Preliminary Report

EXPERIMENTAL INVESTIGATION OF THE CAPACITY OF STEEL DECK/JOIST ROOF SYSTEMS TO PROVIDE LATERAL BRACING

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CHAPTER I

INTRODUCTION

The question of the adequacy of standard steel joist/conventional deck roofing systems as lateral bracing for the compression chords of large trusses has been posed. This method of lateral bracing differs from "textbook bracing" in that the structural components which provide the bracing, the roof panel and joists, also are part of the load path which delivers load to the member requiring lateral restraint, the compression chord. Thus, at load levels where the chord lateral bracing is critical, the components providing the bracing may also be fully loaded.

Numerous references are available on the design of lateral bracing for compression members, the most notable being References 1, 2 and 3. However, in the references cited the bracing member is not considered to be loaded except by the bracing force. The writer is unaware of any literature on the subject of the adequacy of a member as a lateral brace when subjected to loads other than the brace force. Although hundreds of roof systems have been designed and have performed satisfactory using what will be referred to here as an active bracing system, e.g. a bracing system which is also part of the load path, no analytical or experimental studies appear to exist on the subject. Examples of such systems are typical deck/joist/truss systems and deck/cold-formed purlin/frame systems used by the metal building industry. To verify the adequacy of deck/joist systems as lateral bracing for the compression chords of large trusses, particularly for spans greater than 100 ft., an experimental program was undertaken at the Fears Structural Engineering Laboratory, University of Oklahoma.

The determination of the adequacy of a lateral bracing system must answer two questions:

1. What strength and stiffness is required by the member being braced?

2. What strength and stiffness can be delivered by the bracing system?

It is believed that the work of Yura[3] sufficiently answers question 1 for the case of compression chords of large trusses braced at discrete points by standard steel joists which in turn are laterally braced by the roof panel (diaphragm). As previously mentioned no literature is available to answer the second question when an active bracing system is used. This report summarizes the test procedure and pertinent results for a full-scale test of a deck/joist/truss roof system.

CHAPTER II

TEST SETUP AND TESTING PROCEDURE

2.1 Overview of Test

The test setup is shown in Figures 2.1 and 2.2. Three 36LH12 steel joists, 57 ft. 4 in. in length, were used to support the roof deck. The joists were supported at one end by a 31 ft. 0 in. length of W14x211 representing the truss compression chord and at the other end by stands and rollers under each joist seat, Figure 2.2. The joist-to-chord connection details are shown in Figure 2.3. The roof deck was a blend of 3 in. (rib height) Types N and NF (accoustical) panels placed in a ratio of 1:2, respectively. The panels provided a nominal coverage of 2 ft. 0 in. by 30 ft. 0 in. A total of 28 panels were used to construct the setup, 19 NF-type and 9 N-type. The first panel at the simulated truss chord end (south end) was a NF-type panel, the second panel was N-type, the third and fourth were NF-type, the fifth N-type, followed by the repeating pattern of two NF-type and one N-type. A space of 1 ft. 4 in. at the north end of the setup was not covered by panel to allow access to instrumentation at that location.

The panels were attached to the joist chords by spot welding in each non-sidelap valley. Weld washers were used. Sidelaps were fastened using button punching at 24 in. on center.

Simulated gravity load was applied to the system using concrete blocks. Simulated lateral brace force was applied to the joist ends using

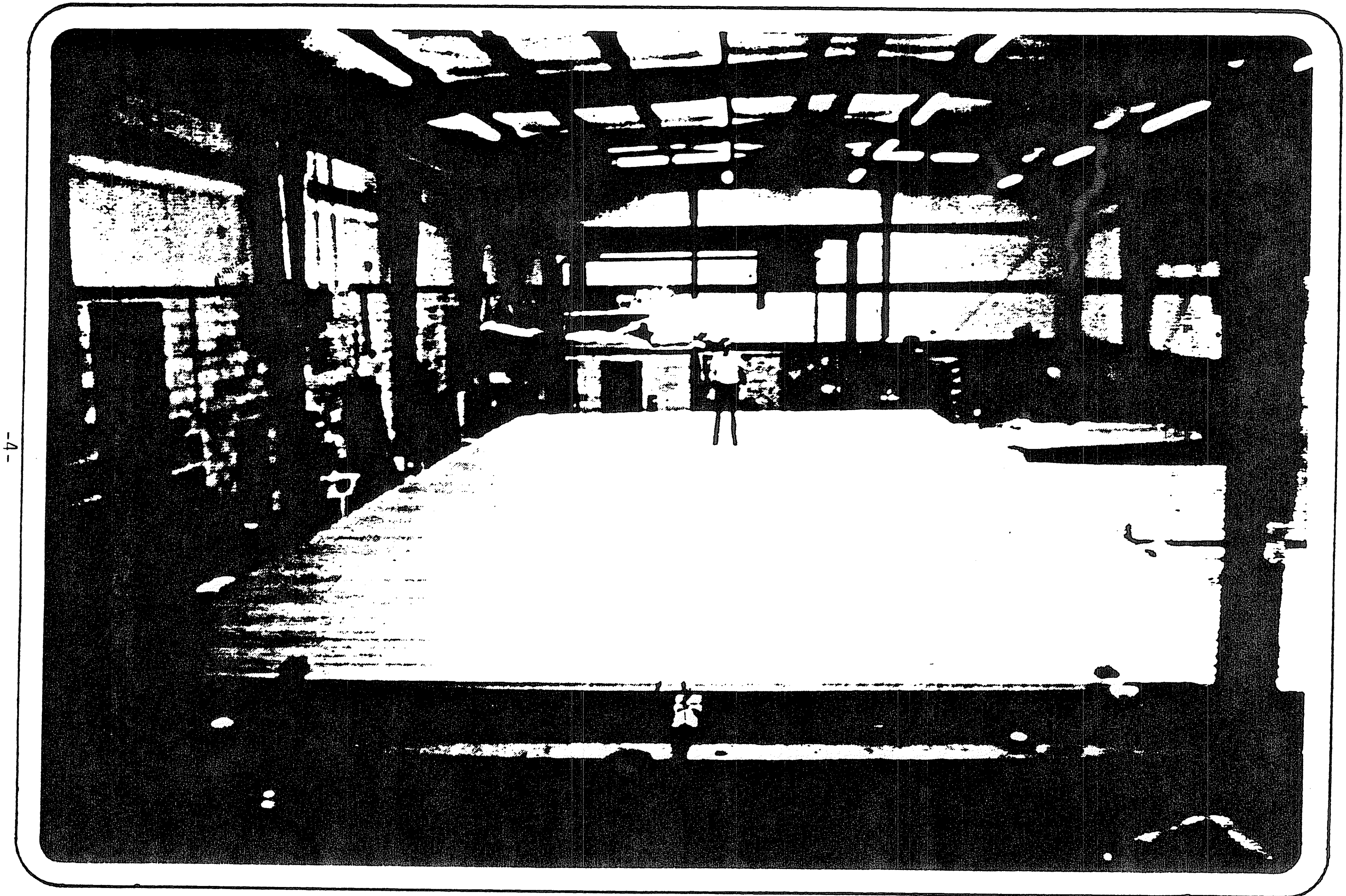


Figure 2.1 Photograph of Test Set-up

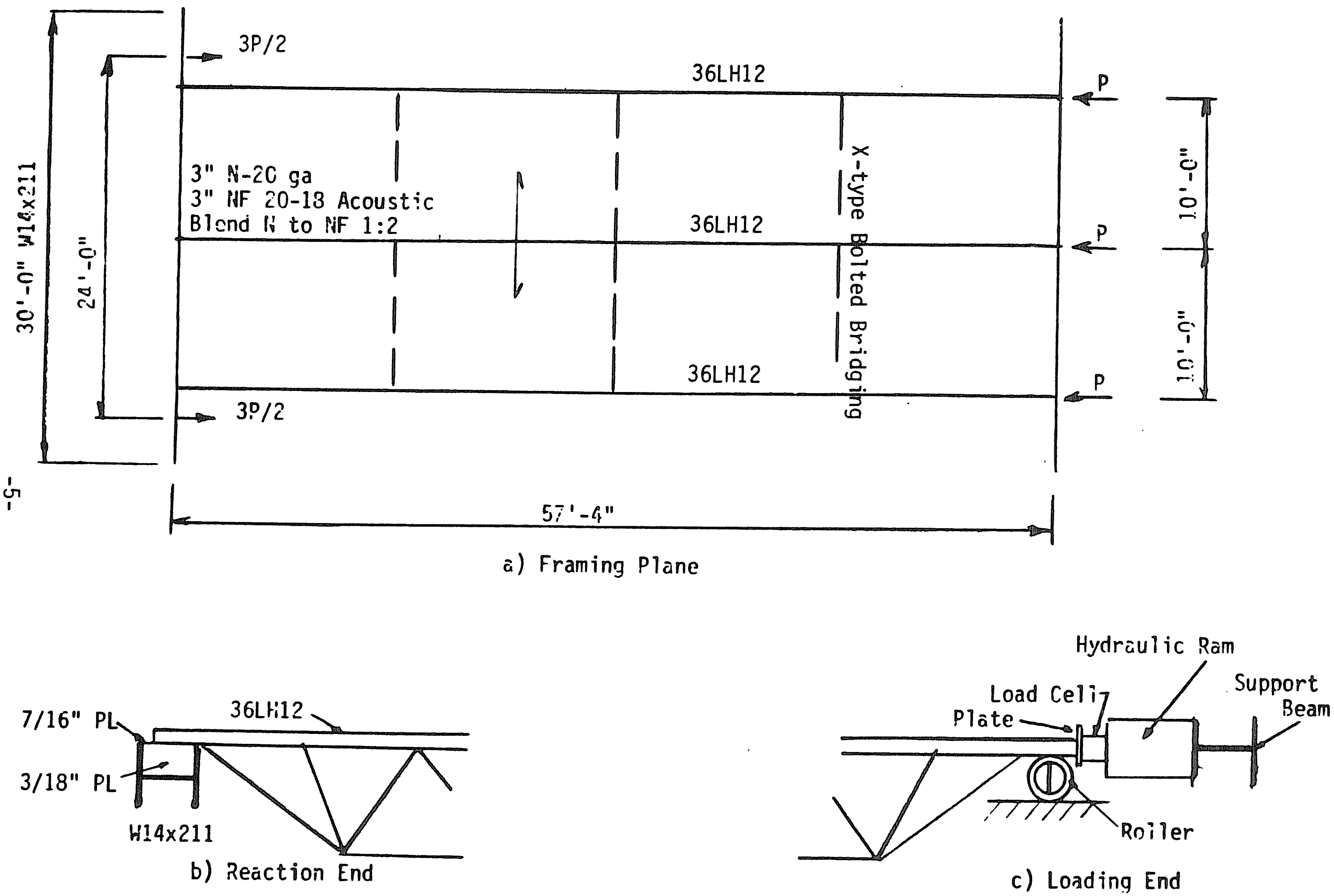
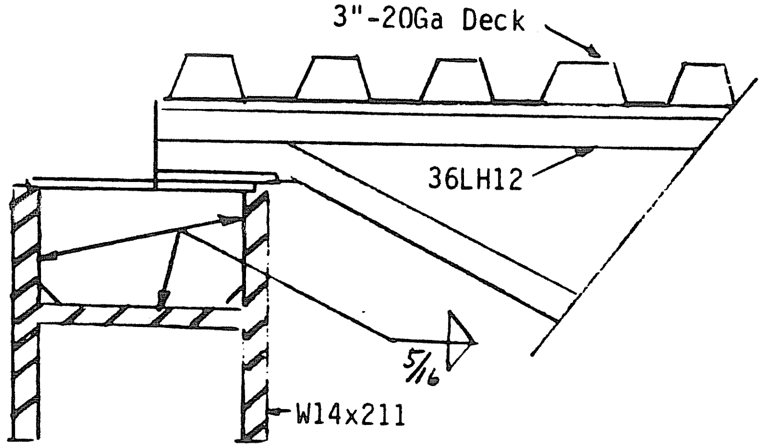
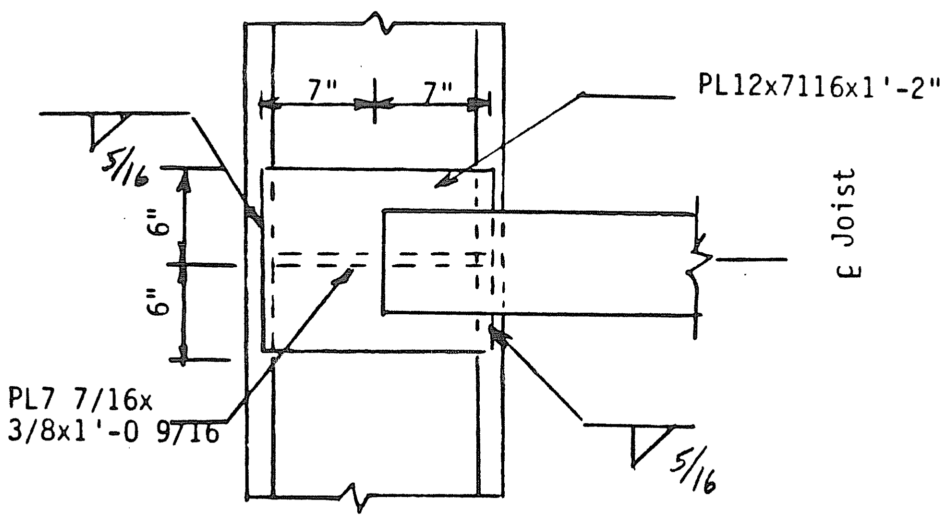


Figure 2.2 General Details of Test Set-up



(a) Section



(b) Plan

Figure 2.3 Joist-to-Chord Connection Details

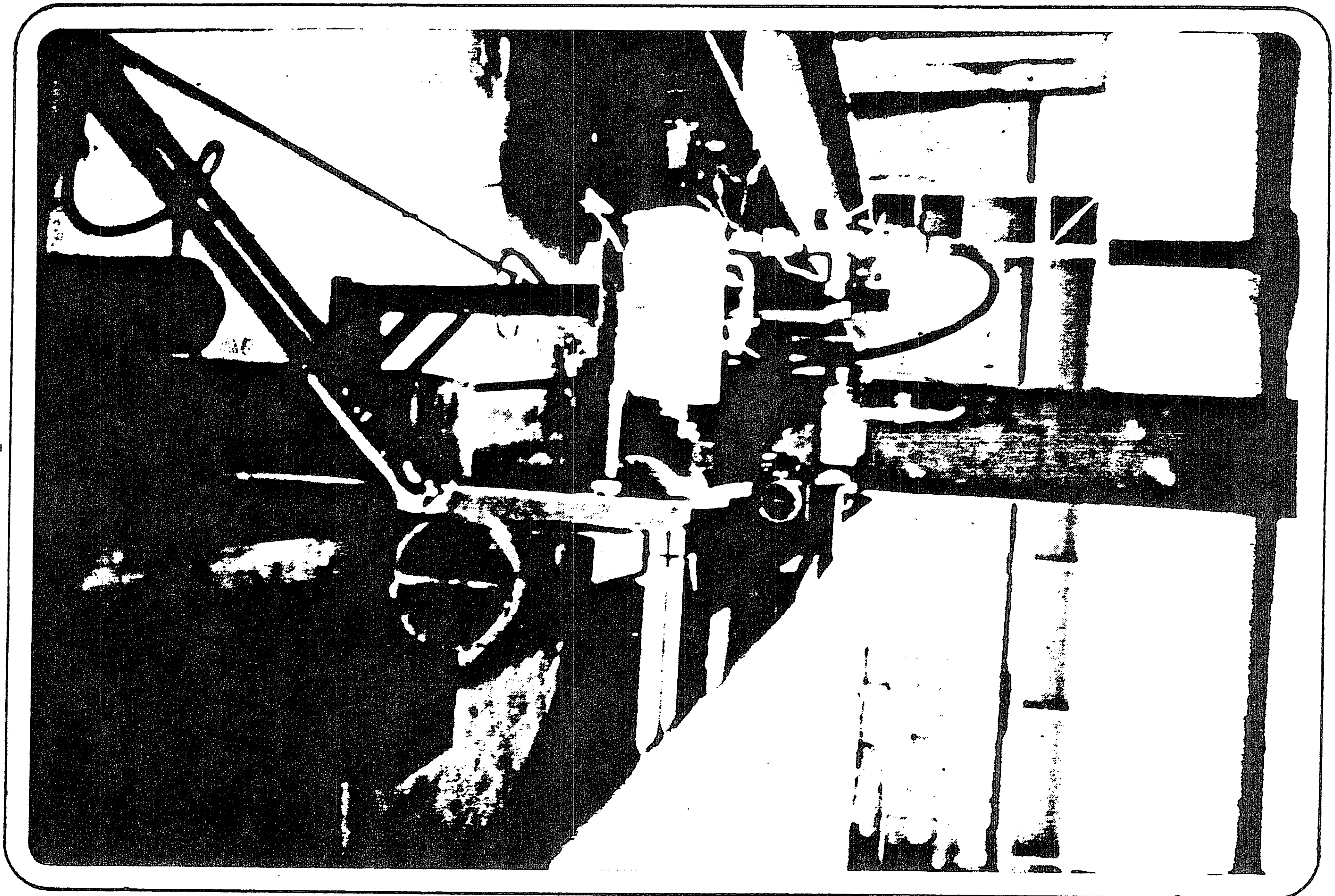


Figure 2.4 Photograph of Lateral Load Application End of Test Set-up

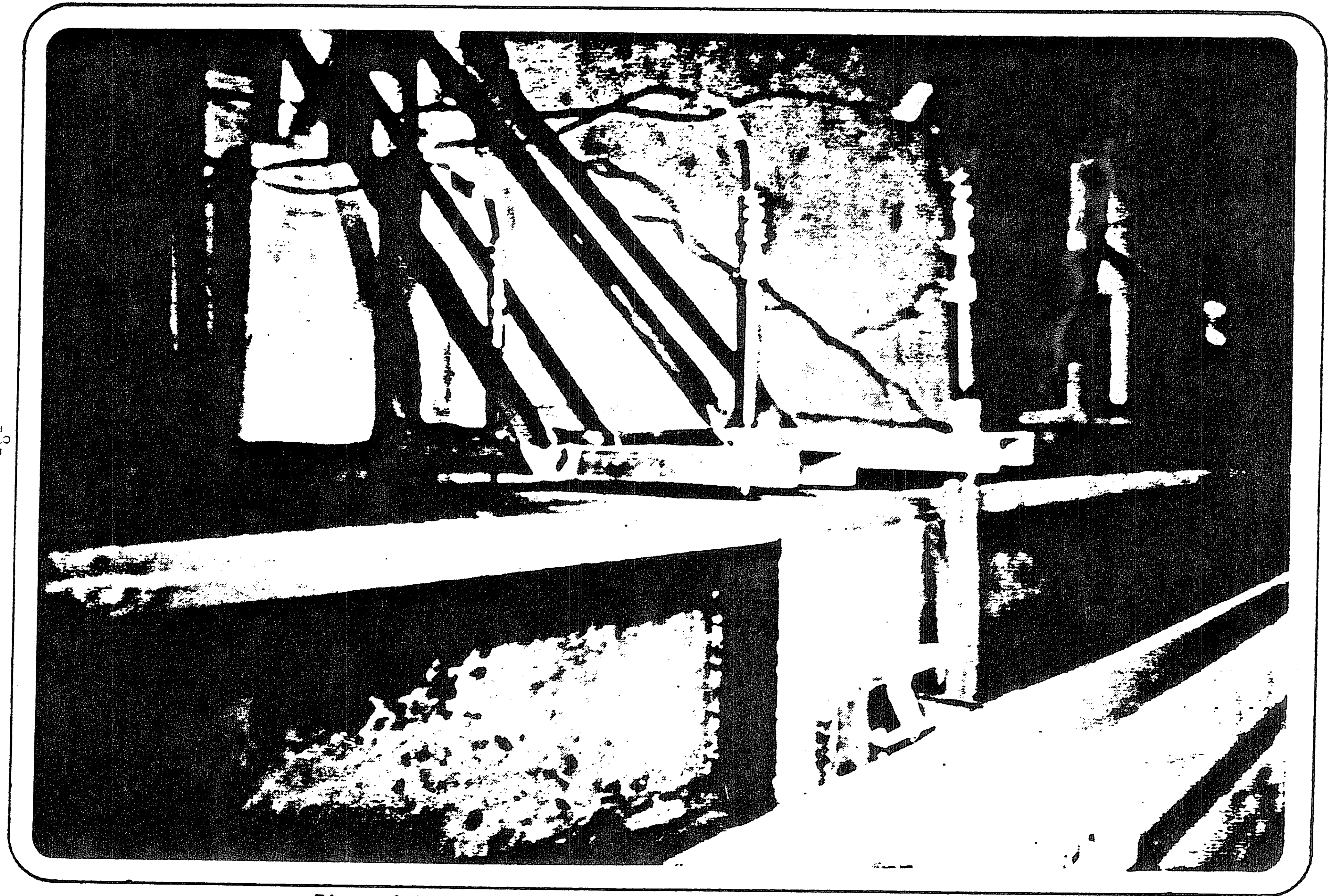


Figure 2.5 Photograph of Instrumentation at Midspan of Truss Chord

three 60 ton capacity hydraulic cylinders connected in parallel to a manual hydraulic pump. The force at each ram was measured using calibrated load cells. See Figures 2.2 and 2.4 for details.

Displacements at sixteen locations on the test setup were measured using wire or probe type displacement transducers. Figure 2.5 shows instrumentation at the midspan of the simulated truss chord.

2.2 Test Components

Deck. The roof deck used in the test was manufactured by Roll Form Products, Inc. and designated as P-34 RFDK Galvanized G60% and C-33 RFDK Galvanized G60% accoustical.

Joists. The three steel joists used were standard SJI 36LH12 joists and were manufactured by VULCRAFT at Grapeland, Texas. The joists were 57 ft. 4 in. long out-to-out of chords. Prior to shipment, the joists were loaded to 85% of their ultimate capacity using VULCRAFT'S production test frame. The load was left on the joists for one hour and then removed. The permanent deflection after removal was reported by VULCRAFT to be less than 20% of the deflection when loaded to 85% of the ultimate joist capacity. (This testing procedure is normally used by VULCRAFT for quality control purposes.)

Bridging. The bridging used was bolted X-type L1 3/4x1 3/4x1/8, and was supplied by VULCRAFT. One 3/8 in. diameter by 1 in. long machine bolt was used to connect each end of each angle to an ear plate welded to the joist. A third bolt connected the two angles at this intersection. The three bridging line locations are shown in Figure 2.2.

Simulated Chord. The simulated member (Figure 2.2(b)) was a W14x211, A36 steel, and was obtained from Robberson Steel Company, Oklahoma City, Oklahoma. All detail plates were A36 steel and were purchased from Robberson Steel Company. All welding was done by the Laboratory technician.

Miscellaneous Components. All support frames, reaction beams, stands, etc. were either owned by the Laboratory or specially constructed for the test setup.

2.3 Instrumentation

Instrumentation consisted of three calibrated load cells and sixteen displacement transducers. The load cells were located between the joist chords and the hydraulic rams (Figure 2.2(c)) and were used to measure the applied horizontal force. Estimated accuracy of the load cells is ±0.1 kip. The estimated accuracy of the transducers used to measure vertical deflections is ±0.05 in. and that of the transducers used to measure lateral displacements is ±0.0025 in.

The location of all displacement transducers is shown in Figure 2.6. All transducers measured relative to the Laboratory reaction floor, a concrete slab 30 ft. by 60 ft. by 3 ft. 6 in. thick weighing over one million pounds. Transducers 1, 2 and 3 were used to measure vertical deflections of each joist (east to west, respectively) at midspan. Transducers 4, 5 and 6 were used to measure joist top chord vertical deflections approximately 18 in. from the centerline of the chord member (Figure 2.4(a)). Transducers 7, 8 and 9 were used to measure vertical deflection of the chord member at the joist support locations. These latter two sets of measurements were made to determine if a "hinge" formed in the

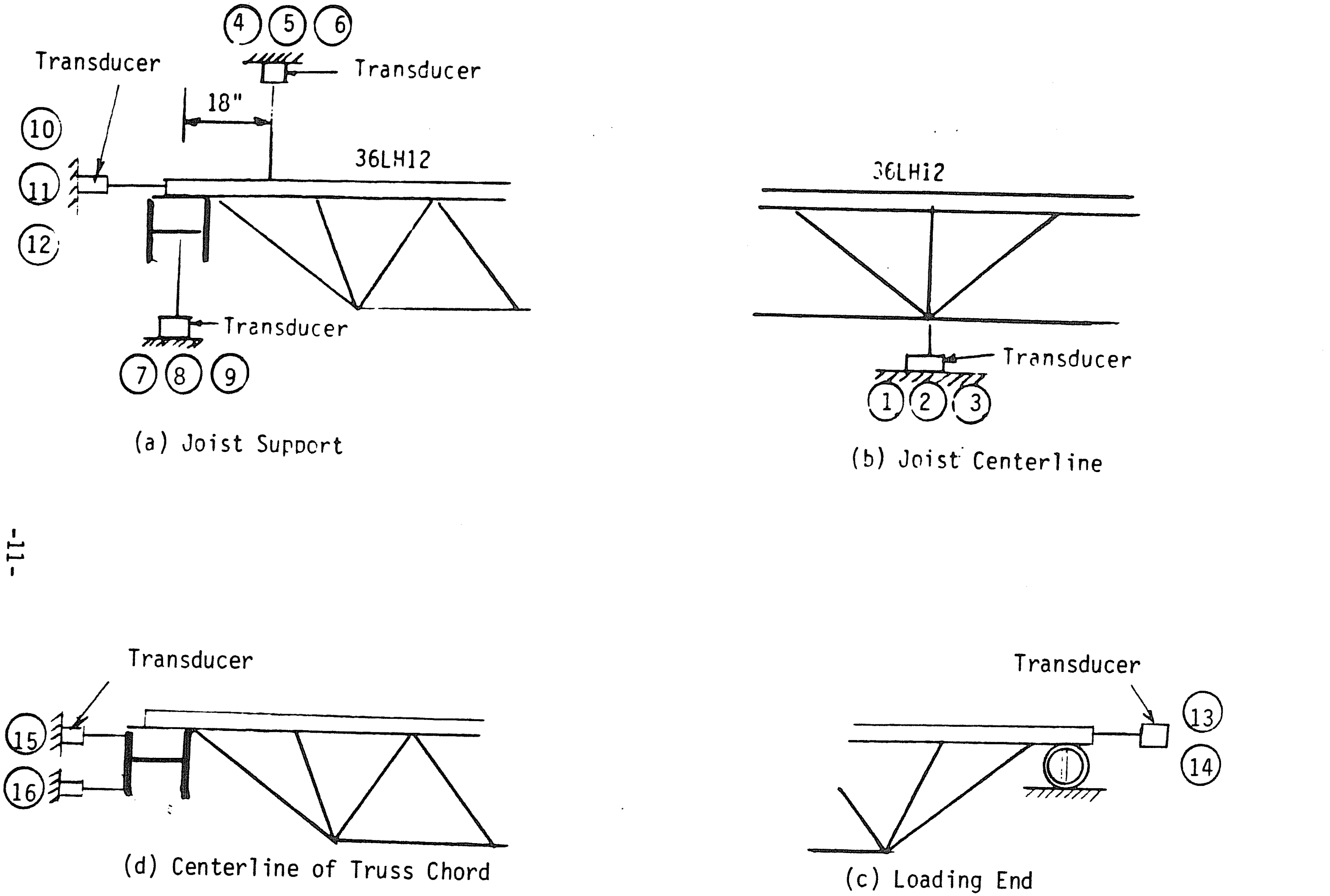


Figure 2.6 Transducer Placement Location

joist chord near the support. In addition, data from transducers 6, 7 and 8 was used to correct the midspan deflections to account for support settlement due to the chord deflection.

Transducers 10, 11 and 12 were used to measure lateral movement of the joist chords at the simulated truss chord end of the setup. Transducers 13 and 14 were used to measure lateral movement of the east and center joists, respectively, at the hydraulic ram end of the setups. Results from these two sets of measurements were used to compute relative movement of one chord end with respect to the other.

Finally, transducers 15 and 16 were used to measure lateral movement of the simulated truss chord (W14x211) near the top and bottom flange edges directly below the center joist support location (Figures 2.5 and 2.6(d)). The measurements were used to determine twist in the chord member.

All data was taken using a micro-computer based data acquisition system. The system consists of an HP85 desk top computer, an HP3497A data acquisition/control unit, and an HP7470A two pen plotter. Computer programs were written to read, record, and print all data and to plot critical load/deflection relationships in real time as the tests progressed.

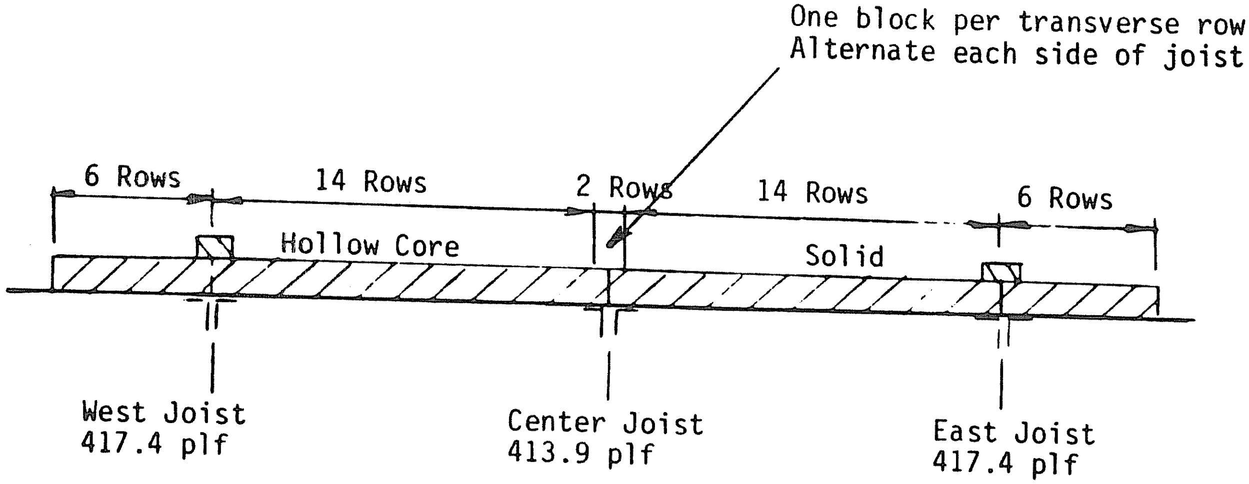
2.4 Testing Procedure

Two types of tests were conducted: (1) gravity load tests and (2) gravity plus lateral load tests.

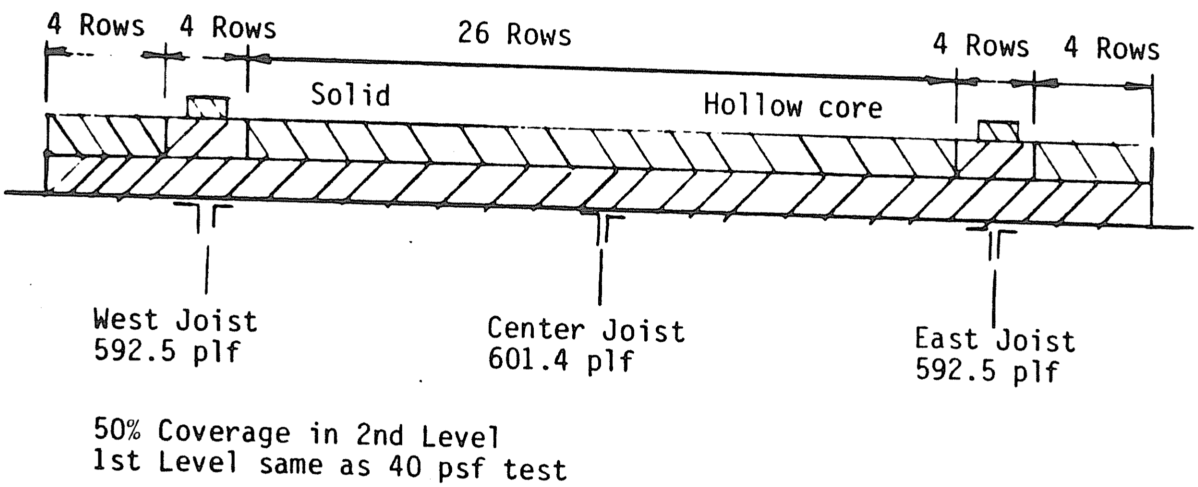
Gravity Load Tests. Two gravity load tests were conducted. The first test was to approximately 40 psf based on a tributary area width of 10 ft. and the second to approximately 60 psf, again based on 10 ft. of width per joist. For both tests, concrete blocks were used to simulate actual dead and live loads. Standard weight, hollow core, 8 in. by 8 in. by 16 in. (nominal) concrete blocks and normal weight, solid, 4 in. by 8 in. by 16 in. (nominal) concrete blocks were used for the tests. Thirteen randomly selected hollow core blocks were weighed and the average weight was found to be 38.6 lbs. with a standard deviation of ±0.7 lbs. Ten randomly selected solid blocks were weighed. Calculated average weight was 33.8 lbs with a standard deviation of ±0.8 lbs. The deviations represent 1.8% and 2.4% of the total weights.

For the 40 psf test, the blocks were placed in four increments and arranged in a pattern so that each joist was approximately equally loaded. Figure 2.7(a) shows the loading pattern. Only 4 ft. 0 in. of each deck cantilever was loaded so that the deck moment at the outside joists was limited to $wL^2/12$ with L equal to 10 ft. A solid block was added over each outside joist and a hollow block was omitted over the center joist to balance the load on each joist. Figure 2.7(a) shows the resulting live load to each joist based on weights of 39 lbs per hollow block and 33 lbs per solid block. These loads were calculated assuming constant moment of inertia over the length of the panel and using stiffness analyses techniques.

The blocks were placed in 43 rows (lengthwise) of 42 hollow core blocks plus two solid blocks each. The loading was applied in 10 psf equivalents by placing each fourth row starting from the simulated truss chord (south) end. All data was recorded after each increment.



(a) 40 psf Gravity Test



(b) 60 psf Gravity Test

Figure 2.7 Concrete Block Placement Patterns

For the 60 psf test, the pattern shown in Figure 2.7(b) was used. The load was increased from the 40 psf level in two increments by placing every other required block (in both directions). Using the same procedures and assumptions as previously discussed, the joist loads shown in Figure 2.7(b) were calculated. All data was recorded after each loading increment.

The test setup loaded to nominal 60 psf is shown in Figure 2.8.

Gravity Plus Lateral Load Tests. Two gravity plus lateral load tests were also conducted. The first after the 40 psf gravity loading was applied and the second after the 60 psf loading was applied. For both tests, the lateral force was applied using the three hydraulic cylinders and was monitored using the load cells. A manual hydraulic pump was used to increase the hydraulic pressure in the cylinders.

The first test was conducted with the nominal 40 psf gravity load in place. Lateral force was applied in 1 kip increments to each of the three joist chords until 10 kips was reached. The 10 kips force was maintained for approximately 5 minutes and then released. Data was recorded at each increment and the test was conducted twice. For the second test, the lateral force was released in 2.5 kips increments with data recorded at each increment.

The second test was conducted with the nominal 60 psf load in place. The lateral force was applied in 2 kips increments to 14 kips and then an additional 1 kip increment was applied. The maximum 15 kips force at each joist location was maintained for approximately 10 minutes. Data was taken at all increments. The lateral force was released in 5 kips increments with data recorded at each increment.

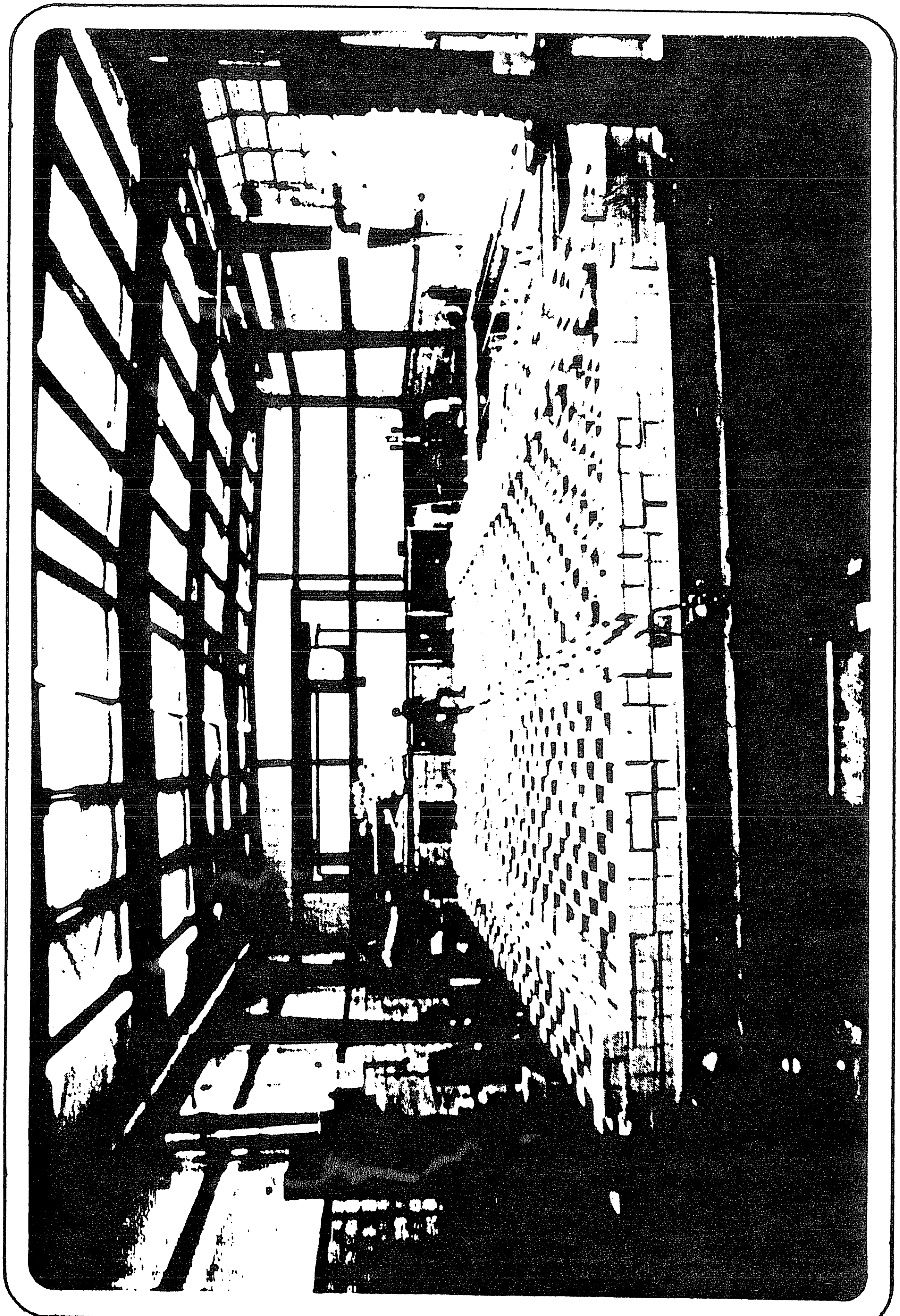


Figure 2.8 Test Setup Loaded to 60 psf

Because of friction inherent in the cylinders, variation in load occurred between the joists. For all tests, at 6 kips of force per joist the maximum variation from the average of the three load cell readings was 6.8%; at 10 kips, 5.0% and at 15 kips, 4.0%. At all increments of all tests, the location with the lowest reading was used to determine the nominal load level. Hence, all loading data is conservative. For instance, at the nominal 15 kip level of the second gravity plus lateral load test, the actual applied force was actually 46.1 kips.

CHAPTER III

TEST RESULTS

3.1 General

Test results consist of gravity or lateral load versus corrected or net displacement relationships. Corrections were made to midspan vertical deflections to account for support settlement due to vertical deflection of the simulated truss chord member. Relative lateral movement of one joist chord end with respect to the other was calculated by summing the lateral displacements measured at each end. Rotations of the joist ends and at the centerline of the simulated truss chord member were calculated using appropriate geometric relationships.

Theoretical vertical deflection of the SJI 36LH12 joists was determined from deflection data found in Reference 4. The theoretical load-deflection relationship was also plotted on the appropriate graphs.

Data reduction was not complete at the time this preliminary report was written. Selected results of the most critical measurements are discussed in the following sections.

3.2 Gravity Loading

Nominal 40 psf Test. Test results for the nominal 40 psf gravity load test are presented in Appendix A. Figure A.1 shows gravity load in plf per joist versus corrected midspan vertical deflection. Both theoretical and measured relationships are shown. The measured data is for the center and east joists. Excellent agreement (less than 0.1% difference) was obtained as can be seen in Figure A.1.

Load versus relative lateral movement of one joist end with respect to the other is shown in Figure A.2. Again, results for the center and east joist are plotted. The relationship is linear to 30 psf (300 plf) where a slight softening occurred. Maximum total movement was less than 0.3 in.

Nominal 60 psf Test. Test results for the nominal 60 psf gravity load test are found in Appendix B. Figure B.1 shows both theoretical and measured load versus midspan vertical deflection relationships. Again, correlation between theoretical and measured deflections for the center and east joists was excellent (less than 0.1%).

Load versus relative movement of one joist end with respect to the other is shown in Figure B.2. The curves for both the center and east joists are similar with slight breaks at the 30 psf (300 plf) and 40 psf (400 plf) load levels. Maximum total movement was less than 4.38 in.

Upon removal of the concrete blocks, a final vertical deflection measurement was made. The residual deflection at the east joist was 0.1 in., at the center joist, 0.08 in. and at the west joist, 0.02 in.

3.3 Gravity plus Lateral Loading

Nominal 40 psf Test. Test results for the nominal 40 psf gravity plus lateral loading tests are found in Appendix C. Two tests were conducted with a maximum force of 10 kips applied in each test. Figures C.1 nad C.2 show results from Test 1 and Figures C.3 and C.4 show results for Test 2. Data was taken during unloading in Test 2.

Figures C.1 and C.3 show lateral force versus joist midspan vertical deflection for Tests 1 and 2, respectively, of the east and west joists. Maximum deflection was less than 0.20 in. for both tests. Figures C.2 and C.4 show lateral force versus lateral movement of one end of a joist with respect ot the other end. Results are shown for the east and center joists. It is believed that the stiffening effect shown in Figure C.2 was caused by a slight out-of-vertical plane rotation of the east joist seat. The measurement at this location was taken using a short piece of angle clamped to the top of the seat (see Figure 2.4) and, hence, slight rotations result in magnified lateral movements. This effect was not observed in Test 2, Figure C.4.

Nominal 60 psf Test. Test results for the nominal 60 psf gravity plus lateral loading are found in Appendix D. The maximum applied lateral force in this test was 15 kips. Data was taken during unloading. Figure D.1 shows lateral load versus joist midspan vertical deflection for the east and west joists. Maximum vertical deflection was less than 0.3 in.

Figure D.2 shows lateral force versus lateral movement of one end of a joist with respect to the other end. Results for both the east and center joists are shown. The erratic behavior of the east joist is unexplained.

CHAPTER IV

CONCLUSIONS

Full-scale tests of a steel joist/steel deck roof system were conducted as part of the research reported here. The primary objective of these tests was to determine if such a system is also capable of providing lateral support to compression chord members of large trusses when fully loaded by gravity loadings. Gravity load tests and gravity plus lateral load tests were conducted.

Although all data had not been analyzed at the time of the writing of this preliminary report, it is concluded that the system tested is capable of supporting a gravity load of 60 psf and simultaneously providing lateral force restraint.

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2. Salmon, Charles G. and Johnson, John E., Steel Structures Design and Behavior, 2nd Edition, Harper and Row, New York, 1980.

3. Yura, Joseph A., "Design of Bracing", University of Texas at Austin, Austin, Texas.

4. "Steel Joists and Joist Girders", VULCRAFT, 1979.

APPENDIX A

Test Results for 40 psf Gravity Load Test

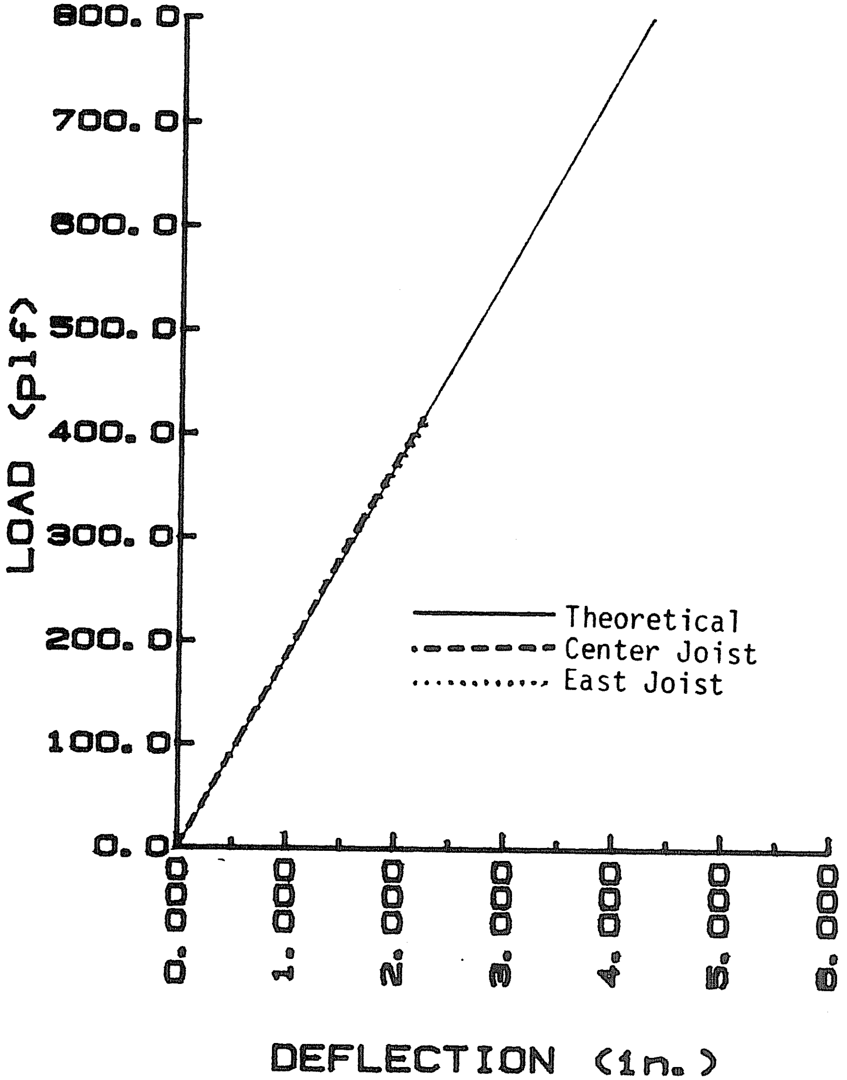

Figure A.1 Load vs. Joist Midspan Vertical Deflection, 40 psf Gravity Load Test

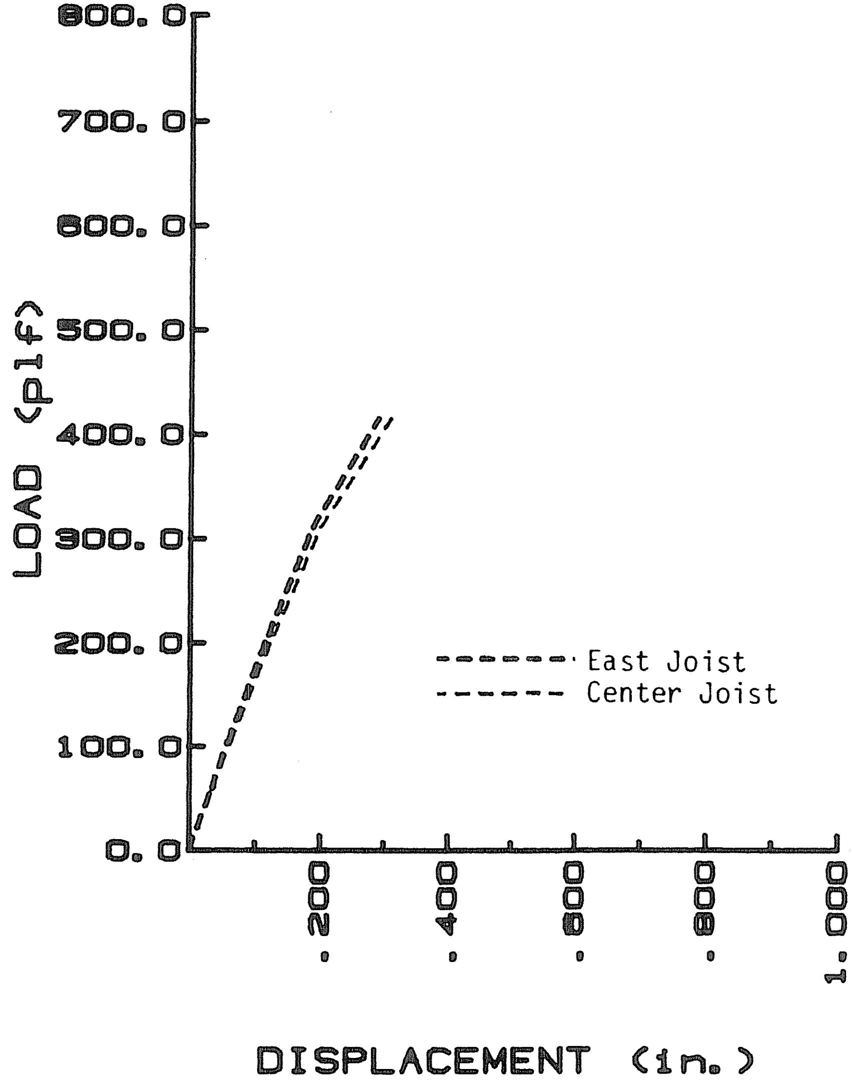

Figure A.2 Load vs. Joist Chord Shortening, 40 psf Gravity Load Test

APPENDIX B

Test Results for 60 psf Gravity Load Test

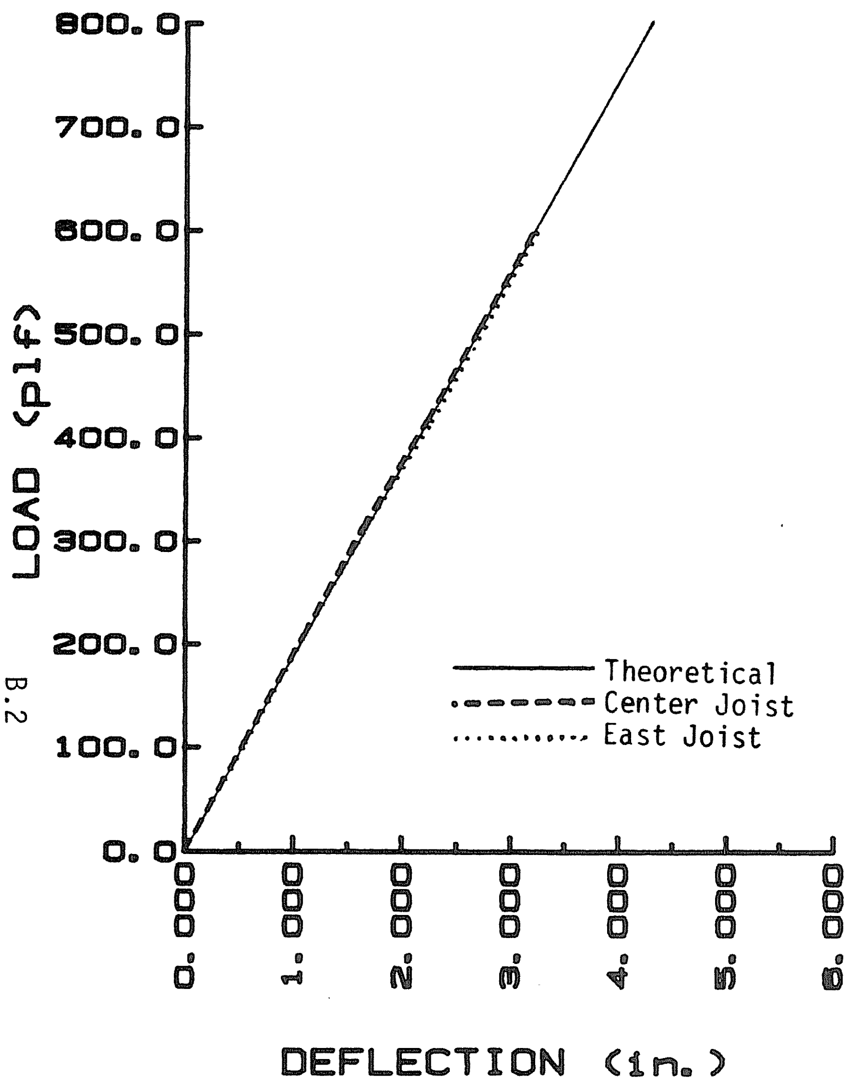

Figure B.1 Load vs. Joist Midspan Vertical Deflection, 60 psf Gravity Load Test

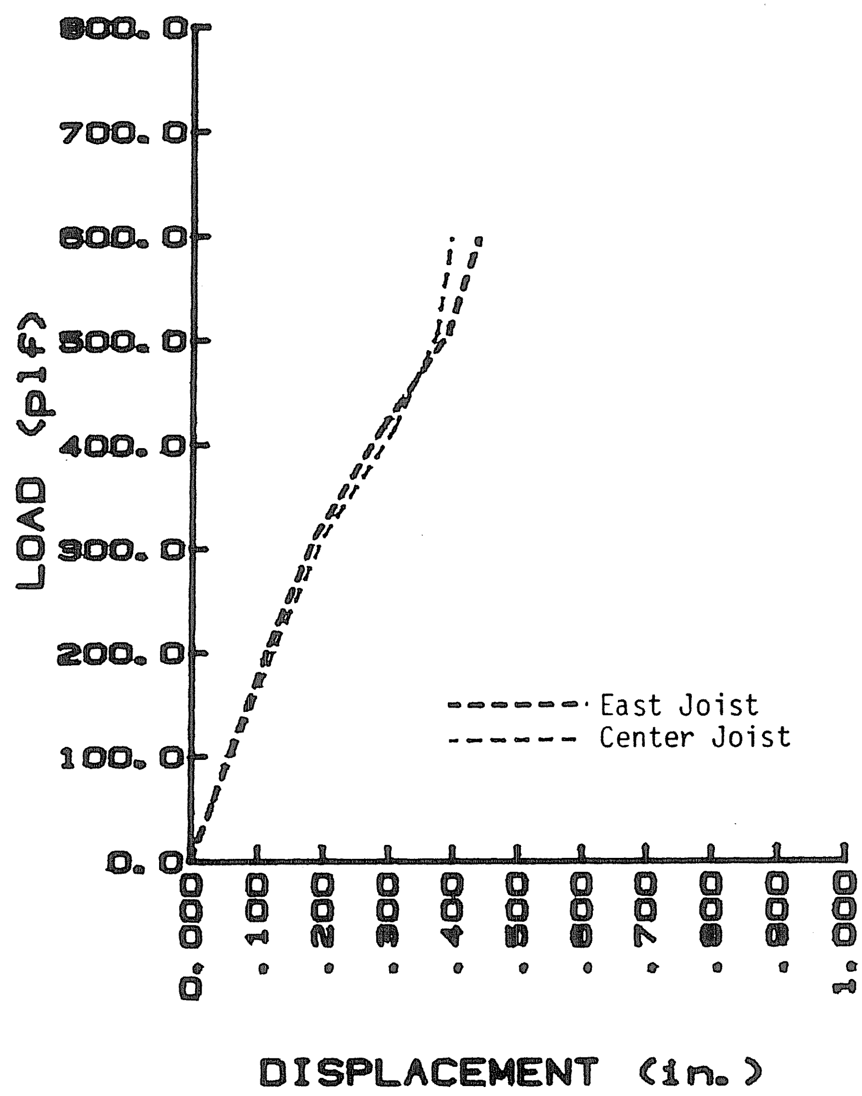

Figure B.2 Load vs. Joist Chord Shortening, 60 psf Gravity Load Test

APPENDIX C

Test Results for Combined 40 psf Gravity plus Lateral Load Test

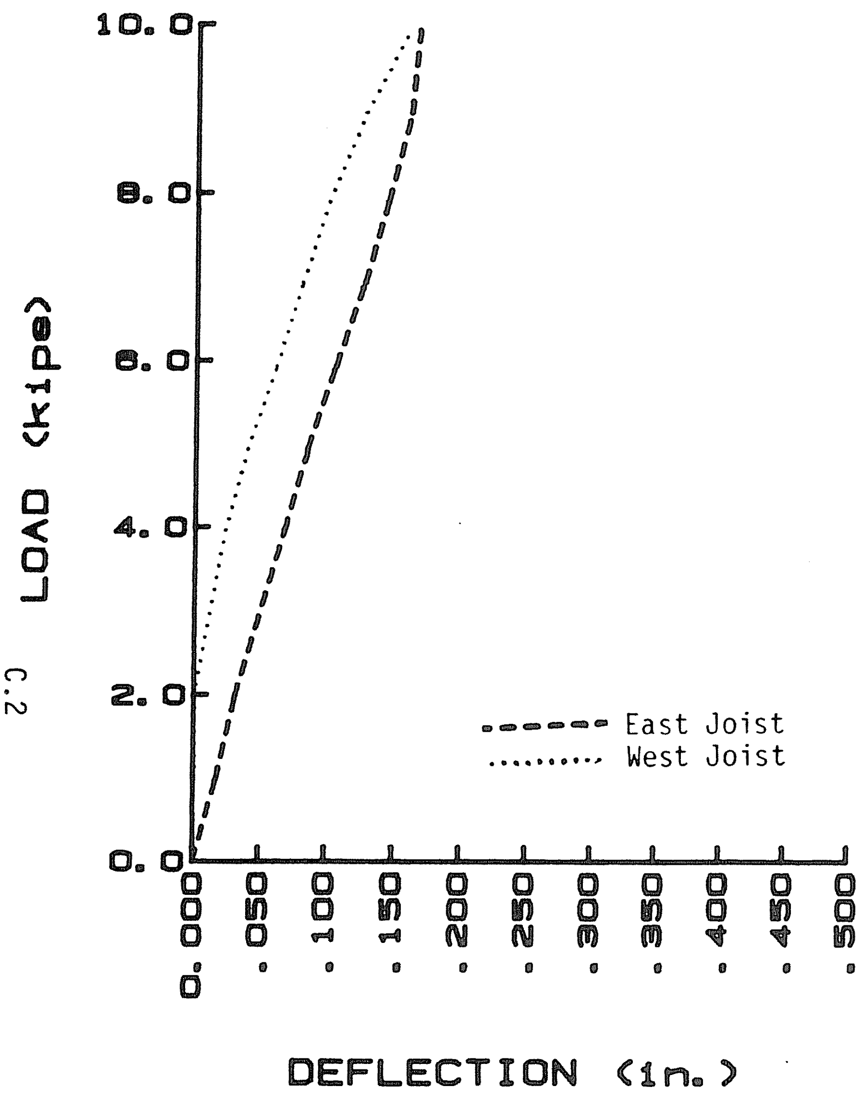

Figure C.1 Lateral Load versus Joist Midspan Vertical Deflection, 40 psf Gravity plus Lateral Load Test 1

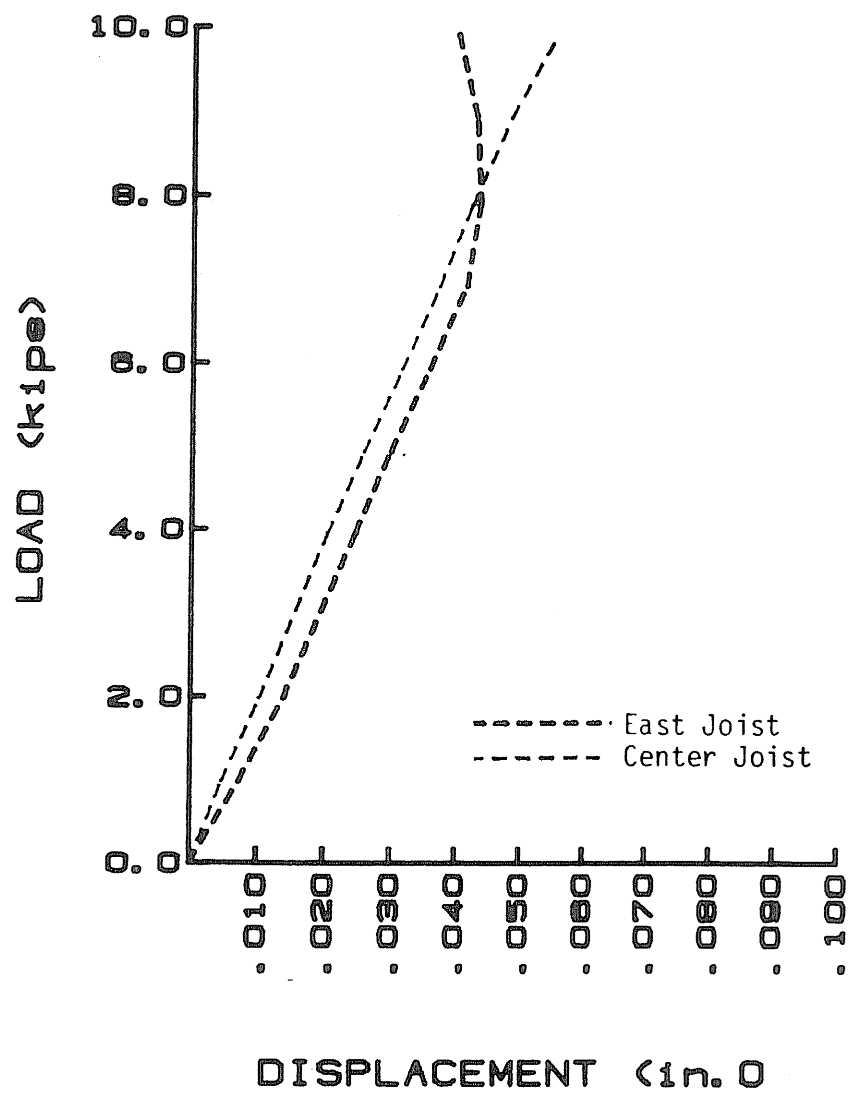

Figure C.2 Lateral Load versus Joist Chord Shortening, 40 psf Gravity plus Lateral Load Test 1

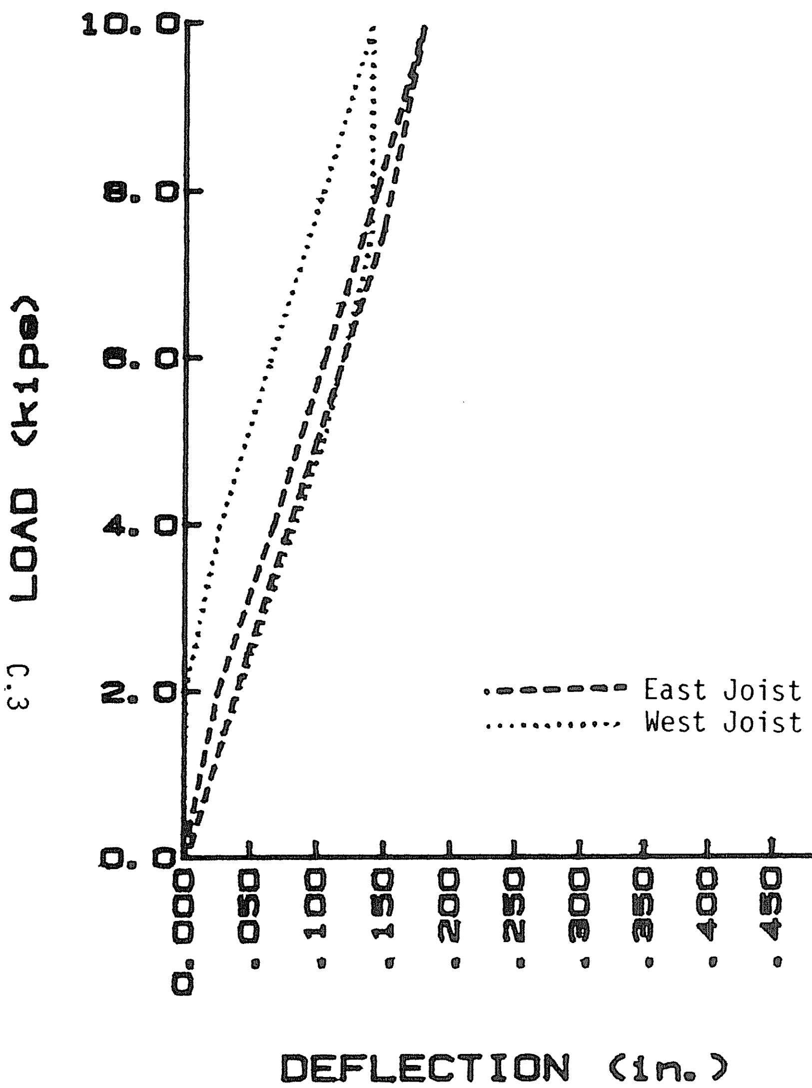

Figure C.3 Lateral Load vs. Joist Midspan Vertical Deflection, 40 psf Gravity plus Lateral Load Test 2

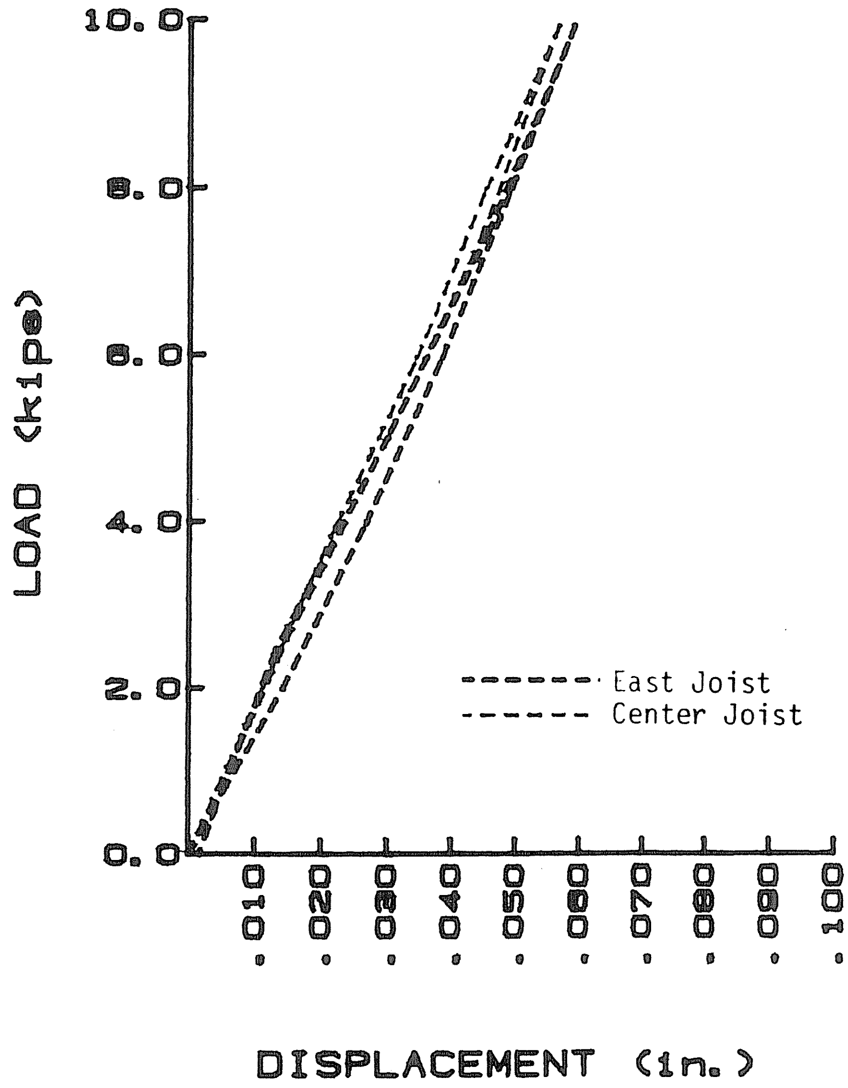

Figure C.4 Lateral Load vs. Joist Chord Shortening, 40 psf Gravity plus Lateral Load Test 2

APPENDIX D

Test Results for Combined 60 psf Gravity plus Lateral Load Test

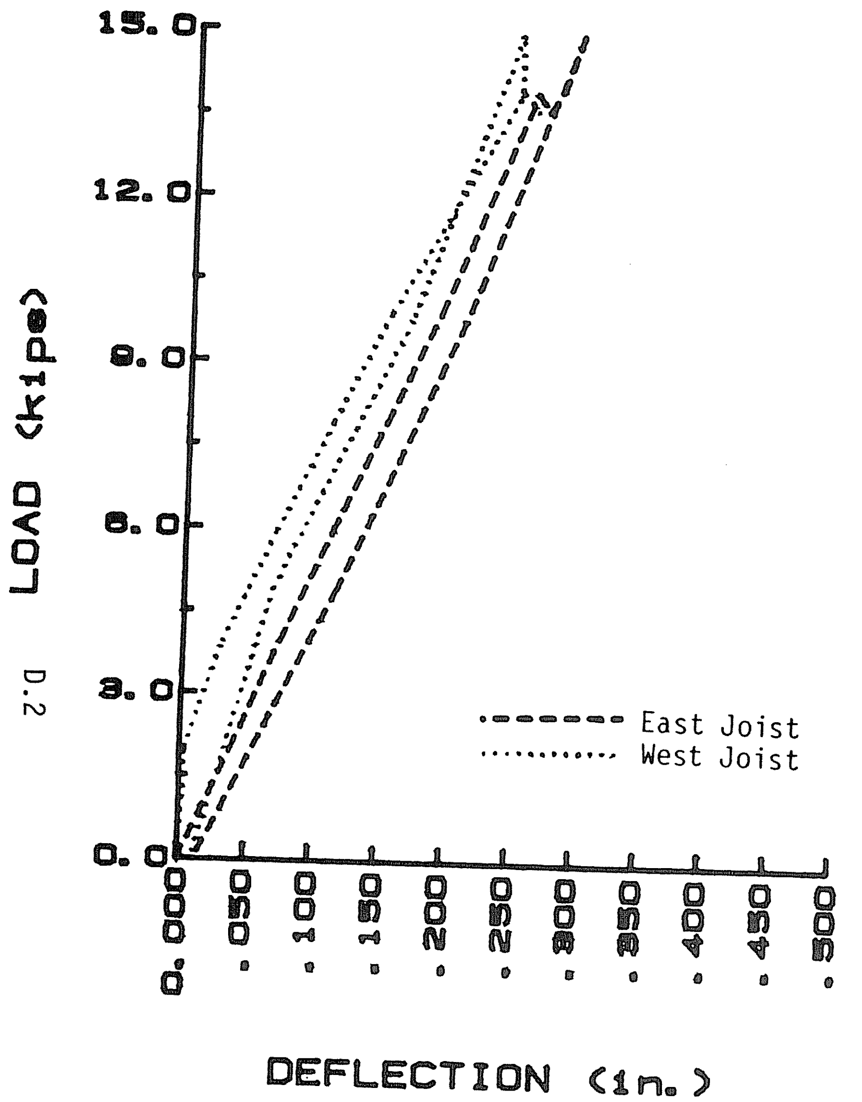

Figure D.1 Lateral Load vs. Joist Midspan Vertical Deflection, 60 psf Gravity plus Lateral Load Test

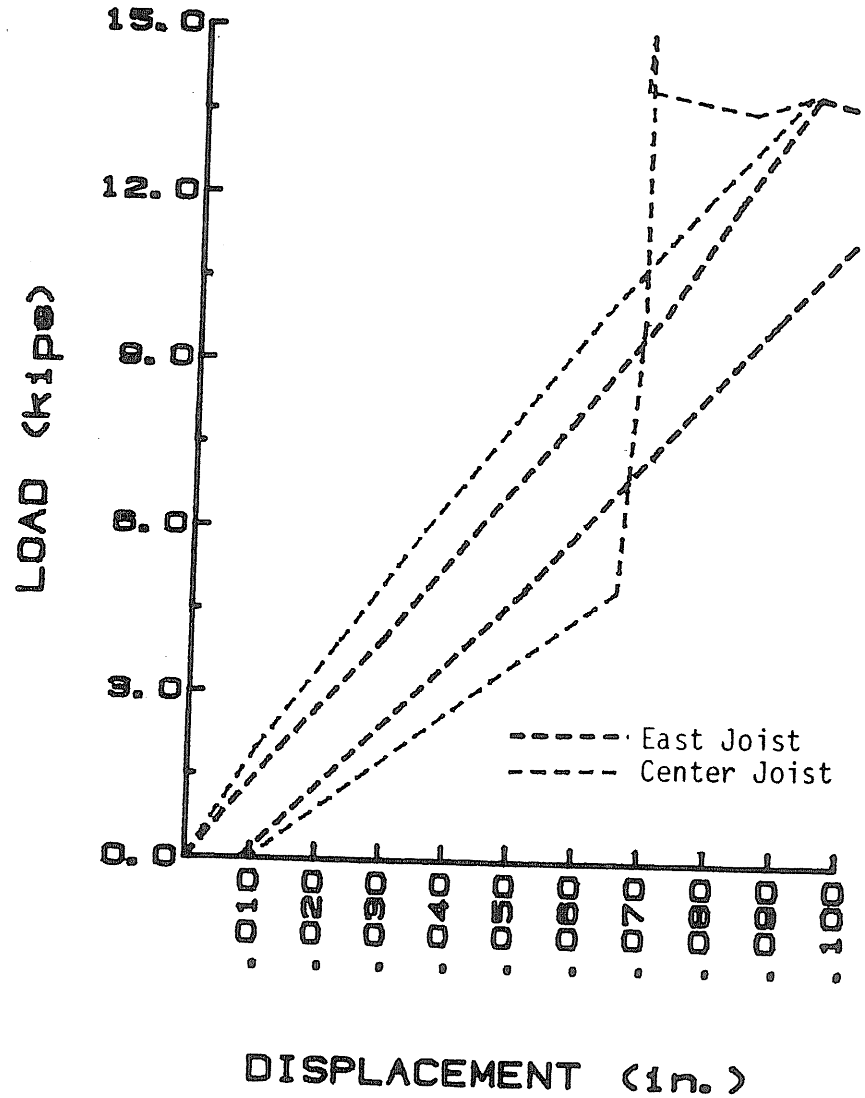

Figure D.2 Lateral Load vs. Joist Chord Shortening, 60 psf Gravity plus Lateral Load Test