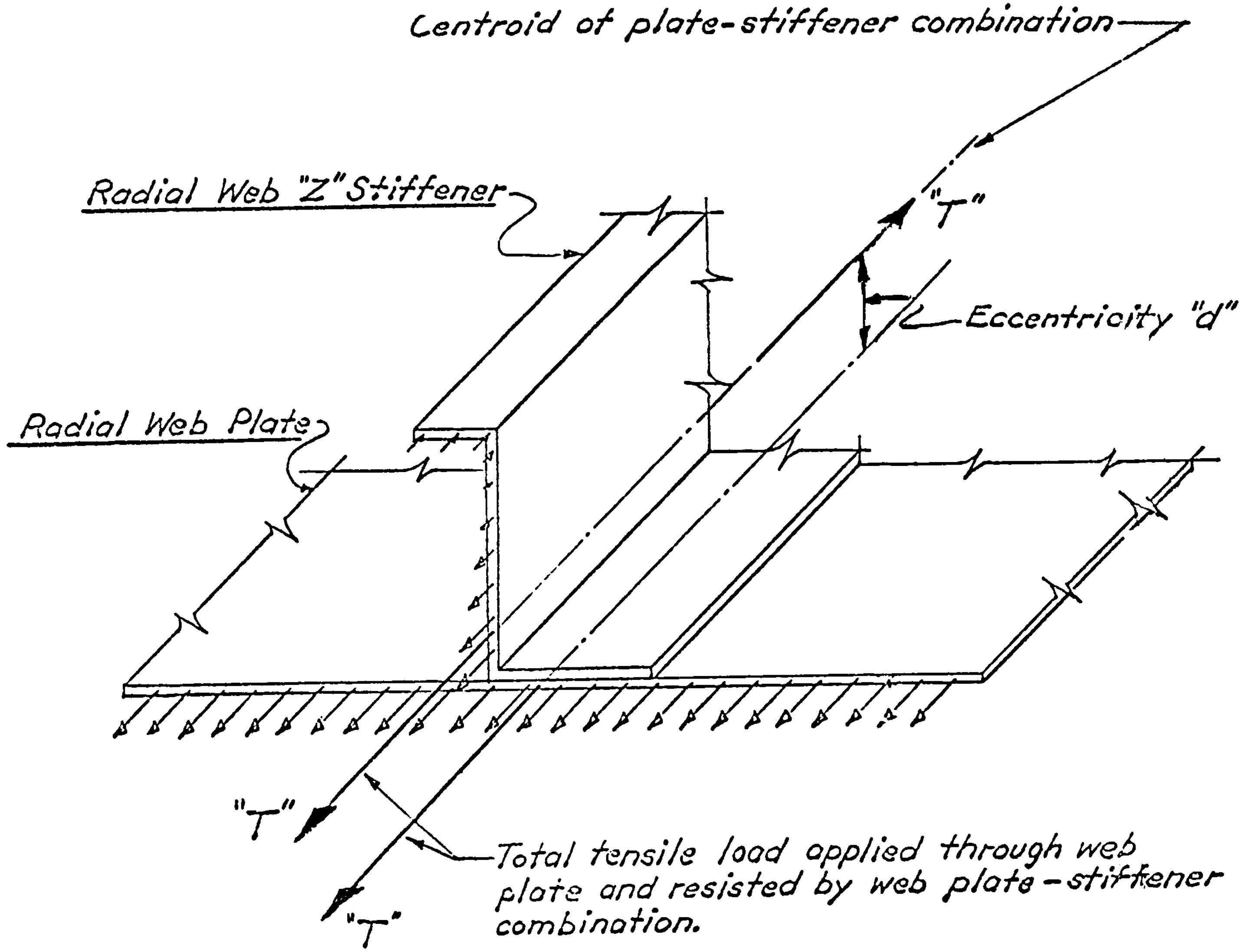
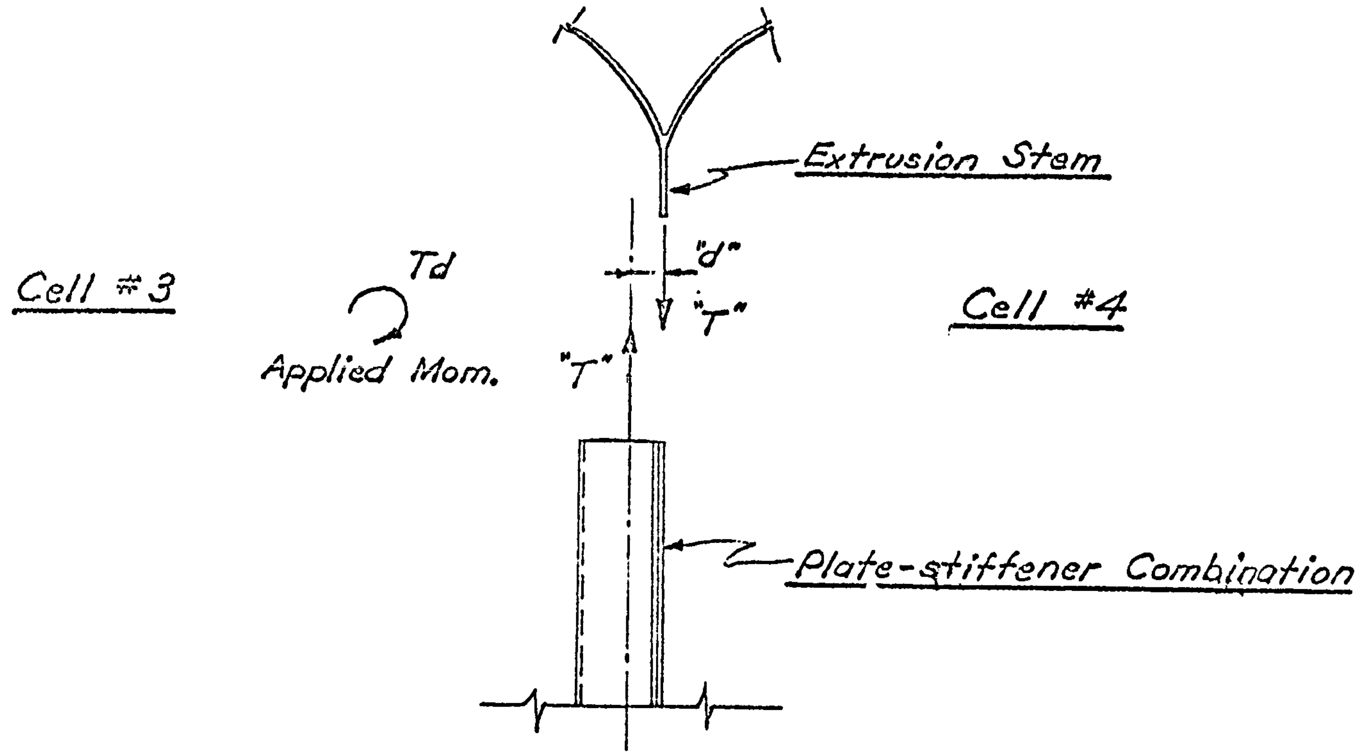


FIGURE 3. ASSUMED LIQUID LOAD PATHS
(Ref. Figure 15, "SER Report,"
pg. 32 for additional information)



(4a)

FIGURE 4. ECCENTRIC STIFFENER EFFECTS



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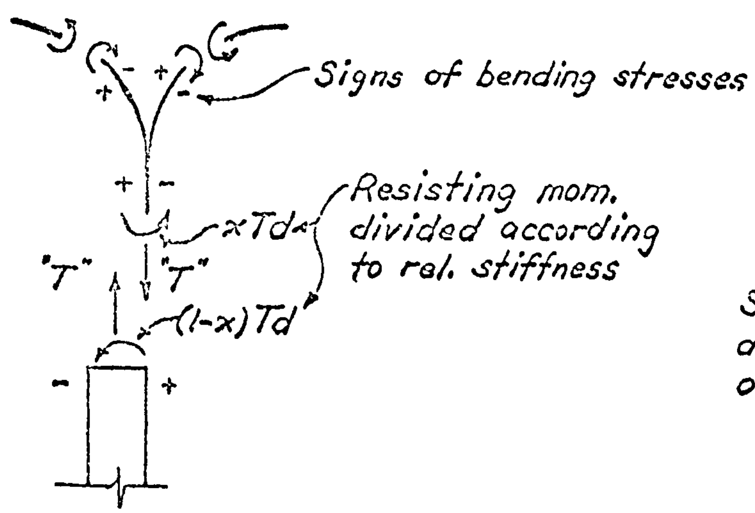
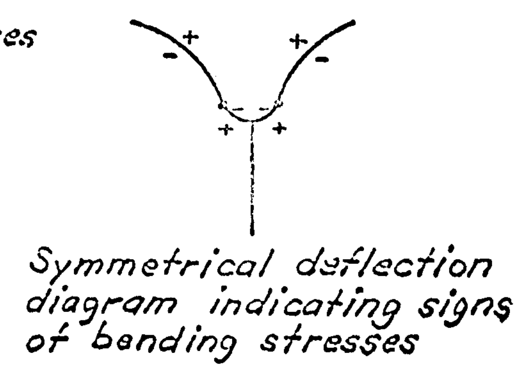


(4c)



(4d)

FIGURE 4. (Concluded)