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BEHAVIOR OF WELDED BUILT-UP BEAMS UNDER REPEATED LOADS

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Fatigue tests on built-up beams indicate that the presence of a splice materially reduces the fatigue strength of a welded beam. A difference in fatigue strength is also revealed for the different splice configurations

BY J. E. STALLMEYER, W. H. MUNSE AND B. J. GOODAL

SUMMARY. Flexural fatigue tests have been conducted on small all-welded beams fabricated from A373 steel. All beams were fabricated by manual arc welding using E7016 electrodes and a back-stepping welding procedure. Several field splice configurations were used in the investigation, and studies made of the difference in their modes of failure as well as the difference in their fatigue strengths. In addition, the program included fatigue tests on control specimens to determine the fatigue strength of the A373 steel as-received from the mill and also with butt-welded joints, either parallel or perpendicular to the direction of stress.

The fatigue tests on the beams indicate that the presence of a splice materially reduces the fatigue strength of a welded beam. A difference in fatigue strength is also revealed for the different splice configurations.

Introduction

Object and Scope of Investigation

The increased use in recent years of all-welded girders along with the variety of procedures used by different fabricators and designers for making splices and attaching stiffeners has resulted in the existence of a large variety of welded bridge details. With the limited number of tests available and because of relatively limited experience, it is not possible to specify which of the splicing procedures is best for maximum resistance to repeated loads. In order to evaluate some of the more common splicing procedures, this investigation on all-welded beams was undertaken.

The primary purpose of the initial phase of the investigation was to study the effect of typical butt-welded field splices on the flexural fatigue strength of all-welded built-up beams and girders. Four splice types, derived from two basic splice configurations either with or without cope holes, were investigated while beams without splices and beams with cope holes only were included in the program as control specimens.

Preliminary tests were carried out on specimens fabricated from a typical structural grade steel to study the effect of varying the thickness of the web and to develop sound welding and fabricating procedures. In addition to these preliminary tests, control specimens of an A373 steel were tested to determine the fatigue strength of plain plate and butt-weld specimens.

Description of Steels

The majority of the tests reported herein were conducted on specimens fabricated from A373 steel; however, the preliminary program was carried out on specimens made from a structural grade steel. This steel was taken from stock which was available in the laboratory, while the A373 steel was ordered for use on this program. The chemical composition and physical properties of materials used are given in Tables 1 and 2. The chemical properties were determined from check analyses and the physical properties were determined from standard flat specimens cut from the parent plates.

All of the A373 steel met both the physical and chemical requirements of ASTM Designation A373-54T.

Table 1—Chemical Composition of Steel Plates

Steel	Plate thickness, in.	Chemical content, % C	Mn	P	S	Si	Cu
Structural	1/4	0.22	0.32	0.012	0.035	..	..
Structural	3/4	0.28	0.44	0.016	0.029	..	..
Structural	1	0.28	0.44	0.016	0.029	..	..
A373	3/16	0.23	0.63	0.022	0.031	0.030	0.17
A373	1	0.21	0.60	0.030	0.030	0.053	0.20

Table 2—Physical Properties of Steel Plate (8-In. Gage Length Tensile Coupons)

Steel	Thickness, in.	Yield strength, psi	Ultimate strength, psi	Elongation in 8 in., %	Reduction of area, %
Structural	3/16	44,800	67,800	25.5	52.7
Structural	1/4	37,100	50,700	32.8	66.0
Structural	3/4	35,300	64,600	30.3	51.3
Structural	1	35,000	61,200	34.2	63.7
A373	3/16	38,800	64,800	29.6	58.0
A373	1	34,600	67,000	28.0	48.6

Preparation of Beams Without Splices

All beams used in the investigation were of uniform cross section throughout their length. The flange and web plates were cut from stock with a dual-torch oxygen cutting machine. Where plates were taken out next to a sheared edge, a strip adjacent to the sheared edge and about 1 in. wide was discarded. Thus, all edges of plates used in the test specimens were flame cut. Any plates which had severe notches or other de-

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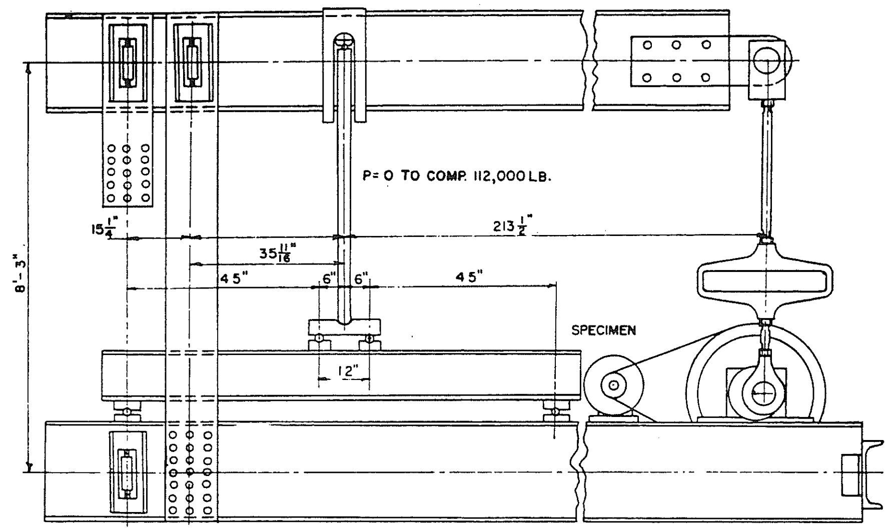


Fig. 1 200,000-lb. Wilson fatigue testing machine adapted to test flexural specimens

fects, due to cutting or handling of the material, were discarded. Plates with minor defects were used, but the severity of such defects was lessened by grinding them to a smooth transition. All slag and burrs on all edges of the plates and mill scale in the region of the weld were removed.

In assembling the specimens, a flange plate was first laid on the flange of an H-beam. (A stiff H-section, approximately as long as the specimen, was used. Such a section could resist the clamping forces required to align the parts and to bring them into proper contact with each other, without undergoing appreciable deformation.) The web plate was then carefully aligned, securely clamped and tacked to the flange by full-size fillet welds spaced about 16 in. apart. The T-section thus formed was turned over, set on the second flange plate, clamped in position and tacked. All tack welds were cleaned and the specimen was ready for deposition of the web-flange fillet welds.

Details of the principal fillet welding sequence are given in Fig. 3. However, this sequence is slightly different than the initial sequence used in fabricating the specimens in the preliminary series and a number of the earlier specimens of the tests reported herein. The two procedures were identical in all but two particulars. In the initial sequence the welder changed location after each deposition of weld. This was changed in the later tests so that three electrode lengths were deposited by the back-step method before the location of deposition was changed. Also, a nine inch release length allowed in the initial sequence was eliminated in the later members.

Distortions which were found in some of the first test specimens resulted from the cutting of the stock and from the welding. The use of the dual-torch cutting machine practically eliminated the first of these two items, but the distortion due to welding varied with the welding sequence. The distortion in the specimens welded in accordance with the initial welding sequence was negligible while in the specimens welded with the later welding sequence the distortion was noticeable. However, the latter sequence is more nearly that found in use in the large fabricating shops.

Fabrication of Spliced Beams

The two parts of a spliced beam were obtained in two different ways. In one case the two halves were fabricated individually in accordance with the welding procedure outlined for beams without splices. In the second case the

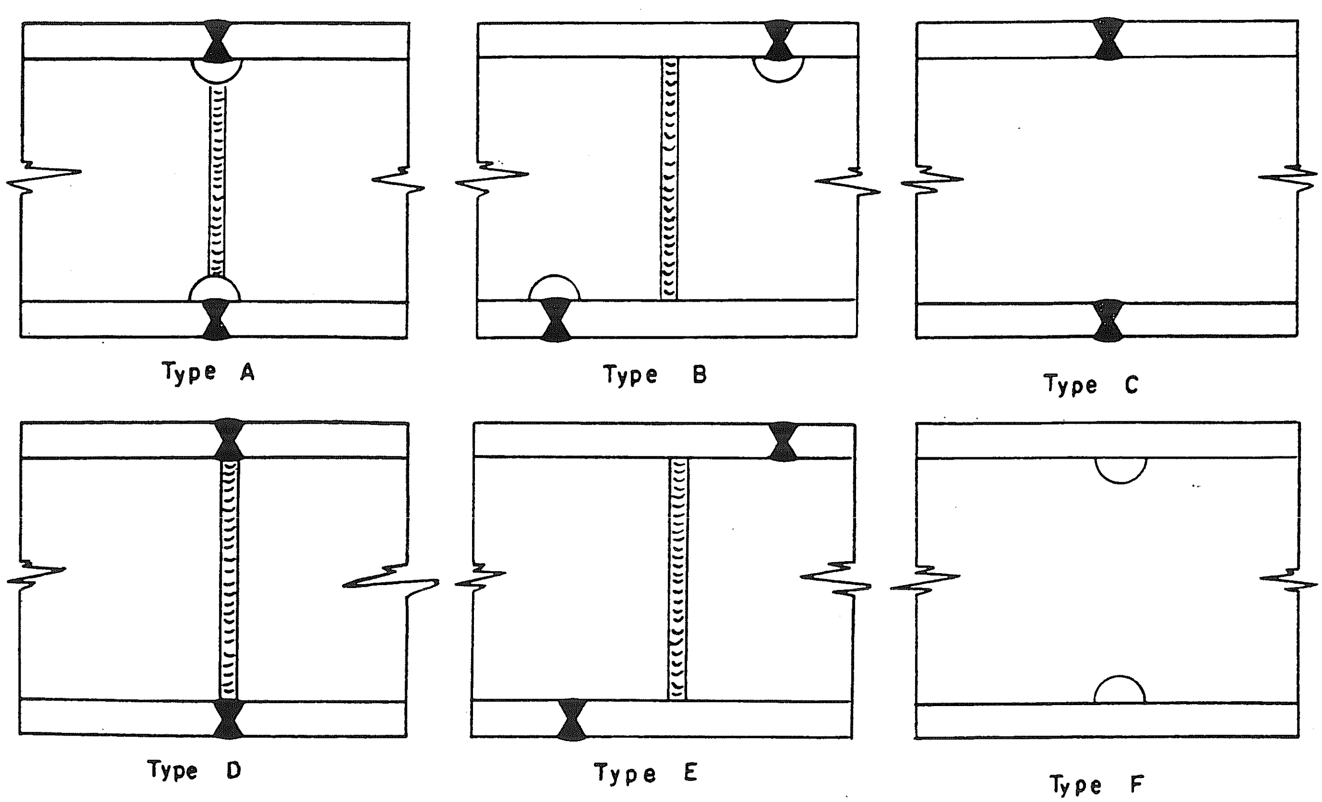
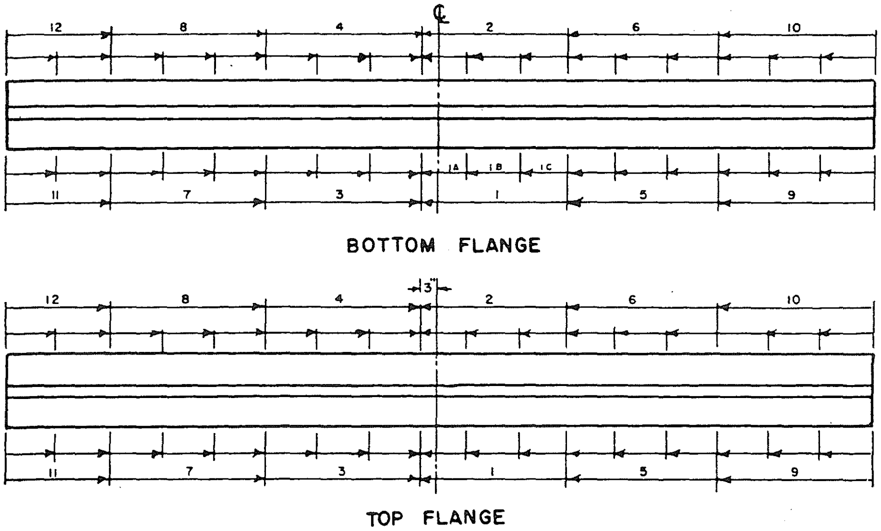


Fig. 2 Splice types



Welding:

1/4" Fillet Weld, 5/32" dia. E7016 Electrode—175 amps

Note:

Inside arrows indicate the deposition of individual electrodes
Outside arrows and the numbers indicate the welding sequence

Fig. 3 Principal fillet welding sequence

spliced beams were fabricated from parts obtained from specimens which had already been tested. This was carried out in the following way.

All specimens were fabricated 2 ft 6 in. longer than the span on which they were tested and provided a 1 ft 3 in. overhang at each end. After failure had occurred, the fracture and a portion of the beam on each side of the fracture were removed. This left two pieces which were of sufficient length to provide an additional spliced specimen. The overhangs had been subjected to no load and, therefore, when turned end for end and rewelded, these two pieces provided an additional spliced beam.

The ends of all flange plates were bevelled with the oxygen cutting machine for a double-V butt joint having an included angle of 60 deg. Since the web material was only $^3/_{16}$ in. thick, the bevels for the single-V web joints were made with a portable disc grinder.

Two procedures were followed in cutting cope holes. In the initial welding sequence, the holes were cut to full size ($^3/_4$-in. radius) before the specimen was assembled (see Fig. 4). In the principal welding sequence a semi-elliptical hole [with 2-in. major axis (flange direction) and 1-in. minor axis] was cut before the specimen was assembled. After specimen was assembled and the web splice completed, the semi-elliptical hole was made into a semi-circular hole with a 1-in. radius (see Fig. 5). This removed the ends of the welds in the web splice.

Designation of Beams

The numbering system used for the test specimens has been chosen so that the various fabrication and test conditions can be identified from the specimen number. The identification number of the initial or preliminary beams consisted of a capital letter and a number, e.g., Specimen D-1. The corresponding specimen of the later tests was identified as Specimen D-1a. Specimens fabricated with the principal welding sequence have an identifying R in the specimen number.

Test Procedure

All of the fatigue tests reported herein

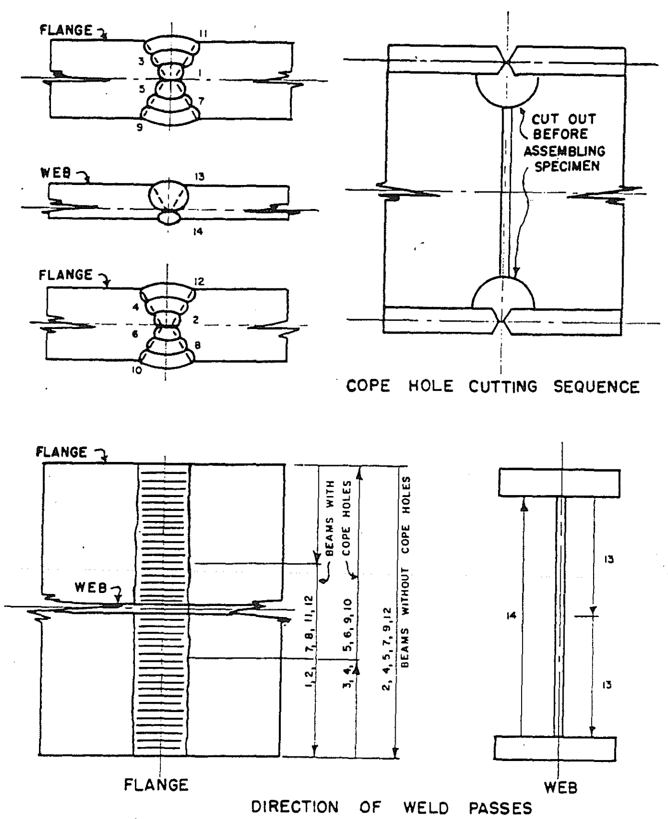


Fig. 4 Initial welding sequence for butt splices

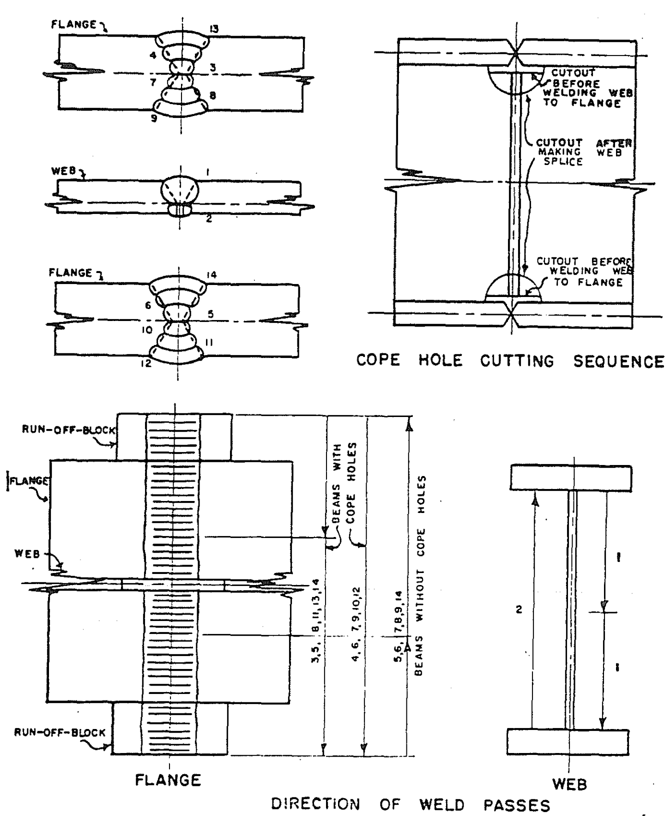


Fig. 5 Principal welding sequence for butt splices

were conducted in 200,000-lb Wilson lever-type fatigue testing machines. A schematic diagram of the machine, adapted to test flexural members, is shown in Fig. 1. Essentially, its operation is as follows: The force is derived from a variable throw eccentric mounted on the end of a shaft driven by an electric motor. As the eccentric revolves it imparts to the overhead walking beam, which is pivoted about a bearing located in the vertical support post, a pumping motion. This pumping motion of the walking beam is in turn transmitted to the specimen through the loading yoke, thereby subjecting the specimen to a cyclic flexural stress.

Installation of the specimen in the machine was generally a simple operation. Longitudinal and transverse centerlines to locate the loading and reaction blocks were marked on the specimen before it was set into the machine. The specimen was then set on the reaction blocks, centerlines on the specimen were matched with their respective lines on the blocks, the blocks were clamped in place, and the loading yoke was lowered into position to set the load.

The specimens were tested on a span of 8 ft 6 in. with two concentrated loads, 12 in. apart, placed symmetrically about the centerline of the span. The stress in the extreme fiber of the beams was calculated by the usual straight line formula, $s = Mc/I$, using a moment of inertia based on the actual dimensions. All tests were conducted on a cycle in which the stress at the critical section, on the extreme fiber, varied from a minimum of 1000 psi to a maximum of 30,000 psi. This one stress cycle was used throughout the study in order that each of the variables included in the program might be evaluated under the same loading condition.

Throughout this report the specimen was considered to have "failed" when the center deflection of the beam, because of the fatigue crack, was 0.05 in. in excess of the deflection at maximum load on the uncracked section. This was found to occur, in general, when approximately one-half of the flange area had fractured.

Test Results

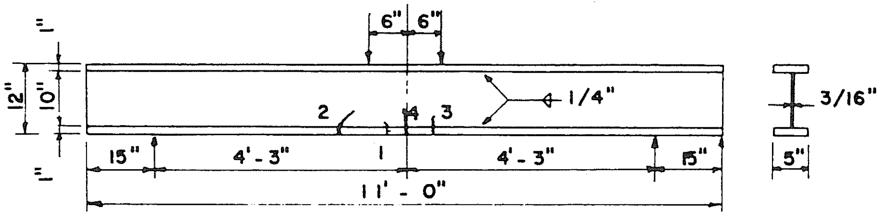
Beams Without Splices

Four beams without splices were tested in this study. In addition to furnishing the fatigue strength of plain, welded built-up beams, the purpose of this series was to establish a datum to facilitate the comparison of data gathered in the program. The results of the tests are presented in Table 3.

In view of the magnitude of scatter generally obtained in fatigue investigations, the results of the first three specimens are somewhat unusual. Such consistency is rarely encountered in fatigue results.

The relatively low value of cycles to failure for Specimen A-4R brings out a fact often observed in fatigue data. In many instances, supposedly identical specimens fabricated with extreme care often have widely differing fatigue lives.

Table 3—Summary of Flexural Fatigue Test Results



Specimen	Splice* type	*Maximum stress in external fiber, 1000 psi*	*Cycles for failure, 10^3*	*Location† of fracture*
		Beams without splices		
A-1	None	30.0	1466.6	1
A-2	None	30.0	1490.4	2
A-3	None	30.0	1443.4	2
A-4R‡	None	30.0	860.7	3
		Avg	1315.2	
		Beams with cope holes only		
C-1R	None	30.0	352.8	4
C-2R	None	30.0	490.7	4
C-3R	None	30.0	442.9	4
		Avg	428.8	
		Spliced beams, group No. 1		
A-1a	A	30.0	206.1	4
A-2a	A	30.0	175.5	4a
A-3aR	A	30.0	280.3	4
A-4aR	A	30.0	207.7	4b
		Avg	217.4	
		Spliced beams, group No. 2		
B-1a	D	30.0	270.9	4a
B-2a	D	30.0	450.8	4
B-3aR	D	30.0	342.7	4a
B-4aR	D	30.0	319.0	4b
		Avg	345.9	
		Spliced beams, group No. 3		
D-1R	B	30.0	209.0	4
D-2R	B	30.0	416.8	4
D-3R	B	30.0	367.5	4
		Avg	331.1	
		Spliced beams, group No. 4		
D-1aR	E	30.0	396.5	4b
D-2aR	E	30.0	412.6	4a
D-3aR	E	30.0	376.9	4a
		Avg	395.3	
		Spliced beams, group No. 5		
B-1	C	30.0	514.5	4b
B-2	C	30.0	775.1	4b
		Avg	644.8	

* See Fig. 2 for Splice Types.

† 1—Edge of flange 2 in. from centerline. 2—Region of change of electrode 9-in. from centerline. 3—Region of change of electrode 4-in. from centerline. 4—Toe of fillet weld at edge of cope hole. 4a—Through butt joint. 4b—Along edge of butt-weld reinforcement.

‡ R—Indicates principal welding sequence.

Table 4—Description of Initial Welding Sequence

Step No.	Pass No.	Remarks
1A	..	Jig web and flange and clamp
2A	..	Deposit fillet welds
Start butt splice welds with web in vertical position		
1	1	Flange weld (see Fig. 4)
2	2	
3	3	
4	4	
5	..	Turn beam over and back-chip passes No. 1 and No. 2
6	5	
7	6	
8	7	
9	8	
10	9	
11	10	
12	..	Turn beam over and complete flange splices
13	11	
14	12	
15	..	Set beam with web in horizontal position
16	13	
17	..	Turn beam over and back-chip pass No. 13
18	14	

NOTE: All welds were made with reversed polarity, in the flat position and with AWS-ASTM E7016 electrodes.

Several factors could have contributed to the lower fatigue life of Specimen A-4R. First, this was the only specimen prepared in accordance with the principal welding sequence. However, it seems doubtful that the change in welding sequence could have affected the fatigue life to this extent. Second, an examination of the fracture surface revealed that a very minor metallic inclusion existed at the root of one of the fillet welds—no inclusions were observed in any of the other three specimens. Closer examination of the fracture surface revealed, however, that the fracture initiated at the root of the weld on the opposite side, where no inclusion was observed. Consequently, there does not appear to be any justifiable explanation for the short life of the member.

Photographs of typical fracture locations and fracture surfaces are shown in Fig. 6. In Specimens A-2, A-3 and A-4R the failure initiated at the root of the fillet weld in the region of a change of electrode, but in the case of Specimen A-1, failure initiated at the edge of the flange. The fracture surface of this latter specimen showed no unusual defects or stress raisers at the point of crack initiation.

The fractures of Specimens A-1 and A-4R occurred in the region of pure bending, between the load points, 2 in. and 4 in. from the centerline, respectively. However, Specimens A-2 and A-3 failed in a zone of combined shear and flexure, 9 in. from the centerline.

In one case, Specimen A-3, there was a major lamination in the plate used for the tension flange; the material appears to be made up of two half-inch thick plates. The fatigue life was, however, unaffected. It appears that, even though the defect is large, it has little or no effect on the life of the specimen if it is oriented in a direction parallel to the applied stress.

Beams with Cope Holes Only

Generally, the quality of double-V butt joints in the flanges of beams and girders is comparable to that found in similar joints in plain plates. However, special precautions are often required to make it so. One area in particular, because of its inaccessibility, is inducive to unsound and imperfect welds; the area at the junction of the web and the flange. A method long used in commercial practice to make the area more accessible has been to cut out a semicircular hole (cope hole) in the web of the beam immediately above the flange splice. By providing the cope hole it is possible, by bringing the electrode through the hole, to start the weld bead in a region where the ends of the weld are accessible for proper cleaning before the adjacent pass is deposited. There can be little doubt that this procedure results in more sound welds. However, there is some question concerning the severity of the stress concentration created by the cope hole. The purpose of this series of cope hole tests was to evaluate the effect of the cope hole.

On the basis of the tests of this series, presented in Table 3, the average life of plain beams with cope holes only is found to be about 29.2% of the average life of plain beams and in all cases, the crack initiated at the top of the cope hole at the centerline of the beam and propagated vertically into the web. After the crack had reached a length of about 1 in., a second crack appeared in the flange at the toe of the fillet weld around the edge of the cope hole.

It is possible that the practice of filling the cope hole could result in an improvement in the fatigue strength provided that in filling the cope hole other serious stress raisers are not created.

Spliced Beams

Two basic splice configurations were studied in the program with the cope hole introduced into each of the basic configurations to yield four splice types. Details of the splice types are shown in Fig. 2 and the results of the tests are included in Table 3.

It should be pointed out that all passes were deposited in the flat position. Such a procedure could hardly be followed in the field where it is impossible to turn the beam over. However, it was felt that this change would not detract from the validity of the investigation. A weld made in the overhead position, by a qualified welder, following recommended practices, is in general considered to be as sound as a similar weld deposited in the flat position. Since the strength of the weld is primarily a function of its quality, welds of equal quality may be expected to have equal fatigue strengths regardless of the position in which they are deposited.

In addition, all of the joints in this investigation were double-V butt joints. It is common practice to use single-V butt joints in field splices, oriented so that most of the welding can be done in the horizontal position. Other investigations (2) of joints in plain plates have shown that the fatigue strength of single-V butt joints is generally as high and often higher than that of double-V butt joints. Therefore, the results of this series of tests should be a fairly good measure of the fatigue strength of welded beams with various types of splices.

Table 5—Description of Principal Welding Sequence

Step No.	Pass No.	Remarks
1A	..	Jib web and flange and tack
2A	..	Deposit fillet welds in sequence shown in Fig. 3
Start butt splice welds with web in horizontal position		
1	1	Web weld (see Fig. 5)
2	..	Turn beam over and back-chip pass No. 1
3	2	Complete web splice
3a	..	Cut cope holes (only where applicable)
4	..	Set beam with web in vertical position
5	..	Tack run-off blocks to flange (place tacks in grooves only)
6	3	Top flange weld
7	4	
8	5	Bottom flange weld
9	6	
10	..	Turn beam over and back-chip passes No. 3 and No. 5
11	7	
12	8	
13	8	
14	10	
15	11	
16	12	
17	..	Turn beam over and complete splice
18	13	
19	14	
20	..	Cut away run-off blocks and grind edge of flange smooth and flush

NOTE: All welds were made with reversed polarity, in the flat position and with AWS-ASTM E7016 electrodes, 5/32 in. diam.

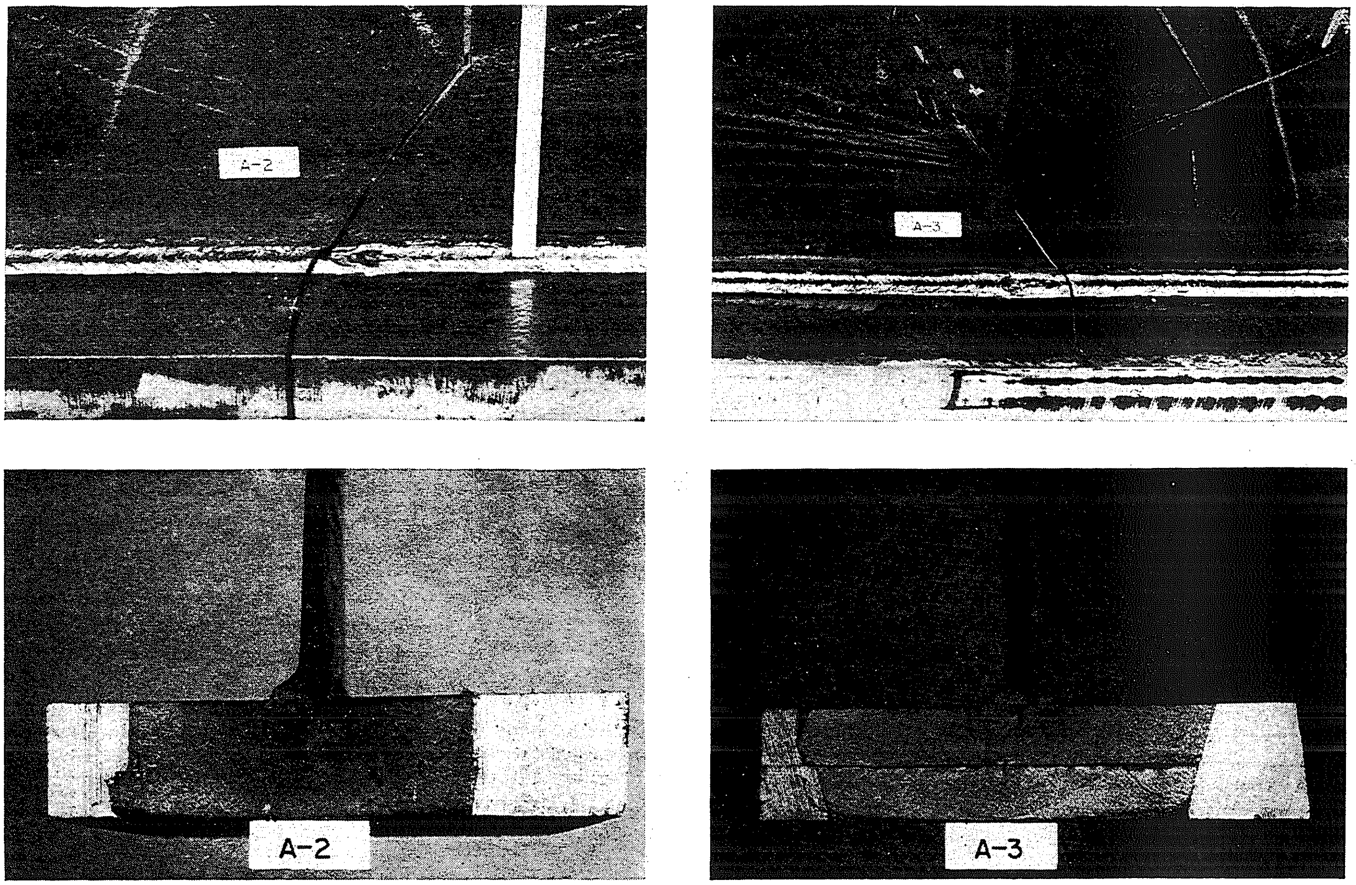


Fig. 6 Typical fractures of beams without splices

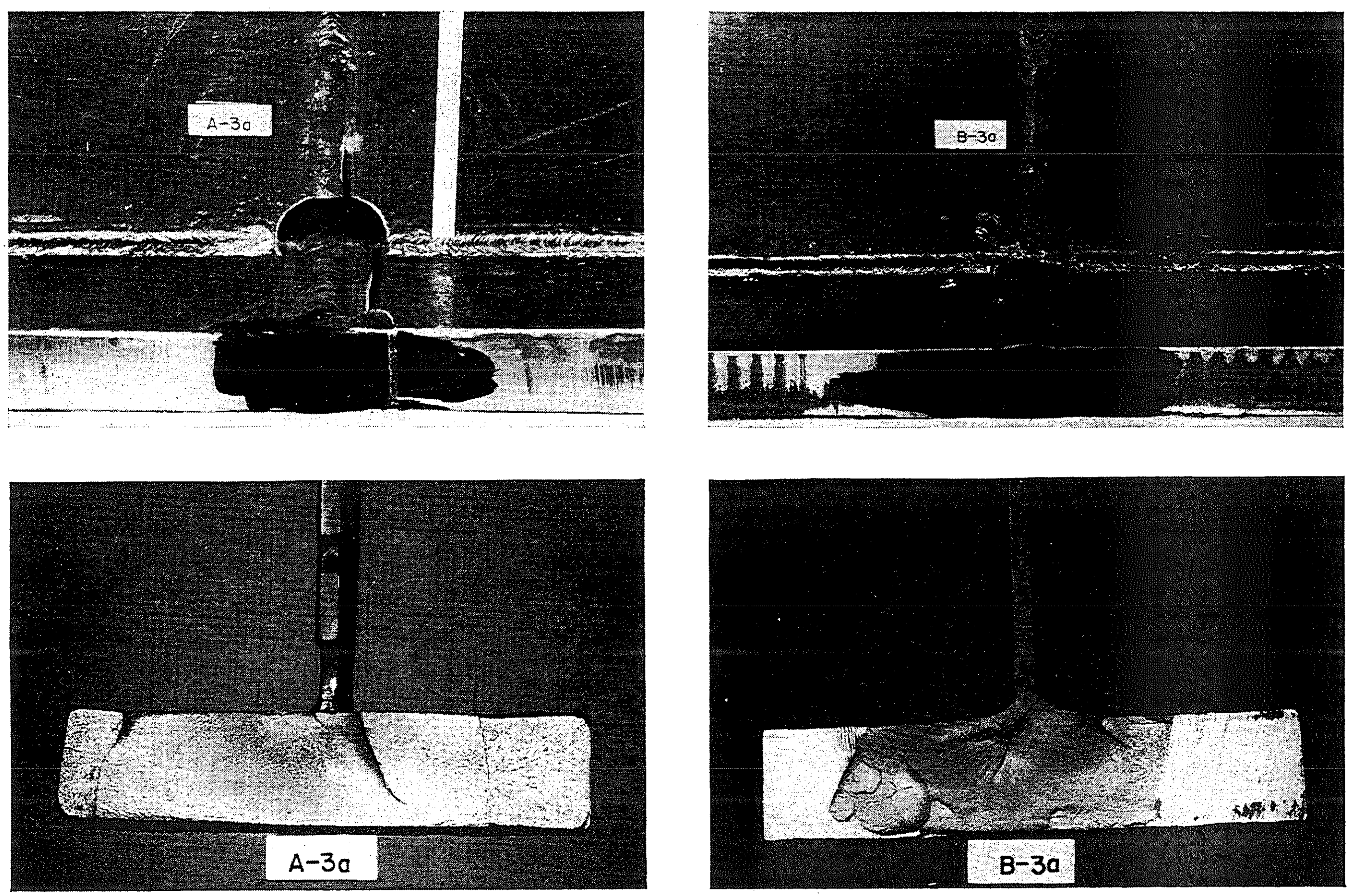


Fig. 7 Typical fractures of spliced beams

Table 6—Results of Fatigue Tests on Plain Plate, Transverse and Longitudinal Butt-Welded Specimens

Specimen	*Stress, psi*	*Cycles for failure, 10^3*	*Fatigue strength**: *A373 steel, $f_{2,000,000}$*	*Fatigue strength**: *A7 steel, $f_{2,000,000}$*	*k*
		Plain plate specimens			
F-1	36,000	1046.0	32,100		
F-2	36,000	964.3	31,600		
F-3	36,000	1751.6	35,200		
		Avg	33,000	34,600	0.18
		Transverse butt-welded joints			
F-1T	25,000	859.7	22,400		
F-2T	25,000	978.8	22,800		
F-3T	25,000	882.1	22,400		
		Avg	22,500	23,800+	0.13
		Longitudinal butt-welded specimens			
F-1L	27,000	1623.1	26,200		
F-2L	25,000	3723.3	25,000+		
F-3L	27,000	3656.0	27,000+		
		Avg	26,100+	26,300	0.13

* Results of tests on A7 steel taken from bibliography Reference 3.

Splice Type C, which is essentially a shop splice because of the manner in which it is fabricated, has been included in this paper to show the advantage in strength of a "partial" splice over a "complete" splice. The splices in the flanges were made before the specimens were assembled. The reinforcement on the inside of the flange was ground flush with the plate so that it would not interfere with the web and the fillet weld at the junction of the web and the flange.

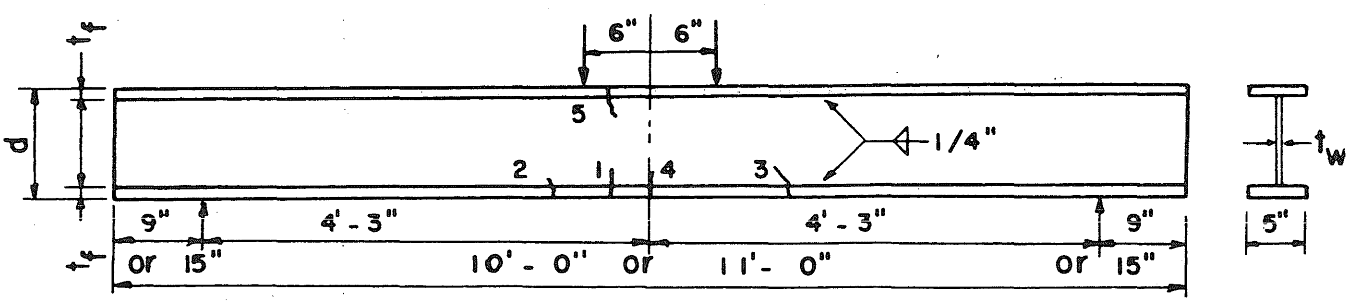
Splice Types A and D

The basic configuration of these two splice types was a complete splice (joints in both flanges and web) made in the same cross section. The specimens were identical with the exception of the cope holes provided in Type A. Fatigue lives determined for four specimens of each type are given in Table 3 along with the average of the test results. Based on the average life of the first three beams without splices, the life of the beams of splice Type A is only 15% as great while the life of Type D was 24% as great. In only one case was there any overlapping of the test results of the Types A and D splices. In all other instances the Type D splices exhibited the greater resistance to repeated loads.

Metallurgical examinations of the fractures revealed that Specimens A-1a and A-3a failed at the edge of the cope hole in the base material of the flange. This type of failure is undoubtedly caused by the stress concentration effect of the cope hole. Specimen A-2a, which had the lowest fatigue life, had poor root bonding of the butt weld in the flange and started to fracture at this point of poor bonding. The fracture in Specimen A-4a initiated at the weld metal-base metal interface in the flange. The results of the fatigue tests are, however, fairly consistent and would indicate that the presence of the cope hole is practically as harmful under repeated loadings as the presence of a severe stress concentration within the weld itself.

A metallurgical examination of the Type D splices revealed that all of the failures initiated at the weld metal-base metal interface in the flange. In Specimen B-2a there were two failures. On one side of the butt weld in the flange the specimen failed completely through the flange, while on the other side there

Table 7—Specimen Description and Summary of Test Results of the Preliminary Series



Specimen	*d, in.*	*b, in.*	*t_f, in.*	*t_w, in.*	*t_f/t_w*	*Splice* type*	*Max stress in ext. fiber, 1000 psi*	*Stress in weld, psi*	*Cycles for failure, 10^3*	*Location† of fracture*
P-1	11 1/2	5	3/4	3/4	1.0	None	30.0	2440	830.1	1
P-2	11 1/2	5	3/4	1/4	3.1	None	30.0	2340	1037.3	1
P-6	11 1/2	5	3/4	3/16	4.3	None	30.0	2340	1793.4	5
P-7	12	5	1	3/16	5.3	None	30.0	3055	2164.3	3
P-3	11 1/2	5	3/4	1/4	...	A	30.0	2340	350.9	4
P-4	11 1/2	5	3/4	1/4	...	B	30.0	2340	450.7	4
P-5	11 1/2	5	3/4	1/4	...	C	30.0	2340	563.6	2
P-2a	11 1/2	5	3/4	1/4	...	D	30.0	2340	1357.5	4a
P-3a	11 1/2	5	3/4	1/4	...	D	30.0	2340	571.9	4a
P-6a	11 1/2	5	3/4	3/16	...	D	30.0	2340	767.5	4a
P-7a	12	5	1	3/16	...	D	30.0	3055	459.4	4b

* See Fig. 2 for splice types.
† 4—Toe of fillet weld at edge of cope hole. 4a—Through butt joint. 4b—Along edge of weld reinforcement.

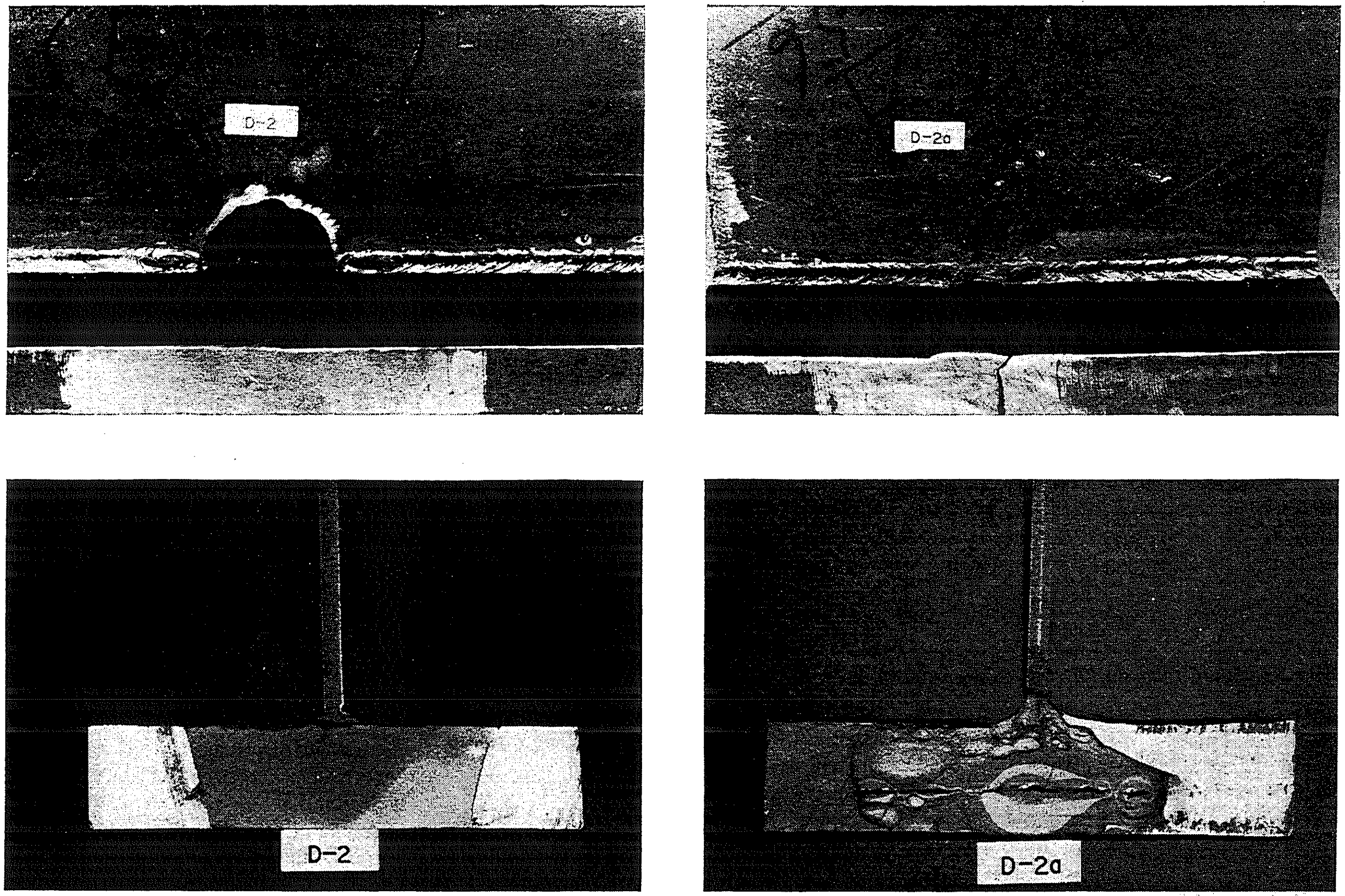


Fig. 8 Typical fractures of spliced beams

was only a partial failure. Typical fracture locations and fracture surfaces are shown in Fig. 7.

A hardness survey across the interface of base metal and weld metal of Specimen B-2a revealed two points of peak hardness in the heat-affected zone of the base metal. This area of high hardness can be interpreted to mean that this region had low ductility compared to the other regions. This discontinuity in the microstructure probably acted as a stress raiser and led to an earlier failure than would be expected if the material in the beam had a more homogeneous microstructure.

Splice Types B and E

In this case the splice was a complete splice made at three points along the beam length. Joints in the flanges were made at sections which were 4 in. on either side of the joint in the web. The major variable again was the cope hole. Splice Type B was made with cope holes and Type E was made without cope holes.

The fatigue test results indicate that the Type B specimens had fatigue lives which were approximately 84% of the fatigue life of the Type E specimens. These results follow the pattern indicated by the previous results in that the splices with cope holes are consistently weaker than the splices without cope holes. Based on the average life of the first three plain beams, the life of the splice Type B was 23% and that of Type E was 27% as great.

In splice Type B the fillet weld was terminated in two different ways at the cope hole. On one side of the cope hole the fillet weld was carried all the way around the cope hole, whereas, on the other side of the cope hole, the weld was brought just up to the cope hole. The metallurgical examination showed that failure occurred on the side of the cope hole where the fillet weld was not carried around. It would appear that the fatigue lives would be somewhat longer if the fillet weld had been carried around on both sides of the cope hole. However, in at least one case there was evidence that a small fatigue crack had started on the side of the cope hole where the fillet weld had been carried around. It would seem, therefore, the increase which would be obtained by this procedure would be relatively small.

An examination of the fatigue failures in the Type E specimens revealed that D-2a and D-3a had poor root bonding of the weld in the butt weld in the flange. This type of failure has already been discussed for Specimen A-2a. In the case of Specimen D-1a the failure occurred at the weld metal-base metal interface of the flange weld and was similar to that reported for B-2a. Typical fracture locations and fracture surfaces are shown in Fig. 8.

Splice Type C

The Type C splice, which is a shop splice, is considerably stronger than any of the other splices tested. Based on the average life of the first three plain beams, the life of this type of splice was 44% as great. This is not unexpected since the welds in the flange plates can be made under better conditions and undoubtedly result in higher quality welds.

Metallurgical examination revealed that all failures initiated at the weld metal-base metal interface in the flange. In one case, however, an additional fatigue crack had started at a change of electrode in the fillet weld just 3 in. from the flange splice. A hardness survey revealed that this latter failure occurred at a location of minimum hardness in the weld metal. This hardness valley was due to the heat treatment of the first weld deposit by the second electrode deposited. As in the case of a peak hardness, this hardness valley may act as a stress raiser and, along with the geometrical notches in the weld, may cause a fatigue crack to initiate.

Results of Control Specimen Tests

No data were available from which

the fatigue strength of the A373 steel could be determined and compared to results from another structural grade steel. For this reason several flat-plate fatigue specimens were prepared and tested on a zero to tension stress cycle. The specimens conform to those which have been used in previous investigations at the University of Illinois on the fatigue strength of welded joints.

The dimensions of the specimens used to determine the fatigue strength of the A373 steel are shown in Fig. 9. The welding procedure, as well as the dimensions of the specimens, was identical to that which was used in previous investigations. For a complete description of the welding procedure the reader is referred to a report of the previous investigation.[1]

Three specimens of each of the three types to be tested were prepared: three plain-plate specimens, three specimens with a butt weld perpendicular to the direction of the applied stress, and three specimens with a butt weld parallel to the direction of applied stress. All specimens were tested in the as-welded condition with the reinforcement on.

The results of the tests, in terms of maximum stress and cycles to failure, are presented in Table 6. In addition to the presentation of the test data and the fatigue strength corresponding to 2,000,000 cycles, the average fatigue strength of each group has been compared with the average fatigue strength of similar specimens in another steel reported in a previous paper.[3] The fatigue strengths were calculated from the test results in accordance with the procedure outlined in the reference paper. The two steels were compared only at 2,000,000 cycles because it was thought that the extrapolation to 100,000 cycles was too great to provide reliable values from the data available.

The fatigue failures in the A373 steel initiated in the same general regions as those which occurred in the steel which had been tested previously. In the case of the transverse butt joint the failures initiated at the edge of the weld reinforcement in the parent plate. The fracture took a random path through the weld metal and base metal with better than 90% of the fracture occurring in the base metal. The failures in the longitudinal butt-welded joints initiated in a region of the outside pass where a change in electrode had been made. This point of initiation of the fatigue failure corresponds to the point of weakness which was observed in the beams without splices.

On the basis of these tests, it may be concluded that the strength of A373 steel is approximately the same as that of the other steel when the tests are conducted on the same type of specimen. There is certainly no marked difference in the fatigue strength in any of the three specimen types which were tested.

Beam Specimens Fabricated from an Ordinary Structural-Grade Steel

As mentioned earlier in the paper, the first beams tested in this investigation were fabricated from a steel which was available in the laboratory. The purpose of these tests was to develop a suitable specimen into which the variables to be studied could be incorporated and also to work out the fabricating and testing procedures.

The results of the preliminary tests conducted in this part of the investigation are reported in Table 7 along with the dimensions of each particular specimen and the type of splice, if any, which was included in the test specimen. Although all failures in the beams without splices initiated in the same region, the initial direction of propagation seemed to depend on the ratio of flange thickness to web thickness. In Specimen P-1, for example, the crack progressed directly into the flange. In specimens where the ratio of flange thickness to web thickness was higher, the crack, upon formation, propagated into the web. Not until the crack had progressed about 2 in. into the web did it start to spread into the flange. In no case was the failure sudden; but, the rate of propagation was much greater through the flange than through the web. The fatigue life reported for Specimen P-1 is 1.5% higher than the life when the first visible crack was observed, whereas the fatigue life for P-7 is 10.8% higher than when the first crack was observed.

It is interesting to note that in the beams without splices, the fatigue lives increased consistently as the ratio of flange thickness to web thickness increased. Of course, with the limited number of tests, no general conclusions can be drawn but the results are certainly encouraging.

The failures in the spliced beams fabricated from stock steel were similar to those which were later found in the beams fabricated from A373 steel.

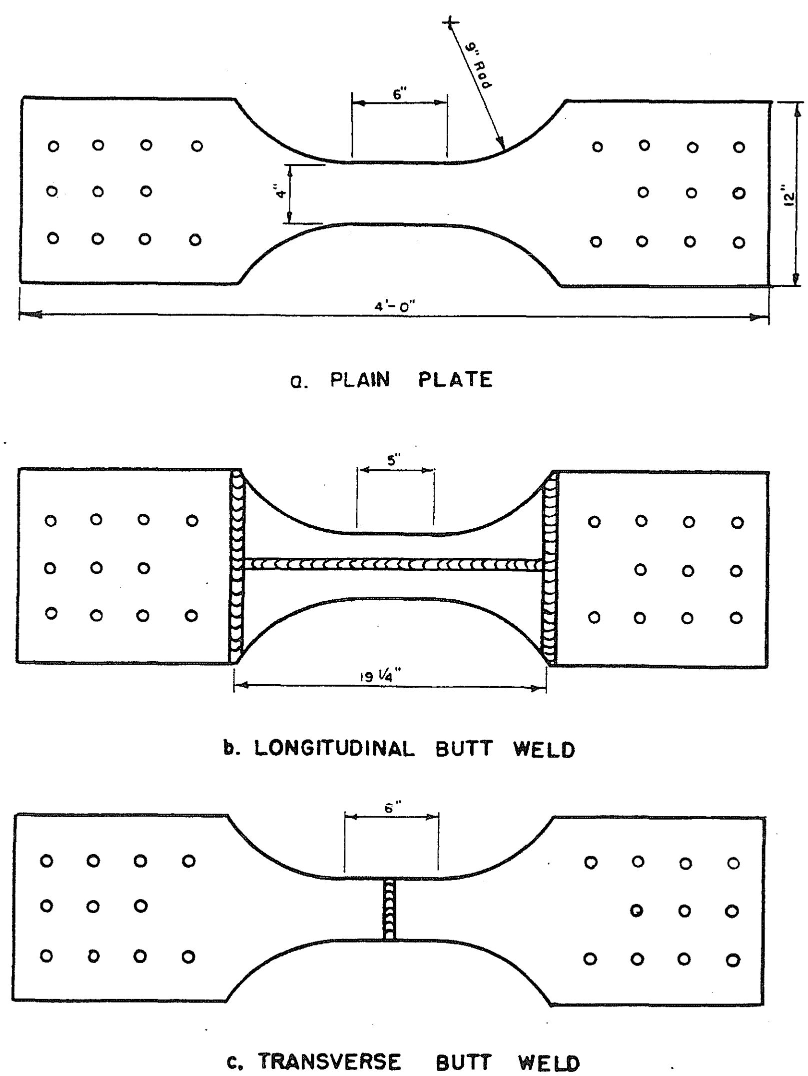


Fig. 9 Details of butt-welded joints

Specimen P-3 and P-4 failed in the tension flange at the toe of the fillet weld around the edge of the cope hole and propagated through the heat-affected zone parallel to the transverse butt weld in the flange. The failures of the other spliced beams initiated at the junction of the web and flange in the butt joint of the tension flange.

Conclusions

The following conclusions are based on the results of the limited experimental program discussed herein. Further tests on similar members of other structural grade steels and fabricated by other welders would probably modify some of the conclusions somewhat. However, it is believed that these tests provide the practicing engineers with realistic values for the fatigue strength that may be expected from properly fabricated welded beams.

1. In beams without splices, the fatigue fractures initiate in the fillet weld at the junction of the web and the flange in a region of change of electrode. Consequently, the use of continuous welding procedures may be expected to provide an increase in the resistance of such members to repeated loads. With the exception of one specimen the test results were extremely consistent.

2. The average life of the plain welded beams with cope holes only was 29% of the life of the beams without splices. All failures in this group initiated at the toe of the fillet weld around the edge of the cope hole. Splices with cope holes failed after a fewer number of cycles than the corresponding splice fabricated without cope holes. Splices with cope holes failed at the toe of the fillet weld around the edge of the cope hole. In splices without cope holes fracture generally occurred at the weld metal-base metal interface at the butt joint in the flange. Thus, the cope hole provides a stress concentration which is more severe than the other notches in a spliced beam and initiates the fatigue failures, although the life of such members is not greatly different than that of a member without cope holes.

3. Splice Type C (a shop splice) had a fatigue life considerably greater than the other types of splices.

4. The fatigue strength of beams without splices was found to increase as the ratio of flange thickness to web thickness increased and the greatest fatigue resistance was obtained for members with relatively thin webs and thick flanges. In addition, specimens with higher values of flange-to-web thickness ratios required a greater number of additional cycles for failure after a visible crack was observed than those with low values. This is the result of a difference in original direction of propagation of the fatigue crack.

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