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BEHAVIOR OF LIGHT GAGE DIAPHRAGMS COUPLED WITH X-BRACING

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Introduction

An experimental program was conducted to determine the behavior of a coupled system of cross bracing and light gage steel diaphragms in resisting lateral forces. The program was specifically conducted to determine if such systems would "work" together, and if so, could the load sharing and ultimate strength behavior be predicted analytically. Three sets of tests using different size tie rods (3/8", 1/2", 5/8") and the same gage diaphragm were conducted. Each set consisted of two tests using the same size rod, but pre-tensioned to different levels (5% and 20% of the bar yield strength). Since normal field installations would result in different preloaded situations, it was imperative to know if this would affect the behavior.

It was felt that the coupled system could result in economic savings in a number of ways. These would include the use of smaller tie rods or lighter gage steel in the panels of these coupled systems.

Description of Tests

The cantilever test frame method (Figure 1) as prescribed by the American Iron and Steel Institute* for testing light gage steel diaphragms was used throughout the test program. The test panel was 10.0 feet in length by 12.0 feet in width. The frame was constructed using 6 x 6 x 5/16 angles. All corner connections were pinned to provide minimum resistance

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* "Design of Light Gage Steel Diaphragms", American Iron and Steel Institute.

of the bare frame to deformation. The frame was secured at corner (D) to prevent lateral movement. A roller was provided at corner (C). Rollers were also placed under the frame to reduce friction forces between the test frame and the structural test floor on which it was resting.

The test specimens were constructed by first bolting .07 inch thick base angles to the frame along lines A-B and C-D. A center girt was connected to the frame using bolted clip angle connections. The tie rod was then placed between points D and B and tightened to its prescribed preload. The panels were then positioned on the frame. Panel-to-panel connections were made on 30 inch centers, and panel-to-structural connections on 6 inch centers. All connections were made using rivet-type fasteners.

In all six tests 24 gage galvanized cold rolled panels were used in combination with the three different tie rods. The load deflection curve for the panel is shown in Figure 2. The rods have rolled threads and the nominal size was based on the root diameter. The 3/8" and 1/2" rods were cold drawn and had body diameters of 0.331 inches and 0.435 inches. The 5/8" rod was hot rolled and had a shaft diameter of 0.544 inches. The physical properties of the rods are shown in Table 1.

The rods were welded to 3/8" x 14" x 3" steel plates with a punched hole, so that a pinned connection could be made into the pinned joints at corners B and D of the test frame, Figure 1.

The load was applied using a hydraulic jack. The loads were measured using a load cell which was connected to a digital voltmeter. The strains in the tie bars were obtained from two foil type strain gages mounted diametrically from one another on the rod. Loads were applied in 200 pound increments from zero to 1000 pounds and in 500 pound increments from 1000 pounds to failure. Strains and deflections were recorded after each load increment.

Test Results

The load deflection curves for the six tests are shown in Figures 2 through 4. The ultimate load and maximum deflection for the six tests are shown in Table 2.

- Ultimate Strength

Comparing the ultimate loads obtained for equal size tie rods, it appears that the greater preload reduces the ultimate capacity for the 3/8" and 1/2" tie rods. This result is due to the fact that these rods do not have a strain hardening capability. In each of these cases, the specimens failed in the root of the threads at the turnbuckle location. The stress concentration at that point and the lack of strain hardening caused a relatively brittle type behavior at failure. The stress in the rods at the gage location was only 88,000 psi and 84,000 psi respectively at failure. Thus away from the stress concentration area neither of the bars yielded prior to failure. The hot rolled 5/8 inch bars behaved quite differently. The preload did not appear to effect the ultimate strength. In fact the 5/8 inch bars were never failed. The system simply kept on deforming. The tests were finally discontinued at a deflection of 5 inches. The strains in the tie rods were well into the plastic region at that time. Thus, for bar exhibiting strain hardening characteristics, one can calculate the ultimate strength quite easily. The capacity of the tie rod can be computed and its proper force component added to the ultimate capacity of the diaphragm. This can be done since both have compatible load deflection curves. This procedure is analogous to finding the ultimate moment capacity of a structural column assemblage knowing the M-θ relationships for the columns entering the joint.

For the cold drawn rods the ultimate strength cannot be predicted unless the complete load-deformation characteristics of the bar is known. That is, if the nominal strain in the rod is known at failure (failure occurring in the thread root) the deformation at failure of the bar could then be determined. The capacity of the diaphragm could then be determined for this deformation by using the load-deformation curve for the diaphragm. The two capacities could then be added to obtain the ultimate capacity.

- Stiffness Behavior

Shown in Tables 3 to 8 are the load distribution results obtained from the tests. The results are tabulated only for the elastic portion of each test. Shown in the second column are the experimentally obtained forces (horizontal component) for the rods. The predicted forces in the rods are shown in column four. These forces were calculated by a simple stiffness analysis of the system, i.e., knowing the stiffnesses of the panels and bars the force is distributed. The portion of the load in the panel is shown in column three. Generally, at all load levels the percent error as shown in column five was less than 15 per cent. Test number two gave erroneous results. One of the gages was damaged during construction of the panel assembly, thus, the bending effects could not be eliminated. The stiffness ratios (bar to panel) were 1.7, 3.0, and 4.7 for the 3/8", 1/2" and 5/8" bars. Many metal diaphragms have shear stiffnesses in excess of 5000 pounds per inch and thus better load sharing capabilities could be expected.

Conclusions

It is assumed in conclusions 1 and 2 listed below that the load-deformation curve for the light gage diaphragm has been previously determined.

1. The distribution of applied shear load between metal diaphragms and the tie rod braces can be analytically determined with sufficient accuracy for design purposes.

2. An ultimate strength design approach of coupled diaphragm X-braced systems can be used for systems using hot rolled tie bars. The ultimate strength for these systems can be accurately predicted. However, for systems using cold drawn tie bars an elastic design procedure would be necessary since the ultimate strength of such systems is not easily predicted.

3. Initial tightness of tie bars between 0 and 20% of the bar yield load does not affect load distribution in systems using either hot rolled or cold drawn ties. Greater preload does appear to detrimentally affect the ultimate strength of the coupled system using cold drawn bars. This same detrimental affect would, however, be expected in uncoupled systems, i.e., simple tie rod action.

Acknowledgements

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BAR TYPE	YIELD STRESS (KSI)	TENSILE STRENGTH (KSI)	PERCENT ELONGATION
3/8" ϕ	102.75	103.00	6.9
1/2" ϕ	94.00	95.00	7.1
5/8" ϕ	46.35	78.00	22

Table 1. Physical Test Results of the Rod Steels.

TEST	ULTIMATE LOAD POUNDS	MAXIMUM DEFLECTION INCHES
3/8" ϕ Rod 5% Preload	8,480	0.800
3/8" ϕ Rod 20% Preload	7,000	0.860
1/2" ϕ Road 5% Preload	11,500	0.750
1/2" ϕ Road 20% Preload	10,200	0.697
5/8" Road 5% Preload	14,000	Test Discontinued at 5.00" Displacement
5/8" Rod 20% Preload	14,500	Test Discontinued at 5.00" Displacement

Table 2. Ultimate Loads and Maximum Deflections.

APPLIED LOAD POUNDS	HORIZONTAL COMPONENT OF BAR FORCE (MEASURED) POUNDS	LOAD IN DIAPHRAGM POUNDS	HORIZONTAL COMPONENT OF BAR FORCE (CALCULATED) POUNDS	PERCENT ERROR
200	144	56	127	+13.38
400	240	160	254	- 5.51
600	349	251	381	- 8.40
800	454	346	508	-10.63
1000	573	427	635	- 9.76
1500	832	668	953	-12.91
2000	1132	868	1270	-10.87
2500	1474	1026	1590	- 7.30
3000	1829	1171	1905	- 3.99
3500	2211	1289	2220	- 0.41
4000	2564	1436	2540	+ 0.95
4500	2992	1508	2860	+ 4.62
5000	3490	1510	3180	+ 9.75
5500	3795	1705	3500	+ 8.43

Table 3. Percent Error between Measured and Calculated Bar Forces

(3/8" Bar, 5% Preload)

APPLIED LOAD POUNDS	HORIZONTAL COMPONENT OF BAR FORCE (MEASURED) POUNDS	LOAD IN DIAPHRAGM POUNDS	HORIZONTAL COMPONENT OF BAR FORCE (CALCULATED) POUNDS	PERCENT ERROR*
400	75	325	254	-70.47
600	242	358	381	-36.48
800	401	399	508	-21.06
1000	565	435	635	-11.02
1500	964	536	953	+ 1.15
2000	1402	598	1270	+10.39
2500	1885	615	1590	+18.55
3000	2294	706	1905	+20.42
3500	2717	783	2220	+22.39
4000	3168	832	2540	+24.72
4500	3623	877	2860	+26.68

Table 4. Percent Error between Measured and Calculated Bar Forces

(3/8" Bar, 20% Preload)

*Errors based on the results of one strain gage, i.e., bending of the bar was uncompensated.

APPLIED LOAD POUNDS	HORIZONTAL COMPONENT OF BAR FORCE (MEASURED) POUNDS	LOAD IN DIAPHRAGM POUNDS	HORIZONTAL COMPONENT OF BAR FORCE (CALCULATED) POUNDS	PERCENT ERROR
600	338	262	450	-24.89
800	344	456	600	-41.00
1000	701	299	750	- 6.53
1500	1148	352	1125	+ 2.04
2000	1602	398	1500	+ 6.80
2500	2030	470	1875	+ 8.27
3000	2469	521	2250	+ 9.73
3500	2911	589	2625	+10.90
4000	3403	597	3000	+13.43
4500	3874	626	3375	+14.79
5000	4263	737	3750	+13.68
5500	4639	861	4125	+12.46
6000	5101	899	4500	+13.36
6500	5552	948	4875	+13.89
7000	5971	1029	5250	+13.73
7500	6453	1047	5625	+14.72

Table 5. Percent Error between Measured and Calculated Bar Forces

(1/2" Bar, 5% Preload)

APPLIED LOAD POUNDS	HORIZONTAL COMPONENT OF BAR FORCE (MEASURED) POUNDS	LOAD IN DIAPHRAGM POUNDS	HORIZONTAL COMPONENT OF BAR FORCE (CALCULATED) POUNDS	PERCENT ERROR
200	179	21	150	+19.33
400	331	69	300	+10.33
600	498	102	450	+10.66
800	641	159	600	+ 6.83
1000	854	146	750	+13.86
1500	1251	249	1125	+11.20
2000	1708	292	1500	+13.86
2500	2145	355	1875	+14.40
3000	2587	413	2250	+14.98
3500	3024	476	2625	+15.20
4000	3517	483	3000	+17.23
4500	3911	589	3375	+15.88
5000	4349	651	3750	+15.97
5500	4820	680	4125	+16.85
6000	5338	672	4500	+29.73
6500	5851	649	4875	+20.02
7000	6305	695	5250	+20.10

Table 6. Percent Error between Measured and Calculated Bar Forces (1/2" Bar, 20% Preload)

APPLIED LOAD POUNDS	HORIZONTAL COMPONENT OF BAR FORCE (MEASURED) POUNDS	LOAD IN DIAPHRAGM POUNDS	HORIZONTAL COMPONENT OF BAR FORCE (CALCULATED) POUNDS	PERCENT ERROR
200	145	55	165	-12.12
400	331	69	329	+ 0.61
600	523	77	495	+ 5.66
800	694	106	659	+ 5.31
1000	895	105	824	+ 8.62
1500	1377	123	1235	+11.50
2000	1836	164	1649	+11.34
2500	2272	238	2060	+10.29
3000	2752	248	2475	+11.19
3500	3218	282	2880	+11.74
4000	3725	275	3300	+12.88
4500	4216	284	3710	+13.64
5000	4677	323	4120	+13.52
5500	5158	342	4530	+13.86
6000	5712	288	4950	+15.39

Table 7. Percent Error between Measured and Calculated Bar Forces
(5/8" Bar, 5% Preload)

APPLIED LOAD POUNDS	HORIZONTAL COMPONENT OF BAR FORCE (MEASURED) POUNDS	LOAD IN DIAPHRAGM POUNDS	HORIZONTAL COMPONENT OF BAR FORCE (CALCULATED) POUNDS	PERCENT ERROR
200	62	138	165	-62.42
400	197	203	329	-40.12
600	377	223	495	-23.84
800	538	262	659	-18.36
1000	694	306	824	-15.78
1500	1138	362	1235	- 7.85
2000	1584	416	1649	- 3.94
2500	2061	439	2060	0.0
3000	2557	443	2475	+ 3.31
3500	2945	555	2880	+ 2.26
4000	3467	533	3300	+ 5.06
4500	3922	578	3710	+ 5.71
5000	4499	501	4120	+ 9.20
5500	4827	673	4530	+ 6.56
6000	5337	663	4950	+ 7.82
6500	5814	686	5350	+ 8.67

Table 8. Percent Error between Measured and Calculated Bar Forces

(5/8" Bar, 20% Preload)

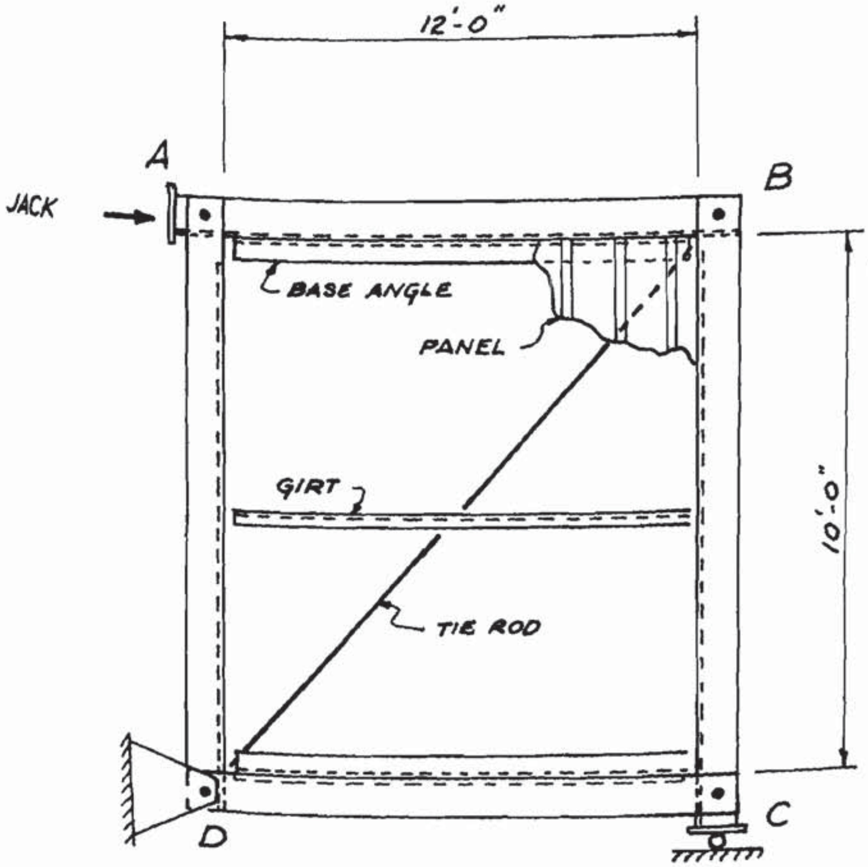

FIG. 1 TEST FRAME

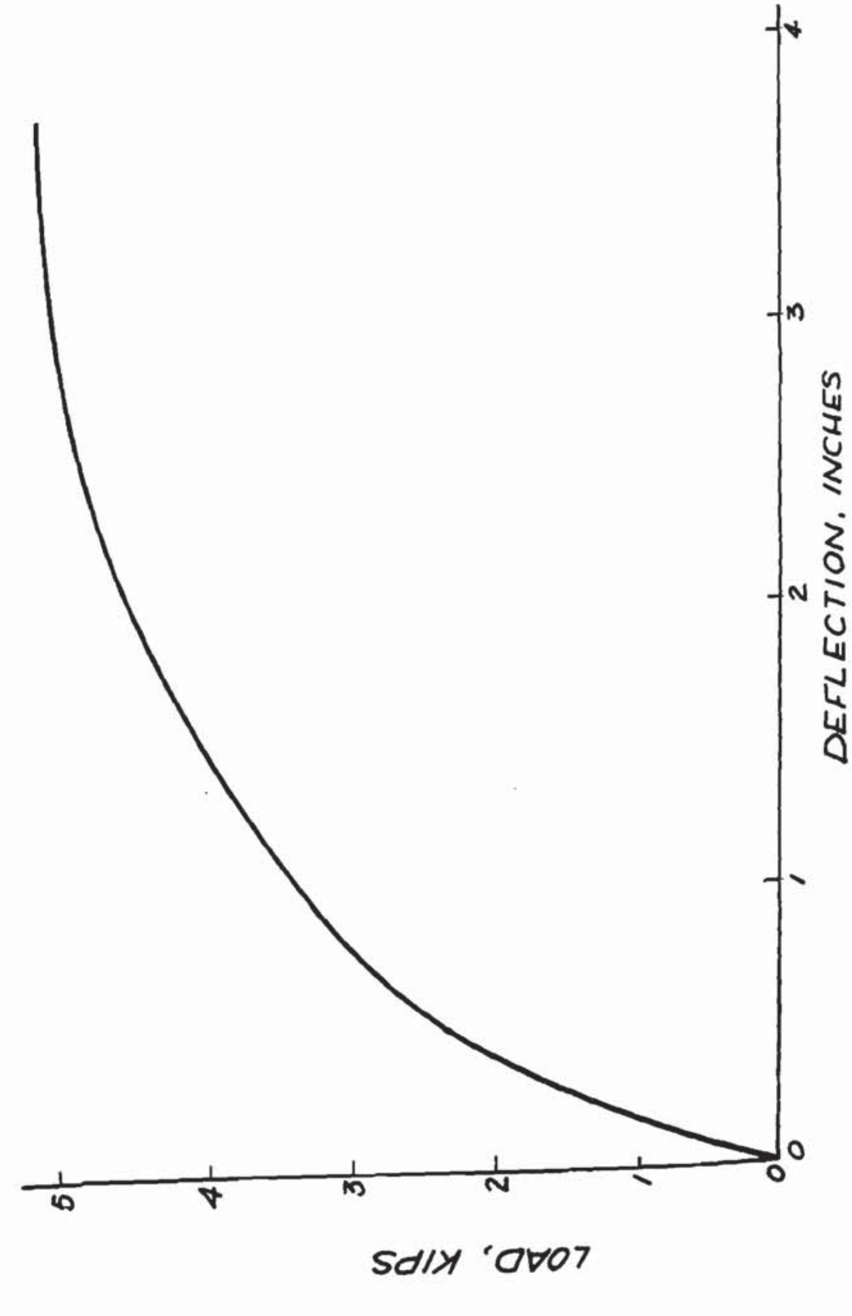

FIG. 2 P-Δ CURVE 24 GA. DIAPHRAGM

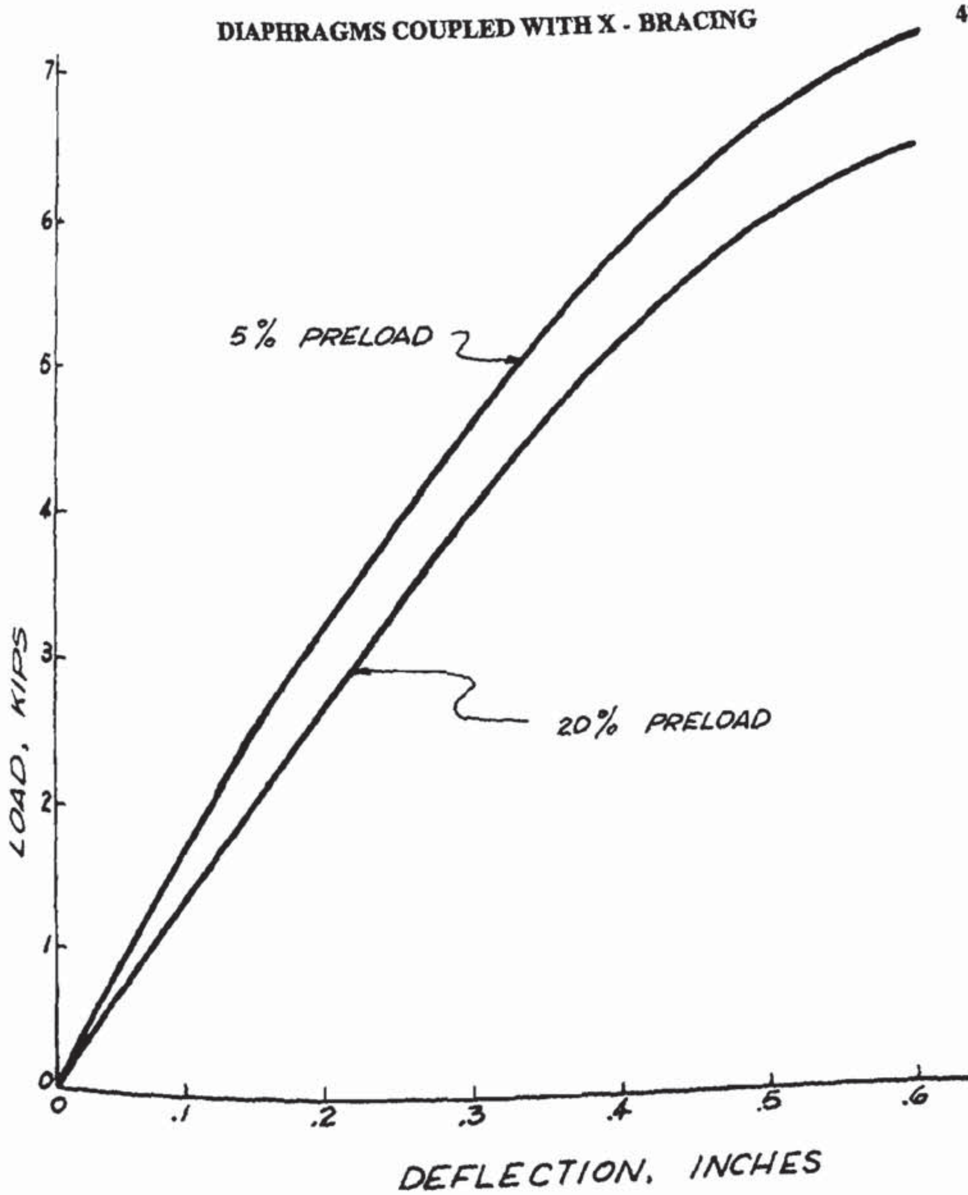

FIG. 3 P-Δ CURVES 3/8" ROD

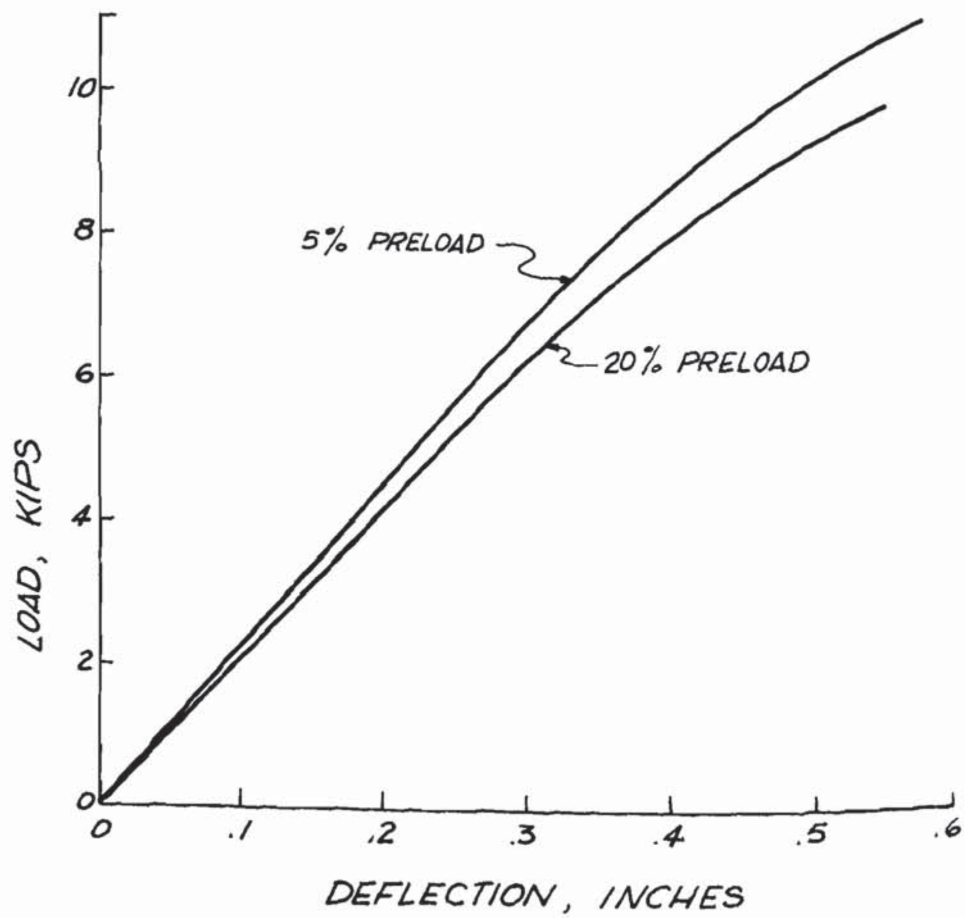

FIG. 4 P-Δ CURVES ½" ROD

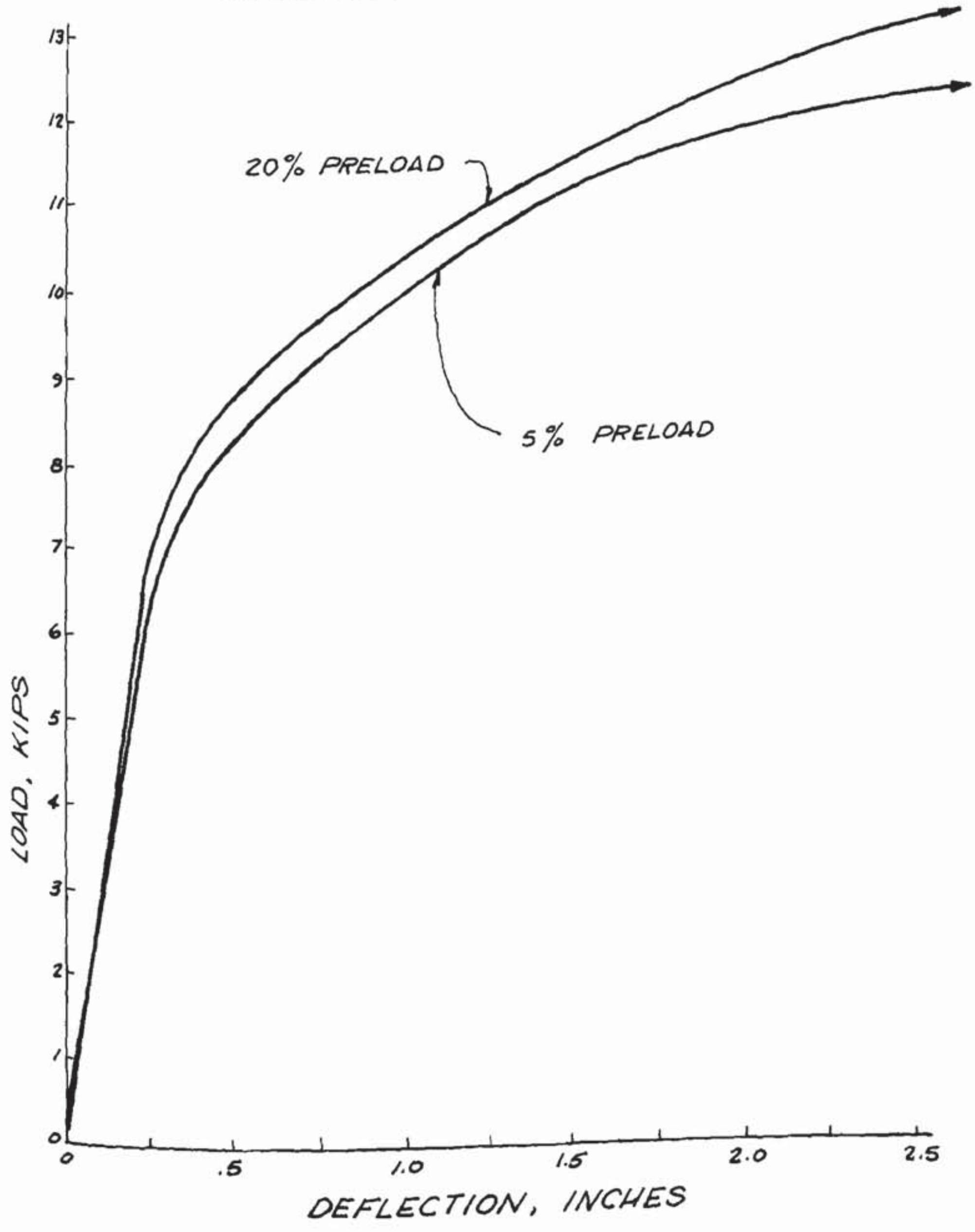

FIG. 5 P-Δ CURVES 5/8" ROD