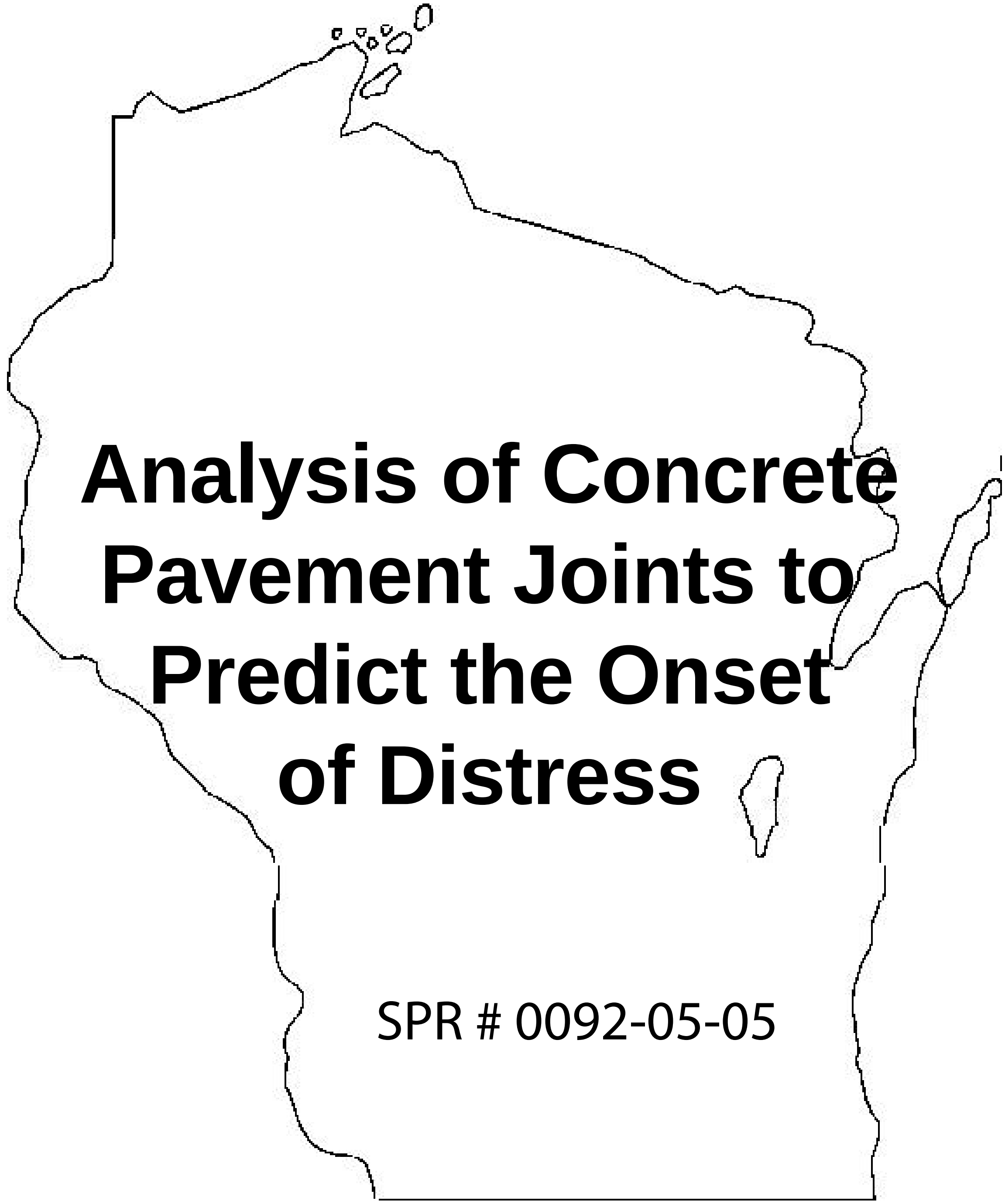
Wisconsin Highway Research Program



Analysis of Concrete Pavement Joints to Predict the Onset of Distress

SPR # 0092-05-05

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The Transtec Group, Inc.

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FINAL REPORT

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DISCLAIMER

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16. Abstract

This report documents the investigation of a 15-mile segment of doweled plain jointed concrete pavement located on Interstate 90/94 in Juneau and Sauk Counties in the State of Wisconsin. This section has experienced a particular mode of early deterioration that had not previously been reported on other concrete pavements in the State of Wisconsin. Coupled with the fact that these pavements were less than ten years old, an investigation was conducted to seek out the causes of the observed distress.

Three primary objectives guided the work in this effort. The first was to investigate the nature of the distress using advanced analytical methods including finite-element methods (FEM), validating the predictions using field observations when possible. The second objective was to identify maintenance and/or restoration activities that can be used to slow or prevent the propagation of the observed pavement distresses. Finally, current WisDOT design standards and specifications were reviewed to determine if previous changes made are likely to address the causes of the premature failure.

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EXECUTIVE SUMMARY

Research Study Summary

This report documents the investigation of a 15-mile segment of doweled plain jointed concrete pavement located on Interstate 90/94 in Juneau and Sauk Counties in the State of Wisconsin. This section has experienced a particular mode of early deterioration that had not previously been reported on other concrete pavements in the State of Wisconsin. Coupled with the fact that these pavements were less than ten years old, an investigation was conducted to seek out the causes of the observed distress.

Background

Three primary objectives guided the work in this effort. The first was to investigate the nature of the distress using advanced analytical methods including finite-element methods (FEM), validating the predictions using field observations when possible. The second objective was to identify maintenance and/or restoration activities that can be used to slow or prevent the propagation of the observed pavement distresses. Finally, current WisDOT design standards and specifications were reviewed to determine if previous changes made are likely to address the causes of the premature failure.

Process

There were two modes of data collection for this research. The first included a review of existing information reported by WisDOT, WCPA, and Marquette University. This information included a number of photographs, deflection and profile data, and various materials and other test results. A second mode of data collection included visual observations made first-hand during a field visit in August 2006.

Following the data collection, analytical methods were employed to gauge the sensitivity of the pavement behavior to the various parameters that are believed to have a contributing role. For example, slab length, joint skewness, and strain gradients were all varied to determine the pavement response.

Linking pavement response and distress was the next step. On this section, three primary distresses were identified: delamination of the slab at the dowel line, corner cracking, and mid-panel cracking. The first two of these distresses are intimately linked.

Based on the results of the analytical investigation, and as validated by the other information that was collected, the likely causes of failure were identified.

Findings and Conclusions

After a careful review of the information, it is concluded that no single factor affected the three primary distresses that were found on this section. It is instead believed that a combination of factors is to blame. Among these factors are:

- Longer joint spacings (greater than 16 ft.) which increased stress states in the slabs, and widened the joints.
- Skewed joints, which increased corner stresses and deflections, and effectively increased the dimensions affecting curling and warping.
- Open-graded base courses (OGBC) that were likely unstable (possessing low shear strength).
- A dowel design that while not uncommon in practice today, may underscore the need for reconsideration of the use of large dowels given that other owner-agencies have reported success with smaller dowels.

Recommendations for Further Action

Because an exhaustive investigation could not be conducted as part of this effort, a number of follow-on activities are recommended for consideration. In the short term, it is recommended that relevant discussions be conducted among the various stakeholders in Wisconsin. Topics could include the recommendations for additional changes to design standards, specifications, and other guidelines with respect to the potential benefits and pitfalls.

Longer-term recommendations include the possibility of a more extensive field evaluation. It is recommended that a comprehensive set of deflection data be collected to baseline the current condition of this highway, as well as possibly others more recently discovered to be experiencing a similar distress. Surface profile data would also be helpful to possibly identify if slab curvature is present along with localized roughness which may be an indication of impending distress development. Finally, a laboratory evaluation of the OGBC could also be conducted to determine the triaxial constitutive properties as they might relate to in-situ behavior.

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1 INTRODUCTION

Interstate 90/94 is a vital strategic corridor within the State of Wisconsin. It serves as the primary route from Minneapolis to Chicago and Milwaukee, is a NAFTA trade link, and is an important artery for both commerce and travel within the State of Wisconsin. Of interest to this study is a 15-mile segment near the Wisconsin Dells. Reconstructed in 1991-93, a new jointed concrete pavement (JCP) was selected in order to accommodate the heavy traffic expected in the decades to follow.

The construction of these segments seemed to go as expected, comparable to other concrete paving projects in the state. However, approximately five years after the segment opened to traffic, the Wisconsin Department of Transportation (WisDOT) District 1 maintenance staff filed a Report of Early Distress (RED). In it, they identified cracking and "potholes" near the joints. In response, the WisDOT Pavements Section and others investigated the pavements in more detail and concluded that while a number of factors may have contributed to the observed distress, no single "culprit" could be found.

Since that time, changes have been made to the standard designs and specifications to minimize potential root causes. However, since no single cause was identified, it was difficult to know for sure if these changes would prove beneficial.

The goal of this research study is therefore to conduct a site-specific investigation of this pavement section. The intent is to gather data from a number of existing sources, and based on them, report the likely contributors to the observed distress. The intent is to learn from these pavements so that the potential for similar distresses on other sections could be minimized.

1.1 Background and Significance of Work

The intent of this research study is to conduct an objective evaluation of the pavements located on the section in question. To accomplish this, accepted principles of forensic engineering must be employed to the greatest degree possible. With the exception of a brief field visit, most of the information used in the investigation was collected by others. During the course of this research study, however, this information was synthesized and used to support a more theoretical approach to determining the likely causes of the observed distress.

Along this pavement section, numerous classical distresses were observed; namely, longitudinal and transverse cracking, and spalling at the joints. Corner cracking was also noted at numerous locations, and furthermore appeared to be the most significant distress in terms of quantity and severity. The mid-panel cracking that was present was in quantities significant enough to be of concern. However, the presence of corner cracking on concrete pavements this thick and relatively new is uncommon, and thus the majority of the investigation during this research study focused on the causes behind this distress.

When evaluating the data that was provided, the research study team employed analytical techniques to test theories of mechanisms behind the observed distress. Various factors were previously identified as possible contributors. Some of these included:

- Open-graded base course (OGBC), with permeability higher than what is commonly used today.
- Longer panels (joint spacing) than what is commonly used today.
- So-called "built-in" curling that is itself a function of a number of material, construction, and climatic factors.
- A support system with potentially poor shear resistance (stability).
- Concrete-dowel interaction – this includes the technique for placing the dowels, and the possibility that they may have corroded.
- Skewed joints – a design that is no longer used today.
- Indications of possible alkali-aggregate reactivity.
- Use of recycled concrete as an aggregate in the mixture for the new concrete pavement.
- Lack of consolidation of the concrete during placement.

The approach used in this research study was to focus on each of these factors, and based on the information available, determine which ones were likely contributors to the mechanisms behind the observed distresses.

1.2 Research Objectives

Three primary objectives of this research, as identified by the Wisconsin Highway Research Program (WHRP), include:

1. Investigate the nature of the JCP distress using advanced analytical methods including finite-element methods (FEM). Identify and develop the models as needed, and validate them using field observations.
2. Identify maintenance and/or restoration activities that can be used to slow or prevent the propagation of the observed pavement distresses.
3. Review current WisDOT design standards and specifications. Determine if the changes recently made are addressing the suspected causes of the premature failure. If needed, make additional recommendations for changes to the standards and specifications to prevent the observed distresses from occurring in the future on other pavement sections.

1.3 Scope of the Report

This report includes the results of this investigation. It begins with a review of the information that was gathered about the pavement section, including the results of a brief field visit during the course of repair operations in 2006.

A mechanistic analysis of the concrete pavements is then described, including the inputs used, and the results. During the course of this research study, the team employed finite element methods to predict the stress state in the slabs, with a particular emphasis on the behavior near the joint. The predictions were varied to include the range of conditions expected in the field. Comparisons were made to the observed performance to validate the overall approach.

Using these models, along with a review of other available information, each of the potential contributing factors to the observed distress was evaluated. From this, likely mechanisms have been identified and reported.

From this, and in order to weave this analysis into practice, an evaluation of the specification changes that have been made to date has been conducted. Additional potential specification changes that could be beneficial have also been identified. Finally, in the recommendations, appropriate maintenance and restoration activities that can slow or prevent further development of the observed distress on this pavement section are reported, along with recommendations for future activities.

2 INFORMATION REVIEW

2.1 A Review of the I90/I94 Pavement Section

Although the products from this research study may have implications statewide, the primary goal is to learn more about a 15-mile segment of concrete pavement located on I90/I94 in Juneau and Sauk Counties. This section has experienced a particular mode of early deterioration that has not been reported as common on other concrete pavements in Wisconsin. Coupled with the fact that these pavements were less than ten years old, this investigation was conducted to seek out the cause(s) of the observed distress.

Prior to this WHRP-sponsored research study, a number of prior studies were conducted on this pavement section. In August 2000, Joe Wilson of the WisDOT Pavements Section published a “Report of Early Distress on I-90/94 near Wisconsin Dells.” This report included a compendium of investigative work conducted by WisDOT and others. It was accompanied by a second report prepared for WisDOT by Jim Crovetti entitled, “Analysis of Pavement Support Conditions under Cement-stabilized Open Graded Base Course for IH-90 near Wisconsin Dells,” dated 31 July 2000. Furthermore, on August 3-4, 2000, members of the research study team joined 30 other individuals as part of a Technical Working Group to evaluate these pavements first-hand. During this meeting, a field visit was conducted, as well as a round table discussion.

A summary of some of the variables that are reportedly present on the pavement section are as follows:

- The jointed concrete pavement is nominally 12 in. over a 4-in. Open-Graded Base Course (OGBC) – “Graded Base Course #1” – reportedly cement stabilized, but with some sections possibly not stabilized. Underlying the OGBC is an existing subbase of 4- to 9-in. of dense graded aggregate. As expected for the rolling terrain, subgrade properties and bedrock depth vary along the section.
- Joints are skewed 1:6 and reported as having “random” spacings of between 12 and 20 ft. An unverified analysis of Pathview data revealed that the distribution of slab lengths is as follows: 12 ft. (8%), 14 ft. (7%), 16 ft. (17%), 18 ft. (27%), 20 ft. (33%), and 8% are either below 12 ft. or above 20 ft. Dowels of 1.5-in. diameter were used on the transverse joints – epoxy coated, 18-in. long, and at a 12-in. spacing. The longitudinal joint was tied with #4 bars, 24-in. long, at 24-in. spacing.
- Panel widths are 12 ft. for the inside lane, and 14 ft. for the outside lane (widened lane). Hot-mix asphalt shoulders are used, and edge drains included that were designed to work with the OGBC.
- The sections in question were built by two paving contractors from 1991 to 1993, with most of the placement reportedly in 1992. James Cape & Sons, Co. constructed the eastern (southern) portion of the section using a dowel-bar inserter. Trierweiler Construction & Supply Co., Inc. constructed the western (northern) portion using dowel baskets.
- The concrete contains coarse aggregate consisting of a mix of recycled concrete (reportedly used on “some” sections) along with virgin crushed gravels including sandstone, chert, and various igneous rocks.
- Cores were extracted and tested in June 1999. The average compressive strength was approximately 7600 psi, with a coefficient of variation of 16%.

Regarding the observed distress on this pavement section, a number of pertinent observations include:

- As of early 2002, distresses were found to be present on 2.1% of the slabs. The most commonly observed were corner cracking (on 1.8% of the panels), mid-panel transverse cracking (0.3%), and mid-panel longitudinal cracking (0.03%). Of those slabs with corner cracks, 82 percent cracked on at least one of the two acute angles.
- From some of the cores, a horizontal delamination is noted to occur in the slab at approximately mid-depth (dowel level). While this delamination was coincident with areas of observed surface distress, it was also noted to occur on uncracked panels, particularly on panels adjacent to those with surface failures, but rarely extending more than 10 in. from the common joint. Cracking is observed through the coarse aggregates.
- Inadequate consolidation of the concrete below mid-depth in the slab was reported in the first RED in 1995. However, subsequent evaluation (including lab testing for unit weight) has not verified this observation. If present, it may be in isolated locations, and is not likely to be a contributing factor.
- Most of the distress is on the outside lanes, with the eastbound direction reported as having “2.5 times” the distress. The “worst” locations have been reported as between MP 86-93 and 100-101 in the EB direction, and between MP 85-89 and 95-96 in the WB direction.
- Some ASR was found to be present, but not believed to be a major factor.
- In Crovetti’s report, he concluded that base densification and loss of support at the edges does not appear to correlate to distress, but emphasized that this is based on limited testing at only one temperature condition.

3 FIELD VISIT

On August 3-4, 2006, members of the research study team had an opportunity to visit the site. During the field visit, sections of the pavement were being repaired by a contractor under contract to WisDOT. The second day, a visit was made to a landfill site where previously-removed slab segments were disposed of.

3.1 Slab Repair Activities

The scope of work for the repair contract included extensive full-depth patching of the concrete pavement in the vicinity of joints exhibiting the characteristic damage. Due to the high traffic volumes along this corridor, all work was conducted at night. The sequence of events that was witnessed is documented in Figure 1 through Figure 6, and includes:

1. Full-depth sawing of the existing pavement at approximately 5 ft. both upstream and downstream of the distressed joint. A third parallel sawcut is made within a few inches of the upstream cut in order to expedite removal of the edge of the repaired area.
2. A hydraulic hammer on a skid steer is used to chip out the corner of the slab within the narrow trench.
3. A concrete cutter is then lowered into the trench starting at the removed corner, and removes the remaining concrete within the trench.
4. A Slab Crab bucket attached to a large excavator then removes the slab pieces, depositing them into a series of end dump trailers for subsequent transportation to a designated landfill.
5. Once removed, the area is cleaned and dowels are drilled and inserted prior to placement of fast-track patching concrete.

Figure 1. Sawing on both sides of repair area (flanking distressed joint).

Figure 2. Removing corner of repair area.

Figure 3. Concrete cutter to remove edge of repair area.

Figure 4. Slab Crab bucket removing damaged concrete in repair area.

Figure 5. Patching repair area using fast-track concrete.

Figure 6. Patching repair area using fast-track concrete.

3.2 Inspection of Removed Slabs

In a bone yard approximately three miles south of the Wisconsin Dells, hundreds of concrete slab segments have been disposed of. During the site visit, these slabs were inspected by the research study team in order to gain a more complete understanding of the physical manifestation of the pavement distress. Because the slabs had been dumped from the trucks, many had “opened up” to allow the subtleties of the dowel-concrete interaction to be observed.

Figure 7 through Figure 13 are representative of the corner cracking distress that is of most significance to this study. As previously reported, the distress was found to occur on the acute angle of the slabs in the vast majority of the cases. The horizontal delamination coincided with the imaginary line intersecting the dowels at mid slab. The cracked area extended approximately 3 to 5 ft. from the slab corner along both joints in most cases. The concrete at mid-depth between the two segments was often observed to be pulverized. The dowel ends that rested between the slab segments had epoxy coating that was loose or non-existent. In some cases, the steel dowels were abraded by (presumably) the grinding action of the two horizontal concrete slab segments.

Figure 14 illustrates the open-graded base course that was found to adhere to the bottom of many of the slab segments. As can be seen, the material is nearly uniform in gradation, which is not surprising given the very strict tolerances of the gradation that was specified.

Figure 7. Distressed slab corner showing delamination of acute corner at mid depth.

Figure 8. Slab corner without surface distress, but showing delamination of acute corner at mid depth.

Figure 9. Distressed slab corner showing delamination of acute corner at mid depth. Note differences in dowel condition on acute corner (right) versus obtuse corner (left).

Figure 10. Side view showing dowel bridging distressed corner. Note differences in dowel condition on acute corner (left) versus obtuse corner (right). Note crack repair material infiltration.

Figure 11 Mid-depth delamination of slab extended from corner (bottom of photo) to approximately 5 ft. from edge (top of photo), before appearing as surface crack.

Figure 12. Loose dowel showing ineffectiveness of epoxy coating once damaged.

Figure 13. Loose dowel showing ineffectiveness of epoxy coating once damaged. Note abrasion due to loose state and interaction with concrete.

Figure 14. Open-graded base material (adhered to bottom of slab).

4 ANALYSIS

To better understand the nature of the observed distress, it was decided that analytical methods would be used. This section first describes the fundamental components of these methods, followed by the specific models used. The results of the analysis as compared to the observed distress are then presented.

4.1 Background

Portland cement concrete pavements (PCCP) are well known for being a heavy-duty high-performance solution for heavily trafficked roads. Their rigidness allows wheel loads to be well distributed across a large area. However, because concrete is also a brittle material, when subjected to the stresses that even a “typical” pavement will experience, it will crack. This is normal though, and it is for this reason that jointed concrete pavements (JCP) are constructed: built with predetermined weak planes, to control the location of the cracks that are inevitable.

However, while joints serve an important purpose, they are also the location of distress for many JCP. Theory tells us that when wheel loads are applied near the edge of a slab (at the joint), stresses in the concrete are much higher than if the load is located in the interior. These higher stresses lead to an increased probability of failure. We know that practice confirms this theory, as "failure" in concrete pavements commonly occurs (or at least, initiates) at the joints.

4.1.1 Doweled Joints

To help relieve these stresses, pavement engineers often specify the use of dowels at the joints. Used for decades in concrete pavements, dowels are smooth bars that when used properly, serve as "bridges", allowing loads applied on one slab to be partially carried by adjacent slabs. As the loads are positioned ever closer to a joint, the dowels at that joint become more critical, transferring increasing levels of load. While dowels are not used on all JCP, most highway and airfield facilities constructed today do employ them. Their use has resulted in a marked decrease in joint faulting and slab cracking.

Dowels, by their very nature, act as discrete load transfer devices. As Figure 15 illustrates, when a wheel load is applied near the edge of a slab, part of the load is carried by the slab through the underlying support. If present, load is also carried by the nearby dowels, and transferred to the adjacent slab. Another load carrying mechanism, aggregate interlock, is also commonly present. However, for simplicity, its discussion herein will be limited.

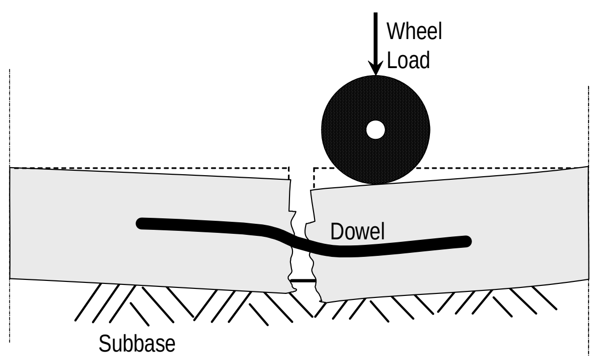
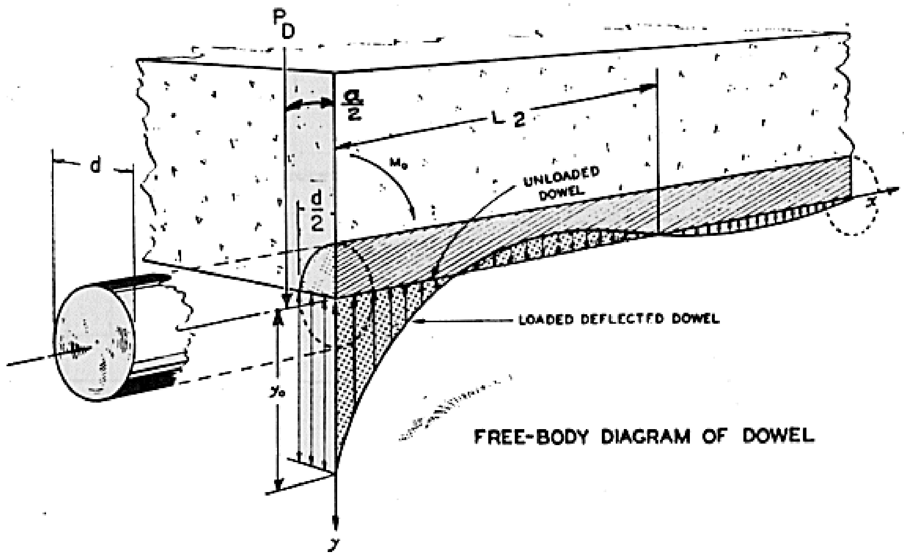


Figure 15. Illustration of load transfer at a doweled joint.

The modeling of the stresses at the joint can be complex. Although Figure 15 illustrates this in simple terms, there are numerous intricacies in the analysis due to the flexural rigidity of the slab, the interaction of the slab with the subbase, and the interaction of the concrete with the dowels. The latter is illustrated in more detail in Figure 16, where the deflected shape of the dowel, as well as the corresponding stresses, can be predicted as a function of a number of material and geometric variables.



Source: *Structural Design Considerations for Pavement Joints,* ACI Title 53-1 report from ACI Committee 325, Subcommittee III, Journal of the American Concrete Institute, Volume 28, Number 1, July 1956, pp. 1-28.

Figure 16. Illustration of load transfer at a joint.

4.1.2 Curling and Warping

Stresses in concrete pavements are not just caused by traffic loading. Concrete pavements are also subjected to environmental influences, which have the tendency to force the slab away from a “flat” position. Temperature and moisture differentials in the slab, termed *curling* and *warping* respectively, can lead to induced stresses that can compound with traffic loading. This is especially true when a “liftoff” occurs at the slab edge or corner, leading to a cantilever effect.

To illustrate how significant curling can be, note Figure 17 where an 18-ft. slab panel is subjected to a negative temperature gradient of 1°F per inch. The colors in the figure indicate the magnitude of stress, with red (positive numbers) representing tension. In Figure 17, it can be seen that a peak stress in the concrete of 220 psi has been induced. When the slab length is increased to 20 ft., as illustrated in Figure 18, the stresses increase by an additional 10%.

4.1.3 Dowel Restraint

A compounding effect that has largely been ignored by pavement engineers until recently is the restraining effect caused by the dowels. While their presence is critical in transferring wheel loads across joints, they also restrict free movement of the slab edges and corners due to curling and warping. To illustrate this effect, compare Figure 17 with an 18-ft. slab without dowels to Figure 19, showing the same slab restrained by the presence of dowels. Not only is the slab profile noticeably different, but the stresses induced mid-panel are increased by 25%.

Figure 20 further illustrates how the curled slabs can induce stresses near the individual dowels. Due to the lack of biaxial rigidity of a slab near a corner, this effect will be especially pronounced at that location. Furthermore, traffic loading can compound this under certain configurations of curl and wheel load. As these stresses continue to increase, they will eventually initiate and propagate cracks in the horizontal direction. Illustrated in Figure 21, it can be seen that the stresses at the dowels decrease with distance from the longitudinal joint. At some point, the stresses that propagate the crack will be smaller than the strength, and under repeated loading cycles, the crack will instead turn upward and appear at the surface of the slab.

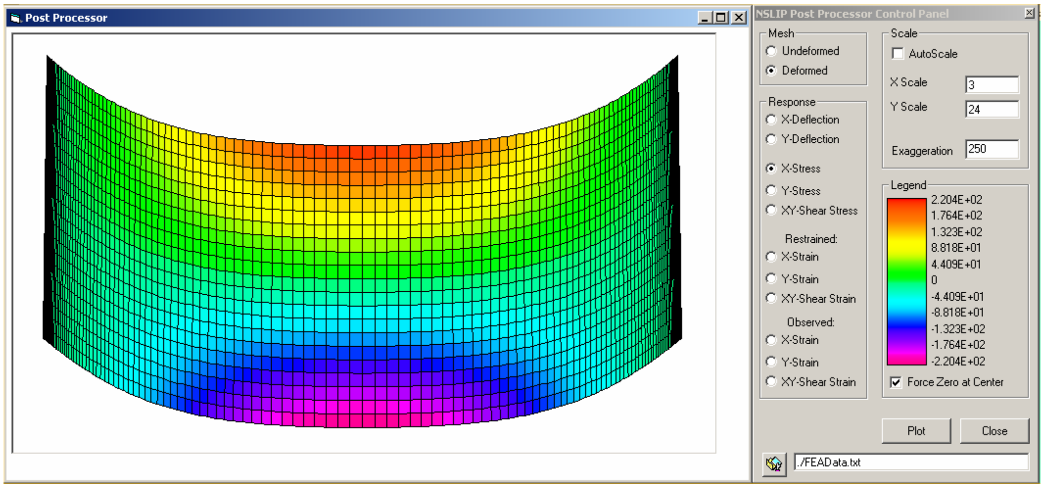


Figure 17. 18-ft. undoweled slab subjected to -1°F/in. thermal gradient.

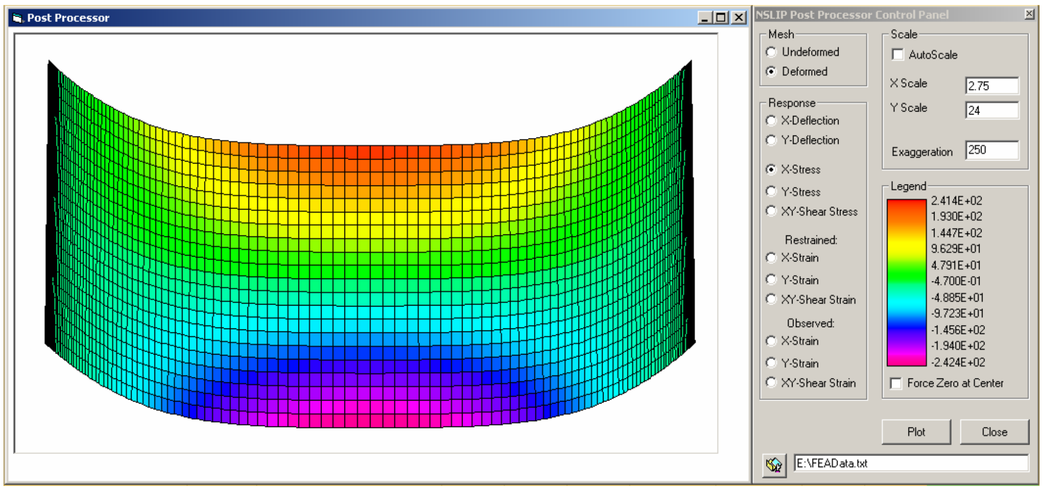


Figure 18. 20-ft. undoweled slab subjected to -1°F/in. thermal gradient.

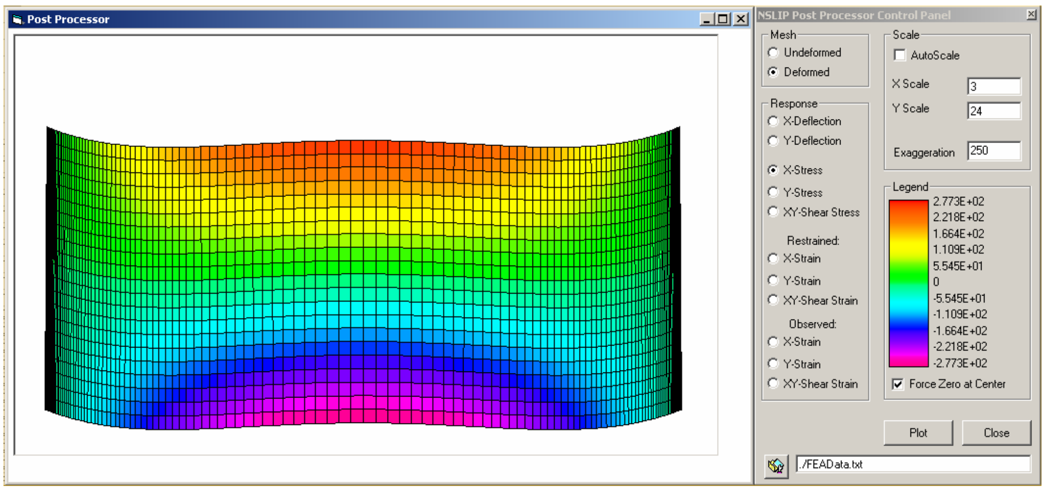


Figure 19. 18-ft. doweled slab subjected to -1°F/in. thermal gradient.

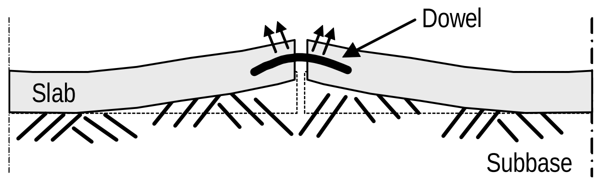


Figure 20. Induced dowel bearing stresses due to slab curl

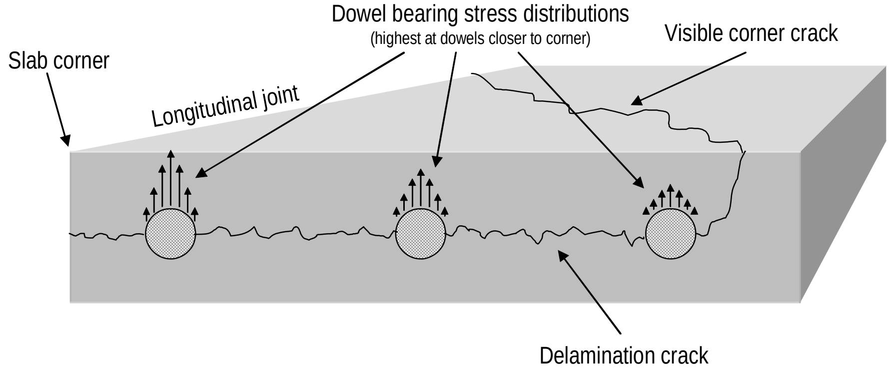


Figure 21. Corner cracking mechanism due to dowel bearing stresses.

4.2 Behavior Modeling

Concrete pavement behavior under both climatic and external wheel loading has been analytically modeled for nearly a century. Classical solutions for slab behavior include stress and deflection predictions based on beam and slab theories common to many engineering mechanics problems. In recent years, finite element methods (FEM) have allowed for more complex boundary conditions and loadings to be modeled with ease. In this section, the application of FEM to this problem is described.

4.2.1 Description of Model

Using the three-dimensional finite-element program, ANSYS, various combinations of concrete pavement configuration and loading were modeled. Typically, symmetry is used in this type of modeling to reduce the computational cost; however, in order to do so, both symmetrical loading and structure would be required. Since the loading that is being modeled here is asymmetric, a full model was used instead. An elastic foundation was used consisting of a two-dimensional grid, produced using the SURF154 element in the ANSYS software. These plane-like, 8-node elements capture the surface effects, and directly mate to the 20-node SOLID95 elements that were used to model the slab.

The SURF154 element has various density, mass, and foundation capabilities. Its elastic foundation stiffness property, EFS, was used to create the foundation in the model used in this research study. The SOLID95 element is a 20-node 3D solid capable of capturing plasticity, creep, stress stiffening, large deflection, and large strain effects. After creating a volume model of the slab, the volume sweep command was used to create the SOLID95 element geometry based on the original SURF154 geometry. This method creates a slab of SOLID95 elements mated to a foundation of SURF154 elements. The following concrete and foundation material values were provided and inputted into ANSYS.

SOLID95 Properties:

- Young's Modulus, E = 5,000,000 psi
- Poisson's Ratio, $\nu = 0.15$
- Slab Thickness, D = 12 in.
- Slab Width, W = 14 ft.
- Slab Length, L = 12, 15, and 20 ft. (varied)
- Corner angle, $\phi = 80.5°$ and $90°$ (corresponding to skewed and square joints, respectively)

SURF154 Properties:

- Dense Liquid Modulus of Reaction, EFS = 50, 300, 1000 psi (varied)

  [Note: this is stiffness per inch of deflection, i.e., k-value]

The appropriate boundary conditions were applied to ensure a unique displacement field with no stress concentrations. These included a UX and UZ restraint at a bottom corner node and a UZ constraint at the opposing corner bottom node. For the loading, two conditions were used:

- Corner load of 9000 lb.
- Strain gradients of +250, 0 and -750 microstrains per in.

The stiffness of the transverse joint was also varied to be both 0 and 1,500,000 psi per in. of deflection. However, the results using this boundary condition proved to be difficult to interpret due to high stress concentrations near the joint.

4.2.2 Model Inputs and Assumptions

The analysis was reduced to six total variables with two to three options each. To complete the analysis, 180 unique runs had to be completed. A summary of the variables includes:

1. Corner Joint Skew: ϕ (90° and 80.5°)
2. Length of Slab: L (12, 15, and 20 ft.)
3. Foundation Stiffness: K_{vS} (50, 300, and 1,000 psi/in.)
4. Strain Gradient (top strain minus bottom): $\Delta\varepsilon$ (-750, 0, and 250 $\mu\varepsilon$)
5. Corner Load: P (0 and 9,000 lb.)
6. Joint Stiffness: K_{vJ} (0 and 1.5 Mpsi/in.)

The corner joint skew and length of slab variables were done by modifying the geometry of the original slab and re-meshing the model as appropriate. The foundation stiffness variable was changed by changing the EFS (Elastic Foundation Stiffness) of the SURF154 elements previously described. The Strain Gradient was done similarly by changing the top and bottom area slab temperatures and fixing the thermal coefficient of expansion to an arbitrary level that corresponds with the intended strains. The Corner Load was applied at the furthest corner from the origin. The Joint Stiffness was estimated by using SURF154 elements embedded into the slab at mid-height. An EFS of 375,000 psi was used corresponding to 1.5 Mpsi of joint stiffness distributed over four inches of slab depth. This four inch dimension was used to prevent local errors that occur when a one dimensional point or spring load is applied to a three dimensional model. Typical deflected slabs under climatic and external (wheel) loading are shown in Figure 22.

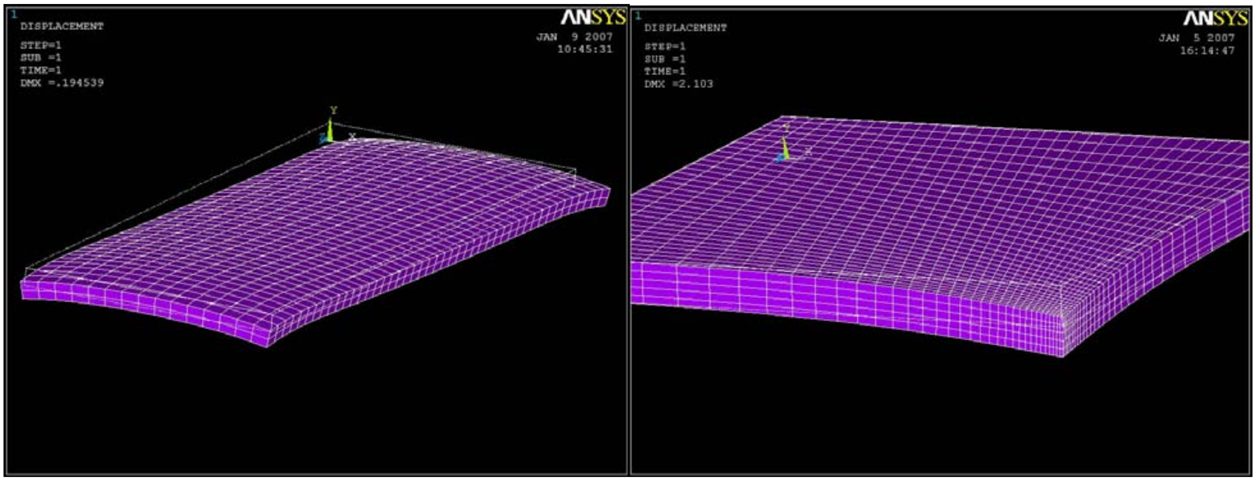


Figure 22. 3D FEM model showing deflections under both climatic and external (corner) loading.

For each of the ANSYS runs, maximum and minimum stresses were recorded in each Cartesian direction, along with the corresponding location. The same was done for the maximum and minimum shear stresses (XY, YZ, and XZ) the principal stresses (1, 2, and 3). Finally, absolute maximum deflections at each corner were recorded. Examples of typical ANSYS responses are illustrated in Figure 23. Where the noted value was believed to be questionable due to close proximity to a stress concentration, it was so indicated. This only occurred in the analysis that included the joint stiffness variable, and thus led to the conclusion that the characterization of this variable was questionable.

4.2.3 Sensitivity Analysis Results

The results of the sensitivity analysis allowed for a better understanding of the slab behavior as it may have been affected by the design and service conditions. The tables in Appendix A summarize the results from these analysis runs. The first two tables (A.1 and A.2) include results from slabs with square joints, and the second two (A.3 and A.4) are from slabs with skewed joints.

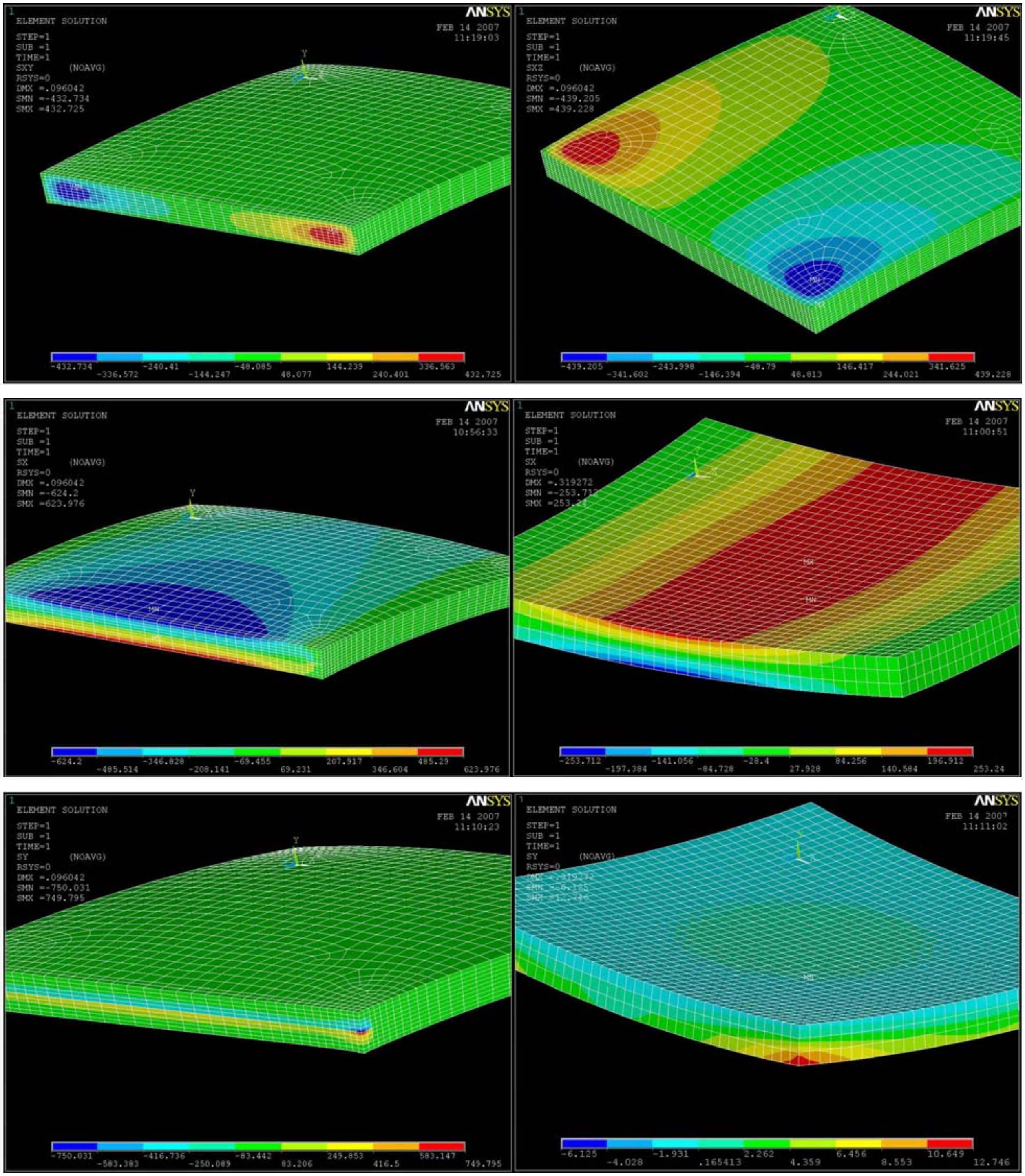


Figure 23. Illustrations of 3D FEM responses.

From these results, trends of slab behavior become evident that are both intuitive and support the hypotheses for failure. For example, increasing slab length increases mid-panel stresses. Increasing the temperature gradient significantly affects both slab shape and critical responses under load. One of the more important observations, however, is the effect of the skewed joint and the resulting acute angle. The responses on these corners are much more critical than those resulting from square joints.

4.3 Distress Interpretation and Modeling

The responses calculated from the 3D FEM can be used as inputs to distress models in order to characterize what is being observed in the field. In this section, both corner and mid-panel cracking mechanisms will be described, as these were the most commonly reported distresses on this pavement section.

4.3.1 Delamination

The most typical distress observed on this pavement section is a form of delamination that is occurring at the dowel line at approximately mid slab. As illustrated in Figure 21, the distress would normally be hidden from view except that it is limited in lateral extent, and within 3 to 5 ft. from the corner, propagates upwards in the form of a corner crack.

Delamination of this kind has not been widely reported, much less modeled. Delamination at known planes of weakness such as the interface between overlays and underlying pavement structures has been modeled, however. These models have demonstrated that stress concentrations along the plane of weakness occur near slab edges and especially at slab corners. The stress decreases in magnitude as the distance from the discontinuity is greater. In the case of this pavement, this would explain the limited extent of the observed distress.

The source of the plane of weakness is not immediately obvious. However, upon review of the data that was made available, it is believed that it can be explained by a combination of factors. Drawing from fracture mechanics theory, it is known that stress concentrations can form in the vicinity of flaws in an otherwise continuous medium that is subject to far field stress and/or stress concentrations at the flaws themselves.

In the case of the pavements in question, it is believed that a combination of curling, acute angles, and an unstable base led to an inherent weakness at the slab corners. Higher than normal deflections resulted which, in turn, led to high stress concentrations at the dowels themselves. Therefore, while the dowels had worked as intended to transfer load between slabs, the concentrated nature of the load transfer had likely led to stress concentrations at the dowels. These stresses exceeded the localized strength which, in fracture mechanics, is characterized by a critical stress intensity factor.

The corner deflections resulted from a combination of diurnal changes in slab shape and repetitive wheel loading. This caused a “prying” effect of one slab upon another, with loads transferred through the dowels. This effect is further exaggerated if the joints were wide, as would be the case adjacent to longer panels.

Once the crack initiates along this plane of weakness at mid-slab, the principles of material fatigue then govern the propagation of the horizontal crack until such a point that the stresses were low enough to slow if not cease crack growth. It is at that point that a corner crack will occur as is described in the next section.

4.3.2 Corner Cracking

Manifestation of the corner cracking distress is illustrated in Figure 24. When an external (wheel) load is applied near the corner of a slab, stresses will develop in the top fibers of the slab. When high enough, these stresses will lead to cracking. This mode of distress is exacerbated by the delamination distress previously described. The development of corner cracking on thick slabs such as those nominally constructed on this pavement is rare. However, the effective slab thickness is approximately half of the nominal thickness due to the presence of the delamination. Furthermore, the presence of the tip of the horizontal crack at mid-depth led to a weakened plane that further promoted crack growth.

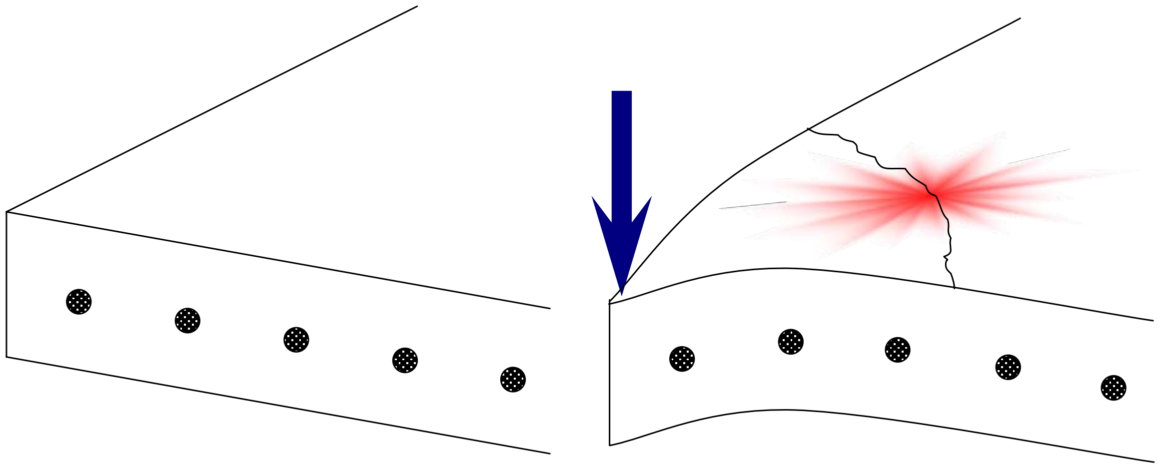


Figure 24. Illustration of corner cracking distress due to external loading.

The corner cracking mode of failure was actually the basis for many of the early concrete pavement design approaches advanced by pioneers such as Goldbeck, Older, and later by Westergaard.

The earliest approaches characterized the stress state by using beam theory. In this case, the condition is modeled as a concentrated load at the end of an infinitely long cantilevered beam of increasing cross section (increasing proportionally as the distance from the corner increases). Using this approach, the maximum stress along any point in the beam is the same. For square joints, this is found to be:

$$\sigma_{\max,corner,square\_jt} = \frac{3P}{h^2}$$

A similar calculation can be made for joints that are skewed 1:6. Applying the same methodology, the maximum stress can be calculated as:

$$\sigma_{\max,corner,skewed\_jt} = \frac{3.55P}{h^2}$$

Comparing these two formulae yields a resulting increase of 18% in maximum corner stress. Furthermore, while corrections can be made for other boundary conditions such as load transfer, this difference will be approximately the same as these corrections are often multiplicative. One exception is the supporting layer stiffness which tends to lessen this difference (as a resulting change in the radius of relative stiffness). This can be observed in the FEM results that show the difference in corner stresses to be negligible for a k-value of 1000 psi/in, but increasing to 8% for a k-value of 50 psi/in. The difference is also attributable to the finite load size assumed in the FEM, versus a point load when using cantilevered beam theory.

Regardless of which theory is applied, the corner stresses due to the presence of a skewed joint (on the acute angle) will be higher than those of a square joint. As a result, the factor of safety is decreased and the likelihood of this distress forming is higher. When combined with the delamination distress previously described, this distress has manifested itself as the prominent distress along this pavement section.

4.3.3 Mid-Panel Cracking

Mid-panel cracking of concrete pavements can be caused by a host of factors. One of the more common is an increase in slab length and/or width. When compounded by volumetric changes due to drying shrinkage and/or temperature changes, stresses can develop due to restraint by self-weight, suction, and/or so-called subgrade drag. The first two restraints often compound with volumetric strain gradients as a function of depth leading to curling and warping phenomena. The latter restraint can lead to stresses even if the volumetric strain is uniform across the slab section.

Lateral slab dimensions are a sensitive input to mid-panel cracking. The longer the effective dimensions, the higher the stress, and the greater the potential for a mid-panel crack. Figure 25 illustrates the dimensions of the extreme example from this pavement section to one that is more typical in JCP construction today. Due to the skewed joints, the effective length of the slab is not the same as the nominal length. As illustrated here, the extreme corner-to-corner dimension of a 20-ft. panel with skewed joints can be as long as 26.4 ft., which is 2 ft. longer than the same dimension for a slab with square joints, and nearly 6 ft. longer than a slab with a square joints and a nominal slab length of 15 ft. The resulting increase in slab length can increase the mid-panel stresses due to curling/warping and subgrade drag. According to the FEM, a typical 5% increase in stress due to the presence of the skewed joint can be expected due to curling/warping restraint. This is illustrated in Figure 26. When subgrade drag theory is applied, an increase in slab length from 15 to 20 ft. can lead to a corresponding increase of stress of 40 to 50%.

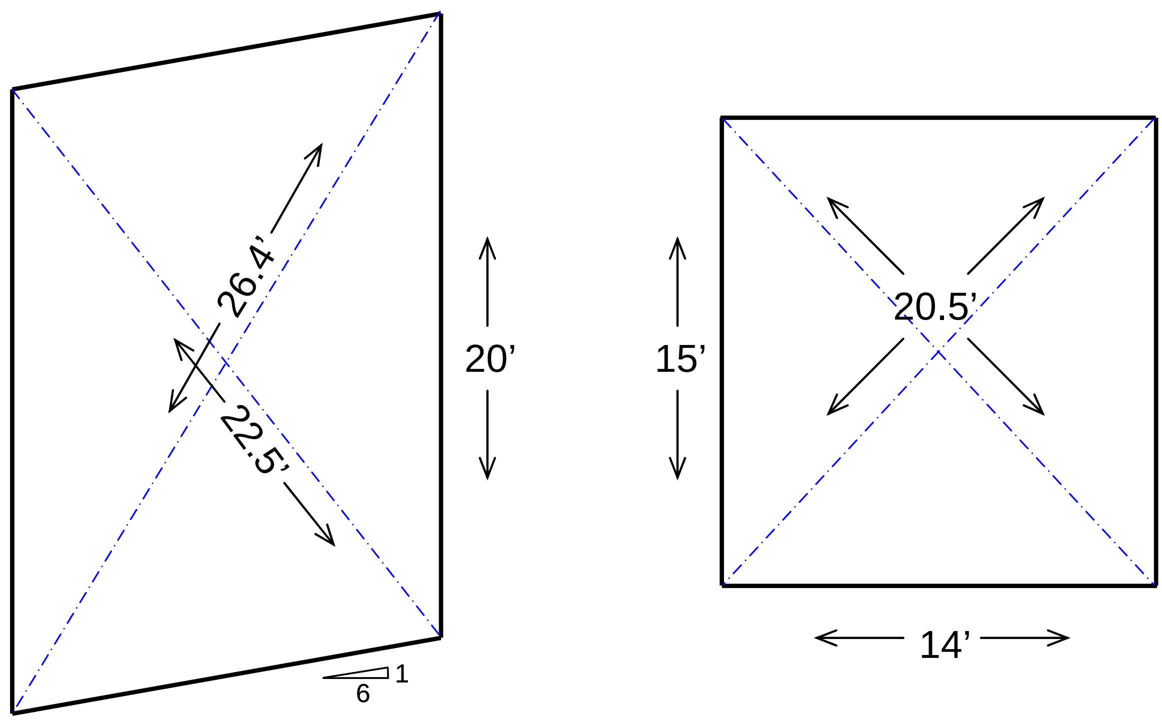


Figure 25. Illustration of longer effective panel lengths due to nominal joint spacing compounded by skewed joints.

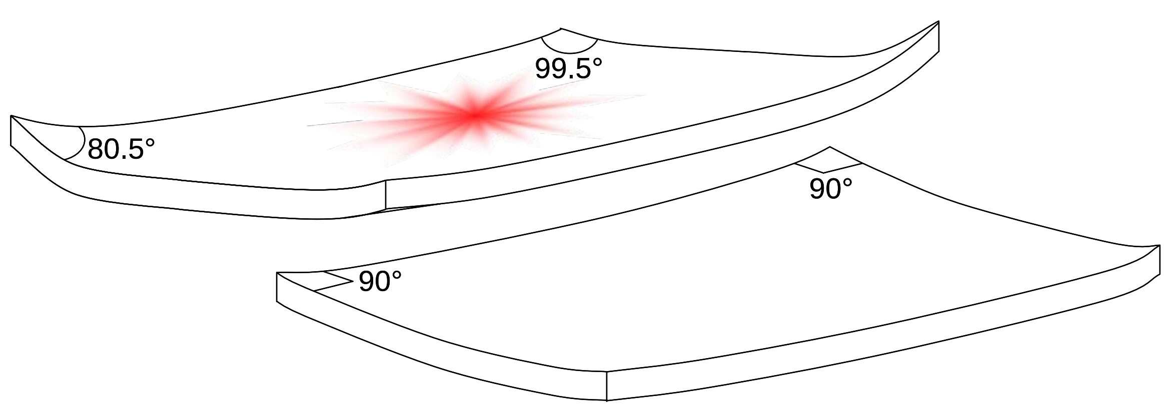


Figure 26. Illustration of higher center slab stress due to skewed joints.

5 CONCLUSIONS AND RECOMMENDATIONS

Based on a thorough review of the information that was available, along with an analysis of the failure mechanisms that are believed to be at work, a number of conclusions and associated recommendations could be made:

5.1 Factors Contributing to Observed Distress

5.1.1 Skewed joints

Conclusion: Skewed joints appear to have been a significant factor in the observed distresses. They led to increased stresses and deflections in the vicinity of the slab corners which led to both the delamination and corner cracking. Furthermore, the slab dimensions are effectively increased which may have increased the potential for mid-panel cracking.

Recommendation: Abandon the practice of skewed joints, and revert back to square joints. WisDOT has already implemented this recommendation.

5.1.2 Long panels

Conclusion: Longer panels are known both in theory and in practice to increase the mid-panel stress. Longer panels have been favored in the past for initial cost reasons, but given the performance issues that can result, they are no longer recommended. Furthermore, longer joint spacings can lead to increased joint opening which can further aggravate the corner distresses due to the corresponding decrease in load transfer.

Recommendation: Abandon the practice of using longer joint spacing – especially those 18 ft. or longer. Instead, revert to a joint spacing no longer than 16 ft. WisDOT has already implemented this recommendation.

5.1.3 Open-graded base

Conclusion: The presence of the open-graded base with such a uniform gradation may have led to an unstable platform for the concrete layer. This instability would take the form of a lower shear strength which, in turn, can increase deflections in the slab, especially at the slab corner.

Recommendation: Find ways to improve the stability of the base course by increasing the density. While permeability will reduce to some degree, a reasonable level of permeability can still be maintained while at the same time providing needed shear strength in this material. WisDOT has already implemented this recommendation.

5.1.4 Dowel size

Conclusion: Stress concentrations at the dowel are believed to be a contributing factor to the observed delamination distress. The dowels used on this pavement section are not uncommon for its thickness. However, it is known from the principles of fracture mechanics that a smaller dowel (and thus flaw) would have resulted in conditions less prone to cracking.

Recommendation: While it is controversial to recommend consideration of a smaller dowel diameter, it is not without basis. It was found in the most recent scanning tour of Europe that dowel bars of a smaller diameter than commonly used in the US appear to successfully work for load transfer.

5.2 Maintenance and Restoration Options

With the probable causes of the distresses identified, attention can be given to identifying the most effective maintenance and rehabilitation strategies. One complication with this, however, is the number of simultaneous factors believed to be at play. The optimum repair strategy will, for example, need to balance the likelihood that the most significant factors will be mitigated, along with cost and feasibility. To guide WisDOT in the proper selection, specific evaluation criteria should first be established. These could include:

- Costs
  - Materials costs.
  - Labor costs.
  - Life-cycle costs.
  - User delay and vehicle operating costs.

- Time factors
  - Time per repair.
  - Production rate including sequencing of traffic control and cure time (if applicable).
  - Expected performance period.
- Quality
  - Experience of potential contractors to conduct the repair.
  - Availability of potential contractors considering other work.
  - Probability of success of the repair considering the time constraints (i.e., under "fast track" conditions).

The various repair options should be gauged on the criteria selected. Based on the weightings of these factors, optimum alternatives should emerge. It is recognized, however, that while this procedure is presented herein in an idealized fashion, the actual execution is often difficult. Instead, "trial and error" approaches in identifying ideal repair strategies are often used. Given the number of years that this pavement section has been undergoing repairs, some degree of optimization is likely already accomplished. As such, the current repair methodologies may be close to ideal given the site-specific conditions.

If, however, failures of the existing repairs are beginning to occur, alternative repair techniques could be explored. Based on the distresses that are present, some of these may include:

- **Crack repair.** Before identifying the specific technique(s) to use, a measure should be made of the nature of the cracking. It should be noted that the "diagonal cracks" that are characteristic on this job cannot be repaired using conventional techniques, since they are a unique type of distress. However, in those instances where full-depth mid-panel cracking has occurred, load transfer retrofit would be the likely solution. In this technique, mechanical load transfer devices (commonly dowels) are retrofitted along cracks that are working (those experiencing daily and seasonal movements). This is most commonly done on mid-panel full-depth transverse cracks, like those found on portions of this pavement section (particularly on the longer panels). To minimize the cost of the repairs, retrofit can be successfully done in the wheel paths only. Guidance on best practices of these repairs can be found from the IGGA (http://www.igga.net).

- **Functional restoration:** Surface (diamond) grinding is the best technique to restore overall ride quality of a distressed and/or repaired section. It can be used in a more limited capacity to eliminate localized roughness (bumps).

On the question of preemptive treatments to prevent the distress from occurring, no specific recommendations can be made. The mechanisms that are in place that are leading to the observed distress cannot be practically modified. The skewed joints, in particular, are an inherent feature of the design that can only be modified by full-depth repair of the joints. Of course, this would be more cost effective if done after a distress at that joint has occurred.

Still, with numerous factors at play, trial sections of various preemptive techniques could be attempted. For example, sawcutting longer panels mid-panel, and retrofitting with dowel bars could possibly reduce the probability of mid-panel cracking. It is recommended that if trial preemptive treatments are conducted, that they be done on a pavement section that is believed (based on adjacent sections) to be a likely candidate for distress in the near future. Baseline sections without preemptive treatment should be left so that comparisons to the treated sections can be made. Based on these observations, rational decisions can then be made that consider the stochastic nature of this distress.

5.3 Concrete Pavement Standards and Specifications

Since the first report of early distress, WisDOT has focused on what effect their current practices may have had. Since that time, design standards, construction specifications, and maintenance procedures have evolved. For example, skewed joints and longer panels are no longer specified, and the specification of OGBC has been modified to improve stability. It appears from the investigation conducted during this research study that there have been significant benefits from these changes.

However, other factors may have been likely contributors to the observed distress. Some of these factors, and the procedural changes that could be explored, include:

- *Dowel bar size and spacing*

  An international scanning tour of concrete pavement technologies which included visits to numerous European countries has recently been completed (see http://international.fhwa.dot.gov/). During this tour, designs for long-life concrete pavements in Europe were identified which included dowel designs that are very different from what is conventionally used in the USA. Similar concrete pavements in Europe, for example, would include 25 mm (1 in.) dowel bars spaced at 250 mm (10 in.) centers in the wheelpaths, and 500 mm (20 in.) centers between the wheel paths. Experience has shown that this design provides the necessary load transfer to ensure long life as long as other complementary design elements are included such as a strong foundation. With the horizontal delamination distress caused, in part, by the flaw inherent with the larger diameter dowel, it may in the best interests of WisDOT to consider alternative dower bar size and spacing configurations, especially if this distress continues to manifest itself on other pavement sections. This alternative design has the added benefit of being more economical.

- *Use of coarse aggregates with a lower thermal coefficient of expansion*

  The coefficient of thermal expansion of the coarse aggregate drives the same property for the concrete mixture as a whole. This property, in turn, describes how much the concrete volume will change for a given temperature change. The higher the value, the more potential volume change there will be, and when restrained, the higher the potential for cracking. Coarse aggregates that are selected with a lower thermal coefficient of expansion are preferred in this regard. Of course, competing aggregate specifications must be considered including freeze-thaw durability, and possibly abrasion resistance.

- *Use of concrete mixtures with a lower shrinkage potential*

  Various concrete constituents and blends can result in mixtures with varying drying shrinkage potential. If possible, mixtures with lower shrinkage potential should be selected. This will help to avoid volumetric changes that can, in turn, lead to cracking.

- *Concrete temperature control during placement*

  The temperature that a concrete mixture will experience at about the time of setting is important as it is a benchmark for subsequent temperature changes that can lead to volumetric changes in the mixture. While the Wisconsin weather is often quite favorable to concrete production, there are still days that may push the upper bounds of good practice for concrete temperatures. During those days, it may be advisable to have controls in place to keep the concrete temperature below a reasonable maximum value.

- *Curing method and timing*

  The curing method that is most commonly used today for concrete paving is the application of a liquid curing compound shortly after placement. The practice of this is not always consistent, however. Questions remain, for example, about the effectiveness of some curing compounds to retain moisture. Added to this is the adoption of good practice for uniform coverage and the proper timing for application. Since curing can, in turn, affect many concrete properties of interest to WisDOT, especially in light of the distresses observed on this pavement section, it may be worth revisiting in terms of specification and/or training.

5.4 Recommendations (Future tasks)

5.4.1 Stage II – Short-Term Implementation

The final product from this research study is a report containing three major findings: 1) an assessment of the potential causes of the distress observed on the I90/94 section; 2) recommendations for repairs that can successfully mitigate these distresses; and 3) recommendations on standards and specifications that would prevent these distresses from occurring on future pavement sections. Due to the implications of the last two items in particular, it is recommended that relevant discussions be conducted among the various stakeholders in Wisconsin. For example, the possibility of additional changes to design standards, specifications, and other guidelines should be discussed in order to identify as many of the potential benefits and pitfalls as possible. With our highway design and construction methodologies becoming ever more interrelated and ever more complex, sometimes changing features can lead to unintended consequences.

5.4.2 Stage III – Long-Term Implementation

While this research study served the role of a project-level forensic assessment, the implications of the findings may be more far-reaching. It is for this reason that outlining potential long-term implementation activities is important. With the limited resources available in this research effort, an extensive field evaluation was not possible. However, recommendations are given herein for additional information that may prove useful. Some of the specific recommendations are as follows.

<u>Collection of deflection data.</u> Dr. Crovetti of Marquette University has previously conducted an analysis of FWD data collected at discrete locations along this pavement section. Some general trends were observed: for example, distress seemed to correlate with poorer support conditions. However, most of the findings were inconclusive. As a follow-on study, it is recommended that additional deflection data be collected. This might include the use of the Rolling Dynamic Deflectometer (RDD) previously demonstrated by Dr. Rasmussen during the TWG meeting in Madison in August 2000.

<u>Collection of profile data.</u> Slab curvature is inherent with one of the potential contributors to the observed distress. While some high-speed profile data (collected using an inertial profiler) was analyzed, it could only be processed on a limited basis due to the lack of coincidence of the current repair locations. Collecting additional profile data and/or linking the existing data with a survey of the current pavement inventory along this pavement section can be used to better understand the nature of the slab behavior. Furthermore, the data can be used to identify localized roughness which may be an indication of impending distress development. Profile data also serves as an excellent baseline, with future measurements used to identify further potential degradation of the pavement condition.

<u>Laboratory evaluation of the OGBC.</u> If desired, fundamental testing of the OGBC material used on this pavement section (as well as others in use by WisDOT) could be conducted. This could include evaluation under triaxial conditions in order to evaluate anisotropic behavior. However, since WisDOT has since moved to a different gradation on the base, the results of this may be of

limited value. Compounding this is the lack of a clear “transfer function” between the more fundamental constitutive properties of the base to observed performance in the field.

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APPENDIX A – PAVEMENT RESPONSES FROM 3D FEM

The following tables include the results of the factorial analysis using the three-dimensional FEM.

Table A.1. Variable Identification, Normal, and Shear Stresses for Square Joint Analysis Runs.

ANSYS	Variables						Normal Stresses												Shear Stresses											
Run #	φ (°)	L (ft.)	K_{VS} (psi/in.)	K_{VJ} (Mpsi/in.)	Δε (mε)	P (lb)	$\sigma_{Xmax/min}$ (psi)		$Location_{max/min}$ (x,z,y)		$\sigma_{Ymax/min}$ (psi)		$Location_{max/min}$ (x,z,y)		$\sigma_{Zmax/min}$ (psi)		$Location_{max/min}$ (x,z,y)		$\sigma_{XYmax/min}$ (psi)		$Location_{max/min}$ (x,z,y)		$\sigma_{YZmax/min}$ (psi)		$Location_{max/min}$ (x,z,y)		$\sigma_{XZmax/min}$ (psi)		$Location_{max/min}$ (x,z,y)	
1	90	12	50	0	250	0	85	-84	84,72,0	84,72,12	2	-4	84,72,0	0,144,0	52	-52	84,72,0	84,72,12	7	-7	132,144,4	36,144,4	5	-5	168,112,4	168,32,4	3	-3	36,8,0	36,136,0
2	90	12	50	0	250	9000	67	-68	73.5,0,0	73.5,0,12	3	-45	159,130,12	149,133,12	48	-48	168,104,12	168,104,0	21	-80	116,0,7	147,144,7	16	-65	0,96,7	168,126,5	94	-89	148,132,12	144,129,0
3	90	12	50	0	-750	0	253	-254	84,72,12	84,72,0	13	-6	0,144,0	84,72,0	155	-156	84,72,12	84,72,0	22	-22	36,144,4	132,144,4	14	-14	168,32,4	168,4,112	9	-9	36,136,0	36,8,0
4	90	12	50	0	-750	9000	312	-311	89,144,12	89,144,0	13	-45	0,0,0	149,133,12	197	-196	168,79,12	162,78,0	33	-105	42,0,5	146,144,7	24	-81	0,36,5	168,123,5	103	-99	148,132,12	142,130,0
5	90	12	50	0	0	9000	79	-79	101,144,12	102,144,0	3	-45	159,130,12	149,133,12	79	-79	168,91,12	168,91,0	17	-86	95,0,7	147,144,7	13	-68	0,72,7	168,126,5	96	-92	148,132,12	144,129,0
6	90	12	50	1.5	250	0	623	-624	84,140,0	84,140,12	443	-444	168,144,5	168,144,7	236	-236	0,133,0	0,133,12	433	-433	153,144,6	15,144,6	437	-8	0,140,6	2,144,11	438	-438	155,134,0	155,134,12
7	90	12	50	1.5	250	9000	622	-623	84,140,0	84,140,12	406	-446	167,144,5	167,144,8	284	-297	168,133,0	168,133,12	446	-434	155,144,6	15,144,6	549	-9	168,140,6	0,144,8	446	-446	155,135,0	155,135,12
8	90	12	50	1.5	-750	0	1870	-1869	84,140,12	84,140,0	1322	-1322	168,144,7	168,144,5	707	-707	0,133,12	0,133,0	1298	-1298	15,144,6	153,144,6	23	-1316	2,144,11	0,140,6	1315	-1315	155,134,12	155,134,0
9	90	12	50	1.5	-750	9000	1869	-1868	84,140,12	84,140,0	1176	-1175	0,143,8	0,143,5	709	-709	0,135,12	0,135,0	1307	-1295	15,144,6	153,144,6	28	-1420	0,144,8	168,140,6	1317	-1317	13,135,0	13,135,12
10	90	12	50	1.5	0	9000	23	-18	146,142,12	150,135,12	25	-63	168,142,5	168,142,8	51	-66	167,133,0	167,133,12	13	-8	158,144,8	148,133,12	58	-10	139,137,0	135,137,12	12	-13	139,137,0	135,137,12
11	90	12	1000	0	250	0	611	-609	84,72,0	84,72,12	16	-41	84,72,0	0,144,0	507	-506	84,72,0	84,72,12	50	-50	136,144,8	32,144,8	45	-45	168,116,8	168,28,8	20	-20	32,8,0	32,136,0
12	90	12	1000	0	250	9000	602	-601	88,65,0	88,65,12	15	-48	90,75,0	168,144,0	500	-499	68,70,0	68,70,12	52	-53	137,0,7	30,144,7	45	-48	0,120,7	168,26,7	54	-47	148,132,12	145,129,0
13	90	12	1000	0	-750	0	1828	-1832	84,72,12	84,72,0	124	-47	0,144,0	84,72,0	1519	-1521	84,72,12	84,72,0	151	-151	32,144,8	136,144,8	136	-136	168,28,8	168,116,8	59	-59	32,136,0	32,8,0
14	90	12	1000	0	-750	9000	1838	-1841	82,79,12	82,79,0	117	-45	0,0,0	149,133,12	1528	-1530	90,75,12	90,75,0	155	-208	30,144,7	142,144,5	139	-179	168,26,7	168,117,5	121	-118	148,132,12	143,135,0
15	90	12	1000	0	0	9000	59	-59	124,140,12	124,140,0	3	-45	159,130,12	149,133,12	68	-68	164,104,12	165,107,0	2	-66	126,0,7	147,144,7	2	-53	153,130,12	168,130,7	71	-64	148,132,12	146,130,0
16	90	12	1000	1.5	250	0	673	-672	84,105,0	84,105,12	372	-376	168,144,5	168,144,7	616	-617	6,84,0	6,84,12	343	-343	156,144,6	12,144,6	415	-43	0,140,6	168,29,6	322	-322	12,137,12	12,137,0
17	90	12	1000	1.5	250	9000	671	-670	84,102,0	84,102,12	337	-380	168,143,5	168,143,8	617	-619	4,85,0	4,85,12	351	-345	155,144,6	12,144,6	524	-44	168,140,6	168,30,6	329	-329	157,135,0	157,136,12
18	90	12	1000	1.5	-750	0	2024	-2025	84,105,12	84,105,0	1137	-1131	168,144,7	168,144,5	1889	-1885	6,84,12	6,84,0	1032	-1032	12,144,6	156,144,6	132	-1266	168,29,6	0,140,6	970	-969	12,137,0	158,135,0
19	90	12	1000	1.5	-750	9000	2024	-2026	84,102,12	84,102,0	1005	-998	0,143,8	0,143,5	1895	-1890	164,88,12	164,88,0	1038	-1026	12,144,6	155,144,6	134	-1395	0,27,6	168,140,6	969	-968	10,134,0	10,135,12
20	90	12	1000	1.5	0	9000	22	-19	146,142,12	150,135,12	22	-61	168,142,5	168,142,8	48	-63	167,133,0	165,133,12	10	-9	159,144,8	148,144,11	51	-12	168,140,6	168,132,11	8	-8	156,139,0	156,139,12
21	90	12	300	0	250	0	346	-345	84,72,0	84,72,12	9	-19	84,72,0	0,144,0	245	-244	84,72,0	84,72,12	29	-29	132,144,8	36,144,8	22	-22	168,112,4	168,32,4	12	-12	36,8,0	36,136,0
22	90	12	300	0	250	9000	328	-327	87,55,0	87,55,12	8	-44	78,68,0	149,133,12	230	-230	68,70,0	68,70,12	35	-51	126,0,7	148,144,7	26	-45	0,108,7	168,130,7	74	-68	148,132,12	145,128,0
23	90	12	300	0	-750	0	1036	-1038	84,72,12	84,72,0	58	-26	0,144,0	84,72,0	733	-735	84,72,12	84,72,0	88	-88	36,144,8	132,144,8	66	-66	168,32,4	168,112,4	35	-35	36,136,0	132,136,0
24	90	12	300	0	-750	9000	1061	-1063	82,79,12	82,79,0	55	-45	0,0,0	149,133,12	755	-756	90,75,12	90,75,0	90	-155	32,0,7	143,144,5	69	-121	0,36,7	168,121,5	112	-108	148,132,12	141,133,12
25	90	12	300	0	0	9000	69	-69	112,144,12	112,144,0	3	-45	159,130,12	149,133,12	75	-75	168,129,7	168,96,0	7	-77	105,0,7	147,144,7	5	-61	0,84,7	168,129,7	83	-78	148,132,12	145,131,0
26	90	12	300	1.5	250	0	629	-630	84,140,0	84,140,12	404	-405	168,144,5	168,144,7	420	-421	132,91,0	162,91,12	397	-397	156,144,6	12,144,6	437	-11	0,140,6	0,17,6	393	-393	155,134,0	155,134,12
27	90	12	300	1.5	250	9000	629	-630	84,137,0	84,140,12	373	-413	168,143,5	168,143,8	425	-426	164,93,0	164,93,12	408	-399	155,144,6	12,144,6	549	-11	168,140,6	168,18,6	400	-399	155,135,0	155,135,12
28	90	12	300	1.5	-750	0	1891	-1888	84,140,12	84,140,0	1209	-1207	0,142,7	0,142,5	1285	-1283	162,91,12	162,91,0	1192	-1192	12,144,6	156,144,6	33	-1322	0,17,6	0,140,6	1180	-1180	155,134,12	155,134,0
29	90	12	300	1.5	-750	9000	1891	-1889	84,137,12	84,137,0	1107	-1104	0,143,8	0,143,5	1293	-1290	3,91,12	3,91,0	1198	-1190	12,144,6	155,144,6	33	-1444	0,19,6	168,140,6	1181	-1181	13,135,0	13,135,12
30	90	12	300	1.5	0	9000	23	-19	146,142,12	150,135,12	23	-62	168,142,5	168,142,8	50	-65	167,133,0	167,133,12	11	-8	158,144,8	148,144,11	54	-11	168,140,6	168,132,11	10	-10	155,138,0	135,137,12
31	90	20	50	0	250	0	100	-100	84,120,0	84,120,12	3	-6	84,120,0	168,0,0	263	-263	84,120,0	84,120,12	8	-8	132,0,4	36,0,4	18	-18	168,186,8	168,54,8	10	-10	162,186,0	6,186,0
32	90	20	50	0	250	9000	88	-88	83,99,0	83,99,12	4	-45	158,226,12	150,230,12	237	-237	8,112,0	0,112,12	13	-80	126,0,5	148,240,7	32	-60	0,176,7	168,226,7	94	-90	148,228,12	143,225,0
33	90	20	50	0	-750	0	300	-300	84,120,12	84,120,0	19	-9	168,0,0	84,120,0	789	-789	84,120,12	84,120,0	24	-24	36,0,4	132,0,4	55	-55	168,54,8	168,186,8	29	-29	6,186,0	162,186,0
34	90	20	50	0	-750	9000	317	-317	83,129,12	83,129,0	19	-45	0,0,0	150,230,12	836	-835	162,123,12	162,123,0	28	-108	42,0,5	145,240,7	63	-116	0,56,7	168,203,7	114	-110	148,228,12	143,224,0
35	90	20	50	0	0	9000	73	-74	97,240,12	97,240,0	3	-45	158,226,12	150,230,12	91	-91	164,173,12	164,173,0	7	-87	84,0,7	148,240,7	16	-71	0,152,7	168,220,5	99	-95	148,228,12	143,224,0
36	90	20	50	1.5	250	0	623	-623	84,236,0	84,236,12	416	-416	0,240,5	0,240,7	462	-463	4,152,0	4,152,12	457	-457	153,240,6	15,240,6	470	-13	0,236,6	0,37,6	466	-466	155,231,0	13,232,0
37	90	20	50	1.5	250	9000	623	-623	84,236,0	84,236,12	441	-480	167,240,5	167,240,8	464	-465	164,155,0	164,155,12	468	-458	155,240,6	15,240,6	581	-14	168,236,6	168,39,6	475	-474	155,231,0	155,231,12
38	90	20	50	1.5	-750	0	1870	-1869	84,236,12	84,236,0	1241	-1240	0,240,8	0,240,5	1398	-1397	4,152,12	4,152,0	1372	-1372	15,240,6	153,240,6	40	-1415	0,37,6	0,236,6	1400	-1400	13,232,0	155,232,0
39	90	20	50	1.5	-750	9000	1870	-1869	84,236,12	84,236,0	1265	-1264	0,239,8	0,239,5	1399	-1398	4,152,12	4,152,0	1378	-1366	15,240,6	153,240,6	41	-1520	0,39,6	168,236,6	1406	-1406	13,231,0	13,231,12
40	90	20	50	1.5	0	9000	23	-18	146,238,12	150,231,12	25	-63	168,238,5	168,238,8	51	-66	167,229,0	167,229,12	12	-7	158,240,8	148,240,11	58	-10	168,236,6	168,228,11	12	-12	135,233,0	135,233,12
41	90	20	1000	0	250	0	647	-646	84,120,0	84,120,12	11	-41	84,174,0	168,240,0	771	-770	84,120,0	84,120,12	51	-51	138,0,8	30,0,8	52	-52	168,204,8	168,36,8	25	-25	162,204,0	162,36,0
42	90	20	1000	0	250	9000	646	-645	83,106,0	83,106,12	11	-48	78,176,0	168,240,0	770	-769	78,121,0	78,121,12	52	-53	134,0,7	36,240,7	54	-53	0,200,7	168,37,7	51	-45	148,228,12	145,225,0
43	90	20	1000	0	-750	0	1939	-1940	84,120,12	84,120,0	122	-34	168,240,0	84,66,0	2310	-2313	84,120,12	84,120,0	154	-154	30,0,8	138,0,8	157	-157	168,36,8	168,204,8	75	-75	6,204,0	6,36,0
44	90	20	1000	0	-750	9000	1941	-1942	85,121,12	85,121,0	117	-46	0,0,0	150,230,12	2311	-2314	85,121,12	85,121,0	157	-212	34,0,7	141,240,5	160	-197	168,37,7	168,209,7	129	-124	148,228,12	145,230,0
45	90	20	1000	0	0	9000	59	-59	122,236,12	122,236,0	4	-45	158,226,12	150,230,12	68	-69	165,203,12	165,203,0	2	-66	150,230,12	148,240,7	2	-53	158,226,12	168,226,7	71	-64	148,228,12	146,227,0
46	90	20	1000	1.5	250	0	672	-672	84,191,0	84,191,12	326	-330	0,238,5	0,238,8	778	-777	84,131,0	84,131,12	348	-348	156,240,6	12,240,6	421	-54	0,236,6	0,37,6	328	-328	155,232,0	13,232,0
47	90	20	1000	1.5	250	9000	671	-670	84,192,0	84,192,12	332	-375	168,239,5	168,239,8	777	-776	84,130,0	84,130,12	355	-349	155,240,6	12,240,6	532	-54	168,236,6	0,34,6	334	-334	157,231,0	157,231,12
48	90	20	1000	1.5	-750	0	2022	-2023	84,196,12	84,191,0	998	-992	0,238,8	0,238,5	2337	-2340	84,136,12	84,136,0	1046	-1046	12,240,6	156,240,6	161	-1283	0,37,6	0,236,6	986	-986	13,232,0	155,232,0
49	90	20	1000	1.5	-750	9000	2024	-2025	84,192,12	84,192,0	990	-984	0,239,8	0,239,5	2338	-2340	84,136,12	84,136,0	1048	-1037	12,240,6	155,240,6	161	-1421	0,34,6	168,236,6	984	-983	10,231,0	10,231,12
50	90	20	1000	1.5	0	9000	22	-19	146,238,12	150,231,12	22	-61	168,238,5	168,238,8	48	-63	167,229,0	165,229,12	10	-9	159,240,8	148,240,11	51	-12	168,236,6	168,228,11	8	-8	156,235,0	156,235,12
51	90	20	300	0	250	0	386	-385	84,120,0	84,120,12	8	-22	84,120,0	168,240,0	629	-628	84,120,0	84,120,12	31	-31	132,0,8	36,0,8	43	-43	168,192,8	168,48,8	22	-22	162,192,0	6,192,0
52	90	20	300	0	250	9000	379	-379	81,113,0	81,113,12	8	-45	89,129,0	150,230,12	620	-619	78,121,0	78,121,12	32	-50	134,0,7	148,240,7	47	-44	0,192,7	168,46,7	70	-64	148,228,12	145,225,0
53	90	20	300	0	-750	0	1156	-1157	84,120,12	84,120,0	65	-25	168,240,0	84,120,0	1885	-1888	84,120,12	84,120,0	93	-93	36,0,8	132,0,8	128	-128	168,48,8	168,192,8	66	-66	6,192,0	162,192,0
54	90	20	300	0	-750	9000	1164	-1165	85,121,12	85,121,0	63	-45	0,240,0	150,230,12	1896	-1898	85,121,12	85,121,0	94	-161	34,0,7	141,240,5	129	-174	0,48,7	168,203,7	126	-121	148,228,12	144,227,0
55	90	20	300	0	0	9000	68	-68	113,235,12	113,235,0	4	-45	158,226,12	150,230,12	78	-78	165,193,12	165,193,0	2	-76	150,230,12	148,240,7	4	-61	0,184,7	168,226,7	84	-78	148,228,12	145,225,0
56	90	20	300	1.5	250	0	628	-629	84,234,0	84,234,12	366	-367	0,238,5	0,238,8	709	-711	4,142,0	4,142,12	412	-412	156,240,6	12,240,6	471	-41	0,236,6	0,42,6	413	-413	155,232,0	13,232,0
57	90	20	300	1.5	250	9000	628	-628	84,233,0	84,233,12	372	-412	168,239,5	3,145,12	710	-711	3,145,0	3,144,12	423	-413	155,250,6	12,240,6	592	-41	168,236,6	168,44,6	419	-419	155,231,0	155,231,12
58	90	20	300	1.5	-750	0	1887	-1885	84,234,12	84,234,0	1104	-1102	0,238,8	0,238,5	2148	-2145	4,147,12	4,147,0	1238	-1238	12,240,6	156,240,6	122	-1424	0,42,6	0,236,6	1239	-1239	13,232,0	155,232,0
59	90	20	300	1.5	-750	9000	1887	-1885	84,233,12	84,233,0	1105	-1102	0,239,8	0,239,5	2150	-2147	164,142,12	164,142,0	1242	-1235	12,240,6	155,240,6	123	-1575	0,44,6	168,236,6	1242	-1242	13,231,0	13,231,12
60	90	20	300	1.5	0	9000	-18	-19	146,238,12	150,231,12	23	-62	168,238,5	168,238,8	50	-65	167,229,0	167,229,12	11	-8	158,240,8	148,240,11	54	-11	168,236,6	168,228,11	10	-10	154,234,0	135,233,12
61	90	15	50	0	250	0	89	-89	84,90,0	84,90,12	2	-5	84,90,0	168,180,0	110	-110	84,90,0	84,90,12	7	-7	130,180,4	38,180,4	9	-9	168,140,4	168,40,4	4	-4	160,143,0	8,143,0
62	90	15	50	0	250	9000	72	-72	79,56,0	79,56,12	4	-45	164,167,12	150,170,12	88	-88	5,84,0	5,84,12	18	-81	118,0,6	147,180,6	23	-64	0,129,6	168,164,6	96	-91	148,168,12	143,165,0
63	90	15	50	0	-750	0	267	-267	84,90,12	84,90,0	15	-7	168,0,0	84,90,0	329	-330	84,90,12	84,90,0	22	-22	38,180,4	130,180,4	27	-27	168,40,4	168,140,4	12	-12	8,143,0	160,143,0
64	90	15	50	0	-750	9000	299	-299	89,111,12	89,111,0	15	-45	0,0,0	150,170,12	376	-375	164,93,12	164,93,0	31	-108	39,0,6	145,180,6	37	-94	0,45,6	168,152,6	108	-103	148,168,12	142,167,0
65	90	15	50	0	0	9000	76	-76	99,176,12	99,176,0	4	-45	164,167,12	150,170,12	86	-86	165,117,12	165,117,0	13	-88	90,0,6	147,180,6	16	-71	0,101,6	168,162,6	99	-94	148,168,12	143,165,0
66	90	15	50	1.5	250	0	624	-624	84,176,0	84,176,12	408	-409	0,180,5	0,180,8	290	-290	3,126,0	3,126,12	445	-445	153,180,6	15,180,6	449	-9	0,176,6	0,180,12	451	-451	155,172,0	13,172,0
67	90	15	50	1.5	250	9000	623	-623	84,176,0	84,176,12	433	-472	167,180,5	167,180,8	310	-323	168,169,0	168,169,12	456	-445	155,180,6	15,180,6	557	-9	168,176,6	0,180,8	460	-459	155,171,0	154,169,12
68	90	15	50	1.5	-750	0	1871	-1870	84,176,12	84,176,0	1219	-1219	0,180,8	0,180,5	879	-878	165,126,12	3,126,0	1335	-1335	15,180,6	153,180,6	27	-1350	0,180,12	0,176,6	1353	-1353	13,172,0	155,172,0
69	90	15	50	1.5	-750	9000	1871	-1871	84,176,12	84,176,0	1234	-1233	0,179,8	0,179,5	878	-877	3,127,12	3,127,0	1340	-1329	15,180,6	153,180,6	28	-1446	0,180,8	168,176,6	1359	-1359	13,171,0	13,171,12
70	90	15	50	1.5	0	9000	23	-18	146,178,12	150,171,12	25	-63	168,178,5	168,178,8	51	-66	167,169,0	167,169,12	13	-7	158,180,8	148,180,11	58	-10	168,176,6	168,168,11	12	-12	135,173,0	135,173,12
71	90	15	1000	0	250	0	634	-633	84,90,0	84,90,12	14	-42	84,90,0	168,180,0	672	-671	84,90,0	84,90,12	52	-52	134,180,8	34,180,8	52	-52	168,146,8	168,34,8	22	-22	160,149,0	160,31,0
72	90	15	1000	0	250	9000	630	-629	86,87,0	86,87,12	14	-49	83,91,0	168,180,0	667	-666	77,90,0	77,90,12	53	-54	134,0,6	34,180,6	55	-54	0,146,6	0,34,6	53	-46	148,168,12	145,165,0
73	90	15	1000	0	-750	0	1899	-1901	84,90,12	84,90,0	126	-41	168,180,0	84,90,0	2012	-2015	84,90,12	84,90,0	155	-155	34,180,8	134,180,8	157	-157	168,34,8	168,146,8	65	-65	8,149,0	160,149,0
74	90	15	1000	0	-750	9000	1905	-1907	83,91,12	83,91,0	118	-45	0,0,0	150,170,12	2018	-2021	82,91,12	83,91,0	158	-215	34,0,6	142,180,6	162	-202	0,34,6	168,150,6	128	-123	148,168,12	143,170,0
75	90	15	1000	0	0	9000	59	-59	123,177,12	123,177,0	4	-45	164,167,12	150,170,12	68	-69	166,142,12	166,142,0	2	-66	150,170,12	147,180,6	2	-53	150,170,12	168,165,6	72	-64	148,168,12	146,166,0
76	90	15	1000	1.5	250	0	676	-676	84,131,0	84,131,12	327	-331	0,178,5	0,178,8	729	-728	84,97,0	84,97,12	347	-347	156,180,6	12,180,6	422	-52	0,176,6	0,34,6	327	-327	155,172,0	13,172,0
77	90	15	1000	1.5	250	9000	675	-674	84,132,0	84,132,12	335	-377	168,179,5	168,179,8	728	-728	84,97,0	84,97,12	354	-348	155,180,6	12,180,6	533	-53	168,176,6	168,36,6	334	-333	167,171,0	167,171,12
78	90	15	1000	1.5	-750	0	2034	-2035	84,131,12	84,131,0	1001	-995	0,178,8	0,178,5	2206	-2207	84,104,12	84,104,0	1044	-1044	12,180,6	156,180,6	157	-1287	0,34,6	0,176,6	984	-984	13,172,0	155,172,0
79	90	15	1000	1.5	-750	9000	2036	-2037	84,132,12	84,132,0	998	-991	0,179,8	0,179,5	2206	-2208	84,104,12	84,104,0	1047	-1036	12,180,6	155,180,6	158	-1423	0,36,6	168,176,6	982	-982	10,171,0	10,171,12
80	90	15	1000	1.5	0	9000	22	-19	146,178,12	150,171,12	22	-61	168,178,5	168,178,8	48	-63	167,169,0	165,169,12	10	-9	159,180,8	148,180,11	51	-12	168,176,6	168,168,11	8	-8	156,175,0	156,175,12
81	90	15	300	0	250	0	365	-364	84,90,0	84,90,12	9	-21	84,90,0	168,180,0	415	-414	84,90,0	84,90,12	30	-30	134,180,8	34,180,8	33	-33	168,143,8	168,37,8	14	-14	160,146,0	160,34,0
82	90	15	300	0	250	9000	352	-352	81,80,0	81,80,12	9	-45	83,91,0	150,170,12	399	-398	71,89,0	71,89,12	33	-50	134,0,6	147,180,6	38	-40	0,141,6	168,167,6	73	-66	148,168,12	143,165,0
83	90	15	300	0	-750	0	1092	-1094	84,90,12	84,90,0	64	-28	168,180,0	84,90,0	1242	-1244	84,90,12	84,90,0	91	-91	34,180,8	134,180,8	99	-99	168,37,8	168,143,8	43	-43	8,146,0	160,146,0
84	90	15	300	0	-750	9000	1107	-1109	83,91,12	83,91,0	61	-45	168,0,0	150,170,12	1261	-1263	83,91,12	83,91,0	94	-161	34,0,6	143,180,6	104	-153	0,39,6	168,149,6	120	-114	148,168,12	143,169,0
85	90	15	300	0	0	9000	69	-69	112,177,12	112,177,0	3	-45	164,167,12	150,170,12	78	-78	165,130,12	165,130,0	3	-77	112,0,6	147,180,6	5	-62	0,124,6	168,164,6	85	-78	148,168,12	146,166,0
86	90	15	300	1.5	250	0	630	-631	84,174,0	84,174,12	361	-362	0,178,5	0,178,8	580	-581	4,110,0	4,110,12	407	-407	156,180,6	12,180,6	459	-27	0,176,6	0,29,6	405	-405	155,172,0	13,172,0
87	90	15	300	1.5	250	9000	629	-630	84,173,0	84,173,12	376	-416	168,179,5	168,179,8	580	-581	164,108,0	164,108,12	418	-408	155,180,6	12,180,6	575	-28	168,176,6	168,30,6	412	-411	155,171,0	155,171,12
88	90	15	300	1.5	-750	0	1892	-1889	84,174,12	84,174,0	1089	-1087	0,178,8	0,178,5	1765	-1762	164,110,12	4,110,0	1222	-1222	12,180,6	156,180,6	82	-1387	0,29,6	0,176,6	1216	-1216	13,172,0	155,172,0
89	90	15	300	1.5	-750	9000	1891	-1889	84,173,12	84,173,0	1117	-1115	0,179,8	0,179,5	1764	-1761	164,108,12	164,108,0	1225	-1218	12,180,6	155,180,6	83	-1522	0,30,6	168,176,6	1218	-1218	13,171,0	13,171,12
90	90	15	300	1.5	0	9000	23	-19	146,178,12	150,171,12	23	-62	168,178,5	168,178,8	50	-65	167,169,0	167,169,12	11	-8	158,180,8	148,180,11	54	-11	168,176,6	168,168,11	10	-10	167,169,0	135,173,12

Table A.2. Principal Stresses and Deflections for Square Joint Analysis Runs.

ANSYS	**Principal Stresses**														**Deflections**					
Run #	$\sigma_{1max/min}$ (psi)		Location$_{max/min}$ (x,z,y)		$\sigma_{2max/min}$ (psi)		Location$_{max/min}$ (x,z,y)		$\sigma_{3max/min}$ (psi)		Location$_{max/min}$ (x,z,y)		σ_2 @ σ_{1max}	σ_3 @ σ_{1max}	Δ_{ymax} (Inches)	Location$_{max/min}$ (x,z,y)	0,0	X,0	X,Z	0,Z
1	85	0	84,72,0	84,72,12	52	-52	84,72,0	84,72,12	2	-84	84,72,0	84,72,12	52	2	-0.0793	168,0,0	-0.0793	-0.0793	-0.0793	-0.0793
2	103	0	146,119,12	0,0,2	21	-45	54,46,0	149,133,12	2	-109	76,56,0	149,133,12	0	-69	-0.1427	168,144,0	-0.0534	-0.0801	-0.1422	-0.0820
3	253	-6	84,72,12	84,72,0	155	-156	84,72,12	84,72,0	0	-254	84,72,12	84,72,0	155	0	0.2424	168,0,12	0.2379	0.2379	0.2379	0.2379
4	319	-7	87,135,12	105,86,0	174	-174	90,75,12	90,75,0	2	-318	0,0,0	87,135,0	8	0	0.2669	0,0,12	0.2624	0.2356	0.1745	0.2337
5	124	0	129,124,12	167,143,12	3	-45	159,130,12	149,133,12	0	-124	0,0,0	129,124,0	0	-45	-0.0634	168,144,0	0.0244	-0.0023	-0.0634	-0.0042
6	641	-1	33,136,0	84,140,12	153	-153	84,144,5	84,144,7	2	-641	84,82,0	33,136,12	0	-78	-0.0901	168,0,0	-0.0901	-0.0901	-0.0050	-0.0050
7	642	-2	135,137,0	117,141,12	176	-177	84,144,5	84,144,8	2	-643	117,141,0	135,137,12	0	-70	-0.0912	168,0,0	-0.0900	-0.0912	-0.0053	-0.0050
8	1922	-5	33,136,12	84,82,0	459	-458	84,144,7	84,144,5	2	-1922	84,140,12	33,136,0	0	-235	0.2767	168,0,12	0.2722	0.2722	0.0104	0.0104
9	1930	-7	37,137,12	121,141,0	532	-531	84,144,8	84,144,5	6	-1930	121,141,12	37,137,0	1	-75	0.2768	0,0,12	0.2723	0.2711	0.0101	0.0104
10	51	-17	165,133,0	149,133,12	5	-8	146,132,5	148,132,9	0	-34	155,129,0	168,129,12	1	0	-0.0013	168,81,6	0.0002	-0.0011	-0.0003	0.0000
11	611	-1	84,72,0	84,72,12	507	-506	84,72,0	84,72,12	16	-609	84,72,0	84,72,12	507	16	-0.0388	168,144,0	-0.0388	-0.0388	-0.0388	-0.0388
12	603	0	88,65,0	88,65,12	500	-499	68,70,0	68,70,12	15	-601	90,75,0	88,65,12	493	15	-0.0482	168,144,0	-0.0389	-0.0386	-0.0482	-0.0387
13	1828	-47	84,72,12	84,72,0	1519	-1521	84,72,12	84,72,0	2	-1832	84,72,12	84,72,0	1519	2	0.1210	168,144,12	0.1210	0.1210	0.1210	0.1210
14	1838	-45	82,79,12	90,75,0	1527	-1530	80,75,12	90,75,0	14	-1841	0,0,0	82,79,0	1509	0	0.1212	168,0,12	0.1209	0.1212	0.1115	0.1210
15	92	-1	142,125,12	139,87,0	5	-45	108,78,12	149,133,12	0	-91	53,22,0	144,122,0	0	-30	-0.0095	168,144,12	0.0001	0.0002	-0.0095	0.0000
16	673	0	84,105,0	28,140,12	606	-606	84,82,0	84,82,12	13	-672	84,82,0	84,105,12	506	12	-0.0391	0,0,1	-0.0391	-0.0391	-0.0041	-0.0041
17	671	-1	84,102,0	32,140,12	606	-606	89,82,0	89,82,12	13	-670	84,83,0	84,102,12	531	12	-0.0391	0,0,1	-0.0391	-0.0391	-0.0044	-0.0041
18	2024	-40	84,105,12	84,82,0	1853	-1854	84,82,12	84,82,0	1	-2025	32,140,12	84,105,0	1565	0	0.1223	0,0,12	0.1177	0.1177	0.0076	0.0076
19	2024	-40	84,102,12	84,83,0	1852	-1853	84,83,12	84,83,0	3	-2026	32,140,12	84,102,0	1638	0	0.1223	168,0,12	0.1177	0.1177	0.0073	0.0076
20	48	-18	165,133,0	149,135,12	5	-5	156,129,0	147,130,9	0	-63	155,129,0	165,133,12	1	0	-0.0006	168,124,5	0.0000	0.0000	-0.0003	0.0000
21	346	0	84,72,0	84,72,12	245	-244	84,72,0	84,72,12	9	-345	84,72,0	84,72,12	245	9	-0.0605	168,144,0	-0.0591	-0.0591	-0.0591	-0.0591
22	329	-2	88,65,0	0,0,0	229	-228	68,70,0	68,70,12	8	-328	78,68,0	87,55,12	222	8	-0.0796	168,144,0	-0.0580	-0.0583	-0.0782	-0.0583
23	1036	-26	84,72,12	84,72,0	733	-735	84,72,12	84,72,0	1	-1038	84,72,12	84,72,0	733	1	0.1862	168,144,12	0.1862	0.1862	0.1862	0.1862
24	1062	-25	82,79,12	90,75,0	754	-755	90,75,12	90,75,0	7	-1064	0,0,0	82,79,0	740	0	0.1872	0,12,0	0.1872	0.1869	0.1670	0.1865
25	108	-1	140,119,12	113,87,0	3	-45	159,130,12	149,133,12	0	-108	168,0,0	136,126,0	0	-34	-0.0191	168,144,12	0.0011	0.0008	-0.0191	0.0003
26	630	-1	103,140,0	36,140,12	341	-341	84,82,0	84,82,12	8	-630	84,82,0	77,140,12	76	1	-0.0636	0,0,0	-0.0621	-0.0621	-0.0031	-0.0031
27	629	-1	78,137,0	36,140,12	342	-342	84,83,0	84,83,12	8	-630	84,83,0	77,140,12	108	2	-0.0637	168,0,0	-0.0620	-0.0622	-0.0034	-0.0031
28	1891	-23	77,140,12	84,82,0	1044	-1045	84,82,12	84,82,0	2	-1888	36,140,12	103,140,0	235	1	0.1963	0,0,12	0.1963	0.1963	0.0137	0.0137
29	1891	-24	84,137,12	84,83,0	1044	-1045	84,83,12	84,83,0	4	-1889	129,141,12	84,137,0	325	1	0.1964	0,0,12	0.1964	0.1962	0.0133	0.0137
30	50	-18	165,133,0	149,134,12	6	-7	156,130,0	147,132,9	0	-65	155,135,0	165,133,12	1	0	-0.0008	168,115,6	0.0000	-0.0001	-0.0003	0.0000
31	263	0	84,120,0	66,222,12	100	-100	84,120,0	66,222,12	3	-263	84,120,0	66,222,12	100	3	-0.1181	168,0,0	-0.1181	-0.1181	-0.1181	-0.1181
32	238	-1	8,112,0	167,239,12	85	-85	83,99,0	83,99,12	3	-238	91,93,0	8,112,12	4	0	-0.1721	168,240,0	-0.1096	-0.1178	-0.1721	-0.1188
33	789	-9	84,120,12	84,120,0	300	-300	84,120,12	84,120,0	0	-789	6,0,0	84,120,0	300	0	0.3590	168,0,12	0.3544	0.3544	0.3544	0.3544
34	837	-9	162,123,12	89,129,0	315	-315	83,129,12	83,129,0	1	-836	0,240,0	162,123,0	8	0	0.3675	0,0,12	0.3630	0.3539	0.3004	0.3538
35	128	-1	144,199,12	167,239,12	3	-45	158,226,12	150,230,12	0	-128	0,0,12	150,194,0	0	-39	-0.0541	168,240,12	0.0085	-0.0005	-0.0541	-0.0006
36	664	-3	29,232,0	84,236,12	344	-344	84,170,0	84,170,12	3	-664	84,142,0	29,232,12	0	-111	-0.1291	0,0,0	-0.1291	-0.1291	-0.0054	-0.0054
37	672	-2	148,230,0	117,237,12	341	-341	84,172,0	84,172,12	3	-683	84,144,0	149,230,12	0	-222	-0.1293	168,0,0	-0.1288	-0.1293	-0.0057	-0.0054
38	1991	-9	29,232,12	84,142,0	1039	-1039	84,170,12	84,170,0	8	-1991	84,236,12	29,232,0	0	-334	0.3926	0,0,12	0.3881	0.3881	0.0116	0.0116
39	1993	-9	135,233,12	84,144,0	1022	-1022	84,172,12	84,172,0	7	-1993	117,237,12	135,233,0	1	-161	0.3929	0,0,12	0.3884	0.3884	0.0113	0.0116
40	51	-17	165,229,0	149,229,12	4	-5	144,226,5	168,227,9	0	-66	160,232,0	165,229,12	1	0	-0.0012	168,190,6	0.0003	-0.0002	-0.0003	0.0000
41	771	-1	84,120,0	0,0,0	647	-646	84,120,0	84,120,12	11	-770	84,174,0	84,120,12	647	10	-0.0384	168,240,0	-0.0384	-0.0384	-0.0384	-0.0384
42	770	-6	78,121,0	150,230,12	646	-645	83,106,0	83,106,12	11	-769	78,176,0	78,121,12	641	10	-0.0478	168,240,0	-0.0384	-0.0384	-0.0478	-0.0383
43	2310	-34	84,120,12	84,66,0	1939	-1940	84,120,12	84,120,0	2	-2313	168,240,0	84,120,0	1939	1	0.1197	168,240,12	0.1151	0.1151	0.1151	0.1151
44	2311	-33	85,121,12	78,176,0	1941	-1942	85,121,12	85,121,0	10	-2314	168,0,0	85,121,0	1941	0	0.1198	0,240,12	0.1151	0.1151	0.1057	0.1151
45	92	-1	142,222,12	135,188,0	5	-45	111,172,12	150,230,12	0	-91	0,240,0	141,219,0	0	-30	-0.0095	168,240,12	0.0000	0.0000	-0.0095	0.0000
46	778	-1	84,131,0	136,236,12	670	-670	84,176,0	84,176,12	11	-777	84,65,0	84,131,12	657	8	-0.0382	0,0,0	-0.0382	-0.0382	-0.0040	-0.0040
47	777	-1	84,130,0	32,236,12	669	-669	84,179,0	84,179,12	11	-776	89,67,0	84,130,12	656	8	-0.0382	0,0,0	-0.0382	-0.0382	-0.0043	-0.0040
48	2337	-33	84,136,12	84,65,0	2018	-2019	84,181,12	84,181,0	3	-2340	136,236,12	84,136,0	1976	0	0.1191	168,0,12	0.1145	0.1145	0.0073	0.0073
49	2338	-32	84,137,12	89,67,0	2018	-2019	84,179,12	84,179,0	2	-2340	32,236,12	84,137,0	1977	0	0.1191	168,0,12	0.1145	0.1145	0.0070	0.0073
50	48	-18	165,229,0	149,231,12	5	-5	156,225,0	148,227,9	0	-63	153,233,0	165,229,12	1	0	-0.0006	168,220,5	0.0000	0.0000	-0.0003	0.0000
51	629	0	84,120,0	84,120,12	386	-385	84,120,0	84,120,12	8	-628	84,120,0	84,120,12	386	8	-0.0682	0,240,0	-0.0667	-0.0667	-0.0667	-0.0667
52	620	-1	78,121,0	168,0,0	379	-379	83,106,0	83,106,12	8	-619	89,129,0	78,121,0	376	8	-0.0870	168,240,0	-0.0669	-0.0668	-0.0856	-0.0663
53	1885	-25	84,120,12	84,120,0	1156	-1157	84,120,12	84,120,0	1	-1888	84,120,12	84,120,0	1156	1	0.2092	0,240,12	0.2092	0.2092	0.2092	0.2092
54	1896	-24	85,121,12	89,129,0	1164	-1165	85,121,12	85,121,0	5	-1898	14,240,0	85,121,0	1164	0	0.2097	0,240,12	0.2090	0.2092	0.1903	0.2097
55	108	-1	138,219,12	115,185,0	5	-45	103,151,12	150,230,12	0	-108	32,64,0	138,219,0	0	-36	-0.0188	168,240,12	-0.0002	0.0000	-0.0188	0.0005
56	715	-2	4,147,0	128,236,12	524	-524	84,181,0	84,181,12	7	-716	84,105,0	4,147,12	1	-5	-0.0674	0,0,0	-0.0659	-0.0659	-0.0029	-0.0029
57	715	-1	7,145,0	40,236,12	523	-522	84,186,0	84,186,12	7	-716	88,103,0	7,145,12	14	-4	-0.0674	0,0,0	-0.0659	-0.0649	-0.0033	-0.0029
58	2165	-21	4,147,12	84,105,0	1583	-1583	84,186,12	84,186,0	4	-2162	128,236,12	4,147,0	2	0	0.2068	0,0,12	0.2068	0.2068	0.0131	0.0131
59	2167	-21	164,149,12	88,103,0	1589	-1590	84,186,12	84,186,0	3	-2164	125,237,12	160,149,0	1	0	0.2068	168,0,12	0.2068	0.2068	0.0128	0.0131
60	50	-18	165,229,0	149,230,12	6	-44	156,229,0	149,229,12	0	-65	157,232,0	165,229,12	1	0	-0.0008	168,211,6	0.0000	0.0000	-0.0003	0.0000
61	110	0	84,90,0	80,90,12	89	-89	84,90,0	80,90,12	2	-110	84,90,0	80,90,12	89	2	-0.0954	0,180,0	-0.0939	-0.0939	-0.0939	-0.0939
62	104	-1	77,90,0	167,179,12	52	-52	70,67,0	70,67,12	2	-114	74,79,0	150,170,12	42	2	-0.1529	168,180,0	-0.0769	-0.0945	-0.1529	-0.0959
63	329	-7	84,90,12	84,90,0	267	-267	84,90,12	84,90,0	0	-330	84,90,12	84,90,0	267	0	0.2907	168,180,12	0.2907	0.2907	0.2907	0.2907
64	385	-8	120,98,12	92,103,0	281	-281	86,99,12	86,99,0	1	-385	92,103,12	120,98,0	194	0	0.3076	0,0,12	0.3076	0.2900	0.2331	0.2887
65	125	-1	137,150,12	167,179,12	4	-45	164,167,12	150,170,12	0	-125	0,0,12	137,150,0	0	-45	-0.0576	168,180,12	0.0170	-0.0006	-0.0576	0.0020
66	652	-3	132,174,0	84,176,12	180	-181	84,180,5	84,180,8	3	-652	84,176,0	36,174,12	1	-11	-0.1101	0,0,0	-0.1086	-0.1086	-0.0038	-0.0038
67	655	-2	135,173,0	117,177,12	180	-180	84,104,0	84,104,12	2	-662	117,177,0	150,171,12	1	-63	-0.1107	168,0,0	-0.1083	-0.1092	-0.0041	-0.0038
68	1956	-9	36,174,12	84,176,0	541	-541	84,180,8	84,104,0	8	-1956	84,176,12	36,174,0	2	-36	0.3364	0,0,12	0.3364	0.3364	0.0158	0.0158
69	1961	-7	33,173,12	117,177,0	541	-540	84,180,8	84,180,5	7	-1961	117,177,12	135,173,0	1	-156	0.3367	0,0,12	0.3358	0.3358	0.0158	0.0158
70	51	-17	165,169,0	149,169,12	4	-5	144,166,5	168,167,9	0	-66	157,172,0	165,169,12	1	0	-0.0012	168,128,6	0.0003	-0.0006	-0.0003	0.0000
71	672	-1	84,90,0	84,90,12	634	-633	84,90,0	84,90,12	14	-671	84,90,0	84,90,12	634	14	-0.0391	0,180,0	-0.0377	-0.0377	-0.0377	-0.0377
72	667	-8	77,90,0	150,170,12	630	-629	86,87,0	86,87,12	14	-666	83,91,0	77,90,12	623	13	-0.0485	168,180,1	-0.0377	-0.0377	-0.0485	-0.0376
73	2012	-41	84,90,12	84,90,0	1899	-1901	84,90,12	84,90,0	2	-2015	84,90,12	84,90,0	1899	2	0.1220	168,180,12	0.1220	0.1220	0.1220	0.1220
74	2018	-40	83,91,12	83,91,0	1905	-1907	83,91,12	83,91,0	4	-2021	0,180,0	83,91,0	1905	0	0.1220	0,180,12	0.1219	0.1220	0.1125	0.1220
75	92	-1	142,161,12	137,128,0	5	-45	110,117,12	150,170,12	0	-91	0,180,0	142,159,0	0	-29	-0.0095	168,180,12	0.0000	0.0000	-0.0095	0.0000
76	729	-1	84,97,0	136,176,12	675	-674	84,121,0	84,121,12	11	-728	84,76,0	84,97,12	663	11	-0.0387	0,0,0	-0.0373	-0.0373	-0.0025	-0.0025
77	728	-1	84,97,0	32,176,12	673	-672	84,120,0	84,120,12	11	-728	84,77,0	84,97,12	663	11	-0.0388	0,0,0	-0.0373	-0.0373	-0.0028	-0.0025
78	2206	-34	84,104,12	84,76,0	2029	-2030	84,121,12	84,121,0	3	-2207	136,176,12	84,104,0	2005	0	0.1208	0,0,12	0.1208	0.1208	0.0119	0.0119
79	2206	-34	84,104,12	84,77,0	2028	-2029	84,119,12	84,119,0	2	-2208	32,176,12	84,104,0	2006	0	0.1209	168,0,12	0.1208	0.1209	0.0116	0.0119
80	48	-18	165,169,0	150,171,12	5	-5	156,165,0	148,167,9	0	-63	154,173,0	165,169,12	1	0	-0.0006	168,160,5	0.0000	0.0000	-0.0003	0.0000
81	415	0	84,90,0	84,90,12	365	-364	84,90,0	84,90,12	9	-414	84,90,0	84,90,12	365	9	-0.0665	0,180,0	-0.0650	-0.0650	-0.0650	-0.0650
82	401	0	77,90,0	167,179,12	350	-350	81,80,0	81,80,12	9	-400	83,91,0	77,90,12	346	9	-0.0853	168,180,1	-0.0647	-0.0646	-0.0853	-0.0646
83	1242	-28	84,90,12	84,90,0	1092	-1094	84,90,12	84,90,0	1	-1244	84,90,12	84,90,0	1092	1	0.2040	168,180,12	0.2040	0.2040	0.2040	0.2040
84	1262	-27	83,91,12	83,91,0	1106	-1108	83,91,12	83,91,0	2	-1264	0,180,0	83,91,0	1106	0	0.2044	0,180,12	0.2043	0.2044	0.1851	0.2044
85	108	-1	138,158,12	122,119,0	5	-45	97,105,12	150,170,12	0	-108	0,180,0	138,158,0	0	-35	-0.0189	168,180,12	0.0003	0.0004	0.0189	0.0004
86	630	-2	84,174,0	128,176,12	506	-505	84,116,0	84,116,12	8	-631	84,97,0	84,174,12	110	1	-0.0677	0,0,0	-0.0663	-0.0663	-0.0031	-0.0031
87	629	-1	78,173,0	36,176,12	502	-501	84,112,0	84,112,12	8	-630	84,97,0	78,173,12	113	1	-0.0678	168,0,0	-0.0662	-0.0663	-0.0034	-0.0031
88	1892	-24	84,174,12	84,104,0	1537	-1537	84,116,12	84,116,0	5	-1889	128,176,12	84,174,0	329	1	0.2082	0,0,12	0.2082	0.2082	0.0135	0.0135
89	1891	-24	84,173,12	84,104,0	1515	-1516	84,112,12	84,112,0	4	-1889	36,176,12	84,173,0	342	1	0.2083	0,0,12	0.2082	0.2082	0.0132	0.0135
90	50	-18	165,169,0	146,170,12	5	-5	156,165,0	147,167,9	0	-65	156,172,0	165,169,12	1	0	-0.0008	168,151,6	0.0000	0.0000	-0.0003	0.0000

Table A.3. Variable Identification, Normal, and Shear Stresses for Skewed Joint Analysis Runs.

ANSYS	Variables						Normal Stresses												Shear Stresses											
Run #	φ (°)	L (ft.)	K_{vS} (psi/in.)	K_{vJ} (Mpsi/in.)	Δε (mε)	P (lb)	$\sigma_{Xmax/min}$ (psi)		$Location_{max/min}$ (x,z,y)		$\sigma_{Ymax/min}$ (psi)		$Location_{max/min}$ (x,z,y)		$\sigma_{Zmax/min}$ (psi)		$Location_{max/min}$ (x,z,y)		$\sigma_{XYmax/min}$ (psi)		$Location_{max/min}$ (x,z,y)		$\sigma_{YZmax/min}$ (psi)		$Location_{max/min}$ (x,z,y)		$\sigma_{XZmax/min}$ (psi)		$Location_{max/min}$ (x,z,y)	
91	80.5	12	50	0	250	0	89	-89	96,71,0	96,71,12	2	-5	96,71,0	0,0,0	50	-50	96,71,0	96,71,12	18	-18	140,142,6	51,0,6	16	-16	184,95,6	8,47,6	21	-21	26,71,0	26,71,12
92	80.5	12	50	0	250	9000	62	-62	84,0,0	84,0,12	9	-44	178,142,12	171,131,12	61	-62	185,101,12	185,101,0	13	-65	126,0,5	168,142,7	11	-58	191,139,12	189,124,7	77	-75	169,128,12	165,124,0
93	80.5	12	50	0	-750	0	266	-266	96,71,12	96,71,0	15	-6	0,0,0	96,71,0	151	-151	96,71,12	96,71,0	54	-54	51,0,6	140,142,6	47	-47	8,47,6	184,95,6	64	-64	26,71,12	26,71,0
94	80.5	12	50	0	-750	9000	334	-333	104,138,12	104,137,0	16	-45	0,0,0	171,131,12	211	-210	179,65,12	179,65,0	63	-119	59,0,7	160,142,5	56	-105	8,50,7	186,110,5	135	-135	170,96,12	170,96,0
95	80.5	12	50	0	0	9000	94	-94	126,139,12	126,139,0	9	-44	178,142,12	171,131,12	87	-87	182,85,12	182,85,0	18	-78	101,0,7	168,142,7	14	-67	13,78,7	188,121,5	90	-89	169,129,12	165,124,0
96	80.5	12	50	1.5	250	0	623	-624	101,138,0	101,138,12	404	-404	24,142,5	24,142,8	302	-302	190,131,0	190,131,12	426	-423	177,142,6	36,142,6	442	-9	23,138,6	24,142,12	447	-447	177,131,0	177,131,12
97	80.5	12	50	1.5	250	9000	623	-623	101,138,0	101,138,12	403	-404	24,142,5	24,142,8	378	-387	190,130,0	190,130,12	455	-421	173,142,6	36,142,6	504	-16	191,138,6	171,142,6	467	-468	178,132,0	178,132,12
98	80.5	12	50	1.5	-750	0	1869	-1868	101,138,12	101,138,0	1360	-1061	24,142,8	26,142,3	931	-887	190,131,12	190,129,0	1270	-1278	36,142,6	177,142,6	44	-1331	24,142,5	23,138,6	1336	-1343	177,131,12	177,131,0
99	80.5	12	50	1.5	-750	9000	1870	-1870	101,138,12	101,138,0	1206	-1206	24,142,8	24,142,5	854	-861	189,125,12	190,130,0	1272	-1302	36,142,6	173,142,6	51	-1289	171,142,6	23,138,6	1323	-1323	177,131,12	177,131,0
100	80.5	12	50	1.5	0	9000	21	-18	169,138,12	172,134,12	31	-46	191,140,5	191,139,8	68	-82	190,130,0	188,128,12	22	-7	181,142,8	170,131,12	63	-12	191,138,6	189,127,11	22	-24	179,136,0	180,136,12
101	80.5	12	1000	0	250	0	606	-605	96,71,0	96,71,12	15	-42	96,71,0	192,142,0	493	-492	96,71,0	96,71,0	78	-78	154,142,6	37,0,6	72	-72	186,108,6	6,34,6	96	-96	15,64,0	176,78,0
102	80.5	12	1000	0	250	9000	601	-599	96,65,0	96,65,12	15	-51	101,72,0	192,142,0	487	-487	90,73,0	90,73,12	40	-73	141,142,7	34,0,7	39	-69	184,96,7	6,35,7	98	-99	17,63,0	17,63,12
103	80.5	12	1000	0	-750	0	1814	-1818	96,71,12	96,71,0	125	-46	192,142,0	96,71,0	1477	-1479	96,71,12	97,71,0	235	-235	37,0,6	154,142,6	217	-217	6,34,6	186,108,6	287	-287	176,78,12	15,64,0
104	80.5	12	1000	0	-750	9000	1821	-1825	96,65,0	96,65,0	122	-45	0,0,0	171,131,12	1485	-1488	101,72,12	101,72,0	219	-268	34,0,7	160,142,5	206	-248	6,36,7	187,111,5	316	-316	176,83,12	176,83,0
105	80.5	12	1000	0	0	9000	65	-66	147,139,12	147,139,0	9	-44	178,142,12	171,131,12	67	-68	185,101,12	185,101,0	2	-57	173,142,12	170,142,7	11	-50	191,139,12	189,126,7	63	-59	170,130,12	168,125,0
106	80.5	12	1000	1.5	250	0	668	-668	102,106,0	102,106,12	336	-340	23,140,5	23,140,8	624	-625	22,92,0	22,92,12	349	-324	180,142,6	36,142,6	432	-66	23,138,6	5,32,6	349	-349	180,131,0	180,131,12
107	80.5	12	1000	1.5	250	9000	666	-666	101,103,0	101,103,12	335	-339	23,140,5	23,140,8	623	-625	22,93,0	22,93,12	369	-325	179,142,6	36,142,6	478	-66	191,138,6	5,30,6	366	-367	179,133,0	179,133,12
108	80.5	12	1000	1.5	-750	0	2008	-2013	102,106,12	102,106,0	1166	-890	23,140,8	23,140,5	1920	-1911	22,92,12	22,92,0	976	-1048	36,142,6	180,142,6	199	-1322	5,33,6	23,138,6	1047	-1052	180,131,12	180,131,0
109	80.5	12	1000	1.5	-750	9000	2012	-2013	101,103,12	101,103,0	1027	-1021	23,140,8	23,140,5	1917	-1913	22,93,12	22,92,0	976	-1039	36,142,6	177,142,6	199	-1276	5,30,6	23,138,6	1037	-1038	179,132,12	179,132,0
110	80.5	12	1000	1.5	0	9000	20	-19	169,138,12	173,140,12	27	-45	191,140,5	171,131,12	64	-78	189,130,0	187,129,12	19	-7	181,142,8	170,131,12	55	-14	191,138,6	170,131,12	18	-20	180,136,0	181,137,12
111	80.5	12	300	0	250	0	349	-348	96,71,0	96,71,12	8	-21	96,71,0	192,142,0	236	-236	96,71,0	96,71,12	56	-56	150,142,6	42,0,6	49	-49	185,101,6	7,41,6	66	-66	21,68,0	171,74,12
112	80.5	12	300	0	250	9000	330	-329	96,56,0	96,56,12	9	-44	178,142,12	171,131,12	223	-223	90,73,0	90,73,12	14	-49	126,142,7	42,0,7	11	-43	181,79,7	7,43,7	62	-63	17,63,0	17,63,12
113	80.5	12	300	0	-750	0	1045	-1047	96,71,12	96,71,0	62	-25	192,142,0	96,71,0	707	-708	96,71,12	96,71,0	167	-167	42,0,6	150,142,6	146	-146	7,41,6	185,101,6	199	-199	96,71,12	21,68,0
114	80.5	12	300	0	-750	9000	1068	-1070	97,82,12	97,82,0	60	-45	0,0,0	171,131,12	724	-725	101,72,12	101,72,0	158	-212	42,0,7	154,142,5	141	-189	7,43,7	186,108,7	245	-245	173,84,12	173,84,0
115	80.5	12	300	0	0	9000	79	-80	139,139,12	139,139,0	9	-44	178,142,12	171,131,12	79	-79	184,94,12	184,94,0	7	-67	118,0,7	168,142,7	11	-59	191,139,12	189,124,7	76	-73	170,130,12	168,124,0
116	80.5	12	300	1.5	250	0	630	-631	100,136,0	100,136,12	370	-371	24,142,5	24,142,8	423	-424	23,97,0	23,97,12	399	-378	177,142,6	36,142,6	443	-31	23,138,6	5,28,6	413	-413	177,131,0	177,131,12
117	80.5	12	300	1.5	250	9000	629	-630	94,138,0	94,138,12	370	-371	34,142,5	24,142,8	424	-426	182,87,0	182,87,12	420	-378	177,142,6	36,142,6	505	-31	191,138,6	5,30,6	431	-431	178,132,0	178,132,12
118	80.5	12	300	1.5	-750	0	1892	-1890	100,136,12	100,136,0	1260	-956	24,142,8	24,142,5	1298	-1291	23,97,12	23,97,0	1136	-1198	36,142,6	177,142,6	94	-1342	5,28,6	23,138,6	1236	-1243	177,131,12	177,131,0
119	80.5	12	300	1.5	-750	9000	1891	-1888	94,138,12	94,138,0	1106	-1103	24,142,8	24,142,5	1296	-1294	22,93,12	22,93,0	1137	-1198	36,142,6	173,142,6	95	-1297	5,30,6	23,138,6	1224	-1225	178,132,12	178,132,0
120	80.5	12	300	1.5	0	9000	20	-18	169,138,12	173,140,12	29	-45	191,140,5	171,131,12	67	-81	189,130,0	188,128,12	20	-7	181,142,8	170,131,12	59	-13	191,138,6	189,127,11	20	-21	180,136,0	180,136,12
121	80.5	20	50	0	250	0	109	-108	101,121,0	106,115,12	3	-7	101,121,0	208,237,0	255	-255	101,121,0	106,115,12	27	-27	150,237,7	58,0,7	34	-34	197,173,7	11,64,7	64	-64	178,127,0	178,127,12
122	80.5	20	50	0	250	9000	91	-91	93,92,0	94,92,12	10	-45	194,237,12	187,226,12	230	-231	22,130,0	22,130,12	4	-62	115,63,12	184,237,6	17	-53	32,189,6	205,219,6	72	-67	185,225,12	183,220,0
123	80.5	20	50	0	-750	0	325	-326	106,115,12	101,121,0	21	-8	0,0,0	101,115,0	764	-764	106,115,12	101,121,0	82	-82	58,0,7	150,237,7	103	-103	11,64,7	197,173,7	191	-191	30,110,12	178,127,0
124	80.5	20	50	0	-750	9000	351	-351	110,132,12	110,132,0	21	-45	0,0,0	187,226,12	821	-819	186,107,12	186,107,0	86	-151	59,0,6	167,237,6	108	-161	12,71,6	199,188,6	243	-243	181,145,12	181,145,0
125	80.5	20	50	0	0	9000	91	-91	139,233,12	139,233,0	10	-45	194,237,12	187,226,12	97	-97	196,169,12	196,168,0	7	-81	92,0,6	183,237,6	14	-71	28,166,6	204,215,6	93	-93	185,223,12	179,217,0
126	80.5	20	50	1.5	250	0	624	-624	116,233,0	116,233,12	446	-447	40,237,5	40,237,8	461	-461	35,163,0	35,163,12	450	-437	192,237,6	52,237,6	468	-29	39,233,6	8,47,6	480	-480	193,227,0	193,227,12
127	80.5	20	50	1.5	250	9000	623	-623	116,233,0	116,233,12	446	-446	40,237,5	40,237,8	461	-461	34,157,0	34,157,12	485	-436	189,137,6	52,237,6	529	-28	207,233,6	8,48,6	499	-500	193,227,0	193,227,12
128	80.5	20	50	1.5	-750	0	1871	-1871	116,233,12	116,233,0	1333	-1333	40,237,8	40,237,5	1393	-1392	35,163,12	35,164,0	1312	-1351	52,237,6	192,237,6	86	-1408	8,47,6	39,233,6	1442	-1442	193,227,12	184,197,0
129	80.5	20	50	1.5	-750	9000	1872	-1871	116,233,12	116,233,0	1334	-1334	40,237,8	40,237,5	1392	-1391	34,157,12	34,157,0	1313	-1393	52,237,6	189,237,6	86	-1398	8,48,6	39,233,6	1424	-1425	193,226,12	193,226,0
130	80.5	20	50	1.5	0	9000	21	-18	184,233,12	188,229,12	30	-45	207,235,5	207,233,8	68	-82	204,225,0	204,223,12	22	-7	196,237,8	186,226,12	62	-12	207,233,6	205,222,11	21	-23	195,230,0	196,230,12
131	80.5	20	1000	0	250	0	637	-637	107,121,0	107,121,12	11	-40	115,167,0	208,237,0	762	-761	101,121,0	106,115,12	73	-73	173,237,7	35,0,7	73	-73	201,196,7	7,40,7	121	-121	21,92,0	186,144,12
132	80.5	20	1000	0	250	9000	637	-637	107,120,0	107,120,12	11	-50	116,169,0	208,237,0	763	-762	107,120,0	107,120,12	40	-73	157,237,6	34,0,6	48	-48	199,184,6	6,36,6	117	-117	27,92,0	27,92,12
133	80.5	20	1000	0	-750	0	1912	-1912	107,121,12	107,121,0	121	-34	208,237,0	115,167,0	2283	-2286	106,115,12	101,121,0	219	-219	35,0,7	173,237,7	218	-218	7,40,7	201,196,7	364	-362	186,144,12	21,92,0
134	80.5	20	1000	0	-750	9000	1915	-1916	107,120,12	107,120,0	119	-46	0,0,0	187,226,12	2287	-2290	107,120,12	107,120,0	219	-273	34,0,6	176,237,6	223	-261	6,36,6	202,204,6	376	-375	188,150,12	188,150,0
135	80.5	20	1000	0	0	9000	65	-66	162,234,12	162,234,0	10	-45	194,237,12	187,226,12	67	-67	201,195,12	201,195,0	3	-57	189,236,12	184,237,6	10	-51	198,234,12	205,219,6	64	-59	185,225,12	184,220,0
136	80.5	20	1000	1.5	250	0	667	-667	116,192,0	116,192,12	343	-347	39,235,5	39,235,8	773	-773	102,132,0	102,132,12	348	-336	195,237,6	52,237,6	435	-74	39,233,6	6,35,6	349	-349	196,227,0	196,227,12
137	80.5	20	1000	1.5	250	9000	665	-665	116,193,0	116,193,12	342	-346	39,235,5	39,235,8	773	-772	102,129,0	102,129,12	368	-336	195,237,6	52,237,6	481	-74	207,233,6	6,39,6	365	-366	195,228,0	195,228,12
138	80.5	20	1000	1.5	-750	0	2008	-2009	116,192,12	116,192,0	1051	-1044	39,234,8	39,234,5	2326	-2329	102,132,12	102,132,0	1010	-1045	52,237,6	195,237,6	223	-1330	6,35,6	39,233,6	1050	-1050	196,227,12	196,227,0
139	80.5	20	1000	1.5	-750	9000	2010	-2011	116,193,12	116,193,0	1049	-1043	39,235,8	39,235,5	2325	-2328	99,136,12	99,136,0	1010	-1036	52,237,6	193,237,6	222	-1317	6,39,6	39,233,6	1034	-1035	195,227,12	195,227,0
140	80.5	20	1000	1.5	0	9000	20	-19	184,233,12	189,235,12	27	-45	207,235,5	187,226,12	64	-78	204,225,0	203,223,12	19	-7	196,237,8	186,226,12	55	-14	207,233,6	205,222,11	18	-20	196,230,0	197,232,12
141	80.5	20	300	0	250	0	384	-384	107,121,0	107,121,12	8	-22	107,121,0	208,237,0	613	-612	107,121,0	107,121,12	56	-56	161,237,7	46,0,7	64	-64	199,175,7	9,52,7	116	-116	184,133,0	184,133,12
142	80.5	20	300	0	250	9000	378	-378	104,106,0	104,105,12	10	-45	194,237,12	167,226,12	607	-606	99,122,0	99,122,12	18	-56	142,237,6	42,0,6	35	-63	196,168,6	8,47,6	114	-114	29,104,0	29,104,12
143	80.5	20	300	0	-750	0	1152	-1153	107,121,12	107,121,0	66	-24	0,0,0	107,121,0	1836	-1838	106,115,12	101,121,0	169	-169	46,0,7	161,237,7	191	-191	9,52,7	199,185,7	347	-347	184,133,12	184,133,0
144	80.5	20	300	0	-750	9000	1162	-1162	107,120,12	107,120,0	64	-45	0,0,0	187,226,12	1848	-1850	107,120,12	107,120,0	168	-230	42,0,6	169,237,6	189	-239	8,47,6	201,195,6	370	-370	186,139,12	186,139,0
145	80.5	20	300	0	0	9000	79	-79	154,234,12	154,234,0	10	-45	194,237,12	187,226,12	80	-80	199,188,12	199,188,0	2	-69	189,236,12	184,237,6	10	-60	198,235,12	205,219,6	77	-74	185,225,12	183,219,0
146	80.5	20	300	1.5	250	0	628	-628	116,230,0	116,230,12	387	-388	39,234,5	39,234,8	716	-717	33,147,0	33,147,12	405	-406	192,237,6	52,237,6	489	-61	39,233,6	8,47,6	423	-423	193,227,0	193,227,12
147	80.5	20	300	1.5	250	9000	627	-628	110,233,0	110,233,12	386	-388	39,235,5	39,235,8	717	-718	33,150,0	33,150,12	425	-406	193,237,6	52,237,6	528	-61	207,233,6	8,48,6	439	-440	193,227,0	193,227,12
148	80.5	20	300	1.5	-750	0	1885	-1883	116,230,12	116,230,0	1171	-1168	39,235,8	39,235,5	2171	-2168	34,155,12	34,155,0	1221	-1217	52,237,6	192,237,6	184	-1482	8,47,6	39,233,6	1271	-1271	193,227,12	193,227,0
149	80.5	20	300	1.5	-750	9000	1885	-1883	116,233,12	116,230,0	1169	-1167	39,235,8	39,235,5	2171	-2169	33,150,12	33,150,0	1221	-1206	52,237,6	193,237,6	182	-1468	8,48,6	39,233,6	1250	-1251	193,226,12	193,226,0
150	80.5	20	300	1.5	0	9000	20	-18	184,233,12	189,235,12	29	-45	207,235,5	187,226,12	67	-81	204,225,0	204,223,12	20	-7	196,237,8	186,226,12	59	-13	207,233,6	205,222,11	20	-21	196,230,0	297,232,12
151	80.5	15	50	0	250	0	96	-95	99,92,0	99,88,12	2	-6	99,92,0	0,0,0	112	-112	99,92,0	99,88,12	22	-22	144,180,7	55,0,7	23	-23	189,124,7	9,56,7	36	-36	171,92,0	171,92,12
152	80.5	15	50	0	250	9000	71	-71	88,51,0	88,51,12	10	-45	184,177,12	177,166,12	84	-83	61,84,0	57,85,12	5	-65	139,0,6	174,177,6	10	-57	190,175,12	195,159,6	76	-73	175,165,12	172,159,0
153	80.5	15	50	0	-750	0	286	-287	99,92,12	99,92,0	17	-7	198,180,0	99,92,0	335	-335	99,92,12	99,92,0	66	-66	55,0,7	144,180,7	68	-68	9,56,7	189,124,7	108	-108	171,92,12	171,92,0
154	80.5	15	50	0	-750	9000	327	-326	105,172,12	105,172,0	18	-45	0,0,0	177,166,12	378	-377	182,82,12	182,82,0	76	-134	59,0,6	162,177,6	79	-127	10,57,6	191,136,6	168	-168	176,112,12	173,117,0
155	80.5	15	50	0	0	9000	92	-92	132,173,12	132,173,0	10	-45	184,177,12	177,166,12	93	-93	187,114,12	187,114,0	14	-80	101,0,6	173,177,6	15	-70	18,110,6	194,157,6	92	-91	175,165,12	170,157,0
156	80.5	15	50	1.5	250	0	624	-624	106,173,0	106,173,12	433	-433	30,177,5	30,177,8	326	-326	195,164,0	195,164,12	439	-427	182,177,6	42,177,6	441	-9	29,173,6	30,177,12	465	-465	183,167,0	183,167,12
157	80.5	15	50	1.5	250	9000	623	-624	106,173,0	106,173,12	432	-432	30,177,5	30,177,8	401	-411	196,164,0	195,163,12	473	-426	179,177,6	42,177,6	511	-19	197,173,6	177,177,6	484	-485	183,167,0	183,167,12
158	80.5	15	50	1.5	-750	0	1872	-1871	106,173,12	106,173,0	1293	-1292	30,177,8	30,177,5	977	-977	195,164,12	195,164,0	1283	-1317	42,177,6	182,177,6	28	-1327	30,177,12	29,173,6	1395	-1395	183,167,12	183,167,0
159	80.5	15	50	1.5	-750	9000	1873	-1872	106,173,12	106,173,0	1293	-1293	30,177,8	30,177,5	941	-939	195,159,12	190,131,0	1284	-1356	42,177,6	179,177,6	58	-1318	177,177,6	29,173,6	1376	-1377	183,166,12	183,166,0
160	80.5	15	50	1.5	0	9000	21	-18	174,173,12	178,169,12	31	-45	197,175,5	197,173,8	68	-82	196,164,0	194,163,12	22	-7	186,177,8	175,166,12	62	-12	197,173,6	195,162,11	22	-23	185,170,0	186,170,12
161	80.5	15	1000	0	250	0	628	-627	99,92,0	99,92,12	13	-41	99,92,0	192,180,0	667	-666	99,92,0	99,92,12	74	-74	160,180,7	38,0,7	74	-74	192,144,7	6,36,7	113	-114	181,100,0	181,100,12
162	80.5	15	1000	0	250	9000	624	-623	100,88,0	100,88,12	14	-51	100,88,0	198,177,0	653	-652	100,88,0	100,88,12	41	-77	147,177,6	38,0,6	47	-76	189,127,6	6,35,6	113	-114	18,79,0	18,79,12
163	80.5	15	1000	0	-750	0	1882	-1884	99,92,12	99,92,0	123	-40	198,180,0	99,88,0	1997	-2000	99,92,12	99,92,0	223	-223	38,0,7	160,180,7	223	-223	6,36,7	192,144,7	341	-340	18,80,12	181,100,0
164	80.5	15	1000	0	-750	9000	1882	-1885	100,88,12	100,88,0	122	-45	0,0,0	177,166,12	1970	-1973	100,88,12	100,88,0	228	-276	38,0,6	166,177,6	227	-265	6,35,6	192,145,6	360	-359	178,108,12	178,108,0
165	80.5	15	1000	0	0	9000	65	-66	152,174,12	152,174,0	10	-45	184,177,12	177,166,12	67	-68	191,136,12	191,136,0	3	-57	179,176,12	174,177,6	10	-51	188,175,12	195,159,6	64	-59	175,165,12	174,160,0
166	80.5	15	1000	1.5	250	0	671	-671	106,132,0	106,132,12	343	-347	29,175,5	29,175,8	720	-719	88,95,0	88,95,12	349	-333	185,177,6	42,177,6	435	-73	29,173,6	6,33,6	350	-350	186,167,0	186,167,12
167	80.5	15	1000	1.5	250	9000	669	-669	106,133,0	106,133,12	342	-346	29,175,5	29,175,8	720	-720	88,97,0	88,97,12	369	-333	185,177,6	42,177,6	482	-73	197,173,6	6,35,6	366	-367	185,168,0	185,168,12
168	80.5	15	1000	1.5	-750	0	2020	-2021	106,132,12	106,132,0	1051	-1044	29,175,8	29,175,5	2182	-2181	26,111,12	88,95,0	1000	-1048	42,177,6	185,177,6	220	-1330	6,33,6	29,173,6	1054	-1054	186,167,12	186,167,0
169	80.5	15	1000	1.5	-750	9000	2021	-2022	106,133,12	106,133,0	1049	-1043	29,175,8	29,175,5	2183	-2184	88,97,12	88,97,0	1000	-1039	42,177,6	183,177,6	219	-1318	6,35,6	29,173,6	1038	-1039	185,167,12	185,167,0
170	80.5	15	1000	1.5	0	9000	20	-19	174,173,12	179,175,12	27	-45	197,175,5	177,166,12	64	-78	194,165,0	193,163,12	19	-7	186,177,8	175,166,12	55	-14	197,173,6	195,162,11	18	-20	186,170,0	187,172,12
171	80.5	15	300	0	250	0	367	-367	99,92,0	99,92,12	9	-22	99,92,0	192,180,0	412	-412	99,88,0	99,92,12	57	-57	152,180,7	46,0,7	58	-58	191,136,7	7,44,7	92	-92	176,100,0	176,100,12
172	80.5	15	300	0	250	9000	352	-352	94,78,0	94,78,12	10	-45	184,177,12	177,166,12	385	-385	93,87,0	93,87,12	18	-57	132,177,6	42,0,6	25	-58	187,114,6	7,44,6	87	-87	22,78,0	22,78,12
173	80.5	15	300	0	-750	0	1100	-1101	99,92,12	99,92,0	65	-27	0,0,0	99,92,0	1235	-1237	99,92,12	99,92,0	170	-170	46,0,7	152,180,7	175	-175	7,44,7	191,136,7	275	-275	176,100,12	176,100,0
174	80.5	15	300	0	-750	9000	1112	-1113	100,88,12	100,88,0	65	-45	0,0,0	177,166,12	1206	-1207	100,88,12	100,88,0	174	-228	46,0,6	159,177,6	178	-222	7,44,6	191,136,6	306	-306	178,104,12	178,104,0
175	80.5	15	300	0	0	9000	79	-79	144,174,12	144,174,0	10	-45	184,177,12	177,166,12	80	-80	189,127,12	189,127,0	3	-68	122,0,6	174,177,6	10	-60	188,175,12	195,159,6	77	-74	175,165,12	175,158,0
176	80.5	15	300	1.5	250	0	629	-630	106,170,0	106,170,12	374	-375	29,174,5	29,174,8	582	-582	26,111,0	26,111,12	405	-392	182,177,6	42,177,6	465	-49	29,173,6	7,41,6	422	-422	183,167,0	183,167,12
177	80.5	15	300	1.5	250	9000	628	-629	100,173,0	100,173,12	374	-375	29,175,5	29,175,8	582	-583	27,116,0	27,116,12	425	-392	183,177,6	42,177,6	519	-48	197,173,6	6,35,6	438	-439	183,167,0	183,167,12
178	80.5	15	300	1.5	-750	0	1890	-1888	106,170,12	106,170,0	1132	-1130	29,175,8	29,175,5	1771	-1768	26,111,12	26,111,0	1178	-1215	42,177,6	182,177,6	146	-1407	7,41,6	29,173,6	1267	-1267	183,167,12	183,167,0
179	80.5	15	300	1.5	-750	9000	1889	-1887	106,170,12	106,170,0	1131	-1128	29,175,8	29,175,5	1773	-1771	27,116,12	27,116,0	1178	-1211	42,177,6	179,177,6	145	-1395	6,65,6	29,173,6	1247	-1248	183,166,12	183,166,0
180	80.5	15	300	1.5	0	9000	20	-18	174,173,12	179,174,12	29	-45	197,175,5	177,166,12	67	-81	194,165,0	194,163,12	20	-7	186,177,8	175,166,12	59	-13	197,173,6	195,162,11	20	-21	186,170,0	187,172,12

Table A.4. Principal Stresses and Deflections for Skewed Joint Analysis Runs.

ANSYS	Principal Stresses														Deflections					
Run #	$\sigma_{1max/min}$ (psi)		Location$_{max/min}$ (x,z,y)		$\sigma_{2max/min}$ (psi)		Location$_{max/min}$ (x,z,y)		$\sigma_{3max/min}$ (psi)		Location$_{max/min}$ (x,z,y)		σ_2 @ σ_{1max}	σ_3 @ σ_{1max}	Δ_{ymax} (Inches)	Location$_{max/min}$ (x,z,y)	0,0	X,0	X,Z	0,Z
91	94	0	96,71,0	24,142,0	45	-45	96,71,0	96,71,12	2	-94	96,71,0	96,71,12	45	2	-0.0946	192,142,0	-0.0946	-0.0631	-0.0946	-0.0631
92	101	-8	166,118,12	186,139,12	34	-44	52,58,0	171,131,12	2	-101	77,74,0	168,113,0	0	-46	-0.1611	192,142,0	-0.0719	-0.0659	-0.1611	-0.0670
93	283	-6	96,71,12	96,71,0	134	-134	96,71,12	96,71,0	1	-283	168,0,0	96,71,0	134	0	0.2882	192,142,12	0.2837	0.1892	0.2837	0.1892
94	361	-6	101,92,12	103,78,0	136	-136	101,72,12	101,72,0	2	-361	168,0,0	101,92,0	112	0	0.3109	0,0,12	0.3063	0.1863	0.2171	0.1852
95	133	-7	148,121,12	187,138,12	3	-45	169,134,12	171,131,12	1	-133	190,140,12	147,123,0	0	-36	-0.0665	192,142,7	0.0227	-0.0029	-0.0665	-0.0039
96	670	-3	161,134,0	59,138,12	176	-177	95,142,5	95,142,8	3	-670	59,138,0	161,134,12	0	-129	-0.1038	0,0,0	-0.1038	-0.0750	-0.0047	-0.0052
97	687	-2	172,133,0	63,138,12	176	-177	95,142,5	95,142,8	2	-699	63,138,0	172,133,12	0	-230	-0.1036	0,0,0	-0.1036	-0.0765	-0.0049	-0.0051
98	2009	-7	161,134,12	63,138,0	630	-481	191,138,6	95,142,5	7	-2013	33,138,6	161,134,0	0	-375	0.3177	0,0,12	0.3132	0.2268	0.0095	0.0110
99	2005	-7	158,135,12	63,138,0	528	-527	95,142,8	95,142,5	6	-2005	63,138,12	158,135,0	0	-228	0.3179	0,0,12	0.3134	0.2254	0.0092	0.0109
100	71	-12	187,130,0	171,131,12	6	-7	168,129,5	168,129,8	0	-85	183,133,0	187,129,12	1	0	-0.0018	181,78,6	0.0002	-0.0015	-0.0002	0.0000
101	610	-1	96,71,0	24,142,0	489	-488	96,71,0	96,71,12	15	-608	96,71,0	96,71,12	489	15	-0.0400	192,142,0	-0.0400	-0.0370	-0.0400	-0.0370
102	603	-32	96,64,0	176,130,12	484	-484	90,73,0	90,73,12	15	-602	101,72,0	96,65,12	480	15	-0.0500	192,142,0	-0.0401	-0.0368	-0.0500	-0.0369
103	1825	-46	96,71,12	96,71,0	1465	-1468	96,71,12	96,71,0	1	-1829	96,71,12	96,71,0	1465	1	0.1247	192,142,12	0.1200	0.1109	0.1200	0.1109
104	1833	-45	96,65,12	101,72,0	1472	-1474	101,72,12	101,72,0	1	-1836	101,72,12	96,65,0	1456	1	0.1246	0,0,12	0.1200	0.1110	0.1100	0.1110
105	91	-8	163,122,12	186,139,12	5	-44	127,82,12	171,131,12	1	-91	190,140,12	163,119,0	0	-22	-0.0100	192,142,7	0.0000	0.0002	-0.0100	0.0000
106	668	-1	101,101,0	51,138,12	597	-596	80,81,0	80,81,0	13	-668	93,81,0	102,106,12	512	12	-0.0404	0,0,1	-0.0404	-0.0376	-0.0039	-0.0042
107	666	-1	101,103,0	51,138,12	597	-596	80,81,0	80,81,12	13	-666	93,81,0	101,103,12	502	12	-0.0404	0,0,1	-0.0404	-0.0376	-0.0041	-0.0042
108	2009	-40	101,101,12	93,81,0	1824	-1827	80,81,12	80,81,0	17	-2015	38,138,6	102,106,0	1581	0	0.1259	0,0,12	0.1212	0.1130	0.0071	0.0081
109	2013	-40	101,103,12	93,81,0	1824	-1826	80,81,12	80,81,0	3	-2014	51,138,12	101,103,0	1547	0	0.1259	0,0,12	0.1212	0.1130	0.0068	0.0080
110	67	-15	187,130,0	171,132,12	6	-6	168,129,5	171,129,9	0	-80	26,142,12	187,129,12	2	0	-0.0008	188,119,6	0.0000	0.0000	-0.0002	0.0000
111	358	-1	96,71,0	24,142,0	227	-226	96,71,0	96,71,12	8	-358	96,71,0	96,71,12	227	8	-0.0657	192,142,0	-0.0642	-0.0523	-0.0642	-0.0523
112	334	-15	96,56,0	182,139,12	219	-218	90,73,0	90,73,12	8	-333	90,73,0	96,56,12	203	8	-0.0862	192,142,0	-0.0636	-0.0517	-0.0847	-0.0521
113	1073	-25	96,71,12	96,71,0	679	-680	96,71,12	96,71,0	2	-1075	168,0,0	96,71,0	679	1	0.2016	192,142,12	0.2016	0.1660	0.2016	0.1660
114	1103	-25	97,82,12	90,73,0	687	-688	101,72,12	101,72,0	5	-1105	24,142,0	97,82,0	659	0	0.2023	0,0,12	0.2023	0.1667	0.1811	0.1663
115	112	-7	157,120,12	186,139,12	4	-44	113,80,12	171,131,12	1	-111	190,140,12	157,120,0	0	-28	-0.0205	192,142,7	0.0006	0.0007	-0.0205	0.0003
116	644	-2	157,134,0	55,138,12	335	-334	80,81,0	80,81,12	8	-644	93,81,0	157,134,12	1	-44	-0.0676	0,0,0	-0.0661	-0.0539	-0.0028	-0.0033
117	657	-2	171,132,0	55,138,12	335	-335	80,81,0	80,81,12	8	-668	93,81,0	171,132,12	1	-172	-0.0675	0,0,0	-0.0661	-0.0571	-0.0030	-0.0033
118	1931	-23	157,134,12	93,81,0	1023	-1026	80,81,12	80,81,12	16	-1936	73,134,8	157,134,0	0	-116	0.2083	0,0,12	0.2083	0.1808	0.0126	0.0141
119	1934	-23	155,135,12	93,81,0	1023	-1024	80,81,12	80,81,0	5	-1934	55,138,12	155,135,0	0	-47	0.2084	0,0,12	0.2084	0.1806	0.0125	0.0142
120	70	-13	187,130,0	171,132,12	6	-6	168,129,5	168,129,8	0	-84	178,133,0	187,129,12	1	0	-0.0011	186,110,6	0.0000	-0.0002	-0.0002	0.0000
121	270	-1	101,121,0	168,0,0	93	-93	101,121,0	106,115,12	3	-270	101,121,0	106,115,12	93	3	-0.1340	206,237,0	-0.1325	-0.0983	-0.1325	-0.0983
122	238	-8	20,118,0	202,233,12	85	-85	96,107,0	96,107,12	3	-238	99,122,0	20,118,12	0	-1	-0.1925	208,237,0	-0.1255	-0.0989	-0.1911	-0.0989
123	810	-8	106,115,12	106,115,0	279	-280	106,115,12	101,121,0	2	-810	40,237,0	101,121,0	279	0	0.4064	208,237,12	0.4019	0.2995	0.4019	0.2995
124	864	-9	117,119,12	122,113,0	289	-289	107,120,12	107,120,0	3	-865	40,237,2	117,119,0	278	0	0.4134	0,0,12	0.4089	0.2988	0.3433	0.2989
125	137	-7	181,192,12	203,233,12	4	-45	185,232,12	187,226,12	1	-137	206,235,12	181,182,0	0	-34	-0.0586	168,237,12	0.0069	-0.0006	-0.0586	-0.0005
126	708	-2	180,227,0	79,233,12	330	-330	99,171,0	99,171,12	3	-708	103,140,0	180,227,12	0	-181	-0.1415	0,0,0	-0.1400	-0.1127	-0.0034	-0.0042
127	732	-2	189,226,0	79,233,12	334	-334	100,170,0	100,170,12	3	-744	103,136,0	187,227,12	0	-254	-0.1411	0,0,0	-0.1411	-0.1145	-0.0051	-0.0057
128	2126	-8	180,227,12	103,140,0	999	-1000	99,171,12	99,171,0	7	-2126	79,233,12	180,227,0	0	-544	0.4298	0,0,12	0.4252	0.3436	0.0102	0.0124
129	2108	-8	179,227,12	104,143,0	1011	-1011	100,170,12	100,170,0	7	-2105	79,233,12	176,228,0	0	-494	0.4301	0,0,12	0.4256	0.3433	0.0100	0.0124
130	71	-12	203,225,0	187,226,12	6	-7	184,224,5	184,224,8	0	-85	199,228,0	203,223,12	1	0	0.0004	207,235,0	0.0004	-0.0003	-0.0002	0.0000
131	766	-3	101,121,0	168,0,0	634	-634	107,121,0	107,121,12	11	-765	115,167,0	106,115,12	634	10	-0.0394	208,237,0	-0.0394	-0.0371	-0.0394	-0.0371
132	767	0	107,120,0	208,237,0	634	-634	107,120,0	107,120,12	11	-766	116,169,0	107,120,12	634	10	-0.0493	208,237,0	-0.0394	-0.0371	-0.0493	-0.0370
133	2294	-34	106,115,12	115,167,0	1901	-1902	107,121,12	107,121,0	8	-2297	40,237,0	101,121,0	1901	1	0.1228	208,237,12	0.1181	0.1113	0.1181	0.1113
134	2297	-34	107,120,12	94,63,0	1905	-1906	107,120,12	107,120,0	11	-2300	168,0,0	107,120,0	1905	0	0.1228	0,0,12	0.1181	0.1112	0.1082	0.1113
135	91	-9	180,215,12	202,233,12	5	-45	142,182,12	187,226,12	1	-91	206,235,12	180,215,0	0	-22	-0.0100	208,237,8	0.0000	0.0000	-0.0100	0.0000
136	775	-1	102,132,0	67,233,12	662	-661	113,171,0	113,171,12	11	-774	90,61,0	102,132,12	647	9	-0.0392	0,0,1	-0.0392	-0.0368	-0.0038	-0.0041
137	775	-1	102,129,0	71,233,12	660	-660	109,176,0	109,176,12	11	-774	90,64,0	102,129,12	645	9	-0.0392	0,0,1	-0.0392	-0.0392	-0.0040	-0.0041
138	2331	-33	102,132,12	90,61,0	1992	-1993	109,179,12	109,179,0	3	-2334	71,233,12	102,132,0	1940	0	0.1223	0,0,12	0.1177	0.1105	0.0067	0.0077
139	2330	-33	102,129,12	90,64,0	1992	-1993	109,176,12	109,176,0	3	-2333	168,0,0	102,129,0	1938	0	0.1223	0,0,12	0.1177	0.1105	0.0064	0.0077
140	67	-15	203,225,0	187,227,12	6	-6	184,224,5	186,223,9	0	-80	155,136,12	203,223,12	2	0	-0.0008	204,213,6	0.0000	0.0000	-0.0002	0.0000
141	626	-2	101,121,0	168,0,0	371	-371	106,115,0	101,121,12	8	-625	107,121,0	101,121,12	341	8	-0.0711	208,237,0	-0.0697	-0.0626	-0.0697	-0.0626
142	618	-16	99,122,0	196,234,12	366	-366	107,120,0	107,120,12	8	-617	107,120,0	99,122,12	365	8	-0.0915	208,237,0	-0.0698	-0.0626	-0.0900	-0.0621
143	1876	-24	106,115,12	107,121,0	1113	-1113	106,115,12	101,121,0	5	-1878	40,237,0	101,121,0	1113	0	0.2180	208,237,12	0.2180	0.1968	0.2180	0.1968
144	1889	-23	107,120,12	107,120,0	1121	-1121	107,120,12	107,120,0	6	-1891	168,0,0	107,120,0	1121	0	0.2178	0,0,12	0.2178	0.1967	0.1976	0.1972
145	112	-8	175,212,12	202,233,12	6	-45	131,165,12	187,226,12	1	-112	206,235,12	175,212,0	0	-27	-0.0204	208,237,7	-0.0002	0.0000	-0.0204	-0.0005
146	720	-1	29,147,0	75,233,12	512	-512	109,179,0	109,179,12	7	-721	98,109,0	29,147,12	2	-4	-0.0703	0,0,0	-0.0688	-0.0621	-0.0026	-0.0032
147	720	-1	29,150,0	75,233,12	515	-515	105,182,0	105,182,12	7	-721	98,108,0	29,150,12	2	-4	-0.0703	0,0,0	-0.0688	-0.0621	-0.0028	-0.0032
148	2181	-20	29,147,12	98,109,0	1543	-1543	109,179,12	109,179,0	4	-2177	75,233,12	29,147,0	7	0	0.2155	0,0,12	0.2155	0.1954	0.0121	0.0139
149	2182	-20	29,150,12	98,108,0	1556	-1557	105,182,12	105,182,0	4	-2178	75,233,12	29,150,0	5	0	0.2155	0,0,12	0.2155	0.1954	0.0119	0.0139
150	70	-13	203,225,0	187,227,12	6	-7	185,225,5	185,225,8	0	-84	194,228,0	203,223,12	1	0	-0.0011	202,204,6	0.0000	0.0000	-0.0002	0.0000
151	132	0	99,92,0	168,0,0	75	-75	99,92,0	99,88,12	2	-132	99,92,0	99,92,12	75	2	-0.1130	0,0,0	-0.1115	-0.0769	-0.1115	-0.0769
152	97	-8	167,157,12	192,173,12	69	-69	90,67,0	90,67,12	2	-97	98,76,0	168,155,0	0	-46	-0.1729	198,177,0	-0.0946	-0.0765	-0.1729	-0.0774
153	397	-7	99,92,12	99,92,0	224	-225	99,92,12	99,92,0	1	-397	168,0,0	99,92,0	224	0	0.3434	0,0,12	0.3434	0.2396	0.3434	0.2396
154	450	-7	112,101,12	108,97,0	220	-220	101,93,12	101,93,0	2	-451	30,177,2	112,101,0	203	0	0.3542	0,0,12	0.3542	0.2345	0.3250	0.2345
155	135	-7	159,147,12	193,172,12	4	-45	175,172,12	177,166,12	1	-135	196,175,12	159,147,0	0	-37	-0.0615	198,177,7	0.0154	-0.0010	-0.0615	-0.0019
156	690	-3	168,170,0	65,173,12	180	-180	101,177,5	101,177,8	3	-690	69,173,0	168,170,12	0	-119	-0.1237	0,0,0	-0.1222	-0.0921	-0.0034	-0.0040
157	711	-2	177,167,0	69,173,12	178	-179	101,177,5	100,177,8	2	-723	69,173,0	177,167,12	0	-235	-0.1233	0,0,0	-0.1218	-0.0929	-0.0036	-0.0040
158	2068	-8	168,170,12	69,173,0	539	-538	101,177,8	101,177,5	7	-2068	65,173,12	168,170,0	1	-359	0.3770	0,0,12	0.3770	0.2869	0.0146	0.0164
159	2057	-7	163,170,12	69,173,0	539	-538	101,177,8	101,177,5	7	-2057	69,173,12	163,170,0	0	-231	0.3773	0,0,12	0.3773	0.2861	0.0144	0.0164
160	71	-12	193,165,0	177,166,12	6	-7	174,165,5	174,165,8	0	-85	189,168,0	193,163,12	1	0	-0.0017	188,121,6	0.0004	-0.0009	-0.0002	0.0000
161	677	-2	99,92,0	168,0,0	618	-617	99,92,0	99,92,12	13	-676	99,92,0	99,92,12	618	13	-0.0400	198,180,0	-0.0386	-0.0363	-0.0386	-0.0363
162	664	-33	93,87,0	182,165,12	613	-612	100,88,0	100,88,12	14	-663	100,88,0	93,87,12	609	14	-0.0501	198,177,0	-0.0387	-0.0363	-0.0501	-0.0363
163	2027	-40	99,88,12	99,88,0	1852	-1854	99,88,12	99,92,0	5	-2030	168,0,0	99,92,0	1852	1	0.1248	198,180,12	0.1248	0.1180	0.1248	0.1180
164	2006	-40	100,88,12	100,88,0	1846	-1849	100,88,12	100,88,0	6	-2009	100,88,12	30,177,0	1846	1	0.1249	0,0,12	0.1249	0.1181	0.1146	0.1181
165	91	-9	167,157,12	192,173,12	5	-45	135,116,12	177,166,12	1	-91	196,175,12	167,157,0	0	-22	-0.0100	198,177,7	0.0000	0.0000	-0.0100	0.0000
166	721	-2	96,95,0	168,0,0	664	-663	99,119,0	99,119,12	12	-722	93,80,0	22,111,12	653	11	-0.0398	0,0,0	-0.0383	-0.0360	-0.0023	-0.0027
167	721	-2	92,97,0	168,0,0	663	-663	99,116,0	99,116,12	12	-722	94,83,0	22,110,12	648	11	-0.0398	0,0,0	-0.0383	-0.0359	-0.0025	-0.0027
168	2197	-34	22,111,12	93,80,0	2001	-2002	99,119,12	99,119,0	5	-2191	168,0,0	22,111,0	11	-1	0.1240	0,0,12	0.1240	0.1170	0.0113	0.0124
169	2196	-34	22,110,12	94,83,0	2001	-2002	99,116,12	99,116,0	5	-2190	168,0,0	22,110,0	15	-1	0.1239	0,0,12	0.1239	0.1170	0.0111	0.0124
170	67	-15	193,165,0	177,1667,12	6	-7	175,165,5	174,165,9	0	-80	58,35,0	193,163,12	2	0	-0.0008	194,153,6	0.0000	0.0000	-0.0002	0.0000
171	441	-1	99,88,0	168,0,0	339	-338	99,92,0	99,92,12	9	-440	99,92,0	99,92,12	339	9	-0.0706	198,180,0	-0.0691	-0.0598	-0.0691	-0.0598
172	408	-16	93,87,0	188,174,12	329	-329	100,88,0	100,88,12	9	-407	100,88,0	93,87,12	329	9	-0.0907	198,177,0	-0.0688	-0.0589	-0.0907	-0.0589
173	1320	-27	99,92,12	99,92,0	1015	-1017	99,92,12	99,92,0	3	-1322	186,0,0	99,92,0	1015	1	0.2164	198,180,12	0.2164	0.1883	0.2164	0.1883
174	1310	-26	100,88,12	100,88,0	1007	-1008	100,88,12	100,88,0	4	-1312	30,177,0	100,88,0	1007	0	0.2157	0,0,12	0.2157	0.1874	0.1953	0.1874
175	112	-8	162,155,12	192,173,12	6	-45	118,106,12	177,166,12	1	-112	196,175,12	162,155,0	0	-28	-0.0204	198,177,7	0.0000	0.0004	-0.0204	0.0004
176	650	-2	167,167,0	65,173,12	489	-488	94,111,0	94,111,12	8	-650	96,95,0	167,167,12	1	-75	-0.0710	0,0,0	-0.0655	-0.0619	-0.0027	-0.0033
177	668	-1	178,165,0	65,173,12	488	-487	90,116,0	90,116,12	8	-680	96,97,0	178,165,12	1	-177	-0.0710	0,0,0	-0.0695	-0.0619	-0.0029	-0.0033
178	1952	-24	167,167,12	97,104,0	1473	-1474	94,111,12	94,111,0	5	-1952	65,173,12	167,167,0	0	-223	0.2180	0,0,12	0.2180	0.1952	0.0125	0.0142
179	1949	-24	160,169,12	96,97,0	1480	-1481	90,116,12	90,116,0	4	-1948	65,173,12	160,169,0	0	-39	0.2181	0,0,12	0.2181	0.1951	0.0123	0.0142
180	70	-13	193,165,0	177,167,12	5	-6	174,163,5	174,163,9	0	-83	184,168,0	193,163,12	1	0	-0.0011	192,144,6	0.0000	0.0000	-0.0002	0.0000

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