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STUB COLUMN STUDY USING WELDED, COLD-REDUCED STEEL

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ABSTRACT

The primary goal of the subject study was to investigate the behavior and load capacity of stub columns using cold-reduced, low-ductility steel versus un-reduced, normal-ductility steel. Specimens that were cold-reduced were also welded transversely across the entire stud cross section. Therefore, this study also yielded data with regard to the axial performance of welded studs. In addition, since stub columns were punched and un-punched, further conclusions can be drawn about the effect of a weld located at a web perforation.

A total of 133 stub column tests were performed at the Dietrich Material Testing Laboratory in Hammond, Indiana, between December 14 and December 20 of 1993, and on January 27 of 1994. Tests were conducted using two procedures. The first test procedure used a track at each end of the stub column. The second test procedure did not use a track. Grouting or welding was not used in either test procedure. There was no need for special end preparations since specimens were cut with very close tolerances regarding end squareness.

From the test data the following conclusions can be drawn. First, the presence of a weld in a stud had no effect on the stub column load capacity. Second, the presence of a weld at a knockout had no effect on the stub column load capacity. Third, reduced stub columns fared very favorably in load capacity when compared to the 1986 AISI Specification as long as 75 percent of the yield strength is used per AISI Specification, Section A3.3.2. Fourth, it is recommended that Section A3.3.1 of the AISI Specification be changed to include steel having F_u/F_y ratios of 1.01, elongations in a 2 in. gage length of three percent, and elongations in a 1/2 in. gage length of ten percent.

INTRODUCTION

Dietrich Industries, Inc. uses a coil build-up program which involves utilizing small size coils, welding the coils end to end in order to create a large size coil, and then cold reducing the large coil to the desired thickness. The large

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coil is then slit to the desired width and cold-formed to produce various sizes of C-Shaped structural framing products. In past studies, Dietrich has investigated the use of such material in long columns and bending members. These studies have shown that using welded, reduced steel does not effect the load capacity of such members when compared to other more frequently used steel types if a 25 percent reduction in design yield stress is used per 1986 AISI Specification Section A3.3.2.

OBJECTIVE

This study investigates the ultimate load capacity and behavior of welded, reduced stub columns versus un-welded, un-reduced stub columns. The stub column and tensile tests are intended to show the relative strength of a weld in a stud compared to that of the parent material. Also, the presence of a weld at a knockout and its effect on the load capacity of the stub column as compared to un-welded stub columns will be investigated. In addition, the applicability of the current 1986 AISI Specification Section A3.3.2 for low ductility steel will be checked to determine if it is an accurate and conservative means for the design of such members. Also, AISI Section A3.3.1 will be scrutinized to investigate if steels having F_u/F_y ratios of 1.01, elongations in a 2 in. gage length of three percent, and elongations in a 1/2 in. gage length of ten percent could be included in future editions of the AISI Specification.

STUD MATERIAL

Four different stub column types were tested. The first type was un-reduced and un-welded without a web knockout; the second type was un-reduced and un-welded with a web knockout at mid-height; the third type was reduced steel with a weld located at mid-height without a web knockout; and the fourth type was reduced steel with a weld and a knockout located at mid-height. Each stud type was designated as NRNW, NRNW-K, RW and RW-K respectively. Figure 1 illustrates the configuration of each stub column type. For any given stud size and gage, the NRNW and NRNW-K specimen types were produced from the same master coil and the RW and RW-K types were produced from the same master coil. In addition, reduced and welded stub columns were produced from single coils that were sheared and welded back together. This produced stub columns with the same steel at each side of a weld. As illustrated in Figure 2, all stub columns were C-Shaped structural studs with a flange width of 1.625 in. and a lip width of 0.5 in. This stud is designated in the Dietrich catalog as a CSJ stud.

Web knockouts were 1.5 in. X 4 in. ovals for all studs except 2.5 in. studs. Web knockouts for 2.5 in. studs were 0.75 in. X 4 in. ovals. A total of 131 stub column tests were conducted using web dimensions of 2.5 in., 3.625 in., 6 in. and 8 in. Stub column gage thicknesses were 20, 18, 16 and 14 gage. The decimal equivalents used for design purposes are .0359, .0478, .0598 and .0747 in., respectively. Twelve gage material was not tested since material thickness beyond 14 gage is excluded from the Dietrich coil build-up program. Table 1 lists the physical and structural properties of each master coil. Un-reduced, un-welded stub columns had yield strengths ranging from about 24 ksi to 30 ksi with F_u/F_y ratios ranging from 1.4 to 1.9, and elongations of about 40 percent. Reduced, welded stub columns had yield strengths ranging from 50 ksi to 85 ksi with F_u/F_y ratios ranging from 1.01 to 1.07, and elongations ranging from three percent to seven percent.

TENSILE TESTS AND CHEMICAL COMPOSITION TESTS

All tensile tests and chemical composition tests were conducted at the Dietrich Testing Facility in Hammond, Indiana. Tensile tests were conducted using a 60 kip Tinius Olsen Hydraulic Testing Machine, last calibration on October 22, 1993. Chemical composition tests were conducted using a Labtest Model V-25 Spectrometer. Table 1 summarizes the tensile test data for each master coil. Each master coil was tested according to ASTM A370, with tensile coupons removed from each slit coil using three different methods whenever possible. For each method, two tensile coupons were tested. For NRNW coils, tensile tests were conducted using coupons that were removed from the coil longitudinally and transversely whenever the coil width permitted. For RW coils, tensile tests were conducted using coupons that were removed longitudinally without a weld, longitudinally with a weld, and transversely without a weld whenever the coil width permitted. Specimens marked XXXX-LX are longitudinal coupons without a weld. Specimens marked XXXX-WX are longitudinal coupons with a weld. Specimens marked XXXX-TX are transverse coupons without a weld. In general, there was little difference between the tensile tests conducted for the welded and un-welded longitudinal specimens. In some instances welded specimens performed better than the un-welded specimens, and in other instances un-welded specimens performed better than welded specimens. Therefore, it can be concluded that the presence of a weld had no affect on the overall strength of the steel. In fact, welded tensile coupons generally failed away from a weld. There was only one instance of weld failure which occurred with tensile coupon: BD20W-W2.

Transverse tensile specimens were conducted in order to investigate the transverse ductility of the steel as compared to longitudinal specimens. There was no significant difference in the ductility of the steel in the transverse direction as compared to the longitudinal direction. This is seen by comparing tensile specimens BD14W-TR1 and BD14W-TR2 to BD14W-L1 and BD14W-L2 in Table 1A. Both transverse and longitudinal specimens have average elongations in a 2 in. gage length of about 18-20%.

Each tensile coupon was evaluated for elongation at two different gage lengths. A 2 in. gage length was used to determine the general ductility of each master coil. A 1/2 in. gage length was used to determine the local ductility of each master coil. Local ductility appears to be important for future AISI specifications since it appears reasonable from the stub column data that the elongation limit of 10 percent over a 2 in. gage length may be permitted to be substituted by 10 percent elongation over a 1/2 in. gage length across the fracture.

In order to maintain consistency, only XXXX-LX tensile coupon values were considered when evaluating stub columns for effective area and AISI compliance.

Table 2 summarizes the chemical composition of each master coil. This table illustrates that all master coils are in compliance with ASTM A-446 for chemical composition.

ROCKWELL HARDNESS TESTS

In order to develop an understanding of weld strength, Rockwell Hardness Tests were conducted on four stud specimens as shown in Table 3. All tests were conducted using a Antonik Tester, Model ADT-8 (last calibrated on October 19, 1993), at the Dietrich Testing Facility in Hammond, Indiana.

Each test was conducted as follows: Each stub column specimen was marked at 1/8" increments on each side of a weld at the web centerline. Rockwell Hardness was then recorded at the weld location as well as at each 1/8" increment on each side of the weld. Rockwell Hardness was recorded using the B-Scale.

Figure 3 shows a graph for average hardness versus distance from weld for each specimen. In general, hardness is at a peak at a weld location and slowly diminishes to reach a constant hardness at about 3/8" away from a weld. Hardness at a weld location as well as the rate and magnitude of diminishing hardness away from a weld is dependent on steel chemistry, gage of steel, and welding heat and technique.

Since welds are produced by resistance welding, no material is added to the weld and therefore, added weld material does not play a role in weld hardness.

From these tests we conclude that since hardness is at a maximum at a weld, steel strength is also a maximum at a weld. Subsequently, this explains why good welds do not fail in tension tests or in stub column tests.

SPECIMEN PREPARATION

Per AISI test guidelines, all stub columns were cut to a length of three times the web depth but not more than twenty times the minimum radius of gyration. In every instance, the stub column length that resulted was three times the web depth. Stub columns were cut to length directly on the roll forming mill, this produced an end condition that was square and flat. Subsequently, the need for elaborate end condition preparation was eliminated.

Stub columns were tested using two end conditions. For the first end condition, a runner track was used at each end of the stub column. At least three specimens for each stub column type, size and gage were tested using this method. For the second end condition, end tracks were not used. For this method, at least two specimens were tested for select stub column types, sizes and gage. Special end condition preparations such as welding or grouting were not used for either test method.

The majority of the stub columns were tested with a track at each end. This was done by simply screw-attaching a 12 in. long piece of 16 gage track to each end of the stub column with #10-16 self-tapping screws as shown in Figure 4. Each stub column was set as tight as possible to the track web. Due to the corner radius of the track, however, there was generally a gap of 1/8 in. to 1/16 in. between the end of the stub column and the track web. The test results show that the gap between the stub column and the track had no significance in the performance of the stub column.

End tracks were utilized to stiffen the flanges and lips at the ends of each stub column forcing a failure toward the mid-height. As it turned out, however, there was little difference in the performance of stub columns with end track as compared to stub columns without end track.

TEST SET-UP AND PROCEDURE

Stub columns were centered in a 60,000 pound Tinius Olson Hydraulic Testing Machine as shown in Figure 5. No special preparation was exercised for the end conditions. Stub columns were simply placed between the loading plates of the testing machine without the use of welding or grouting. Care was taken to vertically align the stub columns. The loads were applied in a slow consistent manner at a set rate of .025 inches per minute. Axial shortening of specimens was not recorded.

RESULTS

In general, the stub columns failed in local buckling characterized by a bulging of the web accompanied by an inward curling of the flanges. The local buckling generally occurred at mid-height or at one-third from the top or bottom of the stub column. There was no significant difference in the load capacity of stub columns tested without end tracks as compared to stub columns tested with end tracks. In addition, there was no difference in the local buckling behavior of reduced, welded stub columns as compared to un-reduced, un-welded stub columns. There were no observations of weld failures, thus welds had no affect on the load capacity of the stub columns.

Table 4 summarizes the stub column test results and effective areas for stub columns with end tracks. The nominal effective area for each stub column has been computed in accordance with Part 7 of the 1986 AISI specification. The value R_a has been computed in order to make a comparison between reduced, welded and un-reduced, un-welded stub columns. R_a was computed separately for stub columns with and without knockouts as follows:

$$R_a = \frac{\textbf{Nominal Effective Area for RW Stub Columns}}{\textbf{Nominal Effective Area for NRNW Stub Columns}}$$

If Ra is greater than unity, the RW stub column performed better than the NRNW stub column. If R_a is less than unity, the opposite holds true.

Two groups of data are given for AISI effective areas. The first group of data uses the full unreduced yield strength to calculate the effective area for reduced, welded stub columns. This yields R_a values that are generally less than 1 which suggests that a reduction in yield stress should be used for the design of steel framing members manufactured from reduced, low-ductility steel. In fact, AISI Section A3.3.2 specifies that .75*Fy or a maximum of 60 KSI should be used for the design of steel members with low ductility. For this reason, a second data group has been added to the tables which lists the effective areas of stub columns using a nominal design strength of .75*Fy for reduced, welded specimens only. Under this data group, R_a is generally greater than unity. This suggests that AISI Section A3.3.2 is an accurate and conservative means to account for low ductility steel. Figure

6 shows R_a versus h/t in graphical form. It also illustrates that there is not a trend for R_a to vary as a function of h/t. Furthermore, R_a for perforated studs does not vary differently from R_a for solid-web studs. Therefore it is concluded that the presence of a weld in a punched stud has no bearing on stub column load capacity.

Table 5 summarizes the stub column test results and comparison to the 1986 AISI Design Specification. In order to make comparisons between reduced and un-reduced stub columns, a value R_{ru} is listed in the tables . R_{ru} is calculated as follows:

$$R_{ru} = \frac{(P_{act}/P_{aisi})_{RW}}{(P_{act}/P_{aisi})_{NRNW}}$$

Where: P_{act} = Actual tested ultimate stub column load
P_{aisi} = Ultimate axial load per 1986 AISI using an effective buckling length of .5*l

If R_{ru} is greater than unity, RW stub columns performed better than NRNW stub columns. If R_{ru} is less than unity, then the opposite holds true. As was done for the calculation of R_a in Table 4, R_{ru} for RW stub columns is calculated using the full unreduced yield and also .75*Fy. When .75*Fy is used, R_{ru} is generally greater than unity. R_{ru} is generally less than unity when the full unreduced yield strength is used. Again, this suggests that AISI Section A3.3.2 is a valid specification. Figure 7 illustrates R_{ru} versus h/t graphically. Again, there is no trend in the data to vary from unity as h/t changes. It should also be noted that the RW stub column performance appears not to be influenced by F_u/F_y or elongation. This suggests that AISI Specification Section A3.3.1 should be changed to include steels having lower F_u/F_y ratios and smaller elongations.

Table 6 and 7 summarizes the data for the stub columns without end track. In general, stub columns without end tracks performed in much the same manner as stub columns with end track.

CONCLUSION

Stub columns tested with a track at the ends performed similar or the same as stub columns without end tracks.

Stub column performance was not influenced by the presence of a weld located at mid-height. Furthermore, tensile tests showed that the strength of a properly produced weld in coiled steel is the same or greater than the parent material.

Knockouts through a weld had no affect on the load capacity of a stub column as compared to punched stub columns of un-welded specimens.

Stub column data suggests that when designing cold-formed framing members manufactured from reduced, low ductility steel, the designer should use .75 times the yield strength for computational purposes. This is implied in Section A3.3.2 of the 1986 AISI specification and is further validated by this study.

Section A3.3.1 of the 1986 AISI specification states that the F_u/F_y ratios shall not be less than 1.08 and the total elongation shall not be less than 10 percent for a two inch gage length. This study suggests that steels having F_u/F_y ratios as low as 1.01 and elongations as low as three percent can be conservatively designed in compression using 75 percent of the yield stress per AISI Specification Section A3.3.2.

APPENDIX - NOTATION

F_u . . . Ultimate tensile strength of stud (ksi)

F_y . . . Yield tensile strength of stud (ksi)

h . . . . Flat width of stud web (in.)

NRNW . . Stub columns that are not reduced and not welded without a webknockout.

NRNW-K . Stub columns that are not reduced and not welded with a web knockout.

P_{act} . . . Actual stub column load capacity as tested (lbs).

P_{aisi} . . . Computed ultimate stub column load capacity per 1986 AISI Specification using an effective buckling length of one-half of the stub column length (lbs).

R_a . . . Ratio of nominal effective area for reduced, welded stub columns divided by nominal effective area for un-reduced, un-welded stub columns.

R_u . . . $\frac{(P_{act}/P_{aisi})_{RW}}{(P_{act}/P_{aisi})_{NRNW}}$

RW . . . Stub columns that are reduced and welded without a web knockout.

RW-K . . Stub columns that are reduced and welded with a web knockout.

t . . . . Gage thickness of steel (in.)

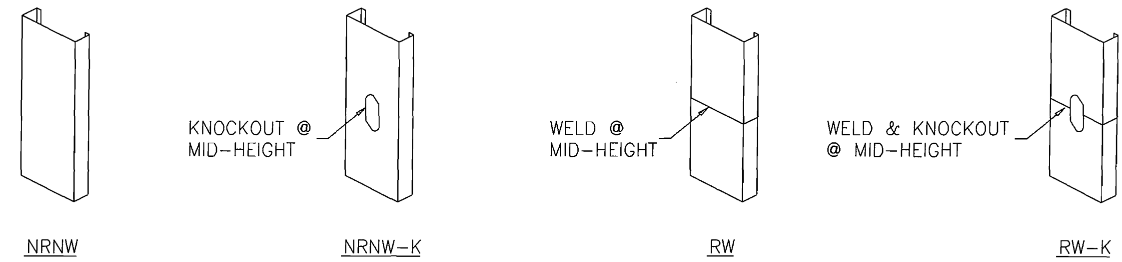

FIGURE 1- STUB COLUMN TYPES

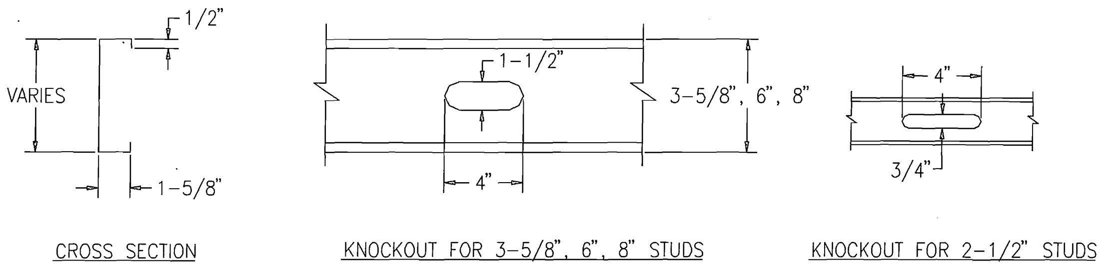

FIGURE 2- STUB COLUMN CROSS SECTION & WEB KNOCKOUTS

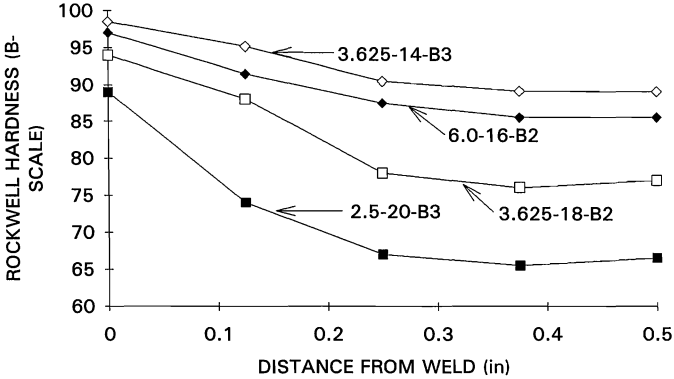

FIGURE 3 -AVERAGE ROCKWELL HARDNESS .VS. DISTANCE FROM WELD

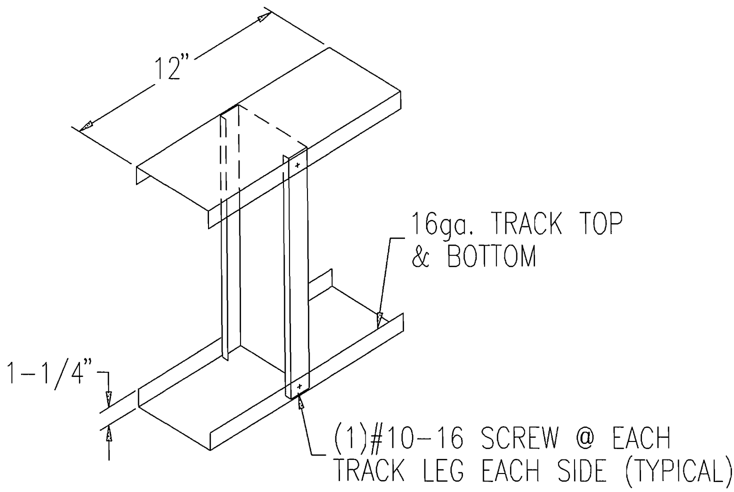

FIGURE 4 - STUB COLUMN SPECIMEN WITH END TRACK

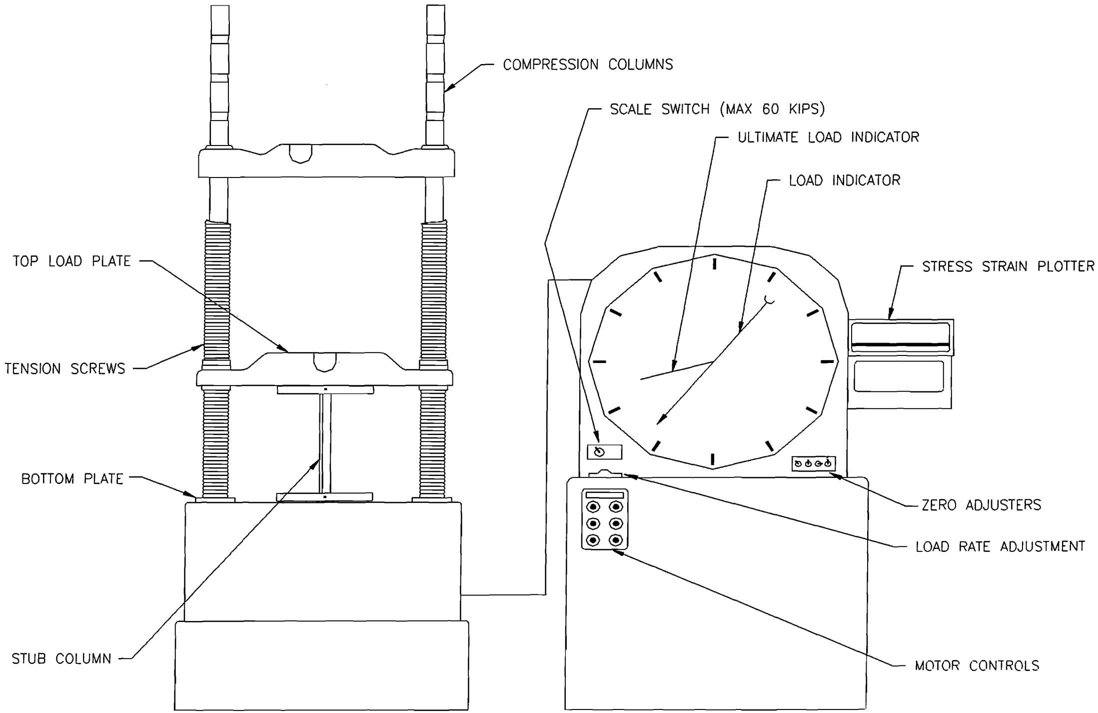

FIGURE 5- STUB COLUMN TEST SETUP

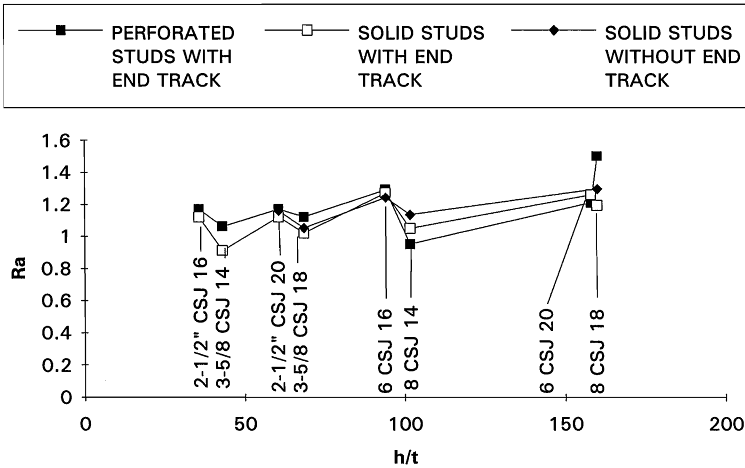

FIGURE 6- Ra .VS. NOMINAL h/t FOR Fy=.75*Fy FOR STUB COLUMNS

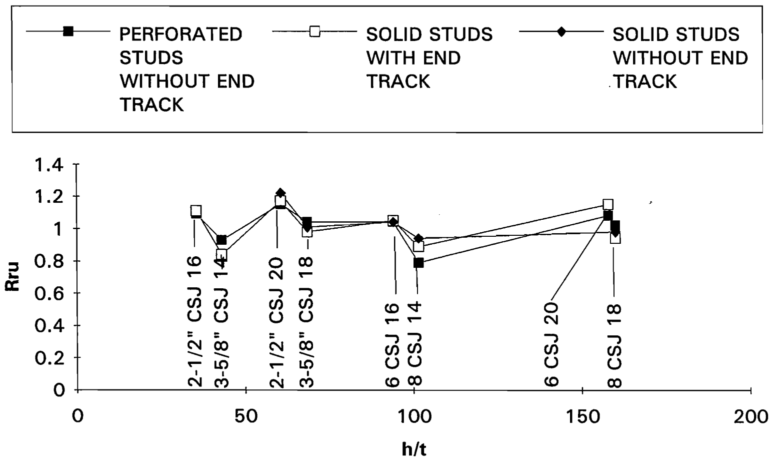

FIGURE 7- Rru .VS. NOMINAL h/t FOR Fy=.75*Fy FOR STUB COLUMNS

TABLE 1A-MASTER COIL ROCKWELL AND TENSILE TEST DATA

MASTER COIL NUMBER	ROCKWELL HARDNESS	TENSILE SPECIMEN	ACTUAL VALUES TH'CK (in)	ACTUAL VALUES FY (psi)	ACTUAL VALUES FU (psi)	ACTUAL VALUES FU/FY	ACTUAL VALUES ELONGATION 2" GAGE LENGTH (%)	ACTUAL VALUES ELONGATION 1/2" GAGE LENGTH (%)	AVERAGE VALUES TH'CK (in)	AVERAGE VALUES FY (psi)	AVERAGE VALUES FU (psi)	AVERAGE VALUES FU/FY	AVERAGE VALUES ELONGATION 2" GAGE LENGTH (%)	AVERAGE VALUES ELONGATION 1/2" GAGE LENGTH (%)
7112842	B44	AC20-TR1	0.0372	29301	43280	1.48	40	56						
		AC20-TR2	0.0366	29076	44022	1.51	39	56	0.0369	29189	43651	1.50	39.5	56
		AC20-L1	0.0372	28763	44624	1.55	39	60						
		AC20-L2	0.0371	28226	44355	1.57	42	66	0.0372	28495	44490	1.56	40.5	63
18273213	B36	AC16-TR1	0.0576	27509	44118	1.60	43	74						
		AC16-TR2	0.0577	27682	44637	1.61	44	68	0.0577	27596	44378	1.61	43.5	71
		AC16-L1	0.0573	26307	44425	1.69	44	72						
		AC16-L2	0.0572	27003	44599	1.65	43	68	0.0573	26655	44512	1.67	43.5	70
18273956	B32	AC18-L1	0.0472	23941	43432	1.81	42	72						
		AC18-L2	0.0472	23729	43220	1.82	44	72	0.0472	23835	43326	1.82	43	72
18270042	B91	BD14W-TR1	0.074	86253	94340	1.09	7	20						
		BD14W-TR2	0.0738	88919	94595	1.06	6	16	0.0739	87586	94468	1.08	6.5	18
		BD14W-L1	0.0735	84011	88076	1.05	7	16						
		BD14W-L2	0.0736	84688	87805	1.04	7	24	0.0736	84350	87941	1.04	7	20
		BD14W-W1	0.0758	84474	86184	1.02	6	24						
		BD14W-W2	0.0739	86216	88108	1.02	6	24	0.0749	85345	87146	1.02	6	24
18273313	B34	AC14-TR1	0.0776	28278	42159	1.49	42	72						
		AC14-TR2	0.0782	32044	45718	1.43	44	80	0.0779	30161	43939	1.46	43	76
		AC14-L1	0.0779	27179	42051	1.55	44	78						
		AC14-L2	0.0777	27763	42159	1.52	44	78	0.0778	27471	42105	1.53	44	78
18270023	B79	BD35818W-L1	0.0454	65639	67401	1.03	7	20						
		BD35818W-L2	0.0454	66079	67401	1.02	8	20	0.0454	65859	67401	1.02	7.5	20
		BD35818W-W1	0.0462	66667	68398	1.03	9	30						
		BD35818W-W2	0.0472	65678	66737	1.02	10	26	0.0467	66173	67568	1.02	9.5	28
18270073	B75	BD818W-TR1	0.0453	71586	75330	1.05	4	12						
		BD818W-TR2	0.0452	71239	74779	1.05	3	10	0.0453	71413	75055	1.05	3.5	11
		BD818W-L1	0.0455	71053	74123	1.04	4	12						
		BD818W-L2	0.0452	71681	75221	1.05	4	16	0.0454	71367	74672	1.05	4	14
		BD818W-W1	0.0458	65939	66376	1.01	7	26						
		BD818W-W2	0.0444	68018	68919	1.01	6	12	0.0451	66979	67648	1.01	6.5	19
18270384	B72	BD20W-TR1	0.0342	59064	59942	1.01	8	52						
		BD20W-TR2	0.0343	58480	59942	1.03	7	24	0.0343	58772	59942	1.02	7.5	38
		BD20W-L1	0.0344	52326	54070	1.03	17	36						
		BD20W-L2	0.0344	51744	54070	1.04	18	48	0.0344	52035	54070	1.04	17.5	42
		BD20W-W1	0.0386	46632	49741	1.07	15	44						
		BD20W-W2	0.0375	47482	50532	1.06	15	48	0.0381	47057	50137	1.07	15	46

TABLE 1B-MASTER COIL ROCKWELL AND TENSILE TEST DATA

MASTER COIL NUMBER	ROCKWELL HARDNESS	TENSILE SPECIMEN	ACTUAL VALUES						AVERAGE VALUES					
							ELONGATION						ELONGATION	
			TH'CK (in)	FY (psi)	FU (psi)	FU/FY	2" GAGE LENGTH (%)	1/2" GAGE LENGTH (%)	TH'CK (in)	FY (psi)	FU (psi)	FU/FY	2" GAGE LENGTH (%)	1/2" GAGE LENGTH (%)
18270389	B86	BD16W-TR1	0.0596	75251	78930	1.05	10	24						
		BD16W-TR2	0.0605	73267	78218	1.07	9	28	0.0601	74259	78574	1.06	9.5	26
		BD16W-L1	0.0596	72148	74497	1.03	15	38						
		BD16W-L2	0.0594	71812	74664	1.04	14	36	0.0595	71980	74581	1.04	14.5	37
		BD16W-W1	0.0597	73579	75585	1.03	14	40						
		BD16W-W2	0.0608	72131	74754	1.04	5	20	0.0603	72855	75170	1.03	9.5	30

TABLE 2-STUB COLUMN MASTER COIL CHEMICAL COMPOSITION

MASTER COIL NUMBER	PERCENT CONTENT OF EACH ELEMENT														
	Fe	C	Mn	P	S	Si	Cu	Ni	Cr	V	Mo	W	Ti	Al	Co
7112842	99.41	0.05	0.322	0.009	0.0034	0	0.0023	0	0.077	0	0.075	0.0001	0.0001	0.041	0
18273213	99.54	0.003	0.237	0.0085	0.006	0	0.005	0	0.064	0	0.083	0.0001	0.0001	0.059	0
18273956	99.68	0	0.101	0.012	0.0059	0	0.0015	0	0.071	0	0.087	0.0001	0.0008	0.038	0.0001
18270042	98.42	0.107	0.961	0.0098	0.006	0.263	0.0059	0	0.104	0	0.074	0.0001	0.0001	0.051	0
18273313	99.51	0.026	0.218	0.011	0.011	0	0.0027	0	0.08	0	0.091	0.0001	0.0001	0.048	0
18270023	99.41	0.039	0.275	0.013	0.013	0	0.0068	0	0.111	0	0.076	0.0001	0.0001	0.049	0
18270073	99.41	0.037	0.275	0.013	0.014	0	0.0068	0	0.111	0	0.083	0.0001	0.0001	0.049	0
18270384	99.59	0	0.165	0.011	0.0067	0	0.0029	0	0.082	0	0.076	0.0001	0.0009	0.062	0.0001
18270389	99.27	0.028	0.419	0.031	0.014	0	0.0043	0	0.092	0	0.082	0.0001	0.0001	0.056	0.0008

TABLE 3- ROCKWELL HARDNESS TEST RESULTS MEASURED ON EACH SIDE OF WELDS

	MEASURED VALUES									AVERAGE VALUES				
	DISTANCE LEFT OF WELD (in)					DISTANCE RIGHT OF WELD (in)				DISTANCE FROM WELD (in)				
SPECIMEN	1/2	3/8	1/4	1/8	AT WELD	1/8	1/4	3/8	1/2	AT WELD	1/8	1/4	3/8	1/2
2.5-20-B3	64	63	71	74	89	74	63	68	69	89	74	67	66	67
3.625-18-B2	77	75	78	91	94	85	78	77	77	94	88	78	76	77
6.0-16-B2	85	85	88	89	97	94	87	86	86	97	92	88	86	86
3.625-14-B3	89	89	90.5	93	98.5	97.3	90.5	89.2	89.1	98.5	95	91	89	89

TABLE 4-AVERAGE STUB COLUMN RESULTS AND EFFECTIVE AREAS FOR STUDS WITH TRACK AT ENDS

		AVERAGE STUB COLUMN VALUES				AISI EFFECTIVE AREAS USING FY=FY			AISI EFFECTIVE AREAS USING FY=.75*FY FOR REDUCED SECTIONS		
STUB COLUMN STUD	TYPE	LGT (in)	GA. (in)	FY (ksi)	ULT. LOAD (lbs)	ACTUAL EFFECTIVE AREA(in^2)	NOMINAL EFF. AREA(in^2) FOR FY=33 KSI	Ra[1]	ACTUAL EFF. AREA(in^2)	NOMINAL EFF. AREA(in^2) FOR FY=33 KSI	Ra[1]
2.5 CSJ 20	NRNW	7.5	0.0371	28.5	4983	0.175	0.16		0.175	0.16	
2.5 CSJ 20	RW	7.5	0.0349	52	6433	0.124	0.153	0.96	0.165	0.179	1.119
2.5 CSJ 20	NRNW-K	7.5	0.0371	28.5	4483	0.157	0.14		0.157	0.14	
2.5 CSJ 20	RW-K	7.5	0.035	52	5823	0.112	0.138	0.99	0.149	0.164	1.171
2.5 CSJ 16	NRNW	7.5	0.0573	26.7	9233	0.346	0.332		0.346	0.332	
2.5 CSJ 16	RW	7.5	0.06	72	20125	0.28	0.33	0.99	0.373	0.372	1.12
2.5 CSJ 16	NRNW-K	7.5	0.0573	26.7	8367	0.313	0.3		0.313	0.3	
2.5 CSJ 16	RW-K	7.5	0.0602	72	18317	0.254	0.318	1.06	0.339	0.351	1.17
3.625 CSJ 18	NRNW	11	0.0471	23.8	6750	0.296	0.253		0.296	0.259	
3.625 CSJ 18	RW	11	0.0453	65.9	10550	0.16	0.223	0.88	0.213	0.265	1.023
3.625 CSJ 18	NRNW-K	11	0.0473	23.8	6147	0.27	0.235		0.27	0.235	
3.625 CSJ 18	RW-K	11	0.0451	65.9	10453	0.159	0.222	0.94	0.211	0.263	1.119
3.625 CSJ 14	NRNW	11	0.0757	27.5	15633	0.568	0.522		0.568	0.522	
3.625 CSJ 14	RW	11	0.0741	84.4	25633	0.304	0.446	0.85	0.405	0.474	0.908
3.625 CSJ 14	NRNW-K	11	0.0764	27.5	13300	0.484	0.44		0.484	0.44	
3.625 CSJ 14	RW-K	11	0.0739	84.4	24717	0.293	0.431	0.98	0.39	0.467	1.061
6.0 CSJ 20	NRNW	18	0.0365	28.5	4800	0.169	0.136		0.169	0.136	
6.0 CSJ 20	RW	18	0.0339	52	5923	0.114	0.145	1.07	0.152	0.172	1.265
6.0 CSJ 20	NRNW-K	18	0.0361	28.5	4787	0.168	0.138		0.168	0.138	
6.0 CSJ 20	RW-K	18	0.0339	52	5727	0.111	0.14	1.01	0.147	0.167	1.21
6.0 CSJ 16	NRNW	18	0.0565	26.7	9400	0.353	0.325		0.353	0.325	
6.0 CSJ 16	RW	18	0.0593	72	18050	0.252	0.348	1.07	0.337	0.413	1.271
6.0 CSJ 16	NRNW-K	18	0.0565	26.7	9333	0.351	0.321		0.351	0.321	
6.0 CSJ 16	RW-K	18	0.0592	72	18000	0.252	0.347	1.08	0.336	0.413	1.287
8.0 CSJ 18	NRNW	24	0.047	23.8	7717	0.326	0.242		0.326	0.242	
8.0 CSJ 18	RW	24	0.0456	71.4	11950	0.169	0.241	1	0.225	0.287	1.186
8.0 CSJ 18	NRNW-K	24	0.0471	23.8	6688	0.282	0.179		0.282	0.179	
8.0 CSJ 18	RW-K	24	0.0446	71.4	10933	0.155	0.226	1.26	0.206	0.268	1.497
8.0 CSJ 14	NRNW	24	0.0759	27.5	15933	0.584	0.516		0.584	0.516	
8.0 CSJ 14	RW	24	0.0741	84.4	25817	0.31	0.455	0.88	0.414	0.541	1.048
8.0 CSJ 14	NRNW-K	24	0.0764	27.5	16817	0.616	0.549		0.617	0.549	
8.0 CSJ 14	RW-K	24	0.074	84.4	24917	0.299	0.44	0.8	0.399	0.523	0.953

NOTES

[1] Ra=NOMINAL EFFECTIVE AREA FOR REDUCED SPECIMENS DIVIDED BY NOMINAL EFFECTIVE AREA OF UNREDUCED SPECIMENS.

TABLE 5-AVERAGE STUB COLUMN RESULTS AND AISI DESIGN SPECIFICATION COMPARISON FOR STUDS WITH TRACK AT ENDS

		AVERAGE STUB COLUMN VALUES				AISI SPECIFICATION COMPARISON WITH FY=FY			AISI SPECIFICATION COMPARISON WITH FY=.75*FY		
STUB COLUMN STUD	TYPE	LTH (in)	GA. (in)	FY (ksi)	ULT. LOAD (lbs)	AISI ULT. LOAD (lbs)	ULT. RATIO Pact/Paisi	Rru[2]	AISI ULT. LOAD(lbs) [1]	ULT. RATIO Pact/Paisi	Rru[2]
2.5 CSJ 20	NRNW	7.5	0.0371	28.5	4983	6255	0.80		6255	0.80	
2.5 CSJ 20	RW	7.5	0.0349	52	6433	8382	0.77	0.96	6906	0.93	1.17
2.5 CSJ 20	NRNW-K	7.5	0.0371	28.5	4483	5746	0.78		5746	0.78	
2.5 CSJ 20	RW-K	7.5	0.0350	52	5823	7928	0.73	0.94	6468	0.90	1.15
2.5 CSJ 16	NRNW	7.5	0.0573	26.7	9233	9559	0.97		9559	0.97	
2.5 CSJ 16	RW	7.5	0.0600	72	20125	22436	0.90	0.93	18715	1.08	1.11
2.5 CSJ 16	NRNW-K	7.5	0.0573	26.7	8367	8478	0.99		8478	0.99	
2.5 CSJ 16	RW-K	7.5	0.0602	72	18317	20664	0.89	0.90	17045	1.07	1.09
3.625 CSJ 18	NRNW	11	0.0471	23.8	6750	7423	0.91		7423	0.91	
3.625 CSJ 18	RW	11	0.0453	65.9	10550	14236	0.74	0.81	11897	0.89	0.98
3.625 CSJ 18	NRNW-K	11	0.0473	23.8	6147	6893	0.89		6893	0.89	
3.625 CSJ 18	RW-K	11	0.0451	65.9	10453	13593	0.77	0.86	11229	0.93	1.04
3.625 CSJ 14	NRNW	11	0.0757	27.5	15633	15085	1.04		15085	1.04	
3.625 CSJ 14	RW	11	0.0741	84.4	25633	36078	0.71	0.69	29485	0.87	0.84
3.625 CSJ 14	NRNW-K	11	0.0764	27.5	13300	13671	0.97		13671	0.97	
3.625 CSJ 14	RW-K	11	0.0739	84.4	24717	33606	0.74	0.76	27175	0.91	0.93
6.0 CSJ 20	NRNW	18	0.0365	28.5	4800	6437	0.75		6437	0.75	
6.0 CSJ 20	RW	18	0.0339	52	5923	8301	0.71	0.96	6902	0.86	1.15
6.0 CSJ 20	NRNW-K	18	0.0361	28.5	4787	6252	0.77		6252	0.77	
6.0 CSJ 20	RW-K	18	0.0339	52	5727	8301	0.69	0.90	6902	0.83	1.08
6.0 CSJ 16	NRNW	18	0.0565	26.7	9400	10804	0.87		10804	0.87	
6.0 CSJ 16	RW	18	0.0593	72	18050	23309	0.77	0.89	19748	0.91	1.05
6.0 CSJ 16	NRNW-K	18	0.0565	26.7	9333	10282	0.91		10282	0.91	
6.0 CSJ 16	RW-K	18	0.0592	72	18000	22827	0.79	0.87	19154	0.94	1.04
8.0 CSJ 18	NRNW	24	0.0470	23.8	7717	7779	0.99		7779	0.99	
8.0 CSJ 18	RW	24	0.0456	71.4	11950	15309	0.78	0.79	12790	0.93	0.94
8.0 CSJ 18	NRNW-K	24	0.0471	23.8	6688	7653	0.87		7653	0.87	
8.0 CSJ 18	RW-K	24	0.0446	71.4	10933	14822	0.74	0.84	12297	0.89	1.02
8.0 CSJ 14	NRNW	24	0.0759	27.5	15933	16840	0.95		16840	0.95	
8.0 CSJ 14	RW	24	0.0741	84.4	25817	36992	0.70	0.74	30746	0.84	0.89
8.0 CSJ 14	NRNW-K	24	0.0764	27.5	16817	16186	1.04		16186	1.04	
8.0 CSJ 14	RW-K	24	0.0740	84.4	24917	36667	0.68	0.65	30210	0.82	0.79

NOTES

[1] AISI ULT LOAD FOR REDUCED SECTIONS USES A YIELD OF .75*FY

[2] Rru=(Pact/Paisi) FOR REDUCED SPECIMEN DIVIDED BY (Pact/Paisi) FOR UNREDUCED SPECIMEN. IF Rru>1 THEN REDUCED SPECIMEN PERFORMED BETTER THAN EXPECTED.

TABLE 6-AVERAGE STUB COLUMN RESULTS AND EFFECTIVE AREAS FOR STUDS WITHOUT TRACK AT ENDS

		AVERAGE STUB COLUMN VALUES				AISI EFFECTIVE AREAS USING FY=FY			AISI EFFECTIVE AREAS USING FY=.75*FY FOR REDUCED SECTIONS		
STUB COLUMN STUD	TYPE	LGT (in)	GA. (in)	FY (ksi)	ULT. LOAD (lbs)	ACTUAL EFFECTIVE AREA(in^2)	NOMINAL EFF. AREA(in^2) FOR FY=33 KSI	Ra[1]	ACTUAL EFF. AREA(in^2)	NOMINAL EFF. AREA(in^2) FOR FY=33 KSI	Ra[1]
2.5 CSJ 20	NRNW	7.5	0.0371	28.5	4900	0.172	0.157		0.172	0.157	
2.5 CSJ 20	RW	7.5	0.0342	52	6425	0.124	0.156	0.99	0.165	0.182	1.16
2.5 CSJ 16	NRNW-K	7.5	0.0569	26.7	8475	0.317	0.306		0.317	0.306	
2.5 CSJ 16	RW-K	7.5	0.0595	72	17600	0.244	0.315	1.03	0.326	0.345	1.13
3.625 CSJ 18	NRNW	11	0.0473	23.8	7305	0.307	0.272		0.307	0.272	
3.625 CSJ 18	RW	11	0.0453	65.9	11750	0.178	0.248	0.91	0.238	0.286	1.05
3.625 CSJ 18	NRNW-K	11	0.0474	23.8	6925	0.291	0.257		0.291	0.257	
3.625 CSJ 18	RW-K	11	0.0451	65.9	11600	0.176	0.246	0.96	0.235	0.284	1.11
6.0 CSJ 16	NRNW	18	0.0569	26.7	9850	0.37	0.343		0.37	0.343	
6.0 CSJ 16	RW	18	0.0596	72	18700	0.262	0.359	1.05	0.349	0.426	1.24
8.0 CSJ 18	NRNW	24	0.0473	23.8	7280	0.308	0.213		0.308	0.213	
8.0 CSJ 18	RW	24	0.0448	71.4	11300	0.16	0.232	1.09	0.213	0.276	1.30
8.0 CSJ 14	NRNW	24	0.076	27.5	15350	0.563	0.489		0.563	0.489	
8.0 CSJ 14	RW	24	0.0742	84.4	26525	0.319	0.467	0.96	0.425	0.555	1.13

NOTES
[1] Ra=NOMINAL EFFECTIVE AREA FOR REDUCED SPECIMENS
DIVIDED BY NOMINAL EFFECTIVE AREA OF UNREDUCED SPECIMENS.

TABLE 7-AVERAGE STUB COLUMN RESULTS AND AISI DESIGN SPECIFICATION COMPARISON FOR STUDS WITHOUT TRACK AT ENDS

		AVERAGE STUB COLUMN VALUES				AISI SPECIFICATION COMPARISON WITH FY=FY			AISI SPECIFICATION COMPARISON WITH FY=.75*FY		
STUB COLUMN STUD	TYPE	LTH (in)	GA. (in)	FY (ksi)	ULT. LOAD (lbs)	AISI ULT. LOAD (lbs)	ULT. RATIO Pact/Paisi	Rru[2]	AISI ULT. LOAD(lbs) [1]	ULT. RATIO Pact/Paisi	Rru[2]
2.5 CSJ 20	NRNW	7.5	0.0371	28.5	4900	6255	0.78		6255	0.78	
2.5 CSJ 20	RW	7.5	0.0342	52	6425	8170	0.79	1.00	6739	0.95	1.22
2.5 CSJ 16	NRNW-K	7.5	0.0569	26.7	8475	9489	0.89		9489	0.89	
2.5 CSJ 16	RW-K	7.5	0.0595	72	17600	22124	0.80	0.89	18504	0.95	1.06
3.625 CSJ 18	NRNW	11	0.0473	23.8	7305	7462	0.98		7462	0.98	
3.625 CSJ 18	RW	11	0.0453	65.9	11750	14236	0.83	0.84	11897	0.99	1.01
3.625 CSJ 18	NRNW-K	11	0.0474	23.8	6925	6910	1.00		6910	1.00	
3.625 CSJ 18	RW-K	11	0.0451	65.9	11600	13593	0.85	0.85	11229	1.03	1.03
6.0 CSJ 16	NRNW	18	0.0569	26.7	9850	10907	0.90		10907	0.90	
6.0 CSJ 16	RW	18	0.0596	72	18700	23516	0.80	0.88	19896	0.94	1.04
8.0 CSJ 18	NRNW	24	0.0473	23.8	7280	7846	0.93		7846	0.93	
8.0 CSJ 18	RW	24	0.0448	71.4	11300	14919	0.76	0.82	12395	0.91	0.98
8.0 CSJ 14	NRNW	24	0.0760	27.5	15350	16871	0.91		16871	0.91	
8.0 CSJ 14	RW	24	0.0742	84.4	26525	37064	0.72	0.79	30864	0.86	0.94

NOTES
[1] AISI ULT LOAD FOR REDUCED SECTIONS USES A YIELD OF .75*FY
[2] Rru=(Pact/Paisi) FOR REDUCED SPECIMEN DIVIDED BY (Pact/Paisi) FOR UNREDUCED SPECIMEN. IF Rru>1 THEN REDUCED SPECIMEN PERFORMED BETTER THAN EXPECTED.