Analysis of ICPP Fuel Storage Rack Inner Tie and Corner Tie Substructures

M. E. Nitzel
R. G. Rahl
ANALYSIS OF ICPP FUEL STORAGE RACK INNER TIE AND CORNER TIE SUBSTRUCTURES

M. E. Nitzel
R. G. Rahl

Published January 1996

Idaho National Engineering Laboratory
Lockheed Idaho Technologies Company
Idaho Falls, Idaho 83415

Prepared for the
U.S. Department of Energy
Assistant Secretary for Environmental Management
Under DOE Idaho Operations Office
Contract DE-AC07-94ID13233

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED
ABSTRACT

Finite element models were developed and analyses performed for the tie plate, inner tie block assembly, and corner tie block assembly of a 25 port fuel rack assembly designed for installation in Pool 1 of Building 666 at the Idaho Chemical Processing Plant. These models were specifically developed to investigate the adequacy of certain welds joining components of the fuel storage rack assembly. The work scope for this task was limited to an investigation of the stress levels in the subject subassemblies when subjected to seismic loads. Structural acceptance criteria used for the elastic calculations performed were as found in the overall rack design report as issued by the rack's designer, Holtec International. Structural acceptance criteria used for the plastic calculations performed as part of this effort were as defined in Subsection NF and Appendix F of the ASME Boiler & Pressure Vessel Code. The results of the analyses will also apply to the 30 port fuel storage rack design that is also scheduled for installation in Pool 1 of ICPP 666.

The results obtained from the analyses performed for this task indicate that the welds joining the inner tie block and corner tie block to the surrounding rack structure meet the acceptance criteria. Further, the structural members (plates and blocks) were also found to be within the allowable stress limits established by the acceptance criteria. The separate analysis performed on the inner tie plate confirmed the structural adequacy for both the inner tie plate, corner tie plate, and tie block bolts. The analysis results verified that the inner tie and corner tie blocks should be capable of transferring the expected seismic load without structural failure.
SUMMARY

Holtec International performed the design and analysis of spent fuel storage racks for installation in the Idaho National Engineering Laboratory's (INEL) Idaho Chemical Processing Plant (ICPP), Building 666, Pools 1 and 5. During the course of the independent review required of the design analysis, questions were raised regarding the adequacy of certain welds to withstand the loading that would be imposed by the motion of the adjacent fuel racks during a seismic event. The welds in question were those that join the various structural components in the immediate areas of the seismic inner tie block and the seismic corner tie block. To resolve the weld adequacy questions it was suggested that "third party" analyses be performed using the more rigorous finite element analysis approach. As a result, separate finite element models representing the tie plate that connects the inner tie blocks of two adjacent rack structures, portions of the fuel rack structure encompassing one inner tie block assembly, and portions of the fuel rack structure encompassing one corner tie block assembly were developed.

The inner tie block and corner tie block structures and the tie plate addressed in this report were taken from a 25 port fuel rack assembly designed for installation in Pool 1. The storage ports in this design are arranged in a 5 X 5 grid array. The details of this rack design are unique for the 25 port racks; however, the portions of the rack and tie plate that were modeled also apply to the 30 port (6 X 5 grid array) rack design that will also be installed in Pool 1. The scope of this analysis was limited to the specific components described in the report and does not apply to the other rack designs for Pool 5.

The elastic analysis results were compared to allowable values described in the Holtec design report. The plastic analysis results were compared to allowable values found in Subsection NF and Appendix F of the American Society of Mechanical Engineers Boiler & Pressure Vessel Code. The structure was treated as an ASME Class 3 plate and shell support structure.

Also included in the work scope for this project was a very brief parameter study of various methods and element types that might be used to represent the welds in the finite element model. This study was undertaken to verify the applicability of various modeling techniques and finite element types in providing reasonable representations of the structural welds. A separate, smaller, model was developed for this purpose so the results could be examined prior to the development of the much larger and more complex finite element model of the inner tie block area of the rack.

The overall scope of this task was purposely limited to only those rack components where a third party analysis was desired. Since the Holtec design calculations had already been independently reviewed, a concerted effort was made to utilize as much of the previously reviewed data as appropriate. This information included items such as material properties, elastic stress allowable values, and geometric data from drawings. This approach helped to limit the review effort required for these analyses and minimize the schedule and budget requirements for the overall task.

All Tresca stresses in the inner tie plate were below the 45 ksi allowable limit for primary membrane plus bending stress intensity. The corner tie plate was not individually modeled; however, geometric similarities to the inner tie plate were used to confirm structural adequacy. A maximum bolt tensile stress of 42.8 ksi, which is less than the 98 ksi allowed, was calculated. Thus, it was concluded that the stress criteria were satisfied for the inner tie plate, corner tie plate, and the tie block bolts.
Examination of the inner tie block model results showed that peak stresses occurred at structural discontinuities. The most severe example of this behavior was seen in the area where the soffit plate, soffit plate-to-port tube weld, back plate-to-port tube weld, and inner tie (seismic) block-to-back plate weld all terminate. Results showed that the maximum shear stresses in the welds in this area decrease rapidly with distance from the structural discontinuity and that the average shear stress levels in the welds were well below the allowable value. Application of the acceptance criteria led to the conclusion that all welds were adequate. The maximum stress intensities (Tresca stresses) in the plate members and inner tie (seismic) block were also shown to be acceptable. These results led to the conclusion that the welds and structural members comprising the inner tie block model were structurally adequate.

The corner tie block design was found to satisfy the acceptance criteria. When peak stress effects were excluded as directed by the acceptance criteria, shear stresses in the welds and Tresca stresses in the structural members were all within allowable limits. Based on these results, it was concluded that the welds and structural members comprising the corner tie block model are structurally adequate.

In summary, the results obtained from the analyses performed for this task indicate that the welds joining the inner tie block and corner tie block to the surrounding rack structure meet the acceptance criteria. Further, the structural members (plates and blocks) were also found to be within the allowable stress limits established by the acceptance criteria. The separate analysis performed on the inner tie plate confirmed the structural adequacy for both the inner tie plate and the corner tie plate. The analysis results verify that the inner tie and corner tie blocks should be capable of transferring the expected seismic load without structural failure.
CONTENTS

ABSTRACT ........................................................................................................ iii
SUMMARY ......................................................................................................... v
1. INTRODUCTION ............................................................................................. 1
2. SCOPE OF ANALYSIS .................................................................................... 2
3. FUEL RACK STRUCTURAL DESCRIPTION .................................................... 3
4. STRUCTURAL ACCEPTANCE CRITERIA ......................................................... 4
5. MODEL DEVELOPMENT .................................................................................. 5
   5.1. Material Properties ................................................................................... 5
   5.2. Weld Element Test Model ....................................................................... 5
   5.3. Tie Plate Model ....................................................................................... 8
   5.4. Inner Tie Block Model ............................................................................ 13
   5.5. Corner Tie Block Model .......................................................................... 16
6. ANALYSIS RESULTS ...................................................................................... 24
   6.1. Tie Plate Model ....................................................................................... 24
   6.2. Inner Tie Block Model ............................................................................ 25
   6.3. Corner Tie Block Model .......................................................................... 32
7. CONCLUSIONS ............................................................................................... 39
8. REFERENCES .................................................................................................. 40

FIGURES

1. Weld test finite element model ....................................................................... 6
2. Graphical depiction of weld element representation .................................. 7
3. Weld element test model shear stresses for axial load case .......................... 8
4. Fuel rack tie plate (inner tie blocks) finite element model ........................... 9
5. Second tie plate model ............................................................................... 11
6. Second tie plate finite element model and boundary conditions .................... 12
7. Side view of second tie plate model showing contact surfaces ....................... 13
8. Relative displacements of inner tie blocks used in second tie plate analysis ........ 14
9. Fuel rack section including inner tie seismic block included in model ............... 15
10. Finite element mesh of the fuel rack model ................................................ 17
11. Inner tie block weld groups included in the fuel rack finite element model ......... 18
12. Area of inner tie block subject to surface pressure loading ......................... 19
13. Finite element mesh of fuel rack corner tie model ....................................... 21
14. Weld groups included in fuel rack corner tie block finite element model .......... 22
15. Shear stress distribution along top plate – port tube weld length .................. 26
16. Shear stress distribution along top plate – soffit plate weld .......................... 26
17. Shear stress along soffit plate – port tube weld, inner weld ......................... 27
18. Shear stress along soffit plate – port tube weld, outer weld ......................... 27
19. Shear stress along top plate – seismic block weld ...................................... 28
20. Shear stress along seismic block – back plate weld ................................... 28
21. Shear stress along back plate – port tube weld ........................................ 29
22. Shear stress along seismic block – soffit plate weld ................................... 29
23. Shear stress along seismic block – back plate top weld ............................... 30
24. Shear stress along soffit plate – port tube weld, inner weld (full pool load case) .... 30
25. Shear stress along soffit plate – port tube weld, outer weld (full pool load case) .......... 31
26. Shear stress along back plate – port tube weld (full pool load case) .............................. 31
27. Top plate – port tube weld shear stress, corner tie block ............................................. 33
28. Top plate – soffit plate weld shear stress, corner tie block, model 2 direction ..................... 34
29. Top plate – soffit plate weld shear stress, corner tie block, model 1 direction ..................... 34
30. Soffit plate – port tube weld shear stress, corner tie block, model 2 direction ..................... 35
31. Soffit plate – port tube weld shear stress, corner tie block, model 1 direction ..................... 35
32. Seismic block – back plate weld shear stress, corner tie block ........................................ 36
33. Seismic block – soffit plate weld shear stress, corner tie block, model 1 direction .............. 36
34. Seismic block – soffit plate weld shear stress, corner tie block, model 2 direction .............. 37
35. Seismic block – top plate weld shear stress, corner tie block ........................................ 37
36. Back plate – port tube weld shear stress, corner tie block ............................................. 38

TABLES

1. Comparison of corner tie block loads ................................................................. 23
2. Tresca stresses in inner tie block model components .................................................. 32

APPENDICES

A. Computer Program Verification Information ............................................................... A-1
B. Model Input Data For The Weld Element Test Model ................................................. B-1
C. Input Data For The Tie Plate Model ........................................................................... C-1
D. Input Data For The Inner Tie Model .......................................................................... D-1
E.  Input Data For The Corner Tie Model ........................................... E-1

F.  Stress Output For The Tie Plate Model .............................................. F-1
Analysis Of ICPP Fuel Storage Rack
Inner Tie And Corner Tie Substructures

1. INTRODUCTION

Holtec International (hereafter referred to as "Holtec") performed the design and analysis of spent fuel storage racks for installation in the Idaho National Engineering Laboratory’s (INEL) Idaho Chemical Processing Plant (ICPP), Building 666, Pools 1 and 5. This work was done as Holtec Project Number 40254 under Lockheed Idaho Technologies Company (LITCO) Purchase Order Number 222833. The design description and associated calculations were documented in Reference 1.

As required by Department of Energy Standard 1020-94 (Ref. 2), the design and the associated calculations have been subjected to an independent peer review as part of the overall quality assurance plan. Advanced Engineering Consultants, Inc., were retained by LITCO to perform this function.

During the course of the independent review, questions were raised regarding the adequacy of certain welds to withstand the loading that would be imposed by the motion of the adjacent fuel racks during a seismic event. The welds in question were those that join the various structural components in the immediate areas of the seismic inner tie block and the seismic corner tie block. Holtec based the original design of these welds on the assumptions and hand calculations contained in the Reference 1 report. The independent reviewer questioned the weld adequacy based on an alternate set of calculations that were performed as part of the review process. To resolve the inner tie and corner tie weld adequacy questions it was suggested that analyses be performed by a "third party" using the more rigorous finite element analysis approach. The Applied Mechanics Group within LITCO’s Specialty Engineering & Sciences Department was given the task of performing these analyses. As a result, separate finite element models representing the tie plate that connects the inner tie blocks of two adjacent rack structures, portions of the fuel rack structure encompassing one inner tie block assembly, and portions of the fuel rack structure encompassing one corner tie block assembly were developed. This report describes the details of the finite element analyses performed on the three models and the results obtained.
2. SCOPE OF ANALYSIS

The inner tie block and corner tie block structures and the tie plate addressed in this report were taken from a 25 port fuel rack assembly designed for installation in Pool 1 of ICPP 666. The storage ports in this design are arranged in a 5 X 5 grid array. The details of this rack design are unique for the 25 port racks; however, the portions of the rack and tie plate that were modeled also apply to the 30 port (6 X 5 grid array) rack design that will also be installed in Pool 1. The scope of this analysis was limited to the specific components described in the following report sections and does not apply to the other rack designs for Pool 5.

Independent reviewer questions regarding the integrity of the welds joining the inner tie blocks and corner tie blocks to the surrounding rack structure initiated this analysis effort. To address these questions and limit the scope of the analysis effort, three finite element models were developed. One model represents the tie plate that is used to transfer seismic loads between the inner tie blocks of adjacent racks. The next model represents an inner tie block (also called a "seismic block") and a portion of the rack structure (top plate, port tubes, soffit plate, and back plate) that immediately adjoin it. The third main model represents a corner tie block and a portion of the rack structure (top plate, port tube, soffit plates, and back plate) that immediately adjoin it. Details of the structural components were obtained from the Reference 3 drawing. The inner tie and corner tie finite element models represent only a section of the rack surrounding one of the tie blocks. The results of the analyses described in this report apply only to the specific models and cannot be construed to apply to the complete rack assembly. Structural adequacy of the overall rack design was addressed in Reference 1.

The elastic analysis results were compared to allowable values described in the Reference 1 report. The plastic analysis results were compared to allowable values found in Subsection NF and Appendix F of the American Society of Mechanical Engineers Boiler & Pressure Vessel Code (hereafter referred to as the ASME Code) (References 4 and 5, respectively). As described in the Reference 1 report, the structure was treated as an ASME Class 3 plate and shell support structure.

Also included in the work scope for this project was a very brief parameter study of various methods and element types that might be used to represent the welds in the finite element model. This study was undertaken to verify the applicability of various modeling techniques and finite element types in providing reasonable representations of the structural welds. A separate, smaller, model was developed for this purpose so the results could be examined prior to the development of the much larger and more complex finite element model of the inner tie block area of the rack.

The overall scope of this task was purposely limited to only those rack components where a third party analysis was desired. Since the Holtec calculations (Reference 1) had already been independently reviewed, a concerted effort was made to utilize as much of the previously reviewed data as appropriate. This information included items such as material properties, elastic stress allowable values, and geometric data from drawings. This approach helped to limit the review effort required for these analyses and minimize the schedule and budget requirements for the overall task.
3. FUEL RACK STRUCTURAL DESCRIPTION

The overall configuration of the 25 port fuel storage rack is that of a 5 X 5 port grid where each fuel storage port is a square tube with outside dimensions of approximately 10.55 inches per side and a length of approximately 219.25 inches. The ports are maintained in relative position by a separate top, middle, and bottom plate assembly. Viewed from above, the rack structure has a square planform measuring approximately 69.25 inches per side. The top plate is formed with a radius at the edges of the port grid so that the plate extends downward approximately four inches where it is joined by welds to horizontal soffit plates. The soffit plates are welded to the sides of the outer port tubes in the rack grid forming the equivalent of a closed section that acts as a stiffening member for the top perimeter of the rack assembly. A corner tie block is located at each of the four corners of the top of the rack assembly while four inner tie blocks are equally spaced along each of the four edges between the corner tie blocks. The corner tie and inner tie blocks are welded into the closed section formed by the top plate and soffit plate. As mentioned above, both the corner and inner tie blocks are also referred to as “seismic blocks” and are used to attach tie plates between adjacent rack assemblies so that overall resistance to seismic loading of all racks located in Pool 1 will be increased. Details of the individual rack design and the inner tie components can be seen in the Reference 3 drawing.
4. STRUCTURAL ACCEPTANCE CRITERIA

The acceptance criteria used by Holtec in the design of the rack structure were described in Section 4 of the Reference 1 report. Briefly, the design was based on criteria defined by the procurement specification (Reference 6) and other governing or guideline documents such as the United States Nuclear Regulatory Commission's (NRC's) Standard Review Plan (Reference 7). The rack was classified as a seismic Category I structure designed under the ASME Code Class 3 rules. Thus, elastic stress criteria given in Section III, Subsection NF, of the ASME Code were used. For ASME Code Service Level D loads such as seismic, the stress allowables as defined in Appendix F of the ASME Code for plate and shell component supports were used. Since the allowable stress values contained in the Holtec design report (Reference 1) received an independent review, they were also utilized for the elastic calculations performed on the tie plate model. The reader is directed to Reference 1 for a more complete discussion of the elastic stress allowable values; however, for convenience, the allowable values used specifically for evaluation of the tie plate are summarized below:

- General primary membrane stress intensity shall not exceed the lesser of $2.4S_m$ and $0.7S_u$ as stated in F–1331.1(a).
- Primary membrane plus bending stress intensity shall not exceed 150% of the limit for general primary stress intensity (see above) as stated in F–1331.1(c)(1).
- Average tensile stress computed on the basis of available bolt tensile stress area shall not exceed the lesser of $S_y$ and $0.7S_u$ as stated in F–1335.

Since the rack structure was classified as a Class 3 plate and shell support structure, the guidelines in Subsection NF–3260 (Design By Analysis For Class 3) apply. Table NF–3553(b)–1 states that the stress limits found in Appendix F of the ASME Code apply for Service Level D conditions. Paragraph F–1340 delineates the appropriate criteria when using plastic analysis while Paragraph F–1342 provides additional criteria specifically for plate and shell type supports. Thus, the criteria found in F–1340 were used for comparison to the plastic analysis stress results.

In summary, the applicable plastic analysis stress limits are as follows:

- General primary membrane stress intensity shall not exceed $0.7S_u$ as stated in F–1341.2(a).
- Maximum primary membrane stress intensity shall not exceed $0.9S_u$ as stated in F–1341.2(b).
- Average primary shear stress across a section loaded in pure shear shall not exceed $0.42S_u$ as stated in F–1341.2(c).
- Also, as stated in F–1342(a), “neither peak stresses nor stresses resulting from thermal expansion within the component support need be evaluated.”

Since the failure mechanism for the welds is typically considered to be a shear failure across the throat area of the weld, the $0.42S_u$ limitation (29.4 ksi) was used as the governing stress limit in the welds.
5. MODEL DEVELOPMENT

5.1. Material Properties

As listed in the Reference 3 drawing, the rack structure was constructed of all stainless steel components. The port tubes, soffit plates, and top plate were all formed from SA240–304L plate material while the tie blocks (both inner and corner) are from SA479–304L. The following material properties are the same as used by Holtec in their analyses and are listed in Section II, Part D, (Reference 8) of the ASME Code. Since the maximum anticipated temperature is 100°F, the properties are given at that temperature.

- Modulus of Elasticity, \( E \) = 28.14 x 10^6 psi
- Mean Coefficient of Thermal Expansion, \( \alpha \) = 8.55 x 10^{-6} \text{ in./in. } ^\circ\text{F}
- Yield Stress, \( S_y \) = 25.0 ksi
- Ultimate Stress, \( S_u \) = 70.0 ksi

The ABAQUS software requires plastic stress and strain data to define material behavior in inelastic analyses. The program requires that values of true stress and plastic strain be entered. The data used (304L stainless steel) were obtained from Reference 9 and are listed below:

<table>
<thead>
<tr>
<th>True Stress (ksi)</th>
<th>Plastic Strain (in./in.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>25.0</td>
<td>0.0</td>
</tr>
<tr>
<td>35.0</td>
<td>0.002</td>
</tr>
<tr>
<td>84.0</td>
<td>0.182</td>
</tr>
</tbody>
</table>

The only variation in material used in the racks was in the weld filler metal. Information provided from Holtec indicated that 308 stainless steel was used. Holtec provided properties of the filler metal that were obtained from four different mill certification tests. These data are summarized below:

- Yield Stress, \( S_y \) = 53.0 – 59.0 ksi
- Ultimate Stress, \( S_u \) = 81.8 – 84.0 ksi
- Percent Elongation = 45%
- Percent Reduction in Area = 62 – 77%

5.2. Weld Element Test Model

The calculations performed by Holtec for the qualification of the welds in the area of the inner tie block and corner tie block were done using conventional “hand calculation” techniques. Typical hand calculation methods determine an average stress on the throat area of the weld and do not include consideration of any peak stresses at structural discontinuities. As discussed above, this approach is in conformance with ASME Code guidelines. However, when using the finite element method, results are usually obtained at several points within each element. By its nature then, the finite element method provides location specific results and will include the effects of peak stresses near structural discontinuities. Since welds are typically treated as failing in shear, we wanted to use a modeling technique that would provide sufficient information about the shear forces in the welds without using excessive modeling detail. A simple intersection of the plate members at a common node would not provide the desired information regarding the shear forces within the welds. Using excessive detail in the finite element model (for example, using higher order three-dimensional solid elements) would result in longer computer solution times and was considered unnecessary for this project.
A small test model was developed early in this task to investigate several possible alternative approaches for modeling the welds. This was done as a very brief parameter study of the use of different plate element types and modeling techniques that might be used. A separate, smaller, model was developed for this purpose so the results could be examined prior to the development of the much larger and more complex finite element model of the inner tie block area of the rack.

The test model that was used consisted of two plates positioned at right angles to form a “T.” The plates were both 0.25-in. thick with the back plate being slightly larger in area than the perpendicular front plate. The back plate was fixed in all six degrees of freedom at each corner. The plates were assumed to be attached by a 0.25-in. fillet weld. The same material properties (304L stainless steel) as the fuel rack were used in the test model. 204 nodes and 174 elements were used in the model that was developed with the I-DEAS Master Series (Version 1.3c) solid modeling software and then translated for solution on the ABAQUS (Version 5.4) finite element analysis software. An overall view of the finite element model is shown in Figure 1.

![Figure 1. Weld test finite element model.](image-url)
The weld test model was run with a variety of loads on the 4-in. X 4-in. plate (axial load is shown in Figure 1) and several different methods of representing the weld were investigated. The results of this study showed that representing the weld with a series of plate elements that had the plate thickness equal to the throat thickness of the weld and the element width adjusted so that the cross-sectional area of the element was equal to the weld cross-sectional area gave reasonable weld element shear stress results. The weld element configuration is graphically depicted in Figure 2.

As mentioned, Figure 1 shows an axial load applied to the perpendicular plate of the test model and this load case will be used to illustrate the results obtained in the test model analyses. A 900 pound axial load was applied for this case. Using conventional hand calculation techniques, the total throat area of the weld is 0.707-in.² (0.707 X 0.25 X 4). This gave an average stress on the weld throat area of 1271.2 psi (900 lb./0.707-in.²). This average stress does not account for any peak stresses that may occur at the ends of the welds. Figure 3 shows a plot of the shear stresses calculated in the weld versus position (at the element centroids) along the weld length. This plot shows shear stress calculated by the finite element solution and the average shear stress calculated by hand methods. As expected, the finite element analysis results clearly include peak stress effects that occur at the ends of the weld near the top and bottom edges of the front plate; however, the stresses in the elements near the center of the weld length are less than the hand calculation average. These results are typical of those obtained with the other load cases.

The results obtained from the weld element study allowed us to select a modeling technique and element that we believe reasonably approximates the shear stress behavior in the welds and would

![Typical Fillet Weld](image1)

<table>
<thead>
<tr>
<th>Typical Fillet Weld</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plate element cross-sectional area (t X wp) equals weld cross-sectional area (0.5 X a X a)</td>
</tr>
</tbody>
</table>

![Plate Representation of Weld](image2)
provide reasonable results when applied to the larger, more complex models of the inner tie and corner tie block areas.

Computer program verification sheets for those computer codes used to perform finite element structural calculations are included in Appendix A. No verification sheet is included in Appendix A for I-DEAS because this code was only used for model development. The geometric correctness of the model developed using I-DEAS was independently verified. As indicated in the table of contents, model input data is included in Appendix B. Most coordinate and element connectivity data is omitted because it is voluminous and not practical to check by examination.

### 5.3. Tie Plate Model

The tie plate was modeled using the ALGOR (Version 11.08-3H) finite element package. The purpose of this model was to determine the stresses in the tie plate and the tie block stud bolts and to provide loads from prying action of the tie plate on the inner tie blocks. A two rack seismic tie plate (an inner tie plate) ties two racks together along their edges. The plate is 2.5-in. wide and 5.5-in. long with two 1.5-in. diameter holes with centers spaced 2.5-in. apart. A corner tie plate connects 4 racks together at their corners. It consists of a square plate, 5.5-in. on each side with 4 holes in a square pattern with centers 2.5-in. apart. The corner tie plate thus approximates 2 inner tie plates side by side and welded together. Both the inner tie plate and the corner tie plate are fabricated from SA240, TP304L, stainless steel as used in most of the other rack components. Only the inner tie plate was analyzed. Results from that analysis were used to draw conclusions about the acceptability of the corner tie and the loads on a corner block.

The ALGOR finite element model consisted of 327 node points, 264 plate/shell elements, 44 beam elements, and 6 boundary elements. The finite element mesh is shown in Figure 4. Loading was based...
Figure 4. Fuel rack tie plate (inner tie blocks) finite element model.
on the Holtec design report (single rack analysis, Reference 1) and consisted of a 26,189 lbf net vertical load on each block connecting to the tie plate. As part of the boundary conditions, a rotational stiffness was input based on data from the fuel rack model (discussed later in Section 5.4) in the area of the inner tie block. The 26,189 lbf load was imposed by applying a vertical deflection that represents relative movement between the 2 blocks. The deflection magnitude was an amount which results in the appropriate 26,189 lbf load. An additional loading case was run for the inner tieplate with the net vertical load reduced from 26,189 lbf to 24,500 lbf but with a horizontal load of 11,833 lbf. This load case was based on Holtec’s results for a coupled analysis of all racks installed in the pool and interconnected with the tie plates. The stresses resulting from these loading cases were calculated using the SUPERSAP finite element solver that is part of the ALGOR package.

The analytical results obtained for this model are discussed in Section 6 (Analysis Results). The verification sheet for the SUPERSAP finite element program is included in Appendix A with the similar documentation for those computer codes used to perform finite element structural calculations. As indicated in the table of contents, model input data is included in Appendix C. Most coordinate and element connectivity data was omitted because it was voluminous and not practical to check by examination.

Subsequent to the analysis of the tie plate model described above, preliminary analytical computer runs of the finite element model that included a portion of the fuel rack and inner tie block (see discussion in Section 5.4 below) indicated that a more refined load distribution of the prying action of the tie plate on the inner tie block would be beneficial. As discussed later in this report (Section 6), the original tie plate model results were used to demonstrate the structural integrity of the tie plate and bolts. It was decided to develop a second tie plate model that included the tie plate and two corresponding inner tie blocks. This model was developed solely for the purpose of investigating the prying load distribution under possible plastic action that might result from relative displacement of the inner tie blocks. This effect could not be investigated with the previous tie plate elastic model.

This second tie plate model was developed using the I-DEAS solid modeling software. This model included the tie plate, two adjacent inner tie blocks, and the bolts and nuts securing the tie plate to the inner tie blocks. A general depiction of the model components is shown in Figure 5. The model contained approximately 2200 three-dimensional solid “brick” type elements and incorporates the material properties of the A240, TP304L, stainless steel appropriate to the actual components. Boundary conditions were imposed on the model to restrain the left inner tie block from translation in any direction while the right block is restrained from motion in the horizontal directions and given a vertical displacement along the right side to simulate the vertical seismic motion of one fuel rack moving relative to an adjacent rack. The bolt is attached to the bottom of the block with a round beam element using the stress area of a 1 inch bolt. The bending stiffness of the attached fuel rack is represented by springs at the bottom of the block and horizontal restraints part way down the side of the block. The stiffness values were determined based on the structural response of the surrounding rack as determined by results obtained from the inner tie finite element model described in the next report section. Contact surfaces were used between each bolt head and the tie plate and between the tie plate and the top surface of each block. The contact surfaces may deform and transmit forces to the other surface, but will not let the elements from one surface penetrate the other surface. The finite element model and the associated boundary conditions are shown in Figure 6. The contact surfaces are shown with greater clarity in the side view of the model contained in Figure 7.

Holtec’s design analysis of the complete rack structure was performed using elastic methods and provided a net load on the inner tie block. Two computer runs were used to refine the distribution of this load on the inner tie block. The first run was performed with a purely elastic solution and the strain
Figure 5. Second tie plate model.
Figure 6. Second tie plate finite element model and boundary conditions.
Figure 7. Side view of second tie plate model showing contact surfaces.

energy needed to reach the net load calculated by Holtec was noted. The second run was performed allowing plasticity and, again, the total strain energy was noted as the relative vertical displacement between the blocks increased. The relative displacement between the blocks, as used in these computer runs, is depicted in Figure 8. The second run was considered completed when the energy equaled that obtained in the first (purely elastic) run. The results of the second run included any plastic action in the tie plate and upper portions of the inner tie blocks and provided the desired refinement and accuracy of the load distribution on the inner tie block. This plasticity tends to soften and spread the effects of the prying action on the right inner tie block (which moves up relative to the left block). The resulting nodal loads were subsequently used as input to the more complex finite element model of the portion of the fuel rack that included the inner tie block.

The ABAQUS (Version 5.4) finite element software with its optional Explicit solver was used for the two computer runs described above. A computer program verification sheet for ABAQUS Explicit is included in Appendix A. No verification sheet is included in Appendix A for I-DEAS because this code was only used for model development. The geometric correctness of the model developed using I-DEAS was independently verified.

5.4. Inner Tie Block Model

The inner tie block finite element model was developed with the I-DEAS Master Series (Version 1.3c) solid modeling software using model geometry data obtained from the Reference 3 drawing. Since the primary object of this task was to investigate the stress levels in the weld groups surrounding the inner
tie blocks, only a portion of the rack structure was included in the model. The modeled area of the fuel rack was selected to provide sufficient detail of the various structural components surrounding the inner tie block so that accurate interaction of the components would be obtained without using a model that was unnecessarily large. The final model included portions of two fuel storage port tubes, a portion of the rack structure top plate, one inner tie block, the back plate that attaches the inner tie block to the port tubes, and portions of the soffit plates that are adjacent to the inner tie block. An overall view of the portion of the rack structure that was included in the model is shown in Figure 9.

The stainless steel material properties previously described in section 5.1 (Material Properties) were used for all components of the model. Symmetry boundary conditions were applied on the “cut” edges of the model where the actual structure is continuous. These boundary conditions will ensure that realistic structural response is obtained in the area of interest around the inner tie block and the attaching welds.

The finite element model contains 14013 nodes and 13306 elements. With the exception of the inner tie block, four-node quadrilateral plate elements were used throughout the model except for a limited number of transition areas where three-node triangular plate elements were used. The inner tie block was represented primarily with eight-node solid “brick” elements except for a limited number of transition...
areas where six-node solid “wedge” elements were employed. The finite element mesh is shown in Figure 10. The model was subsequently translated to the ABAQUS (Version 5.4) finite element analysis software for the solution computer runs.

The node and element grouping functions in both I-DEAS and ABAQUS were used to define groups of nodes for loading and specified output requests. Groups of elements were also defined for specified output requests and post-processing use. Separate element groups were defined for each of the weld groups that exist in the portion of the fuel rack structure that was modeled. These weld element groups are shown in Figure 11.

The primary loading mechanism is a surface pressure on the top of the inner tie block that results from prying action of the tie plate caused by the relative motion of the adjacent fuel racks during a seismic event. This surface pressure is combined with a counter-acting upward vertical force in the bolt installed in the inner tie block to result in the 26,189 lbf net force obtained from the Holtec single rack analysis results. The second tie plate model described in the previous report section was used to determine the area of the inner tie block on which the surface pressure acts and the magnitude of the loads. The loading on the right block shown in Figure 8 was used in this analysis since the loads were more severe on the right block than on the left block. The surface pressure loads were applied to the inner tie block as equivalent nodal forces. The results of the tie plate analysis showed that the surface pressure was only significant on the outer region of the inner tie block top surface. This region corresponds to the outer two rows of elements on the top of the inner tie block as shown in the shaded area of Figure 12. The appropriate equivalent nodal loads were applied to the three rows of nodes that enclosed in this area as shown in Figure 12.

In response to a design review comment, Holtec also performed a seismic analysis of all 25 rack assemblies interconnected as they would be after final installation. This effort was termed as the “full pool analysis.” The results of the full pool analysis were used to provide another set of loads for consideration with the inner tie block finite element model. These alternate loads included a lower net vertical load (20,170 lbf versus 26,189 lbf) than that obtained from the single rack analysis and a horizontal load of 4,933 lbf. No horizontal load was used in the single rack design analysis. An additional computer run was made using the loads from Holtec’s full pool analysis. The vertical load was applied as a series of downward loads on the appropriate nodes making up the pressure surface and a counter-acting upward bolt load to achieve the net vertical load of 20,170 lbf. The horizontal load was applied as a series of nodal forces acting outward (+2 direction shown in Figure 10) on the nodes making up the outer half of the bolt circumference on the top of the inner block. This choice of horizontal load direction and application position was selected because it would produce the most severe loading combination and resulting stresses on the fuel rack structure.

The analytical results obtained for this model are discussed in Section 6 (Analysis Results). The verification sheet for the ABAQUS (Version 5.4) finite element software is included in Appendix A with similar documentation for those computer codes used to perform finite element structural calculations. No verification sheet is included in Appendix A for I-DEAS because this code was only used for model development. The geometric correctness of the model developed using I-DEAS was independently verified. As indicated in the table of contents, model input data is included in Appendix D. Most coordinate and element connectivity data is omitted because it is voluminous and not practical to check by examination.

5.5. Corner Tie Block Model

The corner tie model was developed using the ALGOR finite element package. The model created with ALGOR was subsequently converted to ABAQUS (Version 5.4) to be able to perform a plastic
Figure 10. Finite element mesh of the fuel rack model.
Figure 11. Inner tie block weld groups included in the fuel rack finite element model.
Figure 12. Area of inner tie block subject to surface pressure loading.

analysis solution and for consistency with the inner tie analysis. The primary area of concern was the welds but results for the whole model were considered. The model includes a corner tie block, a one quarter section of the top eight inches of the adjacent port tube, the top plate, soffit plate and diagonal plate connecting the port tube to the block. From the block, the model extends to one half of the width of the port tube. Symmetry boundary conditions were applied along the “cut” surfaces that define the model boundaries. The base of the model was fixed in translation in the vertical direction. The welds were modeled as plate elements consistent with the methods discussed earlier for the weld test model. For example, the 1/4-in. fillet welds were modeled as plates with thickness equal to 0.18-in., the throat distance in the weld. Similarly, the single 1/8-in. fillet weld was modeled as plates with thickness equal to 0.088-in. The double 1/4-in. fillets (i.e. welded on both sides of the plate) were modeled with
thickness equal to 0.36-in., the combined throat thickness of the two welds. In all three cases the welds were modeled as 0.125-in. wide plates connecting the subject pieces.

The stainless steel material properties previously described in section 5.1 (Material Properties) were used for all components of the model.

The finite element model contains 1395 nodes and 1225 elements. With the exception of the corner tie block, four-node quadrilateral plate elements were used throughout the model. The corner tie block was represented primarily with eight-node solid “brick” elements except for a limited number of transition areas where six-node solid “wedge” elements were employed. 937 plate elements and 288 solid (brick and wedge) elements made up the total number of elements in the model. The finite element mesh is shown in Figure 13. Figure 14 depicts the specific weld element groups.

Loading was applied based on the results of the first tie plate analysis. This corresponded to the maximum loads obtained from the single rack design analysis by Holtec. The resulting loads were 37,050 lbf on one outer edge, 3580 lbf on the other outer edge, and a 12,510 lbf bolt load to the block bottom at the bolt center location. The bolt load was applied as a concentrated load on the bottom of the block. The loading on the block top edges was applied as a uniform line load. The dominant loading is an edge load applied to the outer edge of the corner tie block by the corner tie plate. This was originally applied with a uniform line load. The uniform line load caused excessive distortion in the ABAQUS model that prevented convergence to a solution. Appropriate load distribution to effect a uniform displacement along the edge was determined by applying uniform displacement along the line. Results of the uniform displacement run provided a workable nonuniform line load distribution.

In addition to the loading discussed, an additional case was added based on additional analysis work (the full pool analysis) performed by Holtec on their design. The additional case used a somewhat reduced net vertical load on the block but includes a horizontal load. The horizontal load was applied at the top center of the corner block since the load path would be through the tie plate and into the stud bolt. Actual loads applied for the two load cases are shown in Table 1 below.

Since preliminary analysis runs on the inner tie model indicated that plasticity could be expected in that model, it was decided to proceed directly with a plastic analysis solution for the corner tie model. The analytical results obtained for this model are discussed in Section 6 (Analysis Results). The verification sheet for the ABAQUS (Version 5.4) finite element software is included in Appendix A with the similar documentation for those computer codes used to perform finite element structural calculations. As indicated in the table of contents, model input data is included in Appendix E. Most coordinate and element connectivity data is omitted because it is voluminous and not practical to check by examination.
Figure 13. Finite element mesh of fuel rack corner tie model.
Weld Group Legend
1. Top Plate – Port Tube Weld
2. Top Plate – Soffit Plate Weld
3. Soffit Plate – Port Tube Weld
4. Seismic Block – Back Plate Weld
5. Seismic Block – Soffit Plate Weld
6. Seismic Block – Top Plate Weld
7. Back Plate – Port Tube Weld

Figure 14. Weld groups included in fuel rack corner tie block finite element model.
Table 1. Comparison of corner tie block loads.

<table>
<thead>
<tr>
<th>Load Case</th>
<th>Location</th>
<th>Direction</th>
<th>Magnitude (lb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Outer edge 1</td>
<td>Vertical down</td>
<td>37050</td>
</tr>
<tr>
<td>1</td>
<td>Outer edge 2</td>
<td>Vertical down</td>
<td>35800</td>
</tr>
<tr>
<td>1</td>
<td>Block bottom center</td>
<td>Vertical up</td>
<td>12510</td>
</tr>
<tr>
<td>2</td>
<td>Outer edge 1</td>
<td>Vertical down</td>
<td>32370</td>
</tr>
<tr>
<td>2</td>
<td>Outer edge 2</td>
<td>Vertical down</td>
<td>31210</td>
</tr>
<tr>
<td>2</td>
<td>Block bottom center</td>
<td>Vertical up</td>
<td>11930</td>
</tr>
<tr>
<td>2</td>
<td>Block top center</td>
<td>Horiz. axis 1</td>
<td>11833</td>
</tr>
<tr>
<td>2</td>
<td>Block top center</td>
<td>Horiz. axis 2</td>
<td>11833</td>
</tr>
</tbody>
</table>
6. ANALYSIS RESULTS

As previously noted, the finite element analyses to confirm the qualification of the tie plate were performed using the ALGOR SUPERSAP software. All other finite element analysis runs were completed using the ABAQUS (Version 5.4) software.

Since the allowable stress values contained in the Holtec design report (Reference 1) received an independent review, they were also utilized for the elastic calculations performed on the tie plate model.

The plastic analysis stress criteria found in Section F-1340 of the ASME Code were used for comparison to the plastic analysis stress results. In summary, the applicable stress limits are as follows:

- General primary membrane stress intensity shall not exceed $0.7S_u$ as stated in F-1341.2(a).
- Maximum primary stress intensity shall not exceed $0.9S_u$ at any location as stated in F-1341.2(b).
- Average primary shear stress across a section loaded in pure shear shall not exceed $0.42S_u$ as stated in F-1341.2(c).
- Also, as stated in F-1342(a), “neither peak stresses nor stresses resulting from thermal expansion within the component support need be evaluated.”

Since the failure mechanism for the welds is typically considered to be a shear failure across the throat area of the weld, the $0.42S_u$ limitation (29.4 ksi) was used as the governing stress limit in the welds.

6.1. Tie Plate Model

Examination of the finite element analysis results showed that membrane stresses were negligible for the first loading case (vertical load only) discussed in Section 5.3. The maximum primary membrane plus bending stress intensities (Tresca stresses) governed the structural response to the applied loads for this case. Inspection of the stress results showed that all Tresca stresses are below the 45 ksi allowable limit with the exception of two small areas next to one of the holes. Since peak stresses need not be considered, the higher stresses in these areas may be ignored. Thus, the stress criteria are satisfied for the first load case applied to the inner tie plate. The Tresca stresses calculated by the analysis are listed in Appendix F.

An additional loading case was run for the inner tieplate with the net vertical load reduced from 26,189 lb to 24,500 lb but with a horizontal load of 11,833 lb. This load case was based on Holtec’s results for their full pool analysis of all racks installed in the pool and interconnected with the tie plates. The previous load case had negligible membrane stress because loading was perpendicular to the plate. The horizontal load applied in this case results in significant membrane stresses and membrane plus bending stresses greater than the previous case. For this loading case, the maximum membrane plus bending stress intensity (Tresca stress) was 67.7 ksi while the maximum membrane stress intensity was 26.9 ksi. Examination of stress distribution shows that these are peak stresses and may be ignored. The remaining stresses are within allowables. Thus, the stress criteria are satisfied for the second load case applied to the inner tie plate. The stresses calculated by the analysis are also listed in Appendix F.
The corner tie plate was not individually modeled; however, geometric similarities to the inner tie plate can be used to confirm structural adequacy. The corner tie plate is slightly wider than two of the inner tie plates. One half of a corner block tie plate is 2.75-in. wide versus the 2.5-in. width of an inner tie plate. This is a 10% difference. The corner block load is 12% higher (28000/25000=1). Stresses in the inner tie plate have sufficient margins to the allowables to conclude the corner tie plate is adequate and no further analysis is necessary.

The maximum bolt load calculated by the analysis for the first load case was 25,940 lbf. This results in a tensile stress of 42.8 ksi which is less than the 98 ksi allowed. The maximum bolt loads calculated for the second load case were 21,340 lbf in the axial direction and a 6,581 lbf shear load. These loads resulted in a combined stress ratio of 0.544 which is well below the stress ratio limit of 1.0. Therefore, the bolts are structurally adequate.

6.2. Inner Tie Block Model

Preliminary elastic analysis computer runs indicated that plasticity could occur in certain areas of the model. These analyses also indicated that there was difficulty in demonstrating compliance with Service Level D elastic stress limits in Appendix F of Section III of the ASME Code at certain weld locations. Thus, the provisions in Appendix F for plastic analysis were exercised. The plastic analysis capabilities of the ABAQUS software were utilized to provide the computer results reported here. Not surprisingly, examination of the results showed that peak stresses occurred at structural discontinuities. The most severe example of this peak stress behavior was seen in the area where the soffit plate, soffit plate-to-port tube weld, back plate-to-port tube weld, and inner tie (seismic) block-to-back plate weld all terminate. The peak stress behavior occurred when both Holtec’s single rack design loads and the full pool analysis loads were applied to the model.

Since the welds were of primary concern in this task, the shear stresses were calculated throughout each of the weld groups and compared to the allowable value for average primary shear stress (29.4 ksi as noted above) permitted by the acceptance criteria. These shear stresses are the maximum engineering shear stress (half of the maximum Tresca stress) averaged at the three integration points through the weld element thicknesses. Plots showing stress versus distance along the length of each of the welds and the allowable value were prepared to help visualize these results. The stress distribution plots for the single rack design load case appear in Figures 15–23.

The reader should note that Figures 15–23 show results for only the single rack design load case. When the loads resulting from Holtec’s full pool analysis were applied to the fuel rack finite element model, it was found that the single rack design load analysis results were bounding at almost all locations. Plots showing stress versus distance along the length of the two critical welds (soffit plate-to-port tube and back plate-to-port tube) and the allowable value were prepared. These plots appear in Figures 24, 25, and 26. Since the overall structural qualification of the rack is based on the single rack design analysis and since the single rack design load case generally enveloped the full pool design load case results, only the results for the single rack design load case will be discussed further.

As shown in Figures 15–23, the weld stresses are generally well below the allowable value. Several of these plots (e.g., Figures 17, 20, 21, and 22) demonstrate peak stress effects at structural discontinuities as discussed above. In fact, Figures 17 and 21 show that the calculated maximum shear stresses exceed the...
Figure 15. Shear stress distribution along top plate – port tube weld length.

Figure 16. Shear stress along top plate–soffit plate weld.
Figure 17. Shear stress along soffit plate–port tube weld, inner weld.

Figure 18. Shear stress along soffit plate–port tube weld, outer weld.
Figure 19. Shear stress along top plate–seismic block weld.

Figure 20. Shear stress along seismic block – back plate weld.
Figure 21. Shear stress along back plate – port tube weld.

Figure 22. Shear stress along seismic block – soffit plate weld.
Figure 23. Shear stress along seismic block – back plate top weld.

Figure 24. Shear stress along soffit plate–port tube weld, inner weld (full pool load case).
Figure 25. Shear stress along soffit plate–port tube weld, outer weld (full pool load case).

Figure 26. Shear stress along back plate – port tube weld (full pool load case).
allowable shear stress value at one end of each of the respective welds. Closer examination of these plots shows that the shear stresses fall rapidly with distance away from the region of structural discontinuity and that the average shear stress level in these welds in the areas removed from the discontinuities is well below the allowable value. Recalling that the acceptance criteria direct that peak stresses need not be considered, it is evident that the acceptance criteria are satisfied at all weld locations.

The maximum stress intensities (Tresca stresses) in the plate members were also calculated during the analysis. Review of these results shows that all primary stresses are below the allowable limit of 63 ksi. A maximum Tresca stress of 71.7 ksi was calculated in the port tube walls at the area of the structural discontinuity formed by the termination of the soffit plate, soffit plate–to–port tube weld, back plate–to–port tube weld, and inner tie (seismic) block–to–back plate weld discussed above. As discussed above, and reinforced by the definitions found in Paragraph NB-3213.11 of the ASME Code, this is a peak stress. The primary stresses decrease with distance from the area of the discontinuity. The Tresca stresses in the port tube areas removed from the discontinuity are in the range of approximately 5–20 ksi. Thus, the general primary membrane stress limit of 0.7S_y (49.0 ksi) is met. Therefore, the port tube stress levels are acceptable. Peak effects were also seen in the other components near the area of the discontinuity; however, the maximum stress values still did not exceed the allowable value for primary stresses. The general range of Tresca stresses as well as the maximum value observed in each of the components (plates and inner tie block) comprising the model are summarized in Table 2 below. This table clearly demonstrates acceptability of the stress levels.

### Table 2. Tresca stresses in inner tie block model components.

<table>
<thead>
<tr>
<th>Component</th>
<th>Maximum Tresca Stress a (ksi)</th>
<th>Allowable Primary Stress (ksi)</th>
<th>Range of General Area Tresca Stresses (ksi)</th>
<th>Allowable Membrane Stress (ksi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top Plate</td>
<td>39.7</td>
<td>63.0</td>
<td>2 – 12</td>
<td>49.0</td>
</tr>
<tr>
<td>Seismic Block</td>
<td>57.4</td>
<td>63.0</td>
<td>2 – 16</td>
<td>49.0</td>
</tr>
<tr>
<td>Back Plate</td>
<td>57.4</td>
<td>63.0</td>
<td>5 – 36</td>
<td>49.0</td>
</tr>
<tr>
<td>Soffit Plate</td>
<td>59.4</td>
<td>63.0</td>
<td>10 – 20</td>
<td>49.0</td>
</tr>
<tr>
<td>Port Tubes</td>
<td>71.7</td>
<td>63.0</td>
<td>5 – 20</td>
<td>49.0</td>
</tr>
</tbody>
</table>

a. Includes peak stresses.

### 6.3. Corner Tie Block Model

The corner tie block design satisfies the primary stress intensity allowable of 63 ksi for plastic analysis. The maximum Tresca stress is 65.4 ksi in load case 1. This stress, which occurs just below the bottom end of the double 1/4-in. fillet connecting the block to the diagonal plate, includes a peak effect which need not be evaluated for seismic conditions. The Tresca stresses remote from the discontinuities range between approximately 5 – 40 ksi which are less than the general membrane stress limit of 0.7S_y (49.0 ksi).
The allowable general primary membrane stress is 49 ksi. An examination of the model areas where Tresca stresses exceed 49.0 ksi shows that none of these stresses can be classified as general membrane stress.

Since the welds were of primary concern in this task, the shear stresses were calculated throughout each of the weld groups and compared to the allowable value for average primary shear stress (29.4 ksi as noted above) permitted by the acceptance criteria. Examination of the results show the maximum weld shear stress occurs in the single rack design load case (case 1) and is 37.1 ksi. This stress occurs in the weld between the top plate and the corner of the port tube. Once again, this includes localized peak stress which need not be considered. Plots showing shear stress versus distance along the length of each of the welds and the allowable value were prepared to help visualize these results. The stress distribution plots for the single rack design load case appear in Figures 27–36. These welds are the same ones as shown in Figure 14. The shear stresses in the welds, excluding the peak area, generally range between 5 – 23 ksi. Since the overall structural qualification of the rack is based on the single rack design analysis and since the single rack design load case enveloped the full pool design load case results, no stress distribution plots similar to Figures 27–36 were included in this report for the full pool load case. It should be noted that the ABAQUS plate element used in the modeling has three integration points through the thickness. In all cases for the corner tie block model, the integration point which gave the highest stress was used in the evaluation. This is conservative when the stresses are compared to average or membrane stress limits.

Upon independent review of the results obtained for this model it was noted that the stress gradients within and between elements are rather large. Possibly a more detailed model would be more desirable if operating stresses and fatigue were an issue; but, fatigue is not addressed in this analysis. Holtec has separately performed a fatigue evaluation for the racks. Since peak stresses are not a consideration in the Service Level D loading considered, the model is adequate to demonstrate compliance with the acceptance criteria.

![Graph showing shear stress versus distance along the weld length](http://example.com/graph.png)

**Figure 27.** Top plate – port tube weld shear stress, corner tie block.
Figure 28. Top plate – soffit plate weld shear stress, corner tie block, model 2 direction.

Figure 29. Top plate – soffit plate weld shear stress, corner tie block, model 1 direction.
Figure 30. Soffit plate – port tube weld shear stress, corner tie block, model 2 direction.

Figure 31. Soffit plate – port tube weld shear stress, corner tie block, model 1 direction.
Figure 32. Seismic block – back plate weld shear stress, corner tie block.

Figure 33. Seismic block – soffit plate weld shear stress, corner tie block, model 1 direction.
Figure 34. Seismic block – soffit plate weld shear stress, corner tie block, model 2 direction.

Figure 35. Seismic block – top plate weld shear stress, corner tie block.
Figure 36. Back plate – port tube weld shear stress, corner tie block.
7. CONCLUSIONS

Finite element structural analyses were performed to investigate the stress levels in the welds joining the inner tie block and corner tie block to the surrounding rack structure of the 25 port and 30 port fuel rack assemblies designed for installation in Pool 1 at the ICPP. In the course of performing this task three finite element models were developed and analyzed. These models include the inner tie plate, a representative inner tie block assembly and surrounding area of the fuel rack, and a representative corner tie block assembly and surrounding area of the fuel rack. Acceptance criteria defined in the Holtec design report (Reference 1) were compared to the results of elastic calculations performed on the tie plate model. Acceptance criteria defined in Section F–1340 of the ASME Code were compared to the results of plastic calculations performed on the other two models.

All Tresca stresses in the inner tie plate were below the 45 ksi allowable limit for primary membrane plus bending stress intensity. The corner tie plate was not individually modeled; however, geometric similarities to the inner tie plate were used to confirm structural adequacy. A maximum bolt tensile stress of 42.8 ksi, which is less than the 98 ksi allowed, was calculated. Thus, it can be concluded that the stress criteria are satisfied for the inner tie plate, corner tie plate, and the tie block bolts.

Examination of the inner tie block model results showed that peak stresses occurred at structural discontinuities. The most severe example of this behavior was seen in the area where the soffit plate, soffit plate-to-port tube weld, back plate-to-port tube weld, and inner tie (seismic) block-to-back plate weld all terminate. Results showed that the maximum shear stresses in the welds in this area decrease rapidly with distance from the structural discontinuity and that the average shear stress levels in the welds were well below the allowable value. Application of the acceptance criteria leads to the conclusion that all welds are adequate. The maximum stress intensities (Tresca stresses) in the plate members and inner tie (seismic) block were also shown to be acceptable. These results lead to the conclusion that the welds and structural members comprising the inner tie block model are structurally adequate.

The corner tie block design was found to satisfy the acceptance criteria. When peak stress effects are excluded as directed by the acceptance criteria, shear stresses in the welds and Tresca stresses in the structural members were all within allowable limits. Based on these results, it was concluded that the welds and structural members comprising the corner tie block model are structurally adequate.

In summary, the results obtained from the analyses performed for this task indicate that the welds joining the inner tie block and corner tie block to the surrounding rack structure meet the acceptance criteria. Further, the structural members (plates and blocks) were also found to be within the allowable stress limits established by the acceptance criteria. The separate analysis performed on the inner tie plate confirmed the structural adequacy for both the inner tie plate and the corner tie plate. The analysis results verify that the inner tie and corner tie blocks should be capable of transferring the expected seismic load without structural failure.
8. REFERENCES


COMPUTER PROGRAM VERIFICATION INFORMATION

The following pages contain the standard Applied Mechanics Unit computer program verification sheets for each of the computer codes that were used to perform finite element analyses for this task.
The following documentation presents the traceability for computer programs used in the analysis reported here. This documentation should accompany any and all analysis reports transmitted by Applied Mechanics.

**Task:** ICPP Fuel Storage Rack Inner Tie and Corner Tie Analysis

**Charge No. or Work Package:** T99421122

**Report Title:** Analysis of ICPP Fuel Storage Rack Inner Tie and Corner Tie Substructures.

**Author:** M. E. Nitzel and R. G. Rahl  
**Date:** Dec. 1, 1995

**Program Used:** Algor SUPERSAP  
**Version:** 11.08–H  
**Module:** N/A

**Computer Used:** Gateway 2000  
**Model:** P5–90

**Verification Manual/Test Problem Manual/Example Manual:**  

Note that this is a "black box" installation – no access to the source code is available under this license.
The following documentation presents the traceability for computer programs used in the analysis reported here. This documentation should accompany any and all analysis reports transmitted by Applied Mechanics.

**Task:** ICPP Fuel Storage Rack Inner Tie and Corner Tie Analysis

**Charge No. or Work Package:** T99421122

**Report Title:** Analysis of ICPP Fuel Storage Rack Inner Tie and Corner Tie Substructures.

**Author:** M. E. Nitzel and R. G. Rahl

**Date:** Dec. 1, 1995

**Program Used:** ABAQUS

**Version:** 5.4

**Module:** Standard

**Computer Used:** DEC Alpha

**Model:** DEC Alpha 4720 (Casper Server)

DEC Alpha 2100/200 (Durango Server)

**Verification Manual/Test Problem Manual/Example Manual:**

Verification of Version 5.4 (Standard) for this computer installation is documented in letter CCO-4-95 (“Verification of HKS ABAQUS Version 5.4 for the DEC Platform,” C. C. O'Brien to Applied Mechanics Unit, February 7, 1995). Additional examples for verification use can be found in the ABAQUS Example Problems Manual published by Hibbitt, Karlsson, and Sorenson, Inc.

Note that this is a “black box” installation – no access to the source code is available under this license.
The following documentation presents the traceability for computer programs used in the analysis reported here. This documentation should accompany any and all analysis reports transmitted by Applied Mechanics.

Task: ICPP Fuel Storage Rack Inner Tie and Corner Tie Analysis

Charge No. or Work Package: T99421122

Report Title: Analysis of ICPP Fuel Storage Rack Inner Tie and Corner Tie Substructures.

Author: M. E. Nitzel and R. G. Rahl  Date: Dec. 1, 1995

Program Used: ABAQUS  Version: 5.4  Module: Explicit

Computer Used: DEC Alpha  Model: DEC Alpha 2100/200 (Durango Server)

Verification Manual/Test Problem Manual/Example Manual:

Note that this is a "black box" installation – no access to the source code is available under this license.
APPENDIX B

MODEL INPUT DATA FOR THE WELD ELEMENT TEST MODEL
APPENDIX C

INPUT DATA FOR THE TIE PLATE MODEL
APPENDIX D

INPUT DATA FOR THE INNER TIE MODEL
**ELEMENT.TYP=81**   .ELST-TRIANGLE

**TRIANGLE PLATE ELEMENT DATA ENTERED HERE**

**ELEMENT.TYP=49**   .ELST-QUADS

**QUADRILATERAL PLATE ELEMENT DEFINITIONS ENTERED HERE**
<table>
<thead>
<tr>
<th>S. MISES</th>
<th>SP. TRES C</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**END STEP**

The "END STEP" card line shown below is required to terminate all job steps.

**END STEP**
the following two nodes were added to defining elements 1609 and 11795

"to "unhook" them from the port tube wall

17386, 6.64864332-06, 3.74644776-01, 3.34652976-06
12089, 1.89818640-06, 3.74644776-01, 3.34652976-06

*ELEMENT,TYPE=STK13, ELEST=TRIANGLE

TRIANGULAR PLATE ELEMENT DEFINITIONS WERE ENTERED HERE.

*ELEMENT,TYPE=S4R, ELEST=QUAD

QUADRILATERAL PLATE ELEMENT DEFINITIONS WERE ENTERED HERE.

*ELEMENT,TYPE=CD0, ELEST=WEDGE

WEDGE TYPE SOLID ELEMENT DEFINITIONS WERE ENTERED HERE.

*ELEMENT,TYPE=CD10, ELEST=BRICKS

8 NODE SOLID ELEMENT DEFINITIONS WERE ENTERED HERE.

*SOFTPLATE ELEMENT GROUP

ELEST=ELEST=SOFTPL

THE SOFTPLATE ELEMENT GROUP WAS DEFINED HERE.

*BACKPLATE FINITE ELEMENT GROUP

ELEST=ELEST=BACKPL

THE BACKPLATE ELEMENT GROUP WAS DEFINED HERE.

*SEISMIC BLOCK FINITE ELEMENT GROUP - ALL 1-D SOLIDS

ELEST=ELEST=SEISMIC

THE SEISMIC BLOCK ELEMENT GROUP WAS DEFINED HERE.

SEISMIC BLOCK - BACK PLATE (SIDES) WELD ELEMENT GROUP

ELEST=ELEST=SEISMIC

THE TOP PLATE ELEMENT GROUP WAS DEFINED HERE.

SEISMIC BLOCK - SOFTPLATE WELD ELEMENT GROUP

ELEST=ELEST=SEISMIC

THE TOP PLATE WELD ELEMENT GROUP WAS DEFINED HERE.

ELEST=ELEST=TOPPL

THE PORT BOTTOM SURFACE NOSE GROUP - USED TO DEFINE BOUNDARY CONDITIONS

ELEST=ELEST=TOPPL

THE TOP PLATE WELD GROUP WAS DEFINED HERE.

ELEST=ELEST=TOPPL

THE PORT BOTTOM NOSE GROUP WAS DEFINED HERE.

ELEST=ELEST=TOPPL

THE RIGHT AND LEFT SIDE NOSE GROUP WAS DEFINED HERE.

*SOFTPLATE ELEMENT GROUP

THE SOFTPLATE ELEMENT GROUP WAS DEFINED HERE.

*BACKPLATE FINITE ELEMENT GROUP

THE BACKPLATE ELEMENT GROUP WAS DEFINED HERE.

*SEISMIC BLOCK FINITE ELEMENT GROUP - ALL 1-D SOLIDS

THE SEISMIC BLOCK ELEMENT GROUP WAS DEFINED HERE.

SEISMIC BLOCK - BACK PLATE (SIDES) WELD ELEMENT GROUP

THE TOP PLATE WELD ELEMENT GROUP WAS DEFINED HERE.

ELEST=ELEST=TOPPL

THE PORT BOTTOM SURFACE NOSE GROUP - USED TO DEFINE BOUNDARY CONDITIONS

ELEST=ELEST=TOPPL

THE TOP PLATE WELD GROUP WAS DEFINED HERE.

ELEST=ELEST=TOPPL

THE PORT BOTTOM NOSE GROUP WAS DEFINED HERE.

ELEST=ELEST=TOPPL

THE RIGHT AND LEFT SIDE NOSE GROUP WAS DEFINED HERE.
*EL. PRINT, ELSET=SP-FWOD, SUMMARY=YES, FREQUENCY=5
  S, N1, S2
  SP, TRESN
  E
  NE
  PE
  *EL. PRINT, ELSET=IS-FWOD, SUMMARY=YES, FREQUENCY=5
  S, N1, S2
  SP, TRESN
  E
  NE
  PE
  *EL. PRINT, ELSET=IS-FPFWOD, SUMMARY=YES, FREQUENCY=5
  S, N1, S2
  SP, TRESN
  E
  NE
  PE
  *EL. PRINT, ELSET=IS-SPFWOD, SUMMARY=YES, FREQUENCY=5
  S, N1, S2
  SP, TRESN
  E
  NE
  PE
  ... THE "END STEP" CARD LINE SHOWN BELOW IS REQUIRED TO TERMINATE ALL
  JOB STEPS.
  **
  "END STEP"
APPENDIX E

INPUT DATA FOR THE CORNER TIE MODEL
APPENDIX F

STRESS OUTPUT FOR THE TIE PLATE MODEL
Output of Tresca*2 [Stress].

Node : Information
  1: Val= 1.883e+04  110: Val= 4.517e+04  219: Val= 1.920e+04
  2: Val= 1.920e+04  111: Val= 1.521e+03  220: Val= 3.953e+04
  3: Val= 1.920e+04  112: Val= 1.735e+03  221: Val= 2.004e+04
  4: Val= 2.024e+04  113: Val= 1.181e+04  222: Val= 3.986e+04
  5: Val= 1.964e+04  114: Val= 1.434e+04  223: Val= 1.287e+04
  6: Val= 1.766e+04  115: Val= 5.427e+04  224: Val= 2.312e+04
  7: Val= 1.516e+04  116: Val= 2.289e+04  225: Val= 3.734e+04
  8: Val= 1.493e+04  117: Val= 7.123e+03  226: Val= 4.741e+03
  9: Val= 1.774e+04  118: Val= 1.193e+04  227: Val= 4.006e+04
 10: Val= 2.137e+04  119: Val= 3.554e+04  228: Val= 4.433e+04
 11: Val= 1.890e+04  120: Val= 4.908e+03  229: Val= 4.358e+04
 12: Val= 7.757e+03  121: Val= 3.540e+04  230: Val= 2.105e+04
 13: Val= 1.128e+04  122: Val= 5.069e+03  231: Val= 4.718e+04
 14: Val= 2.975e+04  123: Val= 3.372e+04  232: Val= 2.919e+04
 15: Val= 3.680e+04  124: Val= 2.690e+03  233: Val= 2.029e+04
 16: Val= 3.607e+04  125: Val= 4.316e+03  234: Val= 2.914e+04
 17: Val= 3.386e+04  126: Val= 4.708e+03  235: Val= 3.932e+04
 18: Val= 3.163e+04  127: Val= 4.195e+04  236: Val= 1.859e+04
 19: Val= 2.608e+04  128: Val= 1.316e+03  237: Val= 1.060e+04
 20: Val= 1.707e+04  129: Val= 1.449e+03  238: Val= 1.167e+04
 21: Val= 6.273e+03  130: Val= 5.661e+03  239: Val= 4.383e+04
 22: Val= 4.702e+03  131: Val= 3.680e+03  240: Val= 2.075e+03
 23: Val= 8.592e+03  132: Val= 4.517e+04  241: Val= 1.711e+03
 24: Val= 7.284e+03  133: Val= 2.341e+03  242: Val= 1.371e+04
 25: Val= 4.433e+03  134: Val= 1.894e+03  243: Val= 1.690e+04
 26: Val= 1.964e+03  135: Val= 2.139e+03  244: Val= 2.244e+04
 27: Val= 7.185e+02  136: Val= 1.637e+04  245: Val= 2.430e+04
 28: Val= 2.231e+04  137: Val= 3.733e+04  246: Val= 3.896e+04
 29: Val= 1.751e+04  138: Val= 2.842e+04  247: Val= 3.671e+04
 30: Val= 2.155e+04  139: Val= 2.595e+04  248: Val= 1.512e+04
 31: Val= 2.357e+04  140: Val= 1.229e+03  249: Val= 3.848e+03
 32: Val= 2.855e+04  141: Val= 1.466e+03  250: Val= 2.701e+04
 33: Val= 7.113e+03  142: Val= 1.985e+03  251: Val= 2.881e+04
 34: Val= 1.668e+04  143: Val= 2.335e+03  252: Val= 3.363e+04
 35: Val= 1.787e+04  144: Val= 3.773e+04  253: Val= 1.192e+04
 36: Val= 1.909e+04  145: Val= 1.002e+03  254: Val= 3.019e+04
 37: Val= 1.829e+04  146: Val= 1.167e+03  255: Val= 2.097e+04
 38: Val= 1.094e+04  147: Val= 5.316e+03  256: Val= 1.675e+04
 39: Val= 3.465e+04  148: Val= 1.551e+03  257: Val= 1.250e+04
 40: Val= 1.081e+04  149: Val= 3.351e+04  258: Val= 3.641e+04
 41: Val= 1.844e+04  150: Val= 4.932e+02  259: Val= 7.487e+03
 42: Val= 3.814e+04  151: Val= 8.287e+02  260: Val= 3.854e+04
<table>
<thead>
<tr>
<th></th>
<th>Val</th>
<th></th>
<th>Val</th>
<th></th>
<th>Val</th>
</tr>
</thead>
<tbody>
<tr>
<td>43</td>
<td>3.590e+04</td>
<td>152</td>
<td>1.868e+03</td>
<td>261</td>
<td>1.394e+04</td>
</tr>
<tr>
<td>44</td>
<td>7.806e+03</td>
<td>153</td>
<td>1.144e+03</td>
<td>262</td>
<td>1.542e+04</td>
</tr>
<tr>
<td>45</td>
<td>4.284e+03</td>
<td>154</td>
<td>1.669e+03</td>
<td>263</td>
<td>1.621e+04</td>
</tr>
<tr>
<td>46</td>
<td>1.394e+04</td>
<td>155</td>
<td>5.917e+03</td>
<td>264</td>
<td>1.890e+04</td>
</tr>
<tr>
<td>47</td>
<td>1.538e+04</td>
<td>156</td>
<td>3.440e+02</td>
<td>265</td>
<td>1.801e+04</td>
</tr>
<tr>
<td>48</td>
<td>3.677e+04</td>
<td>157</td>
<td>1.928e+04</td>
<td>266</td>
<td>1.824e+04</td>
</tr>
<tr>
<td>49</td>
<td>2.032e+03</td>
<td>158</td>
<td>3.907e+04</td>
<td>267</td>
<td>3.465e+04</td>
</tr>
<tr>
<td>50</td>
<td>1.290e+03</td>
<td>159</td>
<td>3.594e+04</td>
<td>268</td>
<td>1.080e+04</td>
</tr>
<tr>
<td>51</td>
<td>2.050e+04</td>
<td>160</td>
<td>2.480e+04</td>
<td>269</td>
<td>3.960e+03</td>
</tr>
<tr>
<td>52</td>
<td>2.292e+04</td>
<td>161</td>
<td>1.739e+04</td>
<td>270</td>
<td>2.059e+04</td>
</tr>
<tr>
<td>53</td>
<td>3.382e+04</td>
<td>162</td>
<td>2.455e+04</td>
<td>271</td>
<td>2.332e+04</td>
</tr>
<tr>
<td>54</td>
<td>9.446e+03</td>
<td>163</td>
<td>1.672e+02</td>
<td>272</td>
<td>3.679e+04</td>
</tr>
<tr>
<td>55</td>
<td>2.957e+04</td>
<td>164</td>
<td>5.476e+02</td>
<td>273</td>
<td>3.377e+04</td>
</tr>
<tr>
<td>56</td>
<td>2.094e+04</td>
<td>165</td>
<td>8.603e+02</td>
<td>274</td>
<td>9.402e+03</td>
</tr>
<tr>
<td>57</td>
<td>2.420e+04</td>
<td>166</td>
<td>7.292e+02</td>
<td>275</td>
<td>1.871e+03</td>
</tr>
<tr>
<td>58</td>
<td>2.767e+04</td>
<td>167</td>
<td>1.025e+03</td>
<td>276</td>
<td>1.153e+03</td>
</tr>
<tr>
<td>59</td>
<td>3.753e+04</td>
<td>168</td>
<td>5.240e+03</td>
<td>277</td>
<td>2.139e+04</td>
</tr>
<tr>
<td>60</td>
<td>1.218e+04</td>
<td>169</td>
<td>1.481e+03</td>
<td>278</td>
<td>2.338e+04</td>
</tr>
<tr>
<td>61</td>
<td>1.943e+04</td>
<td>170</td>
<td>3.310e+04</td>
<td>279</td>
<td>2.796e+04</td>
</tr>
<tr>
<td>62</td>
<td>2.590e+04</td>
<td>171</td>
<td>5.202e+02</td>
<td>280</td>
<td>7.506e+03</td>
</tr>
<tr>
<td>63</td>
<td>2.823e+04</td>
<td>172</td>
<td>1.939e+03</td>
<td>281</td>
<td>2.252e+04</td>
</tr>
<tr>
<td>64</td>
<td>2.599e+04</td>
<td>173</td>
<td>2.304e+03</td>
<td>282</td>
<td>1.730e+04</td>
</tr>
<tr>
<td>65</td>
<td>3.617e+04</td>
<td>174</td>
<td>3.767e+04</td>
<td>283</td>
<td>1.876e+04</td>
</tr>
<tr>
<td>66</td>
<td>3.496e+04</td>
<td>175</td>
<td>9.053e+02</td>
<td>284</td>
<td>1.911e+04</td>
</tr>
<tr>
<td>67</td>
<td>1.224e+04</td>
<td>176</td>
<td>1.105e+03</td>
<td>285</td>
<td>1.916e+04</td>
</tr>
<tr>
<td>68</td>
<td>1.844e+04</td>
<td>177</td>
<td>1.843e+03</td>
<td>286</td>
<td>2.010e+04</td>
</tr>
<tr>
<td>69</td>
<td>1.636e+04</td>
<td>178</td>
<td>2.864e+04</td>
<td>287</td>
<td>1.971e+04</td>
</tr>
<tr>
<td>70</td>
<td>1.821e+04</td>
<td>179</td>
<td>2.080e+03</td>
<td>288</td>
<td>1.759e+04</td>
</tr>
<tr>
<td>71</td>
<td>3.649e+04</td>
<td>180</td>
<td>1.679e+04</td>
<td>289</td>
<td>1.534e+04</td>
</tr>
<tr>
<td>72</td>
<td>9.141e+03</td>
<td>181</td>
<td>3.754e+04</td>
<td>290</td>
<td>1.496e+04</td>
</tr>
<tr>
<td>73</td>
<td>1.331e+04</td>
<td>182</td>
<td>2.625e+04</td>
<td>291</td>
<td>1.804e+04</td>
</tr>
<tr>
<td>74</td>
<td>2.589e+04</td>
<td>183</td>
<td>1.087e+03</td>
<td>292</td>
<td>2.136e+04</td>
</tr>
<tr>
<td>75</td>
<td>3.942e+04</td>
<td>184</td>
<td>1.325e+03</td>
<td>293</td>
<td>1.896e+04</td>
</tr>
<tr>
<td>76</td>
<td>3.922e+03</td>
<td>185</td>
<td>5.550e+03</td>
<td>294</td>
<td>7.687e+03</td>
</tr>
<tr>
<td>77</td>
<td>1.062e+04</td>
<td>186</td>
<td>3.510e+03</td>
<td>295</td>
<td>1.096e+04</td>
</tr>
<tr>
<td>78</td>
<td>1.164e+04</td>
<td>187</td>
<td>4.451e+04</td>
<td>296</td>
<td>3.020e+04</td>
</tr>
<tr>
<td>79</td>
<td>4.415e+04</td>
<td>188</td>
<td>2.156e+03</td>
<td>297</td>
<td>3.703e+04</td>
</tr>
<tr>
<td>80</td>
<td>2.158e+03</td>
<td>189</td>
<td>4.259e+03</td>
<td>298</td>
<td>3.580e+04</td>
</tr>
<tr>
<td>81</td>
<td>1.861e+03</td>
<td>190</td>
<td>4.691e+03</td>
<td>299</td>
<td>3.395e+04</td>
</tr>
<tr>
<td>82</td>
<td>2.059e+04</td>
<td>191</td>
<td>4.194e+04</td>
<td>300</td>
<td>3.177e+04</td>
</tr>
<tr>
<td>83</td>
<td>2.881e+04</td>
<td>192</td>
<td>1.164e+03</td>
<td>301</td>
<td>2.582e+04</td>
</tr>
<tr>
<td>84</td>
<td>4.086e+04</td>
<td>193</td>
<td>1.359e+03</td>
<td>302</td>
<td>1.699e+04</td>
</tr>
<tr>
<td>85</td>
<td>1.848e+04</td>
<td>194</td>
<td>5.163e+03</td>
<td>303</td>
<td>6.255e+03</td>
</tr>
<tr>
<td>86</td>
<td>4.744e+04</td>
<td>195</td>
<td>3.444e+04</td>
<td>304</td>
<td>4.693e+03</td>
</tr>
<tr>
<td>87</td>
<td>2.908e+04</td>
<td>196</td>
<td>2.611e+03</td>
<td>305</td>
<td>8.979e+03</td>
</tr>
<tr>
<td>88</td>
<td>3.974e+04</td>
<td>197</td>
<td>3.599e+04</td>
<td>306</td>
<td>7.085e+03</td>
</tr>
<tr>
<td></td>
<td>Val</td>
<td></td>
<td>Val</td>
<td></td>
<td>Val</td>
</tr>
<tr>
<td>---</td>
<td>---------</td>
<td>---</td>
<td>---------</td>
<td>---</td>
<td>---------</td>
</tr>
<tr>
<td>89</td>
<td>4.365e+04</td>
<td></td>
<td>198</td>
<td>7.267e+03</td>
<td></td>
</tr>
<tr>
<td>90</td>
<td>4.371e+04</td>
<td></td>
<td>199</td>
<td>1.288e+04</td>
<td></td>
</tr>
<tr>
<td>91</td>
<td>2.046e+04</td>
<td></td>
<td>200</td>
<td>3.552e+04</td>
<td></td>
</tr>
<tr>
<td>92</td>
<td>1.372e+04</td>
<td></td>
<td>201</td>
<td>4.852e+03</td>
<td></td>
</tr>
<tr>
<td>93</td>
<td>1.934e+04</td>
<td></td>
<td>202</td>
<td>1.236e+04</td>
<td></td>
</tr>
<tr>
<td>94</td>
<td>4.011e+04</td>
<td></td>
<td>203</td>
<td>1.347e+04</td>
<td></td>
</tr>
<tr>
<td>95</td>
<td>1.892e+04</td>
<td></td>
<td>204</td>
<td>5.477e+04</td>
<td></td>
</tr>
<tr>
<td>96</td>
<td>1.188e+04</td>
<td></td>
<td>205</td>
<td>2.187e+04</td>
<td></td>
</tr>
<tr>
<td>97</td>
<td>1.812e+04</td>
<td></td>
<td>206</td>
<td>7.254e+03</td>
<td></td>
</tr>
<tr>
<td>98</td>
<td>3.732e+04</td>
<td></td>
<td>207</td>
<td>8.017e+03</td>
<td></td>
</tr>
<tr>
<td>99</td>
<td>7.038e+03</td>
<td></td>
<td>208</td>
<td>4.569e+04</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>2.507e+04</td>
<td></td>
<td>209</td>
<td>1.436e+03</td>
<td></td>
</tr>
<tr>
<td>101</td>
<td>3.040e+04</td>
<td></td>
<td>210</td>
<td>1.641e+03</td>
<td></td>
</tr>
<tr>
<td>102</td>
<td>9.677e+03</td>
<td></td>
<td>211</td>
<td>2.507e+04</td>
<td></td>
</tr>
<tr>
<td>103</td>
<td>3.122e+04</td>
<td></td>
<td>212</td>
<td>3.150e+04</td>
<td></td>
</tr>
<tr>
<td>104</td>
<td>3.903e+04</td>
<td></td>
<td>213</td>
<td>5.253e+04</td>
<td></td>
</tr>
<tr>
<td>105</td>
<td>5.347e+04</td>
<td></td>
<td>214</td>
<td>2.072e+04</td>
<td></td>
</tr>
<tr>
<td>106</td>
<td>2.050e+04</td>
<td></td>
<td>215</td>
<td>1.010e+04</td>
<td></td>
</tr>
<tr>
<td>107</td>
<td>2.230e+03</td>
<td></td>
<td>216</td>
<td>3.167e+04</td>
<td></td>
</tr>
<tr>
<td>108</td>
<td>7.295e+03</td>
<td></td>
<td>217</td>
<td>2.374e+03</td>
<td></td>
</tr>
<tr>
<td>109</td>
<td>8.033e+03</td>
<td></td>
<td>218</td>
<td>1.405e+04</td>
<td></td>
</tr>
</tbody>
</table>

Max Value = 54767.851562 @ 204
Tieplate Horizontal Load = 11,833 lbf

Membrane Stress
Output of Tresca*2 [Stress].

Node Information

<table>
<thead>
<tr>
<th>Node</th>
<th>Val</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.066e+04</td>
</tr>
<tr>
<td>2</td>
<td>1.161e+04</td>
</tr>
<tr>
<td>3</td>
<td>1.165e+04</td>
</tr>
<tr>
<td>4</td>
<td>1.102e+04</td>
</tr>
<tr>
<td>5</td>
<td>9.045e+03</td>
</tr>
<tr>
<td>6</td>
<td>6.693e+03</td>
</tr>
<tr>
<td>7</td>
<td>4.766e+03</td>
</tr>
<tr>
<td>8</td>
<td>5.137e+03</td>
</tr>
<tr>
<td>9</td>
<td>7.965e+03</td>
</tr>
<tr>
<td>10</td>
<td>1.102e+04</td>
</tr>
<tr>
<td>11</td>
<td>1.307e+04</td>
</tr>
<tr>
<td>12</td>
<td>1.261e+04</td>
</tr>
<tr>
<td>13</td>
<td>1.158e+04</td>
</tr>
<tr>
<td>14</td>
<td>1.232e+04</td>
</tr>
<tr>
<td>15</td>
<td>1.377e+04</td>
</tr>
<tr>
<td>16</td>
<td>1.231e+04</td>
</tr>
<tr>
<td>17</td>
<td>1.149e+04</td>
</tr>
<tr>
<td>18</td>
<td>9.474e+03</td>
</tr>
<tr>
<td>19</td>
<td>3.136e+03</td>
</tr>
<tr>
<td>20</td>
<td>3.397e+03</td>
</tr>
<tr>
<td>21</td>
<td>6.312e+03</td>
</tr>
<tr>
<td>22</td>
<td>8.188e-03</td>
</tr>
<tr>
<td>23</td>
<td>7.968e+03</td>
</tr>
<tr>
<td>24</td>
<td>5.545e+03</td>
</tr>
<tr>
<td>25</td>
<td>2.511e+03</td>
</tr>
<tr>
<td>26</td>
<td>1.119e+03</td>
</tr>
<tr>
<td>27</td>
<td>9.844e+03</td>
</tr>
<tr>
<td>28</td>
<td>8.959e+03</td>
</tr>
<tr>
<td>29</td>
<td>1.097e+04</td>
</tr>
<tr>
<td>30</td>
<td>1.026e+04</td>
</tr>
<tr>
<td>31</td>
<td>8.918e+03</td>
</tr>
<tr>
<td>32</td>
<td>5.545e+03</td>
</tr>
<tr>
<td>33</td>
<td>2.511e+03</td>
</tr>
<tr>
<td>34</td>
<td>1.138e+04</td>
</tr>
<tr>
<td>35</td>
<td>9.578e+03</td>
</tr>
<tr>
<td>36</td>
<td>9.485e+03</td>
</tr>
<tr>
<td>37</td>
<td>1.307e+04</td>
</tr>
<tr>
<td>38</td>
<td>1.052e+04</td>
</tr>
<tr>
<td>39</td>
<td>1.099e+04</td>
</tr>
<tr>
<td>40</td>
<td>8.513e+03</td>
</tr>
<tr>
<td>41</td>
<td>8.777e+03</td>
</tr>
</tbody>
</table>

F-6
88: Val= 2.240e+04  197: Val= 1.347e+03  306: Val= 7.917e+03
89: Val= 1.958e+04  198: Val= 6.947e+03  307: Val= 5.416e+03
90: Val= 2.007e+04  199: Val= 2.059e+03  308: Val= 2.158e+03
91: Val= 2.643e+04  200: Val= 2.649e+03  309: Val= 1.049e+03
92: Val= 6.828e+03  201: Val= 6.980e+03  310: Val= 0.000e+00
93: Val= 6.699e+03  202: Val= 1.122e+04  311: Val= 0.000e+00
94: Val= 6.381e+03  203: Val= 6.056e+03  312: Val= 0.000e+00
95: Val= 1.364e+04  204: Val= 4.862e+03  313: Val= 0.000e+00
96: Val= 7.517e+03  205: Val= 9.879e+03  314: Val= 0.000e+00
97: Val= 2.798e+03  206: Val= 4.871e+03  315: Val= 0.000e+00
98: Val= 5.391e+03  207: Val= 5.095e+03  316: Val= 0.000e+00
99: Val= 1.070e+04  208: Val= 3.207e+03  317: Val= 0.000e+00
100: Val= 1.625e+04  209: Val= 4.854e+03  318: Val= 0.000e+00
101: Val= 1.183e+04  210: Val= 5.544e+03  319: Val= 0.000e+00
102: Val= 6.476e+03  211: Val= 1.604e+04  320: Val= 0.000e+00
103: Val= 2.355e+03  212: Val= 1.258e+04  321: Val= 0.000e+00
104: Val= 4.277e+03  213: Val= 1.064e+04  322: Val= 0.000e+00
105: Val= 1.076e+04  214: Val= 2.159e+04  323: Val= 0.000e+00
106: Val= 2.022e+04  215: Val= 6.684e+03  324: Val= 0.000e+00
107: Val= 6.324e+03  216: Val= 2.435e+03  325: Val= 0.000e+00
108: Val= 4.881e+03  217: Val= 6.597e+03  326: Val= 0.000e+00
109: Val= 5.108e+03  218: Val= 6.447e+03  327: Val= 0.000e+00

Max_Value = 26882. @ 230
Inner Tieplate Vertical Load = 24,500 lbf and Horizontal Load = 11.833 lbf
Membrane + Bending
Output of Tresca*2 [Stress].

<table>
<thead>
<tr>
<th>Node</th>
<th>Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Val= 4.818e+03</td>
</tr>
<tr>
<td>2</td>
<td>Val= 8.075e+03</td>
</tr>
<tr>
<td>3</td>
<td>Val= 1.085e+04</td>
</tr>
<tr>
<td>4</td>
<td>Val= 1.286e+04</td>
</tr>
<tr>
<td>5</td>
<td>Val= 1.481e+04</td>
</tr>
<tr>
<td>6</td>
<td>Val= 1.720e+04</td>
</tr>
<tr>
<td>7</td>
<td>Val= 2.190e+04</td>
</tr>
<tr>
<td>8</td>
<td>Val= 2.712e+04</td>
</tr>
<tr>
<td>9</td>
<td>Val= 3.181e+04</td>
</tr>
<tr>
<td>10</td>
<td>Val= 3.279e+04</td>
</tr>
<tr>
<td>11</td>
<td>Val= 2.932e+04</td>
</tr>
<tr>
<td>12</td>
<td>Val= 1.893e+04</td>
</tr>
<tr>
<td>13</td>
<td>Val= 1.539e+04</td>
</tr>
<tr>
<td>14</td>
<td>Val= 1.087e+04</td>
</tr>
<tr>
<td>15</td>
<td>Val= 1.115e+04</td>
</tr>
<tr>
<td>16</td>
<td>Val= 1.363e+04</td>
</tr>
<tr>
<td>17</td>
<td>Val= 1.537e+04</td>
</tr>
<tr>
<td>18</td>
<td>Val= 1.451e+04</td>
</tr>
<tr>
<td>19</td>
<td>Val= 1.105e+04</td>
</tr>
<tr>
<td>20</td>
<td>Val= 7.395e+03</td>
</tr>
<tr>
<td>21</td>
<td>Val= 6.284e+03</td>
</tr>
<tr>
<td>22</td>
<td>Val= 7.433e+03</td>
</tr>
<tr>
<td>23</td>
<td>Val= 8.767e+03</td>
</tr>
<tr>
<td>24</td>
<td>Val= 8.310e+03</td>
</tr>
<tr>
<td>25</td>
<td>Val= 5.886e+03</td>
</tr>
<tr>
<td>26</td>
<td>Val= 2.738e+03</td>
</tr>
<tr>
<td>27</td>
<td>Val= 1.209e+03</td>
</tr>
<tr>
<td>28</td>
<td>Val= 2.892e+04</td>
</tr>
<tr>
<td>29</td>
<td>Val= 1.352e+04</td>
</tr>
<tr>
<td>30</td>
<td>Val= 2.425e+04</td>
</tr>
<tr>
<td>31</td>
<td>Val= 3.172e+04</td>
</tr>
<tr>
<td>32</td>
<td>Val= 1.649e+04</td>
</tr>
<tr>
<td>33</td>
<td>Val= 1.167e+04</td>
</tr>
<tr>
<td>34</td>
<td>Val= 9.118e+03</td>
</tr>
<tr>
<td>35</td>
<td>Val= 1.160e+04</td>
</tr>
<tr>
<td>36</td>
<td>Val= 1.526e+04</td>
</tr>
<tr>
<td>37</td>
<td>Val= 2.777e+04</td>
</tr>
<tr>
<td>38</td>
<td>Val= 1.496e+04</td>
</tr>
<tr>
<td>39</td>
<td>Val= 1.631e+04</td>
</tr>
<tr>
<td>40</td>
<td>Val= 8.693e+03</td>
</tr>
<tr>
<td>41</td>
<td>Val= 1.360e+04</td>
</tr>
</tbody>
</table>

110: Val= 2.508e+04  219: Val= 4.058e+04
111: Val= 5.413e+03  220: Val= 1.464e+04
112: Val= 6.105e+03  221: Val= 1.494e+04
113: Val= 1.962e+04  222: Val= 1.379e+04
114: Val= 3.791e+04  223: Val= 8.377e+03
115: Val= 1.594e+04  224: Val= 4.190e+04
116: Val= 8.805e+03  225: Val= 1.316e+04
117: Val= 8.905e+03  226: Val= 1.169e+04
118: Val= 5.119e+04  227: Val= 3.698e+04
119: Val= 1.106e+04  228: Val= 4.706e+04
120: Val= 7.396e+03  229: Val= 2.828e+04
121: Val= 1.359e+04  230: Val= 3.002e+04
122: Val= 6.366e+03  231: Val= 4.453e+04
123: Val= 3.102e+04  232: Val= 3.199e+04
124: Val= 5.478e+03  233: Val= 1.852e+04
125: Val= 5.662e+03  234: Val= 3.977e+04
126: Val= 4.965e+03  235: Val= 1.818e+04
127: Val= 2.243e+04  236: Val= 1.712e+04
128: Val= 4.956e+03  237: Val= 2.032e+03
129: Val= 6.910e+03  238: Val= 4.949e+03
130: Val= 1.322e+04  239: Val= 2.190e+04
131: Val= 5.868e+04  240: Val= 5.226e+03
132: Val= 1.182e+04  241: Val= 4.408e+03
133: Val= 7.342e+03  242: Val= 8.139e+03
134: Val= 9.956e+03  243: Val= 1.297e+04
135: Val= 1.247e+04  244: Val= 3.406e+04
136: Val= 2.333e+04  245: Val= 2.819e+04
137: Val= 1.494e+04  246: Val= 1.218e+04
138: Val= 1.272e+04  247: Val= 1.540e+04
139: Val= 9.650e+03  248: Val= 1.494e+04
140: Val= 8.554e+03  249: Val= 8.191e+03
141: Val= 2.369e+03  250: Val= 2.918e+04
142: Val= 8.689e+03  251: Val= 3.732e+04
143: Val= 8.611e+03  252: Val= 2.036e+04
144: Val= 2.349e+04  253: Val= 1.693e+04
145: Val= 4.170e+03  254: Val= 3.538e+04
146: Val= 4.190e+04  255: Val= 1.989e+04
147: Val= 1.513e+04  256: Val= 1.174e+04
148: Val= 3.297e+04  257: Val= 1.343e+04
149: Val= 1.012e+04  258: Val= 1.312e+04
150: Val= 7.893e+03  259: Val= 7.893e+03
<table>
<thead>
<tr>
<th></th>
<th>Val</th>
<th></th>
<th>Val</th>
<th></th>
<th>Val</th>
</tr>
</thead>
<tbody>
<tr>
<td>42</td>
<td>1.114e+04</td>
<td>151</td>
<td>9.996e+03</td>
<td>260</td>
<td>1.106e+04</td>
</tr>
<tr>
<td>43</td>
<td>1.412e+04</td>
<td>152</td>
<td>1.051e+04</td>
<td>261</td>
<td>4.580e+03</td>
</tr>
<tr>
<td>44</td>
<td>8.310e+03</td>
<td>153</td>
<td>1.269e+04</td>
<td>262</td>
<td>7.531e+03</td>
</tr>
<tr>
<td>45</td>
<td>6.172e+03</td>
<td>154</td>
<td>1.422e+04</td>
<td>263</td>
<td>9.619e+03</td>
</tr>
<tr>
<td>46</td>
<td>3.462e+03</td>
<td>155</td>
<td>1.449e+04</td>
<td>264</td>
<td>1.501e+04</td>
</tr>
<tr>
<td>47</td>
<td>6.469e+03</td>
<td>156</td>
<td>3.691e+04</td>
<td>265</td>
<td>2.515e+04</td>
</tr>
<tr>
<td>48</td>
<td>1.272e+04</td>
<td>157</td>
<td>2.352e+04</td>
<td>266</td>
<td>1.675e+04</td>
</tr>
<tr>
<td>49</td>
<td>3.334e+03</td>
<td>158</td>
<td>1.237e+04</td>
<td>267</td>
<td>1.567e+04</td>
</tr>
<tr>
<td>50</td>
<td>2.092e+03</td>
<td>159</td>
<td>2.393e+04</td>
<td>268</td>
<td>1.002e+04</td>
</tr>
<tr>
<td>51</td>
<td>1.865e+04</td>
<td>160</td>
<td>1.157e+04</td>
<td>269</td>
<td>5.611e+03</td>
</tr>
<tr>
<td>52</td>
<td>3.217e+04</td>
<td>161</td>
<td>8.347e+03</td>
<td>270</td>
<td>2.038e+04</td>
</tr>
<tr>
<td>53</td>
<td>1.757e+04</td>
<td>162</td>
<td>9.939e+03</td>
<td>271</td>
<td>3.409e+04</td>
</tr>
<tr>
<td>54</td>
<td>1.020e+04</td>
<td>163</td>
<td>1.505e+04</td>
<td>272</td>
<td>1.555e+04</td>
</tr>
<tr>
<td>55</td>
<td>3.231e+04</td>
<td>164</td>
<td>7.926e+03</td>
<td>273</td>
<td>1.748e+04</td>
</tr>
<tr>
<td>56</td>
<td>1.958e+04</td>
<td>165</td>
<td>1.829e+03</td>
<td>274</td>
<td>1.001e+04</td>
</tr>
<tr>
<td>57</td>
<td>2.326e+04</td>
<td>166</td>
<td>3.893e+03</td>
<td>275</td>
<td>3.367e+03</td>
</tr>
<tr>
<td>58</td>
<td>3.340e+04</td>
<td>167</td>
<td>6.881e+03</td>
<td>276</td>
<td>2.103e+03</td>
</tr>
<tr>
<td>59</td>
<td>2.071e+04</td>
<td>168</td>
<td>1.464e+04</td>
<td>277</td>
<td>2.661e+04</td>
</tr>
<tr>
<td>60</td>
<td>1.442e+04</td>
<td>169</td>
<td>3.726e+04</td>
<td>278</td>
<td>3.468e+04</td>
</tr>
<tr>
<td>61</td>
<td>1.539e+04</td>
<td>170</td>
<td>1.025e+04</td>
<td>279</td>
<td>1.599e+04</td>
</tr>
<tr>
<td>62</td>
<td>2.654e+04</td>
<td>171</td>
<td>1.638e+04</td>
<td>280</td>
<td>1.145e+04</td>
</tr>
<tr>
<td>63</td>
<td>3.274e+04</td>
<td>172</td>
<td>8.602e+03</td>
<td>281</td>
<td>3.164e+04</td>
</tr>
<tr>
<td>64</td>
<td>3.445e+04</td>
<td>173</td>
<td>8.487e+03</td>
<td>282</td>
<td>1.349e+04</td>
</tr>
<tr>
<td>65</td>
<td>1.770e+04</td>
<td>174</td>
<td>2.367e+04</td>
<td>283</td>
<td>6.448e+03</td>
</tr>
<tr>
<td>66</td>
<td>2.059e+04</td>
<td>175</td>
<td>4.112e+03</td>
<td>284</td>
<td>9.792e+03</td>
</tr>
<tr>
<td>67</td>
<td>1.615e+04</td>
<td>176</td>
<td>6.925e+03</td>
<td>285</td>
<td>1.250e+04</td>
</tr>
<tr>
<td>68</td>
<td>1.477e+04</td>
<td>177</td>
<td>9.623e+03</td>
<td>286</td>
<td>1.466e+04</td>
</tr>
<tr>
<td>69</td>
<td>1.132e+04</td>
<td>178</td>
<td>1.298e+04</td>
<td>287</td>
<td>1.659e+04</td>
</tr>
<tr>
<td>70</td>
<td>1.703e+04</td>
<td>179</td>
<td>1.197e+04</td>
<td>288</td>
<td>2.003e+04</td>
</tr>
<tr>
<td>71</td>
<td>1.407e+04</td>
<td>180</td>
<td>2.587e+04</td>
<td>289</td>
<td>2.475e+04</td>
</tr>
<tr>
<td>72</td>
<td>1.234e+04</td>
<td>181</td>
<td>1.377e+04</td>
<td>290</td>
<td>2.965e+04</td>
</tr>
<tr>
<td>73</td>
<td>7.959e+03</td>
<td>182</td>
<td>9.979e+03</td>
<td>291</td>
<td>3.379e+04</td>
</tr>
<tr>
<td>74</td>
<td>2.330e+04</td>
<td>183</td>
<td>8.454e+03</td>
<td>292</td>
<td>3.436e+04</td>
</tr>
<tr>
<td>75</td>
<td>1.150e+04</td>
<td>184</td>
<td>2.383e+03</td>
<td>293</td>
<td>2.811e+04</td>
</tr>
<tr>
<td>76</td>
<td>7.407e+03</td>
<td>185</td>
<td>9.416e+03</td>
<td>294</td>
<td>1.558e+04</td>
</tr>
<tr>
<td>77</td>
<td>1.334e+03</td>
<td>186</td>
<td>6.771e+04</td>
<td>295</td>
<td>1.652e+04</td>
</tr>
<tr>
<td>78</td>
<td>4.653e+03</td>
<td>187</td>
<td>1.175e+04</td>
<td>296</td>
<td>1.291e+04</td>
</tr>
<tr>
<td>79</td>
<td>1.854e+04</td>
<td>188</td>
<td>7.257e+03</td>
<td>297</td>
<td>9.820e+03</td>
</tr>
<tr>
<td>80</td>
<td>4.976e+03</td>
<td>189</td>
<td>5.424e+03</td>
<td>298</td>
<td>1.304e+04</td>
</tr>
<tr>
<td>81</td>
<td>4.328e+03</td>
<td>190</td>
<td>4.257e+03</td>
<td>299</td>
<td>1.492e+04</td>
</tr>
<tr>
<td>82</td>
<td>1.960e+04</td>
<td>191</td>
<td>2.334e+04</td>
<td>300</td>
<td>1.407e+04</td>
</tr>
<tr>
<td>83</td>
<td>3.383e+04</td>
<td>192</td>
<td>4.906e+03</td>
<td>301</td>
<td>1.096e+04</td>
</tr>
<tr>
<td>84</td>
<td>1.892e+04</td>
<td>193</td>
<td>6.962e+03</td>
<td>302</td>
<td>7.266e+03</td>
</tr>
<tr>
<td>85</td>
<td>1.730e+04</td>
<td>194</td>
<td>4.380e+03</td>
<td>303</td>
<td>6.357e+03</td>
</tr>
<tr>
<td>86</td>
<td>4.158e+04</td>
<td>195</td>
<td>3.273e+04</td>
<td>304</td>
<td>7.378e+03</td>
</tr>
<tr>
<td>87</td>
<td>3.245e+04</td>
<td>196</td>
<td>5.670e+03</td>
<td>305</td>
<td>9.324e+03</td>
</tr>
</tbody>
</table>

F-10
<table>
<thead>
<tr>
<th></th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>88</td>
<td>$3.562 \times 10^4$</td>
</tr>
<tr>
<td>89</td>
<td>$4.048 \times 10^4$</td>
</tr>
<tr>
<td>90</td>
<td>$2.828 \times 10^4$</td>
</tr>
<tr>
<td>91</td>
<td>$2.974 \times 10^4$</td>
</tr>
<tr>
<td>92</td>
<td>$1.240 \times 10^4$</td>
</tr>
<tr>
<td>93</td>
<td>$3.757 \times 10^4$</td>
</tr>
<tr>
<td>94</td>
<td>$1.461 \times 10^4$</td>
</tr>
<tr>
<td>95</td>
<td>$1.378 \times 10^4$</td>
</tr>
<tr>
<td>96</td>
<td>$1.012 \times 10^4$</td>
</tr>
<tr>
<td>97</td>
<td>$3.750 \times 10^4$</td>
</tr>
<tr>
<td>98</td>
<td>$1.252 \times 10^4$</td>
</tr>
<tr>
<td>99</td>
<td>$1.149 \times 10^4$</td>
</tr>
<tr>
<td>100</td>
<td>$2.698 \times 10^4$</td>
</tr>
<tr>
<td>101</td>
<td>$3.960 \times 10^4$</td>
</tr>
<tr>
<td>102</td>
<td>$6.493 \times 10^3$</td>
</tr>
<tr>
<td>103</td>
<td>$3.936 \times 10^4$</td>
</tr>
<tr>
<td>104</td>
<td>$1.333 \times 10^4$</td>
</tr>
<tr>
<td>105</td>
<td>$2.195 \times 10^4$</td>
</tr>
<tr>
<td>106</td>
<td>$1.994 \times 10^4$</td>
</tr>
<tr>
<td>107</td>
<td>$7.258 \times 10^3$</td>
</tr>
<tr>
<td>108</td>
<td>$2.273 \times 10^3$</td>
</tr>
<tr>
<td>109</td>
<td>$3.084 \times 10^3$</td>
</tr>
<tr>
<td>197</td>
<td>$1.398 \times 10^4$</td>
</tr>
<tr>
<td>198</td>
<td>$6.587 \times 10^3$</td>
</tr>
<tr>
<td>199</td>
<td>$6.144 \times 10^4$</td>
</tr>
<tr>
<td>200</td>
<td>$1.145 \times 10^4$</td>
</tr>
<tr>
<td>201</td>
<td>$7.672 \times 10^3$</td>
</tr>
<tr>
<td>202</td>
<td>$1.767 \times 10^4$</td>
</tr>
<tr>
<td>203</td>
<td>$4.744 \times 10^4$</td>
</tr>
<tr>
<td>204</td>
<td>$1.601 \times 10^4$</td>
</tr>
<tr>
<td>205</td>
<td>$8.957 \times 10^3$</td>
</tr>
<tr>
<td>206</td>
<td>$1.760 \times 10^4$</td>
</tr>
<tr>
<td>207</td>
<td>$2.090 \times 10^3$</td>
</tr>
<tr>
<td>208</td>
<td>$2.684 \times 10^4$</td>
</tr>
<tr>
<td>209</td>
<td>$5.731 \times 10^3$</td>
</tr>
<tr>
<td>210</td>
<td>$6.263 \times 10^3$</td>
</tr>
<tr>
<td>211</td>
<td>$2.493 \times 10^4$</td>
</tr>
<tr>
<td>212</td>
<td>$4.806 \times 10^3$</td>
</tr>
<tr>
<td>213</td>
<td>$2.159 \times 10^4$</td>
</tr>
<tr>
<td>214</td>
<td>$2.119 \times 10^4$</td>
</tr>
<tr>
<td>215</td>
<td>$5.690 \times 10^3$</td>
</tr>
<tr>
<td>216</td>
<td>$4.054 \times 10^4$</td>
</tr>
<tr>
<td>217</td>
<td>$7.661 \times 10^3$</td>
</tr>
<tr>
<td>218</td>
<td>$1.149 \times 10^4$</td>
</tr>
</tbody>
</table>

Max Value = $67711.187500$ @ 186