Oct 19th, 12:00 AM

Structural Behavior of Cold-formed Steel Header Beams for Residential Construction

Roger A. LaBoube
Missouri University of Science and Technology, laboube@mst.edu

Sutton F. Stephens

Recommended Citation

LaBoube, Roger A. and Stephens, Sutton F., "Structural Behavior of Cold-formed Steel Header Beams for Residential Construction" (2000). *International Specialty Conference on Cold-Formed Steel Structures*. 5.
https://scholarsmine.mst.edu/isccss/15iccfss/15iccfss-session7/5

Fifteenth International Specialty Conference on Cold-Formed Steel Structures
St. Louis, Missouri U.S.A., October 19-20, 2000

STRUCTURAL BEHAVIOR OF COLD-FORMED STEEL HEADER BEAMS FOR RESIDENTIAL CONSTRUCTION

S.F. Stephens(1) and R.A. LaBoube(2)

ABSTRACT

The purpose of this experimental and analytical study was to observe the structural behavior of cold-formed steel header beams subject to a combined bending and interior-one-flange loading (IOF) condition as typically occurs in residential construction. This study focussed on the IOF loading of both back-to-back (I-beam) and box-beam configurations as specified in the "Prescriptive Method for Residential Cold-Formed Steel Framing – Second Edition."

Past research conducted in the area of web crippling strength, bending strength and flange buckling of cold-formed steel members was reviewed and is discussed. The data obtained from the experimental study was analyzed and evaluated to determine the interaction between bending and web crippling for the loading configurations used. The findings of this pilot study were used to define future research needed to establish design methodologies for residential header beam construction. Because this was a pilot study and was limited in the number of test specimens, no new design equations or recommendations were developed.

INTRODUCTION

Today, cold-formed steel is a commonly used building material utilized in a wide variety of applications. Used as studs, joists, beams and trusses, cold-formed steel is making significant advances in the residential building industry. Previously in residential construction wood was used almost exclusively as the primary structural building material. Today, because of its light-weight, strength, economy and most of all dimensional stability, cold-formed steel is successfully being used in a growing number of residential structures from single-family dwellings to multi-family apartment buildings.

PURPOSE OF INVESTIGATION

This study was initiated to develop a better understand the behavior of built-up header beams constructed in accordance with the "Prescriptive Method for Residential Cold-Formed Steel Framing (1997)" (hence refered to as the Prescriptive Method). Typical residential construction uses header beams fabricated using two channel sections in either an I-beam or box-beam configuration (see Figures 1 and 2).

SCOPE OF INVESTIGATION

This study consisted of both experimental and analytical investigations into the structural behavior of cold-formed steel header beams. The study focused on header beams fabricated using two C-sections with solid (un-punched) webs, as would typically be used in residential construction.

(1) Graduate Student, Department of Civil Engineering, University of Missouri-Rolla.
(2) Professor, Department of Civil Engineering, University of Missouri-Rolla.

The experimental part of this study was limited to header beams fabricated according to the requirements of the Prescriptive Method. Both back-to-back (I-beam) and box-beam configurations were considered. Member sizes tested and their associated spans were chosen as representative of those used in typical residential construction. Loading was limited to the interior-one-flange (IOF) loading condition which is the typical residential loading configuration.

REVIEW OF PREVIOUS RESEARCH

Prior to 1997, there had been no known experimental work conducted to investigate the structural behavior of cold-formed steel header beams. In 1997, the National Association of Home Builders (NAHB) conducted tests on cold-formed steel back-to-back (I-beam) header beam assemblies. The purpose of the experimental study was to investigate the behavior of built-up I-beam headers as typically used in residential construction.

Tests were made on a total of 24 I-beam specimens. Eight different sizes of C-sections, ranging in depth from 4-inches to 12-inches with varying thickness were used as test specimens. Test specimens were fabricated to correspond to span lengths selected from the header span tables in the Prescriptive Method.

According to the researchers, all beams failed by local buckling of the top, compression flange. In a comparison between the calculated moment capacities and the tested moment capacities, it was found that the ratio of tested to calculated moment capacities varied from 0.897 to 1.45. These results seem to indicate that neither web crippling nor the combination of web crippling and bending need be considered in design.

The researchers did not propose a new or revised design methodology based on the findings of their study.

EXPERIMENTAL INVESTIGATION

The UMR experimental study modeled header beam construction typically found in residential construction and as detailed in the Prescriptive Method. Header beam details presented in the Prescriptive Method are reproduced in Figures 1 and 2.

MATERIAL PROPERTIES

The mechanical properties of the steel used in each of the test specimens was determined by standard coupon tension tests using ASTM A370 procedures. Three test specimens were taken from the web portion of the track and each different C-section used in this study. The galvanized coating was removed from a portion of the specimens so that the base metal thickness could be measured. Table 1 gives the average values of the mechanical properties for each section type.

TEST SPECIMENS

Box-beams (Figure 4) were used for the study of sections with single unreinforced webs and I-beams (Figure 3) were used to study built-up sections with unreinforced webs. C-sections with solid webs (unpunched, i.e. no web holes) were used for this study. Each of the unpunched C-sections and track sections used to build the test specimens for this study were measured and section properties were calculated using the computer program CFS, version 3.03. Dimensions for the C-sections and track section recorded in this study are shown in Figure 6. These dimensions were measured from cut end sections of the specimens and are summarized in Table 2. Span lengths, loading configurations and the test load for each specimen, are given in Table 3 and shown in Figure 9.

All I-beam specimens were fabricated from two identical C-sections connected back-to-back using two rows of No. 8 self-drilling screws spaced at 24 inches (610mm) along the length of the beam (Figure 5). A track member was installed both top and bottom and fastened to the I-beam flanges with No. 8 self-drilling screws spaced at 24 inches (610mm) along the track at the same cross section locations as the web screws. To prevent web crippling at the supports, an aluminum angle 3/4" x 3/4" x 1/8" (19mm x 19mm x 3mm) was used as a stiffener on one side of the beam web and attached using two No. 10 self-drilling screws. A photograph of the end stiffener is shown in Figure 7.

Box-beam specimens were also fabricated using two identical unpunched C-sections. Top and bottom tracks were attached to the flanges of the C-sections to complete the box shape. The tracks were attached with No. 8 self-drilling screws spaced at 24 inches (610mm) along the beam (Figure 5). For the box-beam specimens, a piece of track was installed vertically at each end of the beam to close off the end of the section (Figure 8). The flanges of this end track were attached to the webs of the C-sections to provide stiffening of the webs. Two No. 10 self-drilling screws were used to make this connection.

TEST SET-UP

Each test specimen was loaded to failure and final deflections and ultimate loads were recorded. Two types of loading configurations were used (Figure 9). The single-point loading was used for most of the short spans while the two-point load configuration was used for the longer spans. Two-point loading was used in order to achieve maximum bending moment over the distance between the two load application points. The main reason for using this test set-up was to observe the behavior of the top track in compression.

A total of nine I-beam and six box-beam specimens were tested. A 3-inch (76mm) long steel bearing plate was used at the end reactions and 1.5-inch (38mm) wide bearing plates were used at the interior load points. At one support, a sliding bearing plate was used to allow horizontal movement of the support while the specimen was being loaded. The specimens were not attached to the supports.

Horizontal lateral bracing of the top flange of the beams was accomplished with the use of a stiff horizontal "U" shaped cold-formed steel member placed on each side of the test specimen. Shims were then used to fill in the space between the top track of the specimen and the horizontal support beam (Figure 10) to provide lateral support. The beam slid vertically against the shims as it deflected while providing adequate lateral support to prevent lateral-torsional buckling. The shims were spaced at 24 inches (610mm) along the beam and located at the same points as the screws used to attach the track. This bracing system provided the test specimen with an unsupported length of the top flange, L_y, of 24 inches (610mm). For the 12-inch (305mm) deep, 12-foot (3.66m) long I-beam tests, this method did not provide enough support to keep the ends of the beams at the supports from twisting. For these beams, additional lateral restraint was provided at the supports by placing triangular steel frames against the beam at the end reactions to prevent rotation (Figure 11).

TEST PROCEDURE

The test load was applied continuously until failure. Mid-span deflections were recorded at 200-pound (4.448N) intervals as the specimen was loaded. The loading rate was kept constant until the beam began to undergo local buckling or local yielding. At this point, the rate of deflection increased and the rate of applied load from the testing machine was also increased.

TEST RESULTS AND EVALUATION OF DATA

Generally, all fifteen test specimens failed in web crippling or a combination of web crippling and bending. The test results that were of primary interest in this study were the ultimate moment capacity and the ultimate web crippling capacity of each specimen. The ultimate moment capacity was calculated using AISI Eq. C3.1.1-1 ($M_n=S_eF_y$). For this calculation, any additional moment capacity that may have been provided by the top and bottom tracks was ignored. The effective section modulus, S_e, for each specimen was calculated using the CFS computer program. The ultimate web crippling capacity of each specimen was calculated using AISI equations C3.4-4 (Eq. 1) and C3.4-5 (Eq. 2) for single webs and I-sections respectively.

$$P_n = t^2 k C_1 C_2 C_9 C_\theta [538 - 0.74(h/t)][1 + 0.007(N/t)] \qquad (1)$$

$$P_n = t^2 F_y C_5 (0.88 + 0.12m)(15.0 + 3.25\sqrt{N/t}) \qquad (2)$$

The parameters for the C-sections are given in Table 4.

The results of the tests for both the I-beam and box-beam specimens are summarized by Stephens (1999). The calculations for I-beam web crippling assumed the C-sections were connected in such a way that a high degree of restraint against rotation of the web was provided. For the box-beam specimens, two different methods were used to calculate the web crippling capacities. The first determined the web crippling capacity for two single webs using the AISI equations for IOF loading and shapes having single webs with edge stiffened flanges. The second determined the web crippling capacity for two webs using the equations for IOF loading and webs provided with a high degree of restraint against rotation of the web (as for I-sections) with edge stiffened flanges.

EVALUATION OF RESULTS

I-Beams. The typical failure mode for the I-beam test specimens was by web crippling or a combination of web crippling and bending. Figure 12 photograph shows the bulge in the web characteristic of a web crippling or a combined web crippling and bending failure at the location of the applied load. In addition there was also evidence of local buckling of the top flange immediately under the bearing plates where the load was applied. During testing of the beams it was evident that before the specimens failed, there was significant buckling of the top track between the load points for the longer span beams having two IOF load points. Due to the compression buckling of the track, it was no longer a contributor to the load capacity of the beam through composite action prior to the ultimate capacity of the beam being reached.

A review of the M_t/M_n ratios shows that the ultimate calculated moment was not achieved by any of the test specimens, where M_t is the maximum moment from the test and M_n is the calculated moment resistance of the section. The values of M_t/M_n and P_t/P_n for each specimen were plotted (Figures 13) to show the correlation between the test results and the AISI interaction equation for I-beams with unreinforced webs, Equation C3.5.2-2. The interaction equation is represented by the line on the graph and the test results by the diamonds. The web crippling equation (Eq. 2) was used for the I-beams because the data fit this equation much better than the equation for single unreinforced webs. See Stephens (1999) for a complete presentation of the test results.

Equation (2) was used to calculate P_n for the interaction shown in Figure 13, and shows the test data has a fairly good correlation with the interaction equation. The exception was the longer span 12-inch (305mm) I-beam specimens which gave slightly unconservative results. It was evident from the review of this data that web crippling was the failure mechanism for short span I-beam headers with bearing plate widths of 1.5 inches (38mm).

Box-Beams. The failure mode for the box-beam test specimens was by web crippling or a combination of web crippling and bending. Photographs of typical failures of the box-beam specimens are shown in Figures 14 and 15. In these photographs, the outward bulge of the web indicating web crippling was quite pronounced. Failure occurred at the location of the IOF load point. Also evident was significant top flange deformation immediately under the load bearing plate. In addition, there was significant upward buckling in the top track between the IOF load points of the longer span specimens. Buckling of the top track was not as prominent in the shorter spans which were loaded by a single IOF load point at mid-span. The magnitude of the bending moment produced in the longer specimens was greater than in the shorter spans, causing the top track to buckle from high compression forces.

A review of the test data shows that the ultimate moment capacity as determined by calculations was not achieved by any of the test specimens. Figure 16 plots M_t/M_n versus P_t/P_n using the value of P_n calculated assuming single webs. These show the correlation between the test results and the AISI Specification interaction equation C3.5.2-1 for shapes having single unreinforced webs. Figure 17 plots M_t/M_n versus P_t/P_n using the value of P_n calculated using the built-up section. This graph shows the correlation between test results and the AISI Specification for built-up sections, Equation C3.5.2-2.

OBSERVATIONS

The objective of this pilot study was to develop a better understanding of the structural behavior of cold-formed steel header beams fabricated according to the requirements of the Prescriptive Method. Based upon the limited number of test specimens, the following observations have been developed:

- Web crippling or a combination of web crippling and bending is a factor in header behavior for the IOF loading condition

- Using AISI equation C3.4-4 (Eq. 1) for shapes having single unreinforced webs for the design of I-beam or box-beam headers fabricated according to the Perscriptive Method will give conservative results.
- Web crippling capacities for I-beam headers based on the AISI equation C3.4-5 (Eq. 2) for built-up sections, gives a very good approximation of actual capacities.
- Web crippling capacities for box-beams based on AISI equation C3.4-5 (Eq. 2) over estimated the actual capacities based on test results.

BIBLIOGRAPHY

American Iron and Steel Institute, (1996), "Cold-Formed Steel Design Manual: Specification for the Design of Cold-Formed Steel Structural Members."

American Iron and Steel Institute, (1997), "Cold-Formed Steel Back-to-Back Header Assembly Tests," Publication RG-9719.

American Iron and Steel Institute, (1997), "Prescriptive Method for Residential Cold-Framed Steel Framing, Second Edition."

American Society for Testing and Materials, (1996), ASTM, A370-96.

Stephens, S.F., (1999), "Structural Behavior of Cold-Formed Steel Header Beams for Residential Construction," Masters Thesis, University of Missouri-Rolla.

Yu, W. W., (1991), Cold Formed Steel Design, Second Edition, John Wiley and Sons, Inc., New York.

Table 1 Material Properties and Thickness of Sections used in the Experimental Study

Section Type	t (in)	F_y (ksi)	F_u (ksi)	Elongation (%)
TD 2x4x33	0.0322	30.02	48.75	19.79
C 2x6x43	0.0416	46.66	53.57	17.22
C 2x8x54	0.0525	56.76	65.33	14.16
C 2x10x54	0.0538	54.85	64.32	14.30
C 2x12x68	0.0724	45.25	64.03	14.77

Note: TD: Track Section (Ref. Figure 6)
C: Channel Section (Ref. Figure 6)
(1 in = 2.54 cm, 1 ksi = 6.895 MPa)

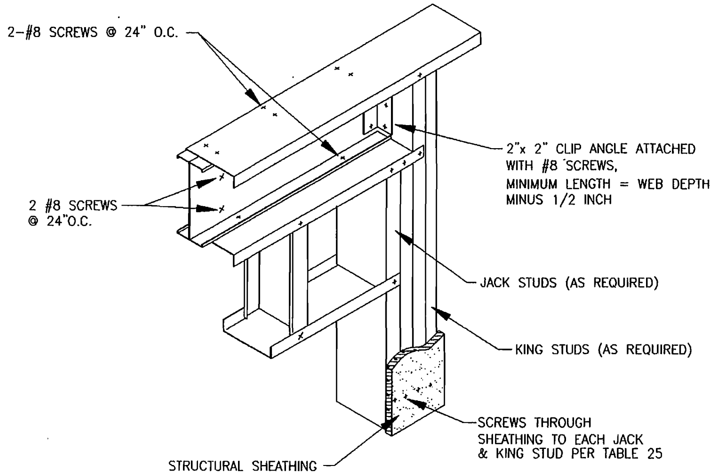


Figure 1 I-Beam Header

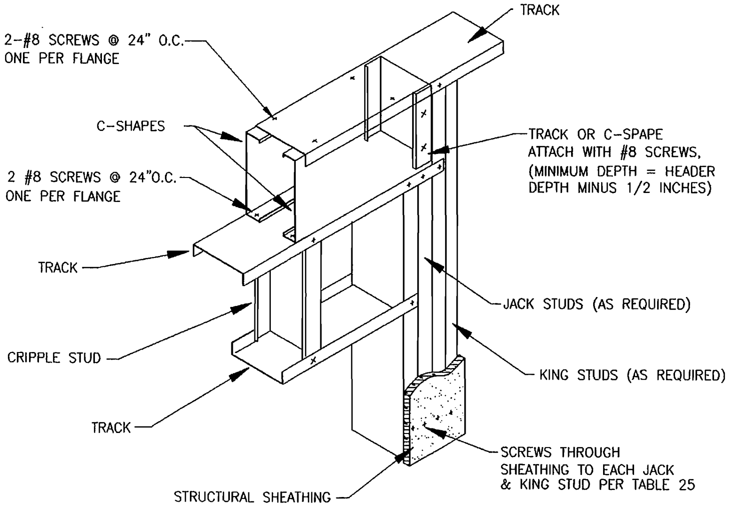


Figure 2 Box-Beam Header

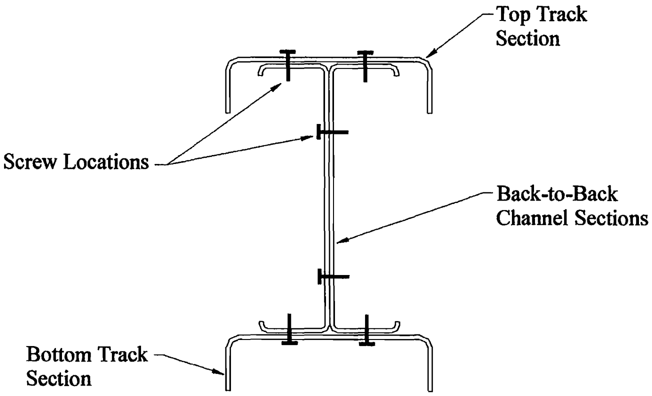


Figure 3 I-Beam Section

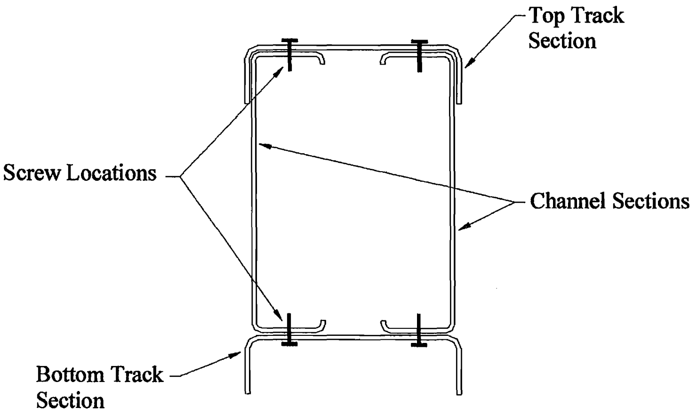


Figure 4 Box-Beam Section

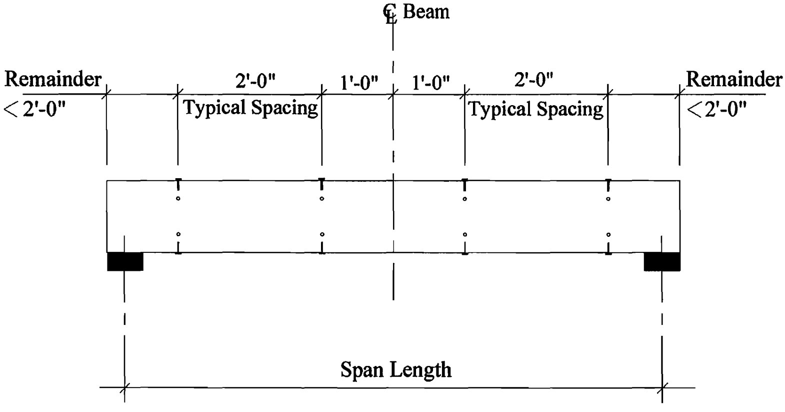


Figure 5 Typical Screw Spacing for Top and Bottom Tracks and Webs of I-Beams
(1 in =2.54 cm)

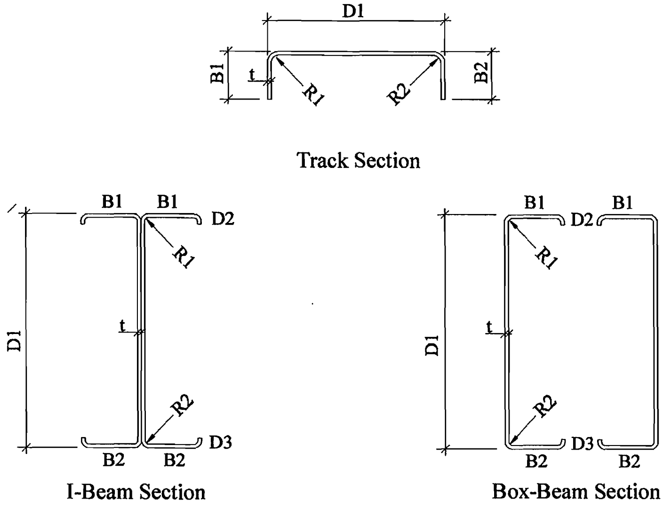
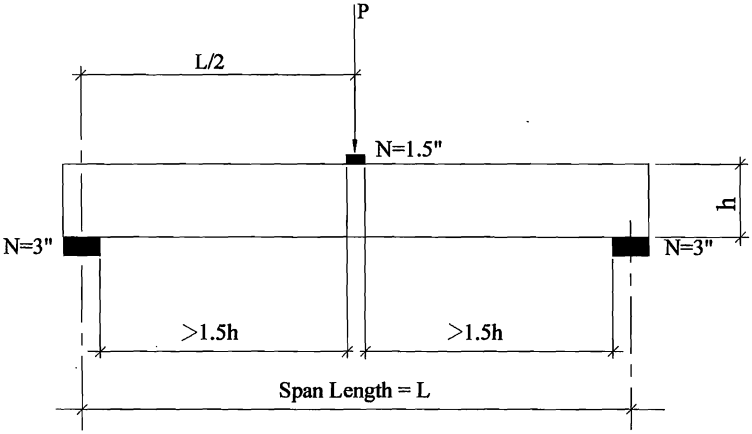
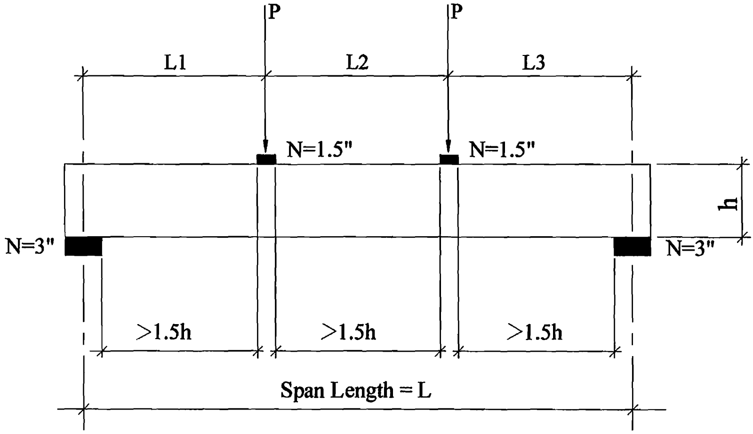


Figure 6 Typical C-Section and Track Section Dimensions



Single Point Load Configuration



Two Point Load Configuration

Figure 9 Typical Loading Configurations.
(1 in = 2.54 cm)

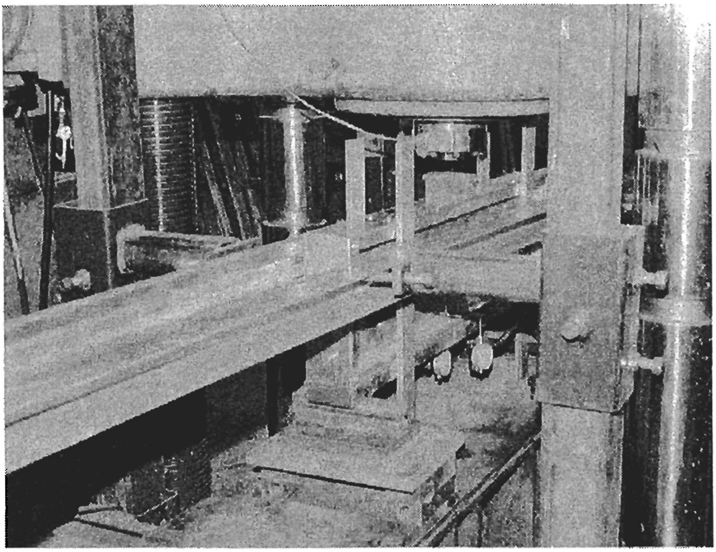


Figure 10: Configuration for a Single Point Load Test

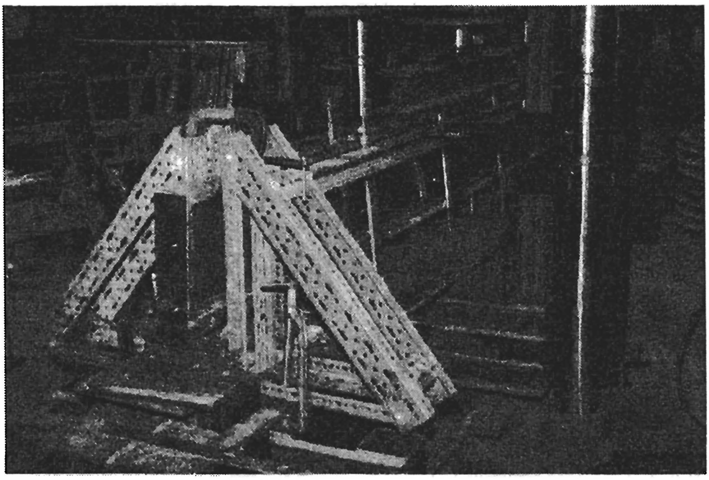


Figure 11: Configuration for a Two Point Load Test

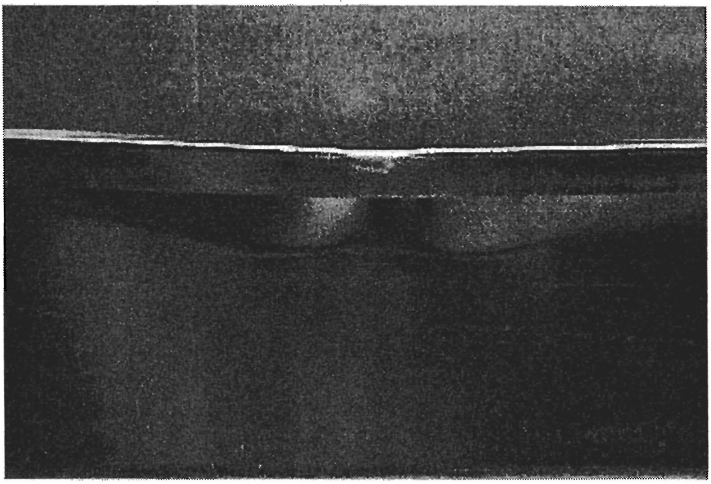


Figure 12 I-Beam Failure

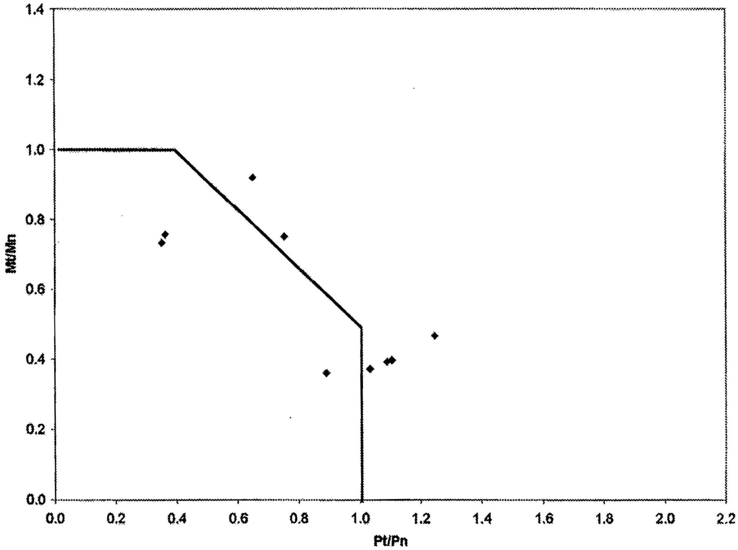


Figure 13 Back to Back Header Beam Data

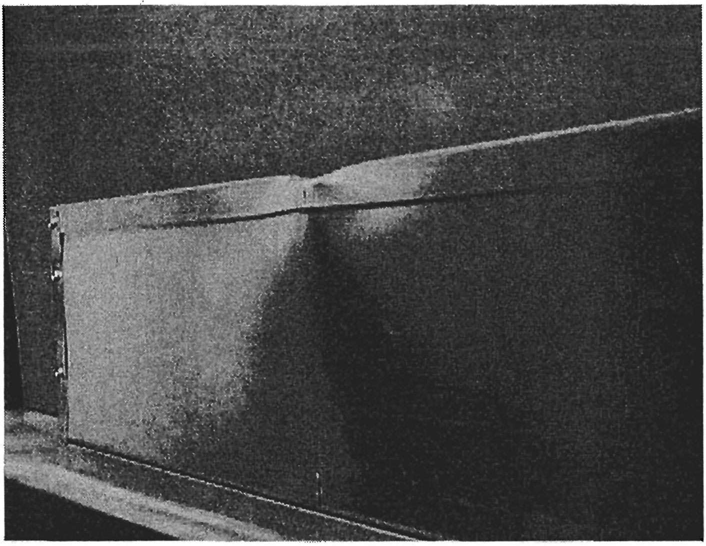


Figure 14 Box-Beam Web Crippling

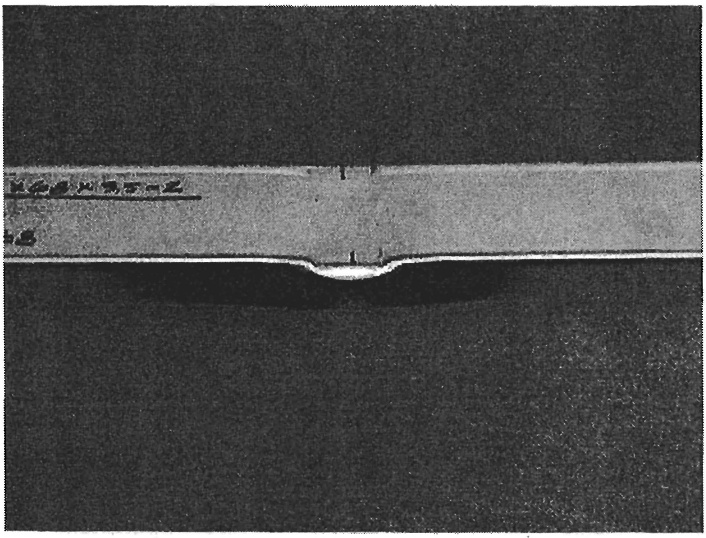


Figure 15 Box-Beam Load Point Track Deformation

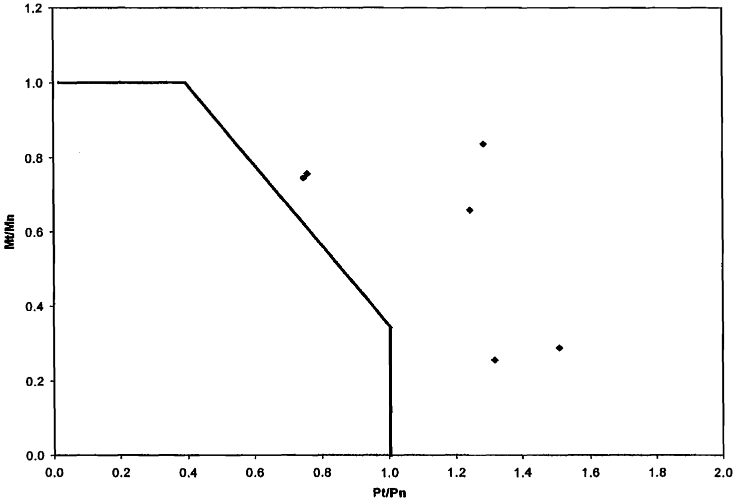


Figure 16 Box Beam Data using AISI Single Web Equation

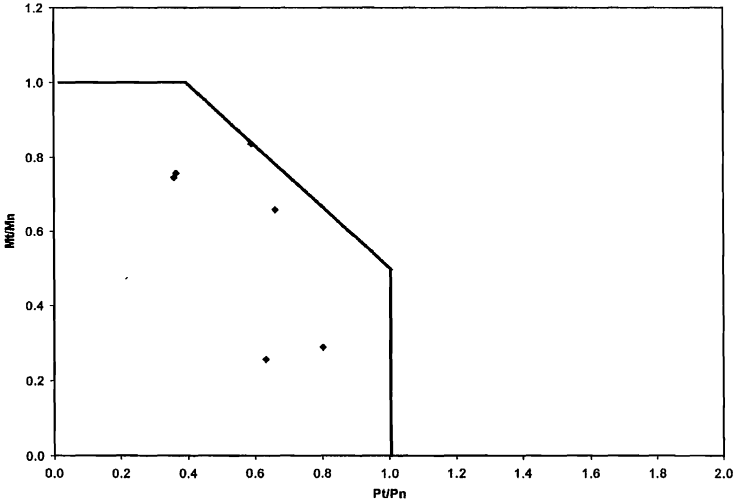


Figure 17 Box Beam Data using AISI I-Section Equation.