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Testing of steel roof deck construction

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TESTING OF STEEL ROOF DECK CONSTRUCTION

by

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I. INTRODUCTION

During recent years, insulated steel, roof deck construction is widely used in industrial and commercial buildings. A Roof Deck Assembly consisting of a 3 in. deep, 22 gage steel deck is being considered by Rooftex, Inc, Houston, Texas for a Class I-60 and Class I-90 assembly. At the request of Rooftex, two types of tests were conducted at the University of Missouri-Rolla in July 1983. These tests included (1) physical tests of steel roof decks and (2) uplift pressure tests of insulated steel roof deck construction. These tests were proposed in June 1983.[1] The objective was to obtain the necessary data for the approval of Factory Mutual Research Corporation.

This report describes the setup and procedures used for the tests and presents the results obtained. Section II deals with the physical testing of the steel roof decks, and Section III covers the uplift pressure tests. A conclusion is presented in Section IV and future tests are proposed in Section V.

II. PHYSICAL TESTING OF STEEL ROOF DECKS

The steel deck used in the tests was Type N2, roof deck (22 gage) manufactured by MAC-FAB Products, Inc., St. Louis, Missouri. Figure 1 shows the profile and nominal dimensions of the Type N2 deck.

As shown in Figs. 2 and 3, three support beams were spaced 12 ft apart under a test frame located in the Engineering Research Laboratory of the University of Missouri-Rolla. On the top flange of each beam, a 1-9/16 x 1-3/16 x 1/8 in. channel section provided by Rooftex was fastened to the beam flange with three U-shaped hooks to simulate actual construction. Three sheets of Type N2 deck were placed over these support beams. These sheets were then fastened to channels at each rib (8 in. spacing) with 12-24 x 7/8 in. TEKS/4 screws manufactured by the Buildex Company and supplied by Rooftex. Side-laps were fastened with 10-16 x 3/4 in. TEKS/1 screws spaced at 3 ft intervals.

Before the roof deck was tested a pilot test was conducted for the purpose of checking the equipment and establishing the test procedure. The actual physical test was conducted on July 21, 1983, to obtain the necessary data. The measured thicknesses of the three sheets used for this test were 0.0312, 0.0312, and 0.0310 in total thickness. The finish was galvanized coating Class G-90. The black steel thickness was 0.0292 inches. This test included the observation and measurement of top flange flatness, side lap securement, damage produced by a simulated heel load, and a mid-span deflection of a two-span continuous sheet. Details of the test and the test results are descirbed below in Items II.A through II.D.

A. Top Flange Flatness

The flatness of the roof deck's top flange was checked with a 24 in. long, straight edge that was placed across the three flanges. The maximum value of concavity or convexity was measured and recorded. As presented in Table 1, the maximum out-of-flatness was found to be 0.06 in., which is less than the limit of 1/16 in. specified in the 1977 FM Standard for adhesive bonding.[2] Because screws were used for this roof system in lieu of adhesive bonding, this requirement is apparently not critical.

B. Measurement of Mid-Span Deflection

In order to measure the mid-span deflection under a concentrated load, the load was applied by using a hydraulic jack with a load cell over a 12 x 12 x 1/4 in. steel plate located at the mid-span of one of the two-span steel decks as shown in Figs. 4 and 5. During the test, the applied load was read directly from a data acquisition monitor, and the corresponding deflection was obtained by placing two dial gages under the bottom flanges of the two central ribs of the steel deck. Figure 6 shows the locations of these dial gages. The deflection readings were recorded for 50 pound increments from the beginning to a total load of 200 pounds. From 200 to 300 pounds, the load increment was reduced to 25 pounds. All the dial gage readings and the average mid-span deflections are presented in Table 2. It can be seen that the measured mid-span deflection under a concentrated load of 300 pounds is 0.394 in., which is less than 1/240th of the span length.

C. Damage Produced by a Simulated Heel Load

A concentrated load of 300 pounds simulating a heel load was applied over a 3 in. diameter steel plate located on the top flange at mid-span of one of the two-span steel decks as shown in Fig. 7. After removing the load, the maximum permanent indentation was measured from a 12 in. straight edge placed parallel to the ribs. As presented in Table 3, the maximum permanent indentation was found to be 0.06 in., which is less than the limit of 1/16 in. specified in the proposal.[1]

D. Side-Lap Securement

In order to check the side-lap securement, a concentrated load of 300 pounds was applied downward to the underlying sheet over a 6 x 3 x 1/4 in. steel plate located 1/2 in. from the side lap web (6 in. dimension parallel to ribs). See Fig. 8 for the location of the steel plate.

It was found that under the applied load of 300 pounds, the steel decks remained securely joined by side-lap fasteners without being dislodged. An engineering level was used to measure the differential deflections between the sheets at nine locations along the span length of the beam. For details, see Fig. 9. Table 4 presents the measurements and differential deflections between two sheets at nine locations. The maximum differential deflection, located a distance of 1 in. from the fastener, was found to be 0.05 in.

III. UPLIFT PRESSURE TESTS OF INSULATED STEEL ROOF DECK ASSEMBLY

A. Construction of the Roof System

The roof systems shown in Fig. 10 were constructed by Rooftex, Inc. and shipped to the Engineering Research Laboratory at the University of Missouri-Rolla for testing. Figure 11 shows three different arrangements of the roof grip fasteners used for the roof assemblies (i.e., four fasteners per 3 x 4 ft board for System No. 1, five fasteners per 3 x 4 ft board for Systems Nos. 2 and 3, and six fasteners per 3 x 4 ft board for System No. 4.

The measured thicknesses of the steel decks for the four different systems are given in Table 5.

B. Test Setup

The uplift pressure test used in this program was similar to the standard test used by Factory Mutual Research Corporation.[3]

The apparatus used for the tests consisted of a test frame (12 ft long, 6 ft wide, and 4 in. deep), an air compressor, a water-filled manometer, and a data acquisition system monitor as shown in Figs. 12 and 13. The water-filled manometer was used to verify the pressure readings obtained from the data acquisition system monitor.

In the test frame, a 1-1/2 in. diameter hole was used on one 6 ft side for an air supply inlet. A 1/2 in. diameter hole on the same side served as a connection to the data acquisition system monitor and the water-filled manometer.

Before placing the roof assembly on top of the test frame, a rubber gasket and a 0.004 in. thick polyethylene film were placed on the top flange of the channel sections around the perimeter of the frame to minimize any air leakage.

When the roof assembly was ready for testing, it was placed on top of the test frame. Boards measuring 7/8 x 2-1/4 in. were placed around the perimeter of the assembly. These were followed by 3 x 2 in. angles. Five C-clamps were securely attached on each 12 ft edge and three along each 6 ft edge (Fig. 12). Both 12 ft edges were also supported by lateral braces (Fig. 14).

C. Test Procedure

During the test, air pressure was supplied with an air compressor. Pressure readings were obtained from a data acquisition system monitor. In addition to the pressure reading, manometer readings were also recorded for the purpose of verification.

Compressed air was introduced beneath the assembly in accordance with the following increments:

Time (Min.)	Pressure (psf)
0.00 to 1:00	30
1:00 to 2:00	45
2:00 to 3:00	60
3:00 to 4:00	75
4:00 to 5:00	90

The pressure was increased in 15 psf increments. After the pressure reached the specified value, it was held for one minute.

Prior to the formal testing, Roof System No. 2 was pilot tested for the purpose of checking the equipment and establishing the procedure.

D. Test Results

Two formal uplift pressure tests (Roof Systems No. 3 and 4) were conducted on July 21, 1983. Pressure and manometer readings were recorded according to the increments described above. All the data are presented in Table 6. The pressures computed from the manometer readings are also given in this table for each test. The minor discrepancies between the air pressure obtained directly from the monitor and the value computed from the manometer readings were due to the fact that it was difficult to read the precise values on the manometer.

During the test, the roof system was carefully observed for the presence of bowing on the top of the assembly. It was noted that when the pressure exceeded 75 psf on Roof System No. 3 (approx. 82 psf) some fasteners pulled through the insulation board. This resulted in a large amount of bowing and failure. When a pressure of 90 psf was applied on Roof System No. 4 the roof assembly was unable to withstand this amount of pressure for a duration of one minute. The assembly failed in flexure after approximately 15 seconds.

After the tests were completed, the assemblies were dismantled and examined to determine the mode of failure. It was found that both roof systems failed in flexure. However System No. 4 performed slightly better than System No. 3 because of the use of an additional fastener for each 3 x 4 ft insulation board. In addition, 2 x 4 in. wood members were connected to the bottom of Roof System No. 4 around the perimeter of the assembly before the system was placed on the test frame.

Figures 15 through 18 are photographs showing the failure modes of Systems No. 3 and No. 4.

IV. CONCLUSION

Two types of tests (Physical Testing of Steel Roof Decks and Uplift Pressure Tests of roof assemblies) were conducted at the University of Missouri-Rolla in July 1983.

From the data obtained by the Physical Testing of Steel Roof Decks (Section II) of this report, the Type N2 roof deck (22 gage) manufactured by Mac-Fab Products, Inc. St. Louis, Missouri is adequate for a Class I-60 roof assembly. The maximum span for these assemblies is 12' - 0".

The physical evaluation either met or exceeded all of the criteria set out by Factory Mutual Research testing procedure.

These same criteria used for physical testing can also be met by the steel roof decks having the same profile made of a G-90 galvanized sheet equal to or greater than 0.031 in. in total thickness.

From the data obtained by the Uplift Pressure Test of Insulated Steel Roof Deck Assembly (Section III) of this report, the Roof Deck System (5 fasteners per 3 x 4 ft board) is adequate for a Class I-60 rating.

V. FURTHER TESTING

In order to obtain a Class I-90 rating for the proposed roof assemblies, additional uplift pressure tests should be conducted. For the future tests, a slightly thicker steel roof deck should be used for the construction of roof assemblies.

VI. ACKNOWLEDGMENTS

The project reported herein was conducted at the Department of Civil Engineering of the University of Missouri-Rolla under the sponsorship of Rooftex, Inc., Houston, Texas.

The financial assistance granted by the sponsor is gratefully acknowledged. The steel decks used for physical testing were supplied by Mac-Fab Products, Inc., St. Louis, Missouri, and the roof assemblies were constructed by Rooftex, Inc., Houston, Texas.

Appreciation is expressed to Messrs. Yaromir Steiner and Andre Desumeur (Rooftex, Inc.), Eugene R. Dunn (Factory Mutual Research), and M.R. Parrish and Elmo Branson (Mac-Fab Products, Inc.) for their advice and technical guidance provided for this project. Messrs. Dunn, Parrish, and Branson also witnessed the physical testing of steel deck and the uplift pressure tests of the roof systems conducted at the University's Engineering Research Laboratory.

Thanks are extended to K. Haas, J.A. Tucker, M.E. Light, and Ross Haselhorst for their help in preparing the test equipment and in conducting the tests. Thanks are due to Messrs. S. Sucharit and L.C. Pan for conducting the tests.

Special thanks are extended to Mrs. DeAnne Larson for typing this report and to Mr. John W. Koenig for his editorial review and suggestions.

VII. REFERENCES

1. Yu, W.W., "Proposal for Testing of Steel Roof Deck Construction", submitted to Rooftex, June 1983.
2. "Approval Standard for Class I Insulated Steel Deck Roofs", Factory Mutual Research Standard 4450, April 15, 1971; Revised August 5, 1977.
3. "Uplift Pressure Test Standard for Class I Insulated Steel Roof Deck Construction", Appendix B, Factory Mutual Research Corporation; Revised August 5, 1977.

Table 1

Top Flange Flatness

Measurement (in.)			Maximum Out-of-Flatness (in.)
No. 1	No. 2	No. 3	
0.06	0.05	0.05	0.06

Table 2

Measured Mid-Span Deflection

Load (pound)	Dial Gage Reading (in.)			Deflection (in.)
	No. 1	No. 2	Average	
0	0	0	0	0
50	0.062	0.063	0.063	0.063
100	0.125	0.123	0.124	0.124
150	0.197	0.188	0.192	0.192
200	0.269	0.256	0.262	0.262
225	0.297	0.284	0.290	0.290
250	0.332	0.317	0.325	0.325
275	0.371	0.354	0.363	0.363
300	0.402	0.386	0.394	0.394

Notes: 1/240th of the span length = 0.60 in.

1/200th of the span length = 0.72 in.

Table 3

Permanent Indentation for a Simulated Heel Load

Measurement (in.)		Permanent Indentation (in.)
Before Loading	After Removing Load	
0	0.06	0.06

Table 4

Differential Deflections Between Adjacent Sheets for Checking Side-Lap Securement

Point of Measurement	Overtopping Sheet (in.)		Underlying Sheet (in.)		Deflection (in.)		Differential Deflection (in.)
	Load=0 lb.	Load=300 lb.	Load=0 lb.	Load=300 lb.	Overtopping Sheet	Underlying Sheet	
1	9.99	10.40	10.07	10.51	0.41	0.44	0.03
2	9.99	10.41	10.06	10.51	0.42	0.45	0.03
3	10.00	10.41	10.05	10.51	0.41	0.46	0.05
4	10.00	10.42	10.05	10.50	0.42	0.45	0.03
5	9.99	10.43	10.06	10.50	0.44	0.44	0.00
6	9.99	10.41	10.06	10.51	0.42	0.45	0.03
7	9.98	10.40	10.05	10.50	0.42	0.45	0.03
8	9.98	10.39	10.05	10.50	0.41	0.45	0.04
9	9.98	10.39	10.05	10.50	0.41	0.45	0.04

Note: See Fig. 9 for the location of measuring points.

Table 5

Measured Thicknesses of Steel Decks
Galvanized Finish Coating Class G-90

Roof System No.	Total Measured Thickness (in.)*		
	1st Sheet	2nd Sheet	3rd Sheet
1	0.0315	0.0315	0.0315
2	0.0310	0.0310	0.0305
3	0.0315	0.0310	0.0310
4	0.0310	0.0310	0.0310

*Black Steel Thickness Subtract 0.002 in.

Table 6

Uplift Pressure Test

Roof System No.	Pressure Reading Obtained from Monitor (psf)	Manometer Reading (in.)			Pressure Computed from Manometer Reading (psf)
		Left Column (in.)	Right Column (in.)	Head (in.)	
3	0	10.7	10.7	0	0
	30	7.8	13.6	5.8	30.2
	45	6.4	15.1	8.7	45.2
	60	4.8	16.6	11.8	61.4
	75	3.3	18.1	14.8	77.0
	82	Failure			
4	0	10.7	10.7	0	0
	30	7.8	13.6	5.8	30.2
	45	6.3	15.2	8.9	46.3
	60	4.8	16.6	11.8	61.4
	75	3.4	18.1	14.7	76.4
	90**	1.8	19.6	17.8	92.6

** Failed to sustain 1 minute duration

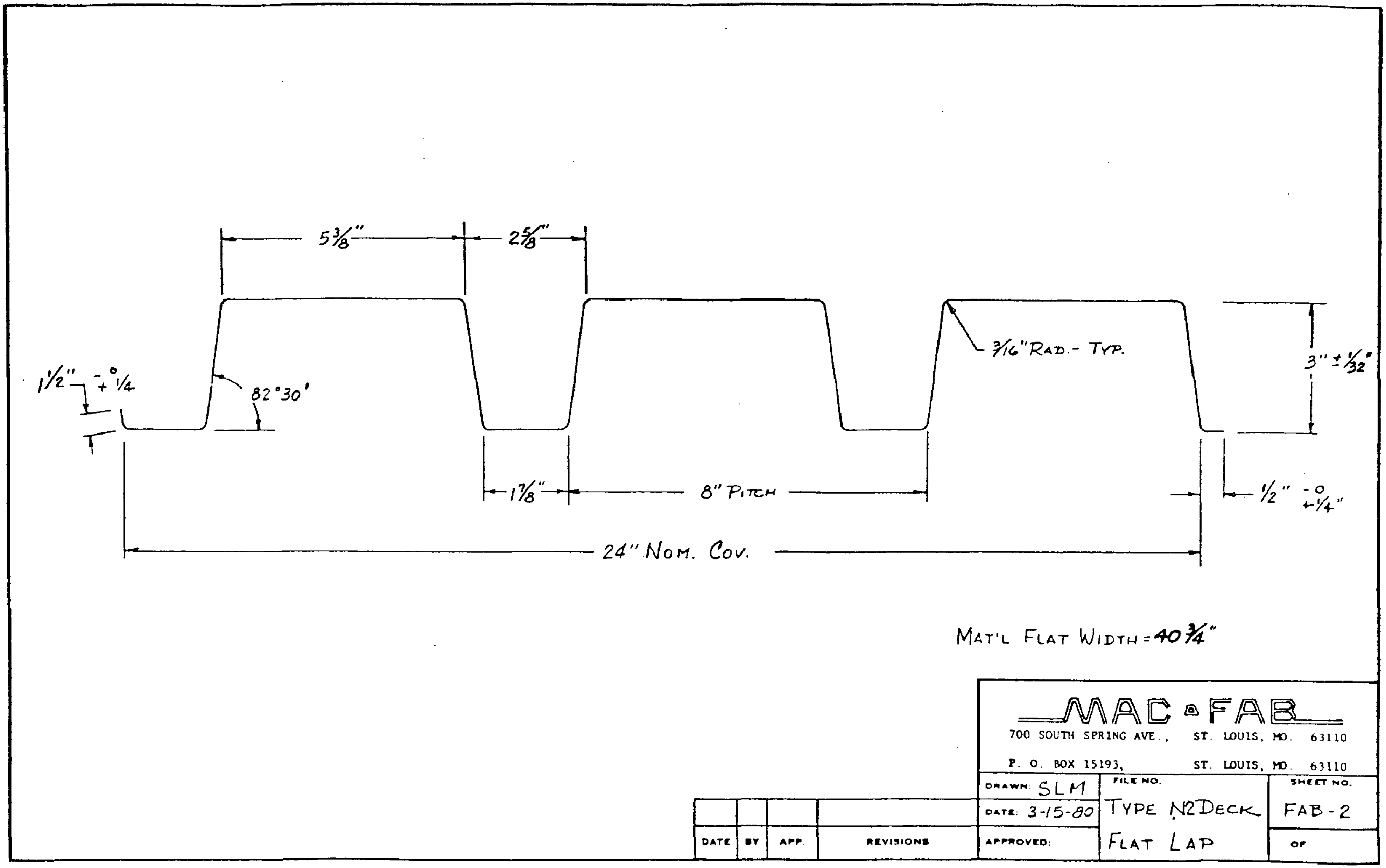


Fig. 1 Type N2, 22 ga. 3 in. deep Steel Deck

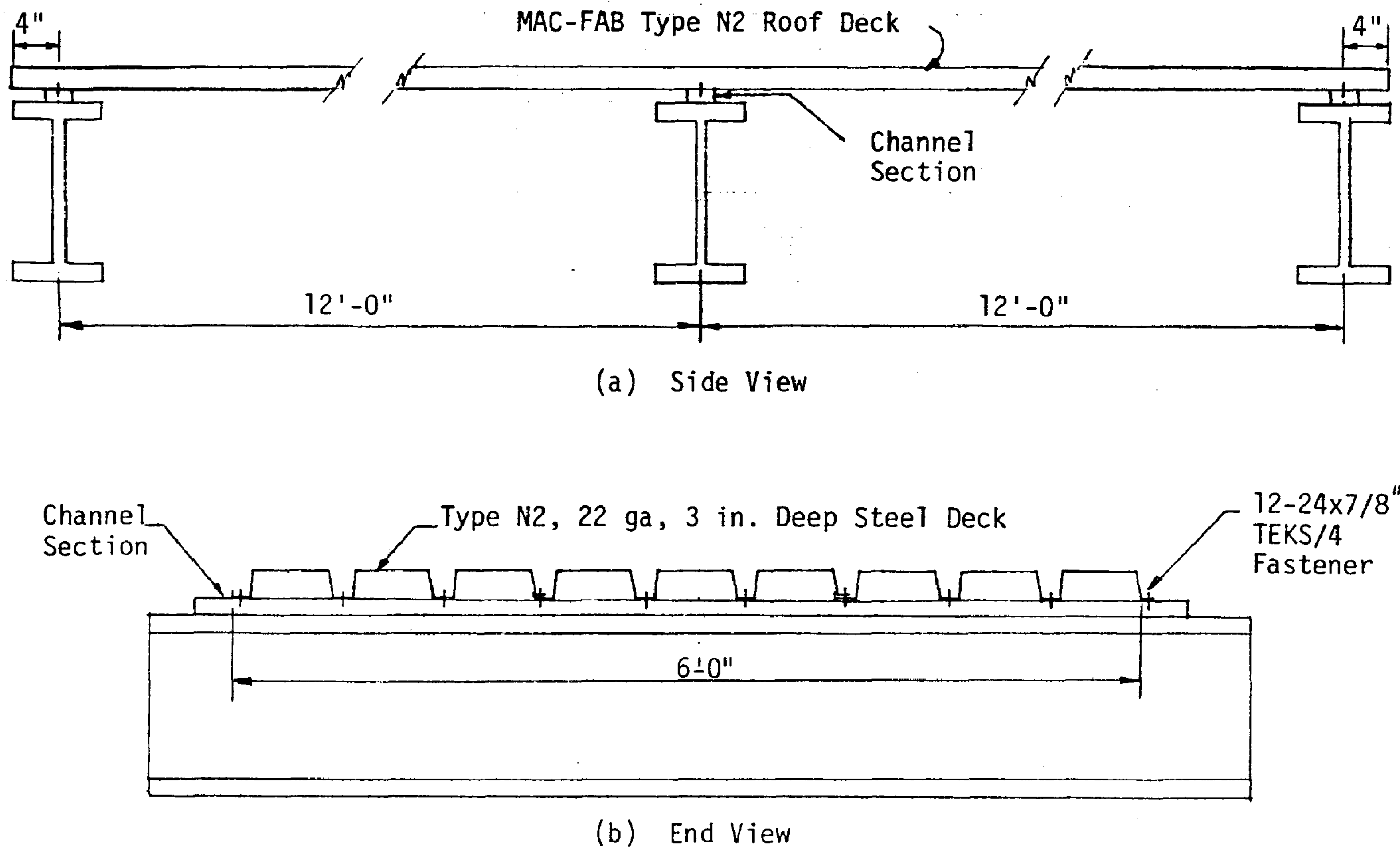


Fig. 2 Test Setup for Physical Testing of Steel Deck

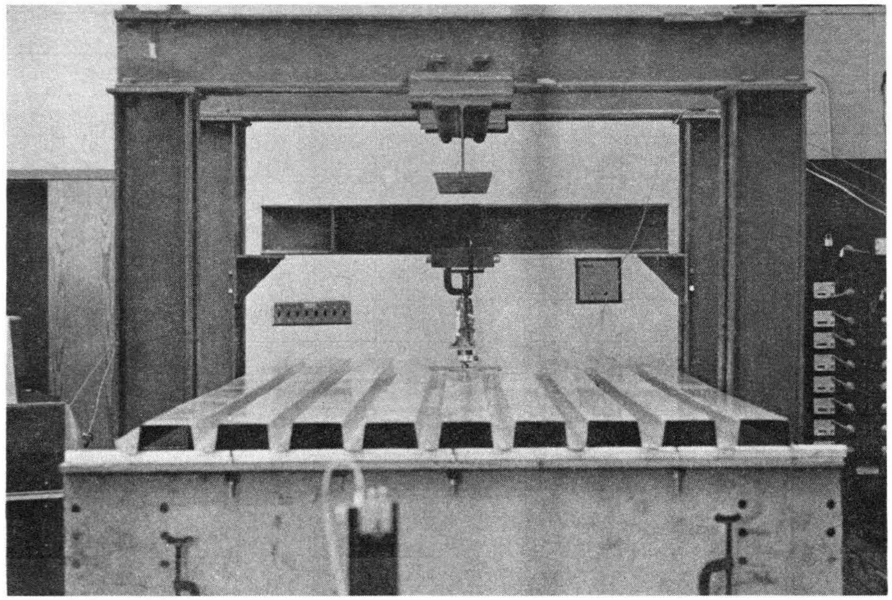


Fig. 3 Photograph Showing the Test Setup Used for Physical Testing of Steel Deck

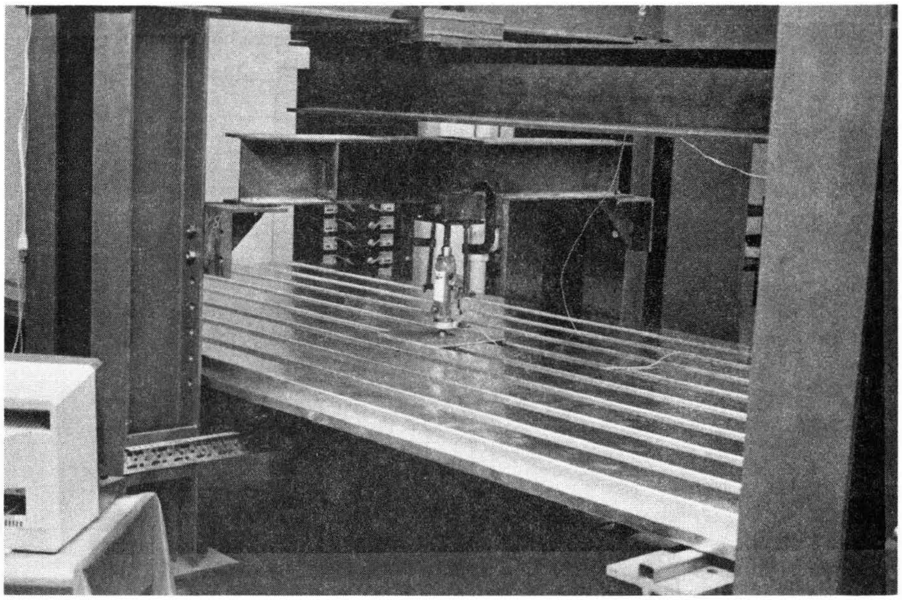


Fig. 4 Mid-Span Deflection Test Setup

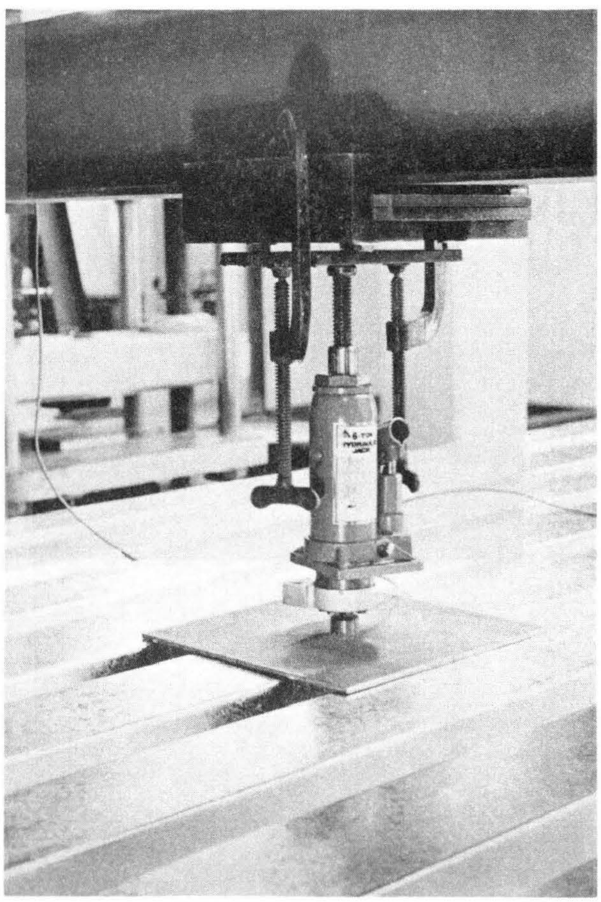


Fig. 5 Loading Condition for Measuring Mid-Span Deflection

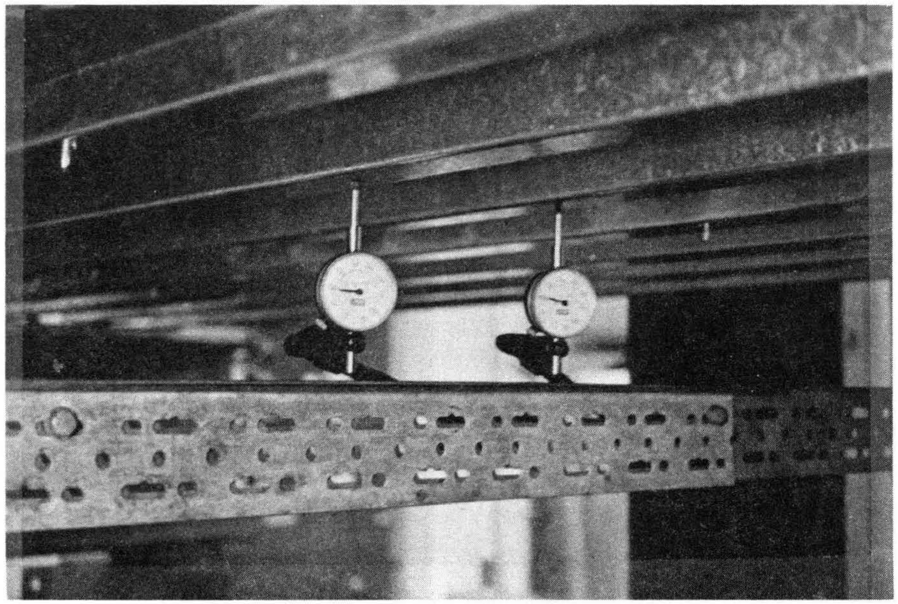


Fig. 6 Dial Gages Used for Measuring Mid-Span Deflection

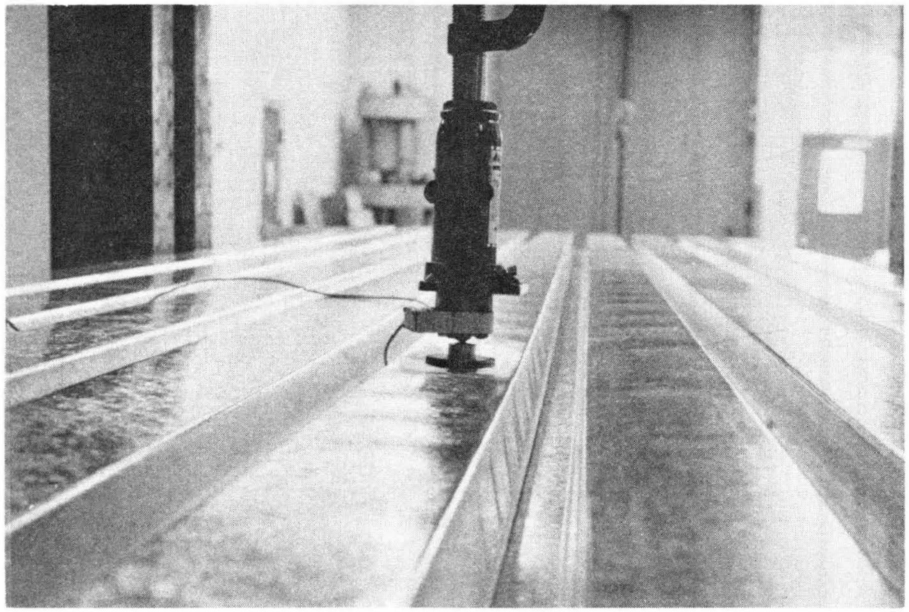


Fig. 7 Steel Deck Subject to Simulated Heel Load

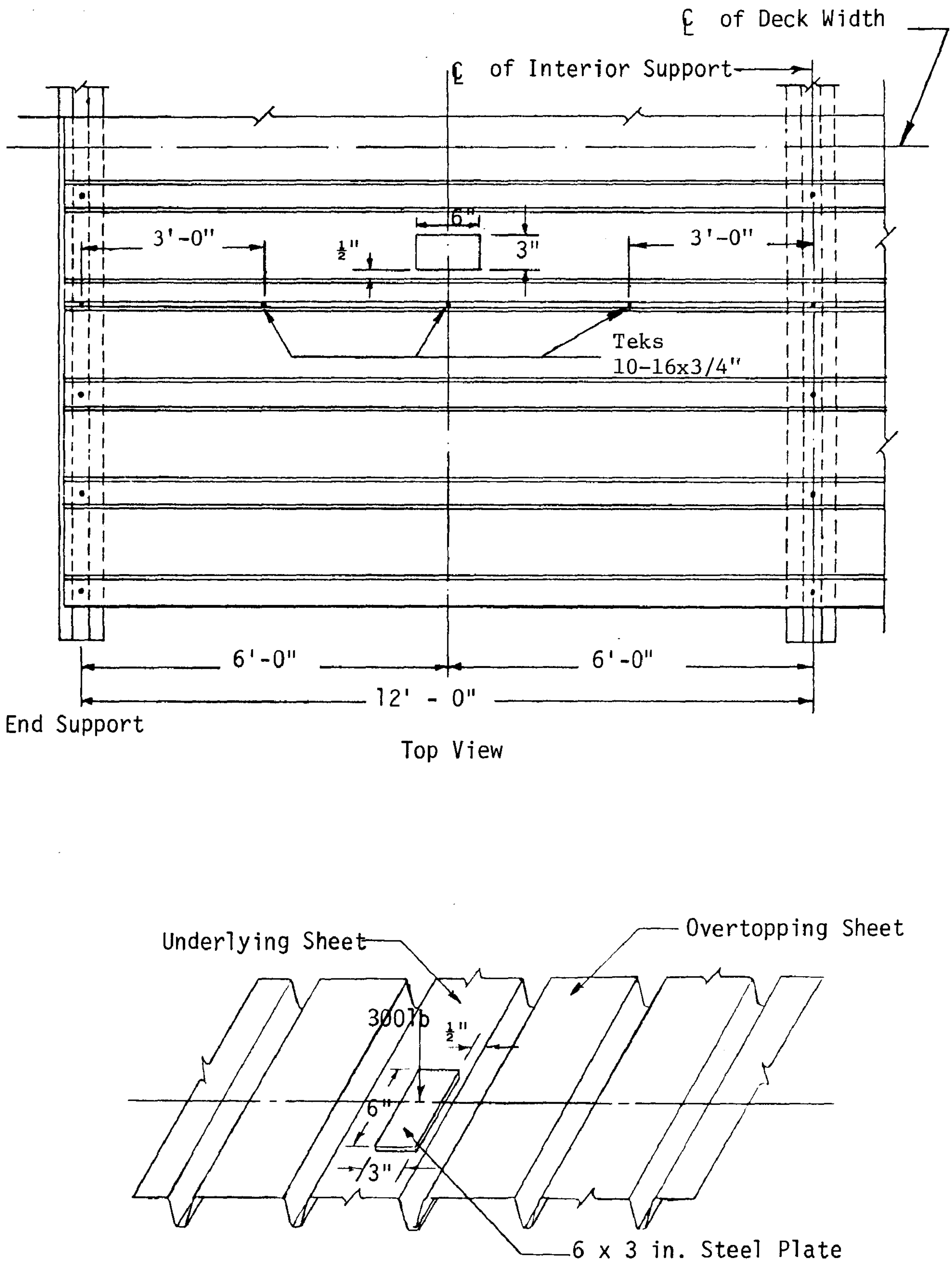
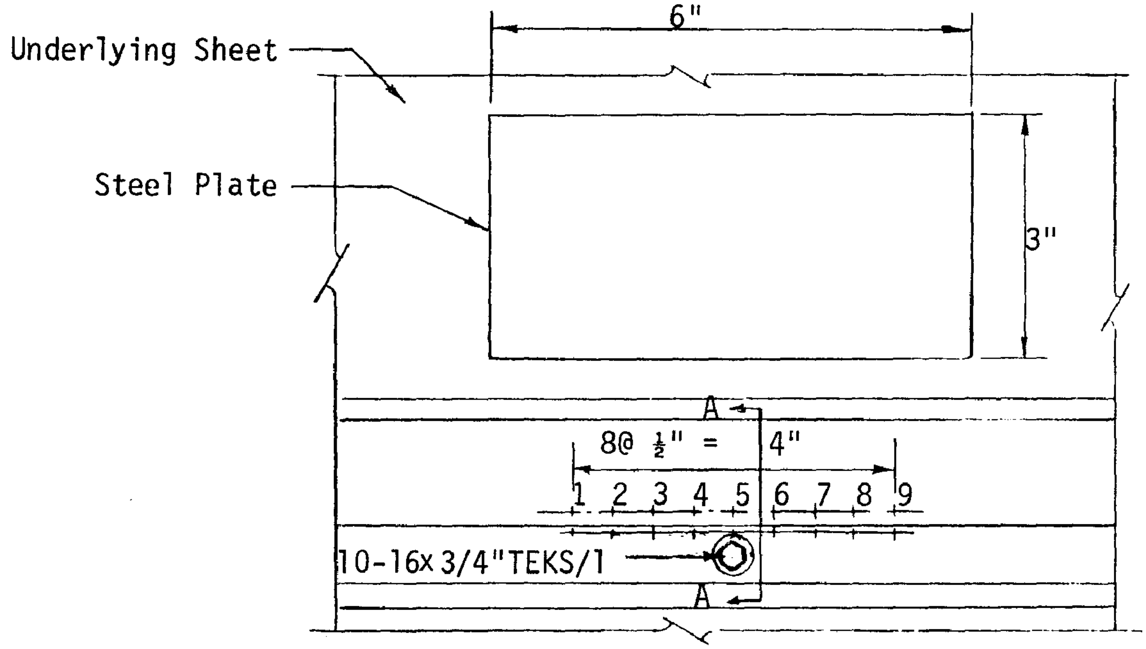
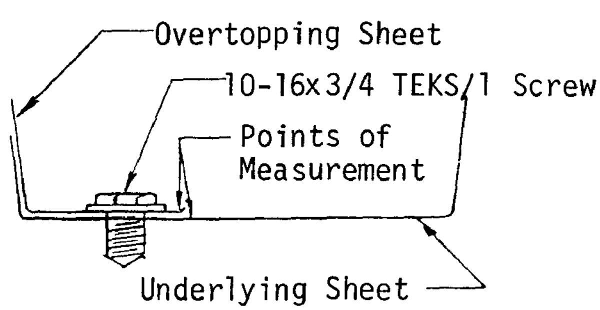


Fig. 8 Location of Loading Plate for Checking Side-Lap Securement



Top View



Section A-A

Fig. 9 Locations for Measuring Differential Deflections Between Adjacent Sheets

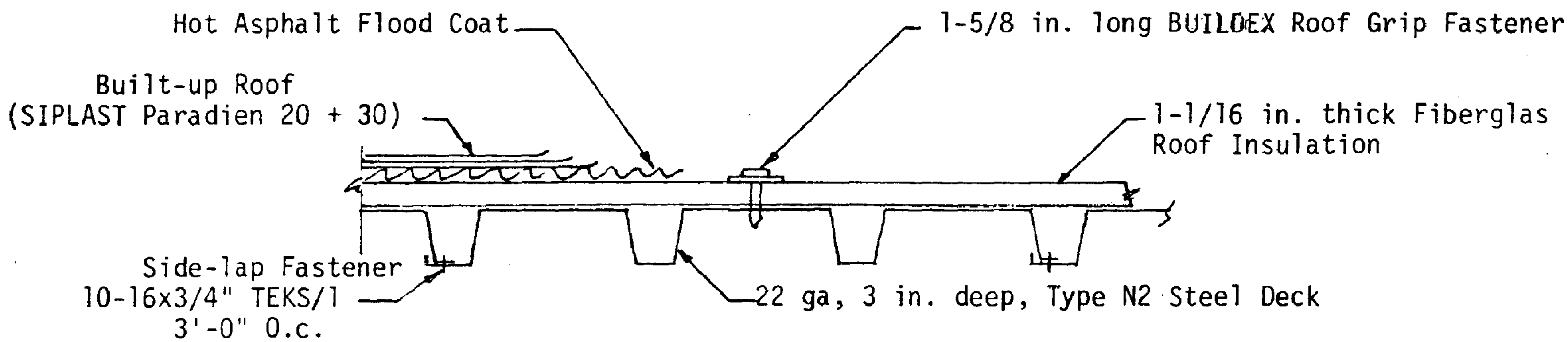
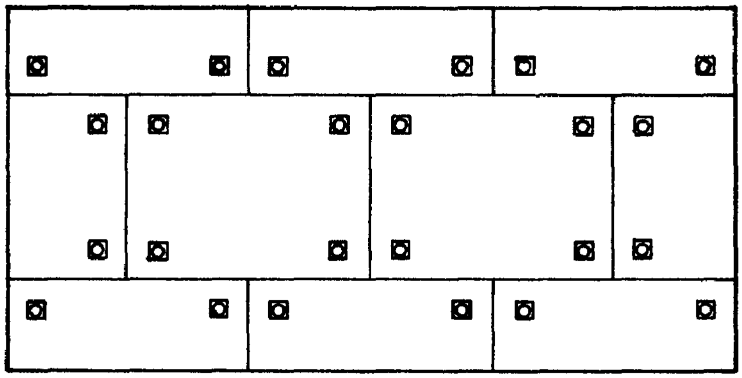
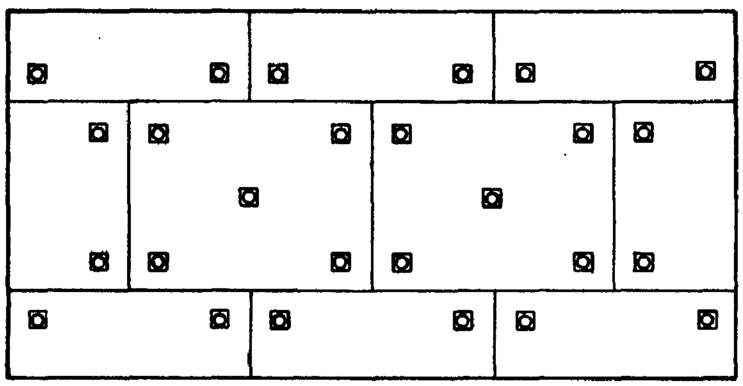


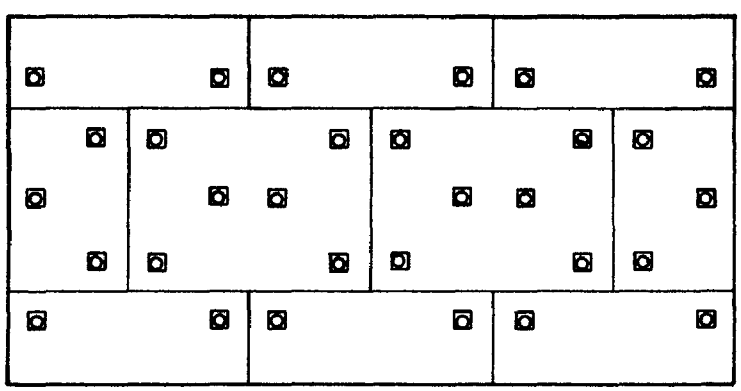
Fig. 10 Insulated Steel Deck Roof Construction



System No. 1



System No. 2 & 3



System No. 4

Fig. 11 Arrangements of Roof Grip Fasteners

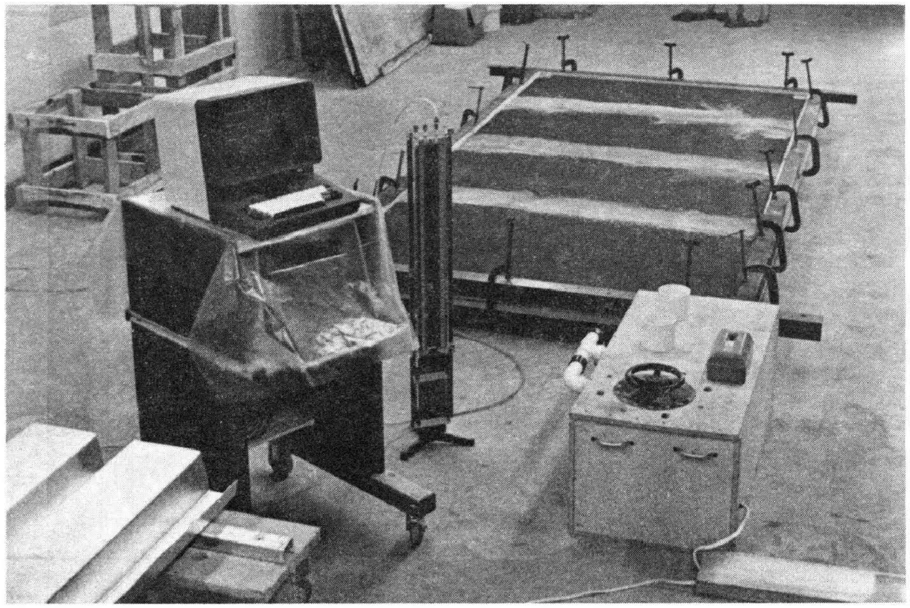


Fig. 12 Photograph Showing the Uplift Pressure Test Setup

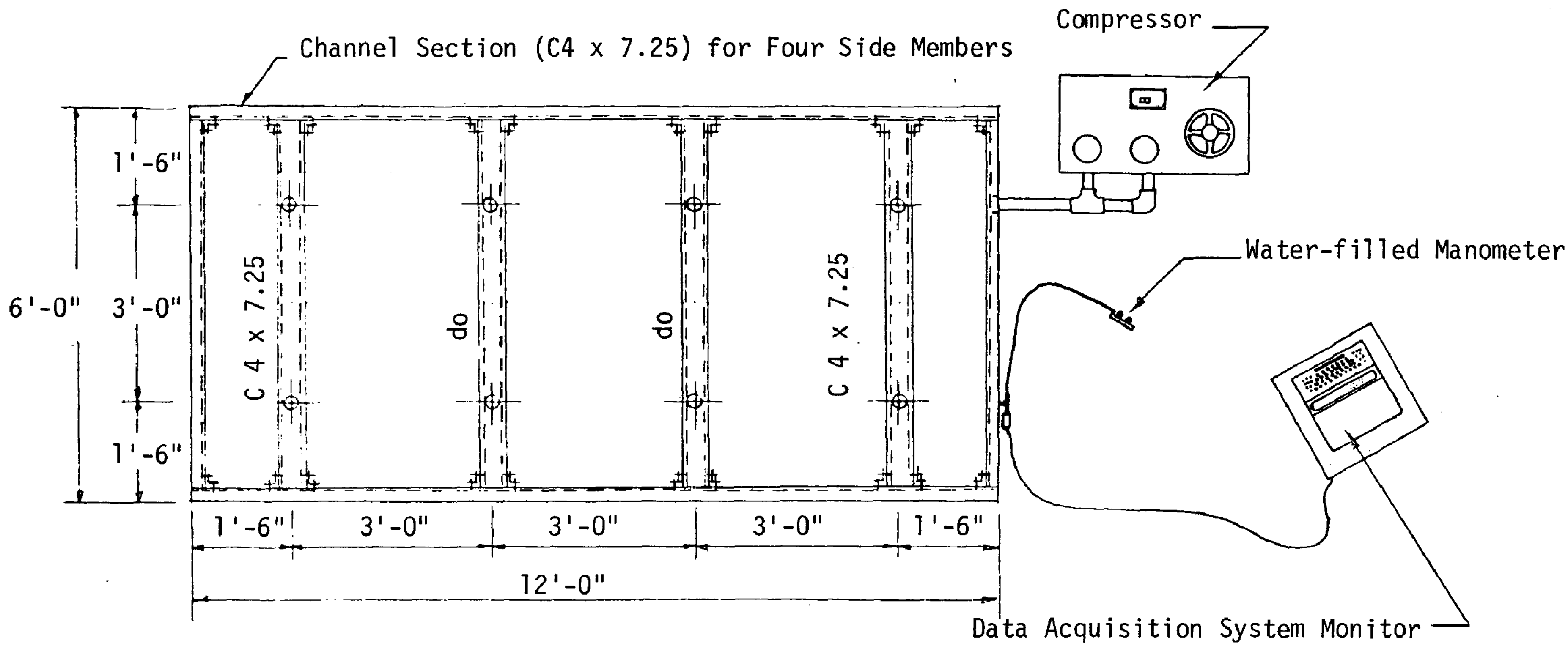


Fig. 13 Uplift Pressure Test Setup

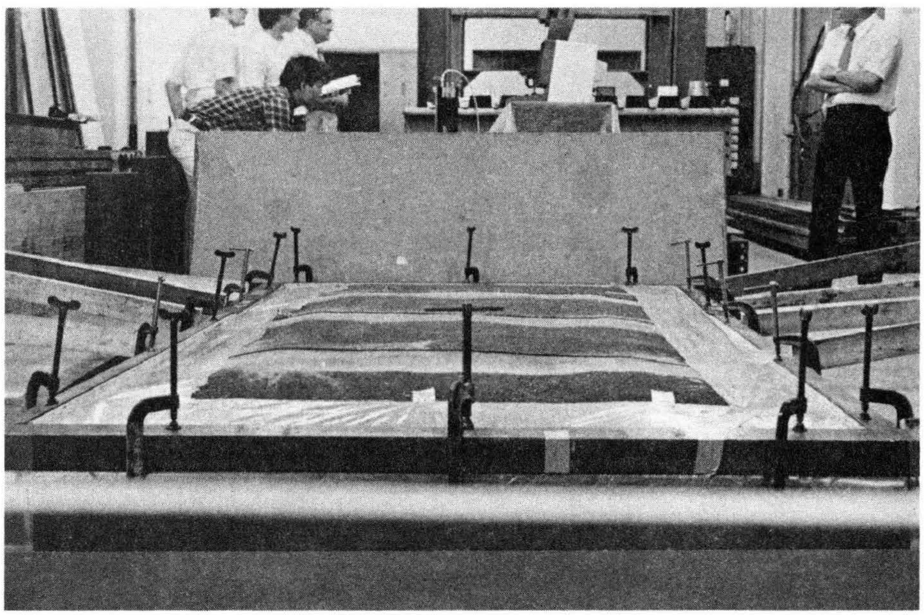


Fig. 14 Side Angles Supported by Lateral Braces

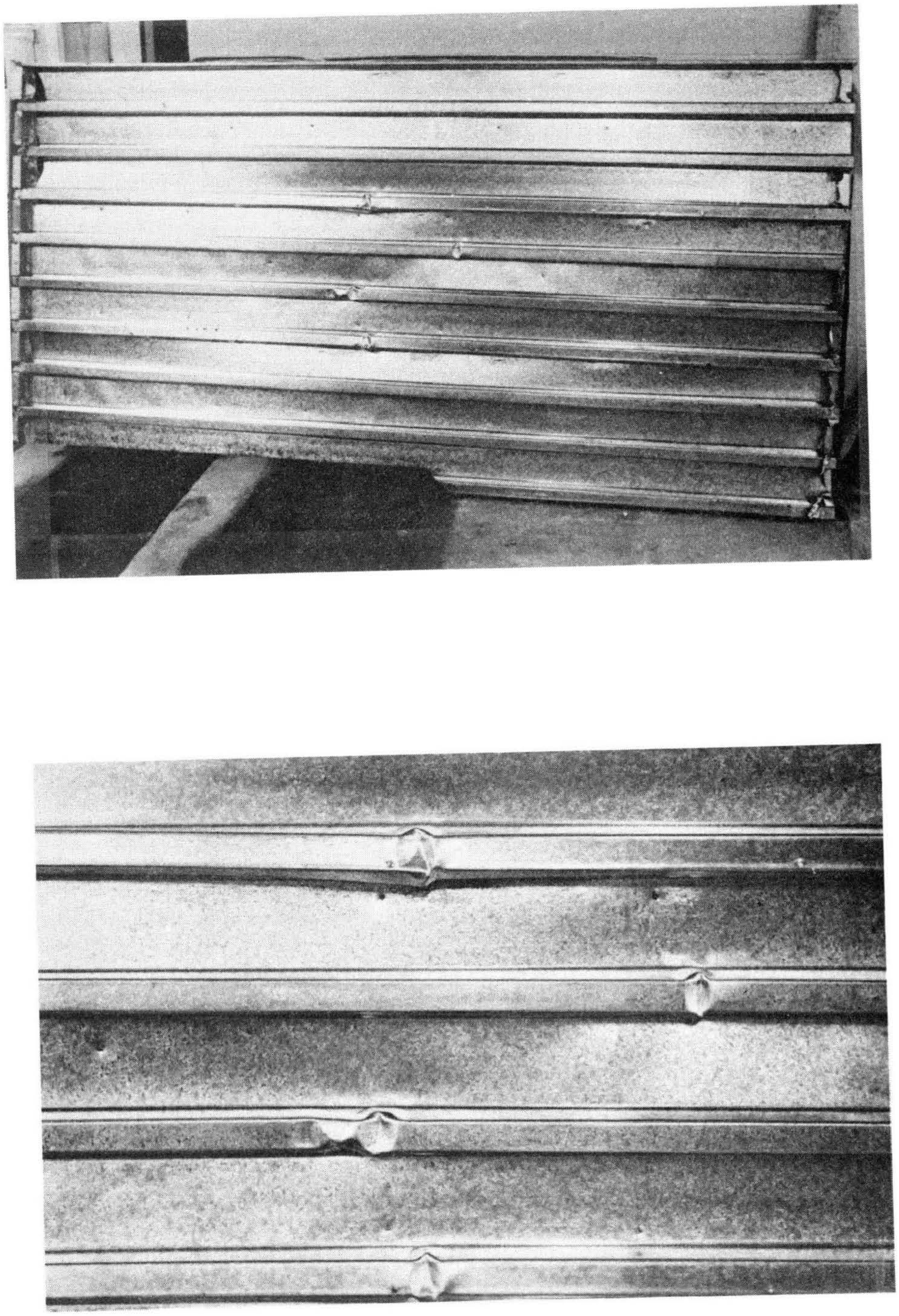
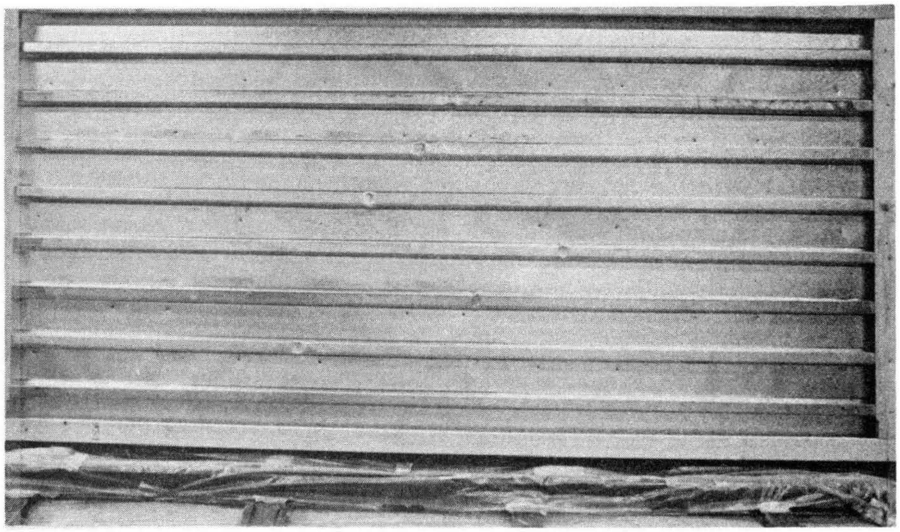


Fig. 15 Flexural Failure of System No. 3



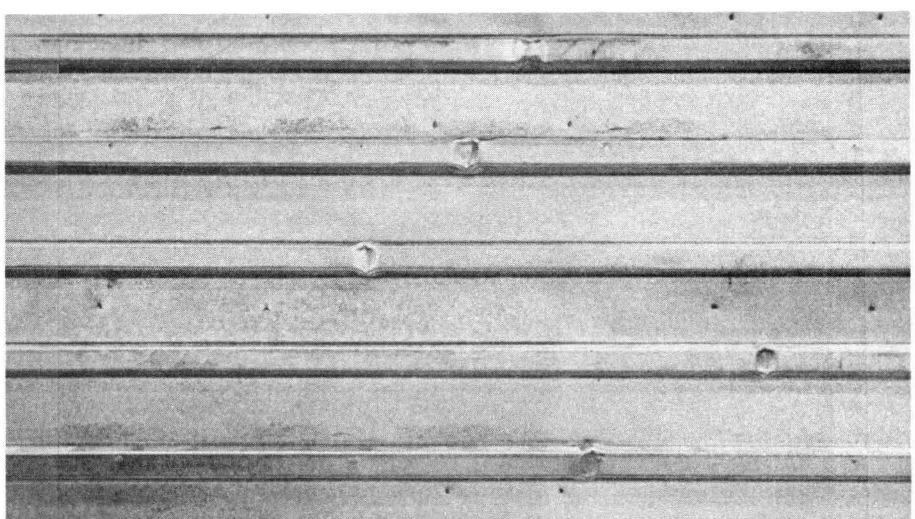


Fig. 16 Flexural Failure of System No. 4

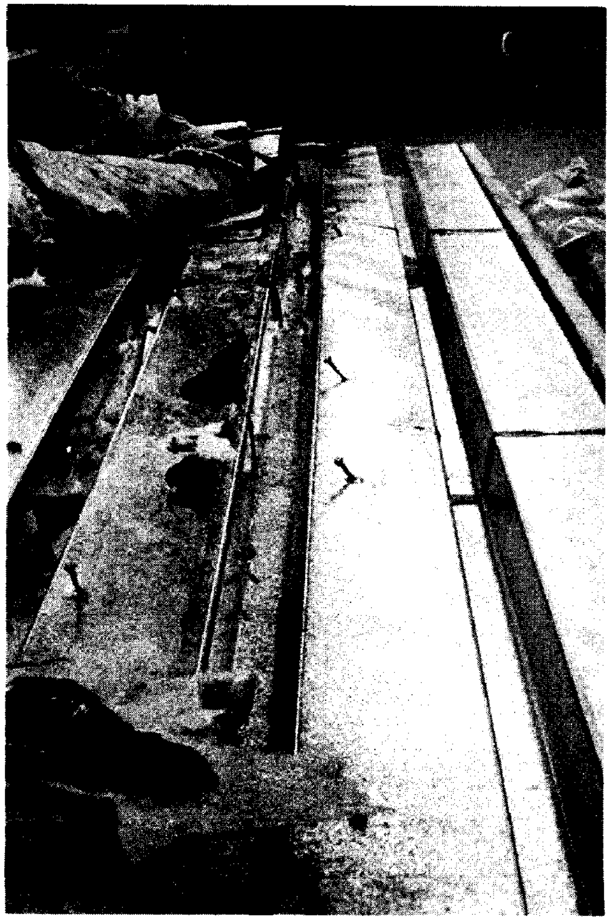


Fig. 17 Top View of Dismantled System No. 4

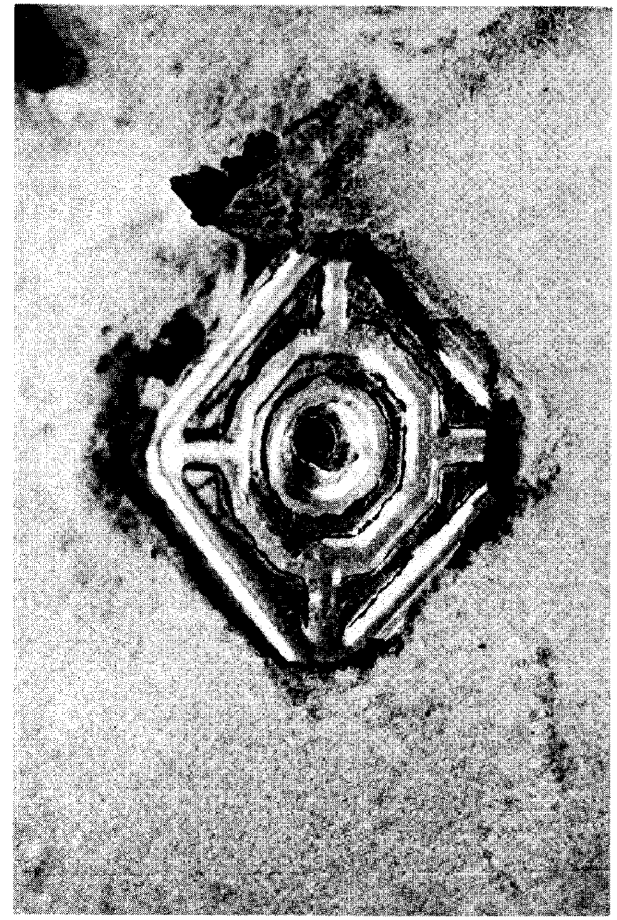


Fig. 18 Roofgrip Plate