The Design and Welding of a Rigid Frame Bent of ASTM A 514 Steels For a Railroad Overpass

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Beaumont, Texas, has long been confronted with a critical problem of traffic congestion in the downtown business district. Four major railroads serve the city and its large maritime port and refineries. Some of the rail lines are within street rights-of-way and a large complex network of main lines and spur tracks is concentrated within a two square mile area of the downtown area.

A commercial firm was given the design problem of relocating railroad tracks and installing grade separations to alleviate the problem. One grade separation was a heavily traveled intersection where three railroad tracks crossed the intersection at a diagonal. Because of the city's low elevation above sea level, depth of depressed roadways must be kept to a minimum. The approach grades of the railroad tracks could not be raised beyond about two feet due to amount of right-of-way required. The design engineers solved the problem of installing a grade separation providing sufficient clearance with the use of a rigid frame bent made of A 514 steels.

The paper discusses the alternates considered for the overpass-underpass structures and the advantages gained in using the rigid frame bent design and the A 514 steels.

The chemistry and physical properties of the A 514 steels used (Armco Steel SSS 100 and SSS 100A) are presented, along with data on fatigue strengths and reports of weldability studies. The details of weld procedure qualification carried out by the fabricator and test results obtained on the plates to a maximum of 3½-in. thickness are reported. Preheat considerations are discussed. Problems caused by the presence of hydrogen are revealed when insufficient preheat is used. The successful welding when proper procedures are followed of the SSS 100 and SSS 100A steels is shown. All shop fabrication was followed by post-weld heat treatment. The highly restrained joints at the knee of the rigid frame bent were welded with three welders simultaneously in order to prevent restraint problems.

The erection of the rigid frame bent and the two continuous spans supported by it is described. Welding operations were successful despite unusually heavy rainfall in the winter.

•BEAUMONT, Texas, has suffered a critical traffic congestion problem in the downtown business district for several years because of the large number of railroad crossings. Four major railroads serve the city, its large maritime port, and its numerous refinery

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and petrochemical plants. A complex network of railroad main lines and spur tracks is concentrated within a two square mile area adjacent to the business district.

The city in cooperation with the railroads initiated a railroad relocation and street improvement program in phases under the guidance of Forrest and Cotton, Inc., Consulting Engineers. A major project in the first phase was the construction of a grade separation to carry three railroad tracks at a diagonal over the heavily traveled intersection of College Street, Business Route US 90, and Railroad Avenue, US 69, 96, and 387.

The purpose of this paper is to discuss the unique design utilizing a 91-ft long rigid frame bent used in this grade separation, and the fabrication, welding, and stress relief of the $3\frac{1}{2}$-in. thick quenched and tempered alloy steel plates required for the bent.

DESIGN

Problems

Several conditions complicated the design of the railroad overpass:

1. Both streets have four lanes and carry heavy traffic. Thus, the intersection had to be full width with left-turn lanes.
2. Ground elevation in Beaumont is quite low with respect to sea level, and rainfall is unusually heavy. Thus, the depression of the roadway had to be kept to a minimum to minimize drainage pumping station costs as well as to minimize excavation costs. However, a full 15-ft vertical clearance had to be maintained.
3. The maximum approach grade of the tracks was limited to 0.85 percent. The elevation of the tracks was held to a 2-ft maximum to prevent expensive additional right-of-way requirements.
4. The three railroad tracks cross the intersection at a diagonal making placement of columns of bents outside the traffic pattern difficult. The closest possible spacing of end bents clear of traffic was 151.4 ft.

Structure Selection

The orientation of the railroad tracks to the intersection required a longer bridge structure than normal. The maximum elevation permitted on the railroad tracks and the minimum depth of roadway depression together with the required 15-ft vertical clearance combined to require shallower depth of superstructure than is normally encountered. Two types of structures were studied:

1. A 5-span ballasted steel deck bridge supported by simple spans of wide-flange beams framing into steel cap beams resting on concrete columns, 2 columns per bent.
2. A 4-span continuous ballasted deck bridge, composite wide-flange beams, one-way slab with a steel rigid frame bent for central support and with end bents and spill through abutments of reinforced concrete.

If framed end bents had been used, a minimum of 3 bents and 6 columns would have been required in order to maintain the shallow cap necessary. It would have been necessary to place the bents perpendicular to the street to obtain the shortest possible cap span. With this arbor arrangement the columns would have literally blocked the intersection, and the bents would not have been utilized economically since the superstructure beams would have framed into only one end of the cap.

The use of a 91-ft long single rigid-frame bent diagonal to the intersection with its shallower cap avoided the problems of the framed end bents. Therefore, the second design was selected. However, the use of 36 or 50-ksi yield steels would also have prohibited the use of a single bent since the cap would have had too much depth. It was necessary to use quenched and tempered low-alloy steel, ASTM A 514, with 90-ksi yield strength in the flanges and 100-ksi yield strength in the webs to obtain the shallowest depth of cap possible, 5-ft 5-in. maximum.

Figure 1 shows the minimum roadway grades ($6\frac{1}{2}$ percent) and depression achieved with this design. Figure 2 shows the appearance of the structure. The columns of the bent do not hinder traffic flow in any direction.

Figure 1. Completed overpass; note minimum grades ($6\frac{1}{2}$ percent) permitted with the rigid frame bent of A 514 D and E, quenched and tempered alloy steels.

Figure 2. Aerial view of completed overpass.

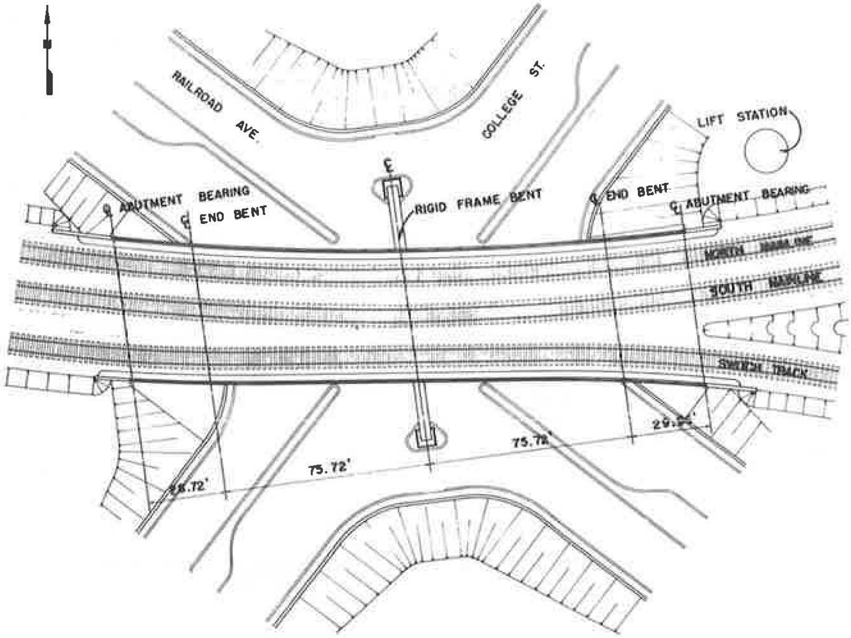


Figure 3. Plan of 212-ft long railroad overpass, Beaumont, Texas; central support is a 96-ft long welded rigid frame bent of ASTM A 514 D and E steels.

Description

The overpass is a 4-span three track structure with an overall length of 212 ft (Fig. 3). The two 76-ft 3-in. long center spans are continuous and frame into the center rigid frame bent. The simple end spans are supported by spill through reinforced concrete abutments and end bents of reinforced concrete. All bents and abutments are founded on prestressed concrete piles.

The superstructure beams, ASTM A 441, 36-in. 194-lb wide flange, support a ballasted deck of cast-in place concrete forming steel-concrete composite beams.

The rigid frame bent is of welded box construction with a span length center to center of bearing pins of 91 ft 10 in. (Fig. 4). Each leg of the rigid frame is supported by reinforced concrete footings resting on sixteen 18-in. square prestressed concrete pilings. The two footings are joined together by a reinforced concrete tie beam 8 ft 6 in. by 4 ft 3 in.

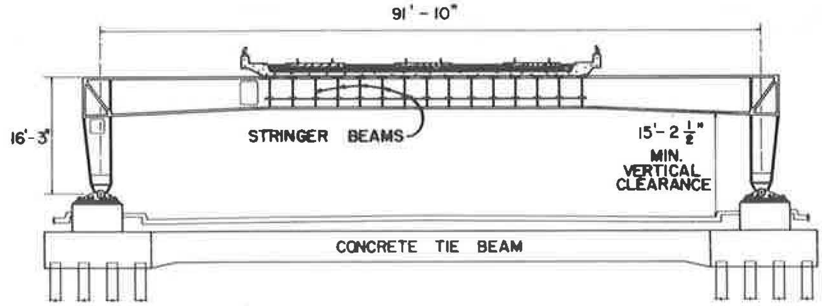
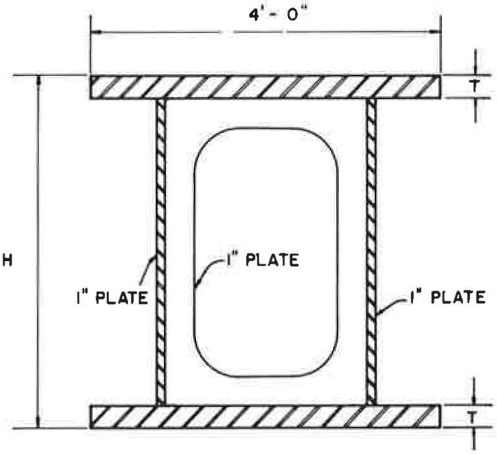


Figure 4. Elevation of rigid frame bent of ASTM A 514 D and E steels.



	T = THICKNESS	H = HEIGTH	
		MIN.	MAX.
BEAM	$3\frac{1}{2}$"	4'- 6"	5'- 3"
COLUMN	3"	3'- 0"	4'- 0"

Figure 5. Typical cross-section of columns and cap at diaphragm plates.

Cross sections of the columns and cap of the rigid frame bent are shown in Figures 5 and 6. Details of the knee section are shown later in Figure 14. The major components of the bent are:

Item	Size	Material
Flanges	48 by 3½-in. plate	A 514 Grade E Armco SSS 100*
Knee stiffeners	48 by 3-in. & 3½-in. plate	A 514 Grade E Armco SSS 100
Webs, internal stiffeners and diaphragms	1-in. plate	A 514 Grade D Armco SSS 100A

*SSS and SSS 100 are registered trademarks of Armco Steel Corporation.

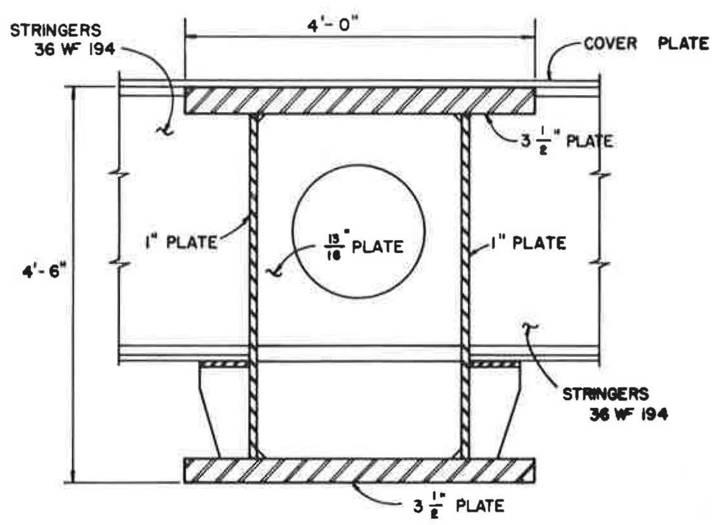


Figure 6. Cross-section of cap at stringer beam continuous connections.

The cap varies in depth from 4 ft 6 in. in the 46-ft long center section to 5 ft 5 in. at the knee. The columns vary in depth from 3 ft at the base to a maximum depth of 4 ft at the knee.

The rigid frame bent was designed to be shop welded in three sections. Consultations with the steel producer and the fabricator proved helpful to the designer in selecting the center section length, the type of corner at the knee, the use of one piece stiffeners at the knee, the joint preparation for the stiffeners, and the use of 1 by $^3/_8$-in. backup bars in the web to flange T-joint weld.

Allowable Stresses

The allowable stresses of the ASTM A 514 steels were determined from calculations based on AREA specifications.

ASTM A 514	Thickness $^3/_4$ In. to $2^1/_2$ In.	$2^1/_2$ In. to 4 In.
Tension:	54,000	49,000
Compression:		
Bending		
Supported	54,000	49,000
Unsupported	$54{,}000 - 46.0(l/b)^2$	$49{,}000 - 37.3(l/b)^2$
Axial loaded columns:		
Riveted, max $l/r = 100$	$43{,}000 - 2.15(l/r)^2$	$40{,}000 - 1.77(l/r)^2$
Pinned, max $l/r = 110$	$43{,}000 - 2.85(l/r)^2$	$40{,}000 - 2.4(l/r)^2$
Shear:		
Gross web section	33,000 psi	30,000 psi
Weld metal stresses:		
Fillet welds	37,600 psi	33,800 psi
Butt welds	39,400 psi	35,400 psi

Maximum Loads, Stress and Deflection

Design was in accordance with the American Railway Association Standard Specification using Coopers E-60 live load and an impact of 38 percent as provided by the Diesel impact formula. The maximum design loads, stresses, and deflections are summarized as follows for the rigid frame bent:

Impact:	
Direct	27%
Rolling	11%
Total impact	38%
Maximum loads	
Cap:	
Axial load	2, 417. 18 kips
Bending moment	27, 354. 6 ft-kips
Knee section:	
Axial load	2, 417. 18 kips
Bending moment	-33, 841. 1 ft-kips
Column (at bottom of cap):	
Axial load	1, 883. 82 kips
Bending moment	-27, 147. 5 ft-kips

TABLE 1

ASTM A 514 GRADES D AND E (SSS 100A AND SSS 100) MECHANICAL PROPERTIES

Property	$^3/_{16}$ In. to $2\frac{1}{2}$ In.	Over $2\frac{1}{2}$ In. to 4 In.	Over 4 In. to 6 In.
Ultimate tensile strength, ksi	115-135	105-135	105-135
Yield strength (at 0.2% offset), ksi, min.	100	90	90
Elongation in 2 in., min, %	18	17	16
Reduction of area, min, %	50*	50	45

*40 percent for plates $^3/_4$ in. and under

SSS 100A is produced to 100-ksi minimum yield to $1\frac{1}{4}$ in., and to 90-ksi minimum yield to 2 in.

Maximum Thickness Limits of ASTM A 514	
Grade D (SSS 100A)	$1\frac{1}{4}$ in.
Grade E (SSS 100)	4 in.

SSS 100 is covered by U. S. Patent # 3,288,600.

Stresses

Location	Axial Stresses			Bending Stresses			Total Ratio
	Actual	Allowable	Ratio	Actual	Allowable	Ratio	
Cap ℄	5,620	39,988	0.141	38,220	48,978	0.780	0.921
Cap knee	5,370	39,199	0.137	38,460	47,563	0.809	0.946
Column	4,510	39,884	0.113	43,880	48,722	0.901	1.014

Live Load Deflection

	Actual	Allowable
Total live load plus impact	1.4254 in.	1.7406 in.

STEEL USED IN BENT

SSS 100 Steels

ASTM A 514 Grade D, Armco SSS 100A, was used in thicknesses up to $1\frac{1}{4}$ in. inclusive. Grade E of the specification, Armco SSS 100, was used for thicknesses over $1\frac{1}{4}$ in. The mechanical properties of the quenched and tempered alloy steels are given in Table 1.

The chemical compositions of SSS 100 and SSS 100A are given in Table 2. The high strength of these steels is obtained by using alloying elements which also provide the best possible weldability.

The ability of the steels to harden throughout their thickness upon quenching is obtained principally from chromium and molybdenum. Boron is added to intensify the hardenability effect. Chromium and molybdenum are varied in modifying the chemical composition to provide the proper hardenability for section thicknesses varying from $^3/_{16}$ to 6 in.

Titanium and/or vandium is added to promote grain refinement and to give the steels the ability to retain their high tensile strengths after tempering or after prolonged stress relief heat treatment. The steels have not been found susceptible to cracking in the heat affected zones of welds during postweld heat treatment (stress relief).

TABLE 2

CHEMICAL COMPOSTION RANGE (PERCENT)

Element	ASTM A 514 D (SSS 100A)	ASTM A 514 E (SSS 100)
Carbon	0.13/0.20	0.12/0.20
Manganese	0.40/0.70	0.40/0.70
Phosphorus, max	0.035	0.035
Sulfur, max	0.040	0.040
Silicon	0.20/0.35	0.20/0.35
Chromium	0.85/1.20	1.40/2.00
Molybdenum	0.15/0.25	0.40/0.60
Titanium	0.04/0.10	0.04/0.10
Copper	0.20/0.40	0.20/0.40
Boron	0.0015/0.0050	0.0015/0.0050
Vanadium	—*	—*

*May be substituted for part or all of titanium.

Fatigue Properties

The fatigue strengths of SSS 100 and SSS 100A have been determined in plain plate and butt welded at stress ratios of R = 0 and R = ½, and in butt welded plate with the weld reinforcement removed at a stress ratio of R = ½. (R equals the minimum stress divided by the maximum stress.) The fatigue strength of the weldment is almost doubled by removing the weld reinforcement.

The fatigue strengths are shown in Figure 7 for 600,000 cycles in a modified Goodman diagram as percent of ultimate tensile strength. The curves for negative stress ratios in plain and welded plates and for stress ratios less than one half for the ground welded plate have been extrapolated linearly. This provides a reasonable estimate since the modified Goodman curves are normally linear in this region.

The largest stress fluctuation in the bent occurs in the outer flange of the columns. The dead load tensile stress is 21 percent of the ultimate tensile strength and the sum of the live load and dead load tensile stresses is 37 percent of the ultimate tensile strength of the steel. This point falls below the intersection of the R = ½ line and the W curve in Figure 7, well below the curves for plain plate and butt welded plate with the weld reinforcement removed.

SHOP FABRICATION

Cleaning

The ASTM A 514 steels were shot blasted before fabrication. Mosher Steel Company had found from past experience that the removal of all mill scale from quenched and tempered steels helps to eliminate cracking and porosity in the welds.

Weldability of SSS 100

Restraint welding tests conducted by the Research Center of Armco Steel Corporation on SSS 100 were reviewed (2). These studies included cruciform tests and Navy

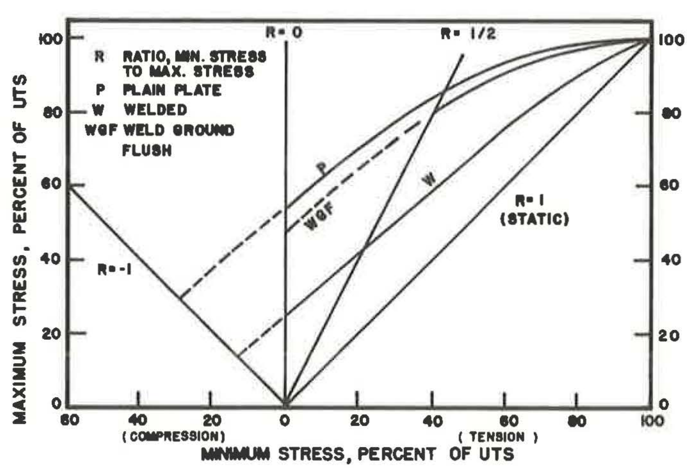
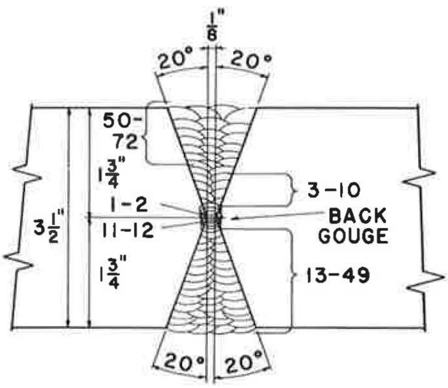


Figure 7. Fatigue strengths at 600,000 cycles of SSS 100 and SSS 100A plain plate, butt welded plate, and butt welded plate with the weld reinforcement ground flush; fatigue strengths are shown as percent of ultimate tensile strength.



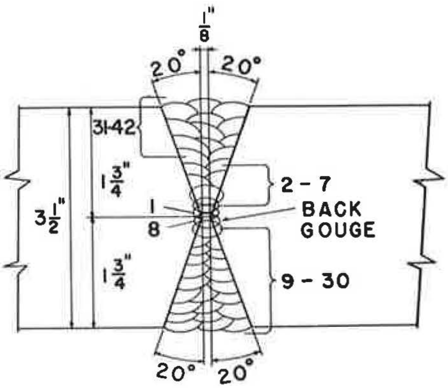
BASE PLATE: ASTM A-514-E (SSS 100)
POSITION: FLAT
PROCESS: SMAW
ELECTRODE: E11018
POSTWELD HEAT TREATMENT: 1050°F, 3-1/2 HRS, AIR COOL

PREHEAT: 250°F MIN
INTERPASS TEMP: 450°F MAX
POLARITY: AC

PASS NO	ELECTRODE SIZE IN.	AMPS	PASS NO	ELECTRODE SIZE IN.	AMPS
1	3/16	220	12	7/32	300
2	7/32	280	13-16	3/16	260
3-4	3/16	250	17-21	7/32	280
5-10	7/32	290-300	22-31	7/32	300
11	3/16	270	32-72	1/4	320-340

AIR-CARBON-ARC BACK GOUGE ROOT TO SOUND METAL PRIOR TO PASS 11.

Figure 8. Welding procedure specification for butt joint, 3½-in. thick ASTM A 514 E plate, using the shielded metal-arc welding process.



BASE PLATE: ASTM A-514-E (SSS 100)
POSITION: FLAT
PROCESSES: SEE TABLE
ELECTRODES: SEE TABLE
POSTWELD HEAT TREATMENT: 1050°F, 3-1/2 HRS, AIR COOL

PREHEAT: 250°F MIN
INTERPASS TEMP: 450°F MAX
SHIELDING: CO_2 GAS, 45 CFH
POLARITY: SMAW, AC VOLTAGE
GMAW DCRP

PASS NO	ELECTRODE TYPE	ELECTRODE SIZE, IN.	VOLTS	AMPS	PROCESS
1	E11018	3/16	—	260	SMAW
2-7	MCKAY 115*	7/64	27	400	GMAW
8	E11018	3/16	—	260	SMAW
9-42	MCKAY 115*	7/64	27	400	GMAW

ROOT AIR-CARBON-ARC BACK GOUGED TO SOUND METAL PRIOR TO PASS 8.

*- FLUX-CORED WIRE

Figure 9. Welding procedure specification for butt joint, 3½-in. thick ASTM A 514 E plate, using the gas shielded metal-arc welding process with flux-cored wire.

Circular Patch Tests. They showed that SSS 100 has a very low susceptibility to cracking under conditions of high restraint. However, they also revealed that to insure crack free welds steps must be taken to eliminate hydrogen from the welding operation. Accordingly, preheat procedures were set up to eliminate moisture from the work surfaces and all electrodes were protected from moisture.

Welding Procedure Specifications

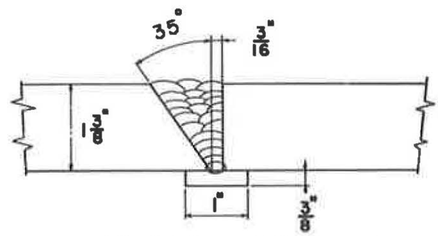
Four welding procedure specifications were qualified on the A 514 steels in accordance with AWS and Texas Highway Department specifications (3, 4, 5). Filler metals permitting the postweld heat treatment specified for shop fabrication were used.

Thick Butt Joints

Two procedures were qualified for this heavy joint (3½ in. thick). The first used the shielded metal-arc welding process with E11018 low hydrogen electrodes (Fig. 8). Test plates were cut square and edges were beveled with mechanized oxygen torch cutting. The torch cut edges were ground to eliminate scale and to smooth.

The test plates were preheated to a minimum of 250 F prior to welding. Multipass and split layer techniques were used with electrodes varying in diameter from 3/16 in. to 1/4 in. in order to maintain the proper amount of metal deposit required. The plate was turned over after the first ten passes and air-carbon-arc back gouged to sound metal. Passes 11 through 49 were then made to finish the bottom side of the plate. The test plate was again turned over and passes 50 through 72 were made with 1/4-in. electrodes to complete the top side. Interpass temperature was maintained at approximately 450 F throughout the test.

The second welding procedure specification established for the 3½-in. thick butt joint used a combination of the shielded metal-arc welding process and the gas metal-arc welding process (Fig. 9). The root pass was deposited with E11018 low hydrogen

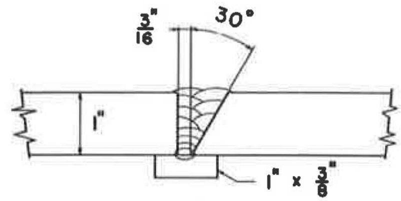


BASE PLATE: ASTM A-514-E (SSS 100)
POSITION: FLAT
PROCESS: SMAW
ELECTRODE: E11018
POSTWELD HEAT TREAT: 1050°F, 1.38 HRS, AIR COOL

POLARITY: AC
PREHEAT: 240°F MIN
INTERPASS TEMP: 450°F MAX
BACKING: A-514-D (SSS 100A)

PASS	ELECTRODE SIZE, IN.	AMPS
1	5/32	180
2-21	3/16	240

Figure 10. Welding procedure specification for T-joint, 1-in. ASTM A 514 D webs to 3 and 3½-in. ASTM A 514 E flanges, using the shielded metal-arc welding process.



BASE PLATE: ASTM A-514-D (SSS 100A)
BACKING: ASTM A-514-D (SSS 100A)
POSITION: FLAT
PROCESS: GMAW
ELECTRODE: MCKAY 115*, 7/64 IN. DIA.
POSTWELD HEAT TREATMENT: 1050°F, 1 HR, AIR COOL

SHIELDING: CO_2 GAS, 45 CFH
PREHEAT: 250°F MIN
INTERPASS TEMP: 450°F MAX
POLARITY: DCRP

PASSES	VOLTS	AMPS
1-11	27	400

*FLUX CORED WIRED

Figure 11. Welding procedure specification for T-joint, 1-in. ASTM A 514 D webs to 3 and 3½-in. ASTM A 514 E flanges, using the gas metal-arc welding process with flux-cored wire.

electrodes. Passes 2 to 7 were deposited using the GMAW process with McKay 115 flux cored wire and CO_2 shielding gas. The plate was turned over and the root was air-carbon-arc back gouged to sound metal and ground. A second pass using the E11018 electrode was deposited. The bottom side was then completed using the GMAW process. The plate was turned over again and the top side completed with the GMAW process.

Web to Flange T-Joints

Two welding procedure specifications were qualified for the web to flange connections. One used the SMAW process (Fig. 10) and the other used the GMAW process with flux cored wire (Fig. 11). The T-joint was designed to permit all welding in the flat position and from the outside of the box section. The groove and the backup bar duplicate the details of the joint used in actual fabrication. Here again multipass and split layer techniques were used.

Testing

All test welds were x-rayed to determine soundness. All test plates were postweld heat treated in accordance with ASME Code (6) at a temperature of 1050 F with a holding time of 1 hr/in. thickness followed by air cooling. Test coupons were prepared in accordance with AWS specification. The test results were all satisfactory (Table 3).

TABLE 3

WELDING QUALIFICATION PROCEDURE TEST RESULTS
ASTM A 514 WELDMENTS

Thickness (in.)	Procedure	UT (ksi)	Free Bend El. (%)	Side Bends
3½	SMAW	119.6	36.0	4-OK
		116.7	35.0	
3½	GMAW-FC	119.2	29.0	4-OK
		120.2	28.5	
1⅜	SMAW	120.4	41.0	4-OK
		120.6	35.0	
1	GMAW-FC	117.4	28.0	4-OK
		117.0	36.0	

Free bend specimens from 3½-in. plate were 1¾ in. thick x 2⅝ in. wide; all other specimens were per AWS D2.0-63.

Figure 12 shows the form used by the fabricator as a record of qualification tests of welding procedures and operators. This test record shows that the welding procedures were witnessed by the testing agency and in addition gives the results of tensile tests, free bend and side bend tests performed by the testing agency. The same testing agency maintained inspection throughout the job.

Cap Center Section

The 46-ft long center section of the cap, weighing 41 tons, was fabricated first. Figure 13 shows a cross section

H 228 M REV.

MOSHER STEEL COMPANY

HOUSTON, TEXAS

FORM Q-1 FOR MANUFACTURERS' RECORD OF QUALIFICATION TEST OF WELDING PROCEDURES AND OPERATORS

Record of Process & Operator (Process or Operator) S.S. No. 456-30-6018

Manufacturer: MOSHER STEEL COMPANY. Address: Houston 1, Texas.

Welding Operator: Name Eli Gorka Designating No. 0 Signature

Material: Kind Plate (Plate or Pipe) Specification ASTM A-514 Gr.E (SSS 100) T.S. 105,000 psi minimum

Thickness 3 1/2" inches Welding Position Flat

Welding Done in Accordance with Manufacturers' Welding Specification No. UM-13 Sk. 16 Dated 10-4-1965

REDUCED-SECTION-TENSILE TEST

Specimen No.	Dimensions		Area	Ultimate total load, lb.	Ultimate unit stress, lb. per sq. in.	Character of failure and location
	Width	Thickness				
2-1	.994	1.430	1.421	107,319	119,634	Parent Metal
2-2	1.013	1.435	1.454	104,883	116,747	" "

FREE-BEND TEST

Specimen No.	Gage Length		Difference	Per Cent Difference	REMARKS
	Before Bending	After Bending			
2-3	1.28	1.74	.46	36.0%	
2-4	1.48	2.00	.52	35.0%	

FACE-BEND TEST

Specimen No.	Describe the location, nature, and size of any crack or tearing of the specimen
E 11018 Electrodes Used.	

Side [illegible]-BEND TEST

Specimen No.	Describe the location, nature, and size of any crack or tearing of the specimen
2-5	Satisfactory
2-6	"

SIDE-BEND TEST

Specimen No.	Describe the location, nature, and size of any crack or tearing of the specimen
2-7	Satisfactory
2-8	"

The undersigned manufacturer certifies that the statements made in this report are correct and that the test welds were prepared, welded, and tested in accordance with the requirements of [illegible] AWS D2.63 & Texas C5 & C6.

Date 10/20/65

Signed MOSHER STEEL COMPANY (Manufacturer)

Witnessed By Donald Sprow

Don Sprow - Southwestern Lab.

By H. F. Crick

H. F. Crick - Welding Engineer

Figure 12. Typical manufacturers' record of qualification for procedure and operator.

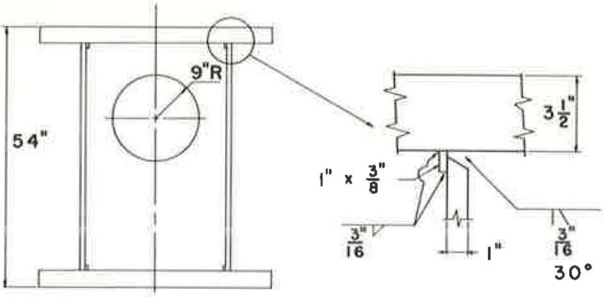


Figure 13. Cross section of cap and details of web to flange T-joint.

of this heavy box and details of the weld joint. The $^3/_8$ by 1-in. backup strips were tacked and then welded to both edges of the webs with a $^3/_{16}$-in. fillet weld. The diaphragms were fitted and tacked to the bottom flange. The webs were fitted and tacked to the bottom flange and to the diaphragms. Finally the top flange was fitted and tacked to both webs. The backup bars were then continuously fillet welded to the top and bottom flanges with a $^3/_{16}$-in. fillet weld from inside the box. All tack and fillet welds were made with E11018 electrodes.

The box section was then placed with the flanges in the vertical position for welding and was preheated to 250 F with natural gas heaters. The GMAW process with flux cored wire was used. Four welders worked simultaneously starting at the center and back stepping towards each end, welding each edge of the web to the flanges. When about one-half of the length of the first side had been completed, the section was turned over, preheated, and the second web was welded completely to the flanges. The box section was then reversed to the original position and the first web finished out to the ends.

Cracks

Upon magnetic particle inspection transverse cracks were found in all four welds. In reviewing the production welding procedure it was determined that preheating had been stopped when the flange surface reached 250 F and had not been continued a sufficient time for the heat to soak through the flange and remove the moisture entrapped between the 1-in. web plate and the backup bar (see insert of Fig. 12). Hydrogen had caused the transverse cracks under the longitudinal restraint imposed by the joint.

Repair

The cracked welds were repaired by air-carbon-arc gouging out the weld to sound metal and grinding. The joints were then preheated to a minimum temperature of 275 F with sufficient hold time to insure even heating throughout thus eliminating all moisture and reducing stresses upon cooling.

The joints were re-welded using the shielded metal-arc welding process with E11018 low hydrogen electrodes. The same sequence of welding was used as before. Interpass temperature was maintained at 450 F max. The section was not allowed to cool until completed.

All welds were magnetic particle inspected after cooling. No cracks were present. Proper preheating had solved the cracking problem.

The last sequence of fabrication of the center section of the cap was the welding of the beam seat stiffeners, the longitudinal beam seat plates, and the diaphragms.

The box section was placed with the webs horizontal so that all of the fillet ($^1/_4$-in.) welds on the stiffeners and longitudinal plates were in the downhand and horizontal position. The diaphragms were welded from the inside with horizontal $^1/_4$-in. fillet welds at this time also. E11018 low hydrogen electrodes were used for fillets and tacks joining A 514 to A 514, and E7018 low hydrogen electrodes were used for fillets and tacks joining A 441 to A 514 for all fabrication.

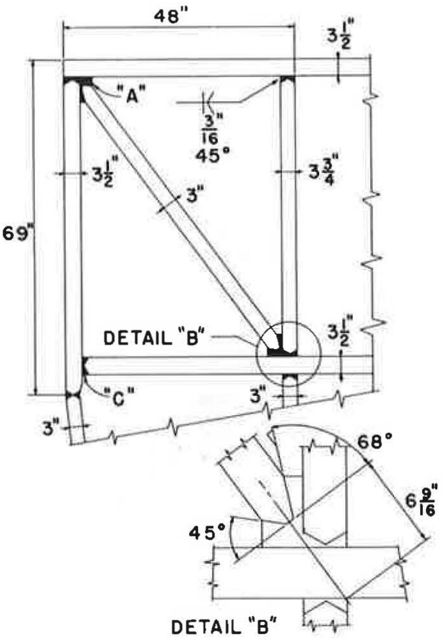


Figure 14. Leg to cap connections with flange to flange butt, corner and T-joints and stiffener to flange T-joints.

Stress Relief

The center section of the cap was stress relieved at 1050 F for $3\frac{1}{2}$ hr in accordance with ASME Code. All T-joint welds were magnetic particle inspected again after stress relief. There were no defects.

End Sections and Columns

The two 25-ft long end sections of the cap and the two columns were fabricated similar to the fabrication of the center section. The T-joints in these four sections were welded with the gas metal-arc welding process with no problems. The preheat temperature of 275 F minimum was again used, and interpass temperatures were again maintained at 450 F maximum. In the assembly of the leg, the butt joint in the outside flange was made first so this weld could be radiographed. These sections were completely fabricated before joining them together to form the knee of the bent. Web plates were not installed at this time in the knee area (Fig. 14).

Knee Section

The fabrication of the knee section (Fig. 14) was complicated by the high restraint imposed by the 3-in. diagonal and the $3\frac{3}{4}$-in. vertical stiffeners. Welding sequences providing even heating and cooling throughout the joint were employed.

The vertical $3\frac{3}{4}$-in. stiffener was tacked in placed and the outside flange of the leg was tacked to the flanges of the cap at A and C. The vertical stiffener was preheated to 275 F and welded with E11018 electrodes at the top.

Next, joints A, B, and C were preheated to 275 F and were welded simultaneously to minimize distortion. These welds were checked with magnetic particle inspection upon completion. Finally, the 3-in. diagonal stiffener was fitted and tacked into place. Joints A and B were again preheated and the stiffener welds were completed. All of the individual welds described above were back gouged to sound metal before completion of the second side, and all were magnetic particle inspected upon completion.

The two triangular shaped web plates at the knee section, also beveled and fitted with the backup bar (Fig. 13) were fitted on each side of the 3-in. stiffener. Webs and flanges were preheated to 275 F and welded with the gas metal-arc welding procedure. These welds were also magnetic particle inspected. One of the 34-ton knee sections is shown in Figure 15 on the furnace car. Bracing was used to prevent distortion during stress relief heat treatment. The corner welds were magnetic particle inspected again after stress relief heat treatment.

Bearing Shoes

The bases of the bearing shoes are $3\frac{1}{2}$-in. by 6-ft square ASTM A 441 plate. The ribs (2 in. thick) and pin plates (3 in. thick) are A 514-E. Figure 15 also shows one of the bearing shoes.

The rib plates and pin plates were fit and tack welded to the $3\frac{1}{2}$-in. base plate. The two shoes were then welded together back to back with splice plates on each side to hold them straight during welding. Both shoes were preheated to a temperature of 275 F. The first shoe was placed in the flat position and welding was started at the center and progressed outward on each rib and on each pin plate, using $\frac{1}{2}$-in. fillet welds.

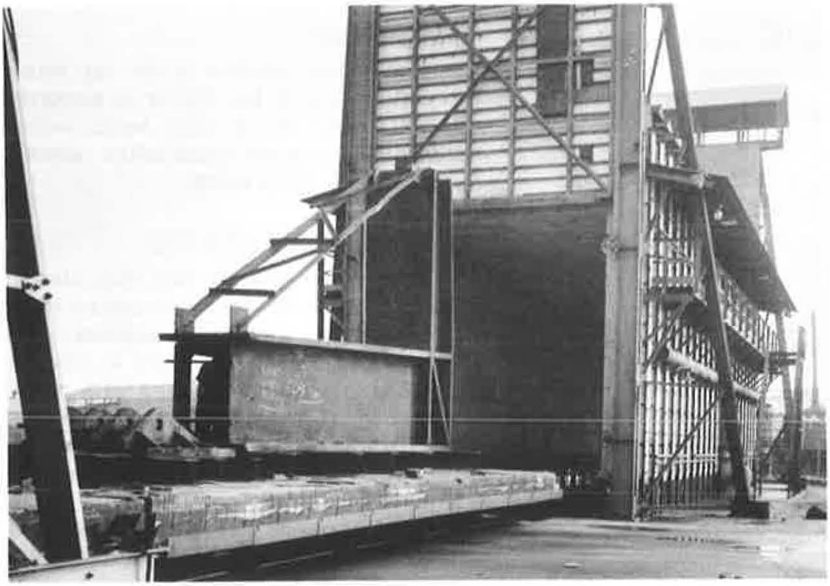


Figure 15. Knee section and base plates after post-weld heat treatment.

After welding about one-half of the ribs and pin plates on the first shoe the shoes were turned over and the second shoe was welded completely. The shoes were then turned back over and the welding was completed on the first shoe.

The shoes were allowed to cool while restrained by the splice plates to keep them straight. After cooling, all welds were inspected with magnetic particle inspection. The temporary splice plates holding these shoes together were gouged off and the shoes were stress relieved with the knee sections.

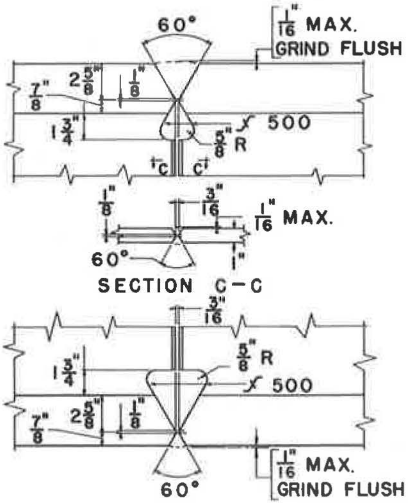


Figure 16. Details of preparation of field butt joints in 3½-in. ASTM A 514 E flange plates and 1-in. ASTM A 514 D web plates.

Leg Pin Plates

Since the stress relieving furnace could not accommodate the full length of the leg vertically it was necessary to leave the pin plates off of the bottom of the legs until after stress relieving to gain the 1 ft 3 in. needed for clearance. The two outside pin plates were built up by plug welding three 1-in. plates together, including the end of the webs, with twenty-three plug welds. The center pin plate was 3 in. thick.

The pin plates were tack welded in place, preheated to 275 F and welded with E11018 low hydrogen electrodes with 9/16-in. fillet welds. Welds were magnetic particle inspected.

Shop Preassembly

The center section of the cap was left long at initial fabrication to allow for shrinkage. After all work was completed the bent was completely shop assembled, measured and the center section was cut to length.

Field Joint

The field butt joints in the flanges and the webs were double beveled with 60-deg included angle on each side. After consultation with the erector and project engineer, the top V in the flange was cut $2\frac{5}{8}$ in. deep and the bottom V was cut $\frac{7}{8}$ in. deep, thus allowing most of the welding in the field to be done in the downhand position. Pear holes were prepared in the web to a distance of $1\frac{3}{4}$ in. from the flange with corners of $\frac{5}{8}$-in. radius and were ground to a finish of ASA 500. Details of the field joint are shown in Figure 16.

Welding Processes

The specifications for this project required that all welders be certified prior to working on any material. Each welder was certified for the positions of welding required of him in accordance with the Texas Highway Department Construction Bulletin C-6 within one month of starting field welding. All welding in the field was with the shielded metal-arc welding process using low hydrogen electrode E7018 for the ASTM A 441 steels and E11018 for the ASTM A 514 steels. Radiographic inspection was required for 100 percent of all flange and web splices. Acceptance criterion was Section 305, "Quality of Weld," of Texas Highway Department Construction Bulletin C-5. This is the same criterion as outlined in Specification for Welded Highway and Railroad Bridges by the American Welding Society.

Erection of Frame

Four erection towers were set on the concrete tie beam connecting the rigid frame footings. The towers were equipped with 50-ton hydraulic jacks to position the frame. The base plates were set on their footings and the legs were erected. The $7\frac{1}{2}$-in. diameter pins were then installed. The center section of the frame was set on erection

Figure 17. Bent supported by towers and jacks for positioning; welding protected from weather by metal house.

towers (Fig. 17). Splice plates were installed on the webs. The base plates and the splice points were brought to designed elevations.

Welding

The sheet metal house (Fig. 17) was set over the field joint to keep out rain and wind. The flanges were preheated to 300 F minimum with four propane burners placed on the bottom of each flange. The required preheat temperature was obtained in about twelve hours. Interpass temperatures of about 400 F were maintained on webs and flanges.

Three welders were used simultaneously, and welding continued until the joint was completed. The first joint was completed before the second was started. Welds were completed in the following order:

1. Welding started on the top of both the top and bottom flange in the downhand position. Root passes were made with $^3/_{16}$-in. diameter electrodes. These were followed with $^1/_8$, $^3/_{16}$, and $^7/_{32}$-in. diameters to complete the top of the flanges.
2. The insides of the webs were preheated with rosebud torches and welded using $^1/_8$ and $^3/_{16}$-in. electrodes.
3. Flanges and webs were back gouged to sound metal and welds were completed on the second side. All preheat was maintained using rosebud torches.
4. The welds were ground flush to improve their fatigue strength.

Radiographic Inspection

All flange butt welds passed x-ray inspection. However, the web butt welds had porosity. The south end web butt welds had to be completely gouged and ground to sound metal and re-welded. The north end web butt had two areas less than 3 in. in length requiring repair. After repair, the web butt welds passed x-ray inspection also.

Welding of Beam Cap Connections

Fifteen wide flange beams were welded to each side of the cap of the rigid frame bent. Preheat was applied with propane heaters on the inside of the cap and the beams were preheated with rosebud torches, all to a temperature of 100 F. The beams were welded to the cap using full penetration welds. A cover plate was fillet welded across the top of the beams and the cap. These welds were all checked by ultrasonic inspection. A few small repairs were required.

One unfortunate event occurred on this part of the project when some youngsters shut off the propane gas at night. When workmen attempted to relight the burners trapped gas exploded inside the cap. The only damage found was bowing of the web plates at the access doors approximately $^1/_2$ in. in 4 ft of length. All welds were magnetic particle inspected again and found to be sound.

Field Erection and Welding Time

Erection and welding of the bent was completed in three weeks, and all steel erection and welding was completed in three months even though the erector was delayed by mud and surface water (Beaumont had 70 inches of rain the year of erection).

The A 514 steels proved to be weldable under field conditions using proper preheat procedures. Preheating in the field was not a major problem.

CONCLUSIONS

1. The use of the single rigid frame bent solved the problem of location of columns in the traffic intersection.
2. The use of ASTM A 514 steels permitted the use of a single rigid frame bent. With lower strength steels the height of the cap would have been excessive.
3. The use of the A 514 steels developed savings in fill, right-of-way, and depth of roadway depression.

4. Grades D and E of ASTM A 514 proved to be weldable in heavy sections in joints of high restraint and were stress relief heat treated with no problem. Low hydrogen procedures had to be used.

5. Field welding of butt joints in $3\frac{1}{2}$-in. thick A 514-E (SSS 100) flanges and 1-in. A 514-D (SSS 100A) webs, and field welding of A 441 beams to the flanges and webs was accomplished with no problems.

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