Fatigue Experiments on Composite Slab Floors

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FATIGUE EXPERIMENTS ON COMPOSITE SLAB FLOORS

by

M. C. Temple[1] and G. Abdel-Sayed[2]

INTRODUCTION

Composite slabs consisting of cold-formed light-gauge steel sheets and normal or lightweight concrete have been used extensively under static loading conditions such as those encountered in office or residential buildings. This type of composite slab is generally not used in structures such as warehouses and bridges because of insufficient information with regard to their behaviour under heavy moving loads. Preliminary tests conducted at the University of Windsor indicated a favorable response when these composite slabs were subjected to repeated loadings (1). Thus further research was warranted.

This paper provides additional fatigue information obtained from testing composite slabs using steel sheets with different embossments and different shear lengths. Three types of cold-formed light-gauge metal sheets are shown in Fig. 1. The relationship between the ultimate load carrying capacity of the composite slabs under static load, the static bond failure load and the fatigue bond failure load were also examined.

PREVIOUS TESTS

Tests conducted on composite slabs subjected to repeated loads were reported by Mouw (3), Errera (2), as well as by the authors (1). Although these tests were limited in number, the results, in general, showed favorable

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response characteristics of the composite slabs when subjected to repeated loads. Fig. 2 shows typical load deflection curves for identical slabs made with steel sheet type No. 1 (see Fig. 1) loaded to failure with three different load histories which may be described as follows:

1. Curve No. 1 - a static test to failure

2. Curve No. 2 - a static test after the slab had been subjected to two million cycles of repeated loading. No dynamic bond failure occurred due to the repeated loading.

3. Curve No. 3 - a static test to failure of a specimen in which a dynamic bond failure had occurred after 3500 cycles of repeated loading.

These curves and the corresponding testing program lead to the following observations:

1. Several distinct features can be identified in the static test load-deflection curve (curve No. 1, Fig. 2). At a load of about 3 kips (13.4 kN) the concrete begins to crack. First slip, however, does not occur until a load of 4.8 kips (21.4 kN) has been reached. First slip, which may be attributed to a chemical bond failure, does not represent the collapse load of the composite slab. The mechanical bond, the result of mechanical interlocking between the concrete and the embossments and indentations in the steel sheets, allow the slab to carry a higher load equal to the ultimate capacity of the composite slab.

2. Repeated loading up to two million cycles at a load level below that required to cause first slip has no adverse effect on the performance or the ultimate capacity of the slab (curve No. 2, Fig. 2). In a static test a few cracks tend to predominate. In a static test after two million cycles of repeated loading many small cracks are formed. The same result could be

obtained from Ref. 2 in which the repeated load had a maximum magnitude of about 50 percent of the ultimate capacity of the slab.

3. When first slip occurs under repeated loading, continued repetition of the load tends to increase deflections and to widen the cracks. The composite slab can be considered to have failed under the repeated loading. If, however, the repeated loading is stopped and a static loading test is carried out the ultimate load carrying capacity of the slab is the same as that for the two loading cases previously discussed (see curve No. 3, Fig. 2).

Previous investigations involved only composite slabs made with steel sheets Types 1 and 2 shown in Fig. 1. In each case only one particular steel thickness, depth of concrete, and shear span were used. In this paper some of these parameters were varied. Steel sheet Type 3, Fig. 1, with two thicknesses (18 and 22 gauge, 0.0478 in. (1.214 mm) and 0.0299 in. (0.759 mm), respectively), was used in the tests. The shear span was varied for the composite slabs made from both thicknesses of steel sheets.

TEST SPECIMENS

A total of nineteen slabs were tested in this phase of the research. Of these seven were static tests and twelve were repeated loading tests. Seven tests (four static and three repeated loading) were conducted on eighteen gauge steel sheets. The other twelve tests (three static and nine repeated loading) were conducted on 22 gauge material. Table 1 lists all the tests and the results.

The steel sheets used in these tests were type 3 shown in Fig. 1. The cross sectional dimensions of the sheets are shown in Fig. 3. These sheets have very distinct embossments and indentations, characterized by sharp corners as opposed to bends of relatively large diameter.

High-early strength normal weight concrete was used. The 28-day strength ranged from about 3000 to 4000 psi (20.7 to 27.6 MN/m^2). The slab specimens were stripped, covered with burlap and kept moist for seven days, then air cured until tested. The concrete cylinders were immersed in a curing tank for seven days and then air cured.

The concrete was cast so that the total depth of the slab was five inches (12.7 cm). The slabs were 24 inches wide (61.0 cm) and six feet long (1.83 m). The steel protruded a few inches past the concrete at both ends.

Although in practice a wire mesh is used near the top surface of the concrete, none was used in these tests since the mesh would not have affected the results.

TEST PROCEDURE

Loading System. All slab specimens were simply supported over a span of 68 inches (1.73 m). The load was applied symmetrically about mid-span. Shear spans of 12, 18 and 24 inches (0.31, 0.46 and 0.61 m) were used. The loading arrangement is shown in Fig. 4. The steel sheet protruding beyond the concrete at each end of the slab was used to facilitate the placing of dial indicators used to measure the slip. The dial indicators can be seen in Fig. 4. (The specimen numbers in the photographs do not correspond to those in Table 1.) The load was applied by using an electrohydraulic testing machine with a capacity of 20,000 lb (89 kN).

Static Tests. Seven specimens were subjected to a static load up to the ultimate load carrying capacity of the slab. The load was applied in increments, normally 200 lb (890 N), until failure occurred. The deflection was measured at each load increment at mid-span by using two dial indicators, one on each side of the slab. The complete load-deflection data was recorded with special attention being paid to first slip and the ultimate load. Typical load-deflection curves are shown in Fig. 5(a) for 18 gauge steel sheets and shear spans of 12, 18 and 24 inches (0.31, 0.46 and 0.61 m). A load-end slip curve is shown in Fig. 5(b). A typical shear-bond type of failure is shown in Fig. 6.

Repeated Loads. A total of twelve tests were carried out with repeated loads. In all cases the slabs were first loaded statically, as in the static tests, until first slip occurred. As soon as first slip occurred the static testing was stopped. A repeated load was then applied at the rate of 4 c.p.s. (4 Hz). The variation of the repeated load was sinusoidal with the maximum load being 100 percent of the first slip load and the minimum 10 percent of the same load.

The repeated loading tests were carried out on a 24 h basis. A dual channel amplifier recorder was used to constantly record the load and deflection. The vertical deflection was measured by means of a linear variable differential transducer attached to the steel form. Thus the number of cycles at failure was easily determined.

Every 500,000 cycles the loading was stopped and the slab was statically loaded from zero load to the first slip load. At suitable load increments the deflection was recorded. Repeated loading was then resumed. This procedure was repeated until failure occurred or two million cycles was reached. Such a load-deflection curve is shown in Fig. 7. The load-deflection curve for the slab loaded statically to failure after two million cycles of repeated loading is shown in the same Figure.

OBSERVATIONS

1. The static load-deflection curves (Fig. 5a) indicate that for this particular type of sheet first slip occurred at 50 to 60 percent of the

ultimate load carrying capacity of the composite slab system. The increase in deflection associated with this slip is much smaller for the steel deck type No. 3 than for the steel deck type No. 1. The types of steel decks are shown in Fig. 1, while a comparison of the deflections at first slip can be made from Figs. 2 and 5a.

2. The repeated load was applied sinusoidally with a magnitude that varied from 10 to 100 percent of the first slip load. In spite of the fact that the slab was cracked when the repeated loading was applied, only four of twelve specimens subjected to repeated loading failed in less than two million cycles. One failed by a dynamic bond failure, and three by a fatigue failure of the steel sheet. This is in sharp constrast to steel deck No. 1 which, after first slip had occurred, could not, for any practical purposes, sustain a repeated load at the level of first slip load.

3. A static load test following two million cycles of repeated load at the level of first slip showed that the ultimate load carrying capacity of the slab is slightly reduced when compared to the ultimate load obtained from a straight static test. This is observed from Table 1 by comparing test results for specimens 6 and 7, 12 and 14, and 16 and 17. This result is different from that observed for steel deck No. 1 for which the ultimate load does not change when the load is repeated at a level below the load at first slip (Fig. 2). The explanation for this is that the chemical bond is not affected by repeated loads at load level below that required to cause first slip. After the first slip occurs, the chemical bond is broken and the shear has to be transmitted by bearing of the concrete against the steel deck embossments and indentations. This type of mechanical interlocking is affected by the repeated loading.

4. Three of four slabs tested with a shear span of 24 inches (0.61 m) failed due to a fatigue failure of the sheets. The maximum stresses calculated in the steel sheets that failed due to a fatigue type failure ranged from 25800 to 27700 psi (178 to 191 MN/m^2). The embossments in the steel sheet No. 3 were very distinct with sharp, as opposed to rounded, corners. This undoubtedly contributed to the fatigue failure of the steel sheets since the failure line always followed a row of the embossments (Figs. 8(a) and 8(b)).

5. The fourth slab subjected to a repeated loading and a 24 inch (0.61 m) shear span went two million cycles without failure (specimen No. 10, Table 1). This can be attributed to the low load at first slip (5600 lb., (25 kN)). Identical slabs (specimens No. 8, 9 and 11) had a first slip load of 7200 lb (32 kN) or greater. This indicates that the slip load of 5600 lb (25 kN) for specimen No. 10 was unusually low. This could also explain why the ultimate load carrying capacity of the slab was not reduced after two million cycles of loading (Table 1).

6. All of the 18 inch (0.46 m) shear span slabs were subjected to two million cycles of loading without any type of dynamic failure occurring.

7. Three of the four 12 inch (0.31 m) shear span specimens went two million cycles without failure. The fourth specimen failed at 7500 cycles and was a shear-bond type of failure.

CONCLUSIONS

1. The response of composite slabs made from sheets type No. 3 when subjected to repeated loading was good. This is particularly true of the shorter shear spans, 12 and 18 inches (0.31 and 0.46 m). Eight of the twelve composite slabs subjected to repeated loading underwent two million cycles of loading without any dynamic type of failure occurring.

2. For the longer shear span, 24 inches (0.61 m), three of four specimens tested failed by a fatigue failure of the steel sheet.

Thus special attention should be paid to cases in which the tensile stresses in the steel sheet are relatively high. A long shear span results in a large moment and hence high tensile stresses. The behaviour of the steel sheet when subjected to repeated loading should be checked since the type of embossments and indentations could have a significant effect on the behaviour of the composite slab.

ACKNOWLEDGEMENTS

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Appendix - References

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2. Errera, S.J., "Lateral Load Distribution and Fatigue Tests of Composite Q-Lock Deck," unpublished report to H.H. Robertson Company, Ambridge, Pennsylvania, May 1968.

3. Mouw, Kenneth W., "Fatigue Testing of Light Gage Metal Forms," Engrg. Research Institute, Iowa State University, Ames, Iowa, January 1969, ERI-348, Project 741.

TABLE 1. TEST RESULTS

Specimen Number	Gauge of Steel Sheet	Type of Test	Shear Span (in.)	Concrete Cylinder Strength (ksi)	Load at First Slip (kips)	Ultimate Load (kips)	Type of Failure
1	18	Static	24	2.9	10200	19200	Shear-Bond
2	18	Repeated Loading 1,803,000 cycles	24	3.9	11400	N.A.	Fatigue Failure of Steel Sheet
3	18	Static	18	3.4	10400	19600	Shear-Bond
4	18	Repeated Loading 2,000,000 cycles	18	3.8	12600	20600	Shear-Bond
5	18	Static	12	3.7	14000	23000	Shear-Bond
6	18	Repeated Loading 2,000,000 cycles	12	3.6	15800	22400	Shear-Bond
7	18	Static	12	3.5	15600	26400	Shear-Bond
8	22	Static	24	4.1	7200	12200	Shear-Bond
9	22	Repeated Loading 413,000 cycles	24	4.1	7600	N.A.	Fatigue Failure of Steel Sheet
10	22	Repeated Loading 2,000,000 cycles	24	4.2	5600	12000	Shear-Bond

TABLE 1. (Concluded)

Specimen Number	Gauge of Steel Sheet	Type of Test	Shear Span (in.)	Concrete Cylinder Strength (ksi)	Load at First Slip (kips)	Ultimate Load (kips)	Type of Failure
11	22	Repeated Loading 743,000 cycles	24	4.3	7200	N.A.	Fatigue Failure of Steel Sheet
12	22	Static	12	3.7	12000	18500	Shear-Bond
13	22	Repeated Loading 7500 cycles	12	3.7	14200	N.A.	Dynamic Shear-Bond Failure
14	22	Repeated Loading 2,000,000 cycles	12	-	12200	15500	Shear-Bond
15	22	Repeated Loading 2,000,000 cycles	12	3.7	13800	19400	Shear-Bond
16	22	Static	18	3.5	7500	14500	Shear-Bond
17	22	Repeated Loading 2,000,000 cycles	18	-	9500	12500	Shear-Bond
18	22	Repeated Loading 2,000,000 cycles	18	-	9800	13000	Shear-Bond
19	22	Repeated Loading 2,000,000 cycles	18	-	9600	12500	Shear-Bond

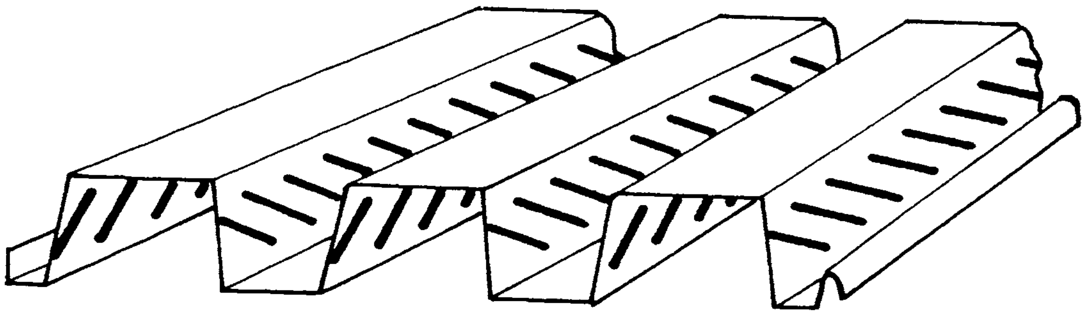
NOTE: The tabulated values in the tables may be converted to SI equivalents as noted below:

1 in. = 2.54 cm.

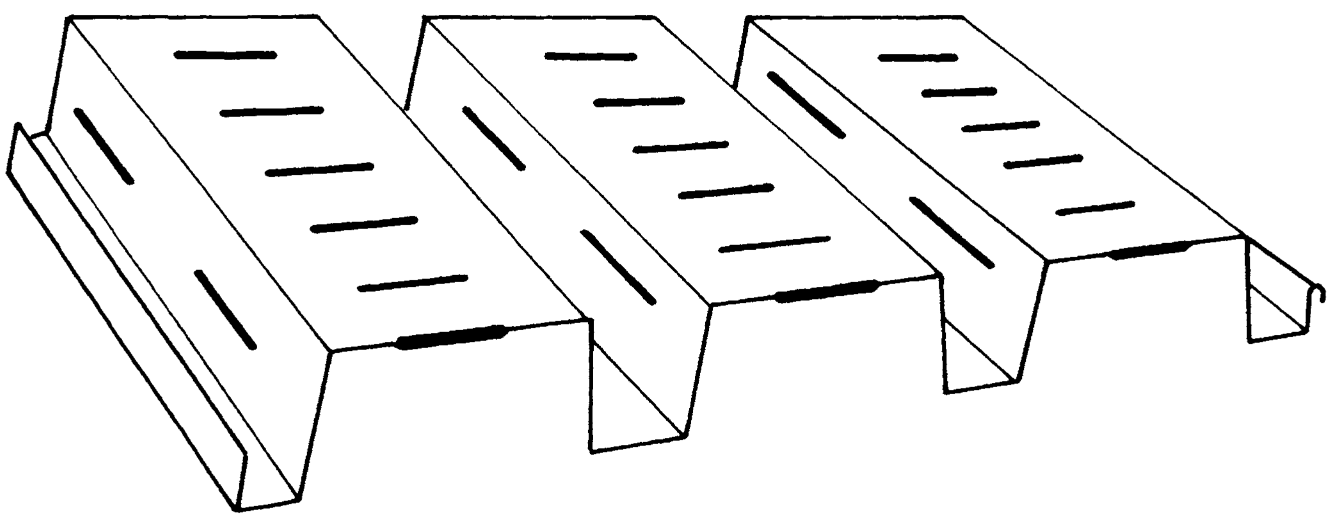
1 k.s.i. = 6.9 MN/m^2.

1 kip = 4.45 kN.

LIST OF FIGURES

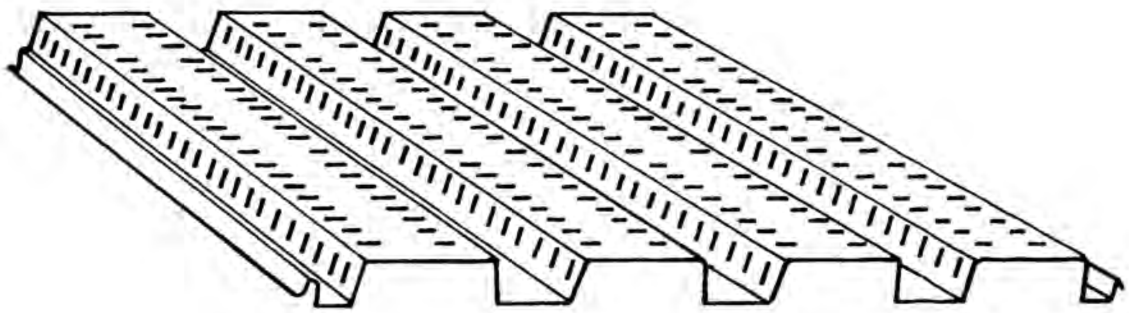


STEEL SHEET TYPE NO. 1



STEEL SHEET TYPE NO. 2

Fig. 1



STEEL SHEET TYPE NO. 3

Fig. 1 (cont'd)

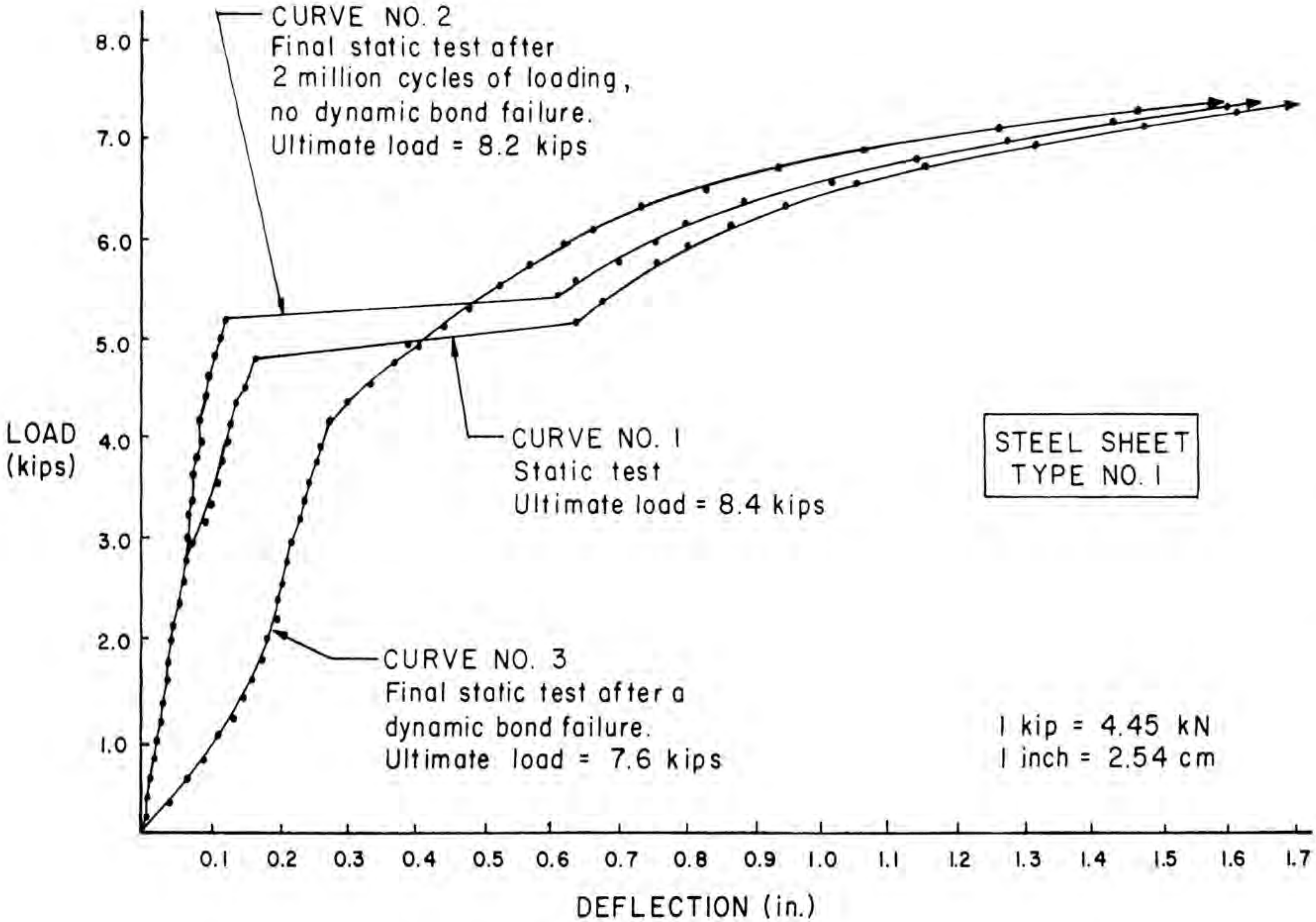

CURVE NO. 2
Final static test after
2 million cycles of loading,
no dynamic bond failure.
Ultimate load = 8.2 kips
CURVE NO. 1
Static test
Ultimate load = 8.4 kips
CURVE NO. 3
Final static test after a
dynamic bond failure.
Ultimate load = 7.6 kips
STEEL SHEET
TYPE NO. 1
1 kip = 4.45 kN
1 inch = 2.54 cm
LOAD
(kips)
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
DEFLECTION (in.)

Fig. 2

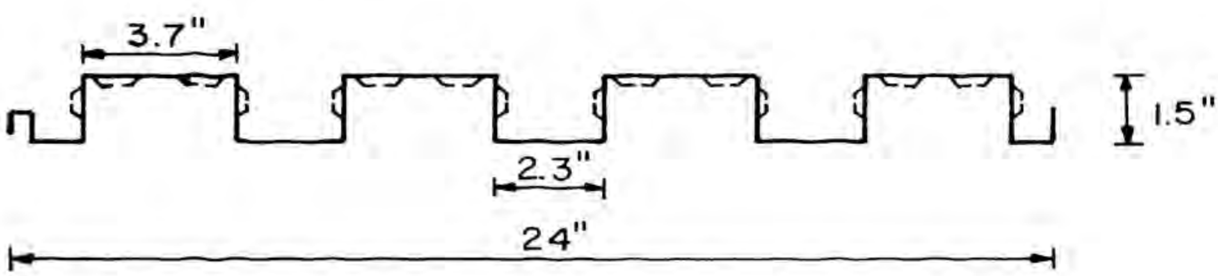


Fig. 3

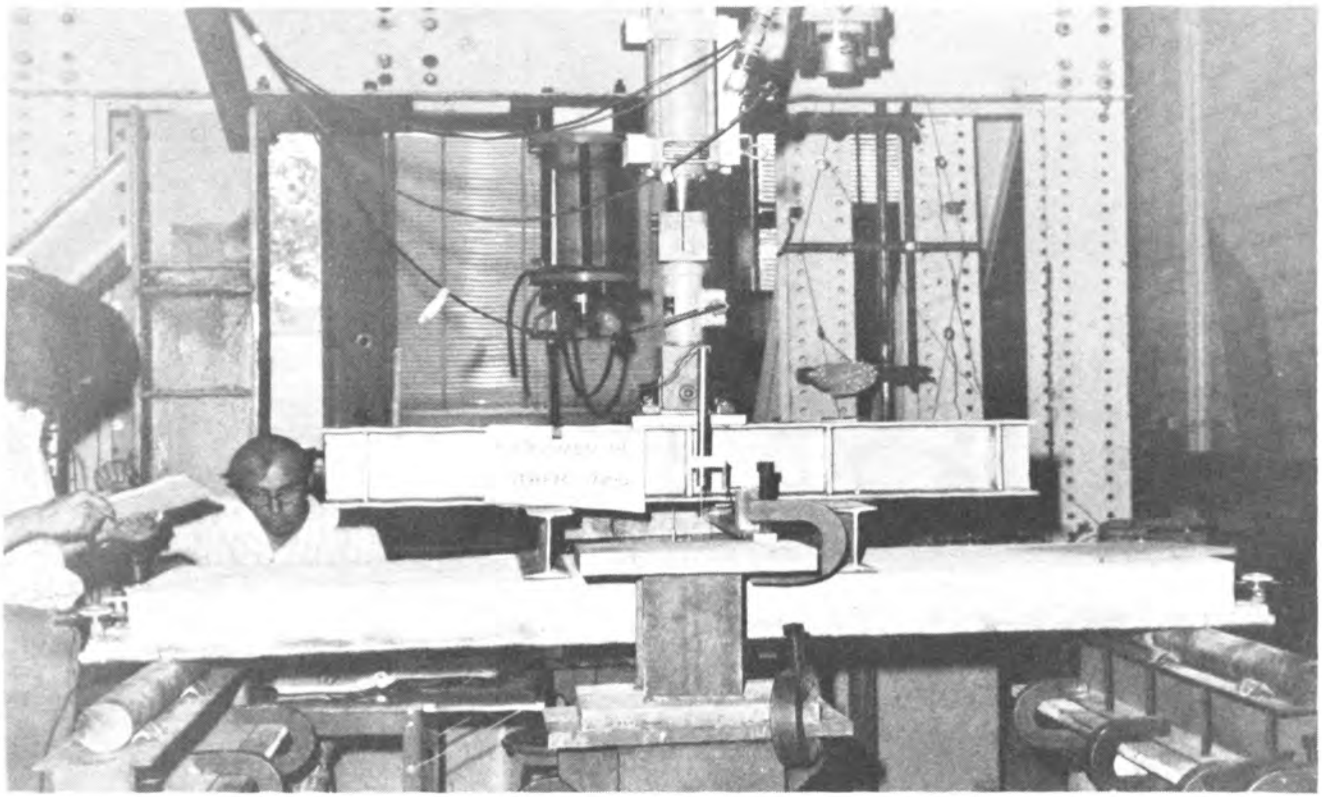


Fig. 4

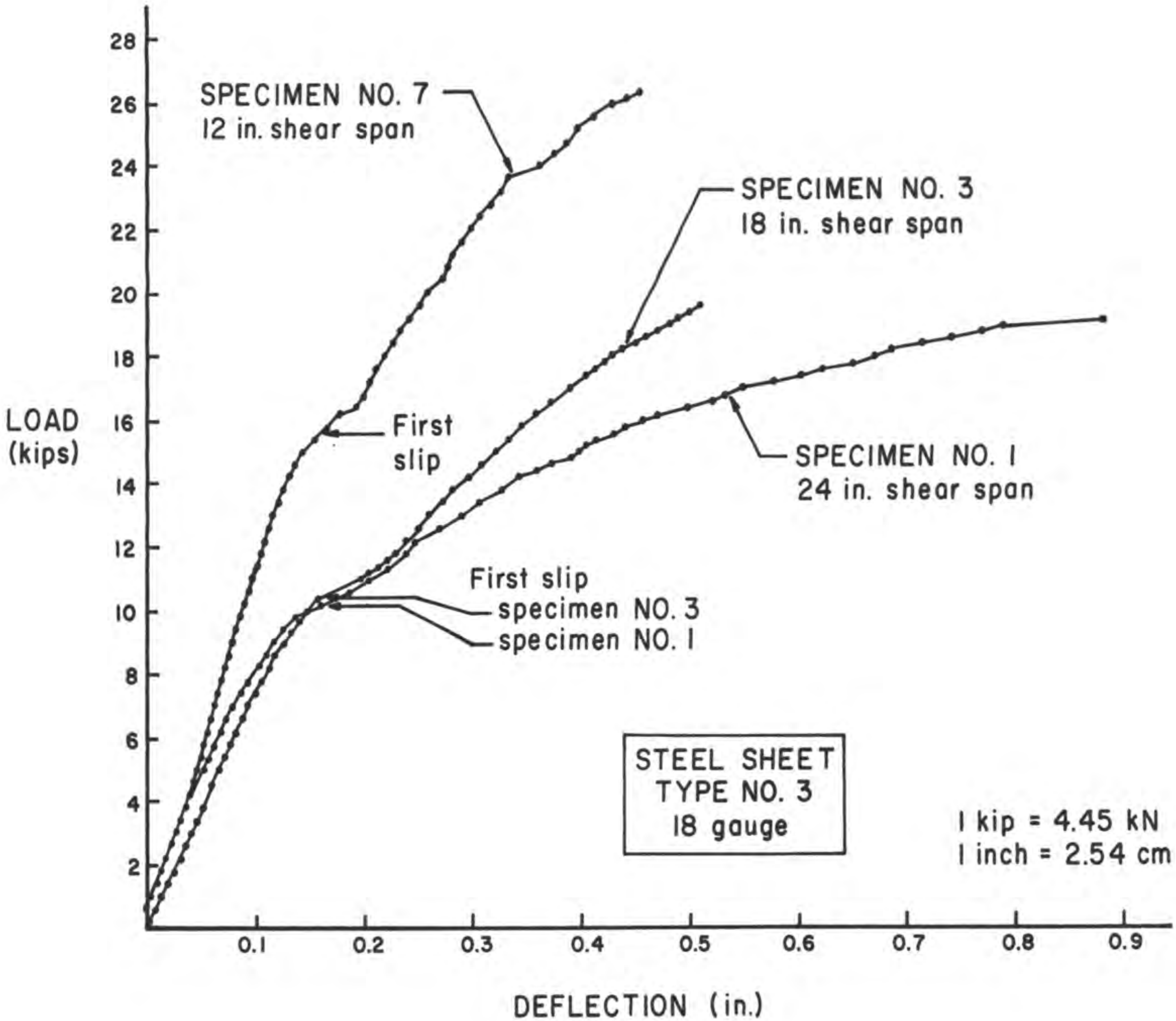
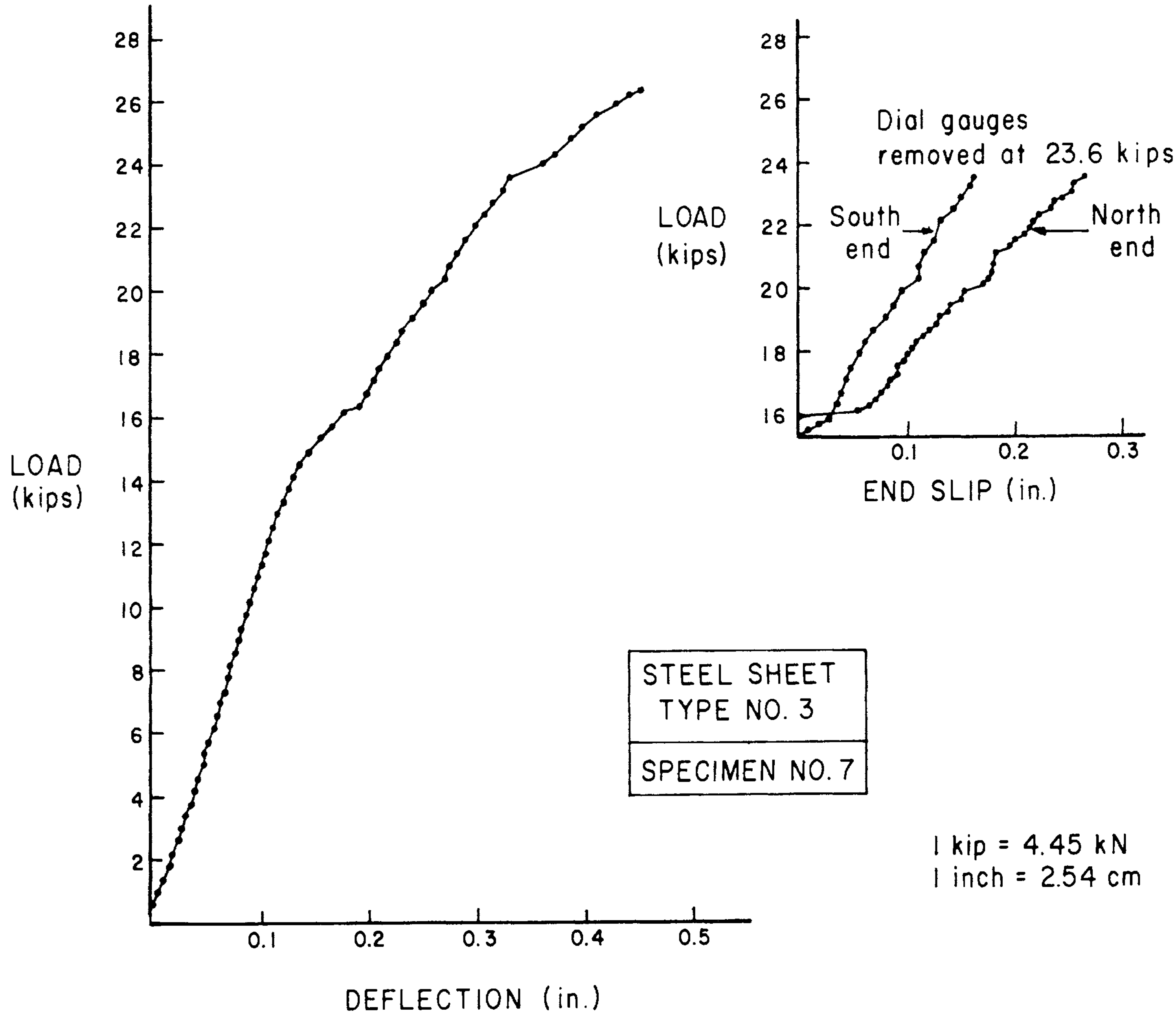

SPECIMEN NO. 7
12 in. shear span
SPECIMEN NO. 3
18 in. shear span
SPECIMEN NO. 1
24 in. shear span
First slip
First slip
specimen NO. 3
specimen NO. 1
LOAD (kips)
DEFLECTION (in.)
STEEL SHEET TYPE NO. 3 18 gauge
1 kip = 4.45 kN
1 inch = 2.54 cm
0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9
2 4 6 8 10 12 14 16 18 20 22 24 26 28

Fig. 5a



LOAD (kips)
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0.1
0.2
0.3
0.4
0.5
DEFLECTION (in.)
LOAD (kips)
Dial gauges removed at 23.6 kips
South end
North end
END SLIP (in.)
STEEL SHEET TYPE NO. 3
SPECIMEN NO. 7
1 kip = 4.45 kN
1 inch = 2.54 cm

Fig. 5b

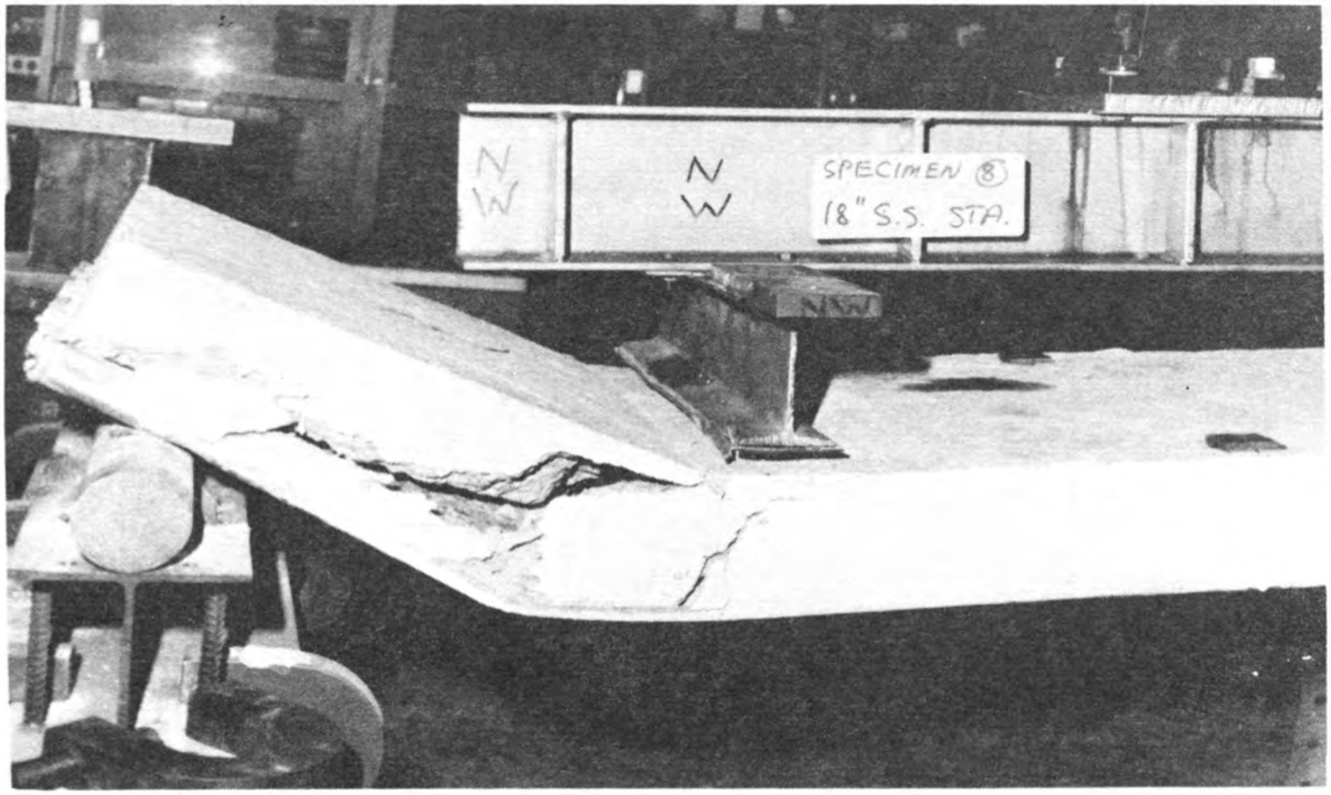


Fig. 6

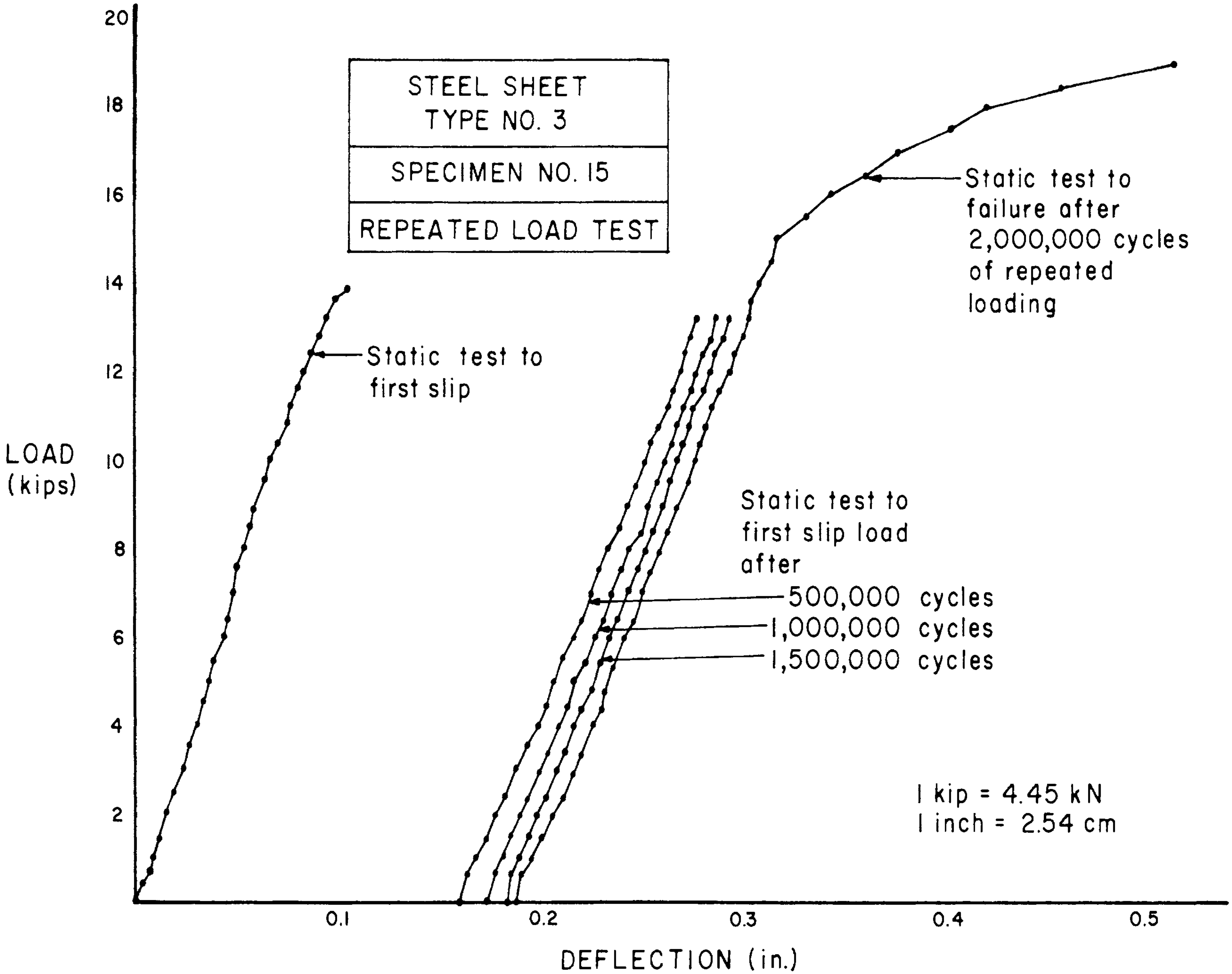

STEEL SHEET
TYPE NO. 3
SPECIMEN NO. 15
REPEATED LOAD TEST
Static test to failure after 2,000,000 cycles of repeated loading
Static test to first slip
Static test to first slip load after
500,000 cycles
1,000,000 cycles
1,500,000 cycles
1 kip = 4.45 kN
1 inch = 2.54 cm
LOAD (kips)
20
18
16
14
12
10
8
6
4
2
0.1
0.2
0.3
0.4
0.5
DEFLECTION (in.)

Fig. 7

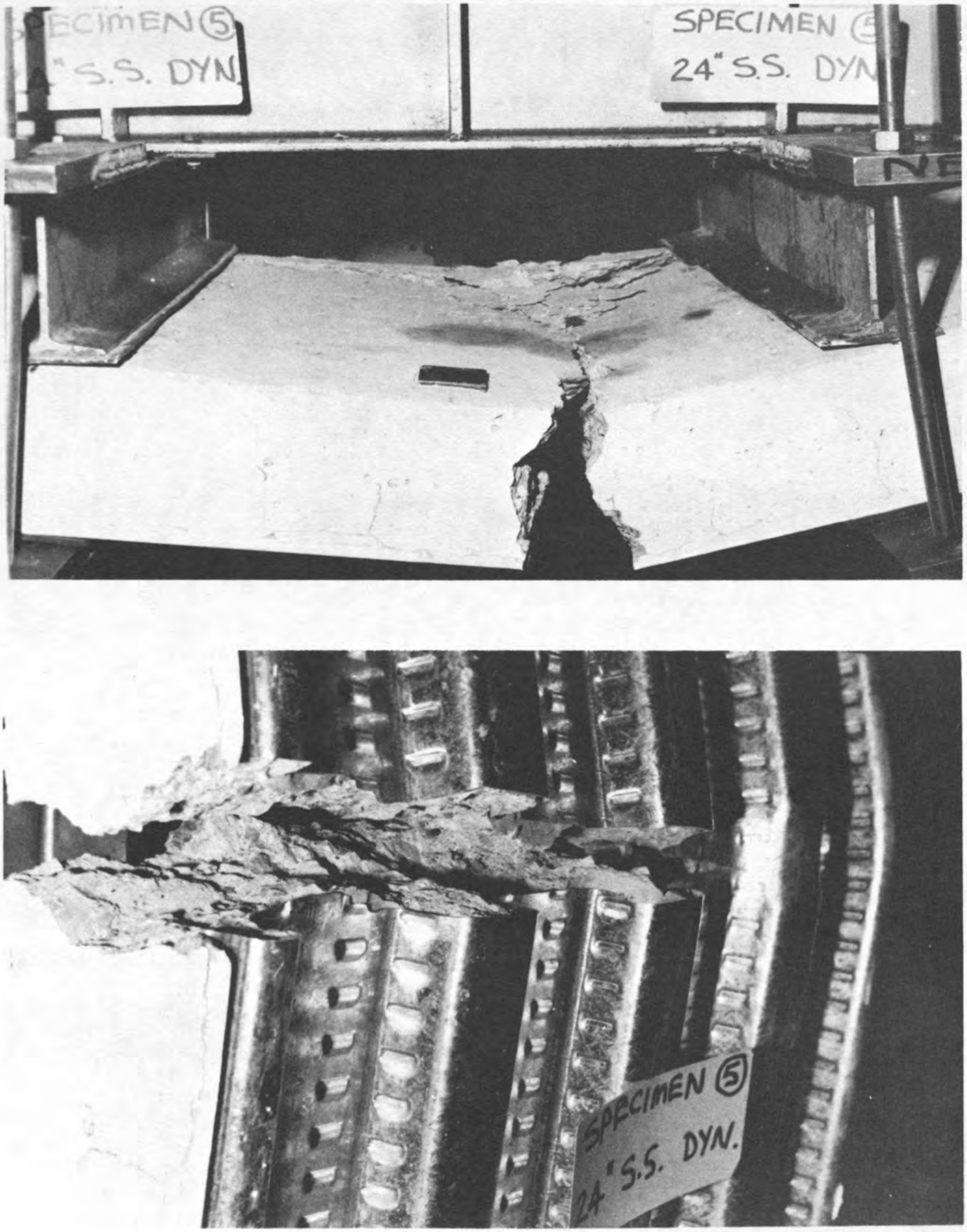


Fig. 8