SAFETY AND STRUCTURAL IMPLICATIONS
OF SEAT BELTS ON TRANSIT BUSES

PHASE III - FINAL REPORT

By

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CHAPTER 1
INTRODUCTION

This report is the result of a study conducted at the Department of Civil and Environmental Engineering, Wayne State University to assess the safety and structural implications of seat belts on transit buses. Phase III of this investigation, jointly funded by the U.S. Department of Transportation and the Michigan Department of Transportation, had two primary tasks:

1. To perform laboratory tests to determine the ultimate shear strength capacity of the bus frame-to-chassis U-bolt connections (both with and without shear tabs) that were used in the 1989 and 1990 CTS buses.

2. To develop and analyze computer models of the structural system consisting of one track-mounted bus seat, and including representative sections of the bus floor, sidewalls, and frame.

Because the design of track-mounted seats has not yet been completed by the bus manufacturer, a decision was made (after consultation with MDOT officials) to perform the following task during Phase III in lieu of Task 2 listed above:

3. To perform preliminary activities related to the development of a finite-element computer model for the 1992 CTS 25-foot bus.

Moreover, the time that would have been devoted to Task 3 during Phase IV of the project will instead be used to perform Task 2 assuming that the design of the track-mounted seats is completed by the bus manufacturer. If this design is not completed during
Phase IV, then another task related to the CTS buses will be performed.

The remaining portion of this Phase III Final Report is presented in three additional chapters. A report on the results of the laboratory tests that were conducted as part of Task 1 listed above is presented in Chapter 2. A brief report on the status of the finite-element modeling and analysis activities that are described under Task 3 listed above is included in Chapter 3. The summary of Phase III activities and the conclusions and recommendations for Phase III with regard to the laboratory tests that were conducted are presented in Chapter 4.
CHAPTER 2
LABORATORY TESTING

2.1 INTRODUCTION

To determine the ultimate shear strength capacity of the frame-to-chassis U-bolt connections in the 1989 and 1990 CTS buses, laboratory tests were conducted with testing activities beginning in Phase 2 of the project and with final connection testing completed in Phase 3. These tests utilized the MTS machine in the Department of Civil and Environmental Engineering at Wayne State University.

2.1.1 Phase II Activities

The following activities were finished during Phase 2 of the project:

1. Design of the load platform for the MTS machine.
2. Design of the test specimens.
3. Design of the MTS connection detail.

The final design for the load platform consisted of the following components:

1. An inverted tee-beam base which was fabricated from a hot-rolled WT 7 x 45 steel section and was bolted to the base of the MTS machine.
2. A 12-inch by 9-inch by 3/4-inch steel base plate which was welded to the web of the tee-beam and which was supported by four 6-inch by 5-inch by ½-inch steel plate stiffeners.
3. Two 5-inch by 3-inch by 3/16-inch hot-rolled
rectangular steel tubes which were welded to the
tee-beam flange and which slope upward to support a
17-inch by 14-inch by 3/4-inch steel top plate.

4. Top and bottom 10-inch by 9-inch by ½-inch steel
collection plates which were bolted to the top and
bottom plates of the load frame and were connected by
two 1-inch by 1-inch square tubes.

The final design for the test specimens consisted of the following
components:

1. A 48-inch segment of the longitudinal chassis channel
   members which was bolted to the top and bottom steel
   connection plates.

2. A 38-inch segment of the longitudinal channel cap
   members which was fastened to the segment of the
   longitudinal chassis channel member with two or three
   U-bolts and with or without shear tabs.

3. A 38-inch segment of 2½-inch by 1-inch oak which was
   sandwiched between the chassis channel segment and the
   channel cap segment.

An MTS connection detail was designed to connect the chassis cap
segment of the test specimen with a 2.5-inch steel rod that was
connected to the loading head of the MTS machine. A schematic
diagram of the load frame, test specimen, and connection detail is
shown in Fig. 1.

All of the materials for the construction of the load
platform, the 30 test specimens, and the MTS connection detail
were ordered and received in the Summer and Fall of 1991. The
chassis channel segments, the channel cap segments, the U-bolts, and the shear tabs were all ordered from the same vendors utilized by the bus manufacturer and using the same specifications as the bus manufacturer.

2.1.2 Phase III Testing

During Phase III, each specimen was mounted and then tested in the MTS machine. Shearing forces representing the inertia of the bus body and passengers were applied to the test specimens through the MTS connection detail and were increased until failure of the specimens occurred. For each test specimen, the maximum shear forces applied and the relative displacements between the channel cap segment (which represents the bus frame) and chassis channel segment were monitored during load application. Thus, the failure mode for each specimen was determined. Six of the 30 test specimens were used for preliminary tests to determine the limits on the parameters that were to be varied in the primary tests. The results of these six preliminary tests are not presented herein, but the findings for the remaining 24 tests are presented and all 24 of these primary tests were videotaped.

2.2 TEST SPECIMEN CONFIGURATIONS

Three parameters were considered in deriving the specimens to be tested: U-bolt torque, number of U-bolts, and utilization of shear tabs. The U-bolt torque used by the bus manufacturer for tightening the nuts on all CTS bus U-bolts is 55 foot-pounds (ft-lb). Because we believed that bolt torque could play a role in maximum shear capacity, six different bolt torques were used in the tests: 45, 50, 55, 60, 65, and 70 ft-lb. Four different
specimens were tested at each of these bolt torques:

1. A specimen having two U-bolts without shear tabs.
2. A specimen having two U-bolts with shear tabs.
3. A specimen having three U-bolts without shear tabs.
4. A specimen having three U-bolts with shear tabs.

Thus, a total of 24 primary specimens were tested.

For each test specimen, loads were applied using a "displacement controls" procedure in which the displacements of the channel cap segment relative to the chassis channel segment were increased at uniform rates. For the 12 test specimens without shear tabs, the rate of application was one inch per minute for the entire six inches of motion allowed. While this rate of application is considerably slower than what an actual bus might experience under emergency conditions, a faster rate of application would have made it much more difficult to adequately record all test results (both measured and videotaped). Two of the six preliminary tests were conducted at much greater rates of application. The results of these two tests indicated that much faster rates of application would result in very little if any change in the test results.

For the 12 specimens with shear tabs, the rate of application was ¼ inch per minute for the first inch of motion and then one inch per minute for the remaining five inches of motion. The very slow initial rate of application was chosen in order to be able to adequately record the failure mechanism for the shear tabs which were expected to fail within the first inch of motion. The rate of application for the remaining five inches of motion, which
should occur after failure of the shear tabs, was the same as the one inch per minute rate of application used for the 12 specimens without shear tabs.

2.3 LABORATORY TEST RESULTS

The final plots of shear force versus relative displacement are depicted in Figs. 2 to 25 for the 24 primary test specimens. The specimen names (such as 45-2-N or 70-3-Y) refer to the bolt torque (45 to 70 ft-lb), the number of U-bolts per specimen (2 or 3), and the use of shear tabs (N = no and Y = yes).

For the 12 specimens without shear tabs (Figs. 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, and 24), the curves were characterized by a gradual buildup of force to a maximum value. This gradual buildup of force ended at a relative displacement of one to two inches when one or more U-bolts slipped. This slippage occurred at the bottom of the U-bolt(s) where the base plate(s) of the U-bolt(s) slid along the bottom flange of the chassis channel segment. In most cases, further cycles of force buildup and slippage then occurred, but in none of the cases did the shear force exceed the value derived before the slippage of the first U-bolt(s). This is a clear indication that the U-bolts reached and exceeded their yield stresses during the initial buildup of forces and were thus longer and offered less resistance during subsequent cycles. Moreover, the results for all 12 test specimens indicated no apparent correlation between U-bolt torque and the maximum shear force capacity. Thus, the maximum shear force capacity for these specimens was a function of the yield stress of the U-bolts and not the initial stress in the U-bolts.
For the 12 specimens with shear tabs (Figs. 3, 5, 7, 9, 11, 13, 15, 17, 19, 21, 23, and 25), the curves were characterized by a rapid buildup of force to a maximum value. This rapid buildup of force ended when the welds on the shear tabs failed which happened before a relative displacement of one inch had occurred. This was followed by a gradual buildup of force similar to the specimens without shear tabs which ended with slippage of the first U-bolt(s). The remainder of the curves were very similar to curves for the specimens without shear tabs. Because the failure mechanism for these specimens was the shear tab welds, the results for all 12 test specimens indicated no apparent correlation between U-bolt torque and the maximum shear force capacity.

Table 1 presents a summary of the results for each test specimen with averages (AV-2-N, AV-2-Y, AV-3-N, and AV-3-Y) for the four different types of specimens listed in Section 2.2 above. The results that are listed in Table 1 for each test include the maximum shear force (Fs) in kips (1000 pounds) that was recorded prior to slippage of the first U-bolt(s), the maximum relative displacement (δs) in inches before the first U-bolt(s) slipped, the angle of tilt (α) in degrees for all of the U-bolts when the first U-bolt(s) slipped, and the maximum shear force (Fst) in kips resisted by the shear tabs for the 12 specimens with shear tabs.

2.4 Calculated Test Results

Table 2 presents the results derived by hand calculations which were based on the test results. These hand calculations are described in more detail below.
2.4.1 Coefficient of Friction

As indicated in Table 1, the angle of tilt (\( \alpha \)) of the U-bolts when the first U-bolt(s) slipped was between 9.3 and 12.9 degrees for each specimen. Assuming the total force in the U-bolt shanks was a constant value (P) due to yielding of the U-bolt shanks, then (as depicted in Fig. 26) the total normal force (N) transferred by the shanks through the base plates of the U-bolts to the bottom flange of the chassis channel segment would be:

\[
N = P \times \cos \alpha
\]  

(1)

Slippage between the oak filler and the top flange of the chassis channel segment began almost immediately upon application of loading. Thus, the shear resistance along this surface and hence the coefficient of friction between the oak and the steel would appear to be very small. Therefore, the shear resistance between the oak filler and the top flange of the chassis channel section is not included in the calculations that follow. Hence, the maximum resisting shear force (Fs) was attributed to friction between the base plates of the U-bolts and the bottom flange of the chassis channel segment. This maximum resisting shear force (Fs) can be calculated as follows:

\[
Fs = \mu s \times N = \mu s \times P \times \cos \alpha
\]  

(2)

where \( \mu s \) is the steel-to-steel coefficient of friction between the base plates of the U-bolts and the bottom flange of the chassis channel segment. Just prior to slippage of the first U-bolt(s), the total shear force (Ft) transferred from the channel cap segment through the U-bolt shanks to the U-bolt base plates would be:
\[ F_t = P \times \sin\alpha \]  \hspace{1cm} (3)

At the time of slippage of the first U-bolt(s):

\[ F_t = F_s \]  \hspace{1cm} (4)

And thus:

\[ \mu_s \times P \times \cos\alpha = P \times \sin\alpha \]  \hspace{1cm} (5)

or:

\[ \mu_s = \frac{\sin\alpha}{\cos\alpha} \]  \hspace{1cm} (6)

The values of \( \mu_s \) derived for each test specimen using Equation 6 are listed in Table 2 and range from 0.164 to 0.229 with an average of about 0.20. The values of \( \mu_s \) were relatively close to 0.20 for most of the 24 test specimens.

2.4.2 Minimum Shear Force Capacity

As indicated in Table 1 (and as discussed in Subsection 2.4.1 above), all 24 test specimens recorded U-bolt tilts before first U-bolt slippage of 9.3 to 12.9 degrees. In order to achieve these angles of tilt, elongations of the 7-inch U-bolt shanks of 0.093 to 0.181 inches would be required. These represent steel strains between 0.0133 to 0.0259 which would all be far in excess of the value required to cause yielding of the steel (0.00114). Thus, it can safely be assumed that when the first U-bolt(s) slipped, the stress in all of the U-bolt shanks had reached the yield stress.

Inspections of the U-bolts after each test indicated that yielding did occur in the U-bolt shanks in the areas at or slightly above the locations of the U-bolt nuts.

Based on information supplied by the fabricators, the steel used to make the U-bolts should have a minimum yield stress of 33 kips per square inch (ksi). The diameter of the U-bolt shanks was
found to be 0.525 inches at the base of the threads. Thus, the minimum area of each U-bolt shank should be 0.2165 square inches (sq). Using this area and a minimum yield stress (Fy) of 33 ksi, the minimum yield force capacity (Ps) of each U-bolt shank should be:

\[ Ps = Ab \times Fy = (0.2165) \times (33) = 7.145 \text{ kips per shank} \quad (8) \]

The minimum calculated shear force capacity (Fc) of each test specimen would then be:

\[ Fc = n \times Ps \times \sin \alpha \]  

(9)

where \( n \) is the total number of U-bolt shanks. For specimens with two U-bolts (\( n = 4 \)):

\[ Fc = 28.6 \times \sin \alpha \]  

(10)

For specimens with three U-bolts (\( n = 6 \)):

\[ Fc = 42.9 \times \sin \alpha \]  

(11)

The minimum calculated shear force capacity (Fc) for each test specimen is listed in Table 2. The percent difference between the actual shear capacity (Fs) of each test specimen and the minimum calculated value (Fc) is also presented in Table 2. These percentages represent the reserve strength of each specimen which may be attributable to one or more of the following:

1. The differences in the steel-to-steel coefficients of friction which have a direct impact on the U-bolt angle of tilt (\( \alpha \)).

2. Some of the U-bolt shanks, especially those with strains at or above 0.02, may have reached the strain hardening stage of stress which would result in axial stresses above the yield stress of 33 ksi.
3. The actual yield stresses for some of the U-bolts may have been somewhat higher than the minimum of 33 ksi which is guaranteed by the manufacturer.

4. Higher grades of steel may have been used to fabricate some of the U-bolts.

5. Some U-bolts or U-bolt shanks may have had small initial angles of tilt before the application of loading began.

6. Deformation of some U-bolt heads, shanks, and threads may have occurred as the U-bolts bit into the channel caps during initial stressing and during testing.

7. Excess bending of the bottom flanges of some of the chassis channel segments may have occurred due to stressing of the U-bolts both initially and during testing.

It should be noted, however, that every attempt was made to avoid anomalies such as item 5 listed above.

2.4.3 Critical Bus Decelerations

While the shear tab in one test specimen did fail at 8.1 kips due to the poor quality of the shear tab welds, the average results from Table 1 indicate that the maximum shear capacity per shear tab should be approximately 21 kips, while the maximum shear capacity per U-bolt should be about 3.5 kips. For the 1989 and 1990 CTS 25-foot buses, the number of shear tabs per bus was two, while the number of U-bolts was 14. Thus, the maximum shear capacity (Fv) of the frame-to-chassis connections in each 1989 and 1990 CTS 25-foot bus should be approximately 42 kips (2 shear tabs...
at 21 kips per shear tab) for the shear tabs and 49 kips (14 U-bolts at 3.5 kips per U-bolt) for the U-bolts. Assuming an average passenger weight of 125 lbs (0.125 kips) and assuming the total weight of the bus body, frame, seats, etc. in the bus passenger compartment to be at least 1,000 pounds (1 kip), then the minimum bus decelerations (Dcr) required to cause failure of the shear tab welds and the U-bolts could be calculated using:

\[ Dcr = \frac{Fv}{[(26 \text{ pass.})(0.125 \text{ kips per pass.}) + 1 \text{ kip}]} \]  

\[ = \frac{Fv}{4.25} \]

The resulting minimum bus decelerations would be 10.0g and 11.5g, respectively, for the shear tab welds and the U-bolts, where "g" is the gravitational acceleration constant (32.2 feet per second\(^2\)). Assuming a bus velocity, \( V \), of 55 miles per hour (mph) or 81 feet per second (fps), these levels of deceleration (10.0g and 11.5g) would translate into stopping distances, \( Lst \), calculated as follows:

\[ Lst = \frac{V^2}{2gDcr} \]  

\[ = \frac{(81)^2}{2 \times (32.2)Dcr} \]

\[ = 102 / Dcr \]

The resulting stopping distances would be 10.2 feet and 8.9 feet, respectively, for failure of the shear tab welds and slippage of the U-bolts. This would clearly require a serious collision. As a comparison, assuming an emergency braking distance (without collision) of 300 feet at 55 mph, the level of deceleration required would only be 0.34g.

It should be noted that for each of the 12 test specimens with shear tabs, the welds that were used to fasten the shear tabs
to the channel cap segments and to the chassis channel segments were wrap-around welds with total weld lengths of approximately 4 inches per side of connection (channel cap side or chassis channel side). Some of the shear tab welds that were observed on a new 1992 CTS 25-foot bus during a field trip to the bus manufacturer were end-welds only, with total lengths of approximately 2 inches per side. Thus, with end-welds only, the expected capacity of the shear tabs would drop to 10.5 kips or less per tab for a total of 21.0 kips or less per bus. This would translate into a minimum bus deceleration for shear tab weld failure of 5g or less.
CHAPTER 3

COMPUTER MODELING

As discussed in Chapter 1, because the bus manufacturer has not yet completed the design of track-mounted seats for the CTS buses, the time that would have been spent during Phase III in the development of a detailed model with track-mounted seats was instead spent performing several preliminary activities related to the development of a finite-element computer model for the 1992 CTS 25-foot bus. These activities included the sizing of the structural members (determination of member shape, length, width, height, thickness, etc.), the calculation of member properties (cross-sectional areas, moments of inertia, etc.), and the calculation of nodal coordinates (x, y, and z). These activities are a time-consuming but necessary precursor to the finite-element modeling and analysis that will be performed during Phase IV of the project. Because the results of these preliminary activities consist of calculations and computer input data which are rather detailed, very repetitive, quite extensive, and largely uninformative in nature, the results of these preliminary activities for the 1992 CTS 25-foot bus have not been included in this Phase III Final Report. It should be noted that these types of preliminary results for the 1989 and 1990 CTS buses were not included in the final reports for Phases I or II of the project.
CHAPTER 4
SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

4.1 SUMMARY

Laboratory tests were conducted to determine the ultimate shear capacity of the bus frame-to-chassis U-bolt connections in the 1989 and 1990 CTS buses. These tests were conducted on 24 primary specimens:

2. With two and three U-bolts.
3. With and without shear tabs.

Preliminary activities related to the Phase IV finite-element modeling and analysis of the new 1992 CTS 25-foot bus were also performed.

4.2 CONCLUSIONS

For the 12 test specimens without shear tabs, no correlation was found between the U-bolt torque and the maximum shear capacity. An average maximum shear capacity of about 3.5 kips per U-bolt was derived. For each specimen, the maximum shear capacity was reached between one and two inches of relative displacement after a gradual buildup of shear force. Failure happened when slippage occurred between the base plates of one or more U-bolts and the bottom flange of the chassis channel segments.

For the 12 specimens with shear tabs, no correlation was found between the U-bolt torque and the maximum shear capacity. The results indicated that the maximum shear capacity that was attributable to the shear tabs was about 21 kips per shear tab with full wrap-around welds. This maximum shear capacity was
reached within the first one inch of relative displacement after a rapid buildup of shear force. After failure of the shear tabs, the shear capacity dropped sharply and then began to gradually increase to a secondary maximum value that was comparable to the maximum shear forces derived for the 12 corresponding test specimens without shear tabs.

4.3 RECOMMENDATIONS

Because the torque that is used to tighten the U-bolts has no apparent effect on the maximum shear capacity of the bus frame-to-chassis connections, no change in the 55 foot-pounds of torque that is currently used by the bus manufacturer is recommended. In addition, based on the test results presented herein, the number of U-bolts (14) used in the 1989 and 1990 CTS 25-foot buses should be adequate to resist a maximum bus deceleration of 11.5g with a corresponding relative bus body to chassis displacement of about 1.5 inches. We would like to note, however, that some additional U-bolt shear capacity could be achieved if the base plates of the U-bolts were welded to the bottom flanges of the chassis channel members. The potential increase in U-bolt shear capacity resulting from U-bolt base plate-to-bottom flange welds will be investigated as part of the Phase IV laboratory tests.

With regard to the shear tabs and shear tab welds, the original design (which utilized two shear tabs per bus) should be adequate up to 10.0g of bus deceleration if full wrap-around welds were used as designated in the bus design plans for the 1989 and 1990 CTS buses. If a maximum bus deceleration of at least 10.0g
is to be reached in the new 1992 CTS buses before the shear tabs fail, then full wrap-around welds should also be designated for these new buses. A recent inspection of a 1992 CTS bus, however, indicated, that end-welds only are currently being used for these new buses. Thus, the maximum bus deceleration before shear tab failure will probably be 5g or less for these new buses. The actual shear capacity of these weaker shear tab welds will be investigate as part of the Phase IV laboratory tests.

The authors believe that the final determination as to what the critical bus decelerations should be for the shear tabs and/or the U-bolts must be carefully considered given the tradeoff between higher shear tab and/or U-bolt capacity and the resulting higher decelerations and stresses that would be felt by the individual bus passengers versus lower shear tab and/or U-bolt capacity and the potential for longitudinal collapse of the bus passenger compartment.
ACKNOWLEDGMENTS

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The authors are grateful to all of the above agencies for providing the financial support for this study. The opinions and comments expressed in this paper are entirely those of the authors, however, and do not necessarily reflect the policies and programs of the agencies mentioned above.
APPENDIX: NOTATION

\( \alpha \) = maximum angle of tilt of U-bolts at first U-bolt slippage, degrees

\( P \) = maximum total axial force in U-bolt shanks at first U-bolt slippage, kips

\( N \) = maximum total normal force transferred by U-bolt base plates to bottom flange of chassis channel segment at first U-bolt slippage, kips

\( F_s \) = maximum total resisting shear force due to friction between base plates of U-bolts and bottom flange of chassis channel segment at first U-bolt slippage, kips

\( F_{st} \) = maximum shear force at shear tab failure, kips

\( \mu_s \) = steel-to-steel coefficient of friction between U-bolt base plates and bottom flange of chassis channel segment

\( F_t \) = maximum total shear force transferred from U-bolt shanks to U-bolt base plates at first U-bolt slippage, kips

\( A_b \) = cross-sectional area of one U-bolt shank, square inches

\( P_s \) = axial force in one U-bolt shank after yielding, kips

\( F_c \) = minimum calculated shear force capacity of all U-bolts, kips

\( n \) = total number of U-bolt shanks per test specimen

\( D_{cr} \) = minimum (critical) bus deceleration required to cause shear failure (shear tab weld failure or U-bolt slippage), g

\( F_v \) = total shear force capacity of frame-to-chassis connections for each 25-foot bus (due to shear tabs or U-bolts), kips

\( g \) = gravitational acceleration constant (32.2 feet per second)

\( L_{st} \) = stopping distance required to generate critical bus deceleration (\( D_{cr} \)) at a velocity of 55 miles per hour, feet
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TABLE 2. Calculated Test Results

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<th>Shear Tabs? yes or no</th>
<th>Test Specimen Name</th>
<th>Steel-To-Steel Coefficient of Friction, µs</th>
<th>U-bolt Shear Forces</th>
<th>Percent Difference*</th>
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* 100 [(F_s / F_c) - 1]
FIG. 1. SCHEMATIC DIAGRAM OF LOAD PLATFORM AND SPECIMEN
FIG. 2: PLOT FOR SPECIMEN 45-2-N
FIG. 3: PLOT FOR SPECIMEN 45-2-Y

Shear Force (kips)

Relative Displacement (inches)
FIG. 4: PLOT FOR SPECIMEN 45–3–N

RELATIVE DISPLACEMENT (INCHES)

SHEAR FORCE (KIPs)
FIG. 5: PLOT FOR SPECIMEN 45-3-Y

RELATIVE DISPLACEMENT (INCHES)
FIG. 6: PLOT FOR SPECIMEN 50-2-N

RELATIVE DISPLACEMENT (INCHES)

SHEAR FORCE (KIPS)
FIG. 7: PLOT FOR SPECIMEN 50-2-Y
FIG. 8: PLOT FOR SPECIMEN 50–3–N
FIG. 9: PLOT FOR SPECIMEN 50-3-Y

RELATIVE DISPLACEMENT (INCHES)
FIG. 10: PLOT FOR SPECIMEN 55–2–N

SEISMIC FORCE (KIPs)

RELATIVE DISPLACEMENT (INCHES)
FIG. 11: PLOT FOR SPECIMEN 55-2-Y

Shear Force (kips)

Relative Displacement (inches)
FIG. 12: PLOT FOR SPECIMEN 55–3–N

Shear Force (kips)

Relative Displacement (inches)
FIG. 13: PLOT FOR SPECIMEN 55–3–Y

RELATIVE DISPLACEMENT (INCHES)

SHEAR FORCE (KIPs)
FIG. 14: PLOT FOR SPECIMEN 60–2–N
FIG. 15: PLOT FOR SPECIMEN 60–2–Y
FIG. 16: PLOT FOR SPECIMEN 60–3–N

Shear Force (Kips)

Relative Displacement (Inches)
FIG. 17: PLOT FOR SPECIMEN 60-3-Y

RELATIVE DISPLACEMENT (INCHES)

SHEAR FORCE (KIPS)
FIG. 18: PLOT FOR SPECIMEN 65-2-N
FIG. 19: PLOT FOR SPECIMEN 65–2–Y

SHEAR FORCE (KIPS)

RELATIVE DISPLACEMENT (INCHES)
FIG. 21: PLOT FOR SPECIMEN 65-3-Y

Shear Force (kips)

Relative Displacement (inches)
FIG. 20: PLOT FOR SPECIMEN 65-3-N
FIG. 22: PLOT FOR SPECIMEN 70-2-N

RELATIVE DISPLACEMENT (INCHES)

SHEAR FORCE (KIPs)
FIG. 23: PLOT FOR SPECIMEN 70–2–Y

RELATIVE DISPLACEMENT (INCHES)
FIG. 24: PLOT FOR SPECIMEN 70-3-N
FIG. 25: PLOT FOR SPECIMEN 70-3-Y

SHEAR FORCE (KIPS)

RELATIVE DISPLACEMENT (INCHES)
FIG. 26. U-BOLT DEFORMATION DIAGRAM