SSC-130

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STUDIES OF BRITTLE-FRACTURE PROPAGATION IN SIX-FOOT-WIDE STEEL PLATES WITH A RESIDUAL STRAIN FIELD

by

F. W. Barton

and

W. J. Hall

SHIP STRUCTURE COMMITTEE

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April 3, 1961

Dear Sir:

As part of its research program related to the improvement of hull structures of ships, the Ship Structure Committee is sponsoring an investigation of Brittle Fracture Mechanics at the University of Illinois. Herewith is a copy of the Sixth Progress Report, SSC-130, Studies of Brittle-Fracture Propagation in Six-Foot-Wide Steel Plates with a Residual Strain Field by F. W. Barton and W. J. Hall.

This project is being conducted under the advisory guidance of the Committee on Ship Structural Design of the National Academy of Sciences-National Research Council.

This report is being distributed to individuals and groups associated with or interested in the work of the Ship Structure Committee. Comments concerning this report are solicited.

Sincerely yours,

EHThiele

E. H. Thiele
Rear Admiral, U. S. Coast Guard
Chairman, Ship Structure Committee

Serial No. SSC-130

Sixth Progress Report
of
Project SR-137

to the

SHIP STRUCTURE COMMITTEE

on

STUDIES OF BRITTLE-FRACTURE PROPAGATION IN SIX-FOOT-WIDE STEEL PLATES WITH A RESIDUAL STRAIN FIELD

by

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University of Illinois
Urbana, Illinois

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ABSTRACT

This investigation was undertaken to study the propagation of brittle fracture in six-foot-wide steel plates containing a residual strain field with primary emphasis placed on a determination of the fracture speeds and strains associated with a moving crack.

Five plates were prepared and tested in which the residual strain field was produced by welding tapered slots cut in the edges of the specimen. The test results clearly showed that the high residual tensile strain at the initiation edge aided the fracture initiation. For specimens with no external applied load, the fractures arrested before completely crossing the specimens; for specimens with external applied loads, even though low in magnitude, the fractures propagated completely across the plates.

The recorded fracture speeds were much lower than any previously noted in tests of six-foot-wide plates, ranging from about 4000 fps near the initiation edge to as low as 50 fps in the compressive strain region. The strain response as measured by gages located at various points across the plate showed that the magnitude of peak strain and the size of the strain field associated with the moving crack tip diminished as the fracture propagated through the compressive strain field at reduced speeds.

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INTRODUCTION

Object and Scope

With the increasing use of welding in shop and field fabrication, the effect of residual stresses in brittle fracture is receiving increasing attention. Little is known presently about either the effect of residual stresses on the initiation and propagation of a brittle fracture or the behavior of a propagating brittle fracture in a material containing residual stresses. Thus far, investigations have failed to conclusively determine what effect, if any, a residual stress field might have in regard to brittle fracture.

The purpose of this limited investigation was to study the effects of a residual strain field on the propagation of a brittle fracture in six-foot-wide steel plates. Primary emphasis was placed on a determination of the fracture speeds and strains associated with a propagating crack. Previous studies in connection with this same program on wide plates with no prestrain[1-4] and two-foot-wide plates containing a residual strain field[5] were valuable in providing an indication of the strain magnitudes and fracture speeds that could be expected and the type of strain fields that would be produced in two-foot-wide plates as a result of various methods of prestraining.

The initial phase of this investigation consisted of determining the most satisfactory method of producing a residual strain field in a six-foot-wide plate. The previous work on two-foot-wide plates had shown that the welding of tapered slots cut in each edge was the most satisfactory method for that particular size of specimen. After consideration of several other methods, it was felt that the same method would probably be the most satisfactory procedure for producing the desired residual strain field in six-foot-wide plates. This procedure, described in detail in the next section of this report, resulted in a high longitudinal tensile strain at both edges of the plate and a region of compressive strain in the central portion.

Six brittle-fracture tests were conducted as a part of this study. The first test, in which only static instrumentation was employed, was designed as a preliminary study in order to determine the strain pattern and corresponding magnitudes that would result from the adopted prestraining procedure and to determine whether or not a brittle fracture would initiate and propagate under such conditions. The second test was conducted on a noninstrumented, plain plate specimen containing no prestrain in order to determine the effect of the initiation technique on the initiation and propagation of a fracture. The remaining four tests were instrumented with strain gages and crack speed detectors, and in this way information was obtained about the behavior of the plate as a crack propagated through the residual strain field. This report consists of a description of the instrumentation, test procedure, and test results, as well as a discussion of the test results. A more detailed description of certain portions of the investigation is given elsewhere.[6]

Acknowledgment

This brittle-fracture mechanics study is a part of the structural research program of the Department of Civil Engineering at the University of Illinois and is sponsored by the Ship Structure Committee. The members of the Brittle Fracture Mechanics Advisory Committee, under the cognizance of the Committee on Ship Structural Design of the National Academy of Sciences-National Research Council, have acted in an advisory capacity in the planning of this program.

The project is under the general direction of N. M. Newmark, Professor and Head of the Department of Civil Engineering. The recording instrumentation and the reduction of test data were under the supervision of V. J. McDonald, Associate Professor of Civil Engineering. M. P. Gaus, Research Associate in Civil Engineering, prepared the computer code for the principal strain computations, and S. T. Rolfe, Research Assistant in Civil Engineering, assisted with the tests and preparation of the figures.

Nomenclature

The following terms are commonly used throughout the text:

Dynamic Strain Gage - SR-4 Type A7, AR7, or AR7-2 (1/4-in. gage length) strain gage whose signal is monitored with respect to time on an oscilloscope during the fracture test; it is also used for static monitoring before and after the test.

Static Strain Gage - SR-4 Type A1 (1-in. gage length) or A7 (1/4-in. gage length) strain gage used only to monitor the static strain level.

Component Strain Gage - One of the three individual strain gages of the rectangular strain rosette.

Crack Detector - A single wire SR-4 Type A9 (6-in. gage length) strain gage located on the plate surface perpendicular to the expected fracture path and intended to be broken by the fracture. A rough measure of the fracture speed and crack tip location may be obtained from a knowledge of the distance between detectors and the time interval corresponding to the breaking of adjacent detectors.

Initiation Edge - The edge of the specimen at which the brittle fracture is initiated.

Notch Line - An imaginary straight line connecting the fracture initiation notches on opposite edges of the plate specimen.

Base Strain - For any gage, the strain corresponding to the applied test load plus the initial residual strain, with due regard for sign.

Zero Strain Level - The reference condition of zero strain corresponding to the as-rolled, slotted, but pre-welded state.

Over-Strain - The maximum value (in the tensile direction) of strain recorded at any gage point during fracture propagation.

DESCRIPTION AND PREPARATION OF PLATE SPECIMENS

General

The initial studies were concerned with investigating various methods for producing a residual strain field across the entire width of a six-foot-wide steel plate and selecting the method most suitable for use in this series of tests. On the basis of previous studies of two-foot-wide plates, it appeared that the most desirable strain field would be one that consisted of high tension at the initiation edge of the plate and a reasonably uniform compression throughout a portion of the central region. This particular strain pattern would make it possible to study the effect of a residual tensile strain on the initiation of a brittle fracture while at the same time allowing a study of the behavior of a propagating fracture through both a tensile and compressive strain field.

The several methods considered for producing a variable strain distribution included (a) flame heating portions of the plate specimen, (b) introducing a high-temperature differential across the width of the plate, (c) compressing a portion of the plate by the use of prestressing rods, and (d) welding tapered slots cut perpendicular to the edges of the plate. It was decided that the method of welding tapered slots would be the most satisfactory procedure for obtaining the desired strain field; all test specimens containing a residual strain field were prepared using this method. The material properties of the plate specimens, the instrumentation procedure used to determine the residual strain distribution, the method of plate preparation, and the resulting residual strain distributions are described in this section of the report.

Specimens and Material Properties

The plate material from which all six specimens were prepared was a 3/4-in.-thick semikilled steel, USS Heat No. 64M487. The mechanical, chemical, and Charpy V-notch data for the steel used in these tests were obtained earlier in connection with tests with plates from the same heat,[1] and the average values are presented in Fig. 1.

All specimens were 72 in. wide, with the lengths varying from 36 in. to 60 in.; the net width of each specimen along the notch line was approximately 2-1/4 in. less than the gross width because of the notches cut in each edge. The notches were used for the notch-wedge-impact method of initiating fractures. This technique is described in detail in a published paper.[4]

For identification purposes, the specimens are hereafter designated as Tests 43 through 48 to maintain a consecutive numbering of tests conducted as a part of the Brittle Fracture Mechanics program. Of the six specimens tested, only the last four were tested in the 3,000,000-lb testing machine. A line diagram of a typical specimen and pull plates and two views of a test setup in the 3,000,000-lb hydraulic testing machine are shown in Fig. 2.

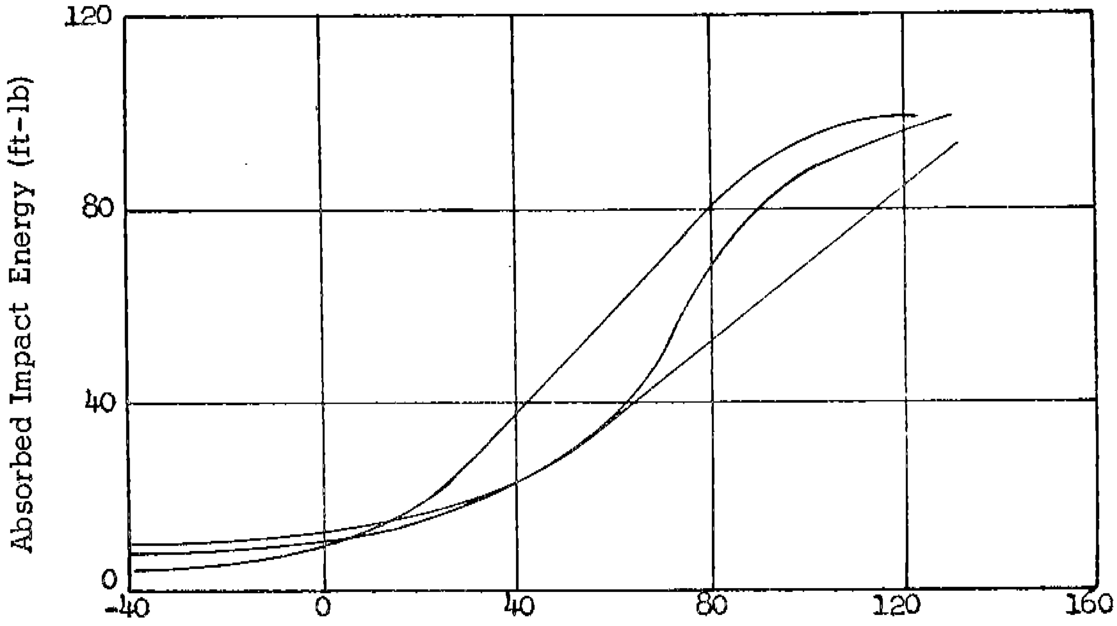
TENSILE TEST DATA

Yield		Maximum		Per cent Elongation		Per cent Reduction	
L*	T*	L	T	L	T	L	T
33.8	34.0	61.8	61.8	40.7	39.1	66.9	61.0

*L = Longitudinal
T = Transverse

CHECK ANALYSIS

C	M_n	P	S	S_i	c_u	N_i	Al
0.19	0.74	0.019	0.028	0.055	0.02	Trace	0.03



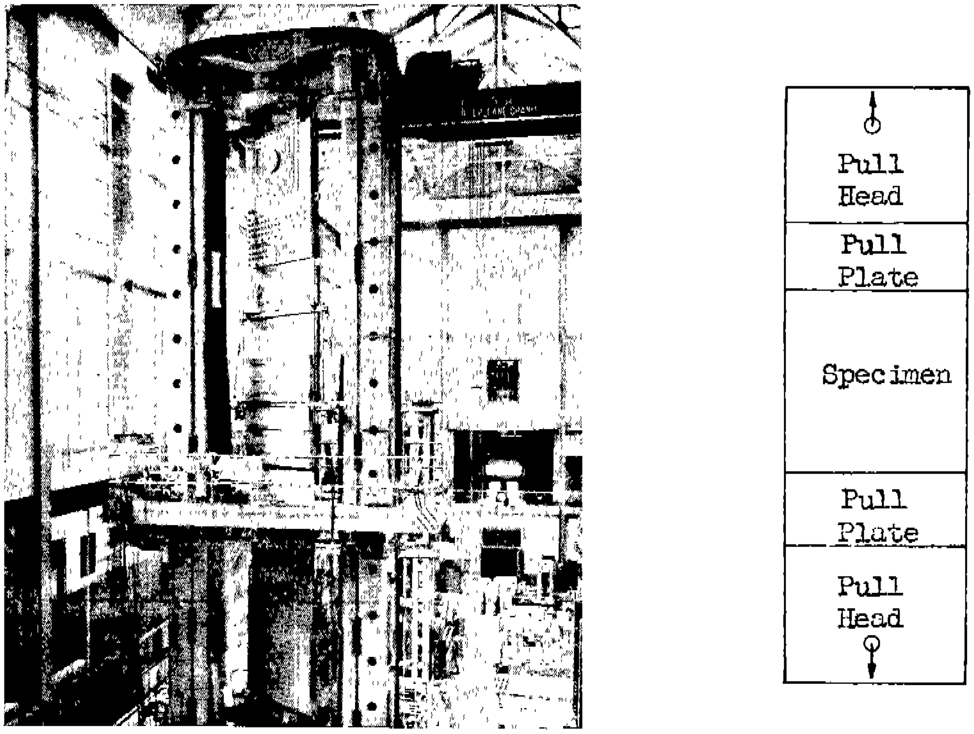
Temperature (F)

Charpy V-Notch Curves

FIG. 1. MATERIAL PROPERTIES

Plate Preparation

The general preparation of each test specimen, with the exception of Test 44, was similar and consisted of sawing the tapered slots to the desired dimensions, welding these slots to produce the residual strain field in the plate, and finally, cutting the edge notches used in the crack initiation. The specimen for Test 44 was a noninstrumented, plain plate specimen and required



Specimen Ready for Testing in 3,000,000-lb Testing Machine

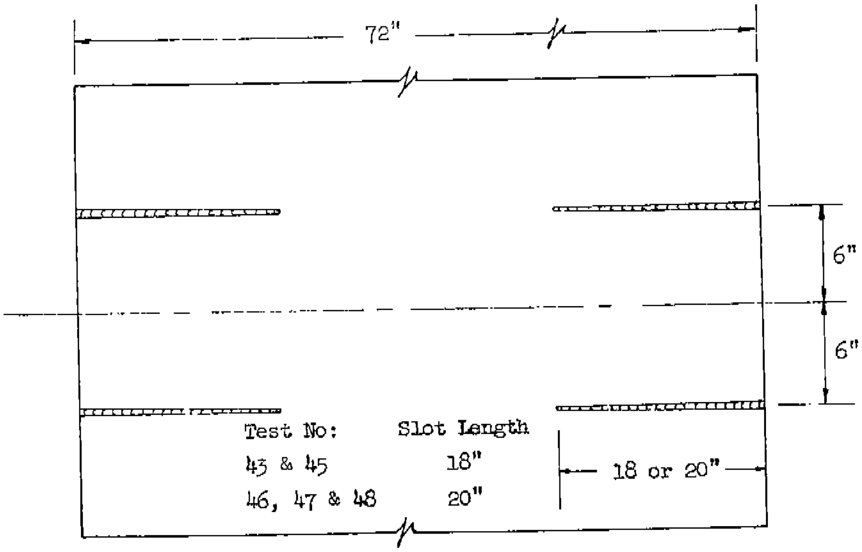
Line Diagram of Specimen

FIG. 2. TYPICAL TEST SETUP

no preparation other than the cutting of the initiation notches.

The location of the tapered slots was the same for all specimens, the dimensions being the only variable. The width of the slot at the edge varied and is given in the specimen description; the width of the slot at the tip was 1/8 in. in all cases. Four slots, two per edge, were cut in each plate as shown in Fig. 3; the vertical distance between the two slots on each edge of the plate was 12 in., 6 in. on either side of the notch line. The depth of all four slots for any one specimen was the same. A typical pair of tapered slots may be seen in Fig. 3.

The welding procedure used was similar for all specimens and the typical sequence was as follows. Welding initially began at a point 4 in. from the tip of one slot and proceeded to the tip of the slot. This 4-in. length was welded using alternating passes on opposite faces of the plate. For the particular dimensions of the slot and specimen, a total of six passes was required to completely close the slot. This same procedure was then followed on simi-



Layout of Tapered Slots

Typical Pair of Slots Prior to Welding

FIG. 3. TAPERED SLOTS

larly located 4-in. segments of the remaining three slots. Four inch lengths were chosen so that one electrode would last for a complete pass; E7016 electrodes were used throughout. All four slots were then welded again in the same manner, this time beginning at a point 8 in. from the tip of the slot and proceeding to the previously completed weld. The remainder of the slot length was welded following the same procedure. It was felt that this particular welding technique would keep bending to a minimum by the symmetrical placing of the weld metal and would produce maximum contraction at the edges of the plate.

Specific comments pertinent to each specimen follow.

Test 43. The dimensions of the specimen were 3/4 in. x 72 in. x 48 in. Two tapered slots, each 18 in. long and 3/16 in. wide at the edge, were cut in each edge of the plate. The welding procedure was carried out with the plate in a vertical position on the laboratory floor; the ends of the plate were completely unrestrained.

Test 44. The dimensions of the specimen were 3/4 in. x 72 in. x 36 in. No tapered slots were cut and no instrumentation was used. The only preparation consisted of sawing the 1-1/8 in. deep notch in each edge of the plate for fracture initiation purposes.

Test 45. The dimensions of this specimen were 3/4 in. x 72 in. x 60 in.; the width of the tapered slots at the edge was increased from 3/16 in. to 1/4 in. to allow for more contraction during welding. Before the tapered slots were welded, the specimen was welded to the pull heads of the testing machine to provide a condition of end fixity before the slots were welded; this appeared to be helpful in increasing the amount of residual compressive strain in the central portion of the plate. Strain readings taken before and after the specimen was welded to the pull-plates in the machine indicated a negligible change in strain along the notch line.

Test 46. A specimen of essentially the same geometry as those of Tests 43 and 45 was prepared using tapered slots which were 20 in. deep and 5/16 in. wide at the edge. The dimensions of the specimen were 3/4 in. x 72 in. x 48 in. This specimen also was welded to the pull-heads of the testing machine before the tapered slots were welded.

Tests 47 and 48. The dimensions of these specimens were 3/4 in. x 72 in. x 60 in.; the tapered slots were 20 in. deep and 5/16 in. wide at the edges of the plates. The welding procedure was carried out with the specimens clamped to the pull-heads of the testing machine. This was done to minimize warping and also to facilitate the mounting of the instrumentation; after final strain readings were taken, the specimens were welded to the pull-heads.

INSTRUMENTATION AND TEST PROCEDURE

Method for Measuring Residual Strains Resulting From Welding

The residual strains produced in the plate specimens were measured by means of both Baldwin SR-4 strain gages and a 6-in. Berry mechanical gage. The use of the Berry gage in addition to the SR-4 gages made it possible to obtain readings at intermediate points between the SR-4 gages and also served as a check on the longitudinal uniformity of the strain distribution. SR-4 gages were placed back-to-back on all specimens except in Test 43. Their locations are shown in the instrumentation layout for each test (Figs. 4-8). Berry gage holes, drilled on both faces of the specimen along the notch line, were placed every 2 in. across the width of the plate in the first test, while in the later instrumented tests, they were placed every 2 in. across a 14-in. width from either edge and a 20-in. width in the center of the plate and every 1 in. for the remaining plate width.

Initial strain readings of SR-4 and Berry gages were taken after the tapered slots had been sawed and with the specimen in an unrestrained condition. These strain readings established the zero strain level, and all other strains were referenced to this prewelded condition. After the specimen had been welded, the final static strain readings were taken at room temperature.

After the residual strain pattern had been established, all subsequent strain readings were obtained from the SR-4 strain gages.

Dynamic Instrumentation

In the brittle-fracture tests, thirty-four channels of cathode-ray oscilloscope recording instrumentation were available; the full 34 channels were utilized only on the last two tests. Baldwin SR-4 Type A7 strain gages and Type AR7 and AR7-2 strain rosettes (1/4 in. gage length) were used to measure the dynamic strains.

Crack speeds were measured in the four final tests using a system of twelve surface crack detectors which broke as the fracture traversed the plate; these crack detectors consisted of Baldwin SR-4 Type A9 strain gages. The failure of a crack detector opened an electrical circuit and fed a step change in voltage to the recording channel. From a knowledge of the distance between detectors and the elapsed time between successive interruptions of the circuit, the average fracture speed could be computed.

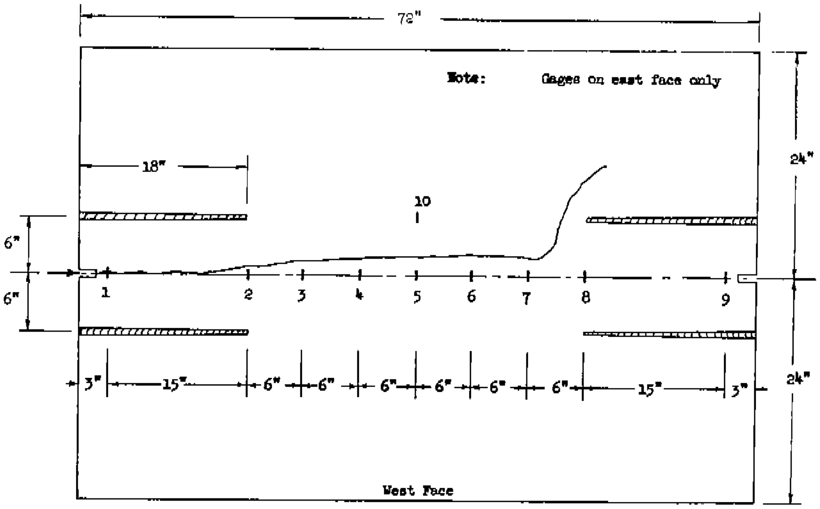


FIG. 4. INSTRUMENTATION LAYOUT AND SLOT CONFIGURATION - TEST 43

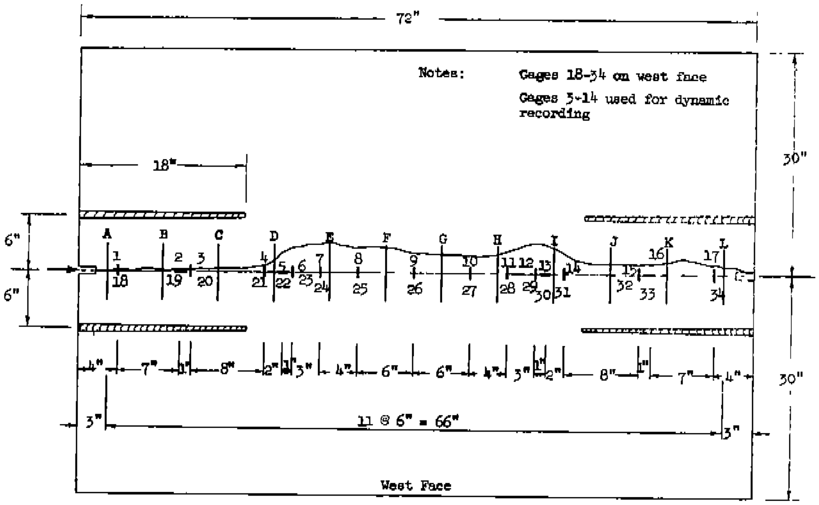


FIG. 5. INSTRUMENTATION LAYOUT AND SLOT CONFIGURATION - TEST 45

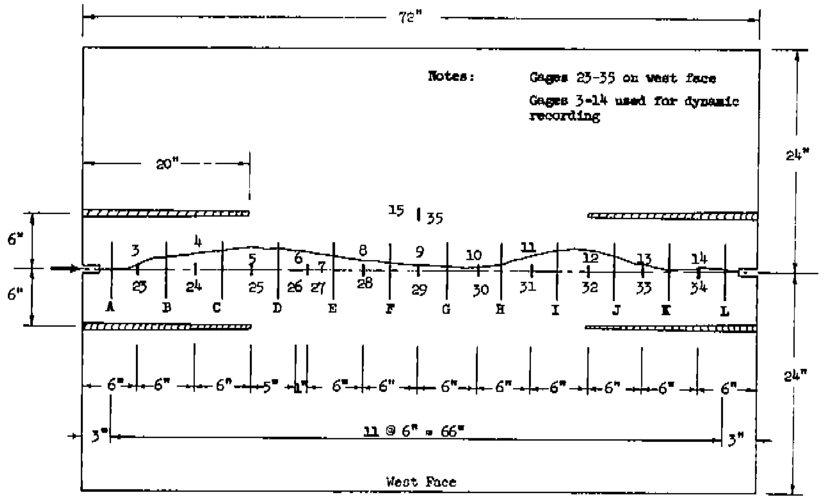


FIG. 6. INSTRUMENTATION LAYOUT AND SLOT CONFIGURATION - TEST 46

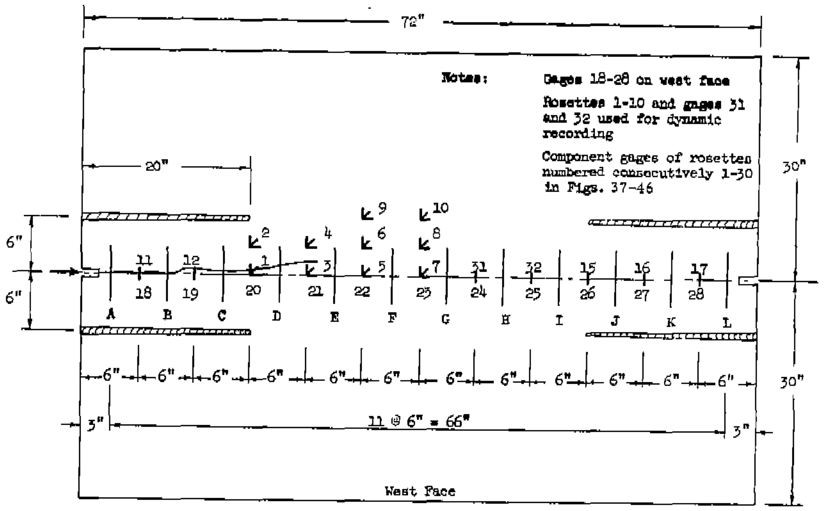


FIG. 7. INSTRUMENTATION LAYOUT AND SLOT CONFIGURATION - TEST 47

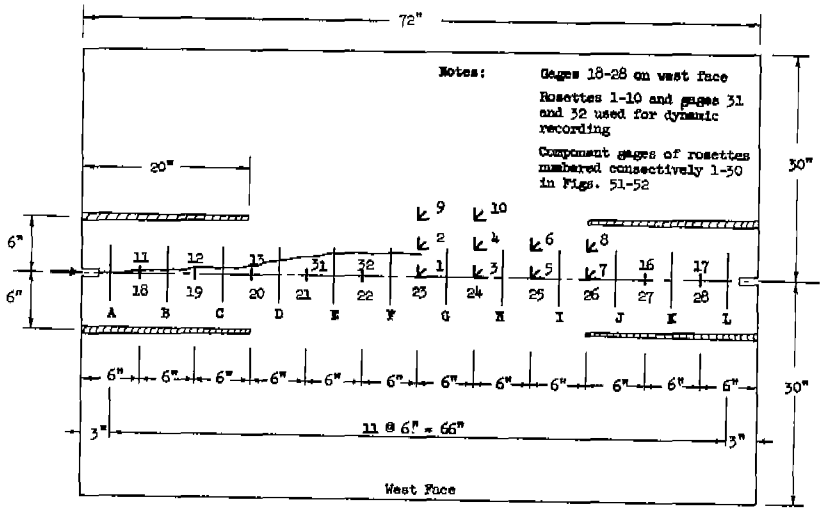


FIG. 8. INSTRUMENTATION LAYOUT AND SLOT CONFIGURATION - TEST 48

A complete description of the recording equipment, including a discussion of the sensitivity of the various units, may be found in reports and papers previously issued as part of this program.[2-6]

Data Reduction

Reduction of the strain data recorded on 35-mm strip film was facilitated with a decimal converter and the University of Illinois high speed digital computer, the ILLIAC. A brief summary of the data reduction procedure is presented below.

The 35 mm-film strips were enlarged and timing marks scaled on the enlargements. It should be noted that in addition to the common timing marks, each individual trace had timing interruptions to insure synchronization of all traces. With the aid of the decimal converter, values of gage strain versus time were simultaneously plotted on an X-Y plotter and typed in tabular form. For Tests 47 and 48, in which strain rosettes were used, the strain-time data also were punched on IBM cards; these data were subsequently transferred from the IBM cards to punched paper tape and processed through the ILLIAC to compute values of the principal strains. For many of the rosettes, the response of the component gages was so slight that computation of principal strains from the component gage readings was considered impractical and therefore was not carried out. The ILLIAC results consisted of tabulated principal strain data, as well as scaled oscilloscope displays of component gage and principal strain traces which were photographed for later enlargement and processing.

General Test Procedure

In most respects, the apparatus and test procedure used for these tests were similar to that used in earlier tests made as a part of this program. The general test procedure consisted of cooling the specimen to the desired temperature, applying the test load if an external stress was to be employed, and initiating the fracture by means of an impact that drives a wedge into a notch in the edge of the plate; a nominal impact of 1200 ft-lb was used for fracture initiation.

BRITTLE-FRACTURE TESTS AND RESULTS

General

Brittle-fracture tests were conducted on all six specimens described in an earlier section. With the exception of the specimen for Test 44, every plate contained a residual strain field produced by welding tapered slots cut in the edges of the specimen.

Although the magnitude of the residual strains varied slightly for the different tests, the over-all patterns were similar for all test specimens. The highest residual strains were produced at the edges of the plates and in every case

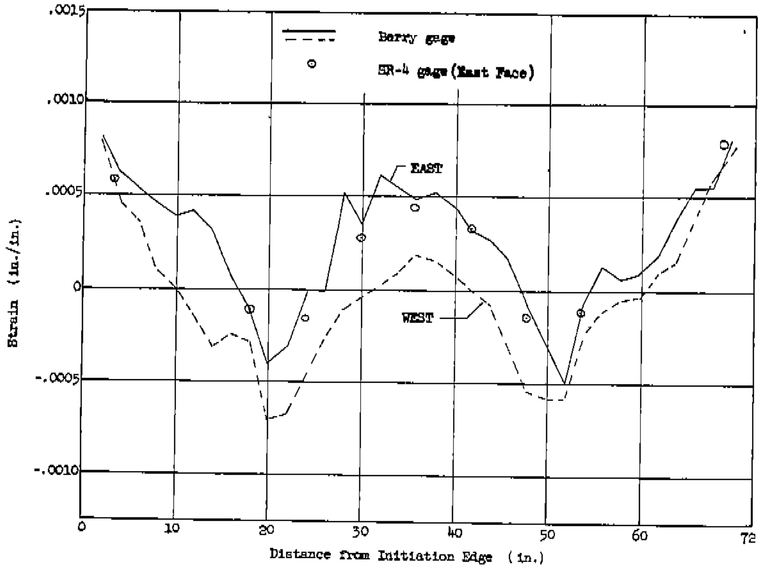


FIG. 9. LONGITUDINAL RESIDUAL STRAIN DISTRIBUTION ACROSS NOTCH LINE - TEST 43

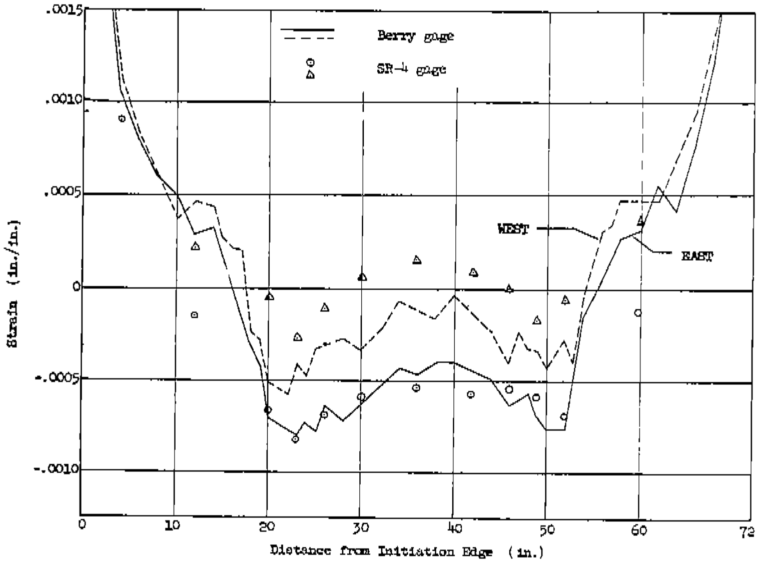


FIG. 10. LONGITUDINAL RESIDUAL STRAIN DISTRIBUTION ACROSS NOTCH LINE - TEST 45

reached yield point magnitude for a distance of several inches in from each edge of the plate (Figs. 9-13). As a result of these high tensile strains at the edges of the specimen, it was possible to initiate fractures with no externally applied load; a nominal load of 150,000 lb (corresponding to a net applied stress of 3000 psi) was applied in Tests 45 and 46 primarily to reduce bending.

Fractures were successfully initiated in all specimens with a residual

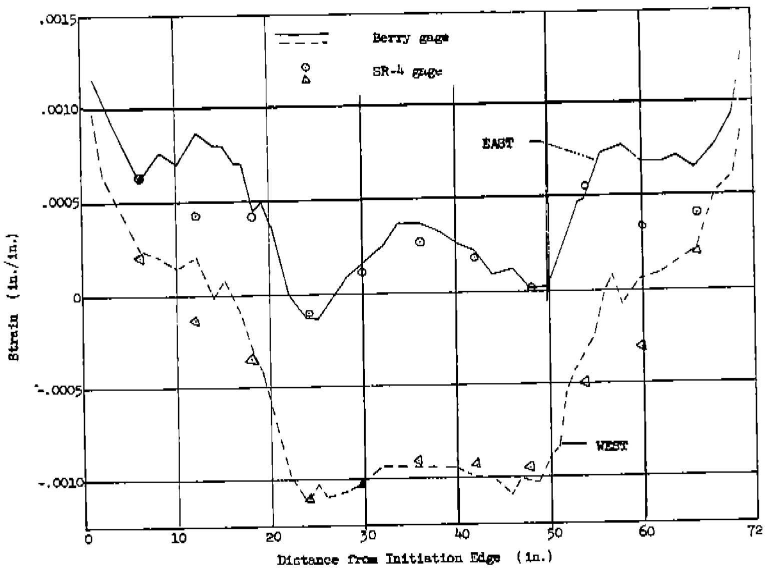


FIG. 11. LONGITUDINAL RESIDUAL STRAIN DISTRIBUTION ACROSS NOTCH LINE - TEST 46

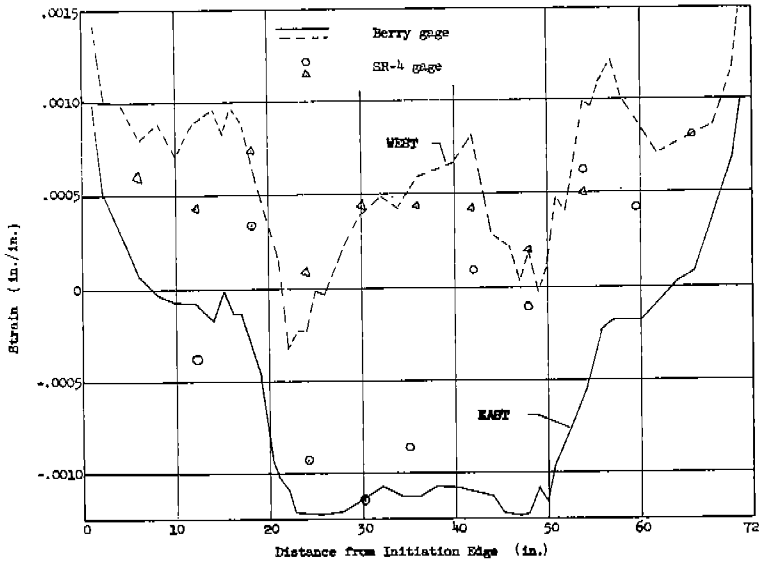


FIG. 12. LONGITUDINAL RESIDUAL STRAIN DISTRIBUTION ACROSS NOTCH LINE - TEST 47

strain field. In Tests 45 and 46, in which a small external load was applied, the fracture propagated across the entire width of the plate. In the remaining specimens, the fracture arrested in the compressive strain region. A summary of the tests is presented in Table 1.

Test Results

Test 43. As the first specimen prepared in this series of tests, Test 43

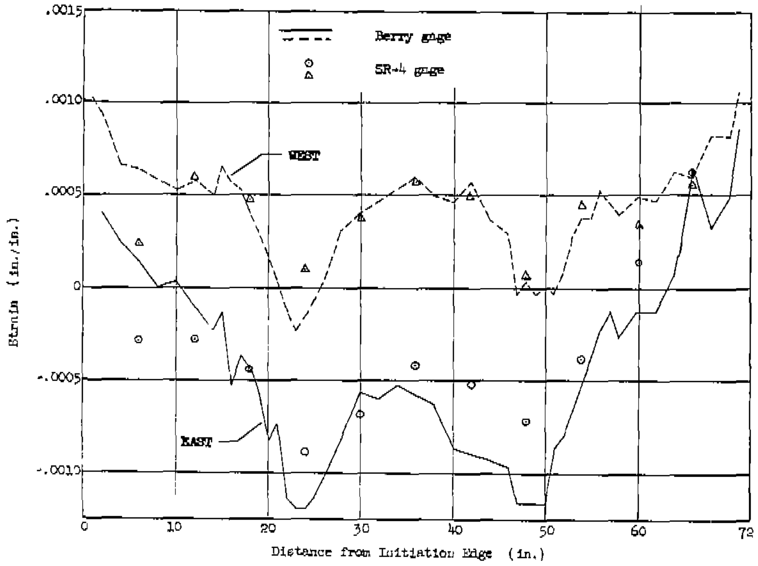


FIG. 13. LONGITUDINAL RESIDUAL STRAIN DISTRIBUTION ACROSS NOTCH LINE - TEST 48

was designed to determine the general pattern of residual strains that could be expected in a six-foot-wide plate with welded tapered slots. In addition, a brittle-fracture test of this specimen would indicate the probable behavior of a fracture propagating through the residual strain field. The residual strain pattern in this specimen consisted of high tension at the edges, moderately high compression in the vicinity of the tip of the slots, and low tension in the central portion. Initial strain readings were taken with the plate in position for welding to establish the zero strain level. Final strain readings were taken after the plate had cooled to room temperature. The strain distribution as determined from the SR-4 gages and the Berry gage is shown in Fig. 9. All strains were plotted assuming that the zero strain level corresponded to the as-rolled, pre-welded condition. After the residual strains resulting from the welding had been recorded, the standard 1-1/8 in. deep notch used in the notch-wedge-impact method of initiation was sawed in both edges of the plate midway between the welded slots. Subsequent strain readings indicated negligible relaxation in strain throughout the width of the plate as a result of sawing the initiation notches. The same observation was true for all subsequent specimens as well.

TABLE 1. SUMMARY OF BRITTLE-FRACTURE TESTS AND RESULTS

Test No.	Avg. External Applied Stress (psi)	Test Temperature (F)	Support Conditions	Avg. Speeds High Low (fps)	Results
43	0	-12	Plate simply supported on laboratory floor	not measured	B.F. prop. approx. 56 in. across plate before arresting
44	0	-12	Plain plate spec.; plate simply supported on lab. floor	not measured	First shot: no effect; second shot: B.F. prop. approx. 19 in. across plate
45	~3000	-20	Welded to pullheads of testing machine	5500 100	B.F. prop. completely across specimen
46	~3000	0	Welded to pullheads of testing machine	4500 50	B.F. prop. completely across specimen
47	0	- 8	Welded to pullheads of testing machine	3800 250	B.F. prop. approx. 25 in. before arresting
48	0	0	Welded to pullheads of testing machine	4150 50	B.F. prop. approx. 36 in. before arresting

Theoretically, the tensile and compressive areas of Fig. 9 should balance from the standpoint of equilibrium. It will be observed that in this case the residual strain distribution shows a tensile unbalance that cannot be readily explained on the basis of the measurements made. For all subsequent specimens, the residual strain distributions will be noted to be approximately in balance. It should be noted, however, that in every specimen bending was present to some extent as a result of the welding, and hence exact agreement would not be expected between SR-4 readings and the Berry gage readings because of the difference in gage length.

This particular specimen was tested with no external applied load at a temperature of -12 F using the notch-wedge-impact method of fracture initiation.

As shown in Fig. 14, the test specimen was in a vertical position in a special jig on the floor of the laboratory. By this arrangement, only the bottom of the plate was simply supported, the top and edges being free from restraint. The cooling tanks and impact gun with associated equipment were suspended from an overhead frame in the normal manner. After the test temperature of -12 F had been reached, the fracture was initiated and propagated approximately 56 in. across the plate.

No dynamic instrumentation was used on this pilot test. Photographs of the crack path and the arrest region are shown in Fig. 15, and photographs of the fracture surface are shown in Fig. 16. As may be noted from the strain distribution curve of Fig. 9, the fracture propagated through successive regions of residual tension, compression, and tension, respectively, before finally being arrested in the last compressive region. The path of the fracture was relatively flat except for the final 6 in., where it curved sharply upward before stopping. This is shown in the enlarged picture in Fig. 15. The curvature of the fracture path is most likely a result of the strain field present in the plate.

Immediately after testing, it was noticed that the wedge used for initiation had come to rest approximately 2 in. into the open fracture as is shown in Fig. 17. Whether this had any effect on the propagation of the fracture could not be determined. It is possible that the wedge merely rebounded into the

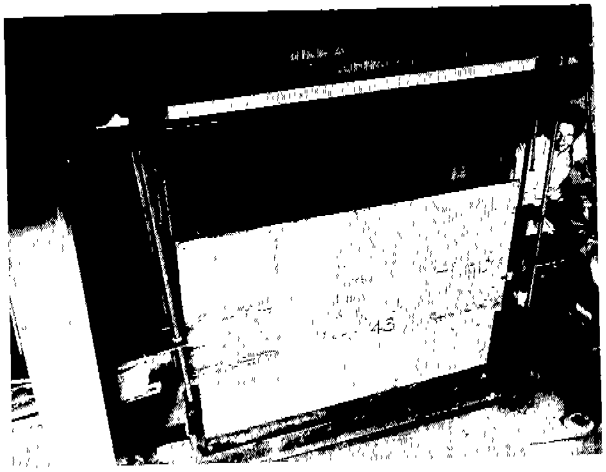


FIG. 14. SPECIMEN IN A SPECIAL JIG ON THE FLOOR OF THE LABORATORY READY FOR TESTING - TEST 43

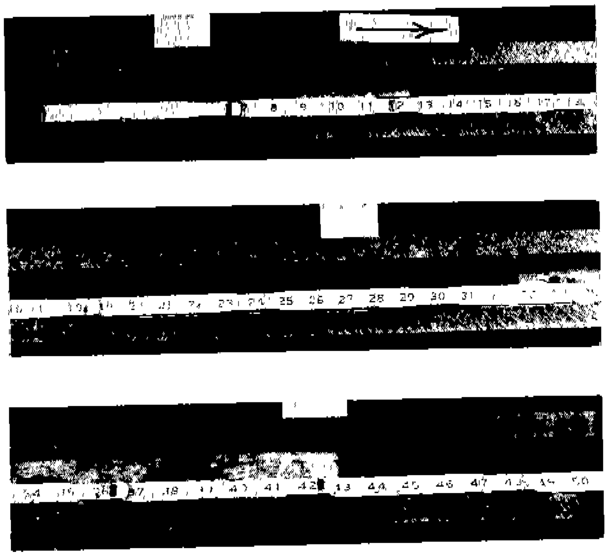


FIG. 16. FRACTURE SURFACE - TEST 43

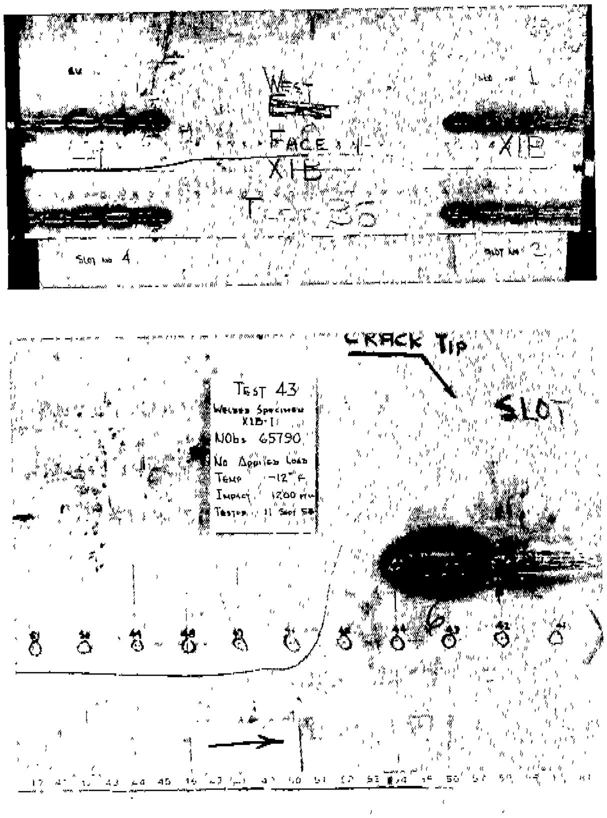


FIG. 15. FRACTURE PATH - TEST 43

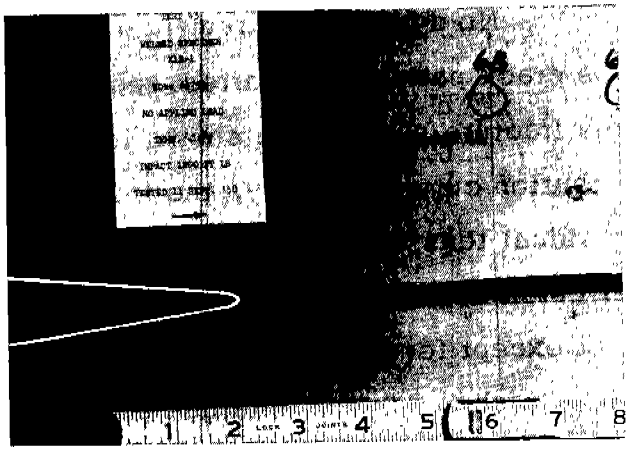


FIG. 17. POSITION OF WEDGE IN OPEN FRACTURE - TEST 43

already open fracture and thus had no effect on propagation. However, it is also conceivable that the forcing action of the wedge contributed to the length of the propagated fracture.

Test 44. This test was designed specifically to determine whether a fracture could be initiated in a six-foot-wide steel plate that contained no residual strain field and that was under no externally applied load; the initiation would be dependent primarily on the initiation technique used. The specimen was similar in geometry and preparation to that of Test 43 except that no slots were cut, and hence no residual strains resulting from welding were present in the plate. The specimen was tested in the same jig used in Test 43 and at approximately the same temperature. After the first impact, investigation of the notch region revealed no evidence of any cracks. After this first attempt to initiate the fracture, it was decided to subject the wedge to a second blow identical in magnitude to the first, with the specimen at the same temperature. This time a fracture was initiated and propagated approximately 19 in. into the plate. A photograph of the crack path is presented in Fig. 18. It is felt that the successful fracture initiation after the second attempt resulted from the fact that the material at the root of the notch had already been considerably strained by the first impact loading.

Test 45. The welding of the slots for this plate resulted in an average compressive strain of -0.00030 in./in. across the central 30 in. of the plate and high tension reaching yield point magnitude in the vicinity of the edges.

The welding of the specimen in the testing machine, along with the welding of the tapered slots, resulted in a slight bending of the plate, which caused strain readings at a given location on opposite sides of the plate to differ. The residual strain distribution along the notch line is shown in Fig. 10.

The specimen was tested at an average net applied stress of 3000 psi, a temperature of -20 F, and with the standard method of initiation. The applied load was arbitrarily selected to be 150,000 lb, which was felt to be sufficient to reduce bending in the plate while being low enough to have a negligible effect on the average strain distribution. Figure 19 shows the residual

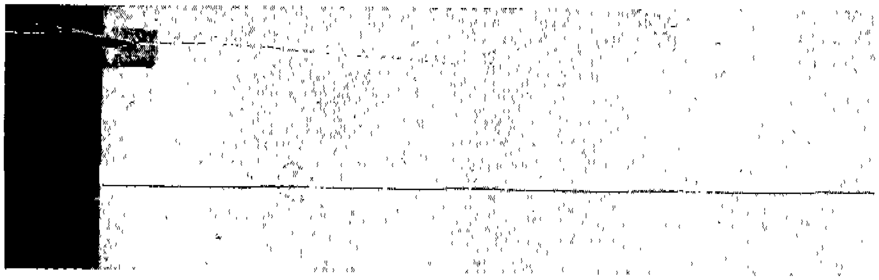


FIG. 18. FRACTURE PATH - TEST 44

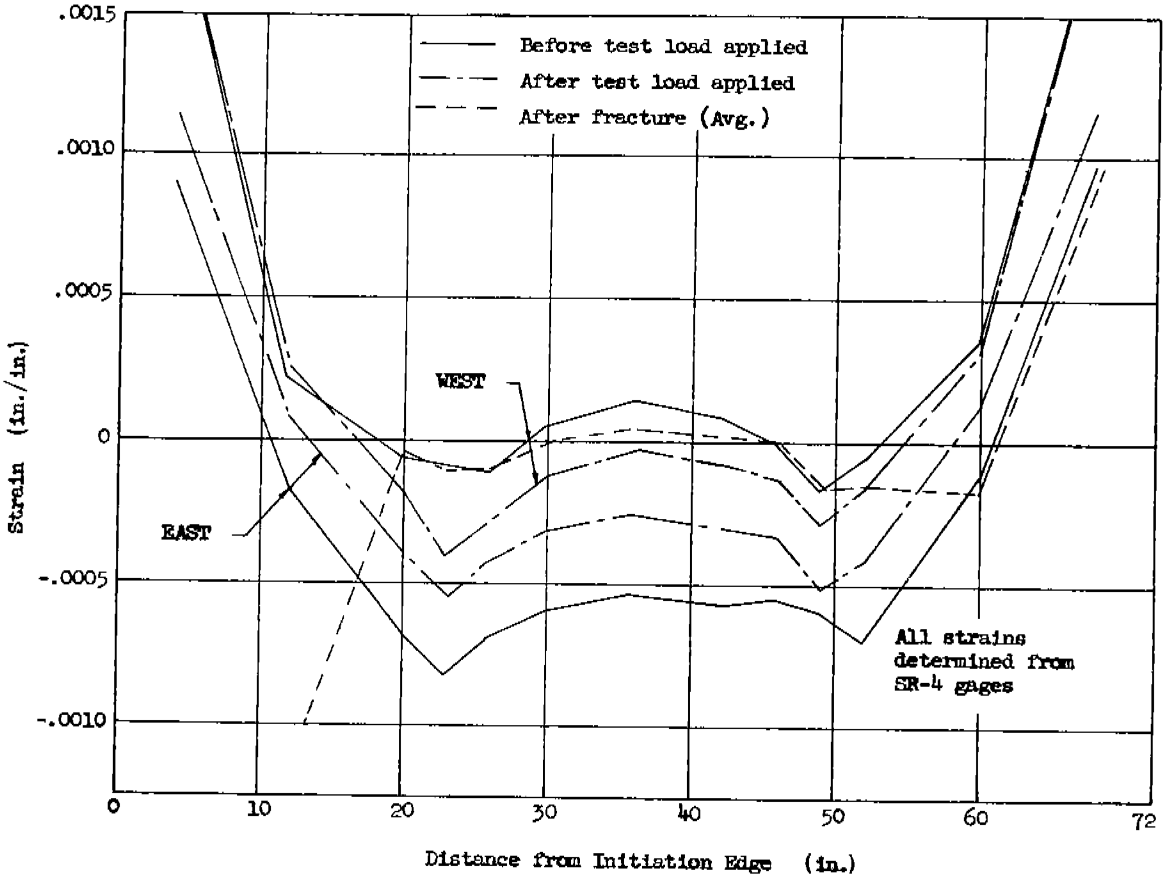


FIG. 19. LONGITUDINAL STRAIN DISTRIBUTION ALONG NOTCH LINE - TEST 45

FIG. 20. FRACTURE PATH - TEST 45

strain pattern on both faces of the specimen before and after application of the load, thus illustrating the reduction in bending effected by the load. From Fig. 19 it may be seen that the average strain level was not markedly changed. Under these conditions, a brittle fracture initiated and propagated across the entire width of the plate. Changes in direction of the fracture were apparent in the vicinity of the compressive regions and may be seen clearly in Fig. 20.

The instrumentation layout and a sketch of the crack path are presented in Fig. 5. The strain gages were located so as to obtain strain response in both the tensile and compressive region with gages being concentrated in the transition region. This was done to determine the dynamic strain response in a gage as the fracture passed from a region of high tension to a region of high compression.

The strain-time traces of the dynamic gages recorded during the fracture process are presented in Figs. 21-24. In order to facilitate interpretation of the strain-time records, a sketch of the location of the gages corresponding to the plotted traces is included with the figures. All strain-time traces in this test and subsequent tests were plotted with the strain at zero time equal to the algebraic sum of the residual strain and the strain corresponding to the applied test load. Zero time is the estimated time at which the wedge strikes the plate. The strain-time records for those gages in the tensile and low compressive regions are similar in appearance to those obtained from non-prestrained plates.[1] For example, the strain trace of gage 4 (shown in Fig. 22) relaxed slightly as the fracture initiated, peaked sharply in tension as the fracture propagated past the gage, and then relaxed immediately to a fairly constant strain level as the fracture propagated across the remainder of the plate.

The traces of gages 6 to 10 (Figs. 21-24), located in the central region of relatively low residual compression, behaved in a similar manner, showing a slight relaxation before peaking into tension. The width of the strain peak had increased noticeably in these gages, averaging approximately 1.5 millisec as compared to the 0.1-millisec width of the peak of gage 4. As may be noted in Figs. 21-24, the width of the strain peaks became progressively wider for the

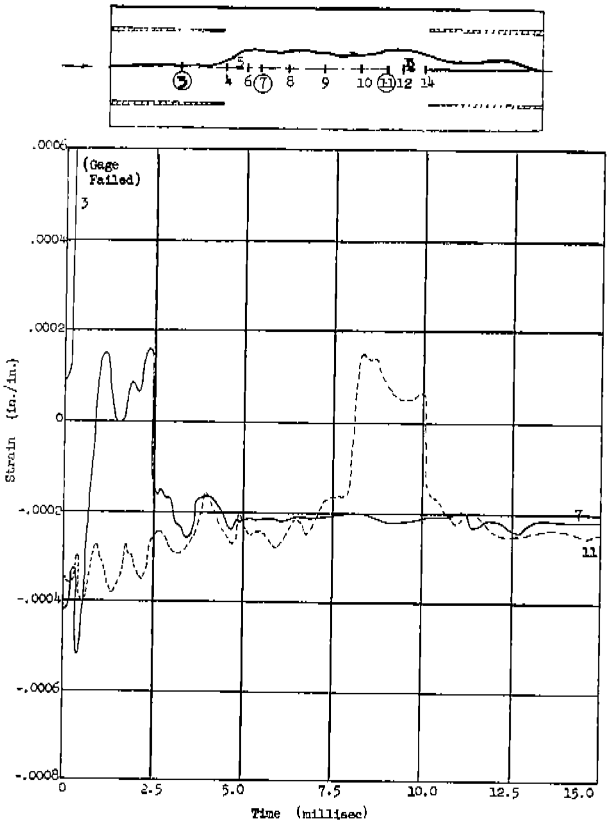


FIG. 21. STRAIN-TIME RECORDS FOR GAGES 3, 7, AND 11 - TEST 45

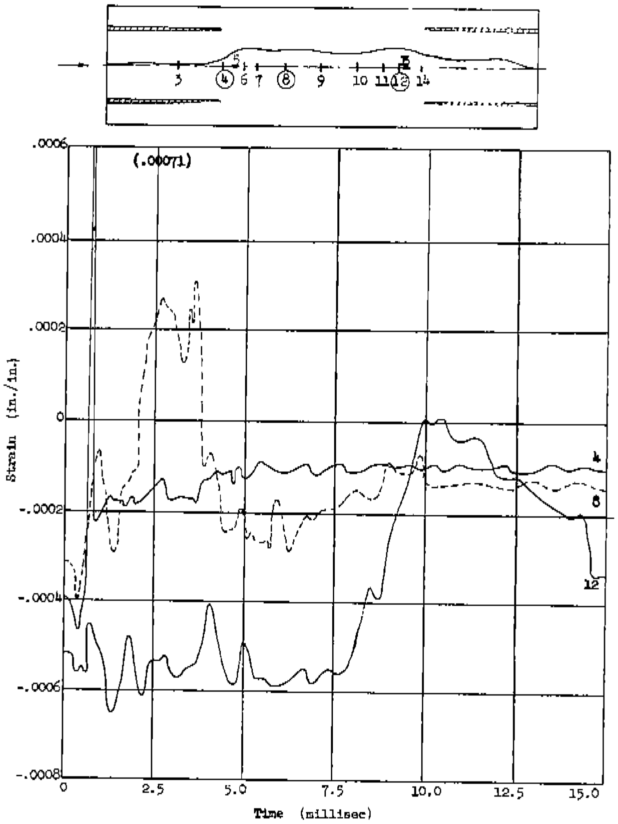


FIG. 22. STRAIN-TIME RECORDS FOR GAGES 4, 8, AND 12 - TEST 45

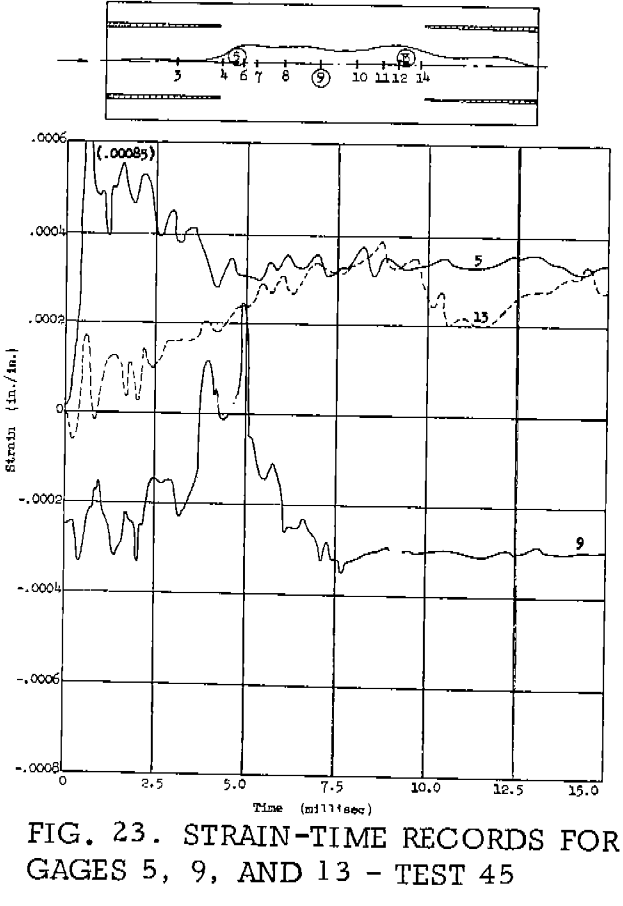


FIG. 23. STRAIN-TIME RECORDS FOR GAGES 5, 9, AND 13 - TEST 45

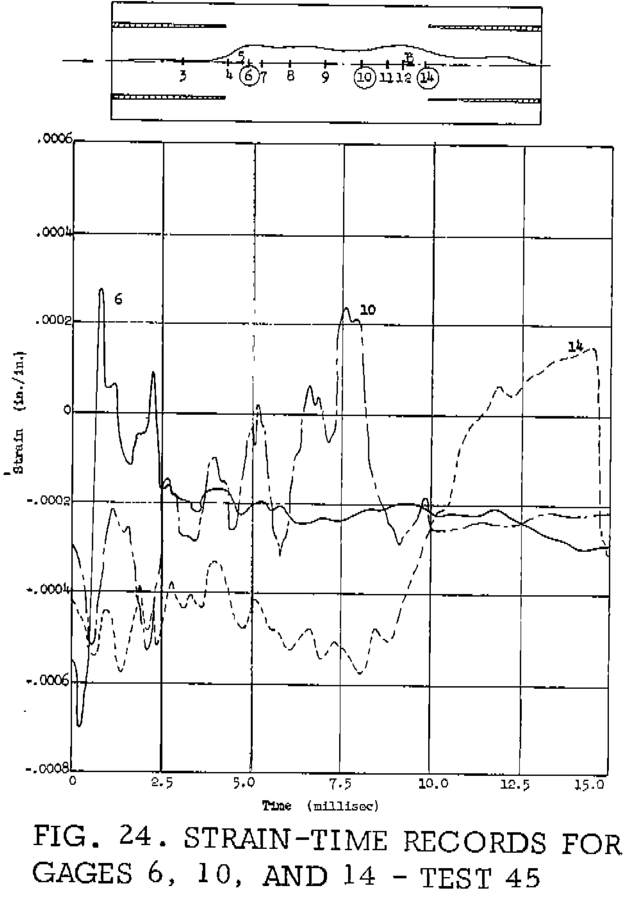


FIG. 24. STRAIN-TIME RECORDS FOR GAGES 6, 10, AND 14 - TEST 45

gages toward the far edge of the plate. For example, the width of the strain peak of gage 14 was approximately 5.0 millisec.

From the strain-time traces it may be noted that the value of overstrain generally decreased across the plate width, although it always had a positive value. Thus the maximum value of the tensile strain associated with the strain field of the propagating fracture was in each case greater than the residual compressive strain of the region through which the fracture passed.

The fracture speed as determined by the crack speed detectors and strain gage peaks was lower than that recorded on any previous six-foot-wide plate tests. Figure 25 includes a table showing the time interval between breaking of the detectors and the corresponding average speeds between each set of detectors. As can be noted from this table, the highest average speed recorded was approximately 5500 fps, while the lowest was 100 fps. A better indication of speeds can be obtained by plotting the detector location on the plate, which is measured along the notch line, versus the detector breaking time, as noted in Fig. 25. Since the fracture mechanism is a more or less continuous process, the slope of a curve through these plotted points gives an average value of the fracture speed at any position along the crack path. Since there was very little difference between the total length of crack path and the width of the plate along the notch line, the latter was used for convenience. The estimated time at which the fracture passed each strain gage also was plotted on the curve of Fig. 25. It can be seen that the fracture speed for the first 20 in. of plate width remained relatively constant at a value of about 4200 fps. The speed then reduced sharply to approximately 200-250 fps, and this speed was maintained through most of the compressive region. At a point about two-thirds of the distance from the initiation edge, which corresponds to the second residual compressive strain peak, the fracture appeared to approach zero velocity and then accelerated to about 2000 fps for a few inches. The speed subsequently returned to about 300 fps across the remainder of the plate width.

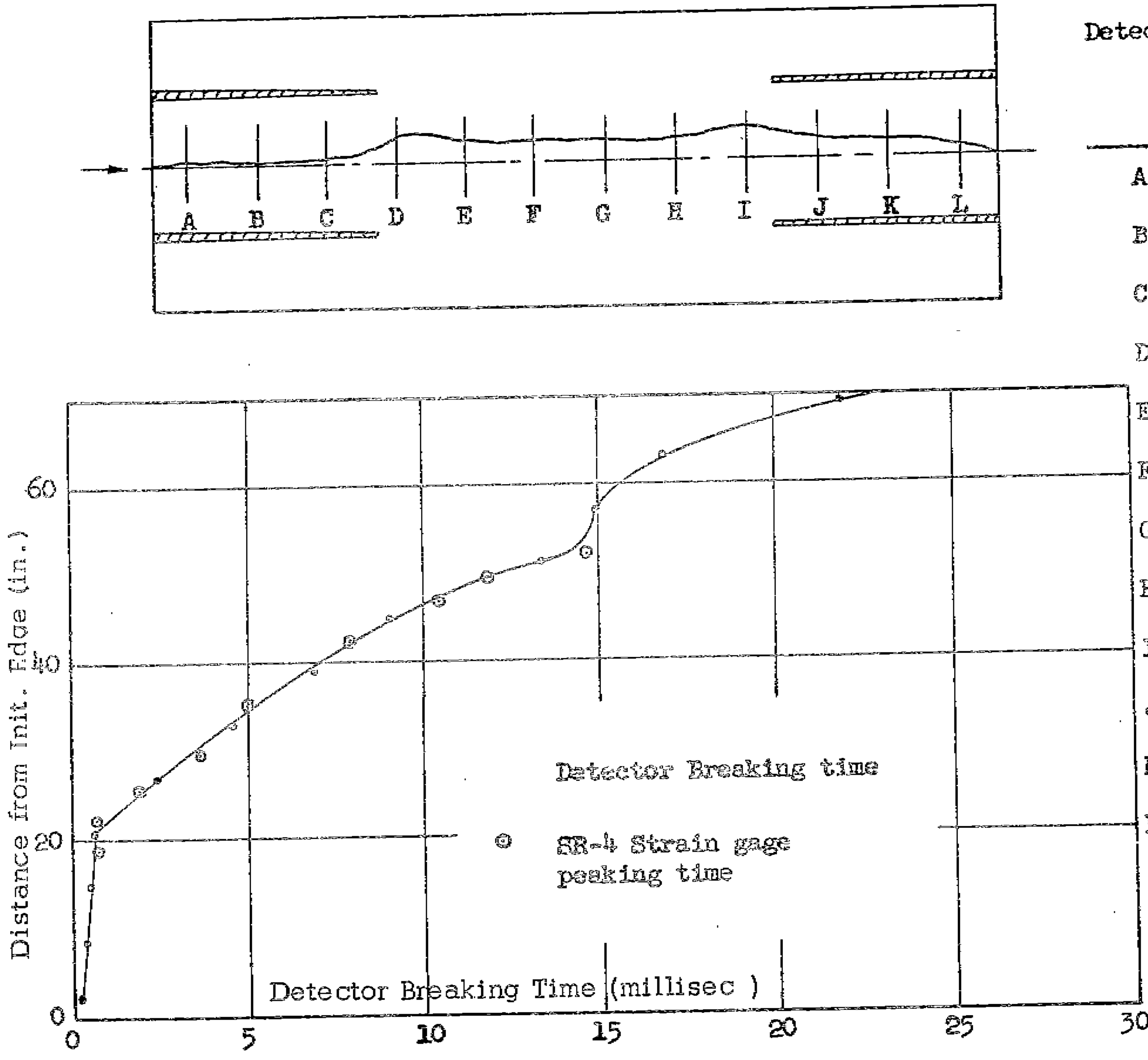


FIG. 25. AVERAGE FRACTURE SPEEDS - TEST 45

Detector	Distance Between Detectors (ft)	Time Interval (millisec)	Average Speed (fps)
A			
	0.50	.09	5550
B			
	0.50	.11	4550
C			
	0.50	.19	2650
D			
	0.50	1.73	300
E			
	0.50	2.28	200
F			
	0.50	2.35	200
G			
	0.50	2.11	250
H			
	0.50	4.29	100
I			
	0.50	1.64	300
J			
	0.50	1.81	300
K			
	0.50	5.15	100
L			

The fracture surface may be seen in Fig. 26. The appearance was not markedly different from that observed in plain plate tests.[1] In general, the fracture texture was fairly smooth, although the texture was coarser in the vicinity of the initiation edge.

Test 46. This test was essentially a duplication of Test 45, except that the length of the tapered slots was increased from 18 in. to 20 in. in an attempt to obtain a still larger magnitude of residual compressive strain. The results were very similar to those of Test 45. Welding of the slots produced a residual compressive strain region extending across the central 36 in. of the plate with an average compressive strain of approximately -0.0005 in./in. across the central 24 in. of the specimen. The residual tensile strain varied from zero at approximately the quarter points to yield point magnitude at the edges of the plate. A plot of the residual strain distribution across the notch line is shown in Fig. 11; the warping of the plate that occurred as a result of welding is apparent.

The specimen was tested with a load of 150,000 lb, corresponding to a net applied stress of approximately 3000 psi, at a temperature of 0°F, and with the same initiation technique. The application of the test load reduced the average compressive strain in the central portion of the plate to approximately -0.00040 in./in. as may be seen in Fig. 27. Again the brittle fracture propagated across the width of the plate. The fracture path, shown in Fig. 28, was similar to that of Test 45, although the fracture remained slightly closer to the notch line. A sketch of the fracture path and the instrumentation layout are shown in Fig. 6.

The strain-time records for this test are presented in Figs. 29-32. Gages 3, 4, and 5, located in the first tensile region, exhibited the usual response of vertical gages, i.e., a sharp tensile strain peak as the fracture propagated by the gage followed by an immediate return to the zero level of the gage. The response of gage 7 was similar to that of gages 3, 4, and 5, but the peak magnitude was considerably less. A relaxation in strain is apparent to some degree in most of the gages before peaking, particularly the gages in the "sensitive region" on the far side of the specimen. The fact

FIG. 26. FRACTURE SURFACE - TEST 45

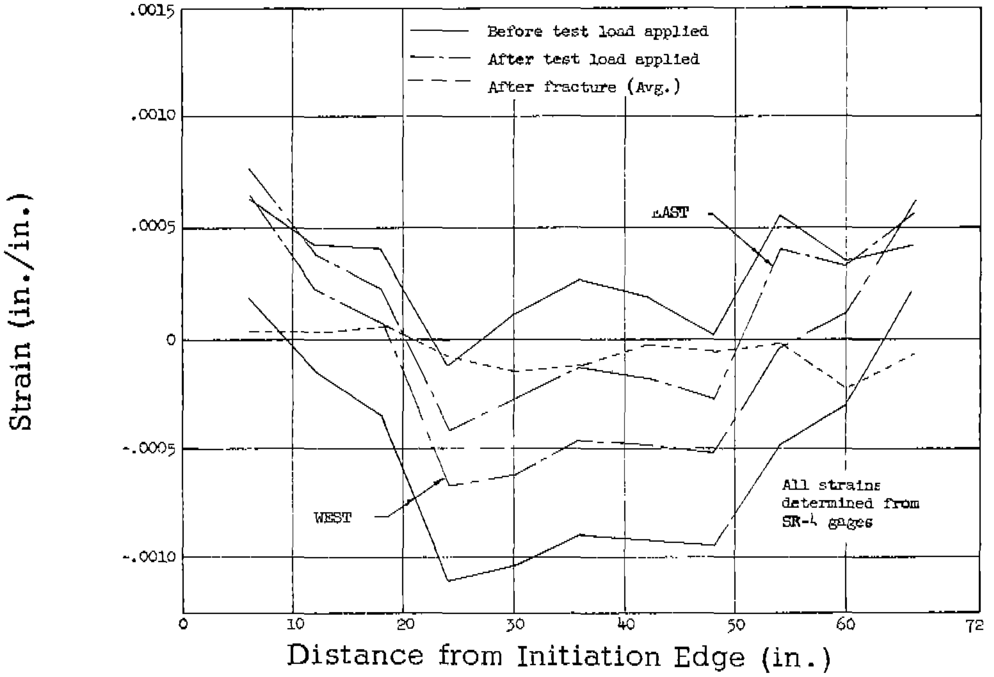


FIG. 27. LONGITUDINAL STRAIN DISTRIBUTION ALONG NOTCH LINE - TEST 46

FIG. 28. FRACTURE PATH - TEST 46

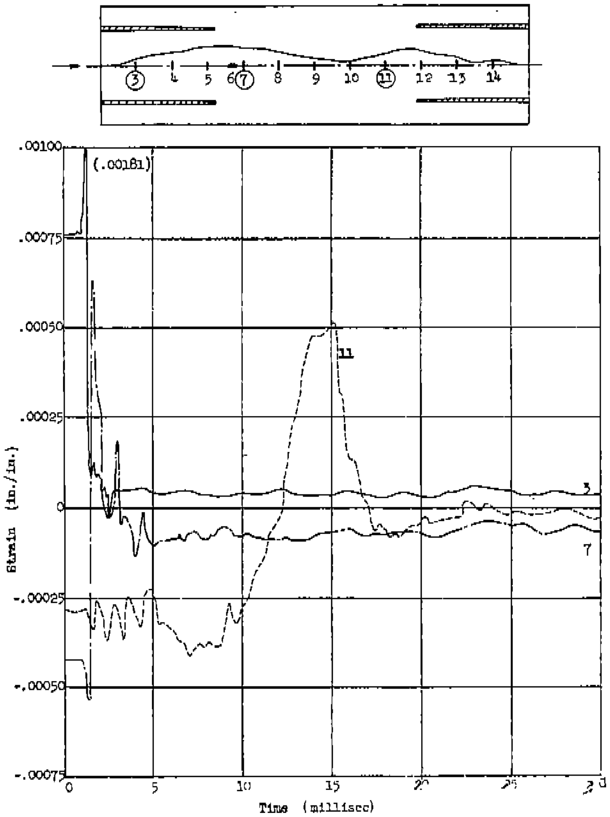


FIG. 29. STRAIN-TIME RECORDS FOR GAGES 3, 7, AND 11 - TEST 46

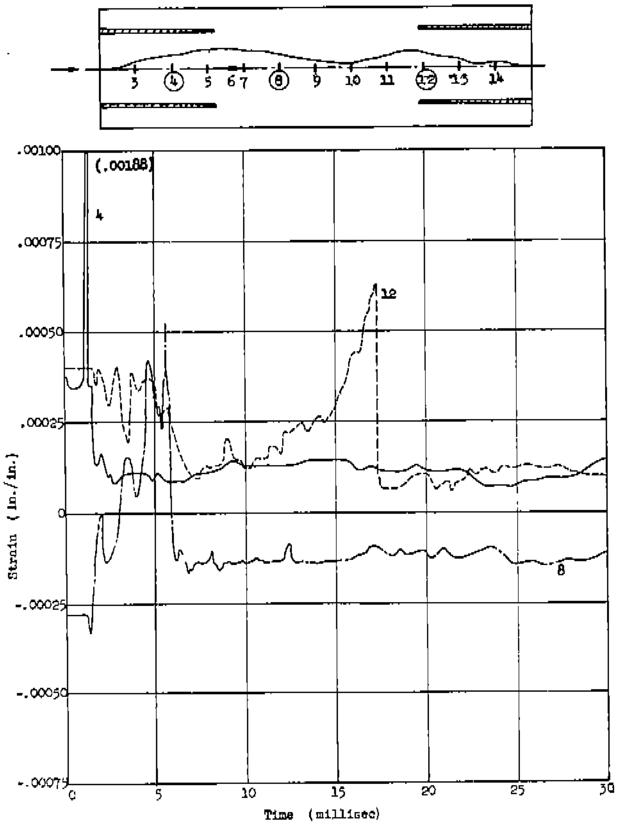


FIG. 30. STRAIN-TIME RECORDS FOR GAGES 4, 8, AND 12 - TEST 46

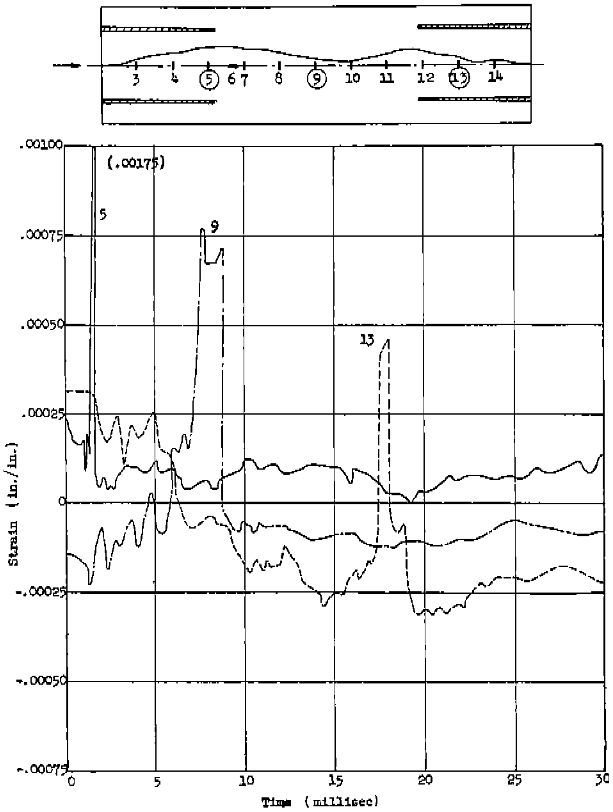


FIG. 31. STRAIN-TIME RECORDS FOR GAGES 5, 9, AND 13 - TEST 46

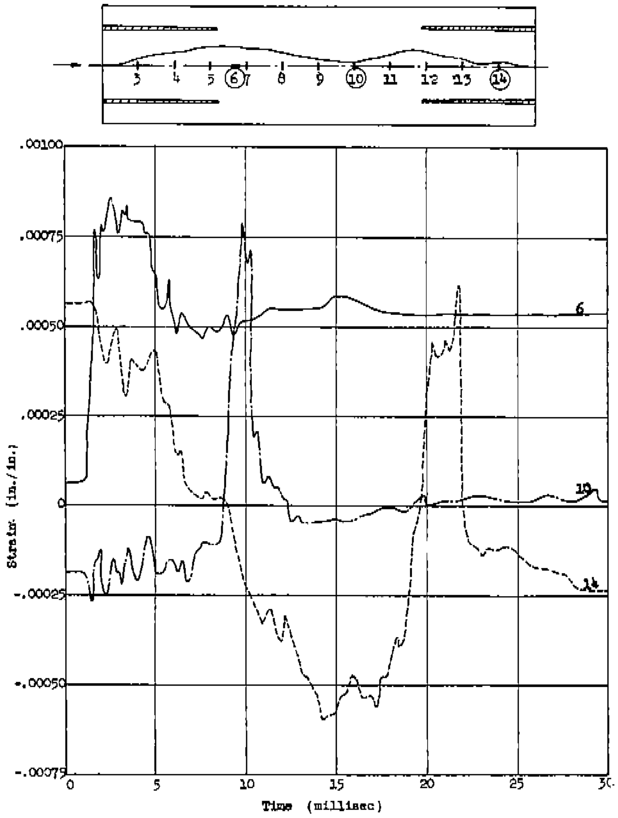


FIG. 32. STRAIN-TIME RECORDS FOR GAGES 6, 10, AND 14 - TEST 46

that the farthest gages showed the biggest relaxation indicates that there was a marked bending relaxation in the plane of the plate associated with the slow speed fractures. From Figs. 30 and 31, an abrupt change in strain can be seen after an elapsed time of about 17 millisec for gages 12 and 13. Although sudden changes are also present in the traces of one or two other gages, the strain behavior that occurs at 17 millisec corresponds to a sudden increase in speed as noted below.

A general pattern of decreasing overstrain was again evident across the plate width; the absolute values of the peak strain magnitudes were all positive, slightly higher than those recorded in the previous test. The maximum value of overstrain recorded was approximately 0.00181 in./in. near the initiation edge, while the lowest value was about 0.0045 in./in. near the far edge.

The range of fracture speeds, as determined from crack detector records and strain gage peaks, was very similar to that observed in Test 45. The detector breaking times and the corresponding computed average speeds are listed in Fig. 33. The highest average speed between detectors was found to be approximately 4500 fps occurring between detectors C and D, while the lowest average speed was found to be approximately 50 fps between detectors K and L at the far edge of the plate. A plot of detector breaking time and time of estimated strain gage peaking versus detector and gage location on the notch line of the plate surface is also presented in Fig. 33. The fracture speed was relatively constant at approximately 3700 fps for the first 20 to 22 in. of crack travel, decreased abruptly for a few inches, and then showed a slight increase, after which the speed again returned to a low value until the fracture had propagated to cross approximately two-thirds of the plate width. At this point, as was also noted in the last test, a sudden increase in speed occurred, lasting less than a millisec, over about 6 or 7 in. of crack travel. The speed then reduced sharply and continued to decrease slightly for the remainder of the fracture.

A photograph of the fracture surface is shown in Fig. 34. As may be noted, the texture of smoothest appearance occurred in the last two-thirds of

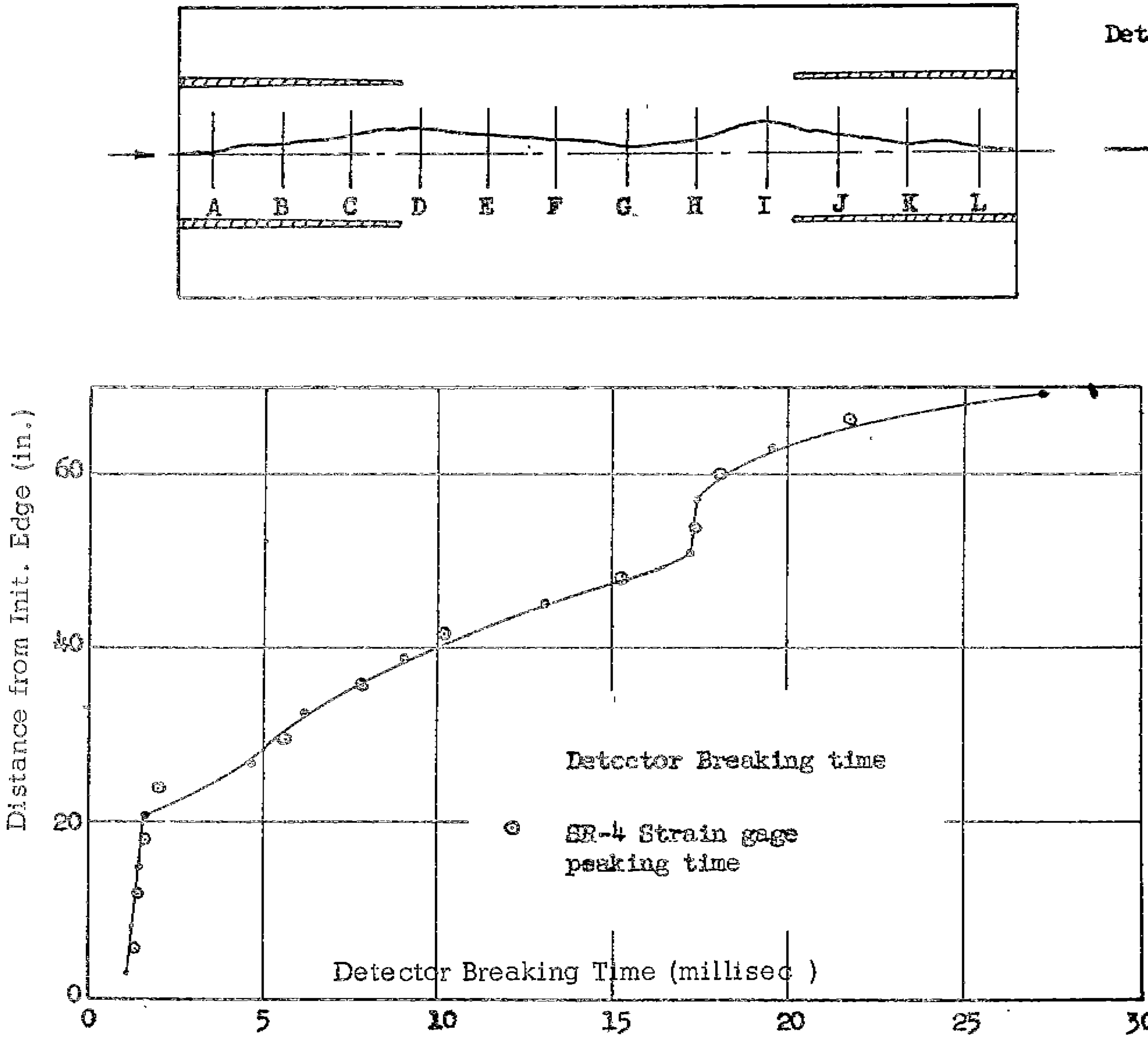


FIG. 33. AVERAGE FRACTURE SPEEDS - TEST 46

Detector	Distance Between Detectors (ft)	Time Interval (millisec)	Average Speed (fps)
A			
	0.50	.19	2650
B			
	0.50	.15	3350
C			
	0.50	.11	4550
D			
	0.50	3.15	150
E			
	0.50	1.40	350
F			
	0.50	3.06	150
G			
	0.50	4.02	100
H			
	0.50	4.08	100
I			
	0.50	.24	2100
J			
	0.50	2.15	250
K			
	0.50	7.77	50
L			

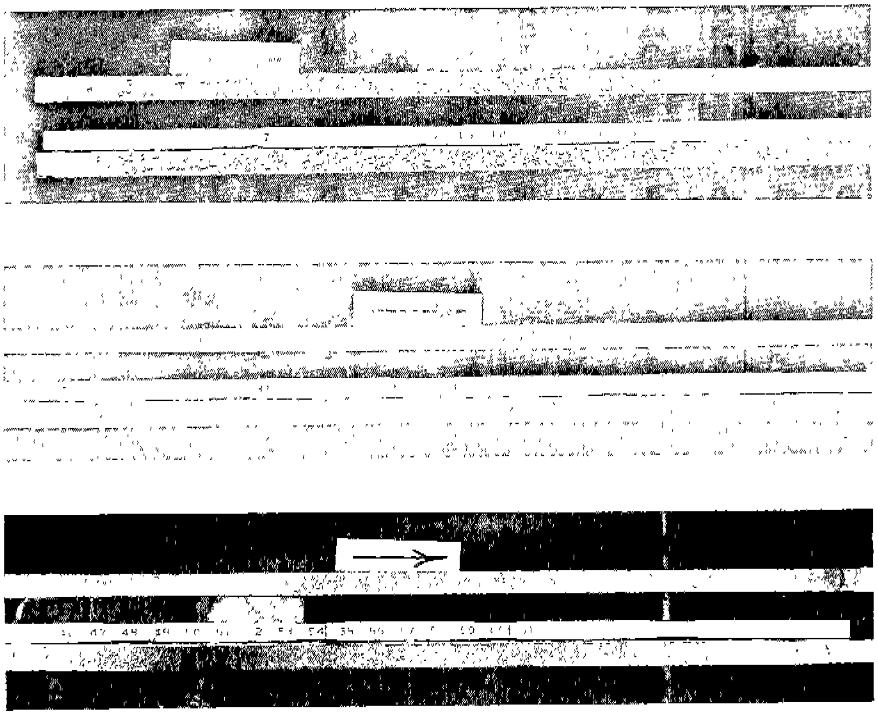


FIG. 34. FRACTURE SURFACE - TEST 46

the fracture, while the region near the initiation edge was rather coarse.

Test 47. Test 47 was the first of two tests in which all 34 channels of dynamic recording equipment were utilized. With the information obtained from the additional instrumentation, principal strains could be calculated at several points across the plate. On the basis of the previous four tests, it seemed probable that a small externally applied load, in conjunction with a residual strain field, would be sufficient to ensure complete fracture of the plate using the standard initiation technique. However, the presence of residual strains alone would probably restrict the fracture length to some portion of the plate width. From the results of Test 43, it seemed reasonable to assume that this partial fracture would propagate across approximately two-thirds of the plate width before arresting. For this reason, the specimen used in this test, and also the specimen used in Test 48, were tested under conditions of zero applied load (except for the dead load of the pull-plates and pullhead) to obtain data on propagating fractures that would be expected to arrest.

A plot of the vertical residual strains along the notch line resulting from the welding procedure is shown in Fig. 12; it may be noted that warping was

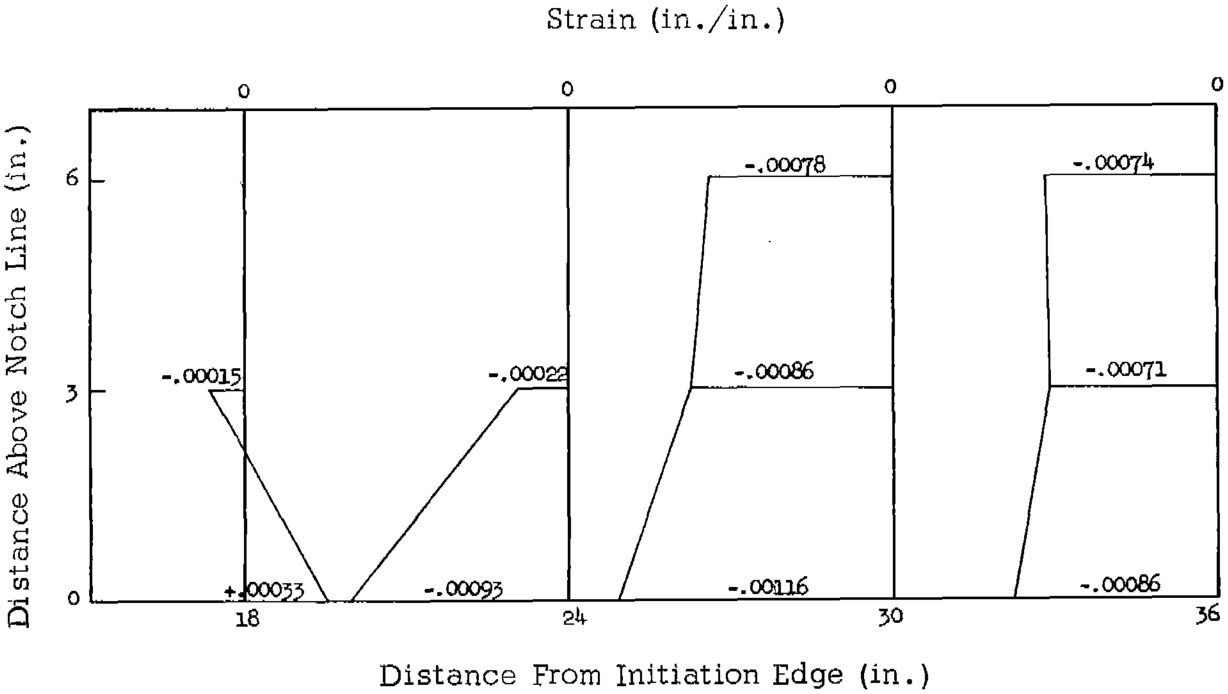
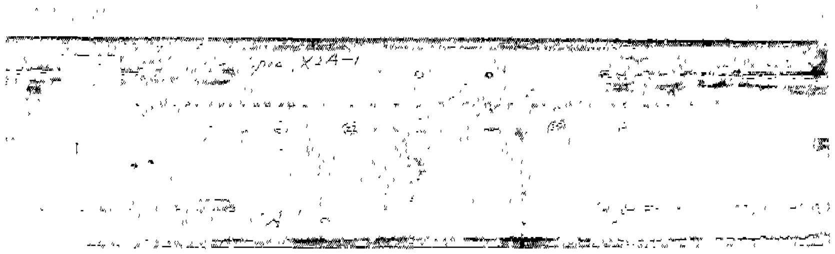


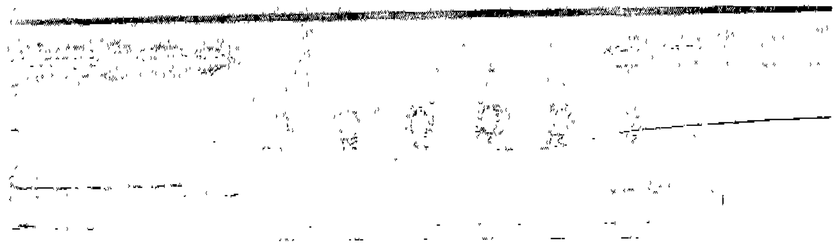
FIG. 35. LONGITUDINAL RESIDUAL STRAIN DISTRIBUTION IN VERTICAL DIRECTION - TEST 47

evident after welding. Although the average of the strain readings obtained by the Berry gage indicates a fairly uniform compressive strain region in the central portion of the plate, there is quite a discrepancy between these values and the corresponding values obtained from the SR-4 strain gages. It was felt that this could have been the result of the different gage lengths involved. As may be seen from Fig. 35, the vertical strain in the longitudinal direction exhibits quite a steep gradient at relatively small distances from the notch line, which quite likely accounts for the difference in strain values for different gage lengths. Unfortunately, on this specimen the welding of the slots was interrupted; this may help to account for the lack of agreement noted between the Berry and SR-4 strain readings.

The average compressive strain across the central portion of the plate was approximately -0.0005 in./in. The specimen was tested in the 3,000,000-lb testing machine with zero applied load, at a temperature of -8 F, and with the standard initiation technique. A brittle fracture propagated approximately 25 in. across the plate before arresting in the compressive strain region. At the point of arrest, the initial residual compressive strain was approximately



Test 47



Test 48

FIG. 36. FRACTURE PATHS - TESTS 47 AND 48

-0.00065 in./in. A photograph of the fracture path is shown in Fig. 36.

The instrumentation layout and a sketch of the crack path are presented in Fig. 7. In Figs. 37-47 are presented the strain-time records for these gages as well as the computed values of the principal strains, direction of maximum principal strain, and the maximum shear strain. The final plotted values represent the final strain level at any gage point. Since the fracture propagated past only four rosettes before arresting, the information available from the strain-time records is somewhat limited.

As may be noted from Figs. 37 and 38, the response of the component gages of rosettes 1 and 2 was similar, first relaxing slightly to a lower strain value, peaking sharply into tension, and then returning to their final strain value. The component gages of rosettes 3 and 4 showed a similar behavior except that after peaking into tension they did not immediately return to a lower strain value but continued to increase slowly in magnitude. It should be noted, however, that these two rosettes were situated very close to the point of arrest of the crack, and therefore they would not be expected to show a response identical to that of the gages of rosettes 1 and 2, since the crack and its associated strain field did not propagate past these gages. The response of the remaining

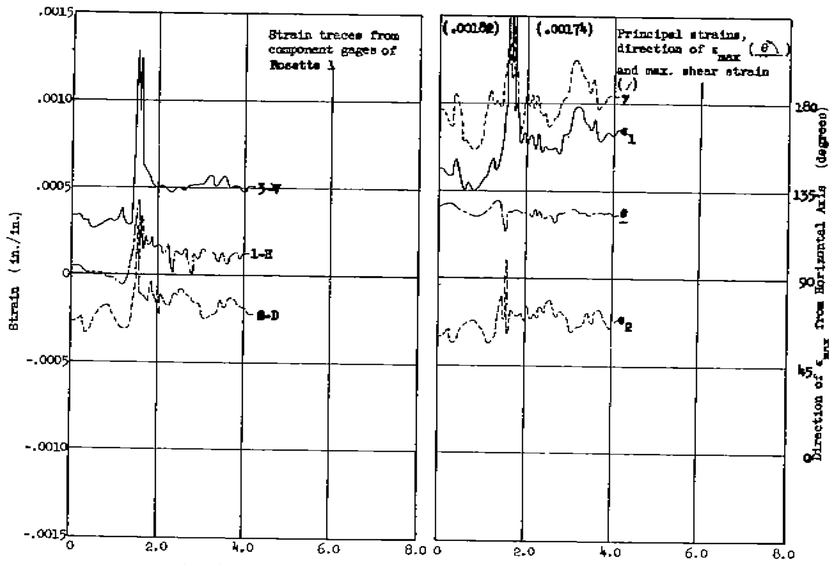


FIG. 37. STRAIN-TIME RECORDS FROM ROSETTE 1

TEST
<——>
47

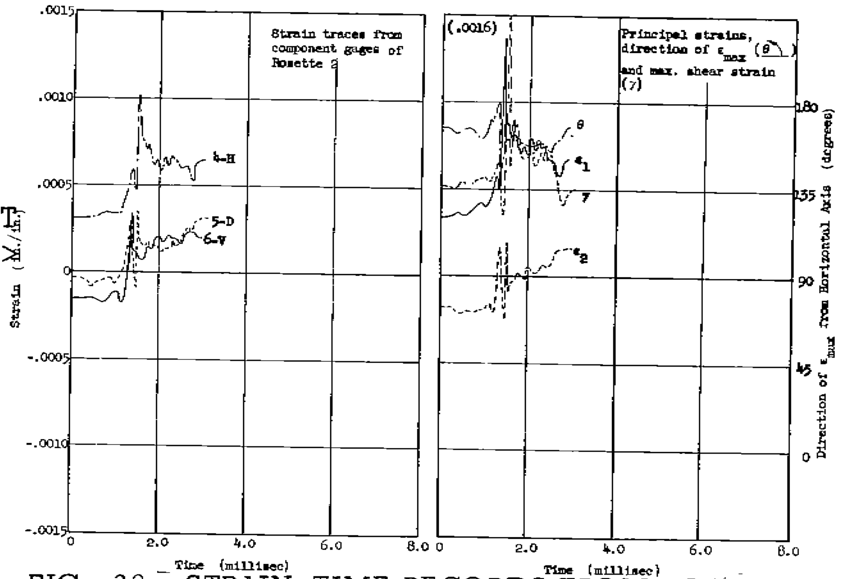


FIG. 38. STRAIN-TIME RECORDS FROM ROSETTE 2

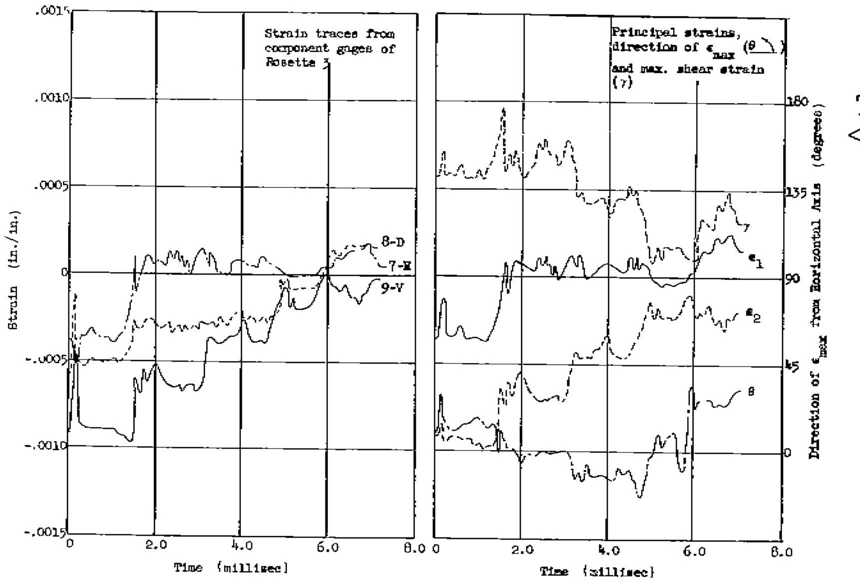


FIG. 39. STRAIN-TIME RECORDS FROM ROSETTE 3

TEST
<——>
47

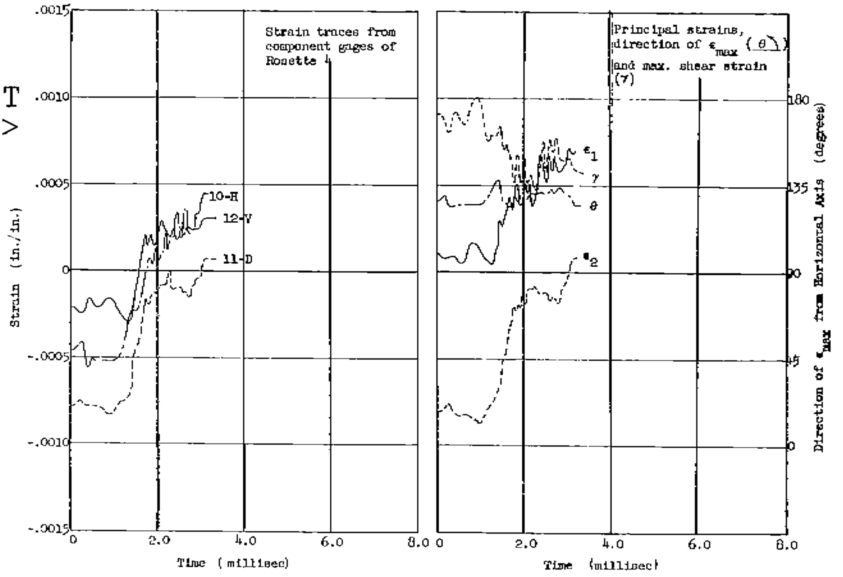


FIG. 40. STRAIN-TIME RECORDS FROM ROSETTE 4

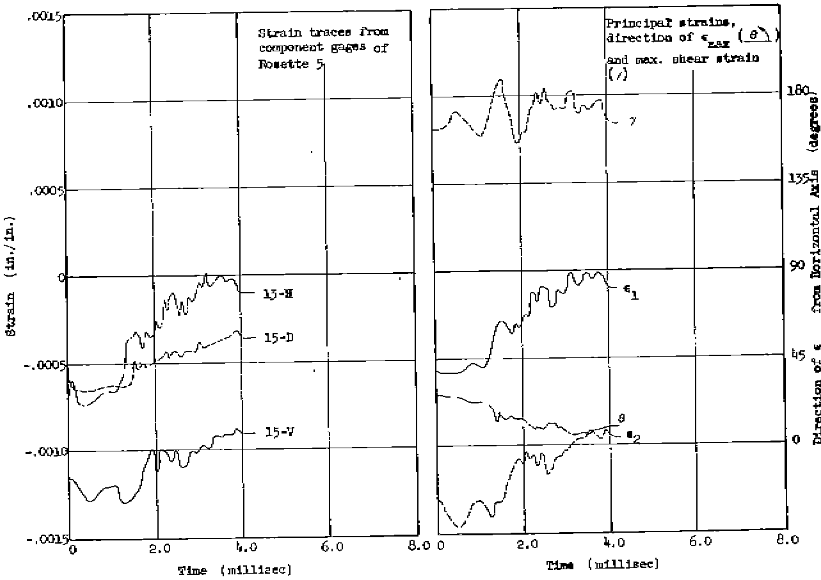


FIG. 41. STRAIN-TIME RECORDS FROM ROSETTE 5

TEST
<——>
47

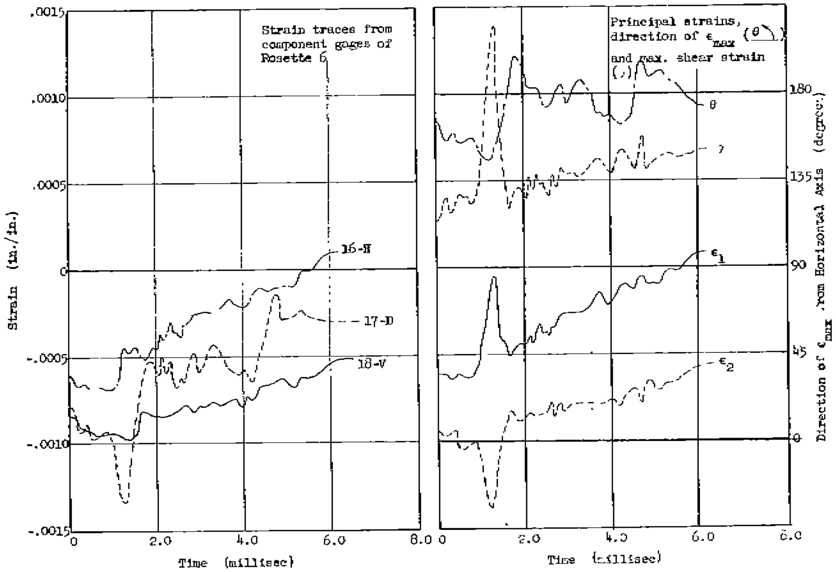


FIG. 42. STRAIN-TIME RECORDS FROM ROSETTE 6

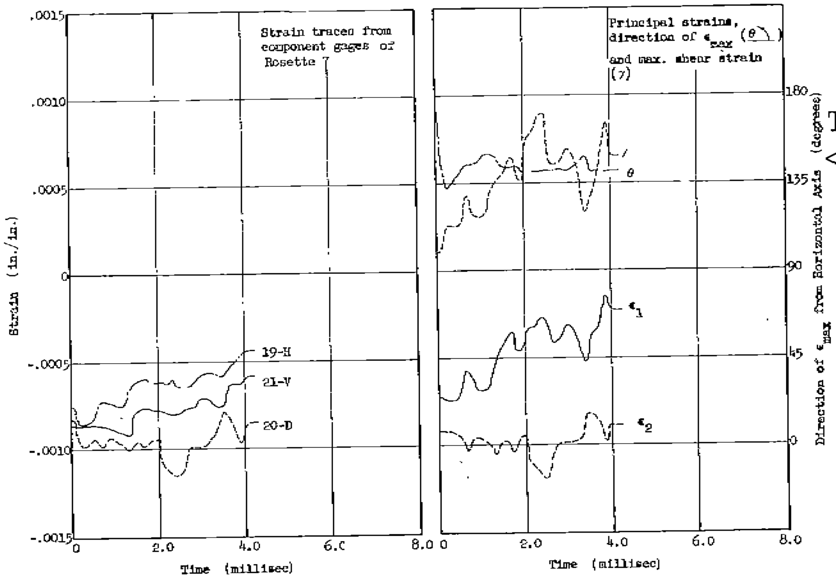


FIG. 43. STRAIN-TIME RECORDS FROM ROSETTE 7

TEST
<——>
47

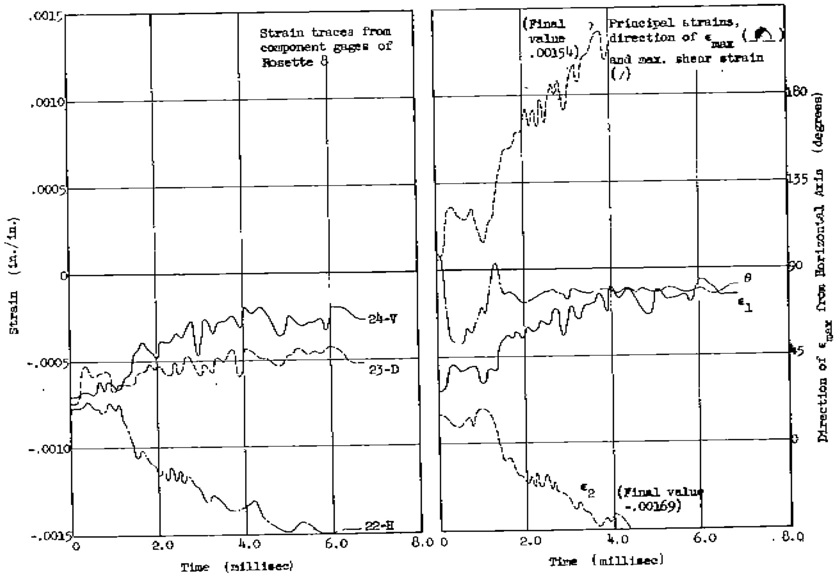
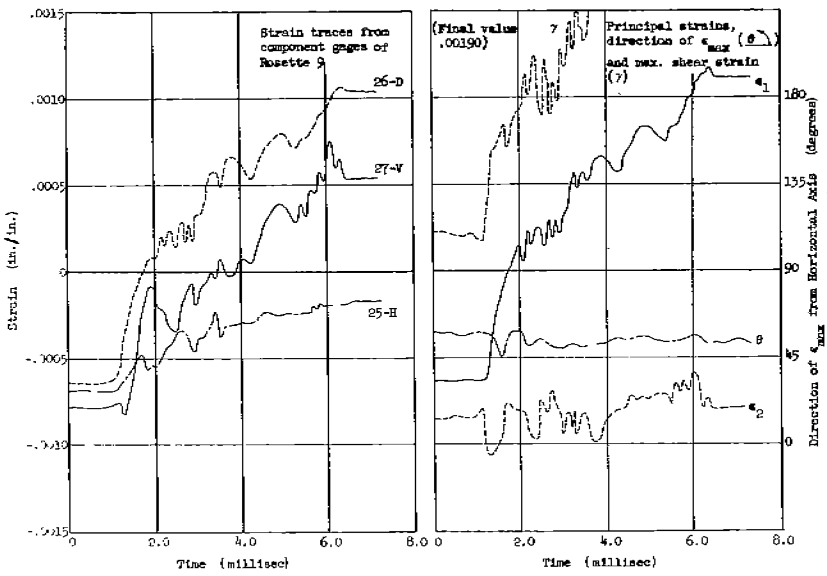


FIG. 44. STRAIN-TIME RECORDS FROM ROSETTE 8



TEST
<——>
47

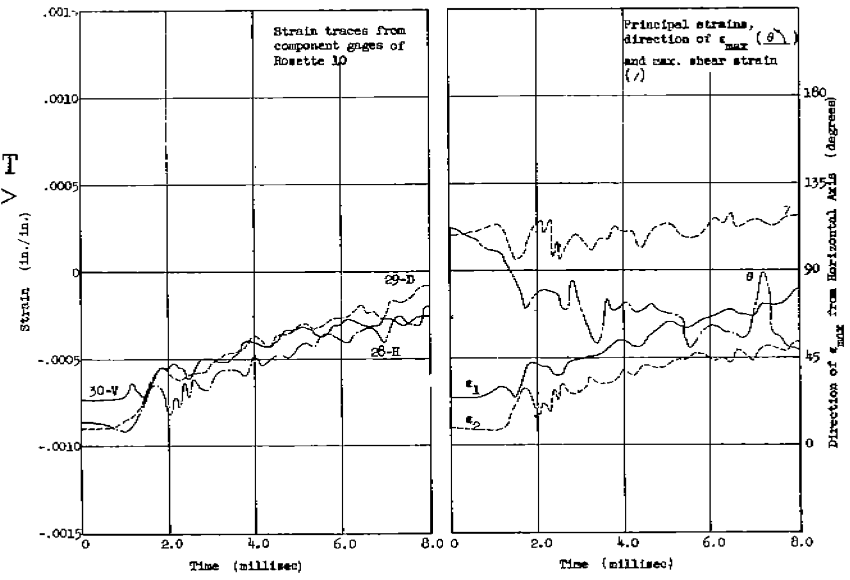


FIG. 45. STRAIN-TIME RECORDS FROM ROSETTE 9

FIG. 46. STRAIN-TIME RECORDS FROM ROSETTE 10

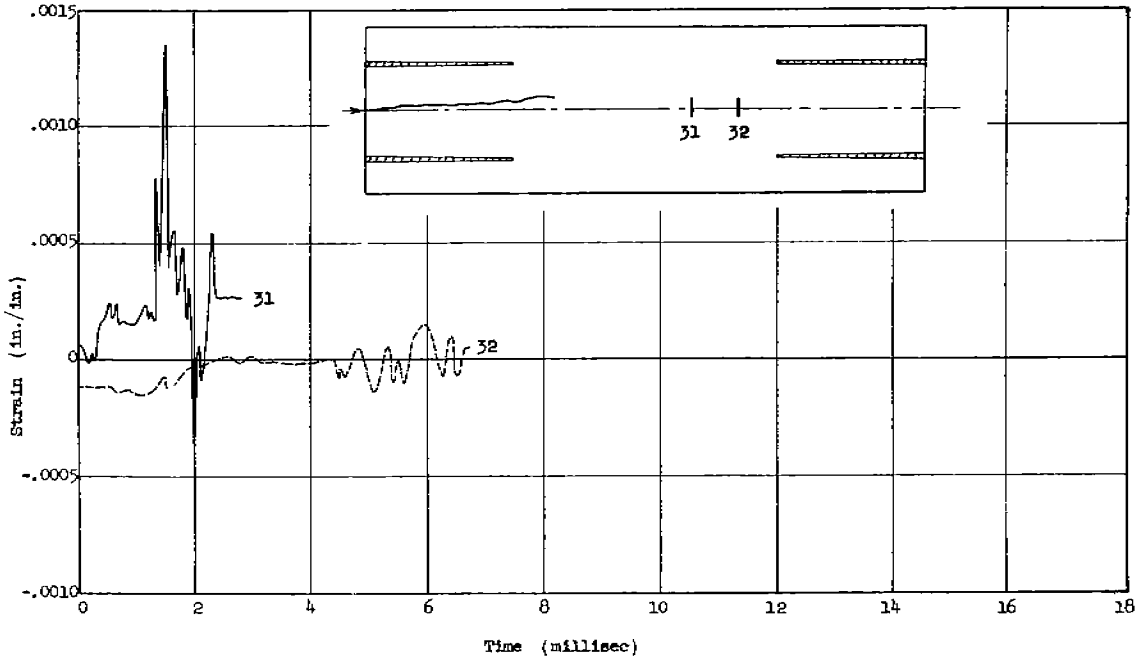


FIG. 47.
STRAIN-TIME
RECORDS OF
GAGES 31 AND
32 - TEST 47

component gages showed only the relaxation of the residual strains as a result of the fracture.

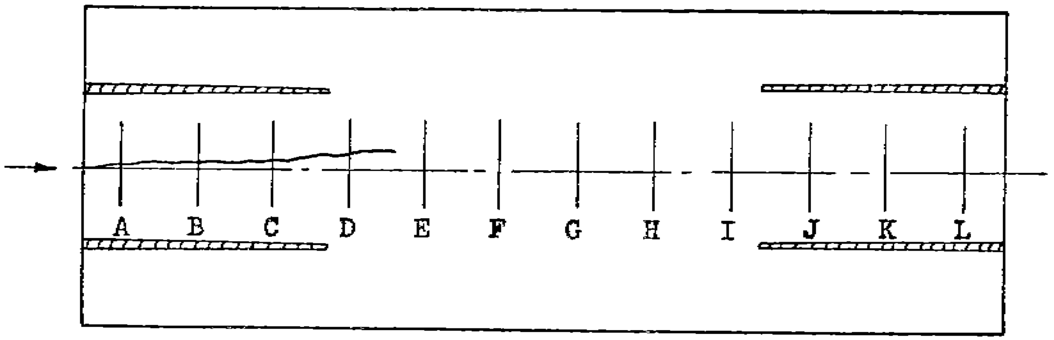
As may be seen from Figs. 37, 39, 41 and 43, the values of overstrain, as determined from the component gages of the rosettes along the notch line and from the computed value of the maximum principal strain for these rosettes, were positive for rosettes 1 and 3 and negative for rosettes 5 and 7. This same pattern is evident along a line 3 in. above the notch line and parallel to it, with rosettes 2 and 4 showing a positive overstrain and rosettes 6 and 8 a negative value. The direction of the maximum principal strain did not change appreciably for any of the rosettes throughout the test.

The fracture propagated through four crack detectors before arresting; in Fig. 48 are presented the detector breaking times for detectors A through D and the corresponding average speeds. The highest average speed determined in this manner was approximately 3800 fps and the lowest average speed, approximately 250 fps. A plot of detector location versus detector breaking time is also shown in Fig. 48. As may be noted from this plot, the speed was fairly constant at approximately 3700 fps for the first 15 in. of crack travel; it then reduced rapidly and continued decreasing until the crack arrested.

After the specimen had been removed from the testing machine, the plate was cut longitudinally about 12 in. beyond the tip of the surface fracture and subsequently pulled apart to permit examination of the fracture surface, particularly the arrest region. The texture of the fracture surface was essentially the same as observed in earlier tests, the coarser texture occurring near the initiation edge. A photograph of the fracture surface and a closeup of the arrest region as shown in Fig. 49 illustrate the fact that the interior fracture extended only a fraction of an inch beyond the surface fracture.

Test 48. Test 48 was essentially a duplication of Test 47 except for the location of the instrumentation.

The average compressive residual strain across the central portion of the plate was approximately -0.0003 in./in. The residual strain pattern resulting from the welding procedure is plotted in Fig. 13. As may be seen from Fig. 13, the



Detector	Distance Between Detectors (ft)	Time Interval (millisec)	Average Speed (fps)
A			
	0.50	.14	3550
B			
	0.50	.13	3850
C			
	0.50	1.85	250
D			

Fracture Arrested

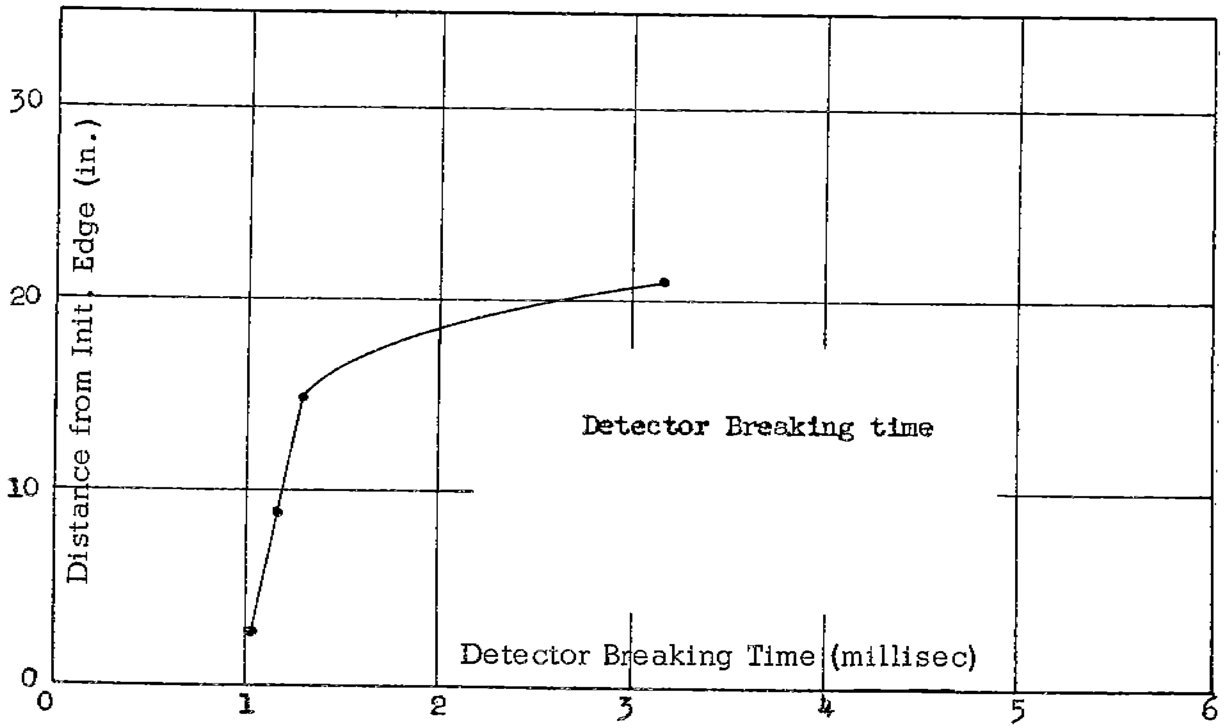


FIG. 48. AVERAGE FRACTURE SPEEDS - TEST 47

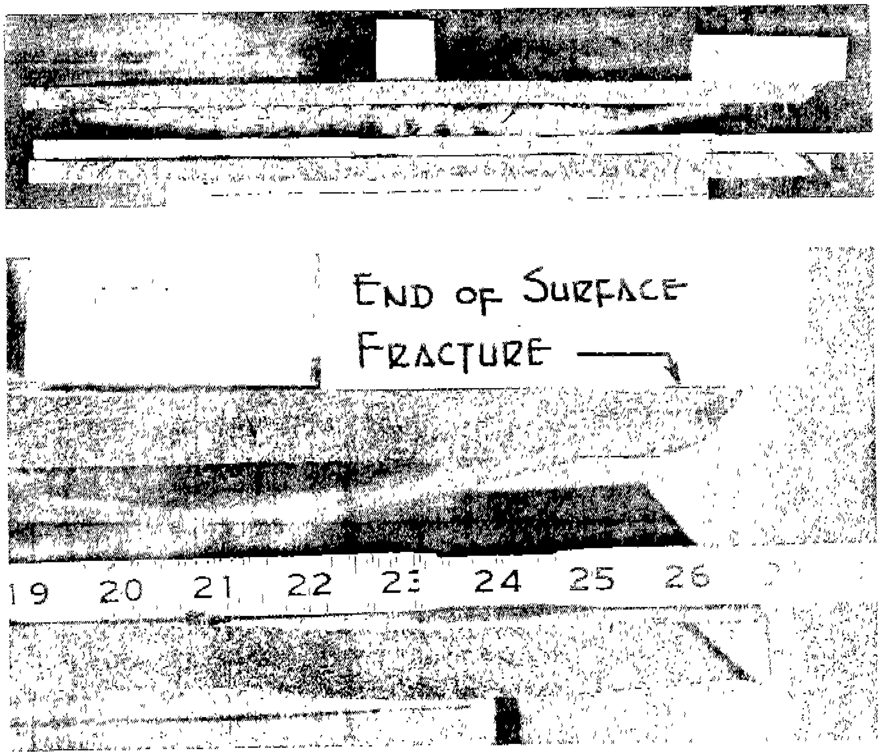


FIG. 49. FRACTURE SURFACE - TEST 47

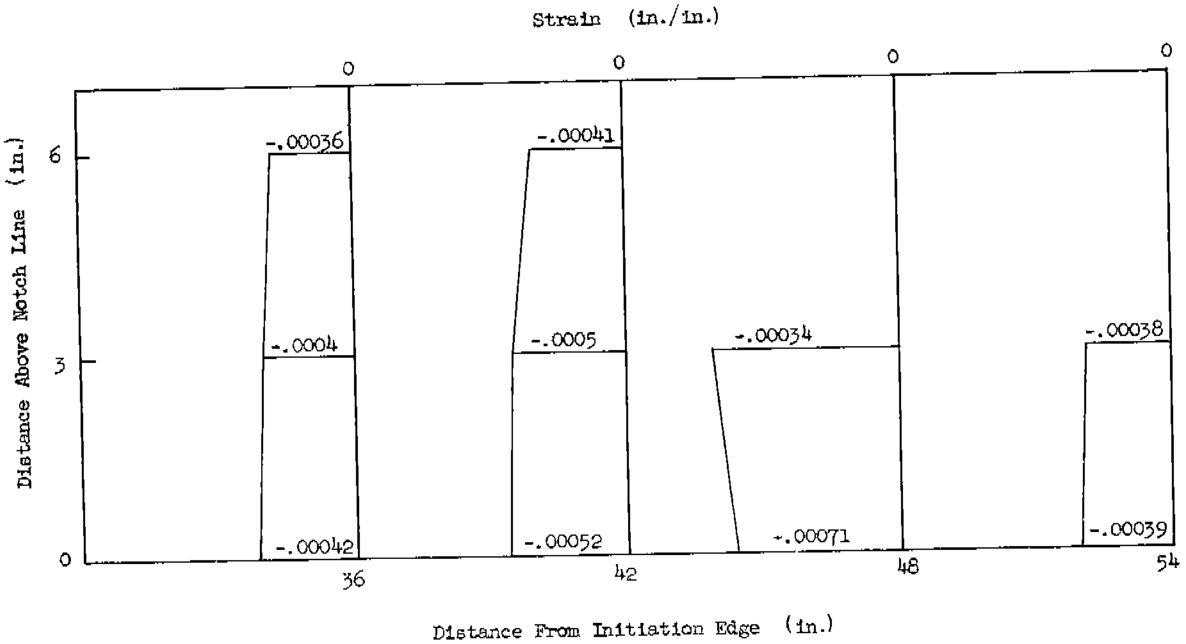


FIG. 50. LONGITUDINAL RESIDUAL STRAIN DISTRIBUTION IN VERTICAL DIRECTION - TEST 48

SR-4 strain gage readings and those obtained from the Berry gage agree closely. Thus, as is evidenced by Fig. 50, the vertical strain gradient in the longitudinal direction is not as steep as that noted for Test 47, Fig. 35.

The specimen was tested with zero applied load, at a temperature of 0°F, and used the standard initiation procedure. A brittle fracture propagated approximately 36 in. across the plate width, as is shown in the photograph of the fracture path in Fig. 36.

The instrumentation layout and a sketch of the crack path are presented in Fig. 8. The information obtained from the dynamic records was again limited since the major portion of instrumentation was located beyond the point of arrest of the fracture. Only the strain records from gages 31 and 32 and rosettes 1 and 2 were reduced; the remaining gages showed negligible strain response. The strain-time records for this test are presented in Figs. 51 through 53; included in Figs. 51 and 52 are the computed principal strains, direction of maximum principal strain, and maximum shear strain as determined from rosettes 1 and 2.

As may be noted from these strain-time records, the traces of gages 31 and 32 showed very little response to the propagating fracture, as did the component gages of rosette 1; the component gage traces of rosette 2, however, showed a sharp peak increase in strain as the fracture propagated by these gages (Fig. 52). This is probably a result of the fact that the fracture passed within 1/2 in. of rosette 2, while it was between 2 and 3 in. away from the other gages. The value of overstrain for gages 31 and 32 was positive, while the overstrain for the component gages of rosettes 1 and 2 was negative. The direction of the principal strains as determined from the two rosettes remained relatively constant throughout the test.

Fracture speed information as determined from the crack detector data is presented in Fig. 54. As in the previous test, the speed for the first 15 in. of crack travel was fairly constant at about 3600 fps, after which it reduced sharply to a much lower value. A slight increase in speed followed by an immediate decrease was evident just prior to arrest.

This specimen was pulled apart after completion of the test to allow an examination of the fracture surface and arrest region. Photographs of the fracture

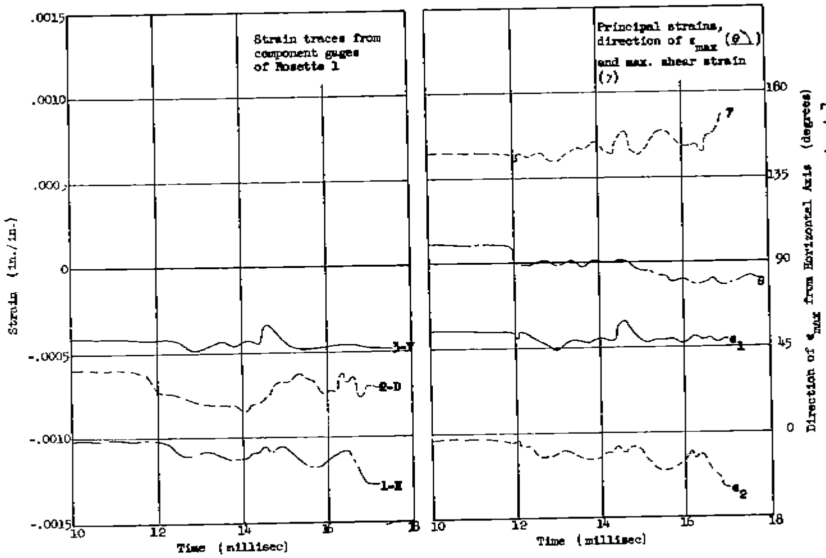


FIG. 51. STRAIN-TIME RECORDS FROM ROSETTE 1

TEST
<——>
48

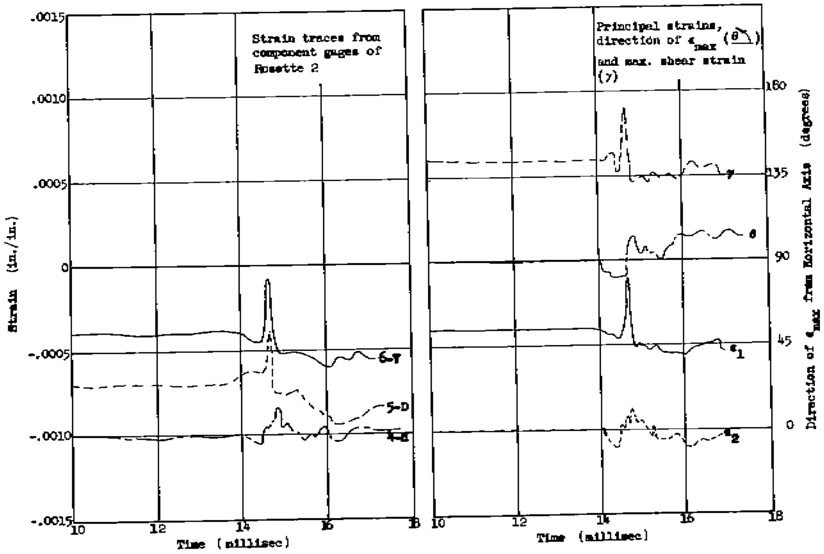


FIG. 52. STRAIN-TIME RECORDS FROM ROSETTE 2

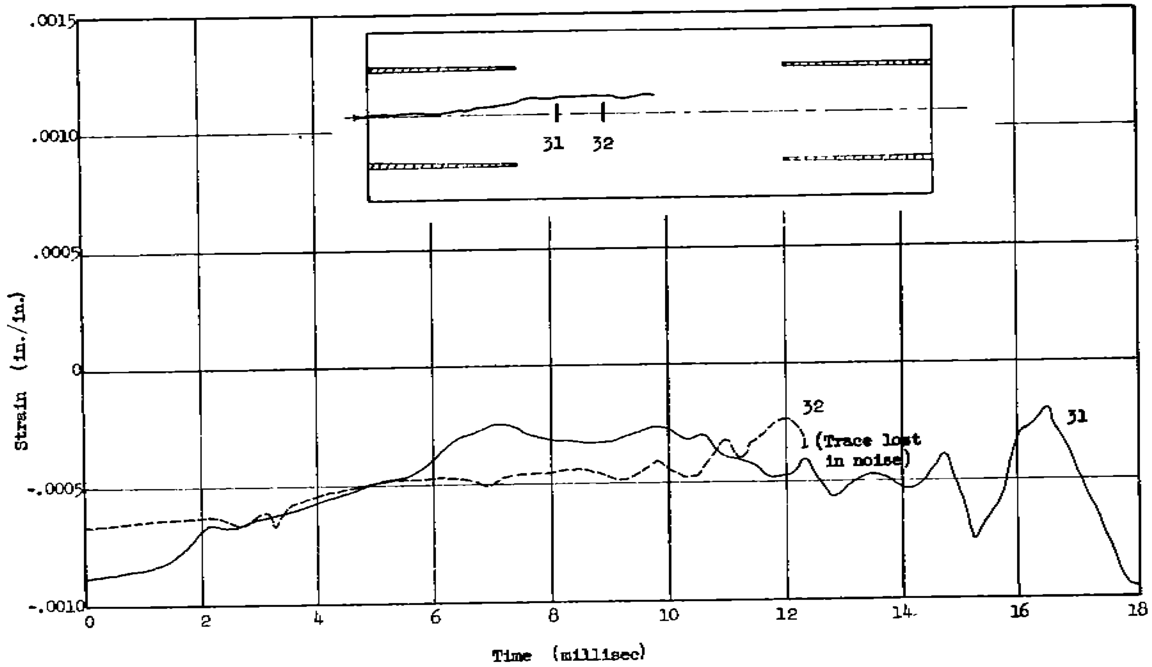
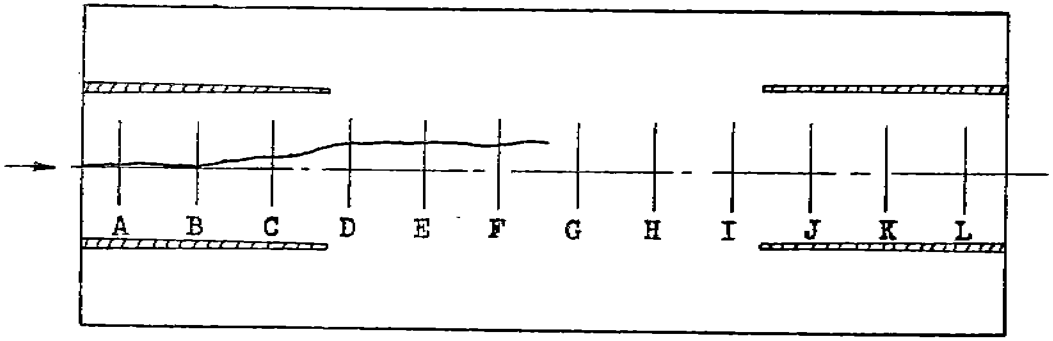
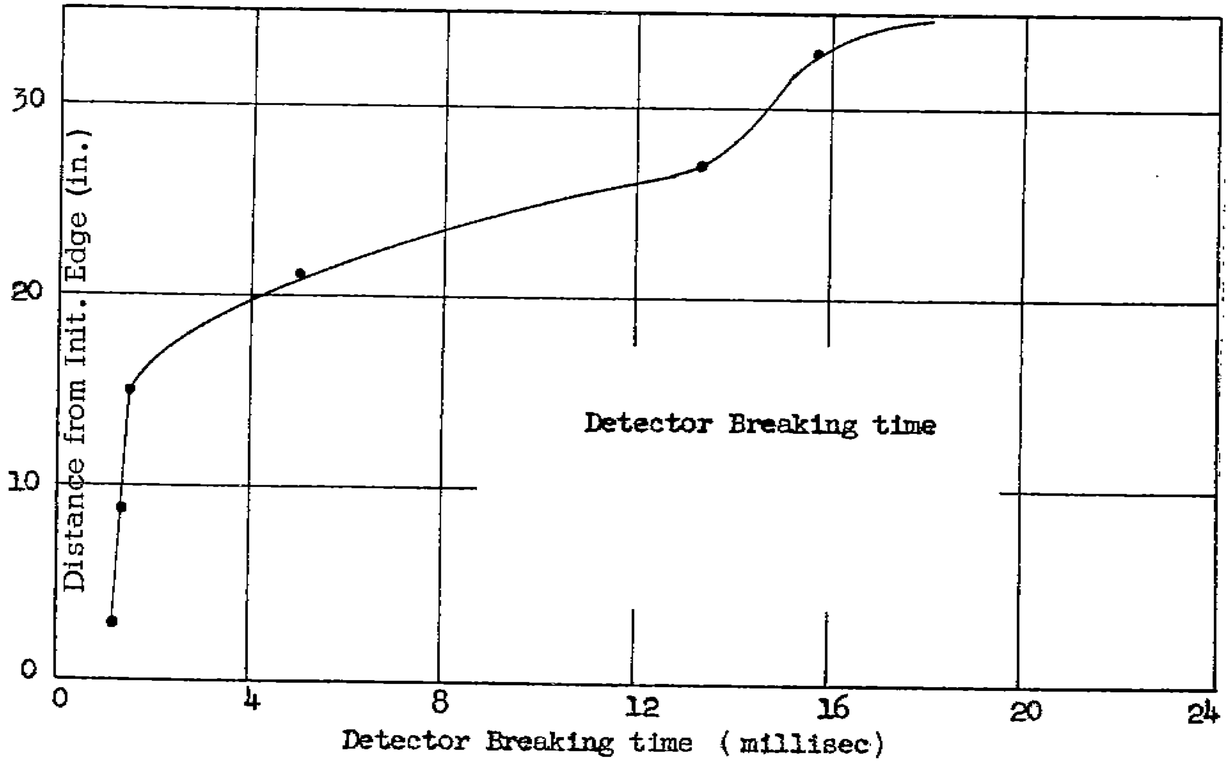


FIG. 53. STRAIN-TIME RECORDS OF GAGES 31 AND 32 - TEST 48

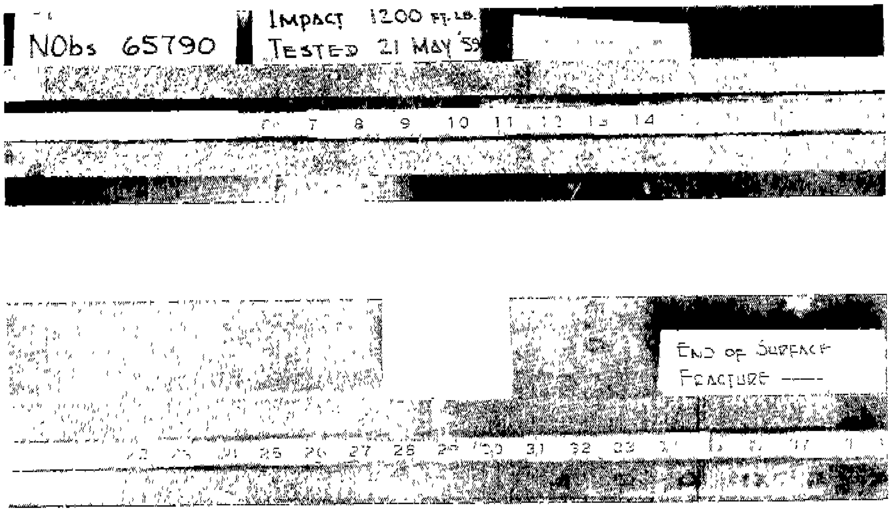




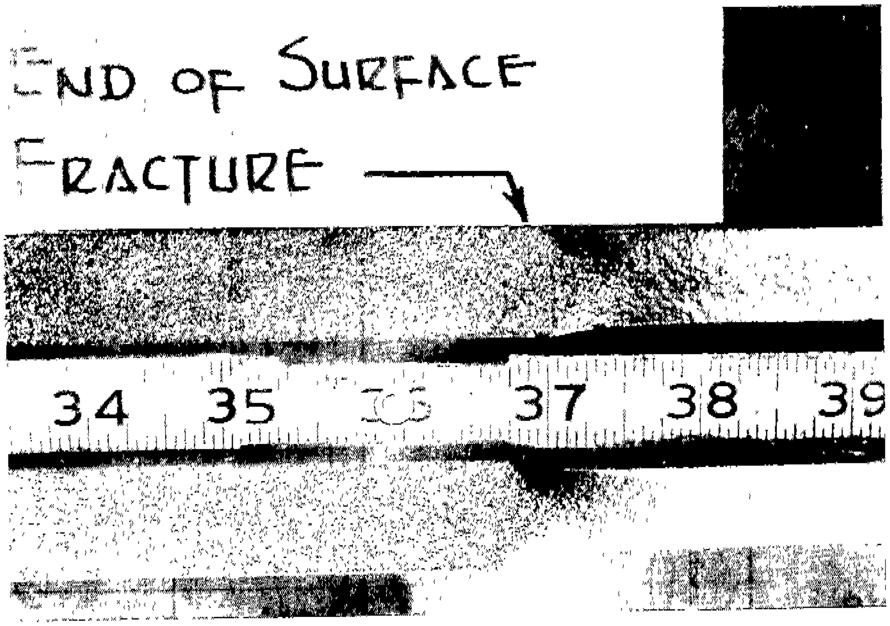
Detector	Distance Between Detectors (ft)	Time Interval (millisec)	Average Speed (fps)
A			
	0.50	.16	3100
B			
	0.50	.12	4150
C			
	0.50	3.38	150
D			
	0.50	8.55	50
E			
	0.50	2.20	250
F			

Fracture Arrested

FIG. 54. AVERAGE FRACTURE SPEEDS - TEST 48



Fracture Surface



Arrest Region

FIG. 55. FRACTURE SURFACE AND ARREST REGION - TEST 48

surface and the arrest region are shown in Fig. 55. As may be noted from the lower photograph, the tip of the interior fracture apparently preceded the surface fracture by only 3/8 in. at the time of arrest. It is also interesting to note the appreciable deformation resulting from the shear-type fracture when the plate was pulled apart. This contrasts sharply with the negligible deformation associated with the brittle fracture.

DISCUSSION OF TEST RESULTS

The purpose of this limited series of tests was to investigate the behavior of a brittle fracture propagating through a six-foot-wide steel plate that contained a residual strain field. A previous investigation conducted as a part of this same program was concerned with a similar study of six-foot-wide steel plates in which no prestrain was present but in which an external load was applied.[1] The results from the present series of tests are markedly different from those obtained in earlier brittle-fracture tests of six-foot-wide plates in several respects.

The primary difference between the specimens used in this investigation and those of earlier studies of six-foot-wide plates was the presence of a residual strain field in those now under consideration. The prestraining procedure of welding tapered slots produced high residual tensile strains in the vicinity of the plate edges and, in general, a compressive strain field throughout the central portion of the plate. As may be noted from the test results in this report, no difficulty was experienced in initiating fractures in plates that were prestrained in the manner described. Apparently, the presence of a high residual tensile strain in the initiation region has the same effect on initiation, and to some extent, on propagation, as an externally applied load of comparable magnitude. Certainly, the impact effect of the wedge striking the plate was also a necessary factor for successful initiation under the test conditions employed in this investigation. Nonetheless, the fact that brittle fractures resulted in every test in which a prestrained specimen was used, even those in which no external load was applied, seems to indicate that re-

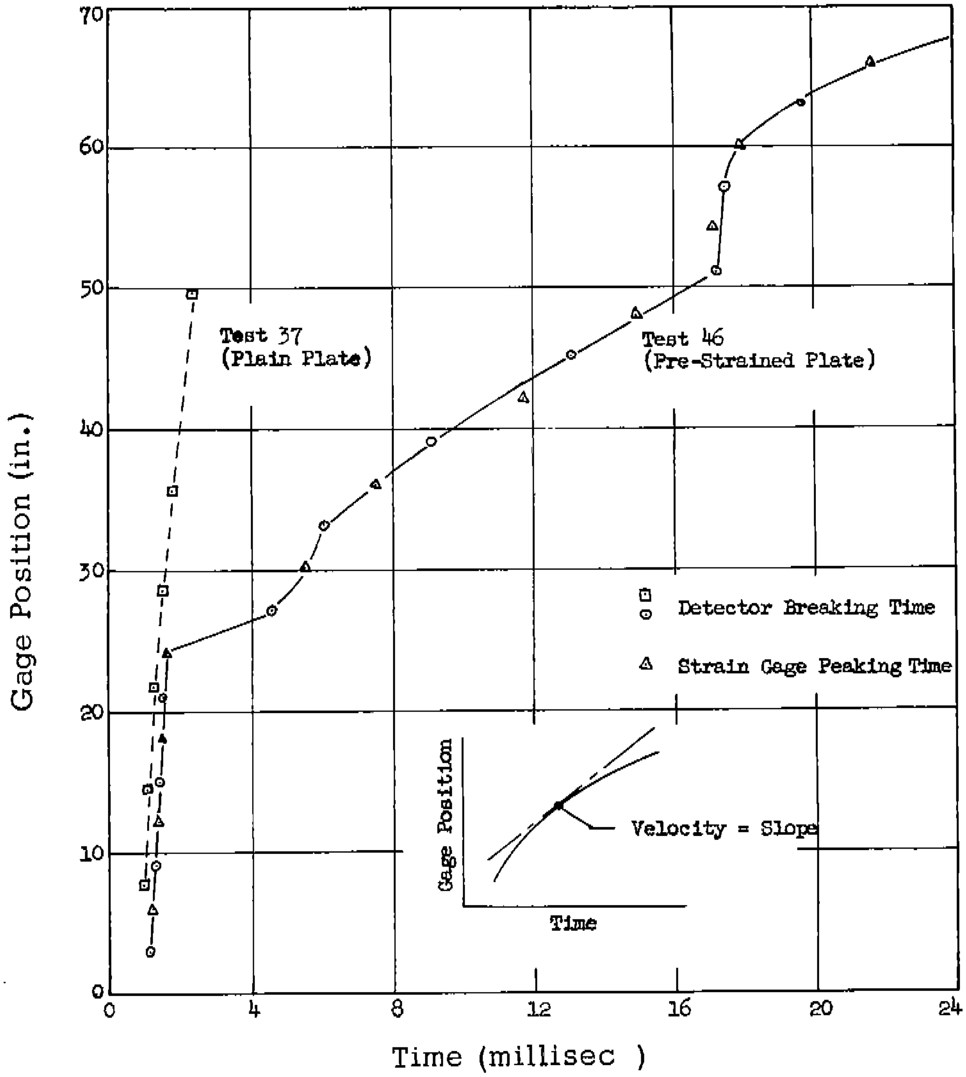


FIG. 56. FRACTURE SPEEDS ACROSS PLATE WIDTHS - TESTS 37 AND 46

sidual tensile strains can be an important factor in the mechanics of initiation and propagation. The compressive strain field in the central portion of the test specimens had just the opposite effect on the fracture characteristics; in addition to causing greatly reduced speeds throughout the central portion of the plate, the compressive strain field acted as an arrestor, causing complete arrest of the fracture in Tests 47 and 48 and, as discussed later in this section, almost causing arrest in Tests 45 and 46.

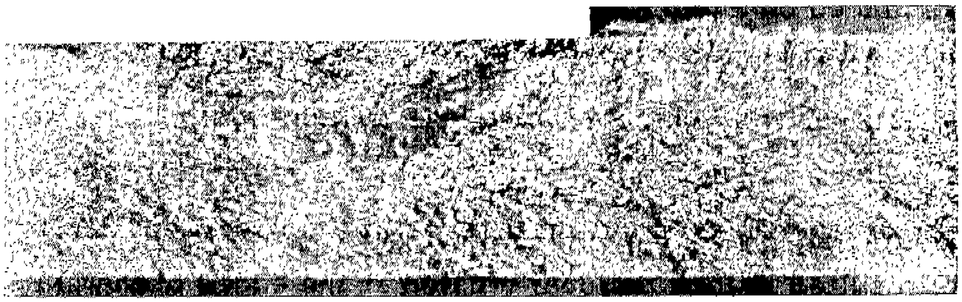
The fracture speeds as determined from the test records are considerably lower than any previously recorded on tests of six-foot-wide plate specimens conducted as a part of this same program. In Fig. 56 is presented a plot of detector location versus detector breaking time for a typical prestrained plate test and, for comparison purposes, for a typical non-prestrained plain plate test. In this graph, the slope of the curve is a rough measure of the fracture speed at any particular time. As may be seen from the figure, the fracture speeds for the two tests are almost identical for approximately the first 20 in. of crack travel. This distance varied slightly in the different tests, always falling within a range of from 15 to 25 in. from the initiation edge. It can be seen that this high speed continued throughout the fracture travel across the plain plate specimen, decreasing only slightly across the plate width, whereas the fracture speed in the prestrained specimen decreased sharply and continued for the remainder of fracture travel at a greatly reduced value. In general, a brittle fracture propagated across the entire width of a plain plate in approximately 3 millisec, while a complete fracture of a prestrained specimen required as much as 30 millisec.

The very high initial speeds and the sudden decrease to a much lower value are probably the result of two factors, namely, the residual strains present in the plate and the initiation procedure employed. In general, the residual strains for the first quarter of the plate width were tensile and for the central half of the plate were compressive. Higher speeds would therefore be expected in the tensile region, while lower speeds would be expected in the compressive region. The effect of the initiation procedure on initiation was illustrated by Test 44. Results of this test indicated that after the area at the root of the notch had been highly strained, the initiation procedure was sufficient in itself to initiate and propagate a brittle fracture approximately 19 in. From this it may be assumed that the initiation procedure contributed significantly to the fracturing process but only during the initial stages.

From the results of fracture tests of prestrained specimens, it can be seen that the fracture speeds in the compressive strain region were in general between 50 and 500 fps and showed a continual decrease as long as the fracture remained in the compressive region. It is likely that the extent and magnitude of the initial residual compressive strain field were sufficient for arrest in every case after the fracture had propagated well into the compressive strain field; however, the length of time required for fracturing was apparently long enough to allow redistribution both of the residual strain field and of any external load. A comparison of the results of Tests 43, 45, and 46 shows that the speed of the fracture approached a zero level in each case; in Test 43 the fracture arrested, while at approximately the same point in Tests 45 and 46 the fracture speeded up suddenly and continued propagating. It is felt that the small external load applied provided enough additional redistribution of load to prevent arrest in the latter two tests.

The dynamic strain records obtained from the instrumented tests indicated the marked effect that the compressive strain field had on the strain field associated with the moving crack. The strain-time records from Tests 45 and 46 show this effect most clearly since in these two tests dynamic measurements were recorded across the entire plate width. It may be seen that, in every case, the peak strain magnitudes decreased as the fracture entered the compressive strain region, indicating that, as the fracture slowed down, the extent of the strain field associated with the fracture diminished. This reduced strain field is evident also from the results of Tests 47 and 48. As may be noted from the strain-time traces, at extremely low fracture speeds gages located between 1 and 3 in. from the fracture showed no noticeable response, and gages located at less than 1 in. from the fracture showed only a small peaking response as a result of the fracture. It should be pointed out, however, that the fracture was on the verge of arrest in Tests 47 and 48 when it reached the dynamic gages. Hence, it is logical to assume that as a propagating fracture decreases in speed, the strain field associated with it also diminishes. As may be noted in the strain records of Tests 45 and 46, the width of the strain peaks generally became progressively wider as the fracture propagated across the plate width. This may be attributed in part to the longer time required for the fracture to pass a particular gage.

Values of overstrain, defined in this report as the maximum peak strain magnitude recorded at any gage point during the fracturing process, may be con-



Region of High Speed

Region of Low Speed

FIG. 57. TYPICAL CRACK TEXTURES

sidered to be a criterion for continued propagation or arrest. The overstrain values obtained from tests in which the fracture did not arrest were always positive, approaching zero as the speed decreased. The results from the two tests in which arrest occurred showed negative values of overstrain at gage locations in the vicinity of the arrest point.

The texture of the fracture surface was noticeably different in regions of fast and slow speeds as noted in the previous section. In every test, the surface texture had a much coarser appearance in the vicinity of the initiation edge where the highest speeds were recorded. Throughout the compressive strain portion, the texture was considerably smoother, as may be seen from the photographs in Fig. 57. Based on the results of this series of tests, the smoother crack textures are apparently always associated with the slower speeds, and the rougher textures are associated with the regions of higher speed.

SUMMARY

The purpose of these tests was to study the propagation of a brittle fracture in six-foot-wide steel plates containing a residual strain field; primary emphasis was placed on a determination of the fracture speeds and strains associated with a moving crack.

Six specimens were prepared for brittle fracture tests. One was a plain steel plate specimen; the remaining five contained a residual strain field produced by welding tapered slots cut in the edge of the specimen. This prestraining procedure resulted in high residual tension at the edges of the plate and residual compression throughout the central portion.

Brittle-fracture tests were conducted on all six plates; two plates were tested with unrestrained ends, two plates with a small applied load, and two with no applied load but with the ends of the plates rigidly attached to the heads of the testing machine. The specimens were cooled prior to testing and the fractures initiated with the notch-wedge-impact method of fracture initiation. Instrumentation provided a record of strain response and crack speed.

The results of the six brittle-fracture tests may be summarized as follows:

1) Initiation of a brittle fracture occurred in every specimen that contained a residual strain field, even when no external load was applied. Apparently, a high residual tensile strain at the initiation edge has the same effect on initiation and, to some extent, on propagation as the strain corresponding to an external applied load.

2) In the plain plate specimen the first attempt at initiation resulted in no fracture; however, when the plate was subjected to a second blow, identical in magnitude to the first, a brittle fracture propagated approximately 19 in. into the plate. The successful initiation on the second attempt probably resulted from the fact that the region at the root of the notch had already been highly strained by the first impact.

3) The recorded fracture speeds were much lower than any previously noted on tests of six-foot-wide plates, ranging from about 4000 fps near the initiation edge to as low as 50 fps in the compressive strain region.

4) The strain response as measured by gages located at various points across the plate showed that the peak strain magnitudes decreased as the frac-

ture propagated through the compressive strain region. Studies of the data show that as the fracture speed decreases, the extent of the strain field associated with the moving crack tip also diminishes.

5) The values of overstrain remained positive as long as the fracture continued to propagate; for fractures that arrested, the values of overstrain beyond the point of arrest were always negative.

6) On the basis of this series of tests, it appears that a rough surface texture is associated with high fracture speeds, while a smoother texture results in regions of low fracture speed.

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