

UNCLASSIFIED

A
D

210240

Armed Services Technical Information Agency

ARLINGTON HALL STATION
ARLINGTON 12 VIRGINIA

THIS

IS A COPY

CONTROL ONLY

1 OF 7

NOTICE: WHEN GOVERNMENT OR OTHER DRAWINGS, SPECIFICATIONS OR OTHER DATA ARE USED FOR ANY PURPOSE OTHER THAN IN CONNECTION WITH A DEFENSE-RELATED GOVERNMENT PROCUREMENT OPERATION, THE U. S. GOVERNMENT THEREBY INCURS NO RESPONSIBILITY, NOR ANY OBLIGATION WHATSOEVER, AND THE FACT THAT THE GOVERNMENT MAY HAVE FORMULATED, FURNISHED, OR IN ANY WAY SUPPLIED THE SAID DRAWINGS, SPECIFICATIONS, OR OTHER DATA IS NOT TO BE REGARDED BY IMPLICATION OR OTHERWISE AS IN ANY MANNER LICENSING THE HOLDER OR ANY OTHER PERSON OR CORPORATION, OR CONVEYING ANY RIGHTS OR PERMISSION TO MANUFACTURE, USE OR SELL ANY PATENTED INVENTION THAT MAY IN ANY WAY BE RELATED THERETO.

UNCLASSIFIED

BEST

AVAILABLE

COPY

NO 210240
ASTIA 111100

FILE COPY
Return to
ASTIA
ARLINGTON HALL STATION
ARLINGTON 12, VIRGINIA
ATTN: TISS

THE ENGINEERING BEHAVIOR OF STRUCTURAL METALS

UNDER SLOW AND RAPID LOADING

by

J. M. Massard and R. A. Collins

Approved by

N. M. Newmark

Final Technical Report

to

Office of Naval Research
Contract Nont-185 (01)
Project NR-C-4-419

Department of Civil Engineering

University of Illinois

Urbana, Illinois

October 1958

ABSTRACT

The purpose of this report is to describe an experimental investigation concerned with the behavior of a few structural metals under a range of stress conditions applied in times that correspond to the responses which might be excited in ship structures by underwater explosion or air blast loading, or in building structures by earthquake shock or the explosion of a large scale weapon. The engineering aspects of material behavior are emphasized.

The tests included uniaxial stress applied in either tension or compression, and flexural stress produced by third-point loading of small beams of rectangular section. The rise times of the loadings were varied from a few milliseconds to several minutes. An attempt is made to correlate the results obtained in the uniaxial stress tests with those obtained in flexure.

The applicability of the results of this investigation to the general problem of determining the behavior of structures under transient dynamic loadings producing extensive inelastic deformations is discussed briefly.

ACKNOWLEDGMENT

The investigation described in this report was performed by staff members of the University of Illinois in cooperation with the Office of Naval Research under Contract Nonr-1834(01), Project NR-064-412. The work was conducted in the Structural Research Laboratory of the Department of Civil Engineering under the general direction of Professor N. M. Newmark, Head of the Department. The project was under the supervision of Dr. J. M. MacHardy, Research Assistant Professor of Civil Engineering. The latter part of the work was the direct responsibility of R. A. Collins, Research Assistant in Civil Engineering. The instrumentation used throughout the investigation was, in general, the responsibility of V. J. McDonald, Research Associate Professor of Civil Engineering.

The initial development of the basic testing apparatus and the preliminary testing was done by Dr. MacHardy prior to the beginning of Contract Nonr-1834(01). For completeness, some of the results of other preliminary studies which predate the contract are included in this report. These were investigations described in Master's Theses submitted to the Graduate College of the University of Illinois by L. B. Smith and J. W. Storm. This early work was supported in part by funds obtained from the Bureau of Ships, Department of the Navy under Contract NObb 62250.

THE ENGINEERING BEHAVIOR OF STRUCTURAL METALS
UNDER SLOW AND RAPID LOADING

TABLE OF CONTENTS

	<u>Page</u>
ABSTRACT	11
ACKNOWLEDGMENT	111
LIST OF TABLES	vii
LIST OF FIGURES.	viii
1. GENERAL INTRODUCTION	1
1.1 Introduction.	1
1.2 Scope	2
2. RAPID LOADING AND STRAINING EQUIPMENT.	4
2.1 Introduction.	4
2.2 Description of Rapid Loading Apparatus.	4
2.3 Control of Loading Pulse.	5
2.4 Past Usage in Testing	6
2.5 Description of Slow Straining Unit.	6
2.6 Summary	6
3. UNIAXIAL STRESS TESTS.	8
3.1 Introduction.	8
3.2 Description of Testing Series	9
3.2.1 Types of Specimens	9
3.2.2 Manufacture of Specimens	10
3.2.3 Metallurgical Properties and Chemical Compositions	11

TABLE OF CONTENTS (Continued)

	<u>Page</u>
3.3 Description of Testing Procedures	12
3.3.1 Instrumentation.	12
3.3.2 Slow Tests	15
3.3.3 Machine Vibration Tests.	16
3.3.4 Residual Microstrain Determination	16
3.3.5 Rapid Tests.	17
3.3.6 Effective Gage Length.	19
3.4 Results of Uniaxial Tests	20
3.4.1 General Time Sensitive Behavior of the Various Metals Tested.	20
3.4.2 Results of Tension and Compression Tests	22
3.4.3 Results of Preliminary Reversed Stress Tests	23
3.5 Summary of Results for Uniaxial Stress Tests.	25
3.5.1 Summary of Results	25
3.5.2 General Significance of Results.	26
4. FLEXURE TESTS.	28
4.1 Introduction.	28
4.2 Description of Testing Series	28
4.2.1 Description of Specimens	28
4.2.2 Material Properties Under Uniaxial Stress.	29
4.3 Description of Testing Procedures	29
4.3.1 Testing Arrangement.	29
4.3.2 Instrumentation.	30
4.3.3 Description of Flexure Tests	31

TABLE OF CONTENTS (Continued)

	<u>Page</u>
4.4 Results of Flexure Tests.	32
4.4.1 Experimental Results	32
4.4.2 Correlation Study.	35
4.5 Summary of Results of Flexure Tests	37
4.5.1 Summary of Results	37
4.5.2 Significance of Results.	38
5. GENERAL SUMMARY.	39
5.1 General Summary	39
BIBLIOGRAPHY	41
APPENDIX -- DETERMINATION OF FLEXURAL RESISTANCE FROM BEAM DEFORMATION AND UNIAxIAL STRESS PROPERTIES	44

LIST OF TABLES

1. Summary of Uniaxial Testing Program
2. Uniaxial Specimen Designation Code
3. Results of Metallurgical Studies
4. Chemical Compositions of Specimen Steels
5. Summary of Uniaxial Stress Tests and Results

LIST OF FIGURES

1. Pressure Panel, and 20-Kip Pulse Loading Unit Arranged for Testing Uniaxial Tension Specimens
2. Schematic Representation of 20-Kip Pulse Loading Apparatus
3. 20-Kip Pulse Loading Unit
4. Some Loading Pulses that Can Be Produced
5. Pulse Loading Unit Being Used to Test Model Frame
6. 60-Kip Pulse Loading Unit in Frame for Testing Beam-Columns
7. 20-Kip Pulse Loading Unit and 20-Kip Straining Unit Connected in Series for Testing Tension-Compression Specimens. Shown with Pressure Control Panels
8. Schematic Representation of 20-Kip Straining Apparatus
9. Dimensions of Tensile Specimens
10. Connection of Tensile Specimen in Pulse Loading Machine
11. Dimensions of Specimens from Sheet Stock
12. Dimensions of Preliminary Tension-Compression Specimens
13. Dimensions of Tension-Compression Specimen and Manner of Connection
14. Metallographs of Specimen Materials
15. CRO Instruments, Pressure Panel, and Pulse Loading Unit Arranged for Testing Preliminary Tension-Compression Specimens
16. Hathaway Oscillographs and Associated Apparatus
17. Representative Oscillograms from Uniaxial Stress Tests
18. Slowly Cycled Stress-Residual Strain
19. Effective Gage Length -- Elongation
20. Representative Stress-Strain-Time Relation for Mild Steel
21. Stress-Strain and Strain-Time Relationships for Various Materials Tested in Tension and Compression

LIST OF FIGURES (Continued)

22. Upper Yield Stress-Elapsed Time to General Yielding
23. Upper Yield Stress Parameter-Elapsed Time to General Yielding
24. Upper Yield Stress Parameter-Elapsed Time to General Yielding (Various Rise Times of Load)
25. Lower Yield Stress-Rate of General Yielding
26. Lower Yield Stress Parameter-Rate of General Yielding
27. Upper Yield Stress Parameter-Secant Modulus
28. Nominal Stress-Elongation; Slow Loading with Reversal
29. Elongation-Time; Rapid Loading with Reversal
30. Stress-Elongation and Elongation-Time; Rapid Reversal from Static Stress
31. Over-all View of Flexural Testing Equipment
32. Arrangement for Testing Small Beams with Third Point Loading
33. View of Pure Flexure Region Instrumented
34. Instrumentation and Dimensions of Flexural Specimens
35. Deflection Gage Circuits
36. Stress-Strain, Delay Time, and Rate of General Yielding Data for Flexural Specimen Material
37. Recorded Data; BF Series
38. Recorded Data; BK Series
39. Recorded Data; BL Series
40. Moment-Curvature Relationships; BF Series
41. Moment-Curvature Relationships; BK Series
42. Moment-Curvature Relationships; BL Series
43. Assumed Moment-Curvature Relationships

LIST OF FIGURES

APPENDIXDETERMINATION OF FLEXURAL RESISTANCE FROM BEAM
DEFORMATION AND UNIAXIAL STRESS PROPERTIES

- A1. Typical Rapid Uniaxial Stress Test;
Applied Stress, Resulting Strain
- A2. Delayed Yielding and Rate of General Yielding Relationships
from Uniaxial Stress Tests of Beam Materials
- A3. Determination of Flexural Resistance from Beam Deformation
and Uniaxial Stress Properties

1. GENERAL INTRODUCTION

1.1 Introduction

The purpose of the investigation which was conducted at the University of Illinois under Contract W-33(01) was to determine the time sensitive stress-deformation characteristics of the more commonly used structural metals, and the engineering significance of this information in the solution of problems concerned with the behavior of metal structures under transient dynamic loads producing extensive inelastic deformations.

The work which was done on the project can be divided arbitrarily into three related parts: (1) The testing of structural metals under uniaxial stress conditions which are produced slowly or rapidly, (2) the correlation of these behaviors with the ones obtained under conditions of slowly or rapidly applied flexural stress, (3) the development of the special testing apparatus required for the experimental work. These phases also form the major divisions of this report.

In the first part of the report is discussed the basic apparatus developed at the University of Illinois for use in the application of slow to rapid loads to uniaxially stressed coupons, small beams, or model frames. Since special fixtures and instrumentation were necessary for each type of test, only the basic apparatus will be discussed in this section. The details of the fixtures and instrumentation will be described in the other sections of the report which pertain to the actual testing programs; these are Sections 2 and 3 which describe respectively the uniaxial stress studies and the flexural stress studies.

The investigations conducted at the University of Illinois as a part of Contract Nour-1834(01) were concerned with the engineering aspects of the behavior of the materials and structural elements under conditions of slow and rapid stressing. The metallurgical and fundamental physical nature of the deformation process was beyond the scope of this project. However, an attempt was made to classify the materials which were tested by evaluating and recording the metallurgical natures and the chemical compositions involved.

1.2 Scope

In the investigation described in this report small specimens of several sizes, shapes, and materials were tested at room temperature under stress conditions which for some steels included uniaxial tension, uniaxial compression, and flexure. These "stressings" were applied with a specially constructed machine that permitted independent control of the "rise" time of the loading, the maximum load, duration of the load, and the time of load decay. (This machine was designed not only for this investigation, but for general use as a pulse loading unit capable of applying a controlled load of 20,000 lb maximum to small structural elements in times as short as 0.005 seconds.)

In most of the tests, the loads were held at constant levels after application until the yielding process had been completed. The main variables of the experimental investigations were:

Uniaxial Tension

1. Rise time of load (0.005 second minimum to approximately 100 seconds)
2. Maximum stress level
3. The type of steel (semi-killed, rimmed, low-alloy)

Uniaxial Compression-Tension

4. Manner of loading (tension, compression, and reverse loadings)

Some secondary variables of the uniaxial tests were:

- a. Manner of treatment (as-rolled, annealed before machining, annealed after machining)
- b. Surface finish (as-machined, polished, notched)

Flexure

5. Level of maximum load

Using oscillographs and associated instrumentation having adequate response characteristics, records with respect to time were taken of the nominal specimen resisting stress, surface strains, and average elongation over the "gage" length of the specimen. From these records the relations between stress, strain, and time were determined for the various tests.

The results of the uniaxial tension and compression tests are presented and discussed in terms of (1) the time delay to the initiation of a significant amount of yielding, (2) the rate of general yielding where applicable, and (3) the general nature of the stress-strain-time behavior of the various metals tested.

In the slow and rapid flexural tests of small beams of rectangular section under third-point loading enough information was obtained that the time dependent stress-strain behavior in the pure flexural region of the beam could be determined. An attempt is made to correlate this behavior with the information obtained from uniaxial tests of the same material.

2. RAPID LOADING AND STRAINING EQUIPMENT

2.1 Introduction

The equipment used for producing the loads and the deformations required during the course of the project consisted of two types; those in which nominal deformation was the quantity most nearly independent of the specimen behavior (standard hydraulic and screw-type universal testing machines and a specially constructed hydraulic actuator), and the slow and rapid pneumatic loading unit with which nominal loads that are nearly independent of specimen response could be produced. The pneumatic unit is hereafter called the pulse loading unit.

The Baldwin universal hydraulic testing machine which was used as the load standard in all dynamometer calibrations, was also used for many of the slow tests run at rates conforming to ASTM specification A 370-56T. However, in the later stages of the project, for convenience in use of the oscillographic equipment with which all slow and rapid tests were recorded, a hydraulic actuator system affording nominal straining control at slow rates of deformation was devised. This could be quickly connected in series with the pulse loading unit so that no change of either instrumentation connections or specimen fixtures was necessary in changing from slow straining tests to rapid loading tests.

2.2 Description of the Loading Apparatus

For the initial purposes of the investigation, a device that would produce a rapid loading pulse, that is, a pulse that is nearly independent of specimen response, was very desirable not only because such a device would permit producing the desired loading without the need of accurate knowledge of the specimen's response characteristics, but also because nearly identical loading pulses

could be applied easily to structural components, coupled , or frames having varying response characteristics. Other requirements were that the minimum rise and decay times of the loading pulse should not exceed approximately ten milliseconds, that both the magnitude and duration of the loading should be independently controllable, and that the maximum loading stroke should be at least four inches with an associated drop in load of not more than 50 per cent.

The 20-kip pulse loading device shown in Figs. 1, 2, and 3 was developed to satisfy these requirements. This unit is a piston device in which the load output is the result of differential pressure. Compressed nitrogen or helium is used as the pressure source. The rapid application and release of the load can be achieved through the use of solenoid triggered slide valves to obtain the timed pressure release from the two chambers of the device.

2.3 Control of Loading

The use of this device permits the application of a loading pulse that may begin from a static level ranging from 20 kips tension to 20 kips compression, undergo a rapid change of plus or minus 20 kips maximum (with the restriction that the prepulse load plus the dynamic change in load can not exceed the limits of plus or minus 20 kips), and then return rapidly to zero load. The duration of the peak load may be varied from a few milliseconds to many hours. The rise and decay times of the loading pulses are controllable by adjusting the size of the pressure release orifices. The minimum time for either rise or decay of the load is approximately six milliseconds. Using the adjustable orifices, it is possible to increase the time for rise or decay of the load to approximately half a second, and, of course, loadings at relatively slow rates can be achieved by the slow build-up of pressures in the chambers of the unit using the manual pressure supply system. A few possible loading pulses are shown in Fig. 4.

2.4 Past Usage in Testing

In the investigation described in this report the 20-kip pulse loading unit was used for the rapid uniaxial tension and compression tests, and also for the experiments involving rectangular beams under third-point loading. In addition to these investigations for which the testing arrangements are shown in Figs. 7 and 31, the loading unit was used also in a series of tests of small model frames under both slow and rapid loadings. The arrangement for these experiments is shown in Fig. 5.

Since the successful development of the 20 kip loading unit, machines of larger capacity based upon its design have been constructed at the University of Illinois. One of these machines is shown in Fig. 6. This machine has a capacity of plus or minus 60 kips and a minimum loading time of approximately 15 milliseconds under ordinary usage.

2.5 Description of the Slow Straining Unit

As was mentioned in the introduction to this section, a hydraulic actuator which can be connected in series with the 20-kip pulse loading unit was provided so that straining tests at slow rates could be performed conveniently without changing the instrumentation or the manner of specimen connection. A schematic diagram of this unit and the associated pressure control system is shown in Fig. 3. The entire testing arrangement is shown in Fig. 7.

2.6 Summary

A general purpose loading unit has been developed which permits control of the load pulse as follows:

- (a) The magnitude of the tensile or compressive load pulse can be varied from approximately 2000 to 20,000 pounds, corresponding to

main chamber pressures of 100 to 1000 psi. (100 psi is the lower limit of consistent operation.)

- (b) The time interval between the initiation of the load and the start of load release can be varied from a 0.007 second minimum to long hand-timed intervals.
- (c) The rise time of the load can be varied from a 0.005 second minimum to 1.5 seconds using the slide valves and variable orifices, or from a 5 second minimum to long times using the pressure regulators and/or needle valves to control pressure.
- (d) The decay time of the load is independently variable. The range possible is the same as that of the rise time since the two slide valve assemblies are identical.

For use in conjunction with this apparatus, an attachment for the control of slow straining rates has been provided. Therefore, in one location, apparatus is available with which slow tests may be run under either loading or straining control, and also with which rapid loading pulses can be applied.

3. UNIAXIAL STRESS TESTS

3.1 Introduction

During the past few decades much effort has been devoted to determining the behavior and the nature of the materials with which man builds. The more commonly used the material, the more extensive have been the investigations. Consequently, a great deal of information is available concerning the most commonly used structural metal, steel. However, the fact that steel is an alloy of iron and therefore can have greatly different properties has made the determination of its behavior in all its various forms a never ending task^{10, 15, 28, 40*}. As fast as new instrumentation capable of more accurate measurement or better time resolution has been developed investigators have attempted to extend their knowledge of materials. The development of the wire resistance strain gage and the common availability of oscillographic equipment useable in the microsecond range has led to the comparatively recent work of Davies, and Clark and Wood, et al., and has therefore resulted in the acquisition of new knowledge pertaining to the time sensitive behavior of metals.

While it is probable that no other materials have been the subject of as many investigations as structural steel and aluminum, little information is available about the stress-deformation characteristics of these metals in the range of strain rates corresponding to those that might be created in the members of typical structures by large dynamic forces, that is, strain rates increasing from "static" to about 1 in./in. per second. Furthermore, as regards iron alloys, the deformation characteristics are greatly affected by extremely small concentrations of the alloying elements and also by the form of their presence (as solutes or precipitates).

* Numbers refer to entries in the bibliography. The bibliography includes references for background information in addition to those references noted in the text.

In addition to these difficulties, no satisfactory theory based on chemical composition has been developed with which quantitative predictions of the time sensitive behavior of these metals can be made, although qualitatively many characteristics can be explained^{6, 16, 17, 29, 41}. Therefore, the time dependent stress-deformation characteristics of specific metals usually must be determined by experimental means.

The uniaxial stress tests described in this report were performed to obtain specific stress-strain-time information for a few of the more commonly used structural materials.

3.2 Description of Uniaxial Testing Series

3.2.1 Types of Specimens

The materials which were investigated included the following: rimmed steel from one inch bar stock in the as-rolled and annealed condition, semi-killed steel from one inch plate stock in the as-rolled condition, fully-killed steel, ASTM A-7 steel obtained from a 1/4" section, two low-alloy steels, a chrome-nickel steel, a steel meeting ASTM specification A-242, and USS T1 steel. In addition 60 61-T6 aluminum was tested. A summary of the materials tested is given in Table 1 and a description of the system used for specimen designation is presented in Table 2.

In the preliminary series, composed of specimens having an area of 0.100 sq in., the rimmed steel bar stock (RB) and the semi-killed steel plate stock (SP) were tested as-rolled (A), annealed after machining (B), and annealed before machining (C). In addition, some of the specimens of the preliminary series were tested polished smooth (S) and some with a small circumferential notch (N).

Following these tests it was decided to test these two steels as-rolled since metallurgical investigations revealed that the microstructures were quite uniform. These were the series called 2 MRBA, 2 SRBA, 2 SSFAL, and 2SSPAT..

The bar stock specimens were, of course, aligned axially with respect to the direction of rolling of the bar. The plate stock specimens were oriented with their longitudinal axes either parallel to the direction of mill rolling (L) or with their axes transverse to the direction of mill rolling (T).

The tests of the NS, NL, and NN series were not instrumented as completely as the others, in that only resisting stress-time and SR-4 gage strain-time information was recorded.

The dimensions of the various specimen types are given in Figs. 9, 11, 12, and 13. The form of the specimens varied from areas of 0.100 sq in. to 0.200 sq in. and in form from the gently curving profile illustrated in Fig. 9 to the profile shown in Fig. 13b which was developed for use in either tension or compression. Table 2 also provides a key to the profile used for the various series of tests.

3.2.2 Manufacture of Specimens

The specimens which were tested in the as-rolled condition were machined from band sawed blanks using a maximum depth of cut on each pass of no more than 0.02 in., which, under the oil coolant used, raised the specimen temperature to no more than 150 degrees F. The final cut was about 0.002 in. oversize for the specimen to be polished, was about 0.005 in. in depth. Following this cut, the specimens were polished by hand held emery cloth to the final dimensions and to a finish that varied from about 11 microinches r.m.s. to some 20 microinches r.m.s., with an average finish of about 15 microinches r.m.s. as indicated by a type PAC, serial 11 (Profilometer) manufactured by the Physicists Research Company, of Ann Arbor, Michigan.

The as machined specimens were cut to the final dimension using a final pass of about 0.005 in. The surface roughness of these specimens varied from about 00 to 200 microinches r.m.s. with an average of about 150 microinches r.m.s.

As was mentioned in Section 3.2.1, a few of the preliminary series specimens were notched circumferentially (1N). These were "V" notches about 0.01 in. wide and 0.01 in. deep.

Following the pretest measurements of surface roughness and diameter, the SR-4 gages, if used, were applied to the gage section of the specimens. During this process the specimens were heated to about 180 degrees F for a period of some four hours. This may have aged the material somewhat with respect to the residual stresses resulting from the machining.

The procedure listed above, which is that followed in the preparation of the as-rolled specimens, was followed in preparing the "annealed before machining" specimens beginning, of course, with the annealed specimen blanks.

In the case of the "annealed after machining" specimens, the heat treatment, performed in an electric furnace by heating a tube containing the machined specimens sealed in an atmosphere of helium, was followed by the removal, by polishing, of the final 0.002 in. left by the machining process.

The ML, MN, and NHY specimens were prepared elsewhere and sent to the University for testing.

3.2.3 Metallurgical Properties and Chemical Compositions

In commenting upon the results of the metallurgical investigation performed by the Metallurgical Department of the University of Illinois on most of the steels used for the specimens described in this report, the authors refer the reader to the summary given in Table 3, and the metallographs of Fig. 14.

These studies did show that the steels were very uniform in their so-called as-rolled condition and that consequently for this reason the annealing and spheroidizing were not necessary to obtain consistent results.

The almost complete decarburization of steel NS, and the broadly decarburized bands of steel NR should be noted. It is possible that this decarburization greatly affected the yield behavior of the materials as compared with that of the other steels.

The chemical compositions of the steels as determined in a check analysis by the R. W. Hunt Company of Chicago, are given in Table 4. Inadvertently the oxygen content of the steels was not requested; this is regrettable since this would probably be one of the more important differences between the rimmed and the semi-killed steels.

3.3 Description of Testing Procedure

3.3.1 Instrumentation

To record the data from the preliminary series of tests, the four channel cathode ray oscillograph shown in Fig. 15 was used. This equipment was virtually flat in response from some five cps to thirty kcs. The lower limit was imposed by the instability of the D.C. preamplifiers which caused significant drift in the traces over times as short as 0.1 or 0.2 seconds. For this reason, the equipment was not satisfactory for the recording of tests involving durations of several seconds.

On the basis of the records obtained with the CRO equipment, it was seen that the Hathaway magnetic oscillographic equipment available in the laboratory would have response characteristics adequate for the faithful recording of the resisting stresses and strains developed in the rapid load tests with the advantage of excellent long time stability that would permit use of the instrumentation for the recording of slow tests as well. Therefore, the magnetic oscillographic equipment, shown in Fig. 16, was used for the main series of tests. This equipment includes a Hathaway Type S-14C magnetic oscillograph, in which were used Type OC2,

Group 2-3 recording galvanometers. The Type MRC-18 Hathaway carrier strain amplifier system was modified using an external carrier oscillator and power supply which had characteristics superior to those of the original equipment. The usable upper frequency limit is about 450 cps, while the lower limit, as mentioned above, is D.C. A block diagram of the Hathaway equipment is shown in Fig. 34.

The phenomena recorded versus time for the preliminary testing series were the following: (1) the output of an SR-4 gage dynamometer recording the stress developed on the end of the specimen opposite that to which the load was applied; and (2) the output of two SR-4 strain gages attached diametrically opposite each other on a gage section of a specimen. On the 2RB, 2SP, NR, NHY, NL, and MN series the output from an extensometer connected across the gage length was recorded also. The dynamometer-specimen-extensometer arrangement used for most of these tests is shown in Fig. 10. In all other testing series, measurements included the output of the dynamometer as before, but strains were obtained from a dual range spring type extensometer connected across the specimen. This extensometer had two independent SR-4 bridges, the outputs of which were recorded with different sensitivities so that the entire range of strains could be resolved adequately.

The various dynamometer-instrumentation systems were calibrated "statically" versus the load measuring system in a 120,000-lb Baldwin universal hydraulic testing machine. In checking the accuracy of the dynamometer-oscillograph load measuring system, measurements from slow straining test oscillograms were compared with the load dial readings taken on the Baldwin machine at corresponding times. Usually the loads were within about 100 lb out of 10,000 lb with an occasional maximum error never greater than 300 lb. That is, the usual error was about ± 1 per cent (and usually lower) with a maximum error never observed to be greater than ± 3 per cent.

In the tests in which SR-4 gages were attached to the gage section of the specimen, bending could be determined. The percentages of bending ranged as high as 15 per cent in some few cases but generally were less than 5 per cent. The alignment procedure possible with the development of the uniaxial tension-compression fixtures was such that the percentages of bending were usually less than 5 per cent.

The extensometers that were used at various times throughout these investigations were all of the flat spring type shown in Figs. 10 and 13. This type of extensometer met requirements for range, sensitivity, dynamic characteristics, and simplicity. In these "transducers", flexural strains in the flat springs were measured with SR-4 gages connected as four arm bridges with all arms active, so that a strain magnification of four was obtained along with temperature compensation. The extensometer last used had two complete bridges of SR-4 gages on them so that two different sensitivities could be used to resolve the total range of specimen extension. Therefore, in these later tests SR-4 gages were not used on the specimens.

Just prior to each test, calibration traces were recorded on the oscillogram by shunting the respective bridges with precision resistors whose equivalence in terms of the quantity being measured had been determined earlier. Usually the complete dynamometer and extensometer-instrumentation channels were calibrated directly before and after every series of tests and, in some cases, in the middle of a long testing series.

It is believed that the total errors associated with measurement of nominal load are no more than ± 3 per cent, and that the total errors measured with the determination of extension between the points of attachment of the extensometers are no more than ± 5 per cent.

A major problem associated with interpretation of the results of the tests in which extension was measured across a reduced gage length is the determination of the effective gage length of the specimens throughout the entire range of deformation. The study which was made of this problem is reported in Section 3.3.6.

3.3.2 Slow Tests

From the summary of the testing, presented in Tables 5, it can be seen that slow tests, with two exceptions, were performed in the Baldwin universal testing machine, or the pulse-loading machine with or without the slow straining attachment. The equivalent elastic strain rates used for these tests were within those allowable under ASTM specification 370-56T. Since a rather complete summary of the conditions under which these tests were run is given in Table 5,* very little discussion is necessary in the text.

It is to be noted that slow tests of the PBA specimens which were tested in the Baldwin machine produced yielding at lower stresses than those which were tested in the pulse loading machine. However, no such difference in yield strength was obtained for specimens of the SPA series. The differences between these series of tests were the following: (1) the static specimens which were tested in the Baldwin machine were "pricked" on the gage area by the extensometer points (which might affect yielding behavior); (2) slightly different loading rates were used in

* In Table 5, the constants C , C_u and C_l are used within a test series to differentiate between the conditions under which each test was run. For the rapid tests, $C = \sigma_{uy} = \sigma_{ly}$.

In Table 5 and in the stress parameters used in this report:

- σ_{uy} = upper yield stress
- σ_{uy}^* = upper yield stress in a slow straining test
- σ_{ly} = lower yield stress
- σ_{ly}^* = lower yield stress in a slow straining test
- $\sigma_{max} = \sigma_m$ = ultimate strength of a material

the two machines, and (3) the smoothness of application of loading between the two machines may have differed.

In Figs. 17a and 17b are shown photographic reproductions (about half size) of the type of oscillograms which were produced during the slow tests in the Baldwin machine as compared with the pulse loading machine.

3.3.3 Machine Vibration Tests

To determine whether any significant difference existed in the smoothness of the loadings produced by the three testing machines used (the Baldwin machine, the pulse loading machine, and a Riehle screw type testing machine), an attempt was made to measure the vibrations induced in the test specimens by operation of these testing machines. Within the sensitivity of the recording instrumentation no vibrations were evident in the loading produced by either the Baldwin machine or the pulse-loading machine. However, vibrations having an amplitude of some 30 or 40 microinches per inch of strain were apparent in the tests performed in the Riehle screw type machine.

3.3.4 Residual Microstrain Determination

Many metals, but not including mild steel, do not exhibit a perfectly linear relationship between applied stress and resulting strain or vice versa, even for relatively low values. Of course, the degree to which this holds true is somewhat dependent upon the sensitivity of measurement possible with the method used for observing stress and strain. While mild steel does have a nearly linear and almost perfectly elastic stress-strain relationship for relatively low levels, a departure from linearity and from elastic action does become evident at stress levels above something on the order of one-half of the nominal yield strength of the steel.

Some investigators^{3b, 3c} have suggested that a critical amount of inelastic "microstrain" may be necessary before a general yielding condition is initiated. (In this report the term microstrain will be applied to all inelastic straining preceding the development of the general yielding condition.) It follows, then, that a difference in the character of the microstraining which precedes general yielding would be related to the nature of the dynamic yielding behavior. However, as a matter of interest, a few cycled loadings were applied to a few specimens of the SRMA, MRBA, and RSFA series in the Baldwin hydraulic testing machine, the pulse-loading machine, and the Richman screw type testing machine. The straining cycles, which had a "period" of about 2 minutes (during which about one minute was required for the straining and one minute for making the residual strain measurements), were of successively increasing magnitude culminating in the yielding of the specimen.

Preceding and following each cycle of straining, the SR-4 gages attached to the gage section of the specimen were read using a Baldwin Type 1 strain indicator. From these readings the residual strain resulting from each strain cycle was determined. The results which are presented in Fig. 18 indicate that in these tests general yielding was preceded by inelastic "microstrains" on the order of 20×10^{-6} in./in.

5.3.5 Rapid Uniaxial Tests

A description of the tests and the results are presented in Table 5. A study of these tables will reveal that in most of the rapid tests loads were applied rapidly to a constant level, and were held at these levels throughout the duration of the test until yielding had nearly stopped, usually some four or five seconds after its commencement. Following this the loads were released rapidly to zero. In most of the test series, identical specimens were tested at either the nominal "static" rates or with rise times of loadings on the order of 0.006

seconds. The tests were run at stress levels ranging between the static upper yield stress and the maximum strength of the specimen material so that a range of delay times and of rates of general yielding could be obtained.*

In the 2RB and 2SP series of tests, three rise times of loadings were used; 0.005 seconds, 0.10 seconds, and 0.50 seconds.

For the NR, PS, Q, K, T, and L series, the loads were applied to a few specimens in tension and to the others in compression. Only in the case of the NR series were the stresses reversed after the specimen had been initially yielded under a stress of the opposite sense.

As has been mentioned earlier, the phenomena recorded versus time for all series included nominal resistance and a measure of strain obtained with either SR-4 gages alone, SR-4 gages in combination with an extensometer, or a dual range extensometer.

Photographic reproductions, about one-half size, of oscillograms illustrating the loadings mentioned above and also typical results are shown in Figs. 17c to 17f.

Before each of these tests, as well as before each slow loading rate test, a small load (corresponding to a stress of no more than 10,000 psi) was applied as an aid in aligning the specimen with respect to the loading axis. If the SR-4 gages on the specimens so instrumented indicated a bending strain greater than about 5 per cent of the axial strain, the specimen was readjusted until the bending was less than that value. On the specimens not having SR-4 gages the small pretest load was applied and released to "settle" the specimen in its seat, a procedure

* In Table 5, the magnitudes of the rapid loads are listed under either σ_{uy} or σ_{ly} . These expressions for stress are equivalent in rapid tests.

which had produced satisfactory alignment of most specimens instrumented with SR-4 gages.

3.3.6 Effective Gage Length

As was mentioned earlier, a problem associated with use of the information obtained from the uniaxial stress investigation is that of relating extension determined from an extensometer attached across the shoulders of the reduced gage length of a specimen to the actual effective strain in the specimen. For small strains of an elastic specimen the effective gage length can be computed and is a constant times the actual gage length of the extensometer. However, when yielding occurs in the specimen, the effective gage length will change with the magnitude of that yielding. This has been indicated by a series of experiments designed to provide information concerning this matter. In Figs. 19 are shown the results of this investigation. Figs. 19a and 19b indicate that prior to the beginning of yielding, the effective gage length of a shouldered specimen of mild steel was approximately equal to the computed "elastic" value. As the specimen yielded, the effective gage length dropped rapidly to its lowest value which coincided with general yielding. As the specimen strain hardened, the value of the effective gage length increased. For specimens made of a material that exhibited no upper-lower yield point phenomena, the variation in effective gage length was less extreme and no increase of effective gage length with strain hardening was indicated. This is illustrated in Figs. 19c and 19d.

In the RB and SF series specimens the effective gage length after yielding had occurred was assumed to be constant. The value used was obtained by direct calibration during slow straining rate tests of the "static" specimens. For the PE, Q, K, T, and L materials, the effective gage length used was that determined from pilot tests of the same material. All strains as reported in this report are corrected for the effect of yielding upon the effective gage length.

3.4 Results of Uniaxial Tests

3.4.1 General Time Sensitive Behaviors of the Materials Tested

It is comparatively well known that metals having a body centered cubic lattice structure usually yield in a discontinuous manner under slow rates of straining. It has been shown that the same materials when subjected to rapid loading or straining yield in a manner indicating relatively large time sensitivity. Steel in the commonly used form is one of these materials, and therefore its yielding behavior differs considerably from that of a material such as aluminum 6061-T6.

It is a characteristic of mild and low-alloy steels that, under a slow relatively constant rate of nominal uniaxial straining at room temperatures, their resistance goes through four rather arbitrary stages: (1) the elastic range terminating in (2) microstraining followed by the development of the condition of (3) general yielding (in which the level of resistance is a function mainly of the rate of straining) which in turn is followed by the advent of (4) strain hardening and subsequent fracture. The four stages of the nominal resistance-deformation characteristics of these metals are quite evident in the slow straining rate tests, but, of course, are no less present in tests run under other conditions, such as slow constant rate of increase in nominal stress. Of the four stages mentioned, the middle two, microstraining and general yielding, are quite time sensitive; the elastic range is almost insensitive to time; and the range beyond the commencement of strain hardening is only slightly time sensitive.

The time sensitivity associated with what in this report is called the microstraining phenomena has been termed the "delayed yield" effect. This is perhaps best revealed under tests involving rapid stressing to a constant stress level such as were performed in this investigation using the 20-kip pulse loading machine.

In the materials studies presented in this report the time delay in yielding is defined arbitrarily as the interval between the time at which the stress first reached a value corresponding to the lowest upper yield stress obtained in a slow test, and the time at which yielding had become general enough that the apparent modulus (nominal stress/nominal strain) had dropped to about $2/3 E$. Delay time so defined has engineering significance in that it is related at one end to a stress level high enough to result in yielding under slow loading or deforming conditions, and at the other end to a parameter involving both stress and strain which has an arbitrary value indicative of an amount of yielding sufficient to mark the beginning of general yielding.

The rate of general yielding effect (usually termed somewhat ambiguously the strain rate effect) is most evident perhaps in tests performed at various constant rates of nominal strain, but it will also be apparent, of course, in tests in which nominal stress rather than nominal strain is the factor most nearly independent of specimen behavior. Such is the case in the "rapid loading to constant stress level" tests. After general yielding has begun (following the delay in yielding if present) the specimen will deform at a rate which is dependent upon the stress level being maintained by the pneumatic loading unit. Since the several tests are run at different constant stress levels, both delayed yield and rate of general yielding information can be obtained from a single test series.

For most mild steels the transition between the general yielding condition (flat yield region in the constant rate of straining test) and the region of strain hardening is somewhat more gradual than that between the other stages. (Of course, this "gradualness" is largely dependent upon the time resolution possible with the recording techniques used.) The tests run at the University of Illinois

on mild and low-alloy steels indicate that for a particular steel the transition begins at about the same total strain regardless of the rates involved.

In a rapid test to a constant stress level the straining finally ceases at a total strain which usually agrees well with that corresponding to the strain obtained at the same nominal stress under slow loading or deforming conditions.

For metals such as high-alloy steel, structural aluminum, etc., yielding under slow rates of straining is not a discontinuous process, and the behavior under rapid loading is not as time sensitive as is the case for mild steel. This is indicated in the results for the NMY, USS T-1, and 6061-T6 materials.

3.4.2 Results of Tension and Compression Tests

In Fig. 20 is presented in three dimensions the relation between stress, strain, and time as obtained from uniaxial tests of mild steel involving slow and rapid loading to constant stress levels. In this relationship the so-called delayed yield and rate of general yielding behavior are quite evident. Stress-strain and strain-time relationships representative of the materials tested are shown in Fig. 21. These contain the same information as is shown for one material in Fig. 20. The information which is presented in these figures is abstracted in the form of delayed yielding and rate of general yielding information where these phenomena were present, and in the form of various times required for yielding to progress to specified values of the nominal secant modulus (nominal stress/nominal strain) where delayed yielding and rate of general yielding behaviors were not pronounced. In Tables 5 are presented these values for all of the tests which were performed.

The delayed yielding and rate of general yielding behavior is presented respectively in Figs. 22, 23, 24, 25, and 26. In the first of the figures of each the values are presented versus the nominal stress, and in the second and

third, versus a stress parameter involving, in the case of delayed yielding the static upper yield stress, and, in the case of rate of general yielding, the lower yield stress obtained under a rate of straining corresponding to approximately 10^{-3} in./in./sec. These basic values were obtained under slow straining of the specimen materials in conformance with ASTM Specification A370-56T, and therefore can serve as a basis for extrapolation of these results to other materials which are similar but which have values of upper and lower yield stress different from those obtained in this investigation.

There was little noticeable difference in the behavior of the materials which were tested under both initial tension and initial compression, that is, ASTM A-242 steel, USS T-1 steel, a fully-killed mild steel, and 6061-T6 aluminum. If the reader wishes to make further comparisons, he may obtain from Table 1 the information concerning the type of test and from both Table 5 and Figs. 22 through 26 the results which were obtained.

5.4.3 Results of Preliminary Reversed Stress Tests

As can be seen from Table 5, a few tests were performed with a reversal of loading subsequent to initial testing. The material from which these specimens were made was the semi-killed plate stock used for the 26SFA series, and the BF series flexure tests described in Section 4 of this report. The dimensions of the preliminary stress reversal specimens, the specimen profile, and the manner of attachment to the testing apparatus are shown in Fig. 12. There were several disadvantages in the use of this type of specimen, namely, the attachment of the extensometer to depressions punched into the surface of the specimen, the non-uniform diameter of the specimen, and the relative difficulty of attaining axiality of the load. However, the results are nevertheless interesting, as can be seen from Figs. 28 through 30.

In Fig. 27 the relation between the upper yield stress parameter and the secant modulus (nominal stress/nominal strain) for the slow loading tests is shown. These curves indicate that yielding was rather gradual in these specimens and began at a stress which was considerably lower than that which was arbitrarily used as the upper yield stress of the material. In Fig. 28 is shown the effect of reversal of loading following slow yielding. This is the so-called Bauschinger effect; the fact that after having been yielded in one direction, subsequent reversal without aging will produce almost immediate inelastic behavior at relatively low strain with no evidence of an upper-lower yield behavior.

The results which were obtained in the four rapid stress reversal tests are shown in Fig. 29 in the form of strain-time relationships. In these tests a reversal of loading was applied within a minute or so of release of loading following yielding in the direction in which the loading was initially applied rapidly. Therefore, these were not rapid in the sense that the entire stress-time relationship including reversal was imposed within a very short period of time. However, the change of stress from the initial zero level to the constant stress levels indicated in the figures was rapid. Again a behavior which could be called the Bauschinger effect in rapid loading is evident in that no delay in yielding was apparent upon reversal of loading in a direction opposite to that used in initial yielding.

Because of the non-uniform diameter of the specimen profile used in these preliminary reversed loading tests and the consequent difficulty in relating extensometer deformation to unit strain, no attempt was made to interpret the results of the rapid reversed loading experiments in the form of rate of general yielding information.

In another series of stress reversal tests, an initial slow loading to a level below that which would cause general yielding was followed by a rapid reversal of loading to a level sufficient to cause yielding. As can be seen from Figs. 30, a delay in yielding was obtained in all of these tests, and this delay agreed well with the delay times obtained in the loadings of virgin material in the previously mentioned rapid tests.

3.5 Summary of Results for Uniaxial Stress Tests

3.5.1 Summary of Results

The results of the slow and rapid uniaxial stress tests which were performed on many materials in initial tension and initial compression, and on one material in complete stress reversal, have been presented in the form of tabulated results in Table 5 and in the various figures mentioned previously. In general terms the results can be summarized as follows.

(1) The metals tested which exhibited a pronounced upper-lower yield point behavior under conditions of slow straining, and had stress-strain relationships with discontinuities in slope, also exhibited the time sensitive behaviors termed delayed yielding and rate of general yielding (defined earlier in this report).

(2) In the only tests in which the rise times of rapid loadings were varied (from 0.006 sec to 0.5 sec), the comparisons of delay time as defined by a stress parameter involving the upper yield point indicated no particular sensitivity to the rise time of loading within the limits indicated above. This result can probably be attributed to the manner in which the elapsed time to general yielding was arbitrarily defined (the interval between the time at which the stress first reached the nominal static upper yield stress level and that at which general

yielding occurred as indicated by a value of stress/strain equal to 20×10^6 psi).

(3) Within the range of rapidity of loadings applied, that is, rise times greater than 0.006 seconds, the value of Young's modulus was constant. The so-called strain hardening region also was relatively insensitive to time effects. The major time sensitivity was associated with initial yielding and subsequent general yielding, the so-called delayed yielding and rate of general yielding behaviors mentioned previously. For the high strength alloys of steel, and for 6061-T6 aluminum for which static stress-strain relationships having no discontinuity of slope were obtained, no delayed yielding or rate of general yielding behavior was evident.

(4) The results of the very few preliminary experiments in slow and rapid reversal of loading indicate that the so-called Bauschinger effect which is commonly observed in slow reversal of stress, is also present in cases involving rapid stress reversal with a consequent absence of delayed yield behavior commonly found in virgin material. Because of the type of specimen used in these preliminary studies, no conclusions could be reached regarding the rate of general yielding behavior.

3.5.2 General Significance of Results

As can be seen from the results described above, the increased resistance which results from the time sensitive behaviors of mild steel arbitrarily termed the delayed yielding and rate of general yielding phenomena can approach values 50 per cent greater than the nominal yield values even for the relatively slow rates of straining which may be created in frame type civil engineering structures in which the actual deformation of the major structural elements results from transfer of air blast or earthquake shock loading through the supports or outer shell.

In the case of many ship structures in which blast loading is applied directly, such as hull plating subjected to underwater explosion, the actual rates of straining can be many times greater than 1 in./in./sec. In these cases it is to be expected that resistances at least as great as the nominal static ultimate strength may be obtained without yielding or may be supported by the rate of deformation. Therefore, estimates of the response of these structural elements based upon nominal resistances derived from static yield values with no increase for the time sensitive effects will be very greatly in error. (The error, however, will be on the safe side unless brittle fracture or fatigue is a consideration.)

4. SLOW AND RAPID FLEXURE TESTS

4.1 Introduction

Structural components undergoing flexure such as beams, plates, and columns, are major elements of almost any structure. Therefore, it is logical, as an intermediate step between the uniaxial stress investigation and application of these results to the behavior of large full-size structures, that flexural stress studies be made of the same materials which were tested under uniaxial stress conditions. Such an investigation is described in this section of the report.

In all, three sets of specimens were tested. These included a preliminary series, BF, made from the semi-killed plate stock designated SPA and PS, a series, BK, made from fully-killed steel K, and a less completely instrumented series, BL, made from 6061-T6 aluminum L.

Each of the series was composed of four specimens, one of which was subjected to a slow loading, while the other three were tested under rapid loading to a constant level.

Since the materials from which the flexure specimens were composed was also tested under conditions of uniaxial stress, a correlation of the two stress conditions was attempted.

The purpose of this section of the report is to describe these flexure tests, the conditions under which they were run, the results and their engineering significance.

4.2 Description of the Flexure Testing Series

4.2.1 Description of Flexure Specimens

The flexure specimens in all cases were small beams of rectangular section approximately 24 in. long. The depth of the section was very close to

2 in., while the thickness or width varied from approximately $2/3$ in. to approximately $7/8$ in. The specimens were band-sawed from the parent plate, then machined in a shaper to very near the final dimensions. Following this, the outer surfaces of the specimen were draw-filed and hand polished to the final dimensions. All of the materials were tested in the as-rolled condition, and the only treatment of any sort that they received other than normal handling was that during the application of SR-4 gages they may have been subjected to prolonged heat of no more than 180 degrees F.

4.2.2 Material Properties Under Uniaxial Stress

As was mentioned in the introduction of this section, uniaxial stress tests were made of the materials from which the flexure specimens were composed. The stress-strain relationships, typical of those which were obtained for these materials are shown in Figs. 36a, 36d, and 36g. In addition to these results, the delayed yield behavior and the rate of general yielding behavior of the two mild steels are shown in Figs. 36b, 36c, 36e, and 36f.

4.3 Description of the Testing Procedures

4.3.1 Flexure Testing Arrangement

Both the slow and rapid loading tests were performed in the apparatus shown in Fig. 32. This is an attachment designed specifically to adapt the 20-kip pulse loading unit for these flexure tests. The loads are applied to the underside of the beam at the third-point, thereby deforming the beam upward as is shown in the figure. The only feature of the testing arrangement that may not be clear from the photographs is the end reaction system. The major bearings in the arrangement are roller bearing assemblies which are attached to the machine frame by means of pins fixed on a 20-in. span. The reaction of the beam ends is transmitted to the outer race of the roller-bearing assembly through plates which are clamped to the

top and bottom of the beams by the bolts which are apparent in the figure. This end-reaction arrangement permits both translation and rotation at each end of the beam with the span length remaining fixed at 20 in. In other words, a change in length of the center line of the beam occurs during a test as the beam ends rotate and the beam deforms upward.

The loads which were applied to the specimen were measured by means of the two dynamometers visible in Fig. 32. The crossbar which can be seen in the photographs was provided to prevent flexure in the dynamometers.

4.3.2 Flexure Test Instrumentation

In these experiments measurements were made of the loads applied at the third-points of the beam, the acceleration of these loading points (except in the case of the aluminum specimen), the deflections at the third-points and at the center of the pure flexure region, and the strains on the outer fibers of the beam in the region of pure flexure. The relative locations of the loading points and the regions of strain measurement are shown in Fig. 34.

All phenomena were recorded on Hathaway magnetic oscillographs of the type mentioned in Section 3.5.1. The SR-4 gages used to measure the outer fiber strains on the specimen, and as the transducing elements in the dynamometers, were connected into four-arm bridge circuits as shown in Fig. 34. The accelerations were measured by means of an AMS-20A Hathaway accelerometer. It was fastened to the side of the loading beam as is evident in Fig. 32. The deflections were measured by means of the slide wire gages shown in the over-all view of the testing arrangement. The circuitry of the deflection measuring system is shown in Fig. 35.

Since two independent oscillographs were used for each test an interlocking timing system was necessary to permit correlation of the records. A timing

signal of 500 cps was recorded by one galvanometer in each oscillograph and the interlock was provided by a switch driven mechanically.

4.3.3 Description of Flexure Tests

As was mentioned in the introductory remarks, there were three series of flexure tests. The first of these was more or less preliminary in nature and, because of evident discrepancies, the results are somewhat questionable. This preliminary series, which has been designated BF, was composed of four tests. The first of these was run at a slow loading rate in the 20-kip pulse loading machine. In the other three, the loadings were applied in approximately 8 milliseconds after which a constant level was maintained until yielding had virtually ceased. Then the loading was released.

The second series designated EK, was tested using slightly different instrumentation. In an attempt to determine whether or not the distribution of strain throughout the depth of the beam section was linear, SR-4 gages were attached to the sides of the specimen at four depths through each half-depth of the beam. These gages may be clearly seen in Fig. 33. In addition, the curvatures in the region of pure flexure were determined for large deformations by means of spring steel curvature gages using SR-4 gages as the transducing elements. These were attached to the nominal center line of the beam on each side as is shown in Fig. 33. A different sensitivity was used in each of the two recording channels attached to the spring-steel curvature gages, so that the entire range of curvature was adequately defined. Deflections were measured only at the loading points in this particular series of tests. Again, as in the preliminary testing series, BF, the first test was performed at a slow rate. However, in this EK series the strain was controlled by means of a hydraulic jack attached to the lower end of the 20-kip pulse loading unit piston rod. This strain control resulted in a reasonably

constant rate of deformation throughout the duration of the test. The other three specimens of the BK series were tested with a load rapidly applied to a constant level. Three different levels of loads were used so that a range of possible delayed yield behavior and rate of general yielding behavior could be determined. Because of faulty film advance during the test of BK4, the records for this specimen were lost.

The last series of flexure specimens was composed of 6061-T6 aluminum. The instrumentation of this particular testing series included measurement of the loads at the third-points, the deflections at the loading points, the strain of the top and bottom fibers in the region of pure flexure, and the curvature in this same region. As with the other testing series, one test was performed slowly and the other three rapidly.

4.4 Results of Flexure Tests

4.4.1 Experimental Results of Flexure Tests

The data recorded in the three series of flexure tests are presented in Figs. 37, 38, and 39. The values of M_y and α_y for the flexural specimens are given in Figs. 36a, 36d, and 36g. Rate of curvature-time relationships for the rapid tests are also included since this information was obtained for use in computing the resisting moments for the sections.

It was planned to determine the resistance of a given beam by subtracting the inertia force as obtained from acceleration measurements at the loading point (and an assumed effective mass of the beam specimen system) from the applied load. However, the acceleration traces were not distinguishable in the region of initial loading. Therefore, the resistances were assumed to be the same as the applied load. The maximum error resulting from this approximation is estimated to be less than 2 per cent. Of course, for large deflections of the beam, a correction was

applied in determining resisting moment from the loads measured at the third-points of the beam.

The previously mentioned correction of resisting moment due to large deflections was made with the use of the loading point deflection gage information. The moment arm between the reaction and the loading point was increased by the factor secant ($\tan^{-1} \Delta/6.67$); the reaction was taken as the dynamometer reading, a vertical force, increased by the same factor since the crossbar between the dynamometers produced a horizontal component of force acting at the loading points; and the moment arm was decreased by the factor tangent $\Delta/6.67$ since the loads were applied half the beam depth, or more, from the longitudinal centerline of the specimen. Actually, a more correct value for this latter factor was 1.8 times tangent $\Delta/6.67$ to account for the thickness of the loading blocks and the roller diameter. This larger correction would have decreased the indicated measured values of resisting moment ratio beyond $\sigma/\sigma_y = 50$ an additional 4 to 6 per cent with respect to what is now shown in Figs. 40a, 41a, and 42a.

Of primary interest to those concerned with the engineering behavior of materials subjected to flexure are the results presented in Figs. 40, 41, and 42. These are the relations between resisting moment and curvature obtained for the specimens tested. At any curvature the resistance obtained for the steel specimens tested rapidly was considerably larger than that obtained for the companion specimens tested slowly. This indicates that there is a time sensitivity associated with the behavior of mild steel in flexure.

In an earlier part of this report, Section 4.3.3, it was mentioned that the results of the RF Series were somewhat questionable since discrepancies were evident in the magnitudes of the measured resisting moments. These measured values were too high in the three regions which can be used for checking the data in both

slow and rapid tests; i.e., the elastic region ($\alpha/\alpha_e \leq 1$) where $M/M_e = \alpha/\alpha_e$, the general yield region ($1 \leq \alpha/\alpha_e \leq 10$) where M/M_e approaches 1.5, and the ultimate region ($\alpha/\alpha_e \approx 80$) for Series BF and BK where $M/M_e = 1.5 \sigma_m^w / r_{ly}^h = 2.9$ in these cases. Re-examination of the original data indicated that the load values assigned to the calibration shunt resistor used with both of the dynamometer channels did not correspond to the load equivalences of the dynamometers at dynamometer strains equal to the apparent strain output of the shunt resistor. This check indicated that the load equivalence of the shunt resistor was 88 to 91 per cent of the shunt value used originally in reducing the data. The original data were therefore reduced by a factor of 0.91. The adjusted data, shown in Figs. 37a and 37e, were used for all subsequent computations pertaining to this test series. Since this change cannot be substantiated, except by noting the reasonable agreement in the three regions of curvature as detailed above, the BF Series results must be considered questionable.

The measured resistances of the rapidly loaded BK specimens, Fig. 42b, indicate that for the particular rise time of load (4 to 10 milliseconds) possible with the machine-specimen system used, an upper limit of resistance was obtained, at least until the work hardening range of curvatures was entered. Specimen BK-3 was subjected to a potential load some 30 per cent greater than was BK-2, yet only at a curvature ratio of about 40 could specimen BK-3 provide sufficient resistance to oppose the acting force.

Mild steel beams were definitely time sensitive; but, the results of the rapid flexure tests of the BK series indicated that there was little, if any, time sensitive behavior of the aluminum members subjected to flexure. The resisting moment-curvature relationship for specimen BF-4 is the only indication of an increase in resistance with the rapidity of deformation of an aluminum beam.

However, this result is questionable since the measured resistance did not agree as well with theory as could be expected in the elastic region, an indication of possible inaccuracies in measurement. Since aluminum coupons stressed uniaxially did not exhibit a time dependent behavior, the lack of such behavior in aluminum flexural specimens was expected.

4.4.2 Correlation Study

An attempt was made to correlate the behavior of these small mild steel beams under flexure with the known uniaxial stress properties of the materials from which the beams were made. In the correlation associated with the preliminary series BF, it was necessary to assume that the distribution of strain was linear throughout the depth of the beam section and that the material behaved the same in both tension and compression. For the next series, BK, it had been determined that these assumptions were valid. Therefore, proceeding from the measured strains of the beams, the resistances in the region of pure flexure were computed using the measured values of the instantaneous strains and the known delayed yielding and rate of general yielding behavior of the materials from which the beams were made. (The procedure used for analyzing the rapidly loaded specimens is described in the Appendix.) In the case of the slowly deformed specimens, BF-1, BK-1, and BL-1, the material stress-strain curves as determined from slow straining coupon tests were used together with the measured strain of the beams.

The results of the correlation studies are shown in Figs. 40, 41, and 42. The measured resistance of BF-1 generally exceeded the computed resistance, but, the opposite was true for specimen BK-1. The failure of measured resistance to be as great as computed resistance has been noted by other investigators of the inelastic behavior of members. The discrepancy has been blamed in part on the severe stress concentrations associated with the application of concentrated loads

to the specimens. The measured resistance curves for specimens BK-1 and BL-1 exhibit a rising characteristic at large curvatures which probably resulted from an inadequate correction for large deflections.

Figures 40 and 41 show the correlation, correct to within 0 to 15 per cent, for the rapidly loaded specimens when their resistance is computed using the delay time-strain rate procedure. It may be noted that the use of strain rate information alone was insufficient to predict the maximum resistance of the specimen before major yielding began, but that this deficiency was satisfied by the inclusion of delay time considerations. Since no uniaxial time dependent properties of these materials deformed into the range of strain hardening were determined, the correlation was continued with respect to curvature using only the available rate of general yielding data until the rate of curvature approached zero. At this limit, the existing resisting stress is theoretically σ_{Ly}^* and the resisting moment is $1.5 M_y$. Actually, the beams had a much greater moment resisting capacity than these computations indicate, because the geometry of the specimen permitted strain hardening without local buckling.

The computations of the flexural resistance of the rapidly loaded beams described in this report agreed within an average of about 10 per cent with the measured resistance. However, the method of analysis presupposes the availability of the deformation-time function for the beam. In a practical problem the resistance and deformation functions, which are interrelated, are initially set arbitrarily before proceeding with the solution. Three common assumptions for beam resistance as a function of displacement are shown in Fig. 43. These are the following: (1) a resistance derived from a stress block (acting at any cross-section of the member) which is the elasto-plastic stress-strain curve for the beam material; (2) an elasto-plastic resistance function with an initial elastic slope

continued to the plastic moment ratio of $M/M_e = 1.5$; (3) an elasto-plastic resistance function with the initial elastic slope continued to a plastic moment ratio of something greater than 1.5 to account for the dynamic effects.

If the measured resistance of the rapidly loaded mild steel beams is interpreted in terms of the arbitrary resistance functions described above, the third method would most adequately predict the observed behavior if the fully plastic resistance is increased by 60 per cent for BF-2 and 40 per cent for BF-3 (probably high due to the questionably high dynamometer data), and 40 per cent for BK-2 and BK-3.

4.5 Summary of Results of Flexure Tests

4.5.1 Summary of Results

The major purpose of the flexure tests was to determine whether or not the resistance of material in flexure could be correlated with the stress-strain-time information obtained in slow and rapid uniaxial stress tests. Therefore, the results of the flexure tests are interpreted in such a manner that this comparison is relatively simple. Basic data which are representative of slow and rapid tests of each of the three materials tested are shown in Figs. 36. In Figures 40a, 41a, and 42a moment curvature relationships obtained from all of the flexure tests are shown.

As was mentioned earlier, the major purpose of the flexure tests was to determine whether or not the behavior of materials when subjected to slow and rapid flexure could be correlated with the behavior (as obtained from slow and rapid uniaxial stress tests) of the materials from which the beams were made. Therefore, the major result of the flexural test investigation is the comparison of beam resistances as determined from measured deformations of the beam specimens and knowledge of material properties with the behavior of the beams as measured directly

in each test. These comparisons are shown for each specimen in Figs. 40, 41, and 42, in which is presented (1) the measured moment curvature relationships, (2) the moment curvature relationship determined using measured deformation of the beam and material properties determined from slow and rapid uniaxial stress tests, and (3) the moment curvature relationship representing the elasto-plastic strain relationship which best represents the basic stress-strain relationship of the specimen material as obtained with slow straining rates. This comparison indicates that the behavior of the material under flexure can be explained within less than 10 per cent error by consideration of material properties as obtained in uniaxial stress tests. This explanation is in almost all cases more accurate than the commonly used elasto-plastic assumption.

4.5.2 Significance of Results

The results of the flexure tests have been correlated (within reasonable limits) with the uniaxial stress properties of the material from which the beams were made. This indicates that it should be possible to progress from the current knowledge of the behavior of structural metals under slow and rapid uniaxial stress to an explanation of the behavior of structures composed of elements such as beams, beam-columns, and medium thick plates when subjected to transient dynamic loadings producing extensive inelastic deformations.

5. GENERAL SUMMARY

5.1 General Summary

As was mentioned in the introduction of this report the primary purposes of the investigation were to determine the time sensitive stress deformation characteristics of several of the more commonly used structural metals, and to determine the engineering significance of this information as regards application in the solution of problems concerned with the behavior of metal structures when subjected to transient dynamic loads producing extensive inelastic deformation.

The work that has been done has included many tests of several of the more commonly used structural metals including mild steels of the rimmed, semi-killed, and fully-killed varieties as obtained from plate, bar, and rolled section stocks; a few of the commonly used alloys of steel; and one very commonly used structural aluminum. The tests have included slow and rapid applications of stress under uniaxial conditions and conditions of pure flexure. In addition, a very few reversed loadings were applied to one material.

The results indicate that in general those materials which have a pronounced upper lower yield point phenomena in slow straining rate tests (that is, a discontinuity in slope of the stress-strain relationship) also exhibit a time sensitive behavior in the region from initial inelasticity through general yielding, and a less significant time sensitive behavior in the region of strain hardening. The so-called elastic region is apparently insensitive to time effects for loadings applied in times no more rapid than a few milliseconds. The results pertaining to the time sensitivity where present have been arbitrarily presented in the form of delayed yield and rate of general yielding information. The results of the tests of materials which were not very time sensitive were presented in the form of

stress-strain and strain-time relationships, and in a few cases, as elapsed times to specific amounts of yielding as defined by various arbitrary selected values of the secant moduli (stress/strain).

A major purpose of the investigation, as was mentioned above, was to provide information which would indicate whether or not the results of uniaxial stress tests could be extended to flexural stress conditions. The results of the flexure tests which were performed in this investigation indicate that this can be done with less than 10 per cent error.

Therefore, in many cases it should be possible to apply the results of uniaxial stress tests in predicting the response of frame and plate type structures to transient dynamic loadings that produce extensive inelastic deformation.

BIBLIOGRAPHY

1. Belshelm, R. O., "Delayed-Yield Time Effects in Mild Steel under Oscillatory Axial Loads," Trans. A.S.M.E., Vol. 79, p. 1619, 1957.
2. Brown, A. F. C., and Vincent, N. D. C., "The Relation Between Stress and Strain in the Tensile Impact Test," Proc. Inst. Mech. Engrs., Vol. 143, 1941, p. 126.
3. Brown, W. F. and Thompson, F. C., "Strength and Failure Characteristics of Metal Membranes in Circular Bulging," Trans. A.S.M.E., Vol. 71, p. 575.
4. Clark, D. S., and Wood, D. S., "The Time Delay for the Initiation of Plastic Deformation at Rapidly Applied Constant Stress," Proc. A.S.T.M., Vol. 49, p. 717, 1949.
5. Clark, D. S., "The Behavior of Metals Under Dynamic Loading," Trans. Am. Soc. for Metals, Vol. 46, p. 34, 1954.
6. Cottrell, A. H., and Bilby, B. A., "Dislocation Theory of Yielding and Strain Aging of Iron," Proc. Phys. Soc. (London), Vol. 62A, p. 49, 1949.
7. Crum, M. J. and Mavis, F. T., "Behavior of Certain Alloys Subjected to Dynamic Loading," A.S.T.M. Bulletin, No. 231, p. 28, July 1958.
8. Davis, E. A., "The Effect of the Speed of Stretching and the Rate of Loading on the Yielding of Mild Steel," Jour. App. Mech., Vol. 6, No. 4, p. A137, 1938.
9. Docherty, J. G., and Thores, F. W., "The Phenomenon of Tensile (Yielding?) in Mild Steel and Iron," Engineering, Vol. 132, p. 295, 1939.
10. Edwards, C. A., Phillips, D. L., and Jones, H. E., "The Influence of Some Special Elements Upon the Strain Aging and Yield Point Characteristics of Some Low Carbon Steels," Jour. Iron and Steel Inst., Vol. 142, p. 199, 1940.
11. Fast, J. D., "Aging of Iron and Steel," Iron and Coal Trades Review, Vol. 150, p. 837, 1950.
12. Freudenthal, A. M., "The Inelastic Behavior of Engineering Materials and Structures," John Wiley and Sons, Inc., New York, 1950.
13. Galletly, G. D., Hosking, N. G. and Offord, A., "Behavior of Structural Elements Under Impulsive Loads III," Report to New England Division, Corps of Engineers, Dept. of the Army, 1951.
14. Goss, N. P., "Grain Displacement in Metal Stressed Below the Elastic Limit," Metal Progress, Vol. 61, p. 87, 1952.
15. Holden, A. N., and Hollomon, J. H., "Homogeneous Yielding of Carburized and Nitrided Single Iron Crystals," Trans. Amer. Inst. of Mining and Met. Engr., Vol. 185, p. 179, 1949.

BIBLIOGRAPHY (Cont'd)

16. Holden, A. N., "The Yielding Behavior of Iron Single Crystals, Jour. App. Phys., Vol. 22, p. 1290, 1951.
17. Holloman, J. H., and Zener, C., "Conditions of Fracture in Steel," Trans. Amer. Inst. Mining and Met. Engr., Vol. 158, p. 283, 1944.
18. Johnson, J. E., Wood, D. S. and Clark, D. S., "Dynamic Stress-Strain Relations for Annealed 2S Aluminum Under Compression Impact," Trans. A.S.M.E., Journal of App. Mech., Vol. 20, No. 4, p. 523, 1953.
19. Johnson, J. E., Wood, D. S. and Clark, D. S., "Delayed Yielding in Annealed Low-Carbon Steel Under Compression Impact," Proc. A.S.T.M., Vol. 53, p. 755, 1953.
20. Keyon, R. L., and Burns, R. S., "Aging in Iron and Steel," Age Hardening of Metals, Amer. Soc. of Metals, 1939.
21. Low, J. R., and Genamer, M., "Aging and the Yield Point of Steel," Trans. Amer. Inst. of Mining and Met. Engr., Vol. 158, p. 207, 1944.
22. MacGregor, C. W., and Fisher, J. C., "Tension Tests at Constant True Strain Rates," Jour. App. Mech., Vol. 12, p. A217, 1945.
23. Manjoine, M. J., and Nadai, A., "High Speed Tension Tests at Elevated Temperatures," Proc. A.S.T.M., Vol. 40, p. 822, 1940.
24. Massard, J. M., "The Stress-Deformation Characteristics of Some Mild Steels Subjected to Various Rapid Uniaxial Stressings," Ph. D. Thesis, Univ. of Ill., 1955.
25. Mental, T. J., "The Elastic Deformation Due to Impact of a Cantilever Beam with an Attached Tip Mass," Brown Univ., Tech. Rpt. 8 to USA Ord. Corps, ASTIA AD 91639, 1956.
26. Nadai, A., and Manjoine, M. J., "High Speed Tension Tests at Elevated Temperatures, Parts II and III," Jour. App. Mech., Vol. 8, p. A77, 1941.
27. Nadai, A., "Theory of Flow and Fracture of Solids," McGraw-Hill Book Company, Inc., New York, 1950.
28. Nabarro, F. R. N., "Mechanical Effects of Carbon in Iron," Report of Conference on Strength of Solids, Phys. Soc. (London), p. 38, 1943.
29. Nabarro, F. R. N., "Deformation of Crystals by the Motion of Single Ions," Report of Conference on Strength of Solids, Phys. Soc. (London), p. 75, 1943.
30. Prager, W., "Stress-Strain Laws of the Mathematical Theory of Plasticity -- A Survey of Recent Progress," Jour. App. Mech., Vol. 15, p. 226, 1948.

BIBLIOGRAPHY (Cont'd)

31. Rees, W. P., Hopkins, B. E., and Tipler, H. R., "Tensile and Impact Properties of Fe-Si, Fe-Ni, Fe-Cr, and Fe-Mo Alloys of High Purity," Jour. Iron and Steel Inst., Vol. 177, p. 93, 1954.
32. Schwartzbart, H., and Low, J. R., "The Yielding and Strain Aging of Carburized and Nitrided Single Crystals of Iron," Trans. Amer. Inst. Mining and Met. Engr., Vol. 185, p. 657, 1949.
33. Smith, L. B., "A Device to Permit Reversed Loading in the U. of I. 20-kip Pulse Loading Machine," M. S. Thesis, Univ. of Ill., 1955.
34. Storm, J. W., "A Device for the Rapid Loading of Small Beams in the University of Illinois 20-kip Pulse Loading Machine," M. S. Thesis, Univ. of Ill., 1955.
35. Taylor, D. B. C., "The Dynamic Straining of Metals Having Definite Yield Points," Jour. Mech. and Phys. of Solids, Vol. 3, p. 38, 1954.
36. Thielsch, H., "Strain Aging of Pressure Vessel Steels," Welding Journal. Welding Res. Supp., p. 283, 1951.
37. Vreeland, T. Jr., Wood, D. S., and Clark, D. S., "A Study of the Mechanism of the Delayed Yield Phenomena," Trans. A.S.M., Vol. 45, p. 620, 1953.
38. Wojcieszak, R. F. and Massard, J. M., "Slow and Rapid Lateral Loading Tests of Simply Supported Beam and Beam-Columns," Report to Dept. of the Air Force, Air Force Special Weapons Center, AFSWC-TR-56-21, 1957. = 40-44532
39. Wood, D. S., and Clark, D. S., "The Influence of Temperature Upon the Time Delay for Yielding in Annealed Mild Steel," Trans. A.S.M., Vol. 43, p. 571, 1951.
40. Wood, D. S., and Clark, D. S., "Delayed Yield in Annealed Steels of Very Low Carbon and Nitrogen Content," Trans. A.S.M., Vol. 44, p. 726, 1952.
41. Yokobori, T., "Delayed Yield and Strain Rate and Temperature Dependence of Yield Point in Iron," Jour. App. Phys., Vol. 25, p. 593, 1954.

APPENDIXDETERMINATION OF FLEXURAL RESISTANCE FROM BEAM DEFORMATION
AND UNIAXIAL STRESS PROPERTIES

As was mentioned in Section 4.4.2 the resisting moment corresponding to the curvature measured in the region of pure flexure was determined by computation using the deformation as determined either from SR-4 gages on the outer fiber of the beam or from the curvature gages applied to the sides of the beam, and three assumptions: (a) that the distribution of strain is linear through the depth of the beam section; (b) that the behavior of the beam material used is the same in both tension and compression; and (c) that the materials information obtained under conditions of uniaxial stress can be applied to the stress gradient conditions existing in the beam.

For single load applications, stress in mild steel is a single valued function of strain. Therefore, the procedure used in computing resisting moment from measured strains is straightforward. It consists of determining the strain distribution in the beam section at the time considered, finding the corresponding stress distribution by use of the comparable stress-strain relationship for the beam material, and computing the resisting moment from the stress distribution and consideration of the geometric properties of the beam section.

For the rapid tests, the procedure used to determine the resisting moment of a specimen section from the measured outer fiber strain or the strain as determined from the curvature gage is complicated by the fact that, under conditions of rapid loading, stress in the material is a function of not only strain, but also strain rate and time. However, by making one other major assumption in addition to those listed above, the desired resisting moment can be obtained. That assumption

is (d) that the stress-time characteristics of the beam material determined from the materials studied under a stress-time relationship that is applied rapidly and is thereafter maintained constant are applicable to the stress-time conditions probably existing in the beam specimens. (The validity of this assumption can be checked later by comparing the stress-time relationship computed for a given fiber in the beam with the stress-time function with which the materials were tested.)

The procedure used for determining the instantaneous resistance of the beam section to an imposed measured straining is described in the following paragraph. This procedure requires the use of the measured strain-time information obtained for the beam section considered, and information similar to that contained in Figs. A1 and A2, which represent the inelastic time dependent and strain rate dependent behavior of one of the beam materials used.

By using the measured beam deformation as determined either from the SR-4 gages on the outer fiber or the curvature gage applied to the sides of the beam in conjunction with the information of Fig. A2, the times at which the various values of apparent modulus were reached could be determined as is shown in Fig. A5*. For each of these times the stress on the outer fiber could then be computed ($\sigma = \epsilon \cdot \sigma/\epsilon$) so that the stress-time history was known for the particular fiber considered from the initial straining through straining corresponding to $\sigma/\epsilon = 20 \times 10^6$ psi (Fig. A3). For strains beyond this value it was assumed that the instantaneous stress level could be determined from the measured strain rate through use of Fig. A2b. In this manner the stress-time relationship was determined for the particular fiber of the beam considered. This, of course, could be done for as many fibers through the depth of the section as desired (assuming that the

* The strain-delay time overlay used in Fig. A5* may be constructed from Fig. A2a since strain as well as stress may be related to delay time by means of the relationship σ/ϵ .

UNCLASSIFIED

AD 210240

Armed Services Technical Information Agency

ARLINGTON HALL STATION
ARLINGTON 12 VIRGINIA

FOR
MICRO-CARD
CONTROL ONLY

2 OF 7

NOTICE: WHEN GOVERNMENT OR OTHER DRAWINGS, SPECIFICATIONS OR OTHER DATA ARE USED FOR ANY PURPOSE OTHER THAN IN CONNECTION WITH A DEFINITELY RELATED GOVERNMENT PROCUREMENT OPERATION, THE U. S. GOVERNMENT THEREBY INCURS NO RESPONSIBILITY, NOR ANY OBLIGATION WHATSOEVER; AND THE FACT THAT THE GOVERNMENT MAY HAVE FORMULATED, FURNISHED, OR IN ANY WAY SUPPLIED THE SAID DRAWINGS, SPECIFICATIONS, OR OTHER DATA IS NOT TO BE REGARDED BY IMPLICATION OR OTHERWISE AS IN ANY MANNER LICENSING THE HOLDER OR ANY OTHER PERSON OR CORPORATION, OR CONVEYING ANY RIGHTS OR PERMISSION TO MANUFACTURE, SELL OR BULL ANY PATENTED INVENTION THAT MAY IN ANY WAY BE RELATED THERETO.

UNCLASSIFIED

distribution of strain is linear with depth) so that instantaneous stress "blocks" and, in turn, instantaneous section resistances could be computed. For the BF and BL series flexure specimens the stress blocks were determined by consideration of strains at six locations through the half depth of the section. For the BK series specimens, in which four SR-4 gages were positioned through each half depth of the beam, a correlation of measured strains was made with the assumed linear distribution of strain mentioned in Section 4.4.2. This comparison indicated that the distribution of strain with depth was virtually linear. Therefore, as many individual strains were computed through the half depth of the beam for the BK specimens as were computed for the other flexure tests.

No "elapsed time to $\sigma/\epsilon = 30 \times 10^6$ psi" data for the BK material were available since no SR-4 strain gages were applied to the coupons and the extensometer was not capable of indicating the time at which the secant modulus first departed from a value of 30×10^6 psi. Therefore, in the analysis of this series of specimens the delay for $t_{\sigma/\epsilon = 30 \times 10^6 \text{ psi}}$ was taken as zero.

TABLE 1

SUMMARY OF UNIAXIAL TESTING PROGRAM

Series	Type of Material (As rolled and as machined except where noted)	Manner of Testing			
		Slow		Rapid	
		Loaded	Strained	Cycled	Loaded
RD	Rimmed steel, ASTM A7	X	X	X	X
	Polished	X	X	X	X
	Notched		X		X
	Polished and annealed		X		X
	Notched and annealed				
SP	Semi-killed steel, ASTM A7				
	Polished	X	X	X	X
	Notched		X		X
	Polished and annealed		X		X
	Notched and annealed		X		X
NS	ASTM A7 steel	X	X		X
NR	ASTM A7 steel, annealed		X		X
NN	Low alloy steel		X		X
NL	Low alloy steel	X	X		X
NTY	Nickel-chromium steel		X		X
FS	Semi-killed steel, ASTM A7		X		X
K	Fully-killed steel, ASTM A7		X		X
Q	Low alloy steel, ASTM A242		X		X
T	USS T-1 steel		X		X
A,B	ASTM A7 steel, From rolled 4M section		X		X
L	6061-T6 structural aluminum		X		X

TABLE 2

INITIAL SPECIMEN DESIGNATION CODE

Series RB, SP (Profile Fig. 9)

The numbers or letters in "digit" order are:

1. Specimen Area
 - 1 = 0.100 sq.in. = 0.357 in. D.
 - 2 = 0.200 sq.in. = 0.505 in. D.
2. Specimen Surface
 - 3 = Polished smooth (to about 15 μ in. r.m.s.)
 - M = As Machined (Surface roughness is about 150 μ in. r.m.s.)
 - N = Polished then notched about 0.01 in. deep
3. Type of Steel
 - R = Rimmed steel
 - S = Semi-killed steel
4. Stock Form of Metal
 - B = Hot rolled bar
 - P = Hot rolled plate
5. Treatment
 - A = As rolled
 - B = Annealed and spheroidized after machining (in Helium atmosphere)
 - 2 1/2 hours at 1690°F.
 - 25 hours at 1540°F.
 - C = Annealed and spheroidized before machining (in Helium atmosphere)
 - 2 5/4 hours at 1690°F.
 - 25 hours at 1510°F.
6. Identical Specimen Number
 - 1 = first specimen of the type, etc.

Example: Specimen 1SRBA1 is a 0.357 in. D. polished specimen of rimmed steel obtained from hot rolled bar stock left as rolled and is the second specimen of this type.

Series RW, WS (Profile Fig. 11)

HL, WHY (Profile Fig. 9)

NR (Profile Fig. 12)

PS (Profile Fig. 13)

The series designation is suffixed to indicate the orientation of the coupon with respect to the direction of mill rolling of the parent material.

L = Longitudinal
T = Transverse

Series K, Q, T, L (Profile Fig. 13)

No suffix precedes or follows specimen number.

Series PSL-A, K-A (Profile Fig. 13)

A = Reduced gage section over full length of the specimen between threads

TABLE 3 RESULTS OF METALLURGICAL STUDIES

Steel Designation	Specimen Studied	Steel Stock and Treatment	Rockwell "B" Hardness 1		Decarburization	Microstructure	A.S.T.M. Grain Size
			Surf.	Center			
REA	1A72A4	Hot rolled 1" ϕ bar As rolled	73	80	---	Fine pearlite in an α matrix Some banding, showing slight directional properties	7
REB	1A72B2	Hot rolled 1" ϕ bar Annealed, spheroidized	47	60	Surface Decarburized 0.015 to 0.020 inches deep	Coarse pearlite in an α matrix Extensive spheroidization of Fe_3C	-
REC	1A72C4	Hot rolled 1" ϕ bar Annealed, spheroidized	62	72	So decarburization	Both coarse and fine pearlite in an α matrix. Some spheroidization of Fe_3C	-
SEPA	1A72PA	Hot rolled 1" plate As rolled	69	79	---	Fine pearlite in an α matrix Little or no directional properties	5
SEPB	1A72PB	Hot rolled 1" plate Annealed, spheroidized	58	66	No decarburization	Both fine and coarse pearlite in an α matrix. Some spheroidization of Fe_3C in the pearlite.	-
ES	T4	Hot rolled 1" gage As rolled	60	45 ⁵	Decarburized total thickness of sheet	A few coarse Fe_3C particles in an α matrix. Some FeS inclusions in center.	-
ER	R2	Hot rolled 1" plate Annealed, exact treatment unknown.	61	78	Decarburized in banded zones	Banded fine pearlite in an α matrix. Strongly directional properties.	-

1 Average of three readings

2 Readings taken on center of section used for metallurgical studies

3 Treated after machining but before polishing final 0.002 in. - 5 1/2 hr. at 1650°F.

4 Treated before machining - 2 1/4 hr. at 1650°F., 25 hr. at 1110°F.

5 Specimen section was narrow and some yielding to sides may have occurred.

TABLE 4 CHEMICAL COMPOSITIONS OF SPECIMEN STEELS

Series	Specimen Checked	Description	Chemical Composition (Tech Analysis)										
			C	Fe	P	S	Si	Cu	Mn	Cr	N	Al	V
REA	5SRDA20	Rimmed steel											
		Hot rolled, 1" ϕ bar	0.29	0.25	0.021	0.052	0.01	--	--	--	0.014	--	--
SPA	253PALL1	Seam-rolled steel	0.27	0.51	0.025	0.026	0.05	--	--	--	0.015	--	--
		Hot rolled, 1" plate											
NC	L4	Hot rolled 14 gage sheet	0.05	0.40	0.026	0.018	0.01	--	--	--	0.015	--	--
NR	R5	Hot rolled 1" plate Annealed	0.24	0.40	0.025	0.022	0.02	--	--	--	0.015	--	--
NR	M11	Hot rolled 5/16" plate Low alloy	0.18	1.01	0.042	0.029	0.22	0.10	None	0.11	0.001	--	--
NE	L71	Hot rolled 1" plate Low alloy	0.16	1.11	0.027	0.029	0.25	0.25	None	0.15	0.010	--	--
NR1	NR12		0.15	0.19	0.006	0.011	0.05	None	2.22	1.24	0.010	--	--
Q		Hot rolled 5/4" plate ASTM A-242	0.19	1.10	0.022	0.028	0.25	0.45	None	None	--	--	0.04
T		Hot rolled 5/4" plate U.S. steel "A-1"	0.11	0.84	0.056	0.015	0.20	0.22	0.99	0.20	--	0.09	0.005
K		Hot rolled 5/4" plate Fully killed steel	0.15	0.87	0.11	0.024	0.16	--	--	--	--	--	--

* Tech Analysis

TABLE 5
SUMMARY OF UNILATERAL STRESS TESTS AND RESULTS[illegible]

elastic value used in stress parameter
 σ_{max} should be a 0.0015 MPa (0.0015 MPa) value
 setting over static yield stress, one
 and a parameter point on the section

TABLE 5b SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Specimen	Type of Loading	Testing Machine Used	Rate of Load, %/min	Nominal Stress, ksi			Elongation in 2 in. gage, %	Yield Stress, ksi	Tensile Strength, ksi	Time to Fracture, sec	Date of Test	Date of Yield
				σ_y	$\sigma_{1/2}$	σ_{max}						
INCPAL	Slow $\dot{\epsilon} = C$	Ballwin	110	28.2	34.5	67.0	34	0.02				
2	Rapid to $\sigma = C_1$	Pulse Lad	2.4	0.006	43.4			0.10	0.22	132	165	
3	Slow $\dot{\epsilon} = C$	Ballwin	250	31.5	33.4	63.7	60	0.00				
4	Rapid to $\sigma = C_1$	Pulse Lad	2.4	0.006	34.7			0.46	0.66	0	8	
INCPAL	Slow $\dot{\epsilon} = C$	Ballwin	180	27.1	25.4	60.3	43	0.02				
2	Rapid to $\sigma = C_1$	Pulse Lad	1.5	0.005	35.0			0.23	0.19	88	125	
3	Slow $\dot{\epsilon} = C$	Ballwin	170	27.4	24.4	60.4	44	0.00				
4	Rapid to $\sigma = C_1$	Pulse Lad	0.8	0.005	47.0			0.72	0.61	0	8	
INCPAL	Slow $\dot{\epsilon} = C$	Ballwin	100	32.0		64.7	51	0.00				
2	Rapid to $\sigma = C_1$	Pulse Lad	0.4	0.005	52.4			0.96	0.35	44	88	
3	Slow $\dot{\epsilon} = C$	Ballwin	100	31.6	33.4	64.2	57	0.21				
4	Rapid to $\sigma = C_1$	Pulse Lad	1.5	0.005	51.6			0.61	0.60	2	11	
INCPAL	Slow $\dot{\epsilon} = C$	Ballwin	200	29.2	25.2	54.4	34	0.11				
2	Rapid to $\sigma = C_1$	Pulse Lad	1.5	0.005	35.0			0.34	0.26	72	135	
3	Slow $\dot{\epsilon} = C$	Ballwin	200	26.2	24.4	52.5	39	0.00				
4	Rapid to $\sigma = C_1$	Pulse Lad	0.4	0.005	44.4			0.69	0.55	2	11	

Basic values used in stress parameter
 define error static upper yield stress, σ_y
 ***Stressometer joint marks on gage section

TABLE 5c
SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS[illegible]

TABLE 54 SUMMARY OF UNIAxIAL STRESS TESTS AND RESULTS

Specimen	Type of Loading	Testing Machine Used	Strain Rate, %/min.	Nominal Stress, ksi			Reduction in Area, %	Elongation in 2 In. gage, %	$\frac{\sigma}{E\epsilon}$	$\frac{\sigma}{E\epsilon}$	$\frac{\sigma}{E\epsilon}$	Time to Failure, seconds	$\frac{\sigma}{E\epsilon}$	$\frac{\sigma}{E\epsilon}$	Rate of Yield $\frac{\sigma}{E\epsilon}$
				σ_y	$\sigma_{0.2}$	σ_{max}									
10000	Cycled	Pulse Lad	2.4	50.2					0.00						
2	Rapid to $\sigma = C$	Pulse Lad	0.3	0.006	56.9				0.34	0.50	1165	1212	0.36	0.74	0.14
3	Rapid to $\sigma = C$	Pulse Lad	1.0	0.006	56.8				0.14	0.50	715	746	0.36	0.74	0.21
4	Rapid to $\sigma = C$	Pulse Lad	5.7	0.006	56.9				0.14	0.50	775	702	0.46	0.74	0.24
5	Rapid to $\sigma = C$	Pulse Lad	2.6	0.006	56.2				0.16	0.68	105	165	0.32	0.63	0.67
6	Rapid to $\sigma = C$	Pulse Lad	3.8	0.20	54.4				0.09	0.32	1440	2250	0.34	0.64	0.18
7	Rapid to $\sigma = C$	Pulse Lad	0.6	0.15	54.6				0.09	0.35	765	322	0.40	0.64	0.15
8	Rapid to $\sigma = C$	Pulse Lad	0.6	0.15	54.2				0.13	0.53	950	974	0.47	0.75	0.37
9	Rapid to $\sigma = C$	Pulse Lad	1.8	0.15	50.4				0.10	0.60	240	267	0.52	0.84	0.67
10000	Slow $\sigma = C$	Bedwin	11.5	50	54.6	40.1	63.8	43	-0.11				0.05	0.04	0.00020
11	Rapid to $\sigma = C$	Pulse Lad	5.6	0.80	53.1				0.04	0.22	750	767	0.36	0.58	0.072
12	Rapid to $\sigma = C$	Pulse Lad	4.6	10	53.3				0.07	0.25	4075	4150	0.37	0.54	0.12
13	Rapid to $\sigma = C$	Pulse Lad	5.0	0.70	56.0				0.12	0.44	1000	1085	0.44	0.70	0.21
14	Rapid to $\sigma = C$	Pulse Lad	4.5	0.70	57.8				0.16	0.57	580	642	0.48	0.72	0.24
15	Slow $\sigma = C$	Pulse Lad	5.7	20.5	53.8				0.08	0.27	4000		0.38	0.61	0.075
16	Slow $\sigma = C$	Pulse Lad	1.8	50.0	54.2				0.08	0.30	15000		0.34	0.63	0.045
17	Slow Increment	Pulse Lad	2.5	22.0	48.3				-0.05				0.24	0.34	0.011
18	Slow Increment	Pulse Lad	1.9	60	53.1				0.06	0.22	4 min		0.36	0.58	0.042
ESCALY	Slow Increment	Pulse Lad	0.7	60	53.6				0.07	0.26	3 min		0.37	0.60	0.029

Reduction in area at stress parameter point within 2 gage section

Stress value used in stress parameter curve over static upper yield stress, ksi

TABLE 3a SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Specimen	Type of Loading	Testing Machine Used	Punching, in	Pulse time, sec	Nominal Stress, ksi		Reduction in Area, %	Elongation in 2 in. gage, %	$\frac{\sigma}{E}$	$\frac{\sigma}{\sigma_y}$	$\frac{\sigma}{\sigma_u}$	Strain to Yield, in./in.	Strain to Fracture, in./in.	Time to Fracture, sec	Time to Fracture, min	Time to Fracture, hr
					σ_y	σ_u										
20	Rapid to $\sigma - C_1$	Pulse 144	1.6	0.006	56.5				0.13	0.47	0.45	621		621		0.27
21	Rapid to $\sigma - C_1$	Pulse 144	1.6	0.006	58.4				0.18	0.65	0.51	110		130		0.65
22	Rapid to $\sigma - C_1$	Pulse 144	1.6	0.006	61.2				0.22	0.85	0.42	120		131		1.17
23	Rapid to $\sigma - C_1$	Pulse 144	1.6	0.006	60.2				0.20	0.77	0.54	125		137		1.85
24	Rapid to $\sigma - C_1$	Pulse 144	1.6	0.12	59.0				0.15	0.64	0.44	1090		1075		0.24
25	Rapid to $\sigma - C_1$	Pulse 144	1.6	0.12	57.1				0.15	0.56	0.42	85		94		0.67
26	Rapid to $\sigma - C_1$	Pulse 144	1.6	0.12	60.4				0.11	0.77	0.55	125		143		1.10
27	Rapid to $\sigma - C_1$	Pulse 144	1.6	0.12	60.4				0.21	0.77	0.55	150		172		1.14
28	Slow $\sigma - C_2$	Self-drain	2.5	89	45.6	53.0	63.5	61	0.11		0.00	0.00		0.00		0.0001
29	Rapid to $\sigma - C_1$	Pulse 144	1.6	0.55	56.0				0.12	0.44	0.44	50		50		0.52
30	Rapid to $\sigma - C_1$	Pulse 144	1.6	0.55	56.8				0.14	0.50	0.46	220		235		0.67
31	Rapid to $\sigma - C_1$	Pulse 144	1.6	0.55	57.4				0.15	0.54	0.47	180		184		0.82
32	Rapid to $\sigma - C_1$	Pulse 144	1.6	0.55	58.2				0.16	0.60	0.47	140		154		1.02
33	Slow A & C	Pulse 144	1.6	26	52.2				0.08	0.35	0.24	2500				0.085
34	Slow A & C	Pulse 144	0.0	16	51.5				0.05	0.10	0.32	1000				0.064
35	Cycled	Pulse 144	1.6		50.0				0.0							
36	Cycled	Self-drain	2.5		50.24	57.01	63.25	61	0.2							

***Extensometer joint marks on gage section

*Basic value used in stress parameter
*Stress over static upper yield stress, σ_y

TABLE 5C SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Specimen	Type of Loading	Testing Machine	Gage Length, in.	Plastic Strain, %	Nominal Stress, ksi			Reduction of Area, %	Extension to Fracture, in.	$\frac{\Delta L}{L_0}$	$\frac{\Delta L}{L_0} \times 100$	Strain Yield Point, $\frac{\Delta L}{L_0} \times 100$	Time to Fracture, sec.	$\frac{\Delta L}{L_0} \times 100$	$\frac{\Delta L}{L_0} \times 100$	Rate of Field Strain, $\frac{\Delta L}{L_0} \times 100$
					σ_y	σ_{ly}	τ_{xy}									
2024-T3 Cycled	1. Rapid to $\sigma = C_1$	Riehle	4.3	0.003	37.0	31.5	65.3	50	45	0.01	0.19	0.26	125	15	0.37	0.17
	2. Rapid to $\sigma = C_1$	Pulse Lad	1.7	0.003	44.6					0.36	0.47	0.57	12	21	0.56	1.87
	3. Rapid to $\sigma = C_1$	Pulse Lad	4.5	0.003	50.2					0.50	0.68	0.73	2	3	0.72	5.27
	4. Rapid to $\sigma = C_1$	Pulse Lad	5.0	0.003	56.1					0.71	0.97	0.93	570	53	0.92	0.008
	5. Rapid to $\sigma = C_1$	Pulse Lad	7.4	0.003	60.0					0.12	0.16	0.28	303	303	0.20	0.942
	6. Rapid to $\sigma = C_1$	Pulse Lad	2.5	0.15	43.1					0.23	0.32	0.32	101	130	0.32	0.32
	7. Rapid to $\sigma = C_1$	Pulse Lad	2.2	0.15	46.1					0.30	0.42	0.42	57	67	0.50	0.43
	8. Rapid to $\sigma = C_1$	Pulse Lad	1.8	0.07	48.7					0.03	0.11	0.24	850	966	0.24	0.016
	9. Rapid to $\sigma = C_1$	Pulse Lad	0.3	0.15	40.4					0.03	0.04	0.04	6500	190	0.19	0.005
	10. Slow to $\sigma = C_1$	Pulse Lad	4.1	0.20	58.7					0.02	0.04	0.04	3000	477	0.00	0.0002
	11. Slow to $\sigma = C_2$	Pulse Lad	4.8	0.60	51.3	38.7	64.5	50	30	0.11	0.15	0.37	450	477	0.27	0.002
	12. Rapid to $\sigma = C_1$	Pulse Lad	4.6	0.60	41.6					0.13	0.21	0.37	295	268	0.37	0.34
	13. Rapid to $\sigma = C_1$	Pulse Lad	0.0	0.40	44.8					0.23	0.23	0.42	140	140	0.42	0.23
	14. Rapid to $\sigma = C_1$	Pulse Lad	5.2	0.26	46.4					0.02	0.12	0.12	1100	1100	0.25	0.060
	15. Rapid to $\sigma = C_1$	Pulse Lad	2.9	0.60	40.8					0.02	0.12	0.12	1100	1100	0.25	0.060
	16. Cycled	Pulse Lad	5.8		37.2					0.02	0.02	0.02				
2024-T3 Cycled		Pulse Lad	4.7		37.5	34.3	64.7	36	34	0.00						

Basic value used in stress parameter
after over static upper yield stress, σ_y

Stress-strain plot on log-log scale

TABLE 50 SOCIETY OF MATERIALS TESTERS REPORT

Material	Type of Loading	Test Method	E	Original Stress, psi		Strain, in/in	Yield Point, psi	Yield Point, % elongation	Yield Point, % reduction of area	Yield Point, % elongation	Yield Point, % reduction of area
				psi	% elongation						
NSL 19	Slow & C ₂	Pulse Lig.	6.5 100	6.5 100	6.5 100	0.00	0.00	0.00	0.00	0.00	0.00
10	Rapid to σ - C	Pulse Lig.	0.005	0.005	0.005	0.10	0.10	0.10	0.10	0.10	0.10
11	Rapid to σ - C	Pulse Lig.	0.005	0.005	0.005	0.10	0.10	0.10	0.10	0.10	0.10
12	Rapid to σ - C	Pulse Lig.	0.005	0.005	0.005	0.10	0.10	0.10	0.10	0.10	0.10
13	Rapid to σ - C	Pulse Lig.	0.005	0.005	0.005	0.10	0.10	0.10	0.10	0.10	0.10
NSL 19	Slow & C	Pulse Lig.	6.5 100	6.5 100	6.5 100	0.00	0.00	0.00	0.00	0.00	0.00
NSL 20	Slow & C ₂	Pulse Lig.	6.5 100	6.5 100	6.5 100	0.00	0.00	0.00	0.00	0.00	0.00
14	Rapid to σ - C	Pulse Lig.	0.005	0.005	0.005	0.10	0.10	0.10	0.10	0.10	0.10
15	Rapid to σ - C	Pulse Lig.	0.005	0.005	0.005	0.10	0.10	0.10	0.10	0.10	0.10
16	Rapid to σ - C	Pulse Lig.	0.005	0.005	0.005	0.10	0.10	0.10	0.10	0.10	0.10
NSL 16	Slow & C	Pulse Lig.	6.5 100	6.5 100	6.5 100	0.00	0.00	0.00	0.00	0.00	0.00

***Exceeds yield point marks on gage section

Basic value used in stress parameter
σ_Y = over static upper yield stress, σ_Y

TABLE 51 SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Specimen	Type of Loading	Testing Machine	Rate of Strain, in./in. per sec.	Nominal Stress, ksi		Reduction of Area, %	Extension to Fracture, in.	$\frac{A_0}{A_f}$	$\frac{A_0}{A_u}$	Yield Point, ksi	Tensile Strength, ksi	Elongation, %	Reduction of Area, %	Fracture Location, in.	Fracture Type	Remarks
				avg	std											
1	Slow Comp.	Baldwin	1.0	1.0	0.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
2	Slow Comp.	Pulse Lag	1.0	1.0	0.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
3	Rapid Comp.	Pulse Lag	1.0	1.0	0.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
4	Rapid Comp.	Pulse Lag	1.0	1.0	0.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
5	Rapid Comp.	Pulse Lag	1.0	1.0	0.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
6	Slow Tension	Baldwin	1.0	1.0	0.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
7	Slow Tension	Pulse Lag	1.0	1.0	0.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
8	Rapid Tension	Pulse Lag	1.0	1.0	0.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
9	Rapid Tension	Pulse Lag	1.0	1.0	0.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
10	Rapid Tension	Pulse Lag	1.0	1.0	0.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
11	Rapid Tension	Pulse Lag	1.0	1.0	0.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
12	Rapid Tension	Pulse Lag	1.0	1.0	0.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0

Extensometer point marks on gage section

static value used in stress parameter
static over static upper yield stress, ksi

TABLE 5
SUMMARY OF UNIAXIAL STRESS EFFECTS AND RESULTS

Spectrum	Type of Loading	Testing Machine Used	Holding Time, sec.	Rise time, sec.	Nominal Stress, ksi σ_u , σ_y , σ_{max}	Reduction in Area, %	Elongation in 2 in., %	$\frac{\sigma_y}{\sigma_u}$, $\frac{\sigma_{max}}{\sigma_u}$	$\frac{A_0}{A_f}$, $\frac{L_0}{L_f}$	Strain Yield, % to 0.002 in/in	Strain Yield, % to 0.01 in/in	Date of Test
REL-1	Slow & = C ₁	Baldwin	90	0.006	54.7, 51.0, 67.5	55	50	0.08	-0.02	-0.05		
2	Rapid to 0 = C ₁	Pulse LAG	7.5	0.006	56.5			0.06	0.25	300		
3	Rapid to 0 = C ₁	Pulse LAG	8.5	0.006	60.5			0.15	0.45	12		
4	Rapid to 0 = C ₁	Pulse LAG	2.5	0.006	65.1			0.17	0.67	12		
5	Rapid to 0 = C ₁	Pulse LAG	4.5	0.006	68.8			0.26	1.07	5		
6	Slow & = C ₂	Baldwin	90	0.006	55.7, 52.4, 67.6	55	50	0.06	0.00	0.00		
7	Rapid to 0 = C	Pulse LAG	0.85	0.006	57.2			0.08	0.50	150		
8	Rapid to 0 = C	Pulse LAG	2.8	0.006	59.0			0.10	0.58	35		
9	Rapid to 0 = C	Pulse LAG	2.9	0.006	67.4			0.26	0.77	25		
10	Rapid to 0 = C	Pulse LAG	0.6	0.006	74.5			0.59	1.50	5		
11 A1	20 ms, Pulse	Pulse LAG	3.7	0.006	54.2			0.11	0.44			
11 A2	Rapid to 0 = C ₁	Pulse LAG	1.8	0.006	59.0			0.10	0.50	86		
REL-2	Slow & = C ₂	Baldwin	90	0.006	55.7, 52.1, 66.5	55	50	0.08	-0.01	-0.02		

*Basic value used in stress parameter before over static upper yield stress, σ_y

**Extensometer point marks on gage section

TABLE 2. SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Test No.	Type of Loading	Testing Machine Used	Rate of Strain, %/sec.	Nominal Stress, ksi			Strain, in./in.	$\frac{\Delta L}{L_0}$	$\frac{\Delta L}{L_0} \div \frac{\Delta \sigma}{\sigma}$	$\frac{\Delta L}{L_0} \div \frac{\Delta \sigma}{\sigma}$	Rate of Yield, %/sec.
				σ_y	σ_x	σ_z					
1	Slow $\dot{\epsilon} = C_2$	Baldwin	30	53.1	51.2	66.5	34	0.00	0.00	0.00	0.00
2	Rapid to $\sigma = C_1$	Pulse 142	1.4	0.006	54.8			0.05	0.07	0.23	
3	Rapid to $\sigma = C_1$	Pulse 142	2.6	0.006	59.1			0.11	0.43	0.52	
4	Rapid to $\sigma = C_1$	Pulse 142	4.3	0.006	64.8			0.22	0.85	0.87	
5	Rapid to $\sigma = C_1$	Pulse 142	9.9	0.006	70.5			0.33	1.25	1.23	
6	Slow $\dot{\epsilon} = C_2$	Baldwin	30	53.5	51.3	66.8	34	0.01	0.00	0.00	0.00
7	Rapid to $\sigma = C_1$	Pulse 142	3.6	0.006	57.0			0.09	0.55	0.43	
8	Rapid to $\sigma = C_1$	Pulse 142	6.8	0.006	59.7			0.12	0.48	0.54	
9	Rapid to $\sigma = C_1$	Pulse 142	2.5	0.006	68.1			0.29	1.11	1.10	
10	Rapid to $\sigma = C_1$	Pulse 142	4.1	0.006	69.3			0.30	1.17	1.15	
11	At 20 mm. Pulse	Pulse 142	1.7	0.006	59.6			0.19	0.47	0.54	
12	Rapid to $\sigma = C_1$	Pulse 142	4.6	0.006	59.4			0.19	0.46	0.52	
13	Slow $\dot{\epsilon} = C_2$	Baldwin	30	52.9	52.4	67.5	34	0.00	0.00	0.00	0.00

Basic value used in stress parameter
ratio over static upper yield stress, σ_y

Estimate point ratio on gage section

TABLE 51
COMPANY OF MAXILLARY CLEFTS—FURTHER RESULTS

Op. No.	Type of Loading	Position of Machine	Initial Stress, psi		2. Pressure in Pneumatic Cylinder	3. Time in min.	4. Rate of Yield $\frac{d\epsilon}{dt}$	5. Rate of Yield $\frac{d\epsilon}{dt}$	
			psi	psi					
1	Slow $\epsilon = \epsilon_c$	Ballistic	180	11.0	30.1	79.2	05	0.00	0.00
2	Slow $\epsilon = \epsilon_c$	Ballistic	180	51.7	30.2	79.3	01	0.00	0.00
3	Slow $\epsilon = \epsilon_c$	Pulse 144	20	10.4				0.04	0.11
4	Rapid to $\sigma = \sigma_c$	Pulse 144	0.1	0.00				0.21	0.55
5	Rapid to $\sigma = \sigma_c$	Pulse 144	1.0	0.00				0.17	0.45
6	Rapid to $\sigma = \sigma_c$	Pulse 144	0.1	0.00				0.34	0.04
7	Rapid to $\sigma = \sigma_c$	Pulse 144	1.0	0.00				0.34	0.05
8	Rapid to $\sigma = \sigma_c$	Pulse 144	0.2	0.00				0.30	0.90
9	Rapid to $\sigma = \sigma_c$	Pulse 144	0.2	0.00				0.30	0.90
10	Slow $\epsilon = \epsilon_c$	Ballistic	180	51.8	54.7	77.3	62	0.00	0.00
11	Slow $\epsilon = \epsilon_c$	Ballistic	180	50.0	54.7	77.4	60	0.00	0.00
12	Rapid to $\sigma = \sigma_c$	Pulse 144	0.0	0.00				0.02	0.13
13	Rapid to $\sigma = \sigma_c$	Pulse 144	0.3	0.00				0.16	0.47
14	Rapid to $\sigma = \sigma_c$	Pulse 144	2.6	0.00				0.80	0.14
15	Rapid to $\sigma = \sigma_c$	Pulse 144	2.5	0.00				0.48	0.70
16	Rapid to $\sigma = \sigma_c$	Pulse 144	3.2	0.00				0.24	0.90
17	Rapid to $\sigma = \sigma_c$	Pulse 144	3.7	0.00				0.29	0.90
MULT								0.42	0.98

...Extensometer potentiometer on 1000 section

elastic value used as stress parameter
 slope over stable primary old stress day

TABLE 3 SUMMARY OF UNIAxIAL STRESS TESTS AND RESULTS

Specimen	Type of Loading	Testing Machine Used	Loading, sec.	Rate of Load, sec.	Nominal Stress, ksi		Reduction in Area, %	Elongation in 2 in. gage, %	$\frac{\Delta L}{L_0}$	$\frac{\Delta L}{L_0} \times 10^3$	Strain in yield, 10 ⁻³	Time to yield, milliseconds	Time to fracture, milliseconds	$\frac{\Delta L}{L_0} \times 10^3$	$\frac{\Delta L}{L_0} \times 10^3$	Rate of Yield, 10 ⁻³ sec.
					σ_y	σ_{max}										
MUTL-1000	SL-1000 - C ₂	Baldwin	0.5	2.0	80.2		32.0	75	20	0.00	0.00					
2	Rapid to $\sigma = C_1$	Pulse 100	1.2	0.006	80.0					0.07	0.32	0	30			
3	Rapid to $\sigma = C_1$	Pulse 100	0.5	0.006	80.2					0.07	0.32	0	2			
4	Rapid to $\sigma = C_1$	Pulse 100	0.5	0.006	80.4					0.13	0.34	0	3			
5	Rapid to $\sigma = C_1$	Pulse 100	3.1	0.006	80.3					0.13	0.34	0	3			
6	Rapid to $\sigma = C_1$	Pulse 100		0.006	81.2					0.15	0.62	0	0			
7	Rapid from $\sigma = C_1$ to $\sigma = C_2$	Pulse 100	2.6	0.006	85.6					0.14	0.18	0	0			
8	"	Pulse 100	3.2	0.006	87.0					0.08	0.36	0	0			
9	"	Pulse 100	1.2	0.006	88.6					0.10	0.45	0	3			
10	"	Pulse 100	3.3	0.006	87.6					0.08	0.39	0	1			
11	"	Pulse 100	4.1	0.006	91.2					0.14	0.58	0	1			
12	SL-1000 - C ₂	Baldwin	3.5	150	80.3		50.8	75	27	0.00	0.00					
13	Rapid to $\sigma = C_1$	Pulse 100	4.3	0.006	83.7					0.04	0.13	0	0			
14	Rapid to $\sigma = C_1$	Pulse 100	4.3	0.006	84.0					0.05	0.20	0	2			
15	Rapid to $\sigma = C_1$	Pulse 100	0.5	0.006	88.5					0.10	0.44	0	3			
16	Rapid to $\sigma = C_1$	Pulse 100		0.006	90.2					0.12	0.33	0	0			
17	Rapid to $\sigma = C_1$	Pulse 100		0.006	90.3					0.15	0.65	0	0			

*Basic value used in stress parameter sensitive over static upper yield stress, 807

sectionmeter point marks on gage section

1. Values at $\sigma_y = 20 \times 10^3$ psi

TABLE 5a SUMMARY OF UNIAxIAL STRESS TESTS AND RESULTS

Spectrometer	Type of Loading	Testing Machine Used	Bleeding, %	"Rise time" of Load, sec.	Nominal Stress, psi		Reduction in Area, %	Elongation in 2 In. gage, %	$\frac{\sigma}{E}$		Time to Strain Rate Change, milliseconds	Rate of Yield at $\sigma = \frac{1}{2} \sigma_y$, in./in.-min.
					σ_y	ϵ_y max			$\frac{\sigma}{E}$	$\frac{\epsilon}{\dot{\epsilon}}$		
MTL-6	Rapid from $\sigma = 85$ ksi to $\sigma = 0$	Pulse Ltd	15.6	0.003	85.5				0.07	0.28	0	7
20	-	Pulse Ltd	2.0	0.003	85.5				0.07	0.26	0	2
20	-	Pulse Ltd	9.5	0.003	86.7				0.06	0.55	0	0
21	-	Pulse Ltd	2.6	0.003	91.1				0.15	0.58	0	1
22	-	Pulse Ltd	1.7	0.003	91.2				0.18	0.59	0	0

*Basic value used in stress parameter curves over static upper yield stress, σ_y

Extensometer point marks on gage section
1 values at $\sigma/\sigma_y = 20 \times 10^3$ psi

TABLE 50 SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Spectrum	Type of Loading	Testing Machine Used	Strain Rate, in./in./sec.	Nominal Stress, ksi		Refractive Index	Strain Rate, in./in./sec.	Time to Failure, sec.	Time to Failure, min.	Time to Failure, hr.	Time to Failure, days	Time to Failure, weeks	Time to Failure, months	Time to Failure, years	Rate of Strain, in./in./sec.
				σ_x	σ_y										
1	Rapid to $\sigma = C_1$	Ballistic	5.4	180	85.2	27.5	68	20	0.01	0.01	0.01	0.01	0.01	0.01	0.01
2	Rapid to $\sigma = C_1$	Pulse 144	5.4	0.006	85.4				0.02	0.02	0.02	0.02	0.02	0.02	0.02
3	Rapid to $\sigma = C_1$	Pulse 144	1.0	0.006	86.4				0.03	0.03	0.03	0.03	0.03	0.03	0.03
4	Rapid to $\sigma = C_1$	Pulse 144	1.2	0.006	86.8				0.04	0.04	0.04	0.04	0.04	0.04	0.04
5	Rapid to $\sigma = C_1$	Pulse 144	0.5	0.006	86.5				0.05	0.05	0.05	0.05	0.05	0.05	0.05
6	Rapid to $\sigma = C_1$	Pulse 144	1.0	0.006	91.0				0.06	0.06	0.06	0.06	0.06	0.06	0.06
7	Rapid to $\sigma = C_1$	Pulse 144	0.5	0.006	85.0				0.01	0.01	0.01	0.01	0.01	0.01	0.01
8	"	Pulse 144	5.4	0.006	84.4				0.02	0.02	0.02	0.02	0.02	0.02	0.02
9	"	Pulse 144	0.5	0.006	84.5				0.03	0.03	0.03	0.03	0.03	0.03	0.03
10	"	Pulse 144	3.4	0.006	83.1				0.11	0.11	0.11	0.11	0.11	0.11	0.11
11	"	Pulse 144	0.2	0.006	83.2				0.14	0.14	0.14	0.14	0.14	0.14	0.14
12	Slow $\dot{\epsilon} = C_2$	Ballistic	5.0	150	84.1	100.3	69	29	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	Rapid to $\sigma = C_1$	Pulse 144	0.1	0.006	84.8				0.09	0.09	0.09	0.09	0.09	0.09	0.09
14	Rapid to $\sigma = C_1$	Pulse 144	0.5	0.006	86.1				0.02	0.02	0.02	0.02	0.02	0.02	0.02
15	Rapid to $\sigma = C_1$	Pulse 144	0.1	0.006	86.2				0.03	0.03	0.03	0.03	0.03	0.03	0.03
16	Rapid to $\sigma = C_1$	Pulse 144	1.2	0.006	91.3				0.05	0.05	0.05	0.05	0.05	0.05	0.05
17	Rapid to $\sigma = C_1$	Pulse 144	0.006	90.7					0.08	0.08	0.08	0.08	0.08	0.08	0.08

Basic value used in stress parameter
series over static upper yield stress, σ_y

***Parameter: point value on wire section
1. Values at $\sigma_y = 20 \times 10^3$ psi

TABLE 5p SUMMARY OF UNIAxIAL STRESS TESTS AND RESULTS

Specimen	Type of Loading	Testing Machine Used	Pulse Rate, sec.	Nominal Stress, ksi		Reduction in Area, %	Elongation in 2 in. gage, %	$\frac{\sigma_y}{E}$	$\frac{\sigma_{0.2}}{E}$	$\frac{\sigma_u}{E}$	Time to Yield, sec.	Time to Fracture, sec.	Rate of Yield, in./in./sec.
				σ_y	$\sigma_{0.2}$								
18	Static	Pulse 144	0.2	86.1	0.006	0.2	0.12	0	0	0	0	0	0
19	"	"	"	89.1	0.006	0.2	0.12	0	0	0	0	0	0
20	"	"	"	91.5	0.006	0.2	0.12	0	0	0	0	0	0
21	"	"	"	92.2	0.006	0.2	0.12	0	0	0	0	0	0
22	"	"	"	92.4	0.006	0.2	0.12	0	0	0	0	0	0

Basic value used in stress parameter σ_y over static upper yield stress, σ_y

Extensometer point marks on gage section

Values at $\sigma_y = 20 \times 10^6$ psi

TABLE 57 SUMMARY OF UNIAxIAL STRESS TESTS AND RESULTS

Specimen	Type of Loading	Testing Machine Used	Rate of Load, % of Load, sec.	Nominal Stress, ksi		Elongation in Area, %	Elongation in 2 In. Gage, %	$\frac{\sigma_y}{\sigma_u}$	$\frac{\sigma_y}{\sigma_u}$	Strain Yield, 10 ⁻⁴ /in./in.	Time to Yield, 10 ⁻⁴ sec.	$\frac{\sigma_y}{\sigma_u}$	$\frac{\sigma_y}{\sigma_u}$	Rate of Yield, 10 ⁻⁴ /in./in.
				σ_u	σ_y									
Q15-2-A														
T-144-1E Slow $\dot{\epsilon} = C_1$		Baldwin		31.4	37.4	60.7	36							
T-144-1E Rapid to $\sigma = C_1$		Pulse Lad	7.0 P.000	44.0										
T-144-1E Slow $\dot{\epsilon} = C_1$		Baldwin		33.2	33.0	60.8	31							
T-144-1E Rapid to $\sigma = C_1$		Pulse Lad	3.6 P.005	42.8										
T-144-1E Slow $\dot{\epsilon} = C_1$		Baldwin		32.6	33.3	61.6	34							
T-144-1E Rapid to $\sigma = C_1$		Pulse Lad	0.001 P.000	41.3										
T-144-1E Slow $\dot{\epsilon} = C_1$		Baldwin		41.3	40.6	60.6	36							
T-144-1E Rapid to $\sigma = C_1$		Pulse Lad	0.2 P.003	44.8										
T-144-1E Slow $\dot{\epsilon} = C_1$		Baldwin		44.3	40.0	60.8	40							
T-144-1E Rapid to $\sigma = C_1$		Pulse Lad	0.1 P.006	34.3										
T-144-1E Slow $\dot{\epsilon} = C_1$		Baldwin		32.0	35.6	60.7	34							
T-144-1E Rapid to $\sigma = C_1$		Pulse Lad	0.003 P.005	44.3										
T-144-1E Slow $\dot{\epsilon} = C_1$		Baldwin		32.8	30.4	60.8	31							
T-144-1E Rapid to $\sigma = C_1$		Pulse Lad	No Record											
T-144-1E Slow $\dot{\epsilon} = C_1$		Baldwin		38.8	36.2	61.5	36							
T-144-1E Rapid to $\sigma = C_1$		Pulse Lad	7.9 P.000	44.3										

Static value used in stress parameter
 σ_y over static upper yield stress, σ_y

See extensometer point marks on gage section

TABLE 5a SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Specimen	Type of Loading	Testin. Machine Used	Emdng. s	Rate of load, sec.	Nominal Stress, ksi		Reduction in Area, %	Elongation in 2 in. gage, %	Time to failure, sec.		Rate of field strain, %/min.	Rate of field strain, %/sec.
					σ_y	σ_{max}			σ_y	σ_{max}		
B-2448-17	Slow $\dot{\epsilon} = C$	Baldwin	2.6		34.2	61.5	58	36				
T-1448-27	Rapid to $\sigma = C$	Pulse Load	17.5	0.006	42.7							
T-2448-17	Slow $\dot{\epsilon} = C$	Baldwin			32.4	60.1	60	38				
T-2448-27	Slow $\dot{\epsilon} = C$	Baldwin										
T-2448-17	Slow $\dot{\epsilon} = C$	Baldwin			35.5	60.8	60	35				
T-2448-27	Rapid to $\sigma = C$	Pulse Load	8.5	0.006	48.5		63	35				
B-1448-17	Slow $\dot{\epsilon} = C$	Baldwin			40.7	60.2	60.8	35				
B-1448-27	Rapid to $\sigma = C$	Pulse Load	12.5	0.006	54.0							
B-2448-17	Slow $\dot{\epsilon} = C$	Baldwin			43.5	62.4	59	35				
B-2448-27	Rapid to $\sigma = C$	Pulse Load	10.6	0.006	50.2							
B-1448-17	Slow $\dot{\epsilon} = C$	Baldwin			35.9	60.8	58	34				
B-1448-27	Rapid to $\sigma = C$	Pulse Load	5.8	0.006	48.6							
B-2448-17	Slow $\dot{\epsilon} = C$	Baldwin			34.2	60.0	58	38				
B-2448-27	Rapid to $\sigma = C$	Pulse Load	2.4	0.006	54.1							
B-2448-17	Slow $\dot{\epsilon} = C$	Baldwin	10.7		37.8	61.0	59	35				
B-2448-27	Rapid to $\sigma = C$	Pulse Load	10.06		55.3							

Basic value used in stress parameter σ_y over static upper yield stress, ksi

see specimen point marks on gage section

TABLE 54 SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Specimen	Type of Loading	Testing Machine Used	Stress, ksi	Nominal Stress, ksi		Reduction in Area, %	Elongation in 2 in., %	Elongation in 4 in., %	Elongation in 8 in., %	Elongation in 16 in., %	Elongation in 32 in., %	Ratio of Elongation to Yield	Ratio of Elongation to Yield
				σ_y	σ_{max}								
Group 12													
12-100-17	Slow $\dot{\epsilon} = C_1$	Baldwin		34.2	60.5	61	39						
12-100-27	Impact to $\sigma = C_1$	Pulse Load	0.6	42.6									
12-200-17	Slow $\dot{\epsilon} = C_1$	Baldwin		32.0	59.8	61	38						
12-200-27	Impact to $\sigma = C_1$	Pulse Load	0.005	42.2									
12-300-17	Slow $\dot{\epsilon} = C_1$	Baldwin		35.7	60.2	59	36						
12-300-27	Impact to $\sigma = C_1$	Pulse Load	0.005	49.7									
12-400-17	Slow $\dot{\epsilon} = C_1$	Baldwin		41.5	60.5	65	35						
12-400-27	Impact to $\sigma = C_1$	Pulse Load	0.1	46.5									
12-500-17	Slow $\dot{\epsilon} = C_1$	Baldwin		43.5	61.1	64	34						
12-500-27	Impact to $\sigma = C_1$	Pulse Load	0.005	47.5									
12-600-17	Slow $\dot{\epsilon} = C_1$	Baldwin		37.0	60.2	60	36						
12-600-27	Impact to $\sigma = C_1$	Pulse Load	5.7	47.6									
12-700-17	Slow $\dot{\epsilon} = C_1$	Baldwin		36.2	60.0	58	40						
12-700-27	Impact to $\sigma = C_1$	Pulse Load	5.5	45.9									
12-800-17	Slow $\dot{\epsilon} = C_1$	Baldwin		35.6	60.9	60	40						
12-800-27	Impact to $\sigma = C_1$	Pulse Load	0.6	42.9									

***Extensometer point marks on gage section

Basic value used in stress parameter, σ_y
 = 1/2 of static upper yield stress, σ_y

TABLE 5

Specimen	Type of Loading (All 2 cycles)	Testing Machine (Type)	Enlrg. of Load, per in. of length	Plas. time, sec.	Nominal Stress, ksi		Plas. time, sec.	Comp. time, sec.	Yield strength, ksi	Tensile strength, ksi	Elongation, %	Modulus of elasticity, ksi
					σ_{cy}	σ_{ty}						
B.R. Slow to σ_c	Pulse Idg.				39.9*							
Both Cycles												
1 Tension-Comp.			4.9		42.2							
2 Tension-Comp.			13.5		41.4							
3 Compression-Ten.			6.5		44.5							
4 Compression-Ten.			16.0		47.2							
A.R. Rapid to σ_c - C	Pulse Idg.				39.9*							
Both Cycles												
1 Tension-Comp.			2.6		44.0					670		
2 Tension-Comp.			8.5		46.0					400		
3 Compression-Ten.			1.0		44.0 Tens					150		
4 Compression-Ten.			3.7		49.5					150		
B.D.R. Slow to σ_{cy} - C	Pulse Idg.				39.9*							
Rapid to σ_{cy} - C												
1 Tension-Comp.			2.2		43.6					190		
2 Tension-Comp.			0.7		44.0					160		
3 Compression-Ten.			1.6		49.7					750		
4 Compression-Ten.			2.0		44.6					1180		

* Plastic value used in stress-strain plot
 *** No yield following 4th ksi compression

TABLE 1. SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Specimen	Type of Loading	Testing Machine Used	Ending, %	"Rise time" of load, sec.	Nominal Stress, ksi			Reduction in Area, %	Elongation in Gauge, in.	$\frac{\Delta L}{L_0}$	$\frac{\Delta A}{A_0}$	$\frac{\Delta V}{V_0}$	Rate of Yield
					σ_{avg}	$\sigma_{1/2}$	σ_{max}						
MSL 1	Slow $\delta = 0.1$ Tension	Pulse Ldg	0.9	0.96		41.0	66.4	56	25.6	0.01	0.02	0.23	0.23
2	Rapid to $\sigma = 0$ Tension	Pulse Ldg	0.6	0.000		45.5			0.12	0.19	0.36	0.37	0.176
3	Rapid to $\sigma = 0$ Tension	Pulse Ldg	3.4	0.006		51.5			0.27	0.42	0.54	0.55	2.43
4	Rapid to $\sigma = 0$ Tension	Pulse Ldg	2.1	0.006		59.5			0.46	0.73	1	0.76	7.43
5	Rapid to $\sigma = 0$ Compression	Pulse Ldg	7.3	0.006		42.5			0.06	0.09	0.45	0.38	0.045
6	Rapid to $\sigma = 0$ Compression	Pulse Ldg	2.8	0.006		55.6			0.36	0.52	1.2	0.60	3.76
7	Rapid to $\sigma = 0$ Compression	Pulse Ldg	3.2	0.006		65.0			0.62	0.95	1	0.95	11.65
8	Slow $\delta = 0.1$ Compression	Pulse Ldg	6.1	82.0		40.0			0.00	0.00		0.20	0.014

"referred records of been entered."

116 Ex'amenator point marks on game section

TABLE - SUMMARY OF UNIAxIAL STRESS TESTS AND RESULTS

Specimen	Type of Loading	Testing Machine Used	Strain Rate, in./in. sec.	Nominal Stress, ksi			Reduction in Area, %	Elongation in 2 in., %	Yield Strength, ksi	Tensile Strength, ksi	Strain at Yield, in./in.	Strain at Fracture, in./in.	Rate of Yield Strain, in./in. sec.
				σ_y	σ_{ly}	σ_{max}							
9	Slow $\dot{\epsilon} = 1$	Pulse Id.	1.7	16.6	40.4	17.6							0.0023
	Compression												
10	Slow $\dot{\epsilon} = 0.1$	Pulse Id.	6.5	17.0	41.0	15.3							0.0022
	Compression												
11	Slow $\dot{\epsilon} = 0.1$	Pulse Id.	0.5	41.0	43.5	31.4	56	26.8					0.0024
	Tension												
12	Slow $\dot{\epsilon} = 0.1$	Pulse Id.	1.4	40.0	41.0	33.4	65.0	27.2					0.0020
	Tension												

***Extensometer point marks on gage section

Elastic value used in stress parameter
ratio over static upper yield stress, σ_y

TABLE 1. SUMMARY OF UNIAxIAL STRESS TESTS AND RESULTS

Specimen	Type of Loading	Testing Machine Used	Time, sec	Nominal Stress, ksi		Reduction in Area, %	Elongation in 2 in. gage, %	Time to Failure, sec	Time to Failure, min	Time to Failure, hr	Rate of Load, in./in.	Rate of Load, %/sec
				σ_y	σ_{max}							
9	Slow $\dot{\epsilon} = 0.1$ Compression	Pulse Ld	1.7 16.6	40.4	37.6							0.0023
10	Slow $\dot{\epsilon} = 0.1$ Compression	Pulse Ld	6.5 17.0	40.0	35.3							0.0022
11	Slow $\dot{\epsilon} = 0.1$ Tension	Pulse Ld	0.6 40.0	40.6	31.4	56	26.5					0.0024
12	Slow $\dot{\epsilon} = 0.1$ Tension	Pulse Ld	1.4 40.0	41.0	37.6	57	27.2					0.0020

Classic value used in stress parameter σ_y is over static upper yield stress, σ_{uy} ***Extensometer point marks on gage section

TABLE 5a SUMMARY OF UNIAxIAL TESTS - 2024 A-100-10

S. No.	Type of Loading (All 2 cycle)	Testing Machine Used	Nominal Stress, ksi	Rate of Load, ksi/min	Time, min	Displacement, in	Elongation, in	Area, sq in	Volume, cu in	Weight, lb	Remarks
S.R. 1	Slow to C ₁	Pulse 144	29.9*								
2	Both Cycles										
1	Tension-Comp.	40	42.2	4.9							
2	Tension-Comp.	40	41.4	12.5							
3	Compression-Ten.	40	40.5	6.5							
4	Compression-Ten.	40	47.2	16.0							
D.R. 1	Rapid to a - C	Pulse 144	29.9*								
2	Both Cycles										
1	Tension-Comp.	40	44.0	2.6							
2	Tension-Comp.	40	46.0	8.5							
3	Compression-Ten.	40	44.0	1.0							
4	Compression-Ten.	40	49.5	3.7							
S.D.R. 1	Slow to a - C	Pulse 144	29.9*								
2	Rapid to a - C										
1	Tension-Comp.	40	43.6	2.2							
2	Tension-Comp.	40	44.0	0.7							
3	Compression-Ten.	40	45.7	1.6							
4	Compression-Ten.	40	46.6	2.0							

*Each value used in stress ratio
 with a over static or yield stress, etc.
 ***No yield following 46.4 ksi compression

TABLE 27 SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Specimen	Type of Loading	Testing Machine Used	Bending, %	"Rise time" of load, sec.	Nominal Stress, ksi			Reduction in Area, %	Elongation in Gauge, %	$\frac{\sigma}{E}$	$\frac{\sigma}{E}$	$\frac{\sigma}{E}$	$\frac{\sigma}{E}$	Time to Strain Yield, milliseconds	Time to Fracture, milliseconds	$\frac{d\epsilon}{dt} = 20 \times 10^{-6}$	$\frac{\sigma}{E}$	$\frac{\sigma}{E}$	$\frac{\sigma}{E}$	Rate of Yield Strain, $\frac{d\epsilon}{dt}$
					σ_y	σ_x	σ_z													
REL 1	Slow $\delta = 0_1$	Pulse Idg	0.9	0.006	43.0	66.4	56	25.6	0.01	0.02							0.23	0.23	0.032	
2	Tension																			
3	Rapid to $\sigma = 0$	Pulse Idg	0.6	0.006	45.5				0.12	0.19				250			0.36	0.37	0.176	
4	Tension																			
5	Rapid to $\sigma = 0$	Pulse Idg	3.4	0.006	51.5				0.27	0.42				17			0.54	0.55	2.43	
6	Tension																			
7	Rapid to $\sigma = 0$	Pulse Idg	2.1	0.006	50.5				0.46	0.73				1			0.78	0.79	7.63	
8	Tension																			
9	Rapid to $\sigma = 0$	Pulse Idg	7.3	0.006	42.5				0.06	0.09				545			0.27	0.28	0.045	
10	Compression																			
11	Rapid to $\sigma = 0$	Pulse Idg	2.8	0.006	53.6				0.34	0.52				15			0.60	0.61	3.76	
12	Compression																			
13	Rapid to $\sigma = 0$	Pulse Idg	3.2	0.006	65.0				0.62	0.95				1			0.95	0.96	11.65	
14	Compression																			
15	Slow $\delta = 0_1$	Pulse Idg	6.1	82.0	40.0				0.00	0.00							0.20	0.20	0.014	
16	Compression																			
17																				
18																				
19																				
20																				
21																				
22																				
23																				
24																				
25																				
26																				
27																				
28																				
29																				
30																				
31																				
32																				
33																				
34																				
35																				
36																				
37																				
38																				
39																				
40																				
41																				
42																				
43																				
44																				
45																				
46																				
47																				
48																				
49																				
50																				
51																				
52																				
53																				
54																				
55																				
56																				
57																				
58																				
59																				
60																				
61																				
62																				
63																				
64																				
65																				
66																				
67																				
68																				
69																				
70																				
71																				
72																				
73																				
74																				
75																				
76																				
77																				
78																				
79																				
80																				
81																				
82																				
83																				
84																				
85																				
86																				
87																				
88																				
89																				
90																				
91																				
92																				
93																				
94																				
95																				
96																				
97																				
98																				
99																				
100																				

*Basic value used in stress parameter σ is static upper yield stress, σ_y

static upper yield stress

TABLE IV
SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS[illegible]

TABLE 3.

Specimen	Type of Loading	Testing Machine Used	Bending, %	Rise time of load, sec.	Nominal Stress, ksi			Reduction in Area, %	Elongation in 175 in. gage, %	$\frac{\sigma_y}{\sigma_u}$	$\frac{\sigma_{0.2}}{\sigma_u}$	$\frac{\sigma_b}{\sigma_u}$	$\frac{K_t \sigma_b}{\sigma_u}$	Strain yield	Time to Strain yield	Strain to fracture	Time to fracture	Rate of yield	In./in./sec.
					σ_y	σ_u	σ_{max}												
PSL 1A	Slow Tension	Pulse Ldg	3.5	38.0	38.6	32.6	63.8	59	40.5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2A	Rapid to slow Tension	Pulse Ldg		0.006		54.3			0.1	0.62		0.67	0.70	15.5					
3A	Rapid to slow Tension	Pulse Ldg	5.1	0.006		43.8			0.13	0.21		0.34	0.36	0.249	202				
4A	Rapid to slow Tension	Pulse Ldg	1.8	0.006		47.5			0.23	0.35		0.46	0.48	1.32	24				

^a Elastic value used in stress parameter estimation over static upper yield stress, dry

Extensometer built into rate section

TABLE 1. SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Test	Type of Loading	Testing Machine Used	Pulse Lag, sec	Pulse Width, sec	Nominal Stress, ksi		Reduction in Area, %	Elongation in Inches, in. gage	Yield Point Stress, ksi	Yield Point Strain, in./in.	Tensile Strength, ksi	Tensile Strain, in./in.	Poisson's Ratio	Modulus of Elasticity, ksi	Modulus of Resilience, in.-lb./in. ³	Toughness, in.-lb./in. ²	Impact Strength, ft.-lb.	Charpy, ft.-lb.	V-notch, ft.-lb.
					σ_y	σ_{max}													
1	Slow	1	Pulse Lag 1.0	0.006	41.7	65.9	48	22.4	0.05	0.27	0.23	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
2	Rapid	2	Pulse Lag 3.7	0.006	42.8				0.07	0.11	0.27	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29
3	Rapid	3	Pulse Lag 7.6	0.006	50.4				0.26	0.42	0.49	0.53	0.53	0.53	0.53	0.53	0.53	0.53	0.53
4	Rapid	4	Pulse Lag 1.7	0.006	57.8				0.45	0.71	0.71	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76
5	Rapid	5	Pulse Lag 1.5	0.006	47.9				0.09	0.15	0.21	0.27	0.27	0.27	0.27	0.27	0.27	0.27	0.27
6	Rapid	6	Pulse Lag 0.9	0.006	54.5				0.36	0.57	0.51	0.63	0.63	0.63	0.63	0.63	0.63	0.63	0.63
7	Rapid	7	Pulse Lag 6.2	0.006	64.9				0.61	0.98	0.79	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
8	Slow	8	Pulse Lag 3.4	0.006	40.8				0.01	0.02	0.13	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16

Basic values used in stress parameter series over static upper field stress, ksi

at extensometer point marks on gage section

UNCLASSIFIED

A
D 210240

Armed Services Technical Information Agency

ARLINGTON HALL STATION
ARLINGTON 12 VIRGINIA

FOR
MICRO-CARD
CONTROL ONLY

3 OF 7

NOTICE: WHEN GOVERNMENT OR OTHER DRAWINGS, SPECIFICATIONS OR OTHER DATA ARE USED FOR ANY PURPOSE OTHER THAN IN CONNECTION WITH A DEFINITELY RELATED GOVERNMENT PROCUREMENT OPERATION, THE U. S. GOVERNMENT THEREBY INCURS NO RESPONSIBILITY, NOR ANY OBLIGATION WHATSOEVER; AND THE FACT THAT THE GOVERNMENT MAY HAVE FORMULATED, FURNISHED, OR IN ANY WAY SUPPLIED THE SAID DRAWINGS, SPECIFICATIONS, OR OTHER DATA IS NOT TO BE REGARDED BY IMPLICATION OR OTHERWISE AS IN ANY MANNER LICENSING THE HOLDER OR ANY OTHER PERSON OR CORPORATION, OR CONVEYING ANY RIGHTS OR PERMISSION TO MANUFACTURE, USE OR SELL ANY PATENTED INVENTION THAT MAY IN ANY WAY BE RELATED THERETO.

UNCLASSIFIED

TABLE 5.2 SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

[illegible]

*elastic value used in stress parameter
*σ₁ = over static upper yield stress, σ_{wy}

Metreometer for 100 ft. to 1000 ft.

TABLE 5a SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Specimen	Type of Loading	Testing Machine Model	Penetration, s	Rise time of load, sec	Nominal Stress, ksi			Reduction in Area, %	Time to Strain yield, sec	Strain yield, %	Time to fracture, sec	Rate of yield, %/in./sec	Rate of fracture, %/in./sec
					σ_y	σ_{ly}	σ_{max}						
1	Slow $\dot{\epsilon} = 0.1$ Tension	Pulse Ldg		17.5	40.8	36.4	65.0	67.0	30.7			0.01	0.0023
2	Rapid $\dot{\epsilon} = 0$ Tension	Pulse Ldg		0.006		60.7				0.76		0.69	0.80
4	Rapid $\dot{\epsilon} = 0$ Tension	Pulse Ldg		0.006		54.1				0.51		0.50	0.55
5	Rapid $\dot{\epsilon} = 0$ Tension	Pulse Ldg		0.006		47.8				0.27		0.33	0.38
7	Rapid $\dot{\epsilon} = 0$ Tension	Pulse Ldg		0.006		43.9				0.12		0.22	0.25
8	Slow $\dot{\epsilon} = 0.1$ Tension	Pulse Ldg		15.4	37.5	36.0	67.0	65.5	29.3			0	0.0015

*Basic value used in stress parameter
settle over static upper yield stress, σ_y

***Extensometer point marks on gage section

TABLE 56b SUMMARY OF UNIAxIAL STRESS TESTS AND RESULTS

[illegible] Basic value used in stress parameter | $\sigma_{\text{max}} / \sigma_{\text{ys}}$ over static upper yield stress, σ_{ys}

***Transometer point marks on race section

TABLE 5-2 SUMMARY OF UNIAXIAL STRESS TESTS ALL RESULTS

Specimen	Type of Loading	Testing Machine Used	Beam Length, in.	Rate of Load, lb./sec.	Nominal Stress, ksi		Displacement, in.	Load, lb.	Strain, in./in.	Modulus of Elasticity, ksi	Poisson's Ratio, ν	Volume Change, %	Time to Failure, sec.	Time to Failure, min.	Time to Failure, hr.	Time to Failure, days	Time to Failure, weeks	Time to Failure, months	Time to Failure, years
					σ_y	σ_{max}													
9	slow $\dot{\epsilon} = 0.1$ Compression	Pulse 14g		56.8	40.3	35.8*	67.0		0	0	0	0	0	0	0	0	0	0	0
10	Rapid $\dot{\epsilon} = 0$ Compression	Pulse 14g		0.006		142.0			0.04	0.06			440	0.17	0.26	0.20	0.215		
11	Rapid $\dot{\epsilon} = 0$ Compression	Pulse 14g		0.006		45.3			0.12	0.19			72	0.26	0.30	0.30	0.425		
13	Rapid $\dot{\epsilon} = 0$ Compression	Pulse 14g		0.006		48.5			0.20	0.31			14	0.35	0.41	1.52			
15	Rapid $\dot{\epsilon} = 0$ Compression	Pulse 14g		0.006		53.3			0.32	0.49			5	0.49	0.56	6.3			
16	slow $\dot{\epsilon} = 0.1$ Compression	Pulse 14g		49.0	41.9	36.8								0.03	0.03	0.0028			

*Basic value used in stress parameter

†Time over static upper yield stress, day

‡Extensometer point marks on reference line

TABLE 50d
STABILITY OF UNILATERAL STRESS TESTS AND RESULTS[illegible]

*Basic value used in stress parameter σ_{upper} over static yield stress, σ_{upper}

^aBasic value used in stress parameter setting over static upper yield stress, σ_{ys}

● Explanations point back on gap between

TABLE 5a SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Specimen	Type of Loading	Tertiary Machine Used	Rate of Load, % of Load, sec	Nominal Stress, ksi			Reduction in Area, %	Extension in Gauge Length, in.	Elongation in Gauge Length, %	Time to Failure, sec	Time to Failure, min	Time to Failure, hr	Time to Failure, day	Time to Failure, yr	Time to Failure, sec
				σ_y	σ_{ly}	σ_{max}									
9	Slow $f = 0.1$ Compression	Pulse lag	2.0	53.6	52.6	50.5	79.6	0	0	0	0	0	0	0	0.0018
10	Rapid $\sigma = c$ Compression	Pulse lag	3.5	0.005		56.2		0.07	0.13	175	0.09	0.20	0.34	1.5	0.0016
12	Rapid $\sigma = c$ Compression	Pulse lag	2.5	0.005		60.5		0.15	0.29	17	0.20	0.34	1.5	0.0016	
13	Rapid $\sigma = c$ Compression	Pulse lag	0.005			55.0		0.22	0.42	4	0.27	0.46	2.5	0.0016	
15	Rapid $\sigma = c$ Compression	Pulse lag	0.005			69.2		0.31	0.61	3	0.37	0.64	5.9	0.0015	
16	Slow $f = 0.1$ Compression	Pulse lag	2.2	70.4	56.1	50.7									

Extension point marks on gage section

Basic value used in stress parameter
 σ_{t-u} over static upper yield stress, σ_{uy}

TABLE 27: SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Specimen	Type of Loading	Testing Machine Used	Loading Rate, %/min.	Time to Release Load, sec.	Nominal Stress, ksi			Reduction in Area, %	Elongation in 8 in., %	$\frac{\sigma_y}{\sigma_u}$	$\frac{\sigma_y}{\sigma_u}$	Time to Strain Yield, sec.	Time to Fracture, sec.	$\frac{\sigma_y}{\sigma_u}$	$\frac{\sigma_y}{\sigma_u}$	Rate of Yield, %/min.
					σ_u	σ_y	σ_{max}									
T 1	Slow $\dot{\epsilon} = 0.1$	Pulse Log	6.5	110	113.5			130.1	89							
	Rapid to $\dot{\epsilon} = 0$		0.006	115.5										0.11	0.69	1.1
	Rapid to $\dot{\epsilon} = 0$		0.006	122.5										0.08	0.52	0.22
	Rapid to $\dot{\epsilon} = 0$		0.006	120.4										0.06	0.40	0.15
	Rapid to $\dot{\epsilon} = 0$		0.006	117.2										0.03	0.22	0.08
	Slow $\dot{\epsilon} = 0.1$		2.0	77	113.5			130.1	89	10.2						
T 9	Slow $\dot{\epsilon} = 0.1$	Pulse Log		69	120.0											
	Rapid to $\dot{\epsilon} = 0$		0.006	116.8										0.05	0.31	0.10
	Rapid to $\dot{\epsilon} = 0$		0.006	120.6										0.06	0.41	0.16
	Rapid to $\dot{\epsilon} = 0$		0.006	121.7										0.07	0.47	0.20
	Slow $\dot{\epsilon} = 0.1$		62	120.0												

Basic value used in stress parameter
 σ_y over static upper yield stress, σ_{uy}
 extensometer point marks on gage section

TABLE 5a2 SUMMARY OF UNIAXIAL STRESS TESTS AND RESULTS

Specimen	Type of Loading	Testing Machine Used	Reading, %	Rise Time of Load, sec.	Nominal Stress, ksi			Reduction in Area, %	Elongation in 2 in., %	$\frac{\sigma_y}{\sigma_{max}}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma_y}{\sigma_y}$	$\frac{\sigma_y}{\sigma_{max}} - \frac{\sigma$
----------	-----------------	----------------------	------------	-------------------------	---------------------	--	--	----------------------	------------------------	---------------------------------	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	--

*Basic value used in stress parameter

†Stress over static upper yield stress, σ_{uy}

**Extensometer point marks on gage section

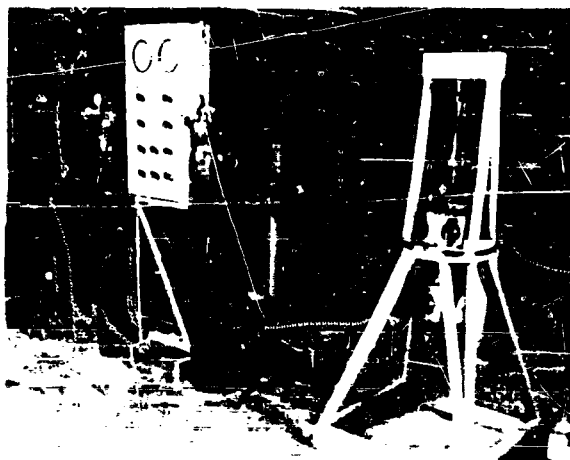
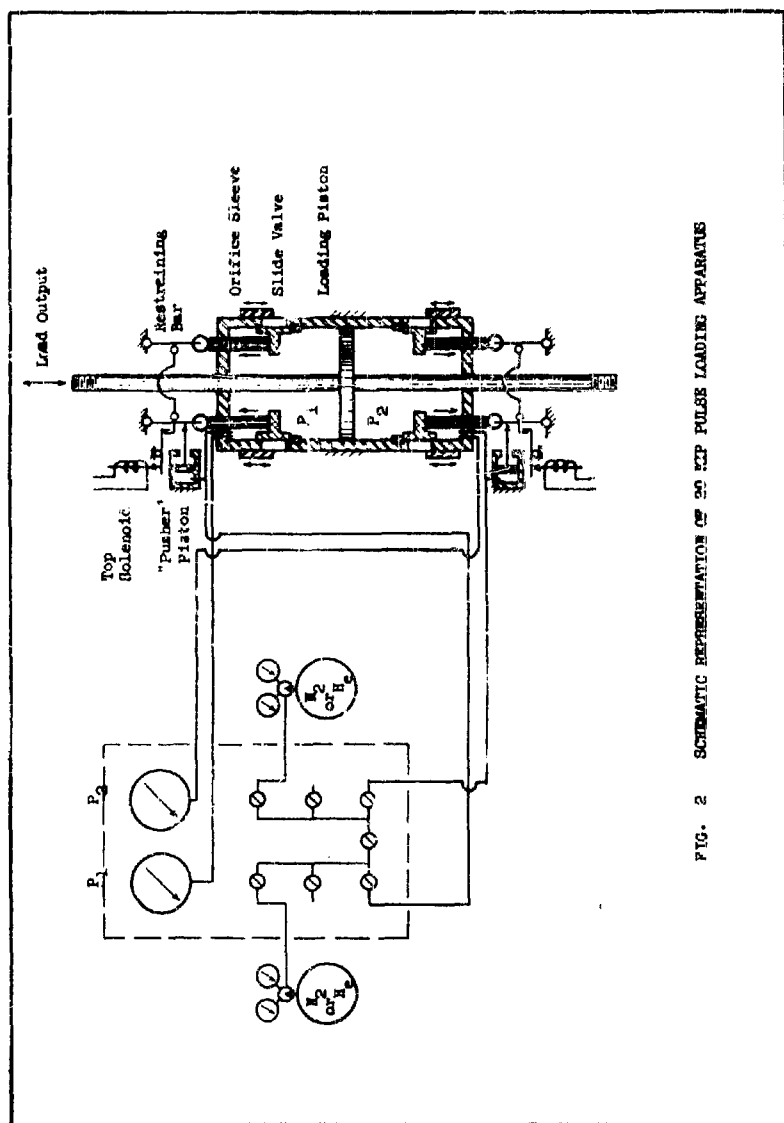


FIG. 1 PRESSURE PANEL, AND 20 KIP PULSE LOADING UNIT ARRANGED FOR TESTING UNIAXIAL TENSION SPECIMENS



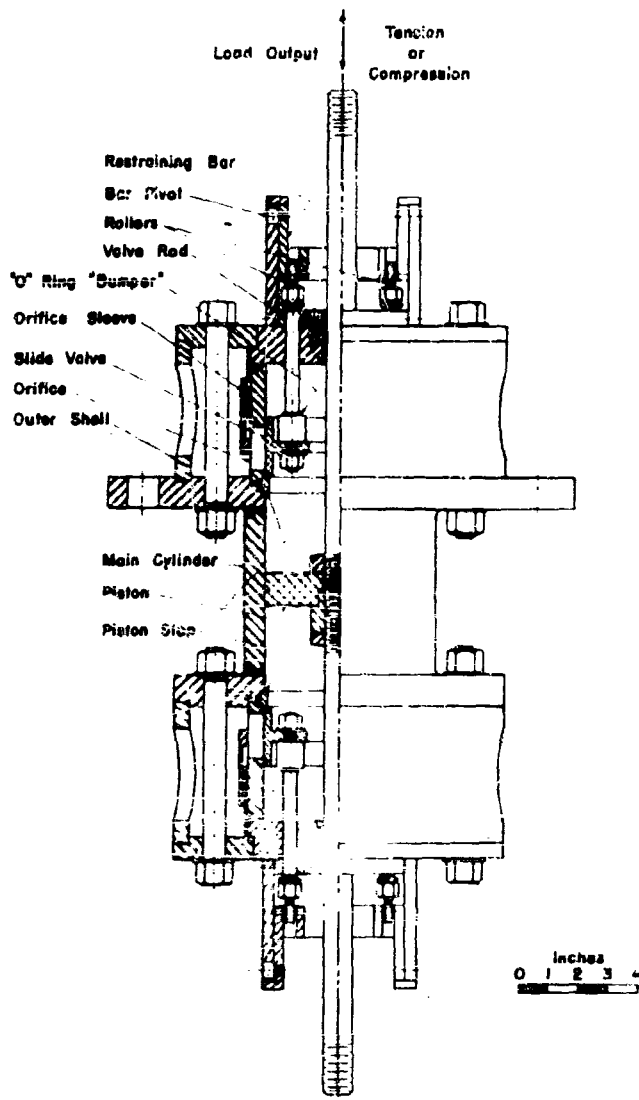


FIG. 3 20 KIP PULSE LOADING UNIT

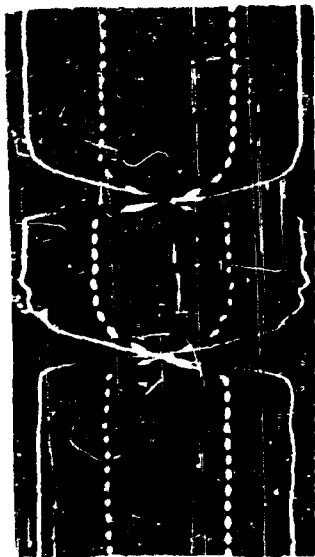


FIG. 4a 10,000 LB. PULSE - RAPID LOADING,
RAPID UNLOADING - 1000 CPS TIMING

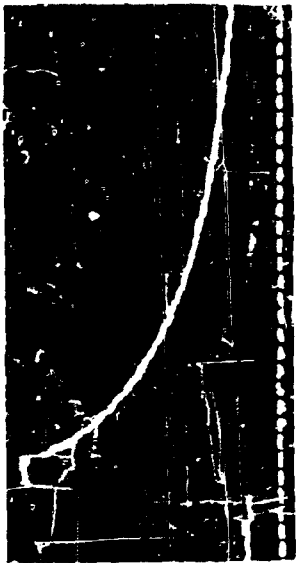


FIG. 4b 10,000 LB. PULSE - RAPID LOADING,
RELATIVELY SLOW UNLOADING - 60 CPS TIMING



FIG. 4c 10,000 LB. PULSE - RAPID LOADING,
RAPID UNLOADING - 60 CPS TIMING



FIG. 4d 10,000 LB. PULSE - RELATIVELY SLOW LOADING,
RAPID UNLOADING - 60 CPS TIMING

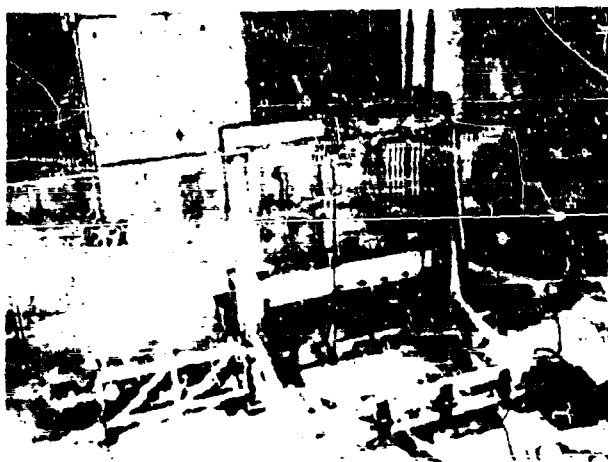


FIG. 5 PULSE LOADING UNIT BEING USED TO TEST MODEL FRAME
(Frame Down After Testing)

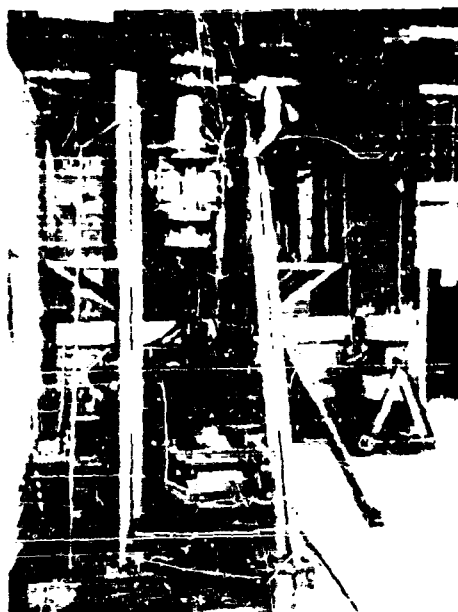


FIG. 6 60 KIP PULSE LOADING UNIT IN FRAME FOR TESTING LEAN-COLUMNS
(A 60 Kip Unit with Outer Chambers is in Background)

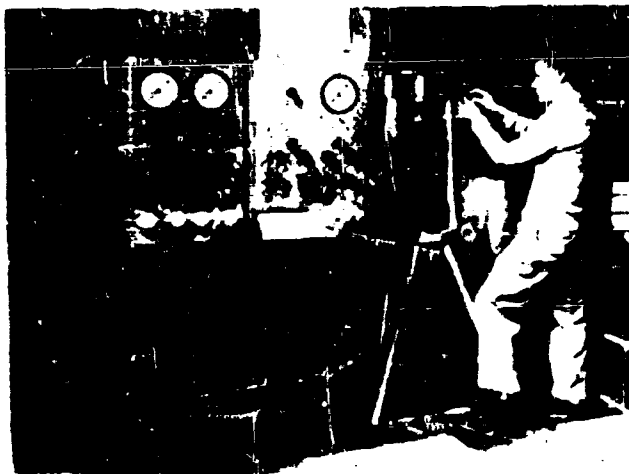


FIG. 7 20 KIP PULSE LOADING UNIT AND 20 KIP STRAINING UNIT CONNECTED
IN SERIES FOR TESTING TENSION-COMPRESSION SPECIMENS;
SHOWN WITH PRESSURE CONTROL PANELS

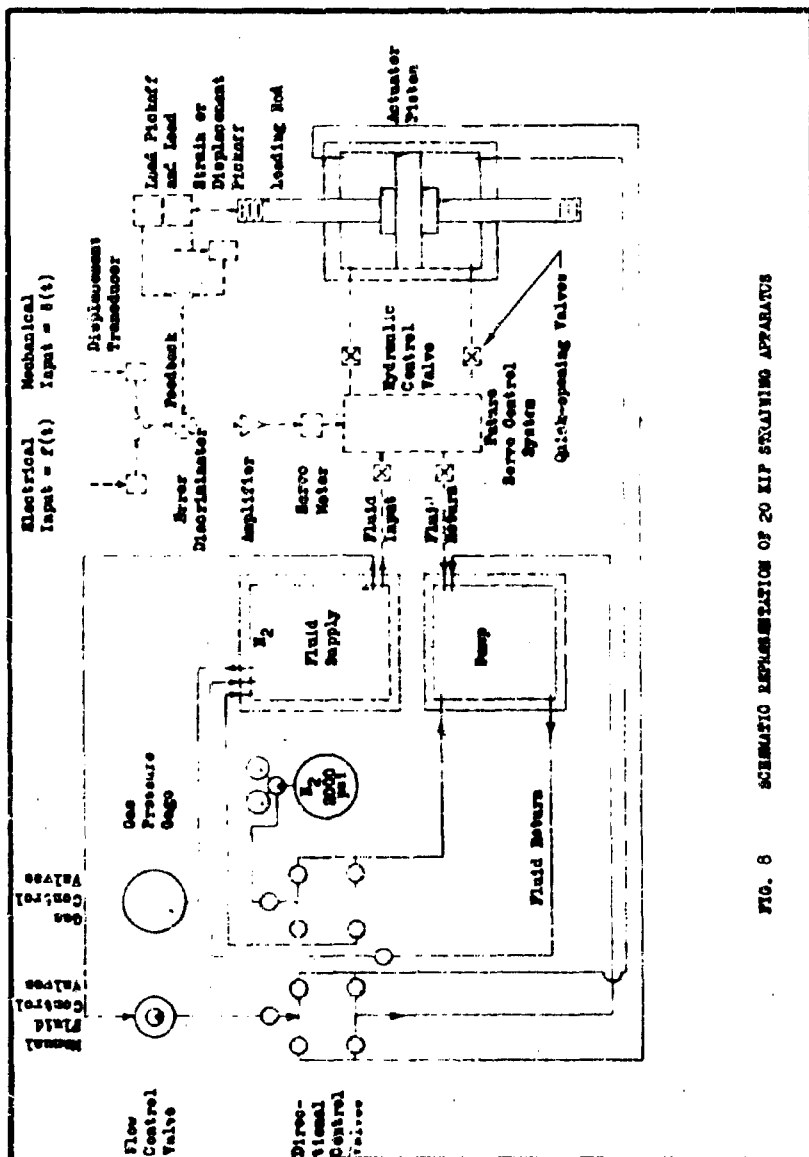


FIG. 8 SCHEMATIC REPRESENTATION OF 20 KIP STRAINING APPARATUS

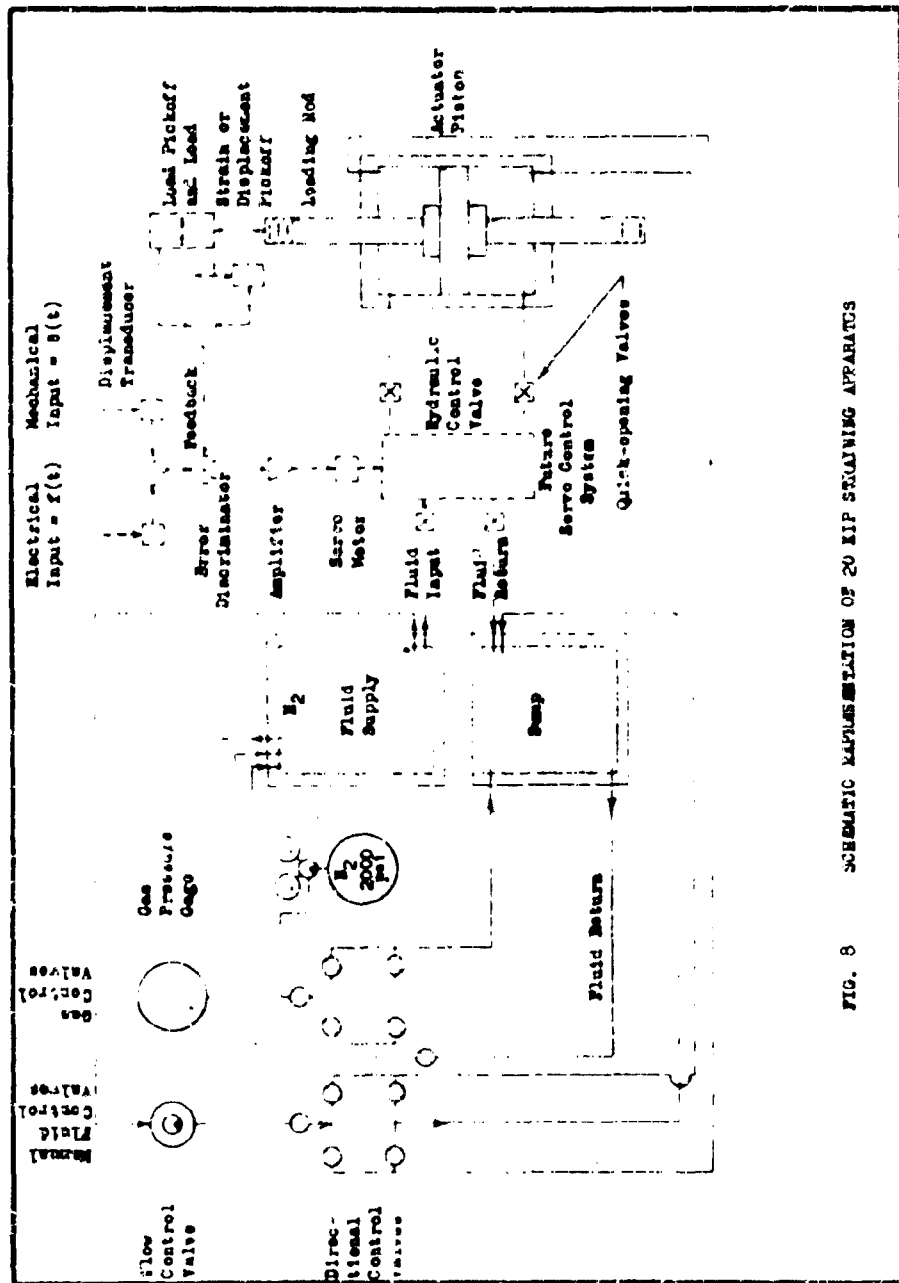


FIG. 8 SCHEMATIC REPRESENTATION OF 20 KIP STRAINING APPARATUS

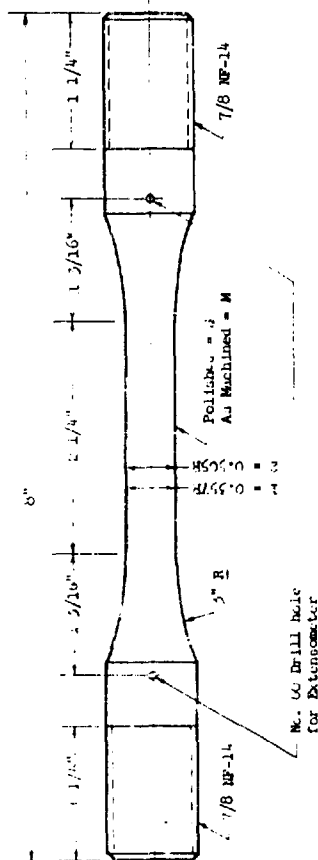
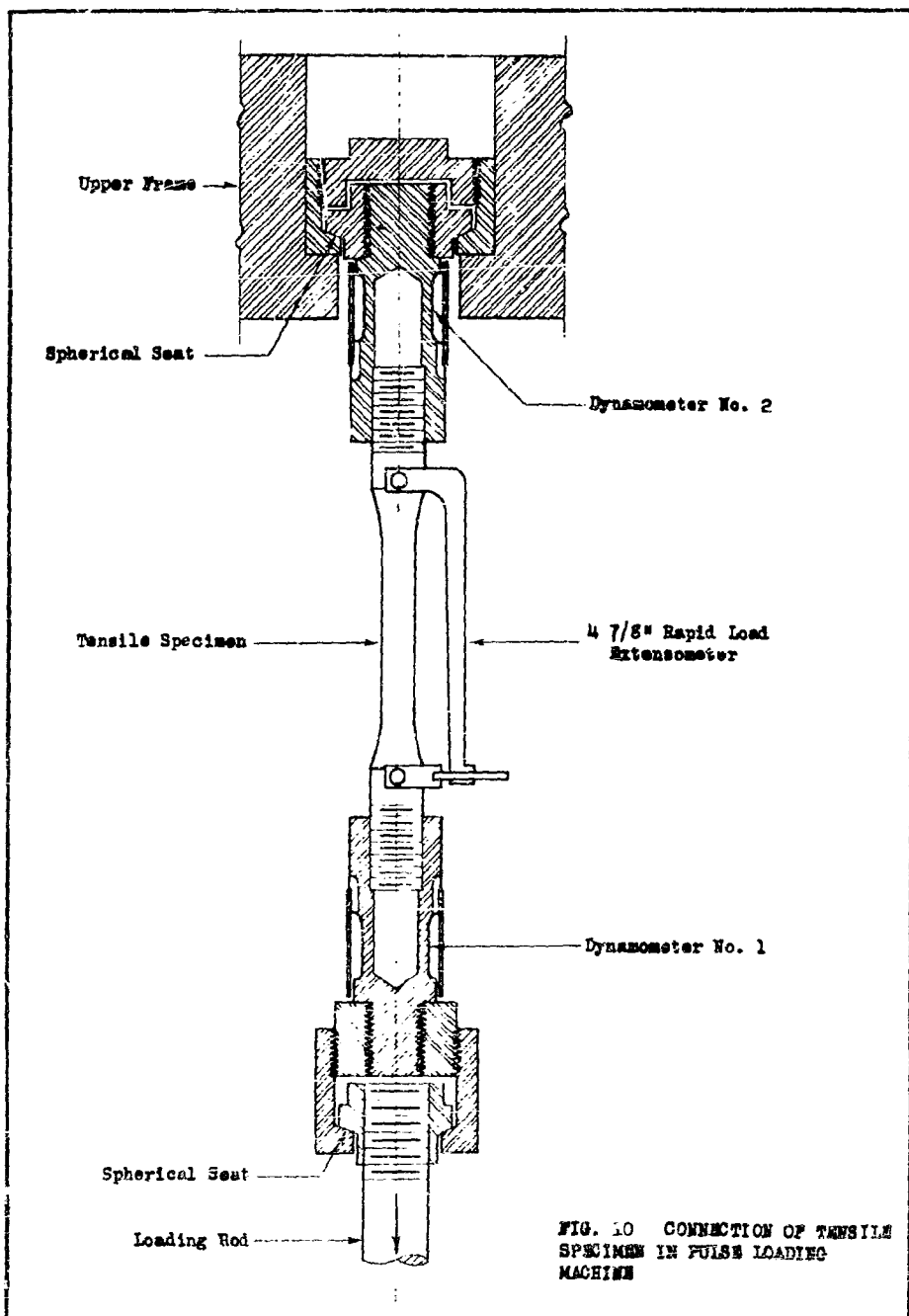


FIG. 9 DIMENSIONS OF TENSILE SPECIMENS
(Series ED, SP, NL, NT)



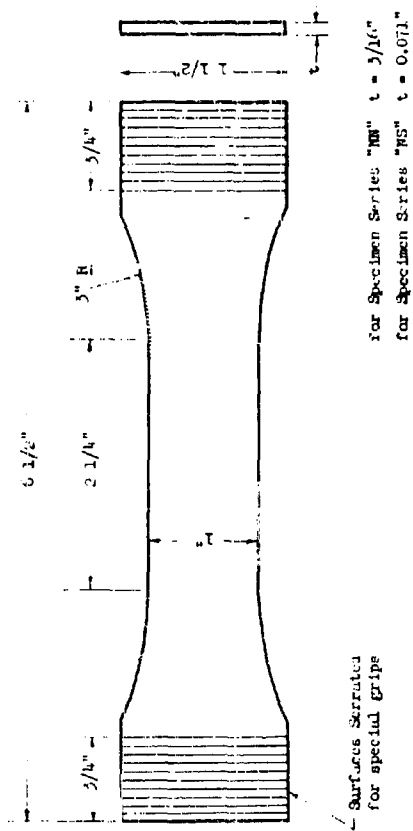
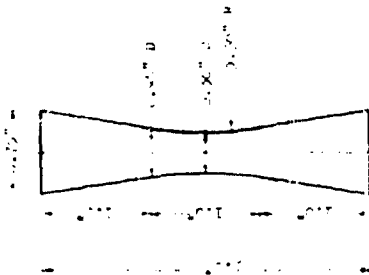
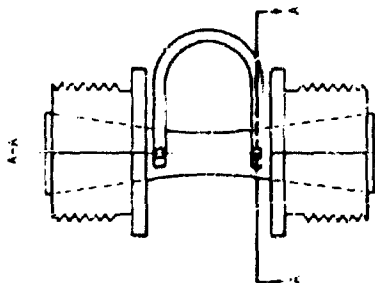
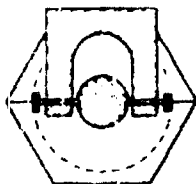


FIG. 11 DIMENSIONS OF SPECIMENS FROM SHEET STOCK
(Series WN, NS)



(a) Tension-Compression Specimen



(c) Batching Unit Attachment

729. 12 DIMENSIONS OF PRELIMINARY TENSION-COMPRESSION SPECIMENS
(Series MB)

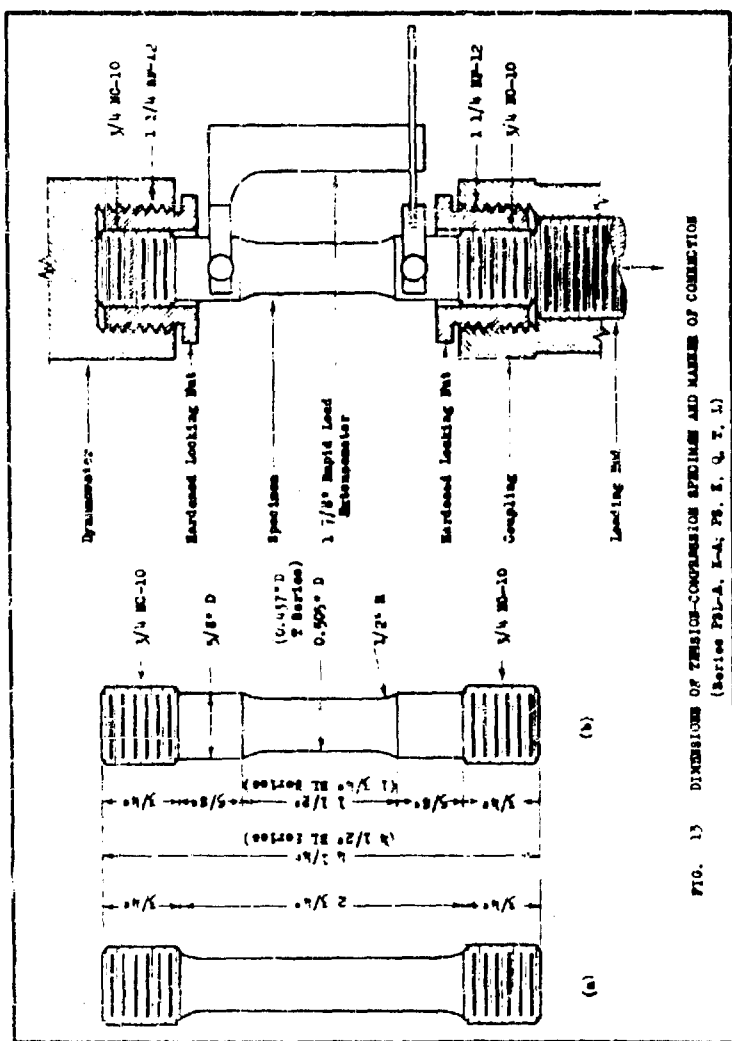


FIG. 15 DIMENSIONS OF TORSION-COMPRESSION SPECIMENS AND MANNER OF CONNECTION
(Series PA-1, PA-2, PA-3, PA-4, PA-5, PA-6, PA-7, PA-8)



FIG. 14a "RBA" STEEL, EDGE OF SPECIMEN 18RRA4
(4% Picrol - 200X)



FIG. 14b "RRB" STEEL, EDGE OF SPECIMEN 18RBA4
(4% Picrol - 200X)



FIG. 14c "RBC" STEEL, EDGE OF SPECIMEN 18RBC4
(4% Picrol - 200X)

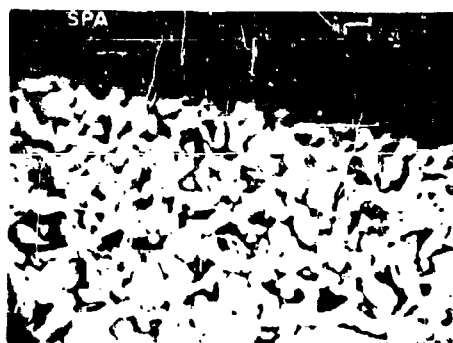


FIG. 144 "SPA" STEEL, EDGE OF SPECIMEN 14SPA-
(45 Picrol - 200X)



FIG. 146 "SPB" STEEL, EDGE OF SPECIMEN 14SPB-
(45 Picrol - 200X)

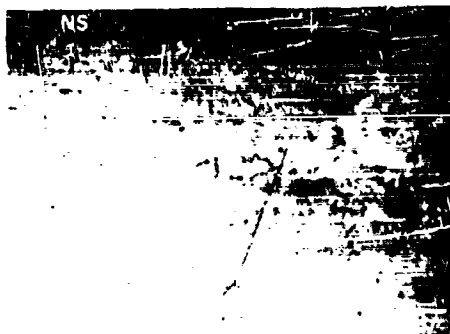


FIG. 14f "NS" STEEL, EDGE OF SPECIMEN NST-4
(4% Picrol - 200X)

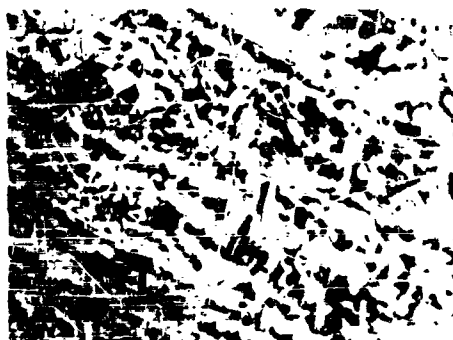


FIG. 14g "RR" STEEL, CENTER OF SPECIMEN NRC
(4% Picrol - 200X)

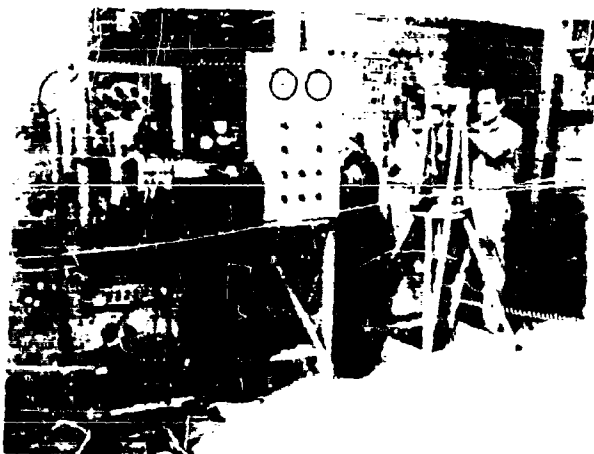


FIG. 15. CRY. INSTRUMENTS, PNEUMATIC PANEL, AND RAPID PULS. LOADING UNIT APPARATUS FOR TESTING PRELIMINARY TENSION-COMPRESSION SPECIMENS

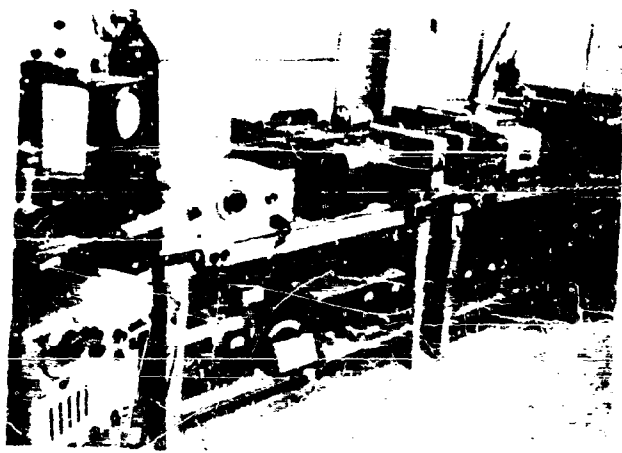
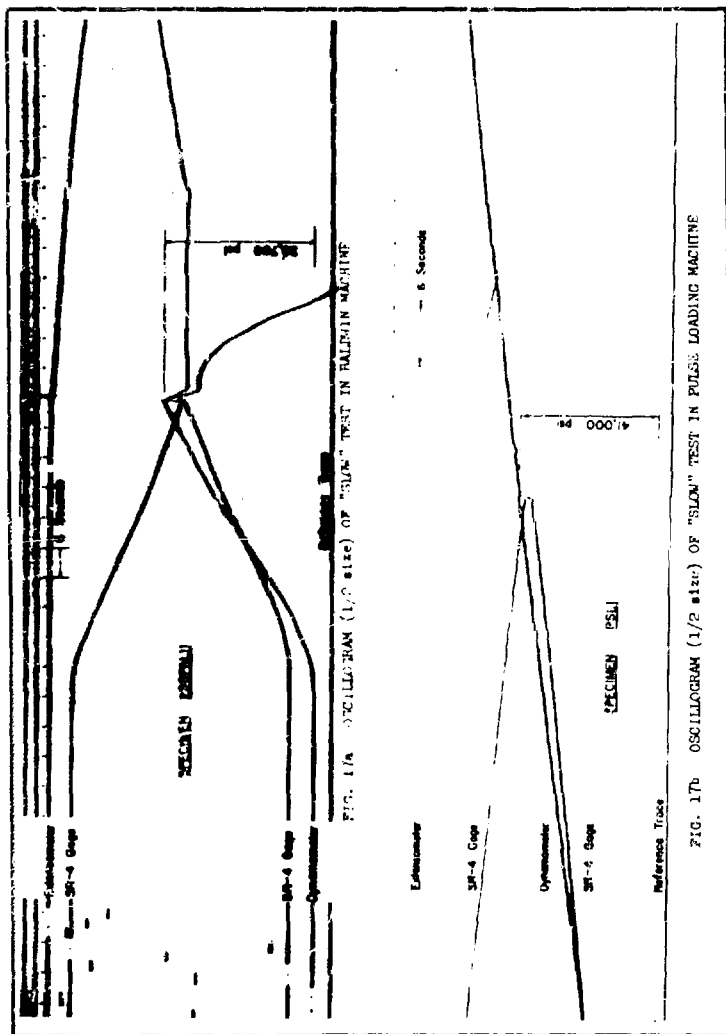
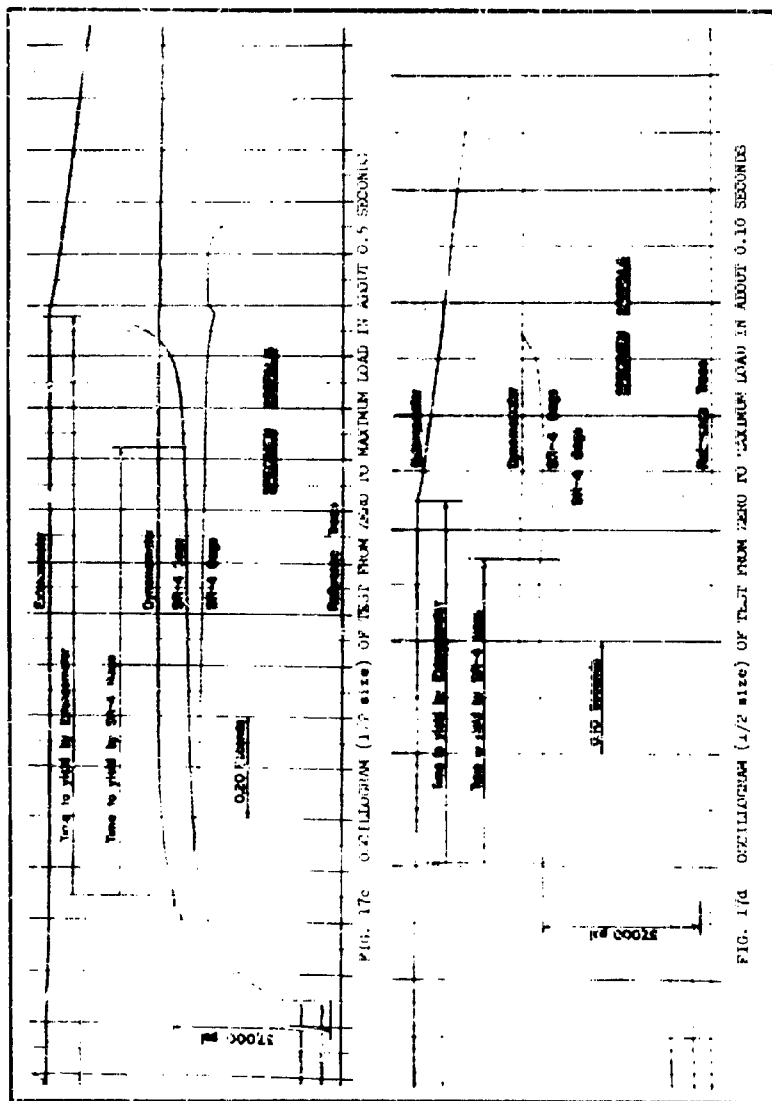
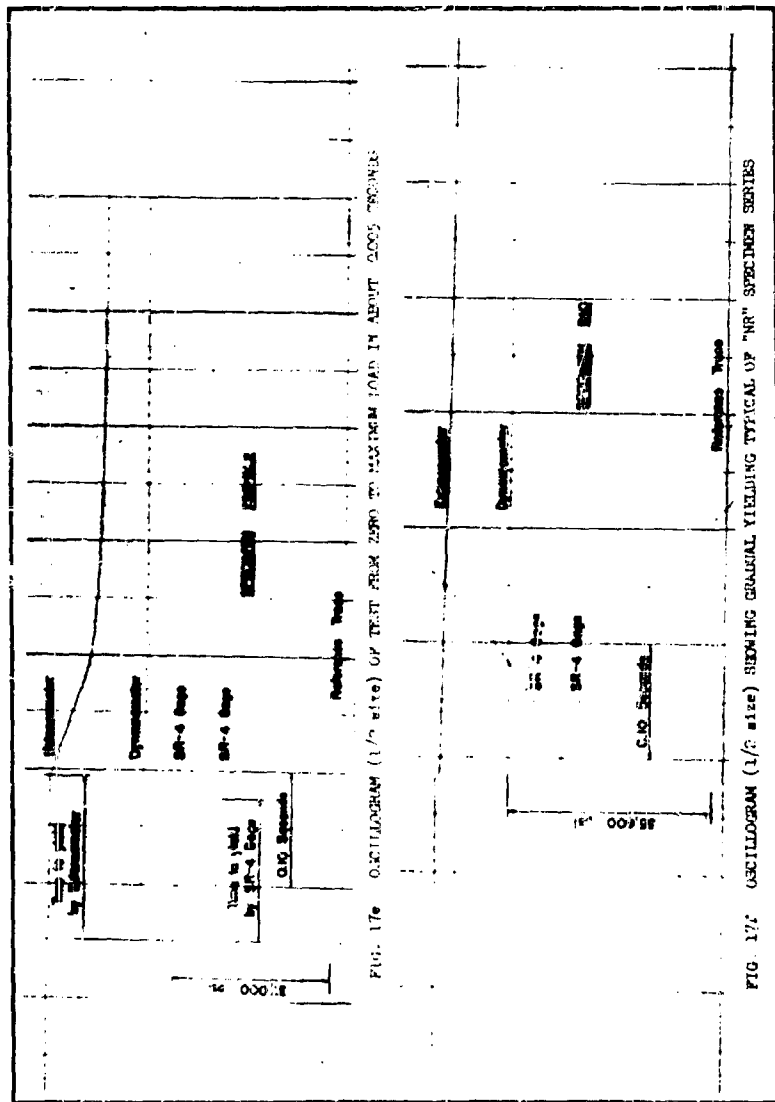
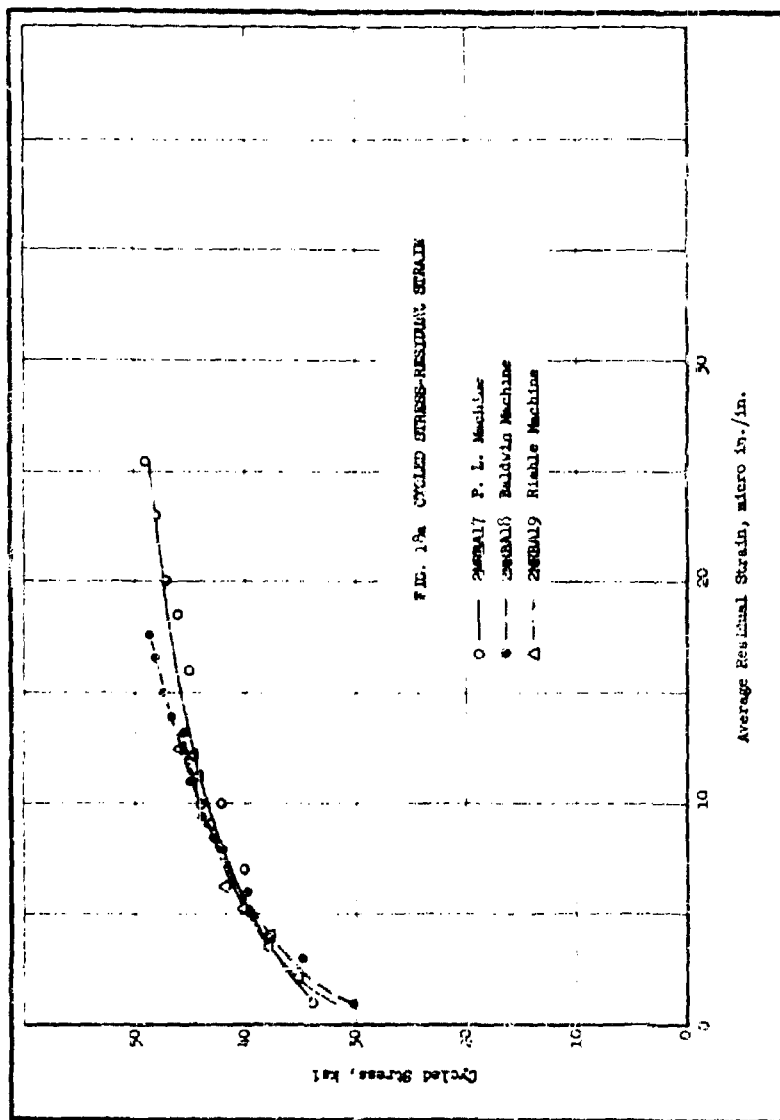


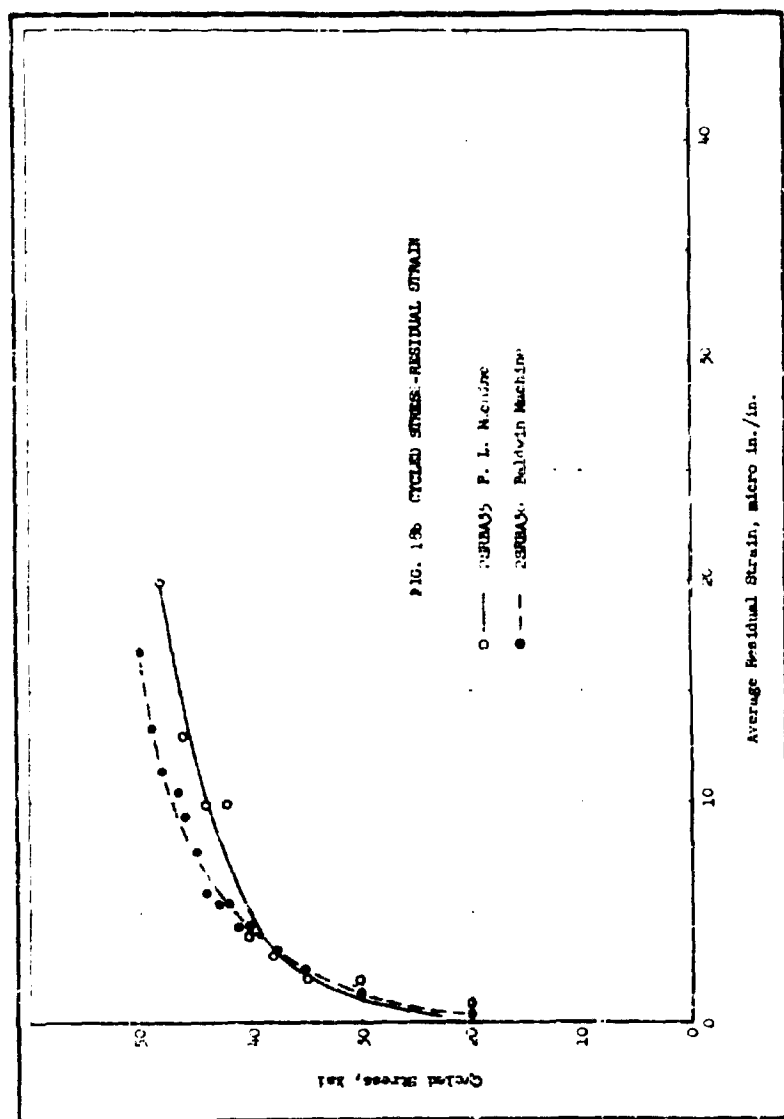
FIG. 16. HATHAWAY OSCILLOGRAPHS AND ASSOCIATED APPARATUS
(Two units used for flexure tests; one unit
used for rapid uniaxial stress tests)

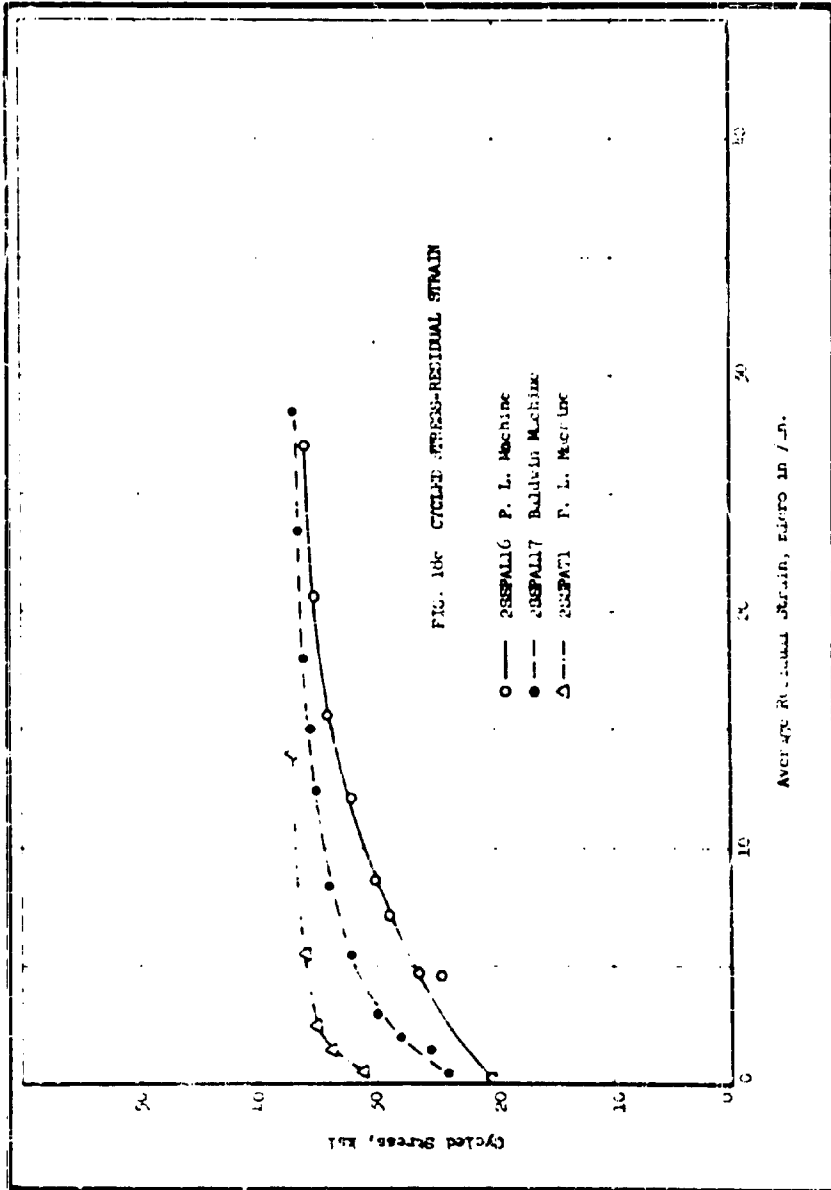












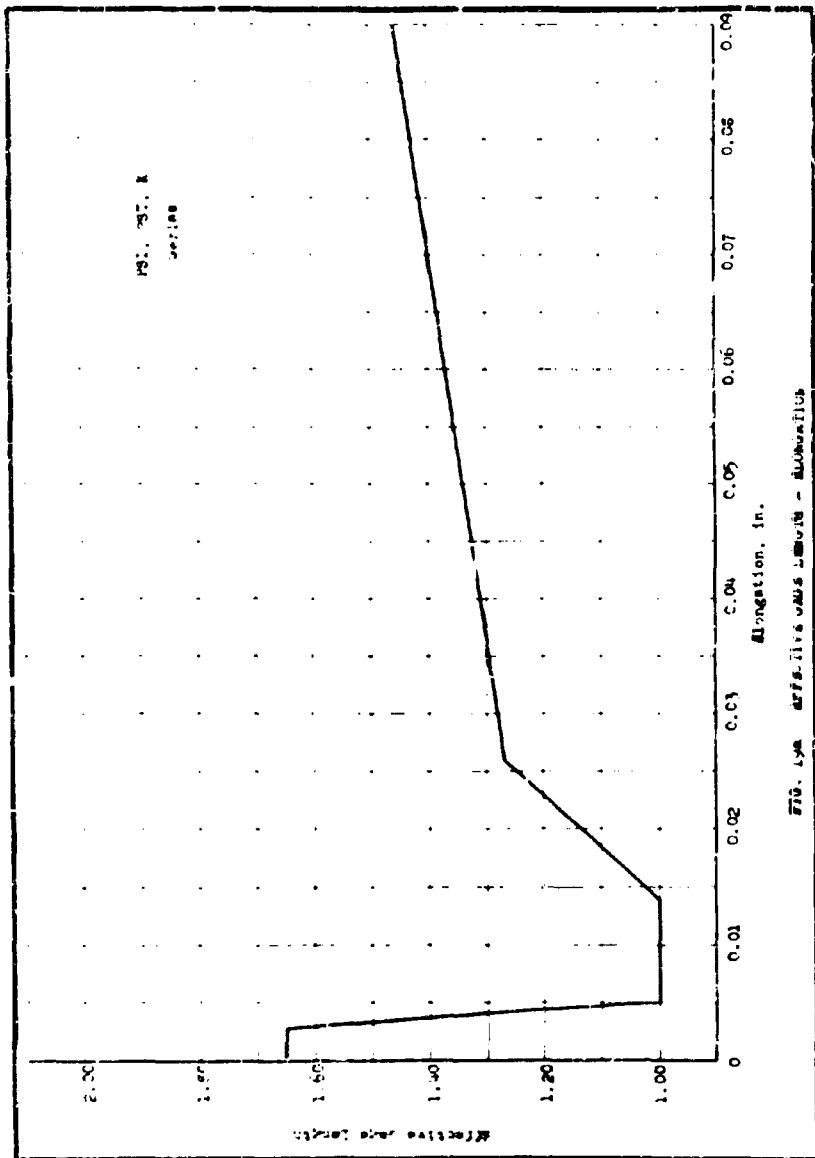


Fig. 15a *arbitrarily smooth - aluminum*

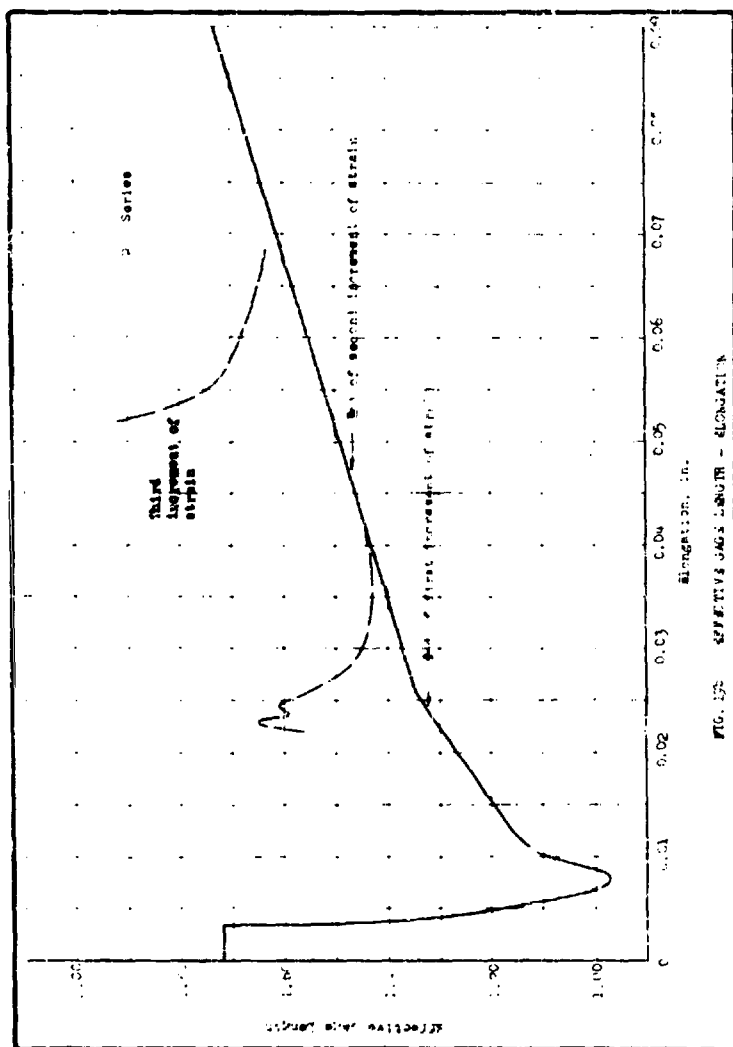


FIG. 122. EFFECTIVE JAWS LENGTH - ELONGATION

UNCLASSIFIED

A
D 210240

Armed Services Technical Information Agency

ARLINGTON HALL STATION
ARLINGTON 12 VIRGINIA

FOR
MICRO-CARD
CONTROL ONLY

4 OF 7

NOTICE: WHEN GOVERNMENT OR OTHER DRAWINGS, SPECIFICATIONS OR OTHER DATA ARE USED FOR ANY PURPOSE OTHER THAN IN CONNECTION WITH A DEFINITELY RELATED GOVERNMENT PROCUREMENT OPERATION, THE U. S. GOVERNMENT THEREBY INCURS NO RESPONSIBILITY, NOR ANY OBLIGATION WHATSOEVER; AND THE FACT THAT THE GOVERNMENT MAY HAVE FORMULATED, FURNISHED, OR IN ANY WAY SUPPLIED THE SAID DRAWINGS, SPECIFICATIONS, OR OTHER DATA IS NOT TO BE REGARDED BY IMPLICATION OR OTHERWISE AS IN ANY MANNER LICENSING THE HOLDER OR ANY OTHER PERSON OR CORPORATION, OR CONVEYING ANY RIGHTS OR PERMISSION TO MANUFACTURE, USE OR SELL ANY PATENTED INVENTION THAT MAY IN ANY WAY BE RELATED THERETO.

UNCLASSIFIED

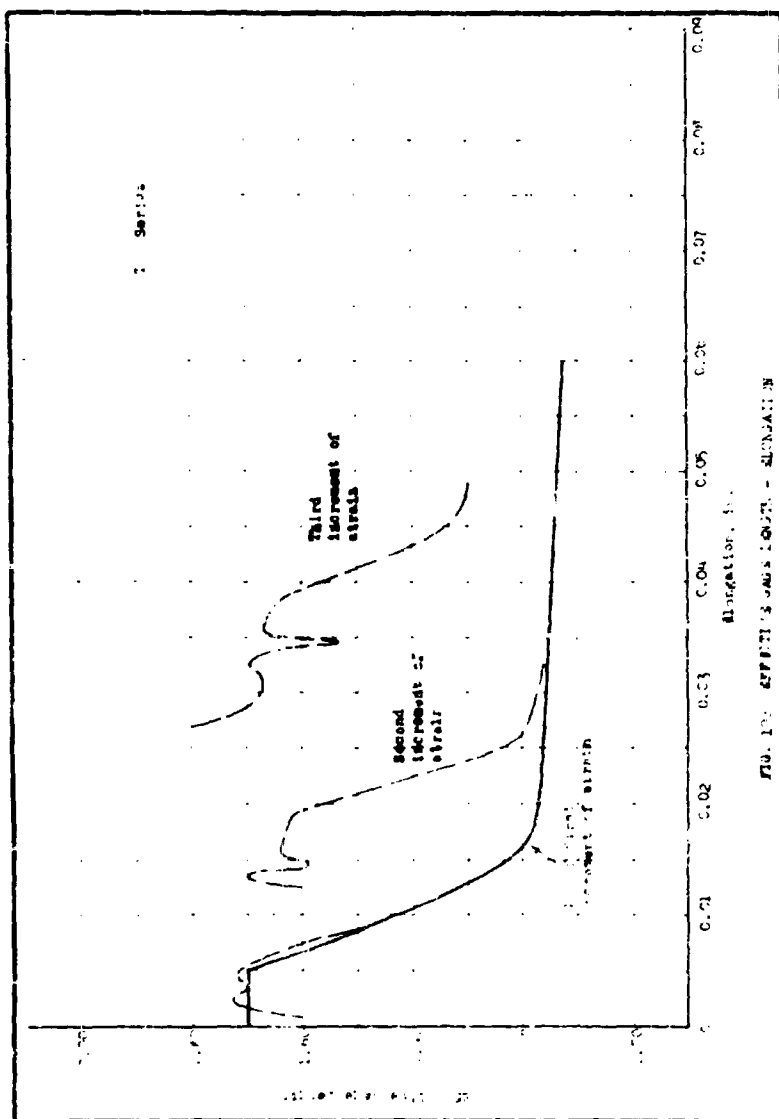


FIG. 10. EFFECT OF STRAIN ON ELONGATION

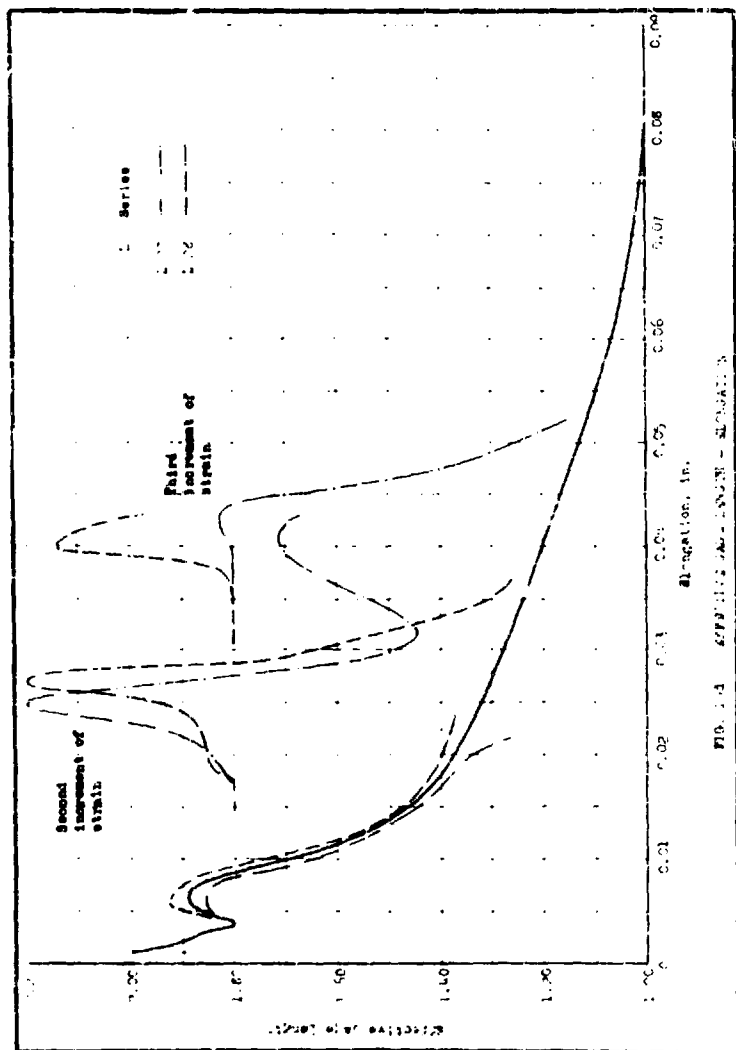


FIG. 1-3 STRESS-ELONGATION - ALUMINUM

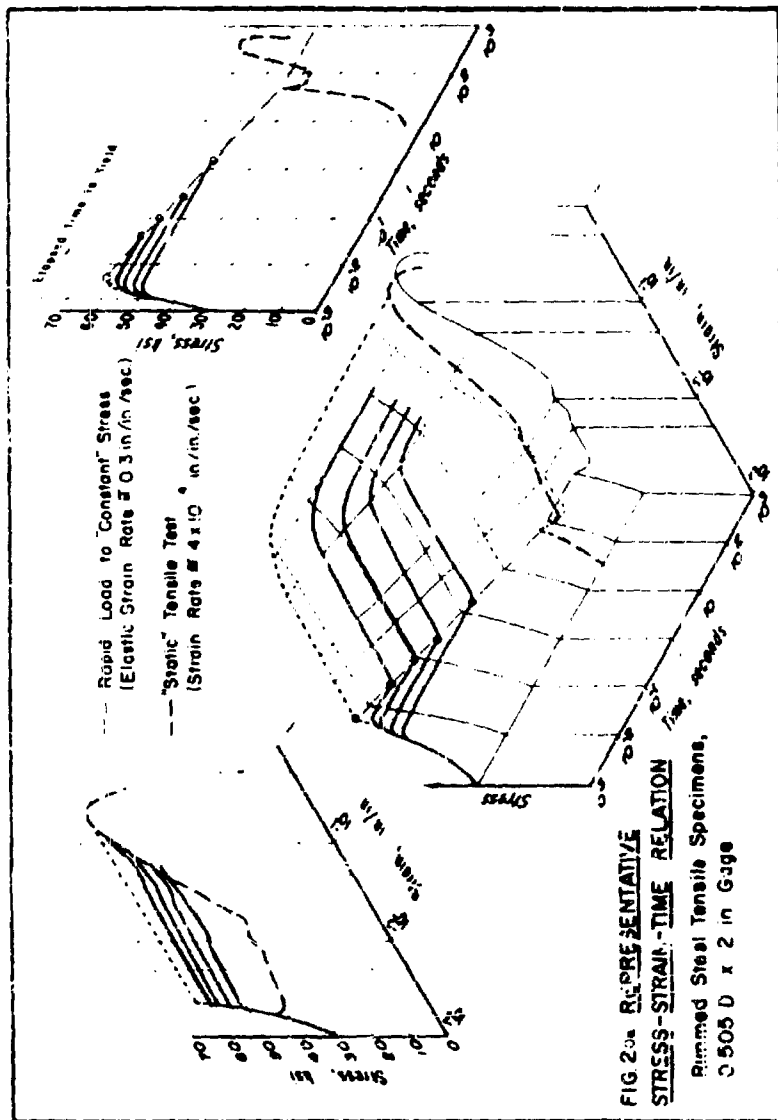


FIG 2.0a REPRESENTATIVE
 STRESS-STRAIN-TIME RELATION

Rimmed Steel Tensile Specimens,
 0.505 D x 2 in Gage

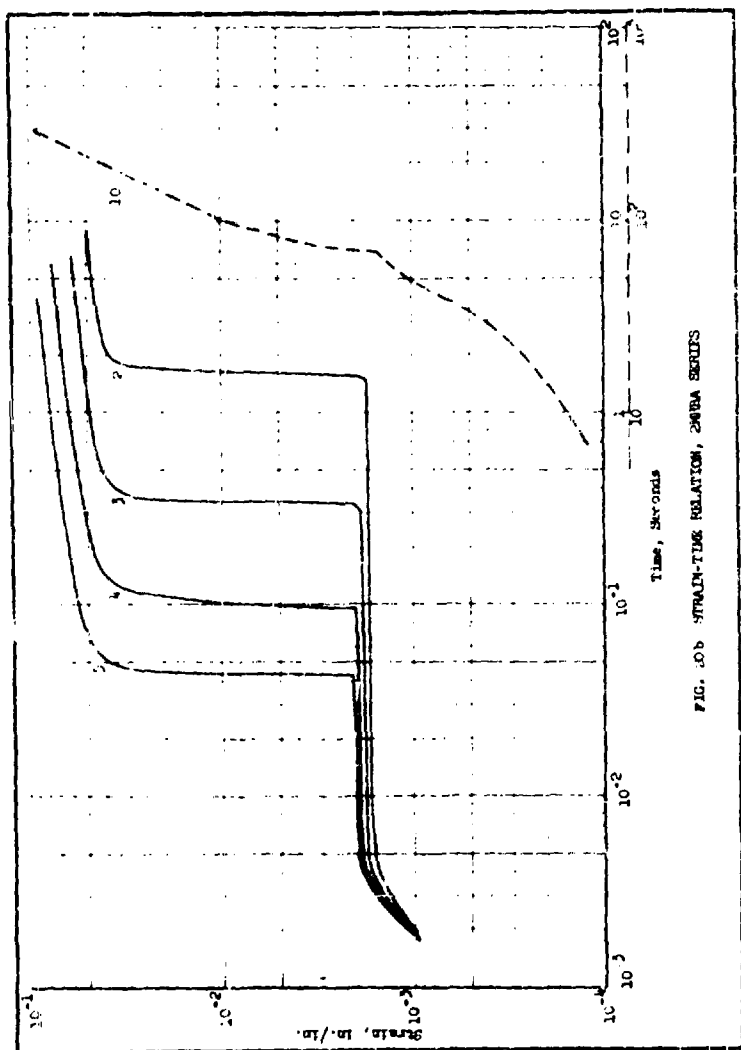


FIG. 10b STRAIN-TIME RELATION, CURVA SERIES

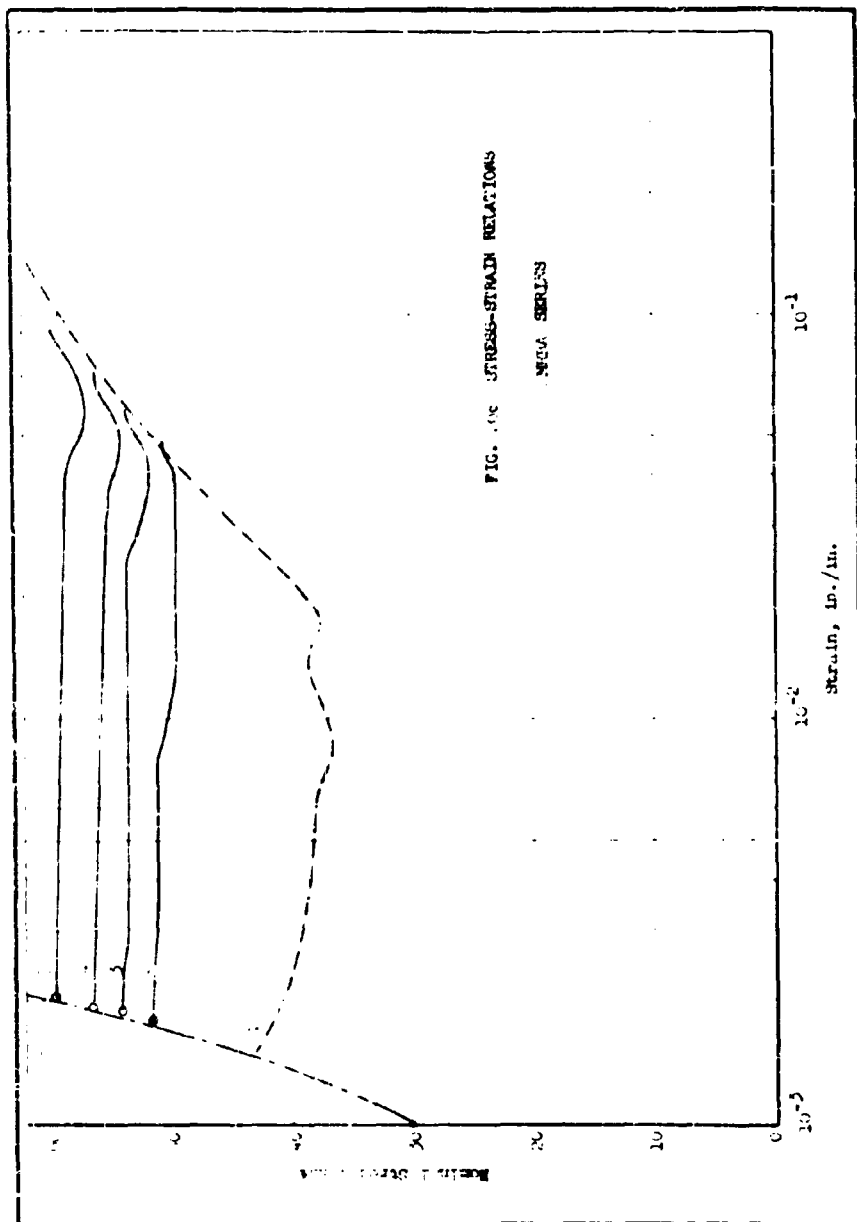


FIG. 10c STRESS-STRAIN RELATIONS

NCA SERIES

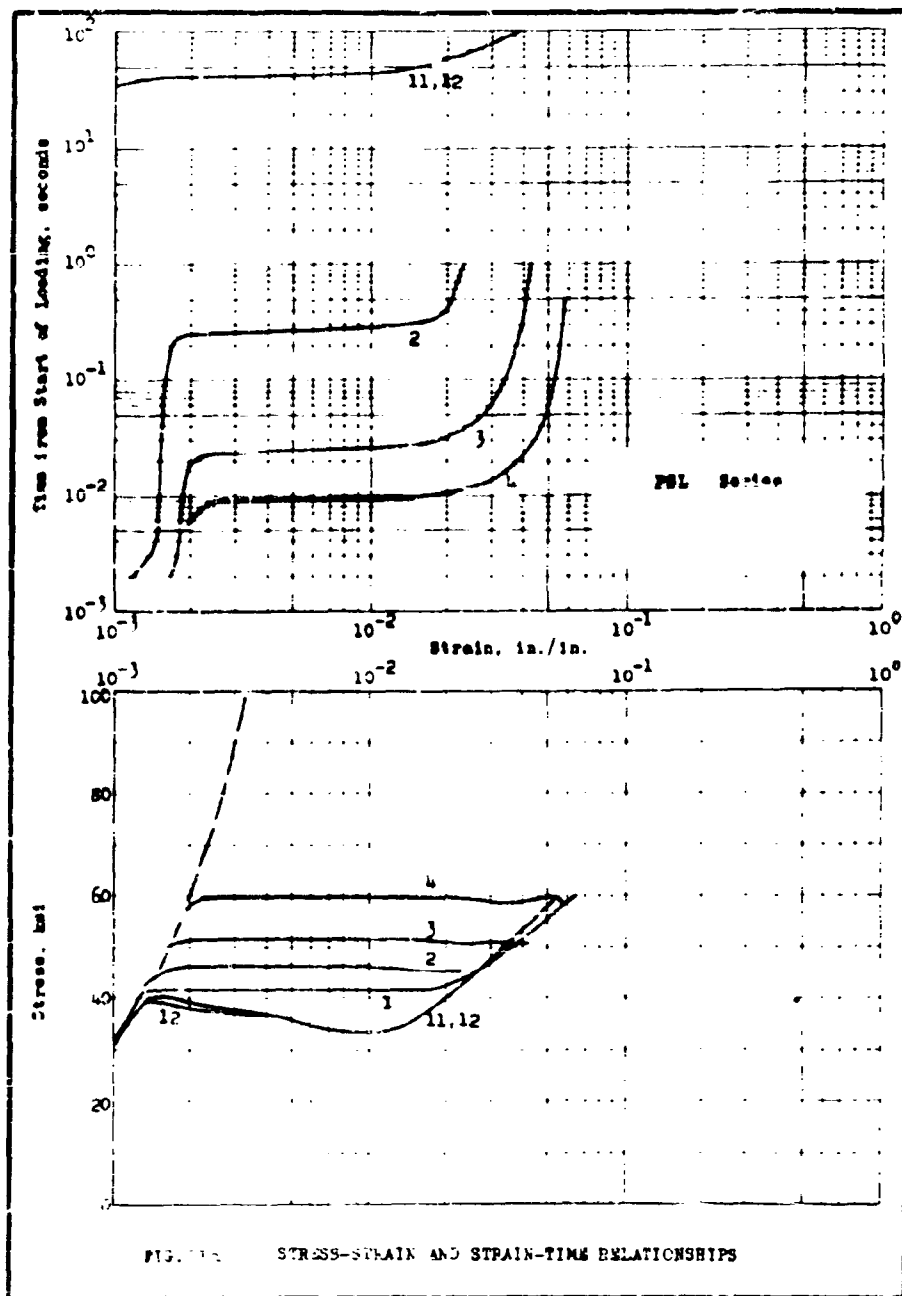


FIG. 1. STRESS-STRAIN AND STRAIN-TIME RELATIONSHIPS

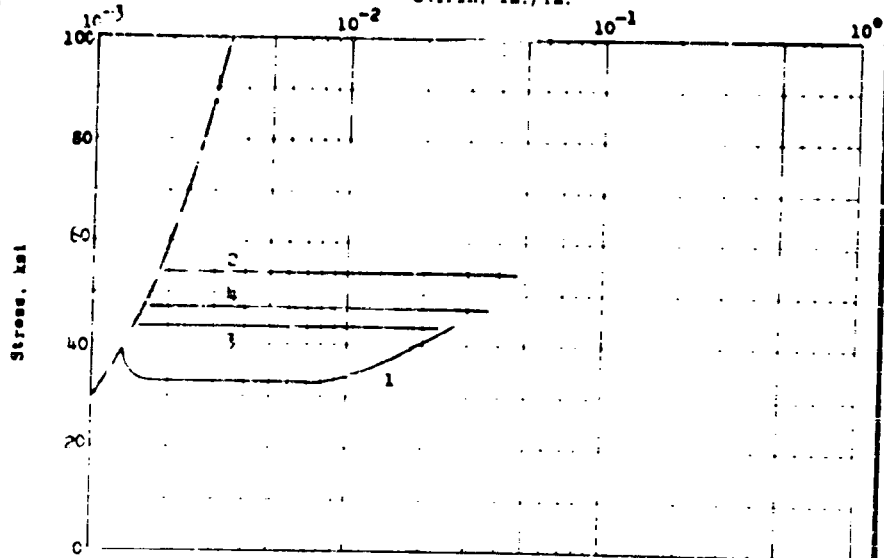
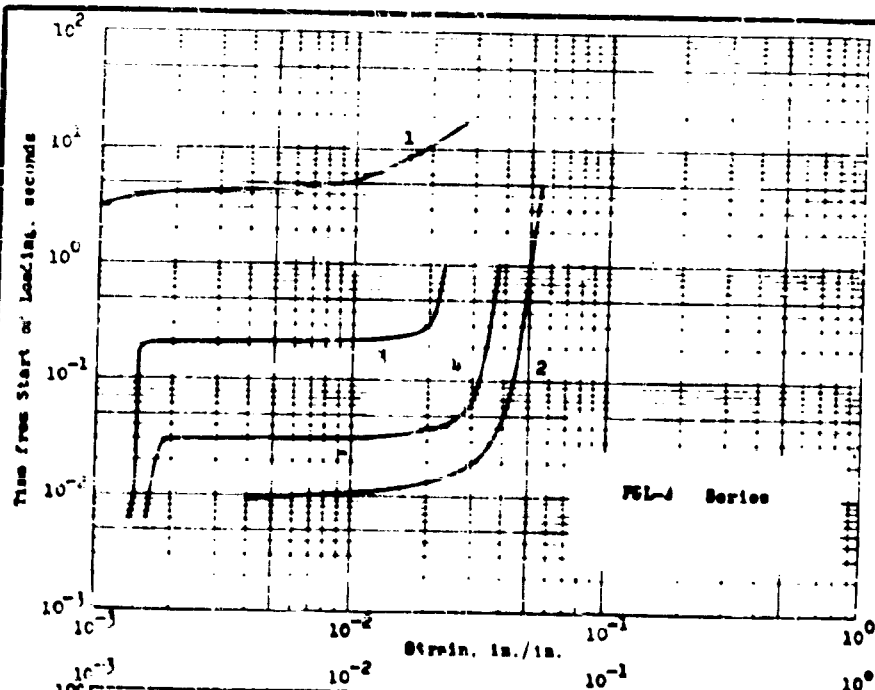


FIG. 1. STRESS-STRAIN AND STRAIN-TIME RELATIONSHIPS

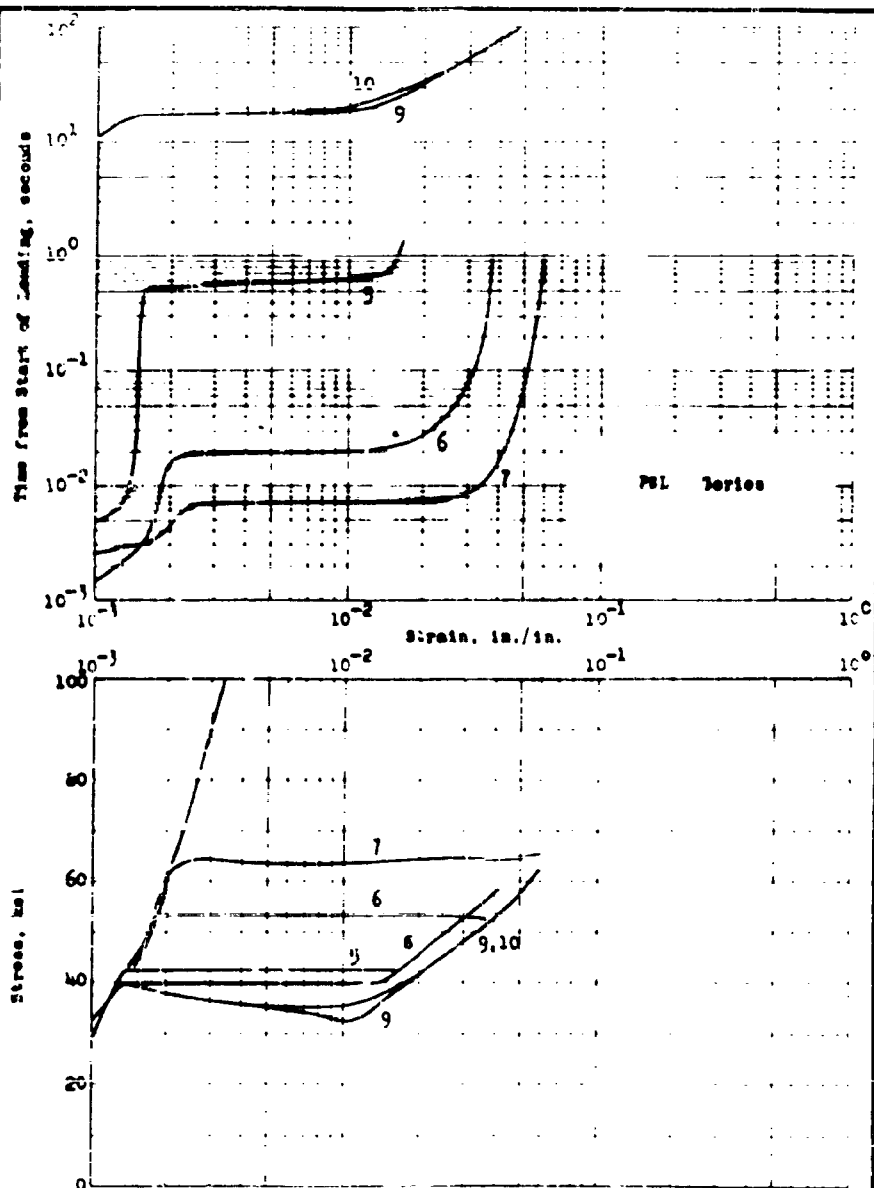


FIG. 2.10 STRESS-STRAIN AND STRAIN-TIME RELATIONSHIPS

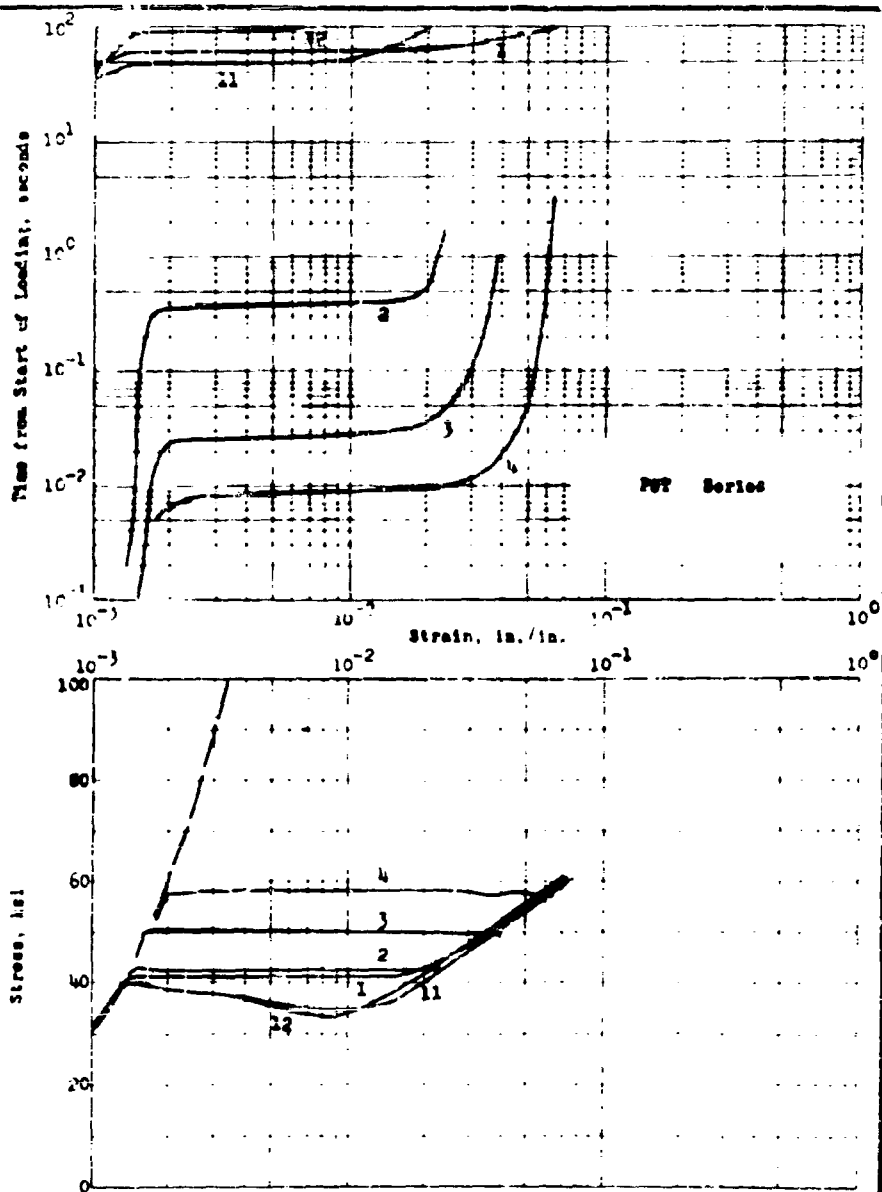


FIG. 2A STRESS-STRAIN AND STRAIN-TIME RELATIONSHIPS

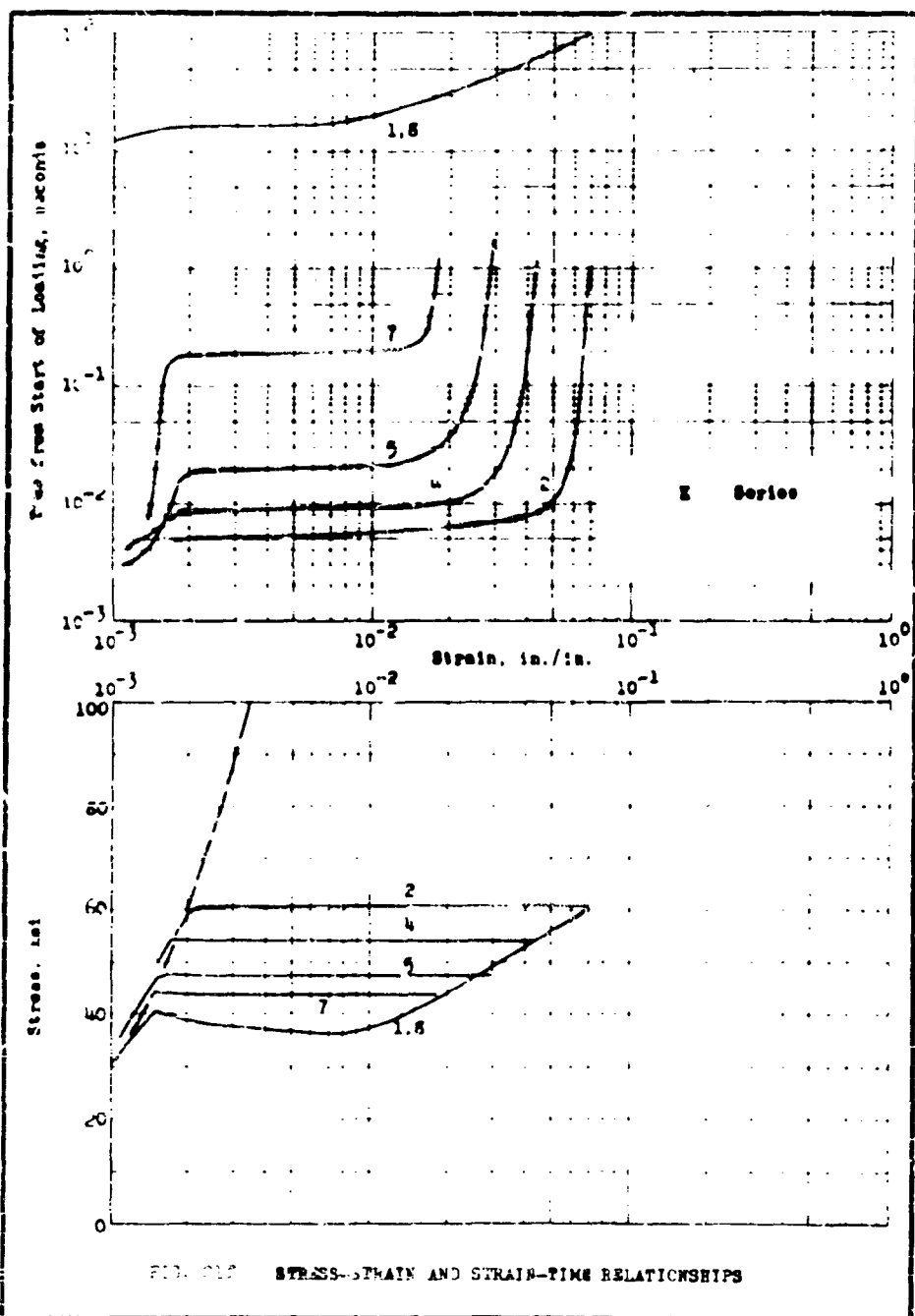
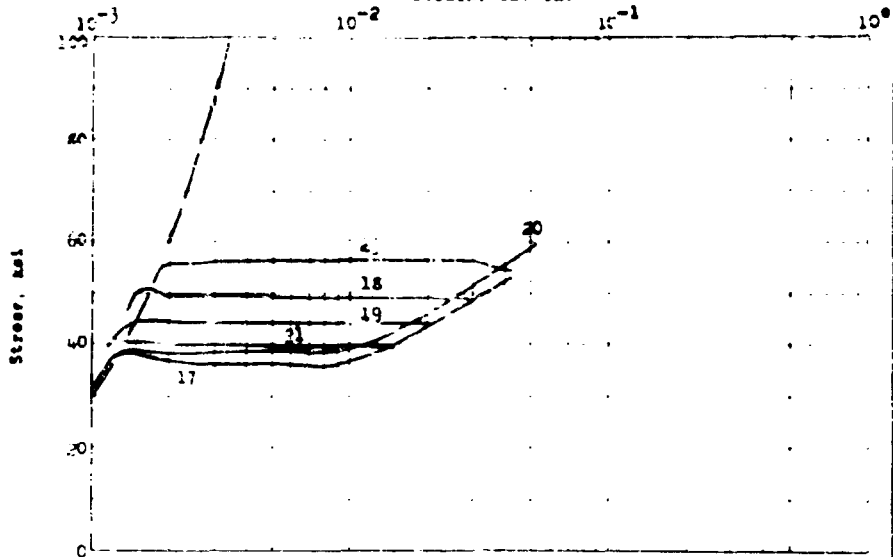
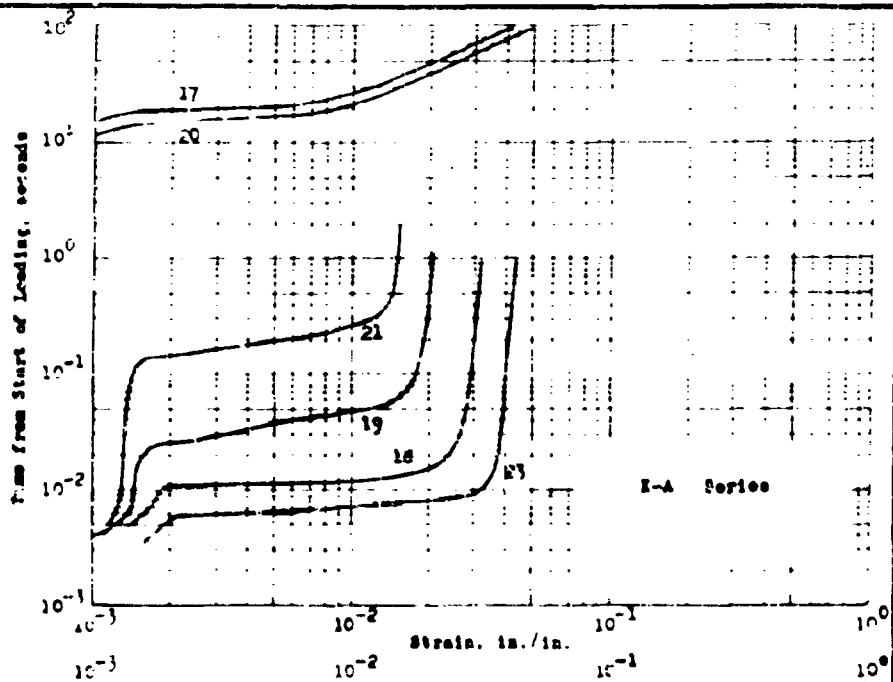


FIG. 112 STRESS-STRAIN AND STRAIN-TIME RELATIONSHIPS



STRESS-STRAIN AND STRAIN-TIME RELATIONSHIPS

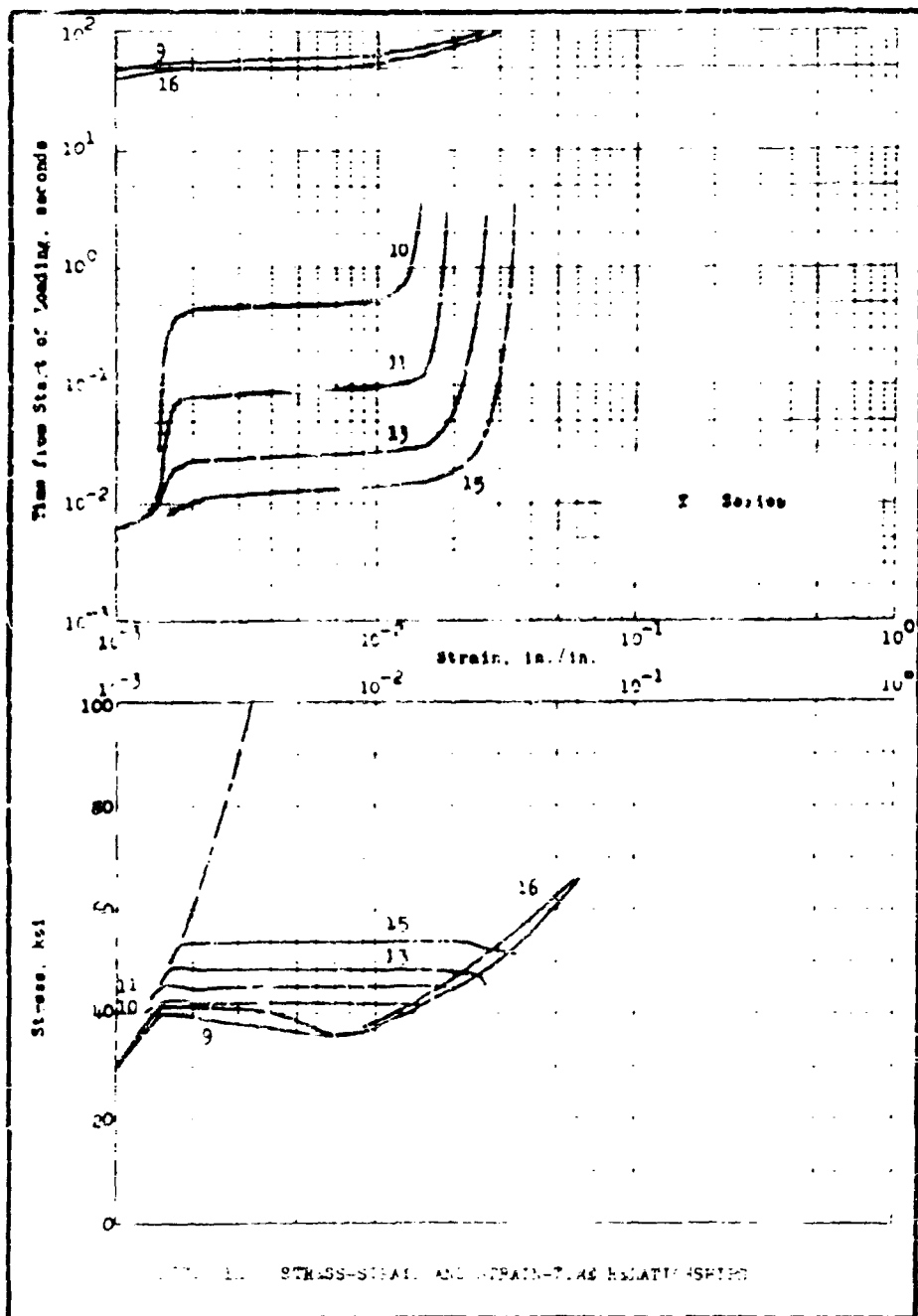


FIGURE 11. STRESS-STRAIN AND STRAIN-TIME RELATIONSHIPS

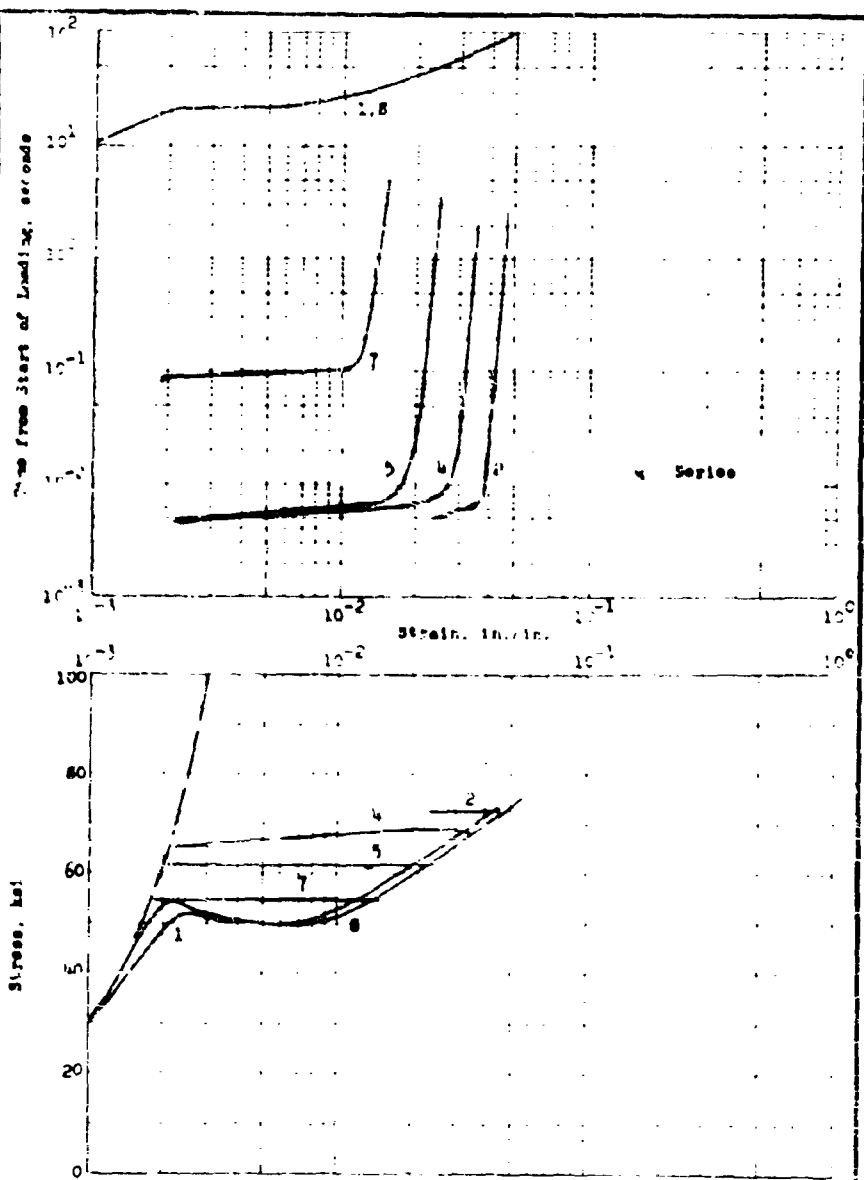


FIG. 11. STRESS-STRAIN AND STRAIN-TIME RELATIONSHIPS

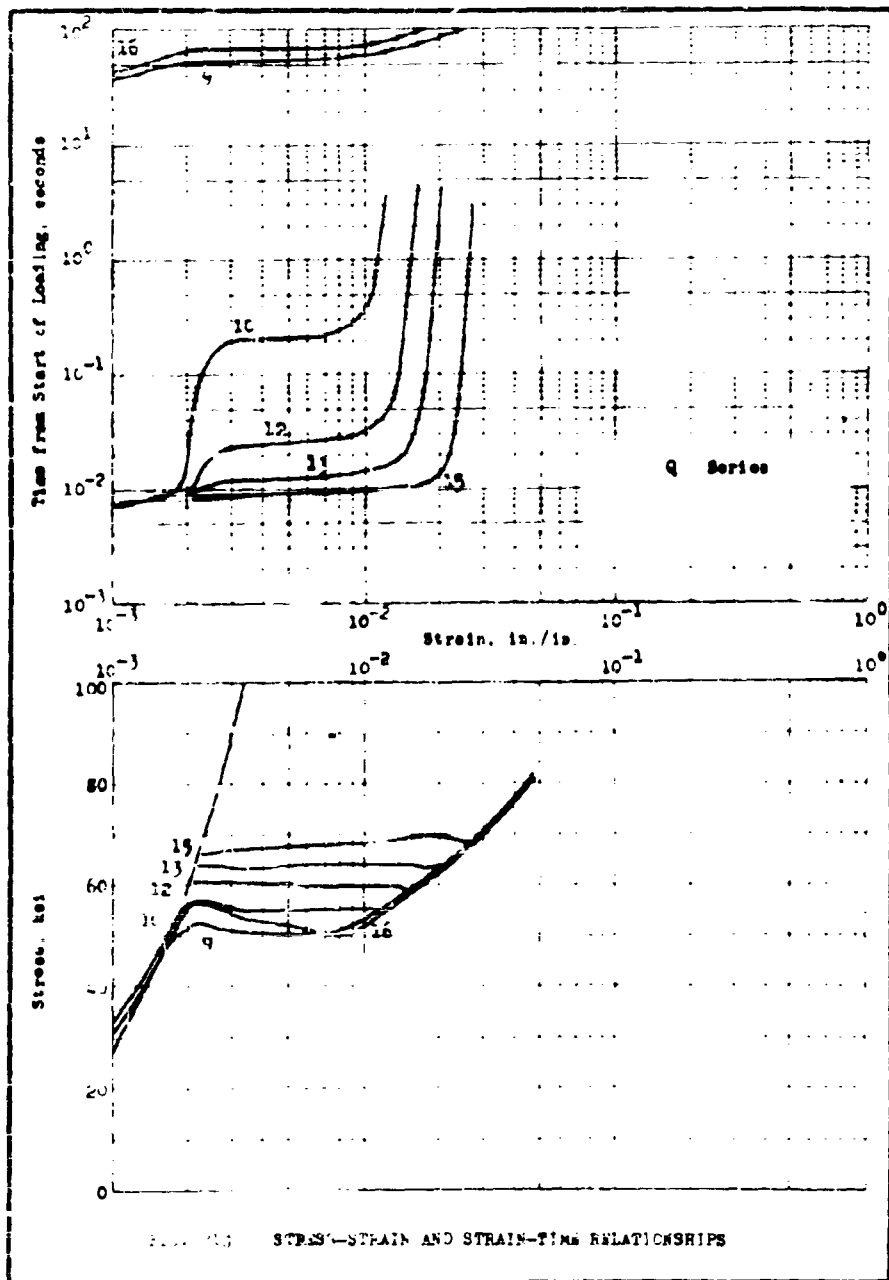


FIG. 10 STRESS-STRAIN AND STRAIN-TIME RELATIONSHIPS

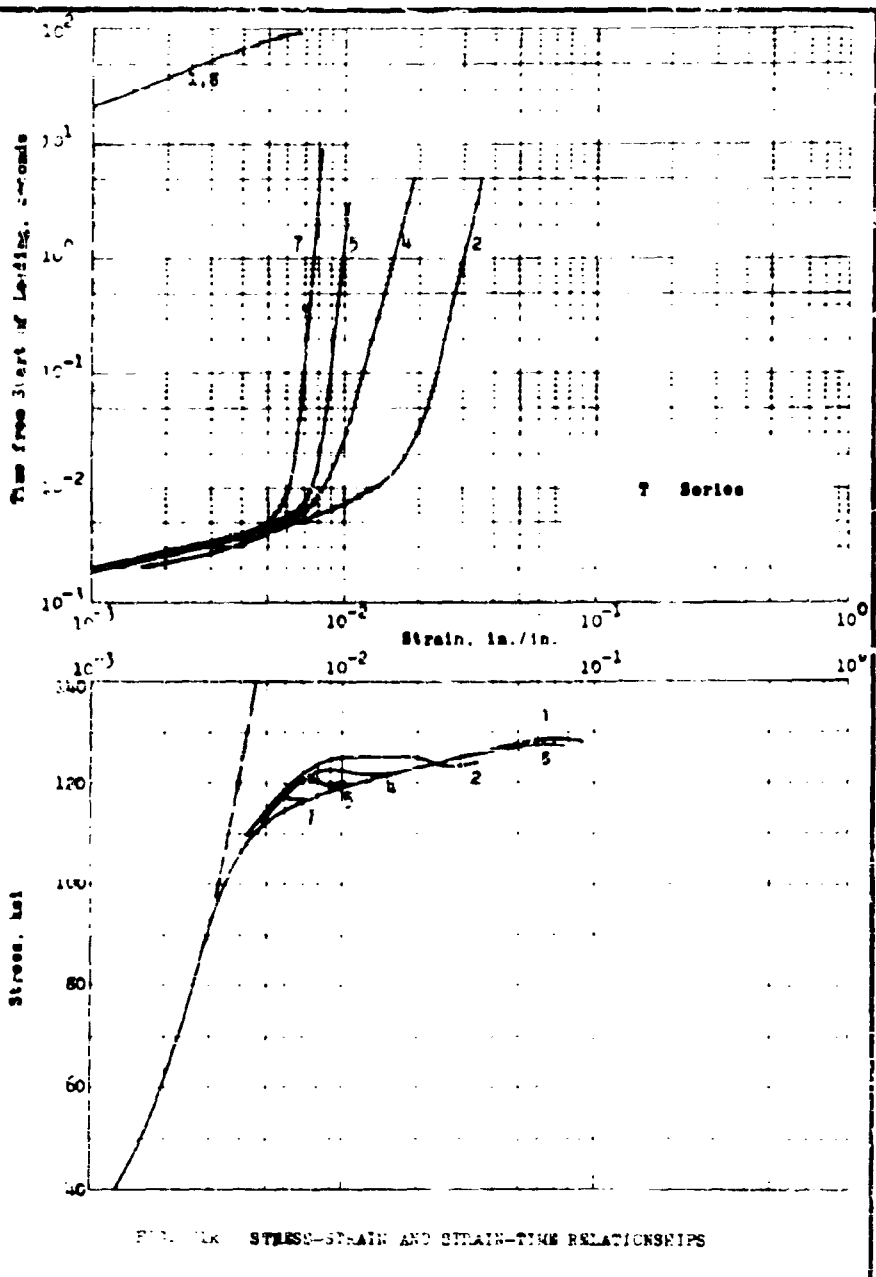


FIG. 10K STRESS-STRAIN AND STRAIN-TIME RELATIONSHIPS

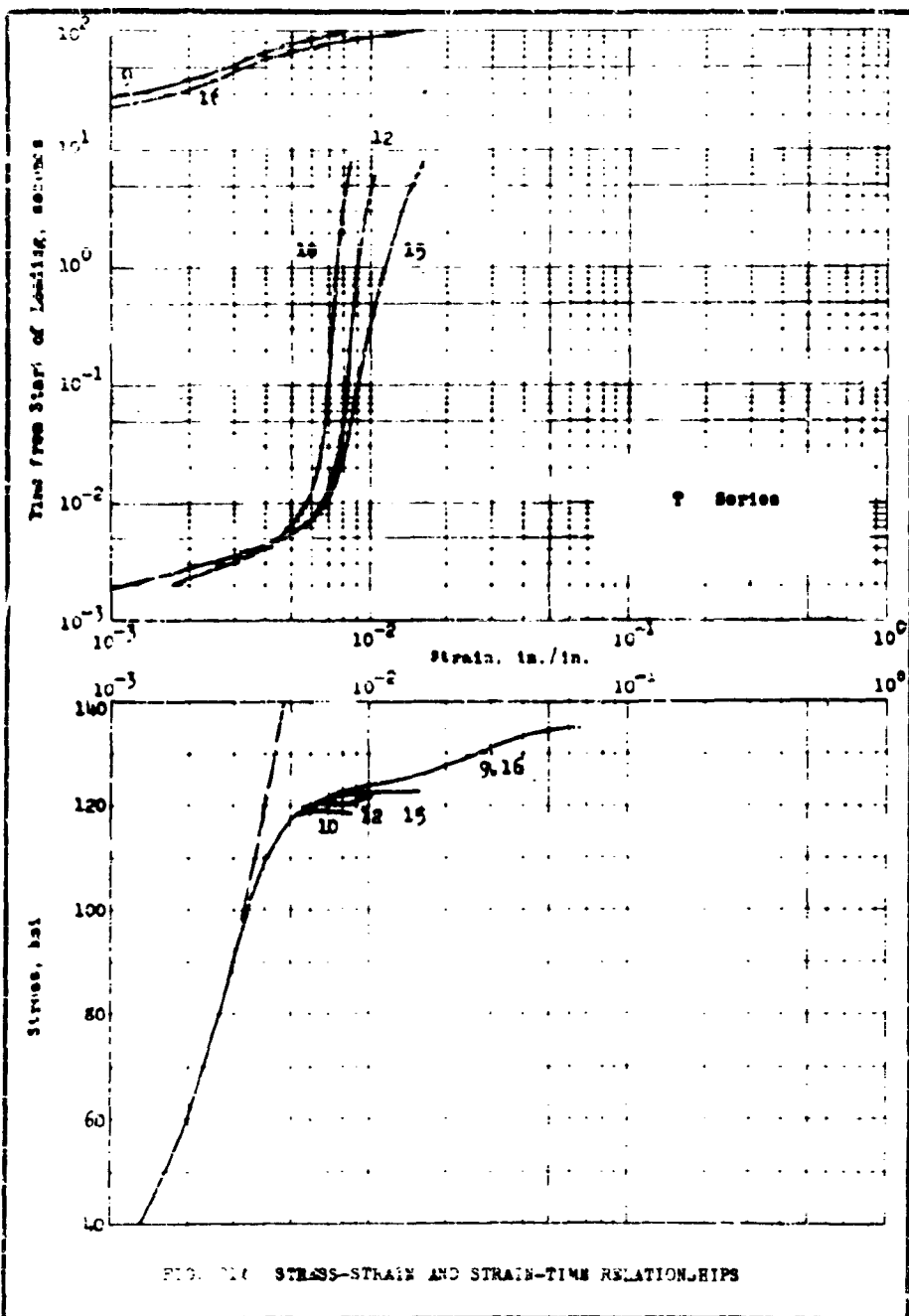


FIG. 110 STRESS-STRAIN AND STRAIN-TIME RELATIONSHIPS

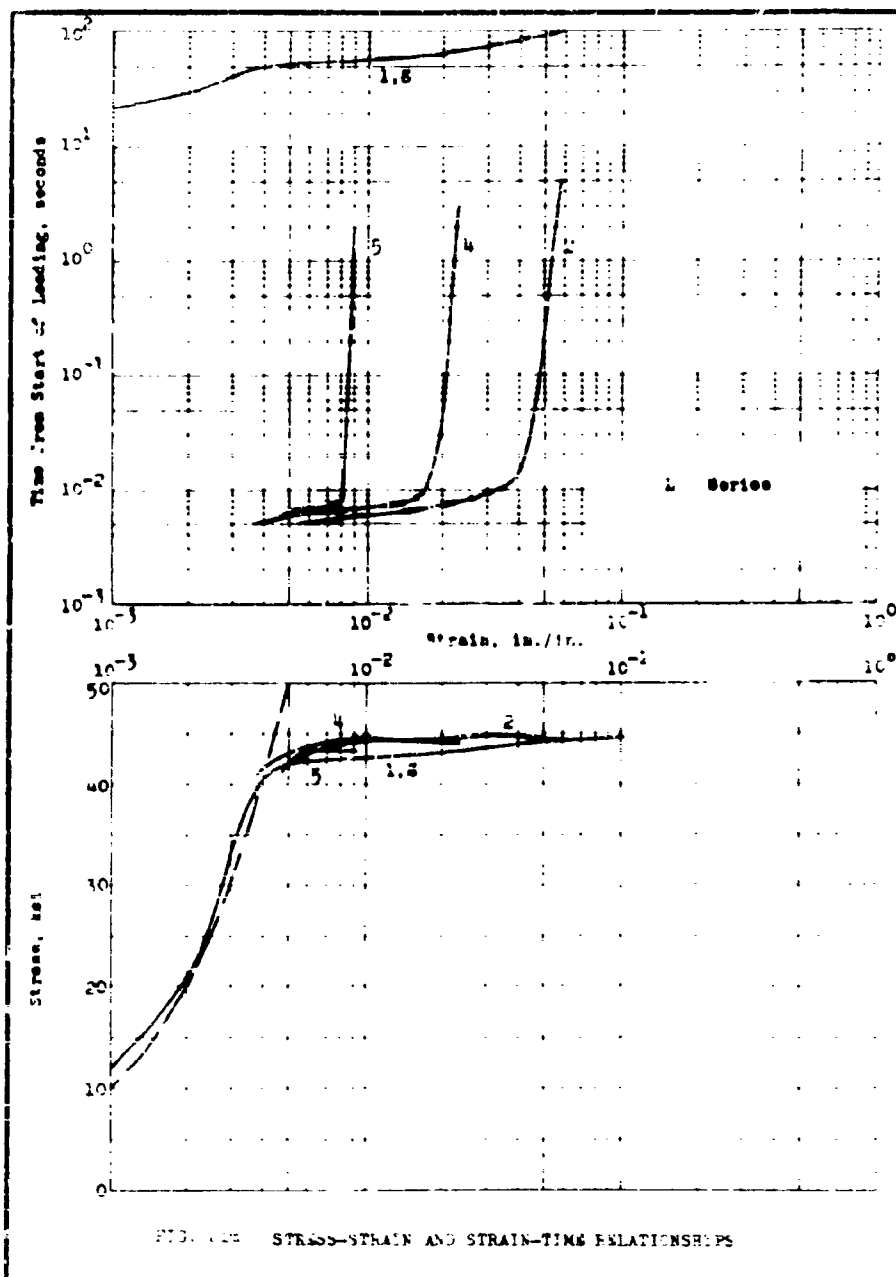
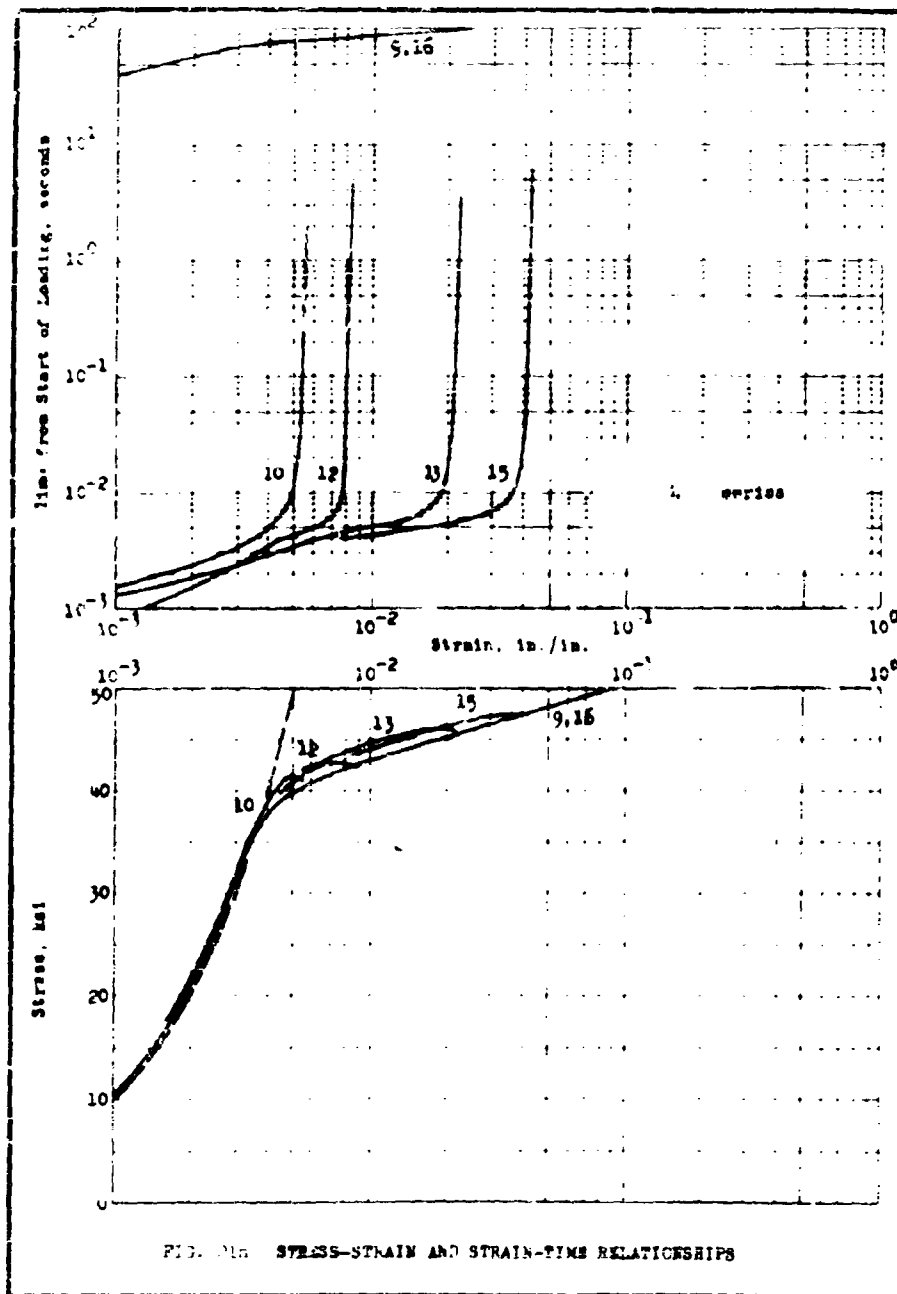
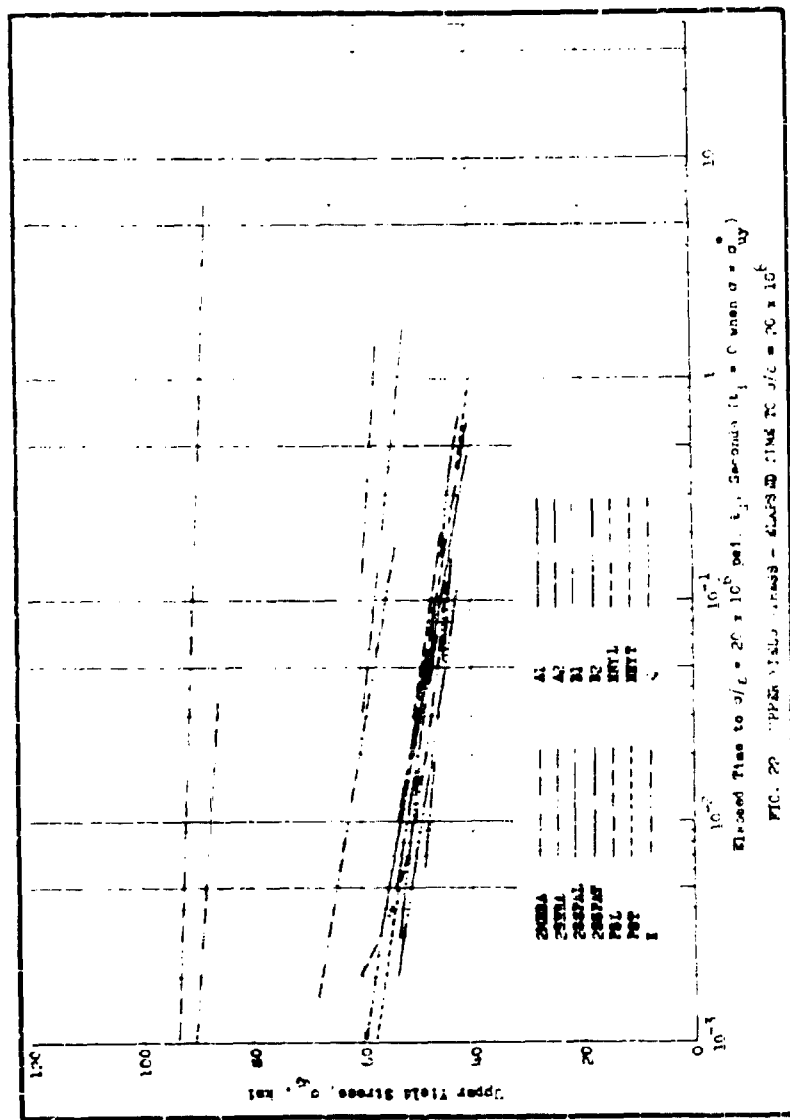


FIG. 105 STRESS-STRAIN AND STRAIN-TIME RELATIONSHIPS





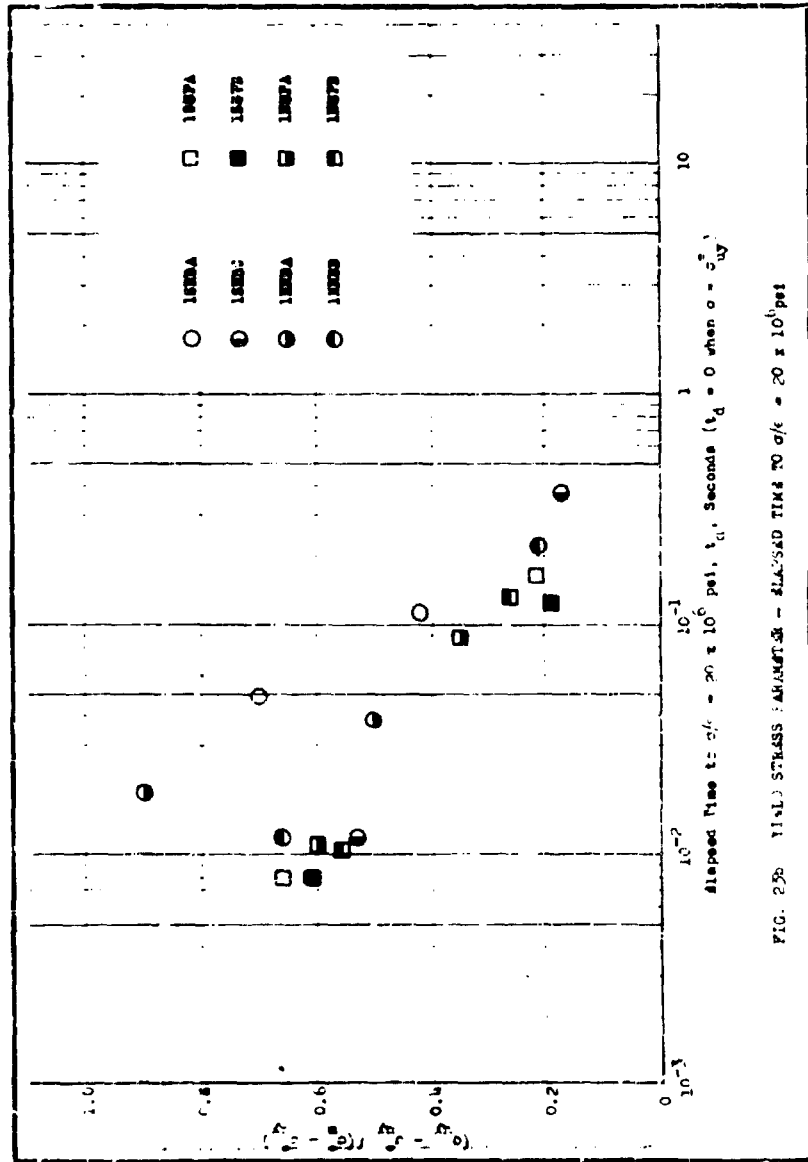
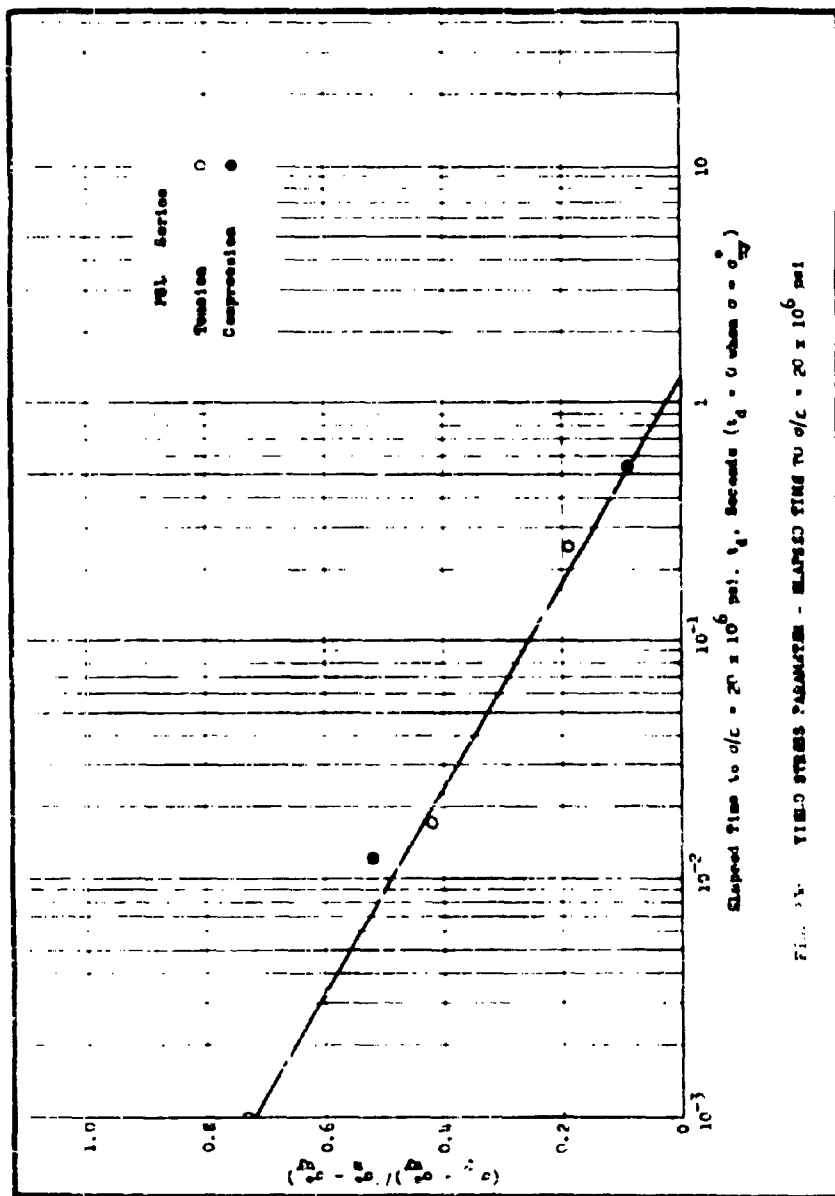
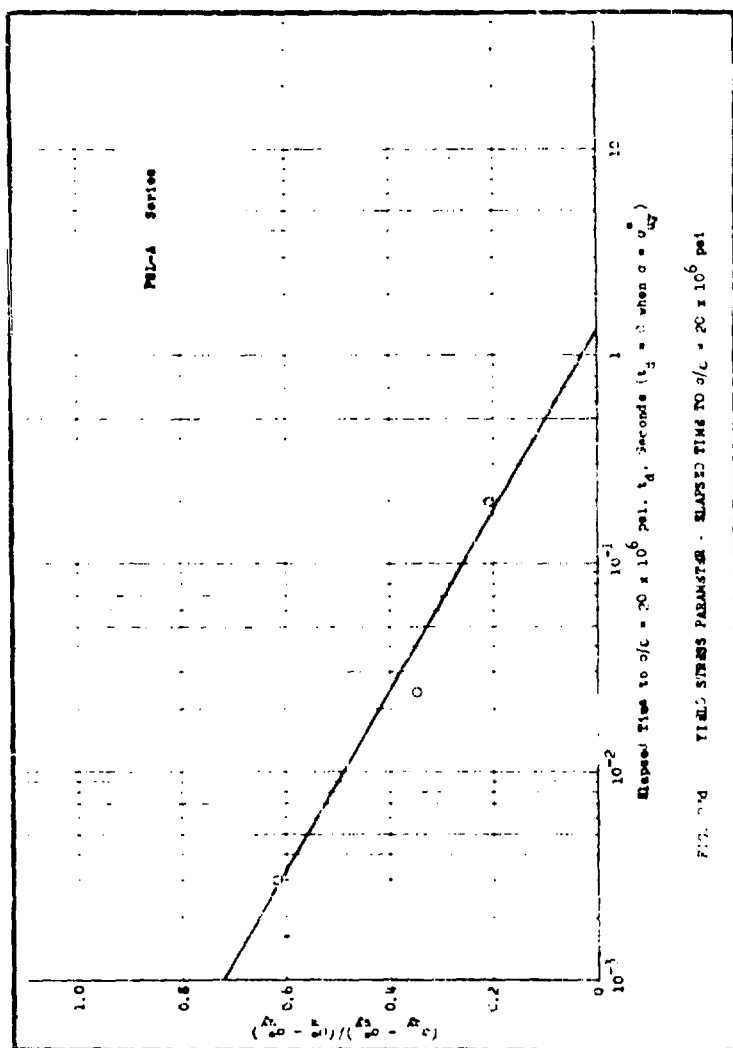
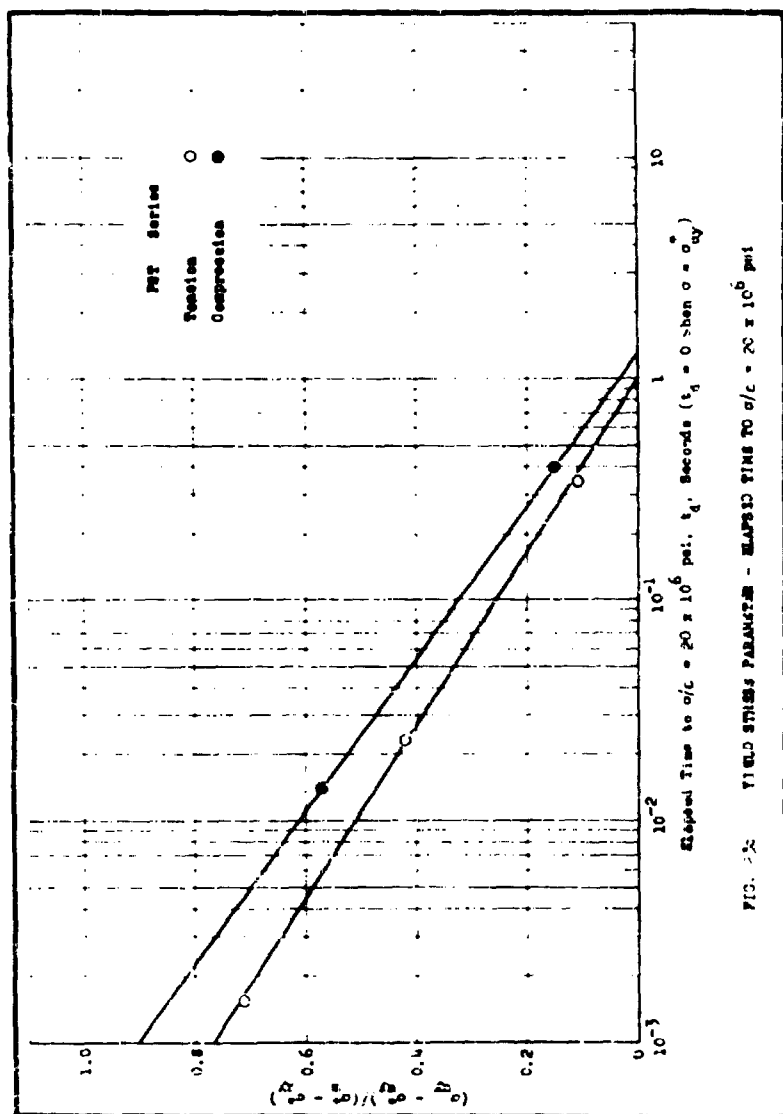
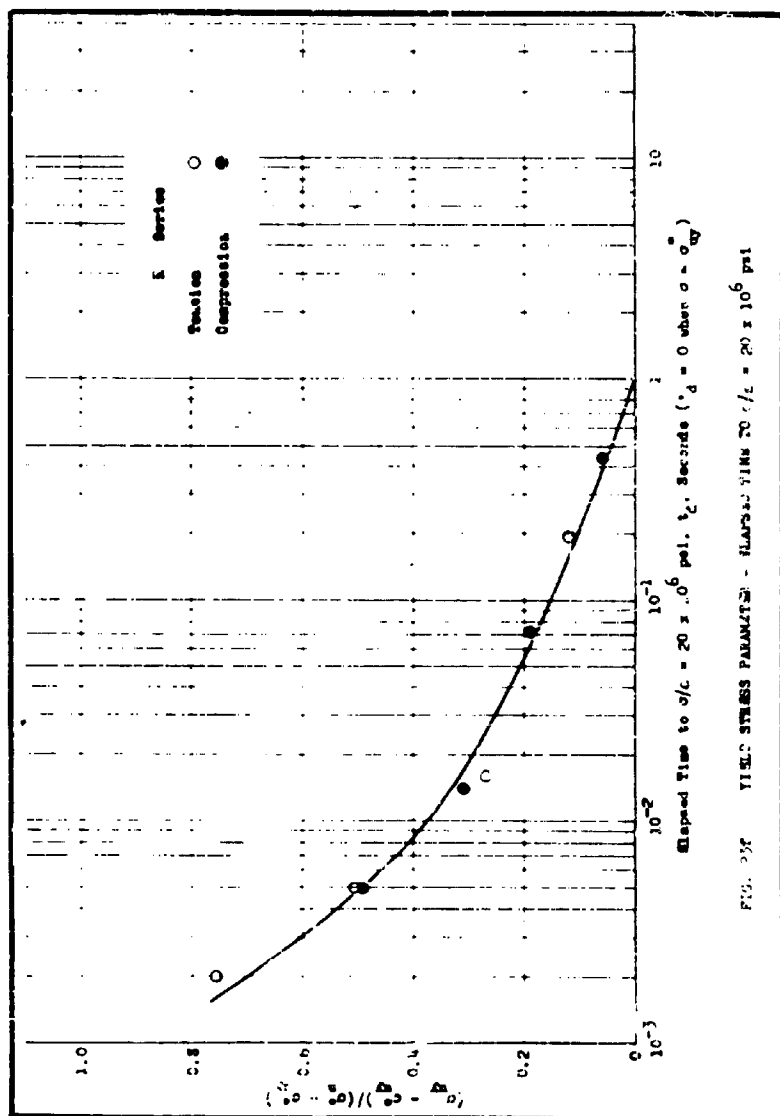


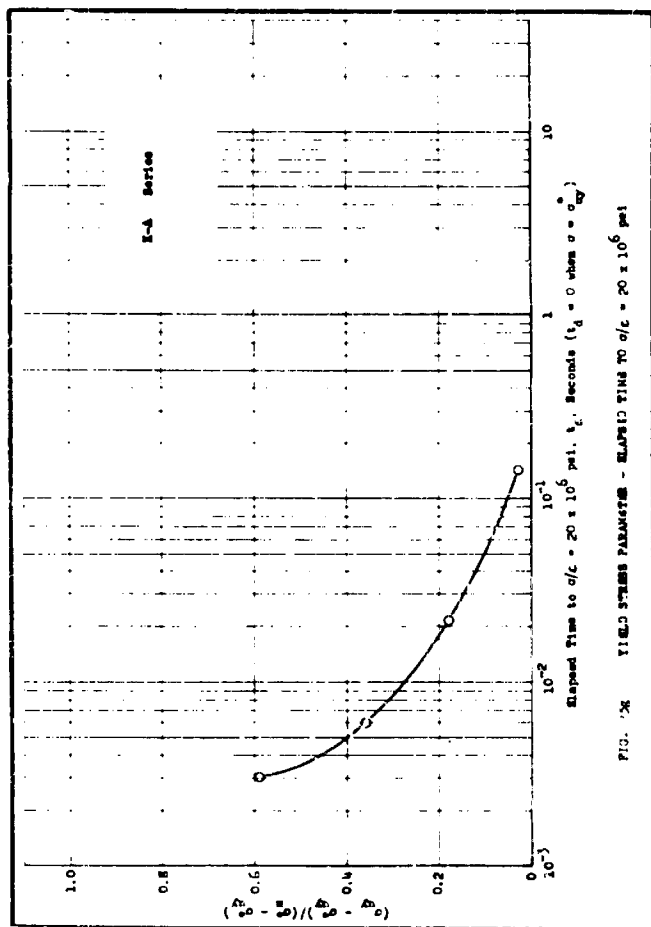
FIG. 25b YIELD STRESS (ANALYTICAL) - PLASMA TREATMENT - $t_d = 20 \times 10^6$ sec











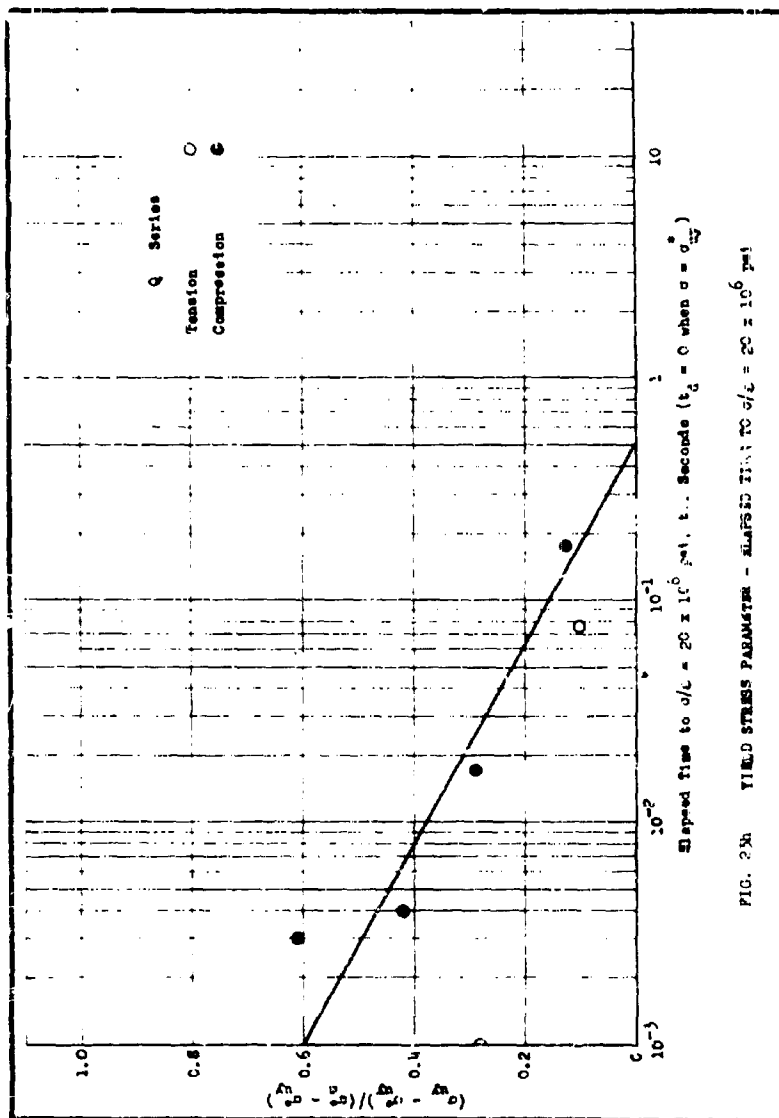
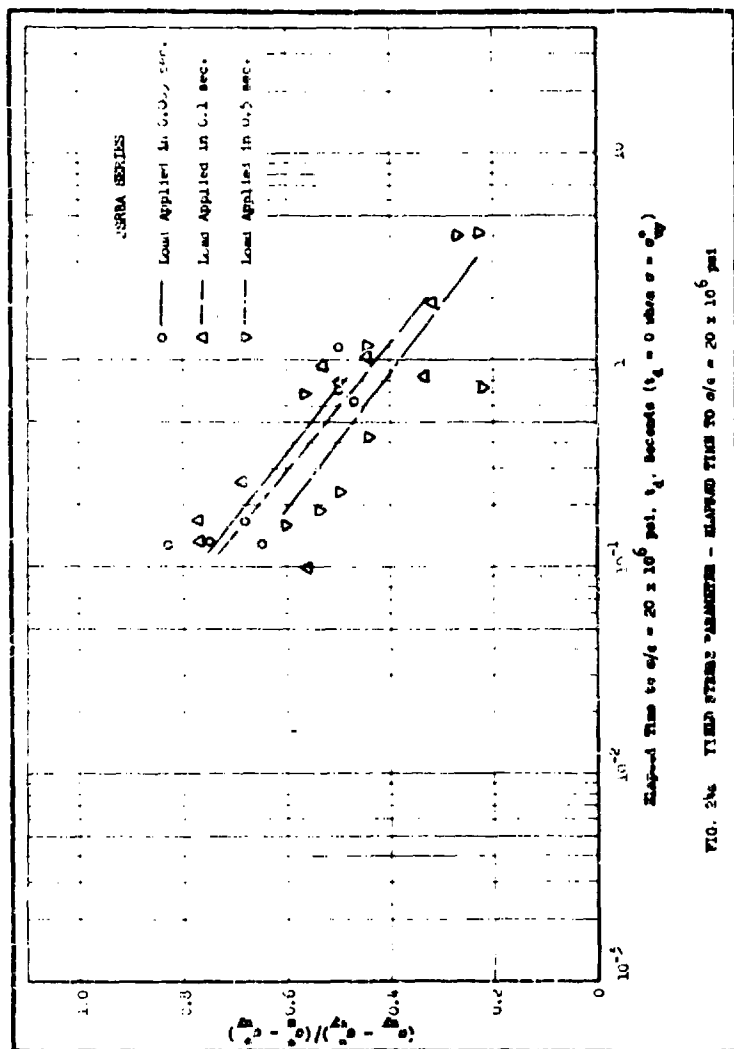
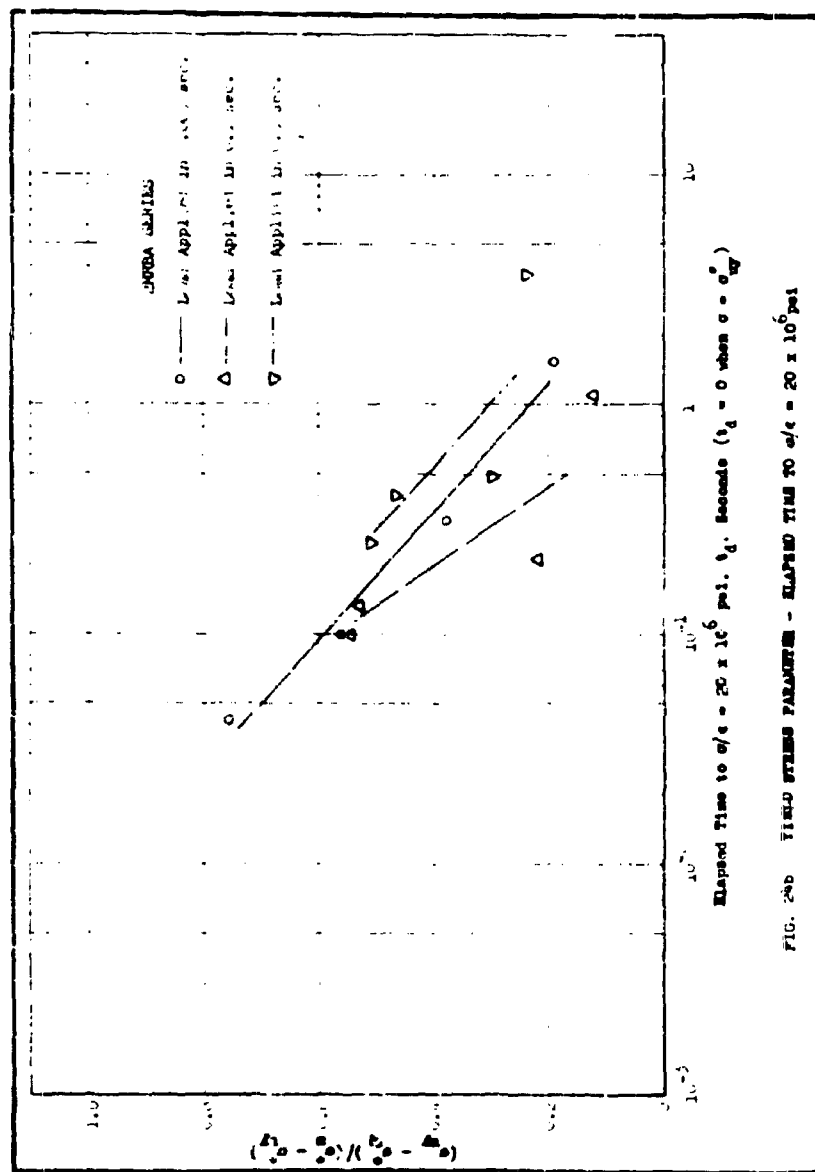
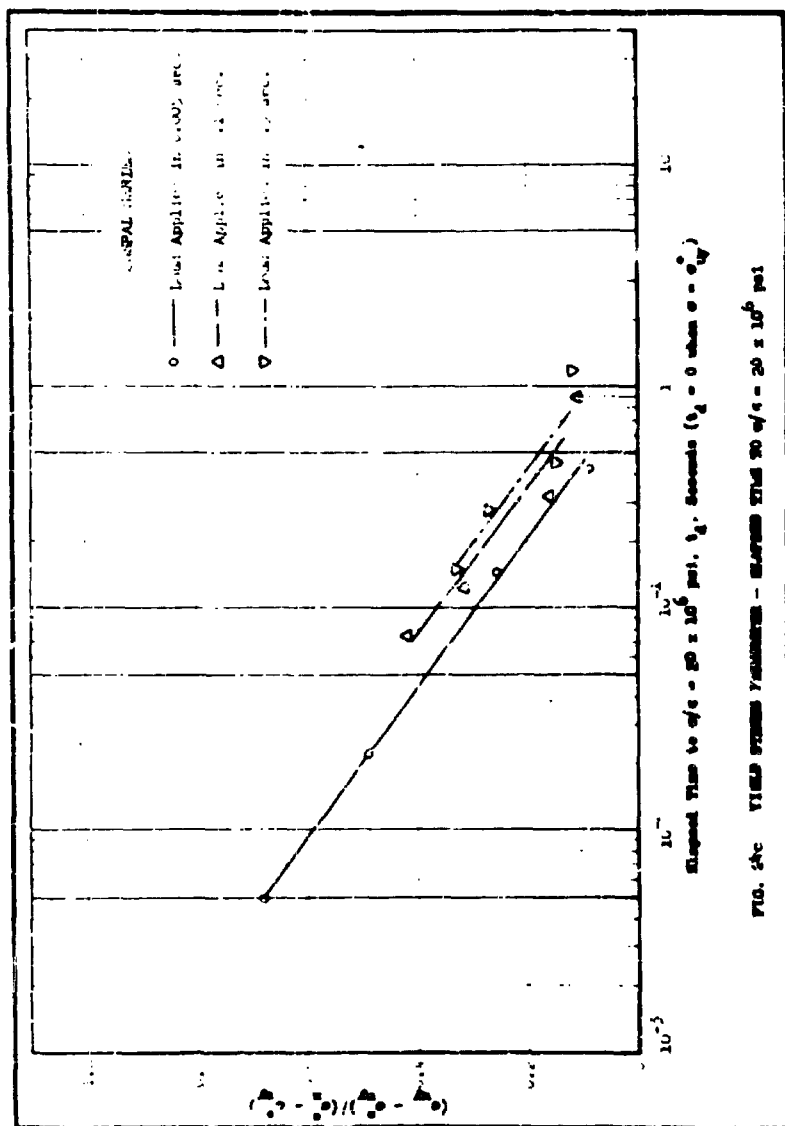


FIG. 2M YIELD STRESS PARAMETER - ELAPSED TIME TO $\sigma_y^0 = 20 \times 10^6$ psi







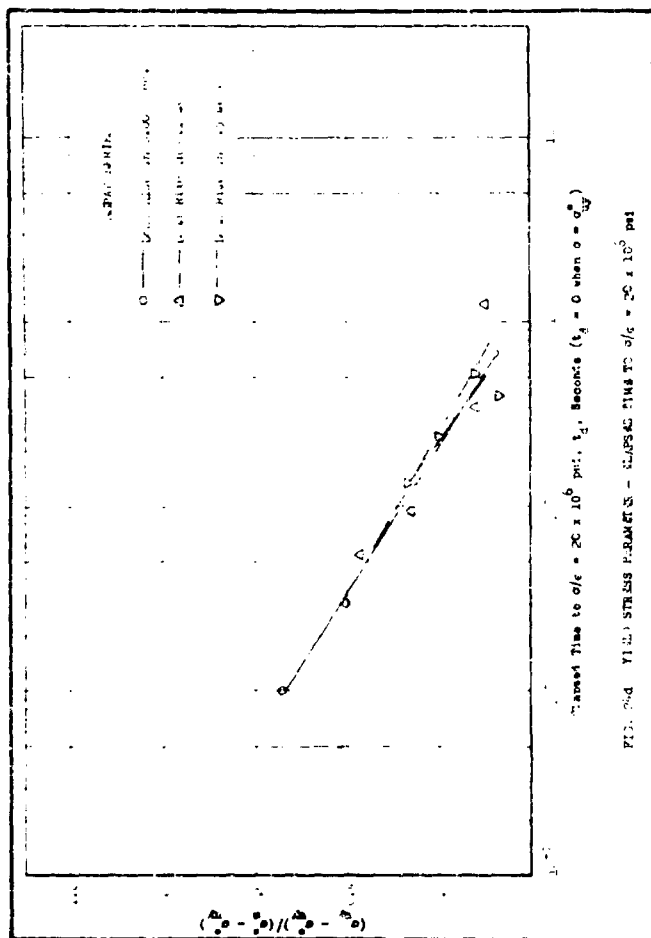
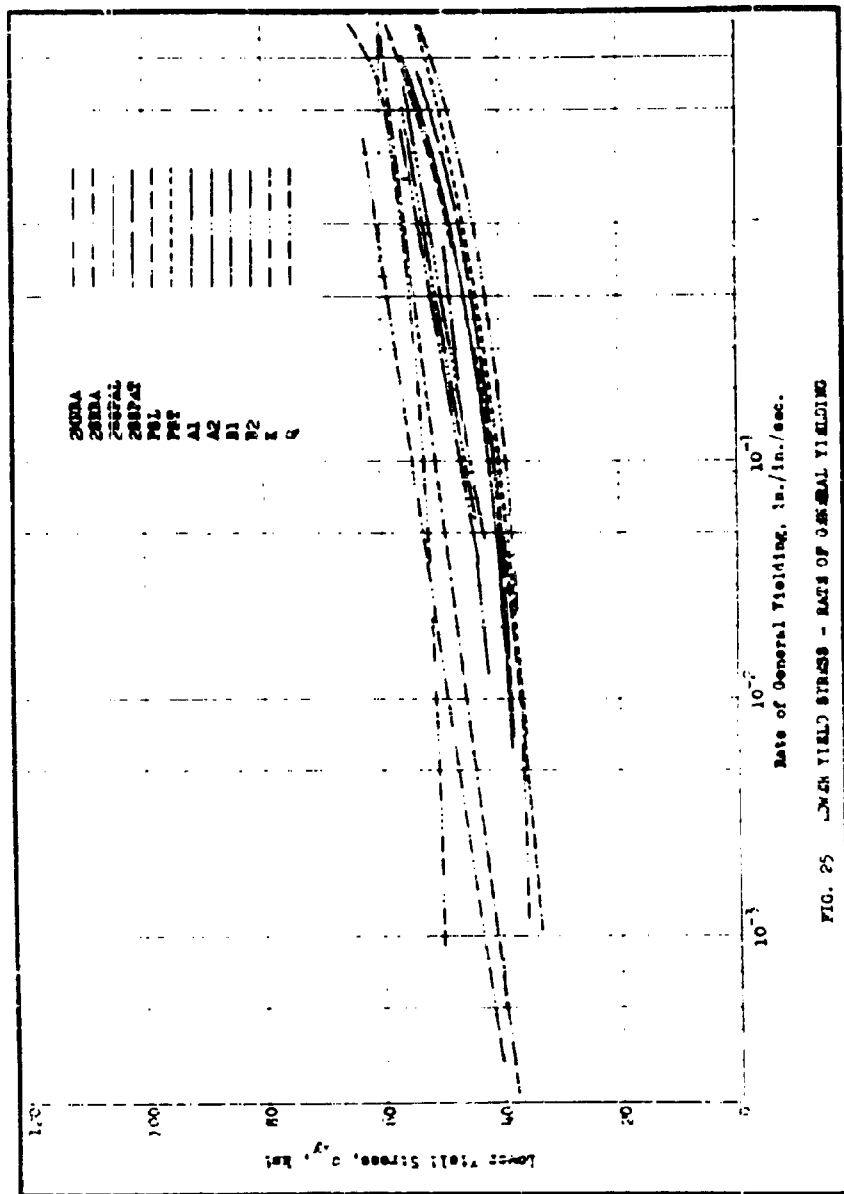
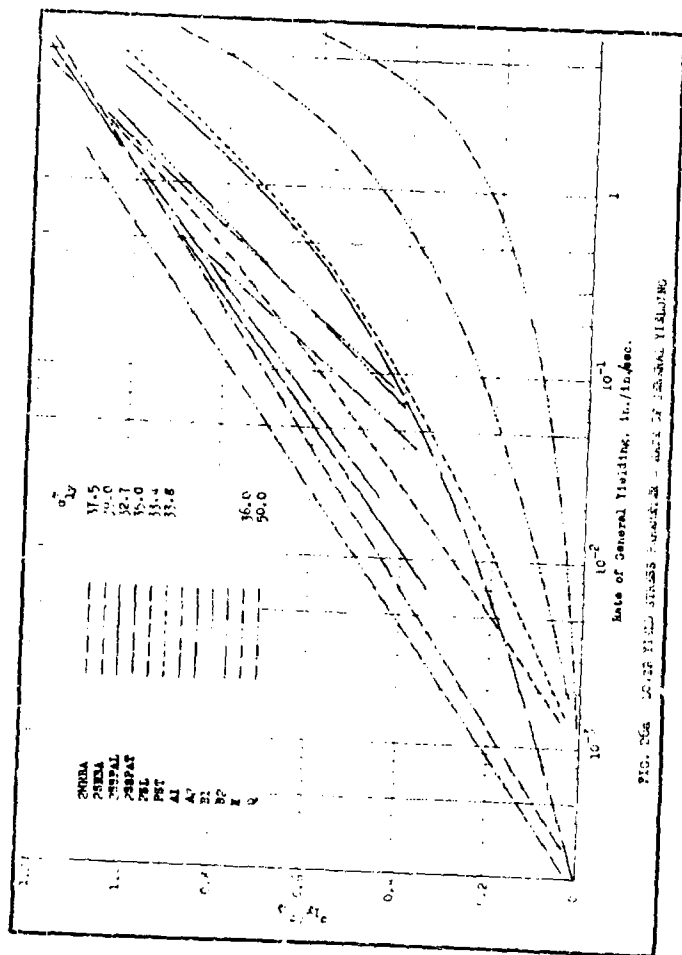


FIG. 2. YIELD STRESS PARAMETER - ELAPSED TIME TO $\sigma/\sigma_0 = 20 \times 10^5$ psi





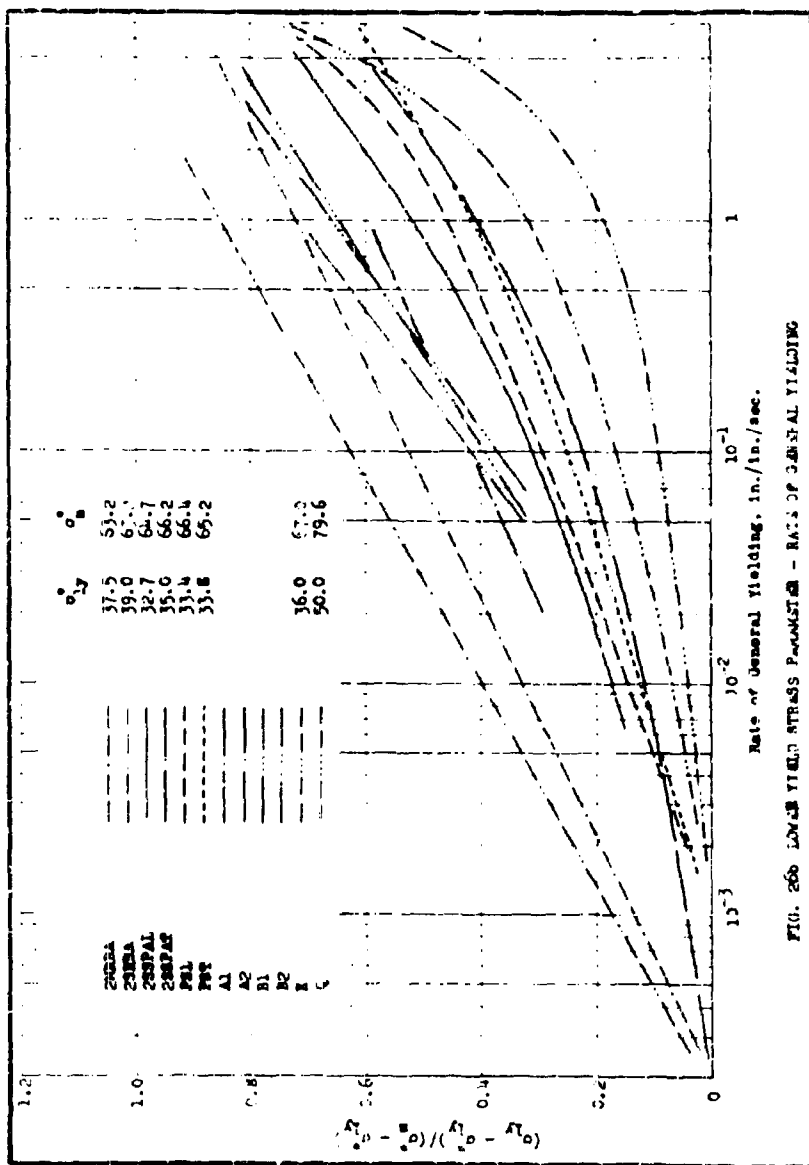


FIG. 266 LOW-LEVEL YIELD STRESS PARAMETERS - RATES OF GENERAL YIELDING

UNCLASSIFIED

A
D 210240

Armed Services Technical Information Agency

ARLINGTON HALL STATION
ARLINGTON 12 VIRGINIA

FOR
MICRO-CARD
CONTROL ONLY

510F7

NOTICE: WHEN GOVERNMENT OR OTHER DRAWINGS, SPECIFICATIONS OR OTHER DATA ARE USED FOR ANY PURPOSE OTHER THAN IN CONNECTION WITH A DEFINITELY RELATED GOVERNMENT PROCUREMENT OPERATION, THE U. S. GOVERNMENT THEREBY INCURS NO RESPONSIBILITY, NOR ANY OBLIGATION WHATSOEVER; AND THE FACT THAT THE GOVERNMENT MAY HAVE FORMULATED, FURNISHED, OR IN ANY WAY SUPPLIED THE SAID DRAWINGS, SPECIFICATIONS, OR OTHER DATA IS NOT TO BE REGARDED BY IMPLICATION OR OTHERWISE AS IN ANY MANNER LICENSING THE HOLDER OR ANY OTHER PERSON OR CORPORATION, OR CONVEYING ANY RIGHTS OF PERMISSION TO MANUFACTURE, USE OR SELL ANY PATENTED INVENTION THAT MAY IN ANY WAY BE RELATED THERETO.

UNCLASSIFIED

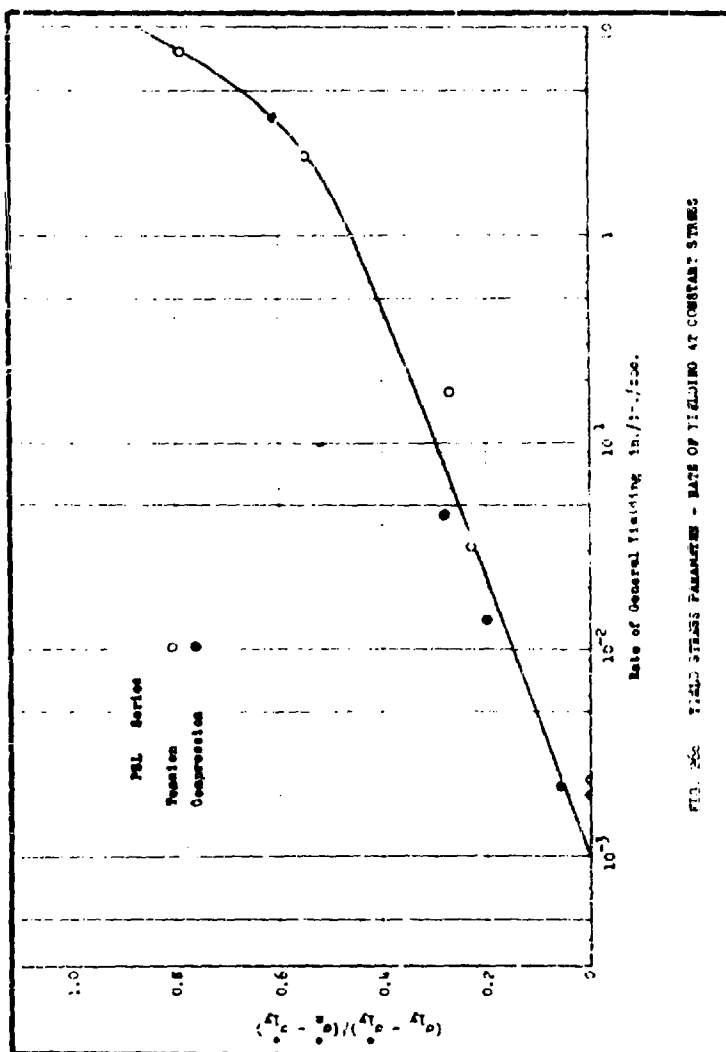


FIG. 266 YIELD STRESS PARAMETER - RATE OF YIELDING AT CONSTANT STRESS

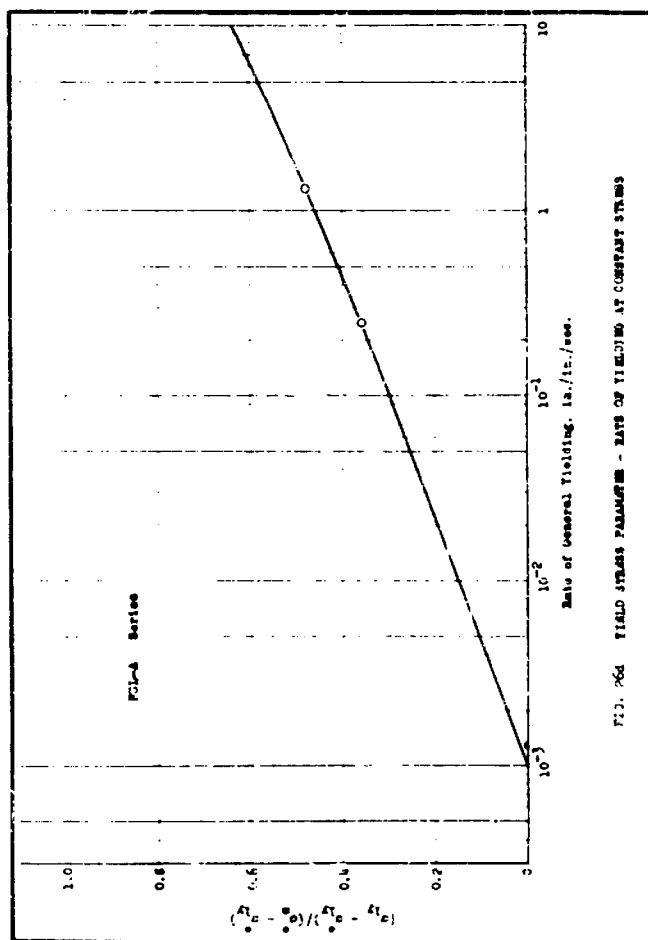
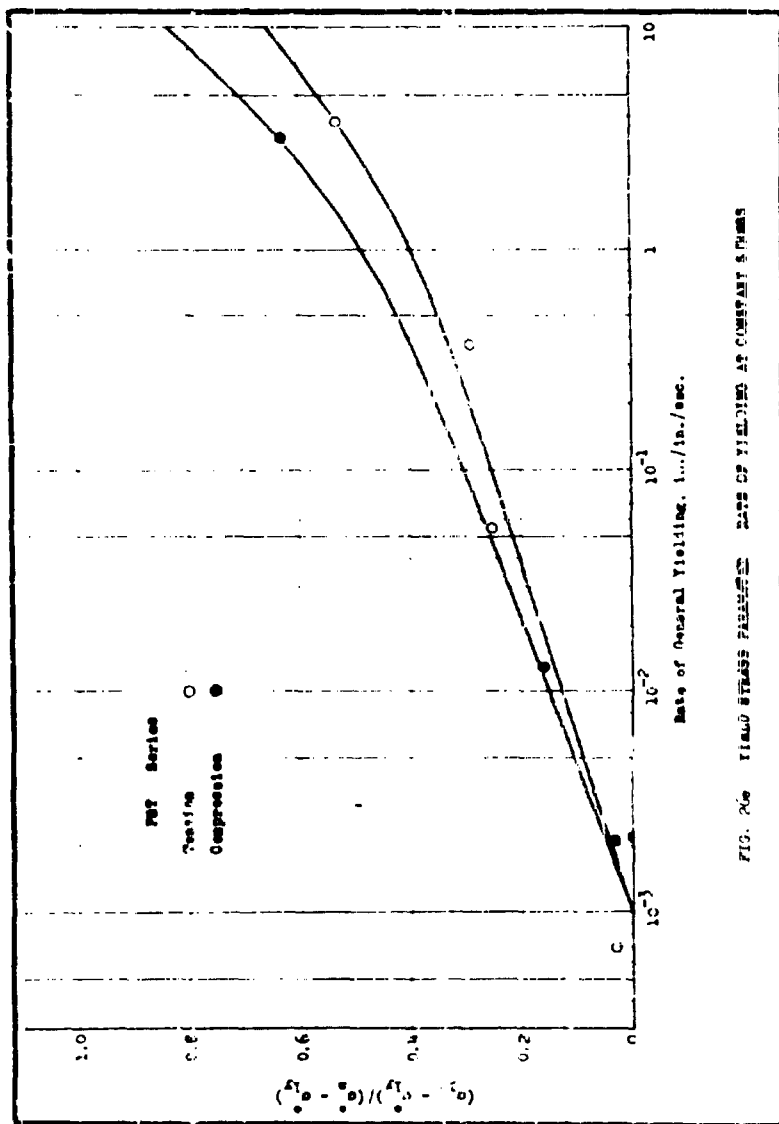


FIG. 76d YIELD STRESS PARAMETER - RATE OF YIELDING AT CONSTANT STRESS



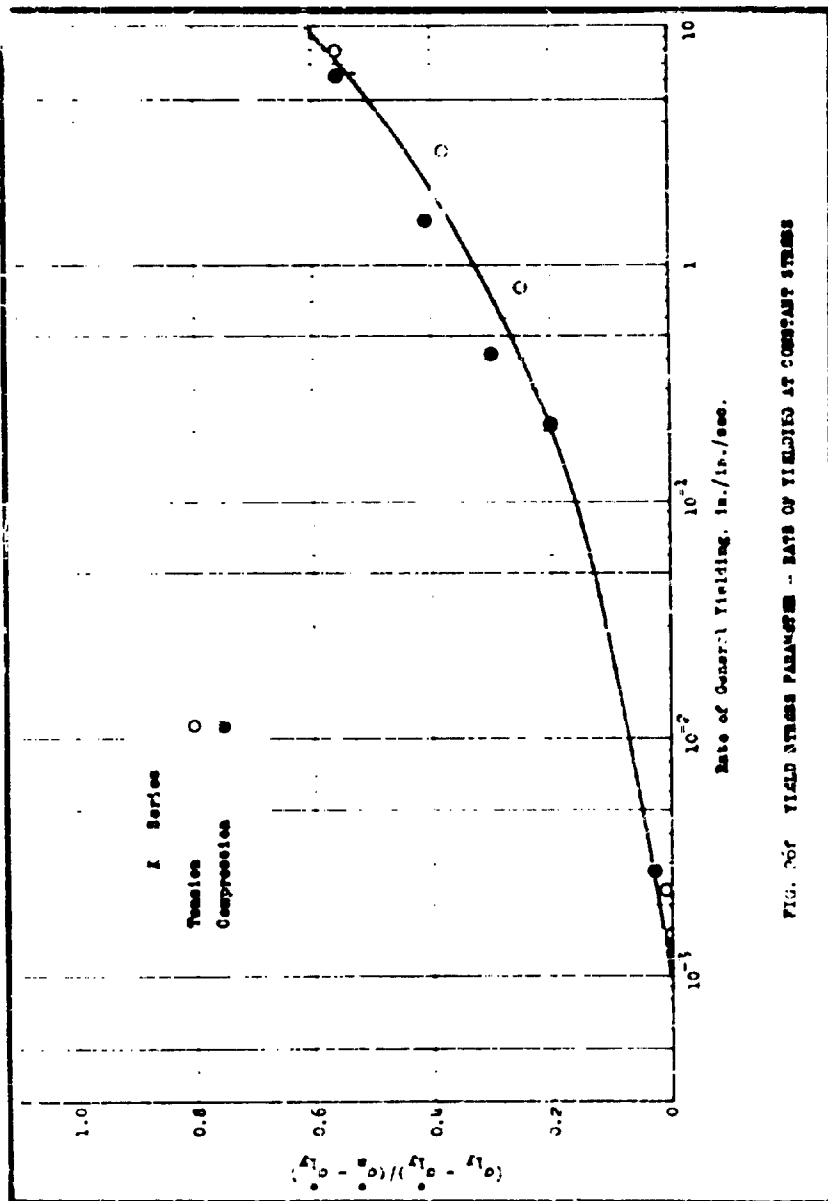
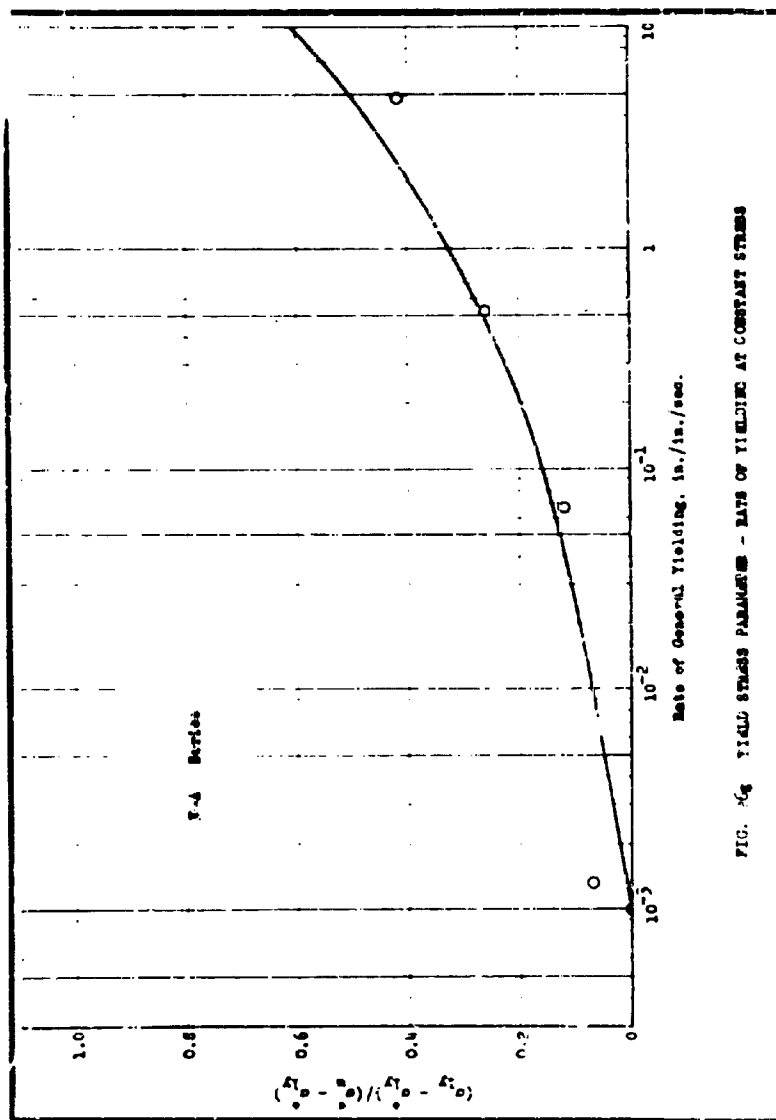


FIG. 106 YIELD STRESS PARAMETER - RATE OF YIELDED AT CONSTANT STRESS



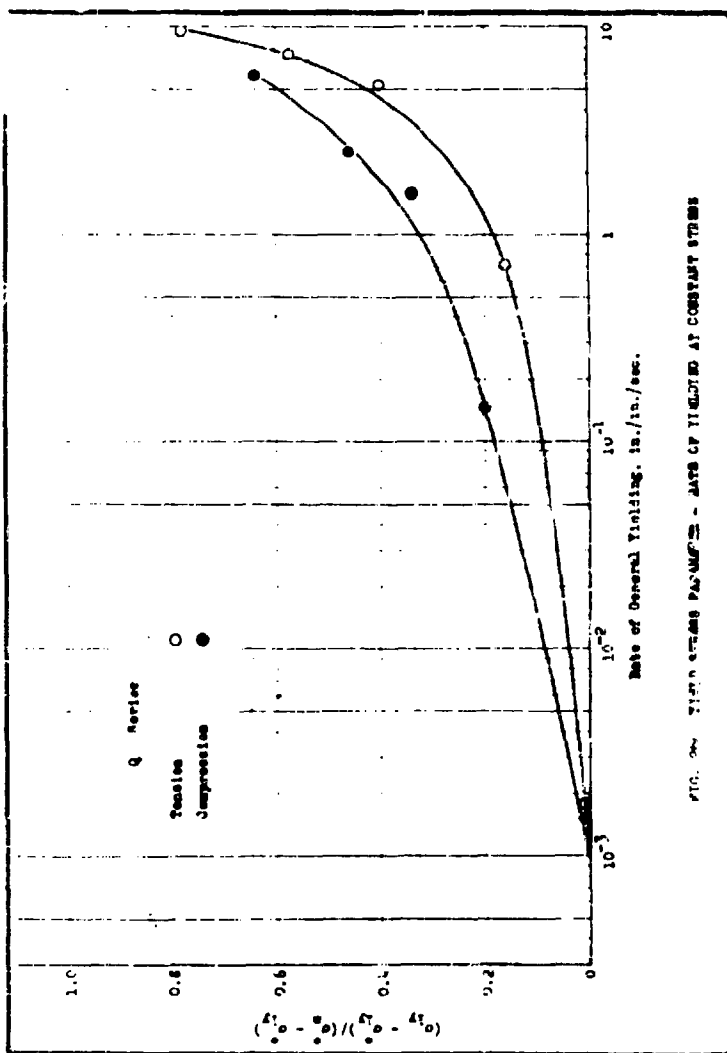


FIG. 10. TENSION AND COMPRESSION - RATE OF YIELDING AT CONSTANT STRESS

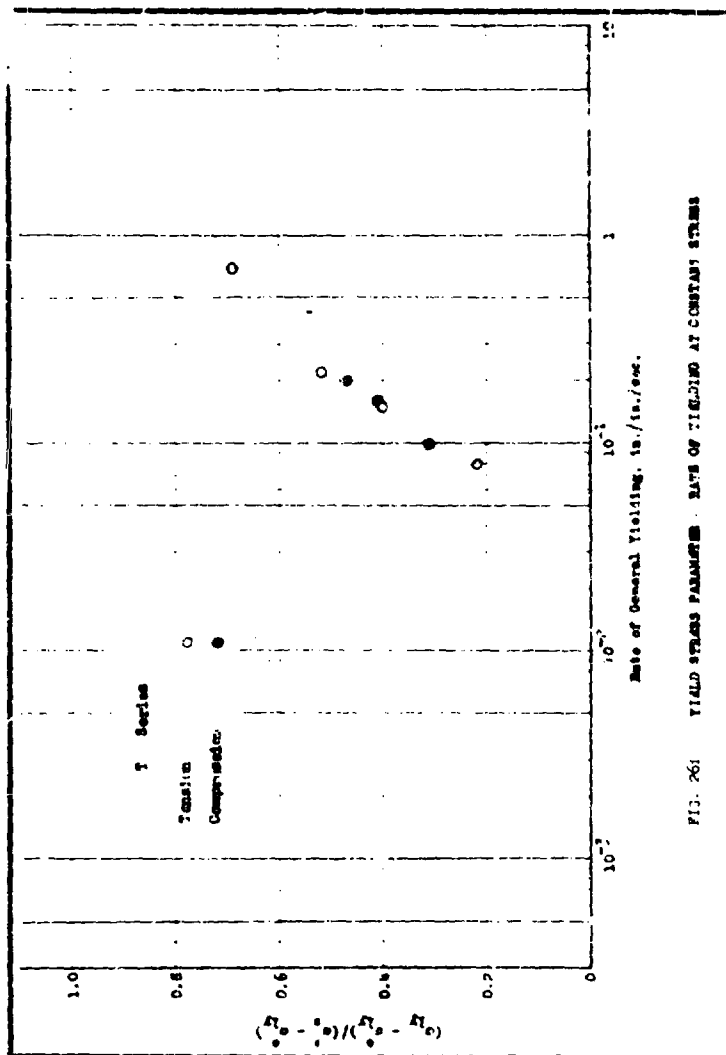


FIG. 261 YIELD STRESS PARAMETER - RATE OF YIELDING AT CONSTANT STRESS

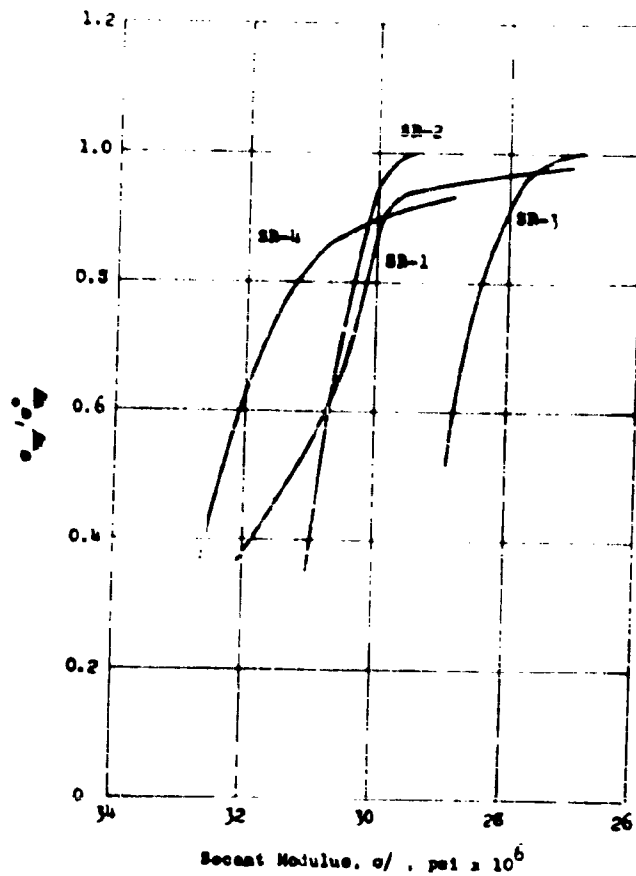


FIG. 27 UPPER YIELD STRESS PARAMETER = SECANT MODULUS

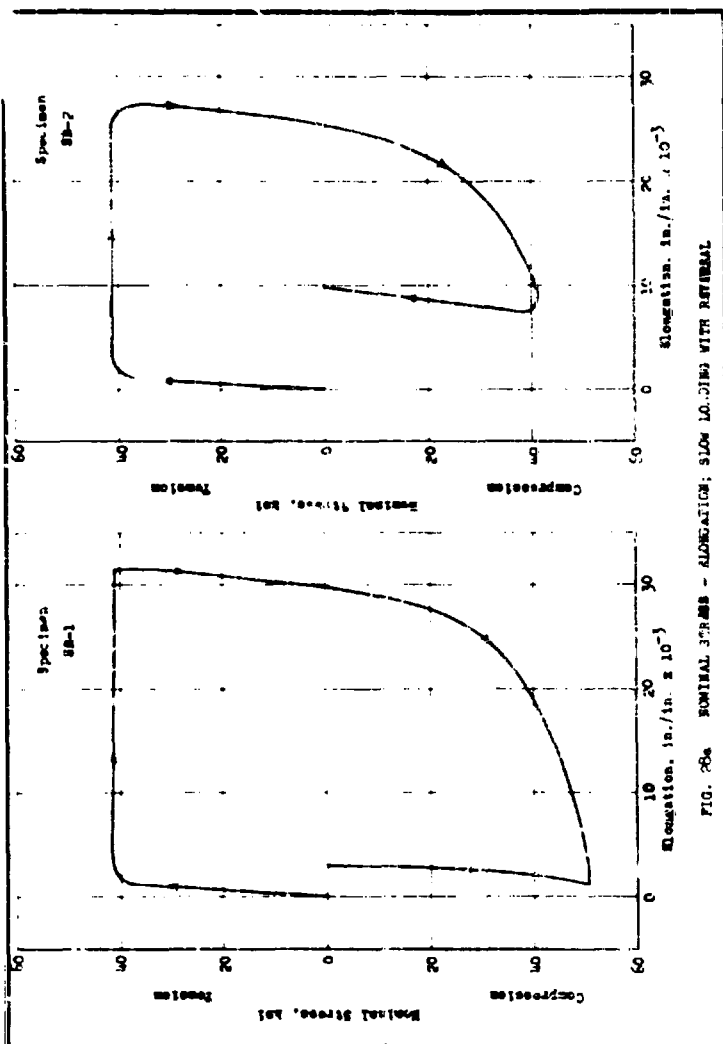


FIG. 28a. NOMINAL STRESS - ELONGATION; SLOW LOADING WITH RETRAVAL

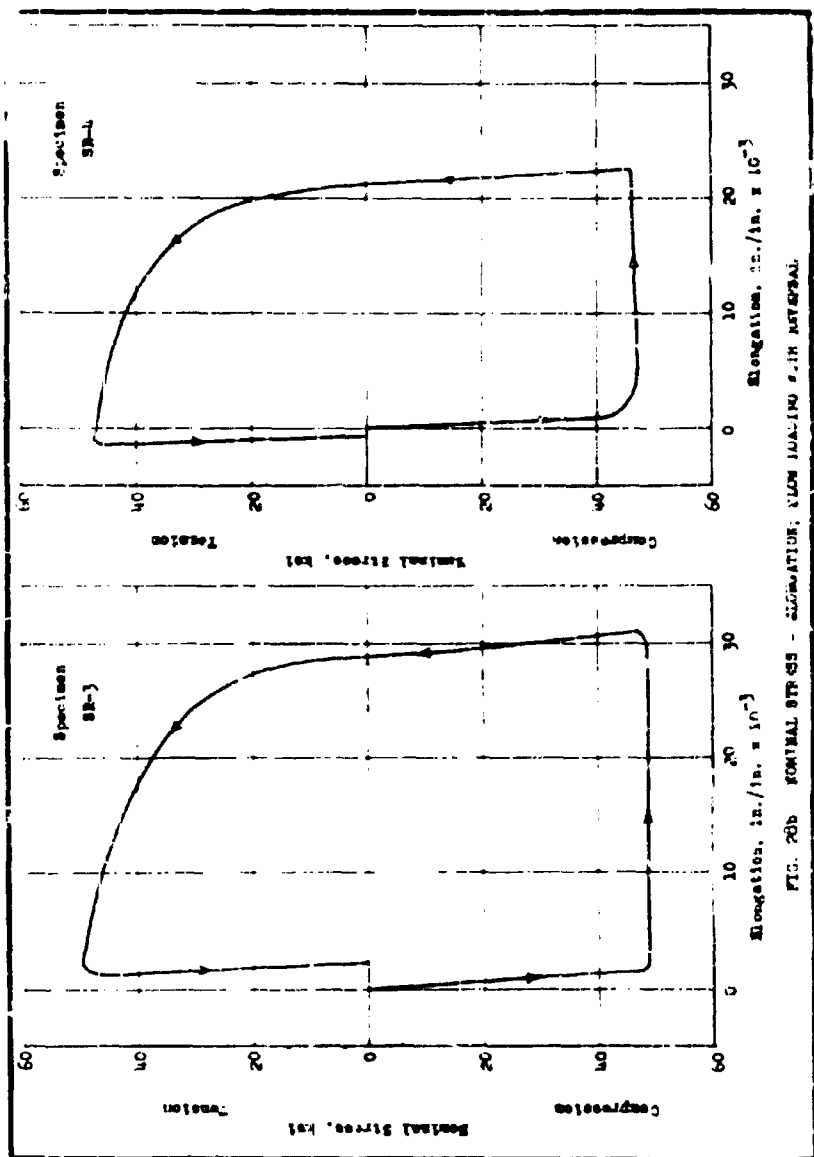


FIG. 20b NOMINAL STRESS - ELONGATION; LOW LOADING 0.1% REVERSAL

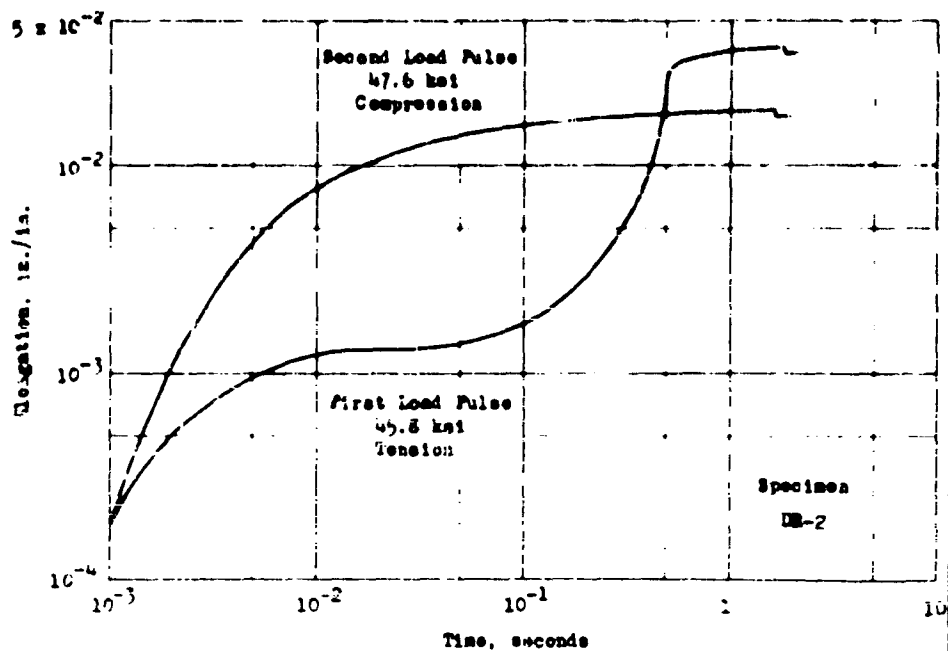
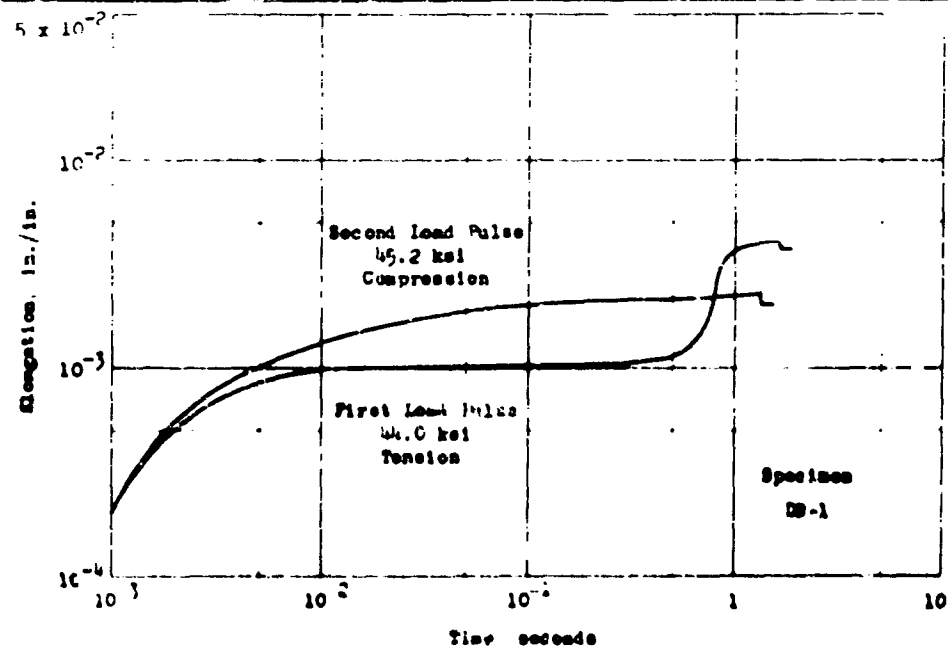


FIG. 29a ELONGATION - TIME; RAPID LOADING WITH REVERSAL

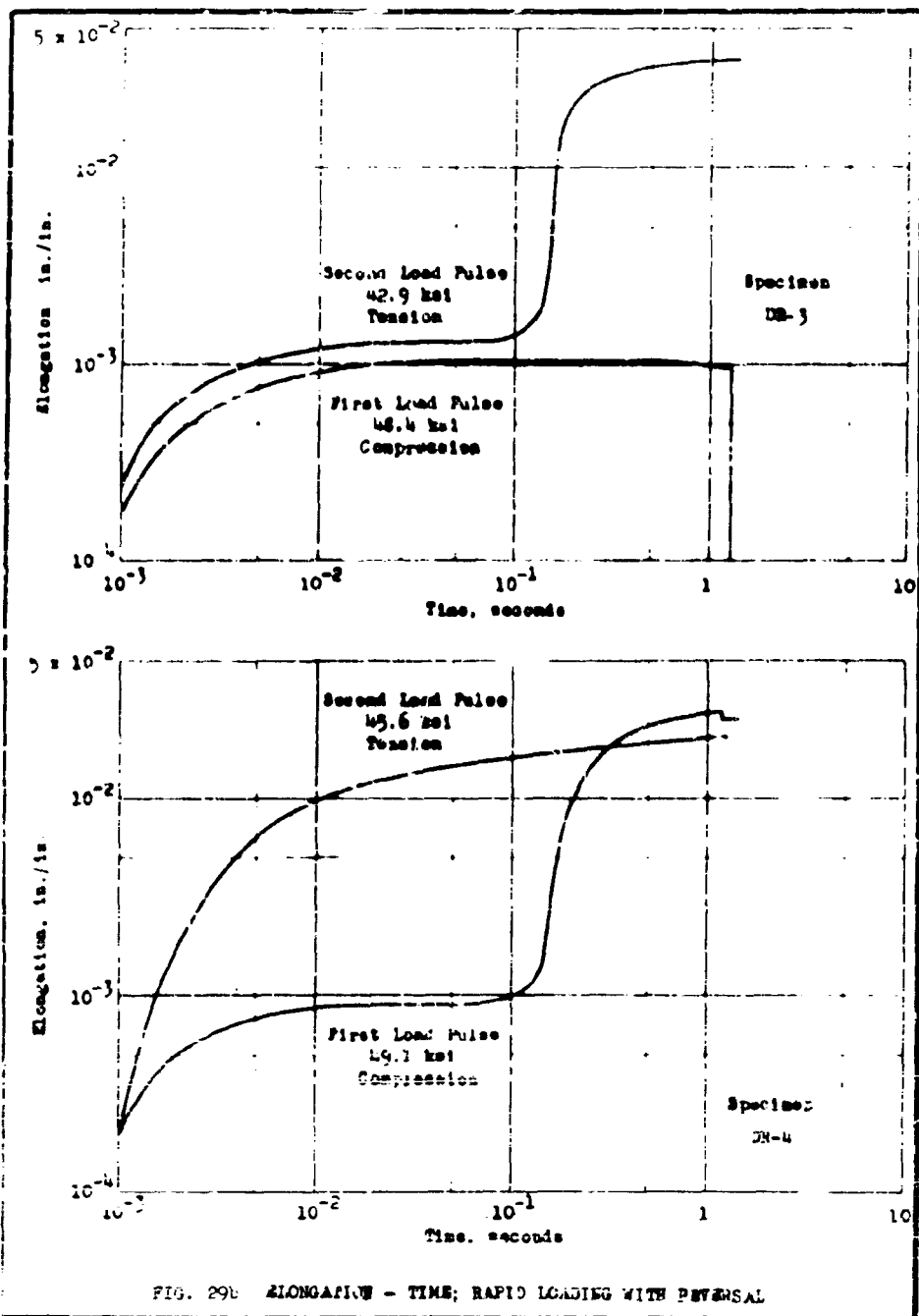
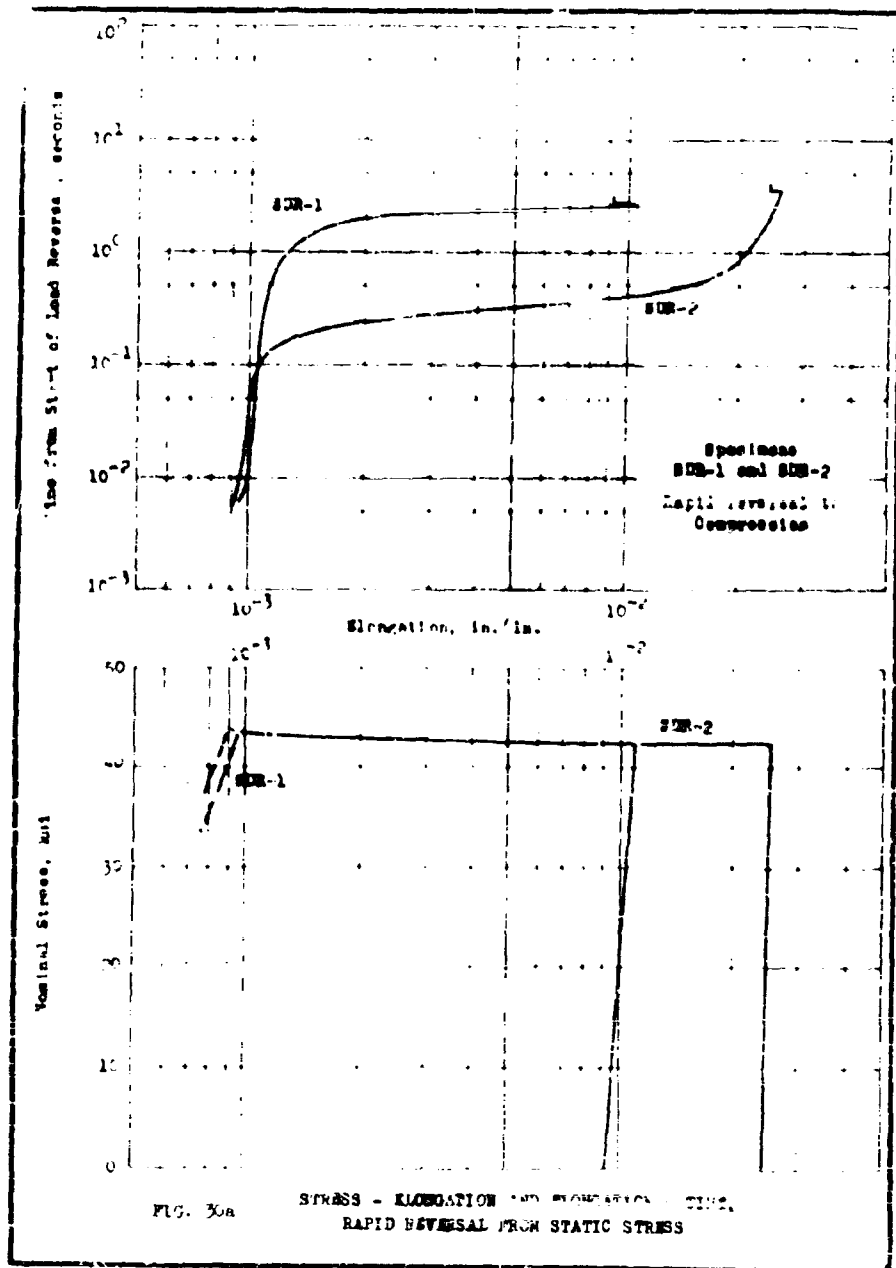


FIG. 29b ELONGATION - TIME; RAPID LOADING WITH REVERSAL



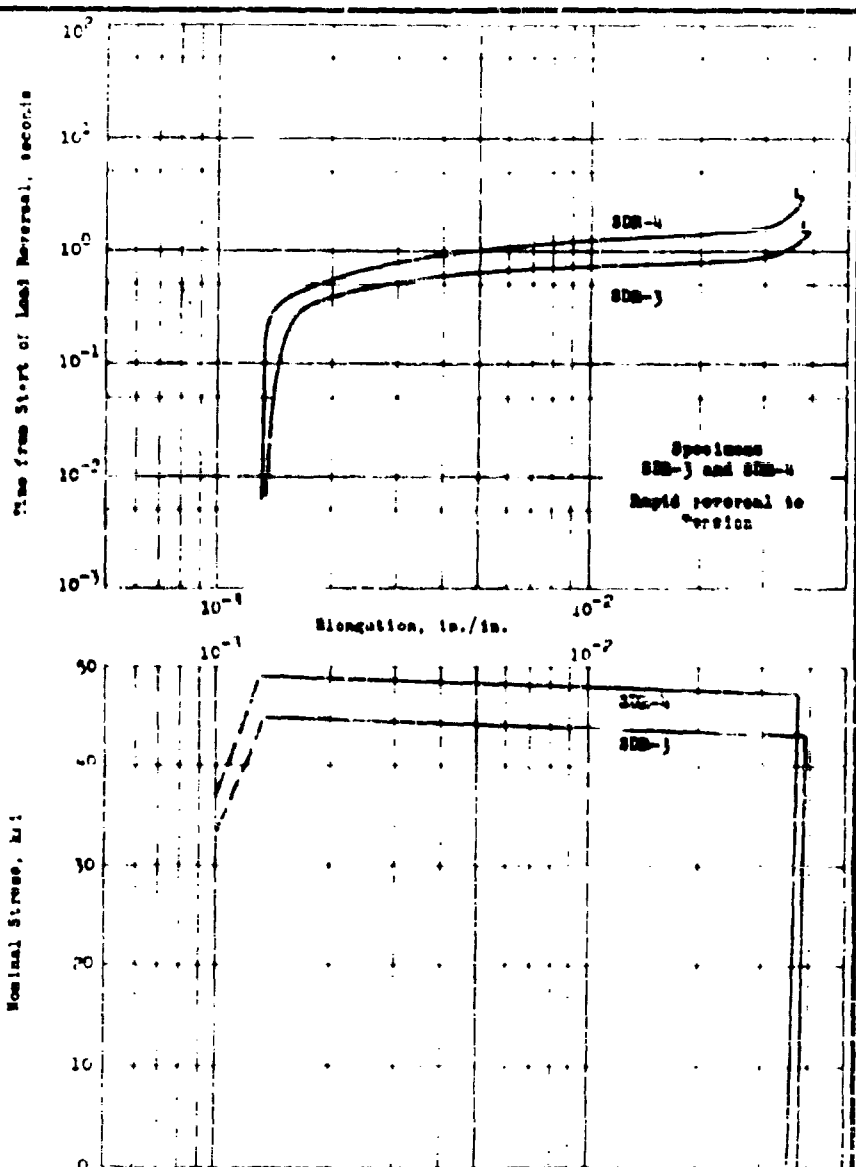


FIG. 30b

STRESS - ELONGATION AND ELONGATION - TIME;
RAPID REVERSAL FROM STATIC STRESS

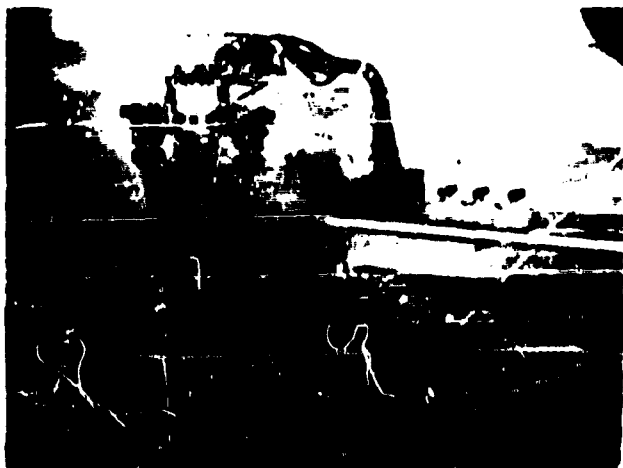


FIG. 51 OVERALL VIEW OF FLEXURAL TESTING EQUIPMENT

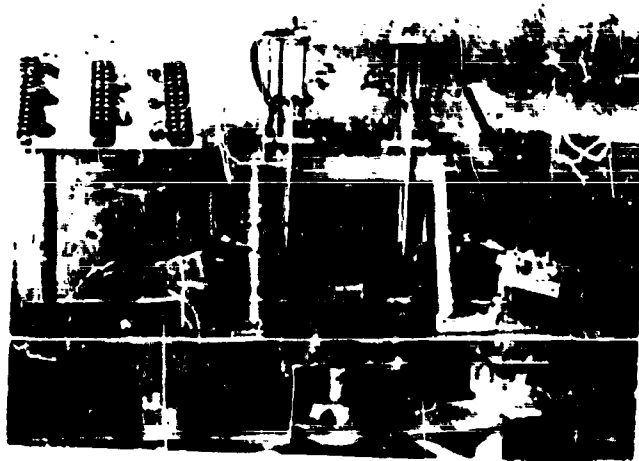


FIG. 31 ARRANGEMENT FOR TESTING SMALL ARMS TARGETS AT THE TEST RANGE

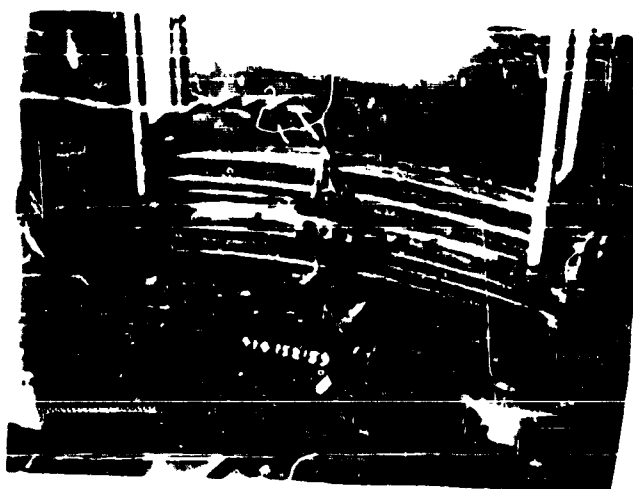


FIG. 32 VIEW OF THE TARGET STAND WITH TARGETS

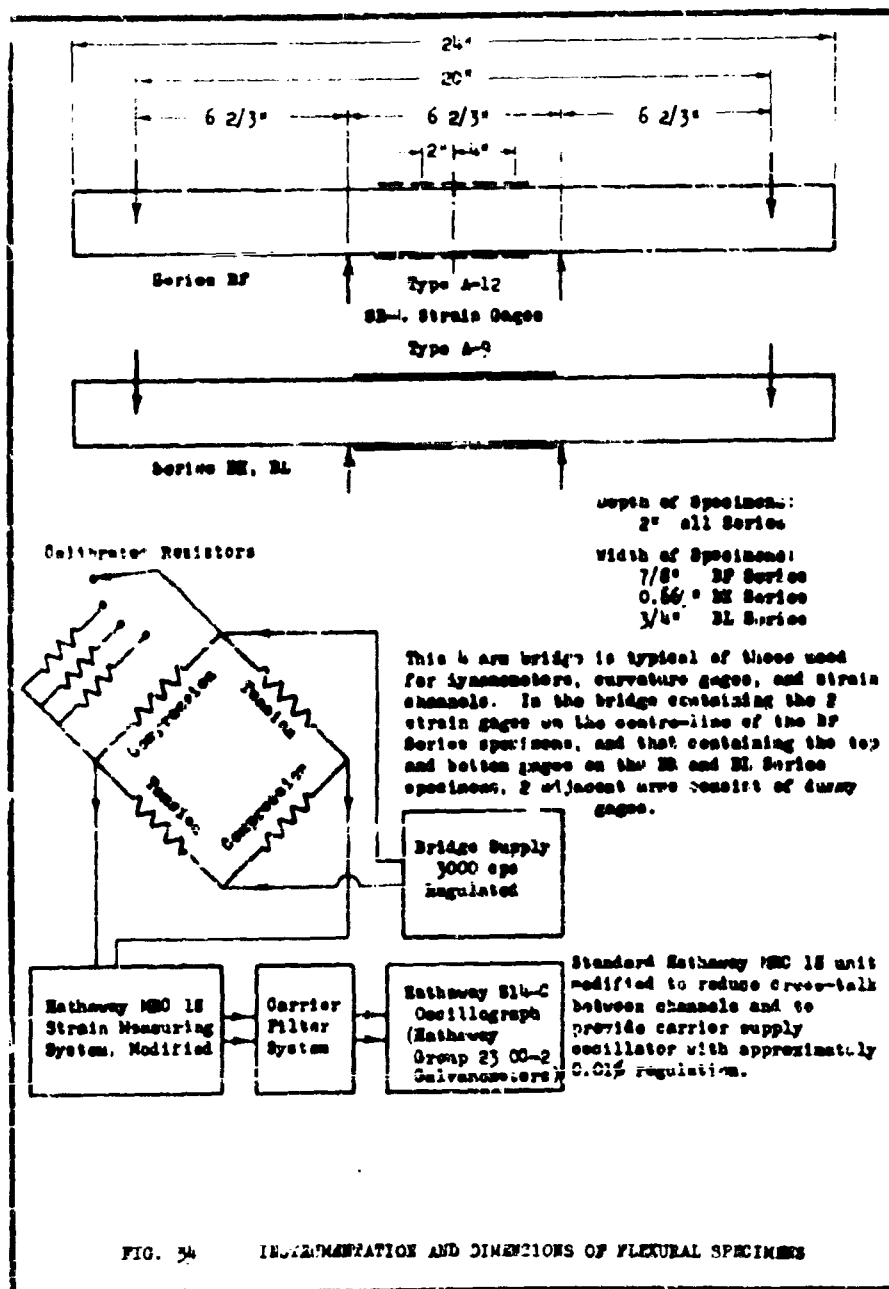
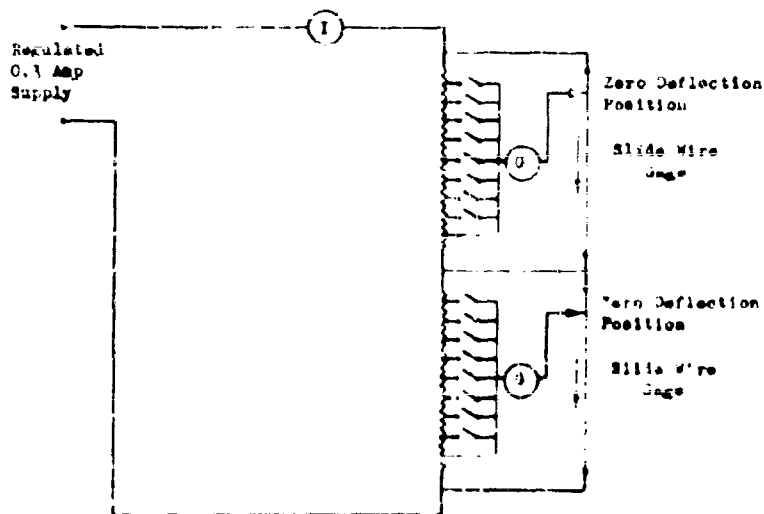


FIG. 34

INSTRUMENTATION AND DIMENSIONS OF FLEXURAL SPECIMENS



At zero deflection, bridge circuit had maximum unbalance. Both calibration switches and slide wagers were moved bridge towards balance.

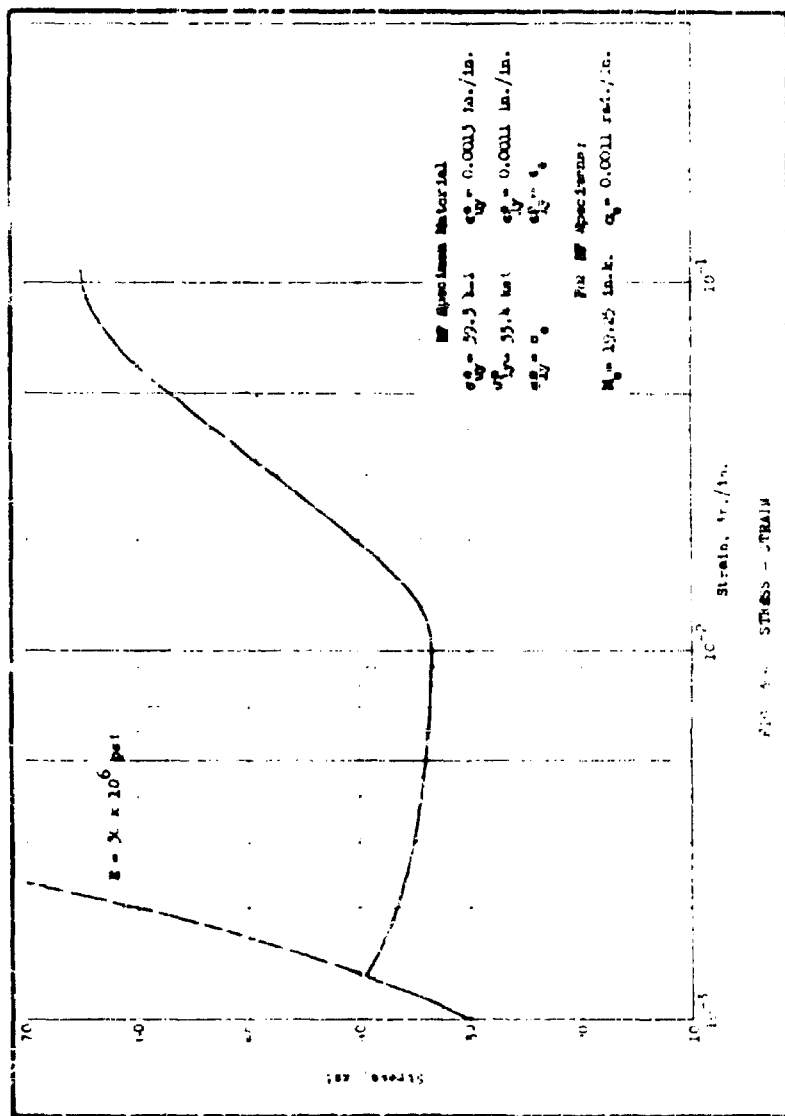
The switches were used to set the sensitivity of the bridge circuit. When used as calibration switches, they are roughly equivalent to 1% of deflection each.

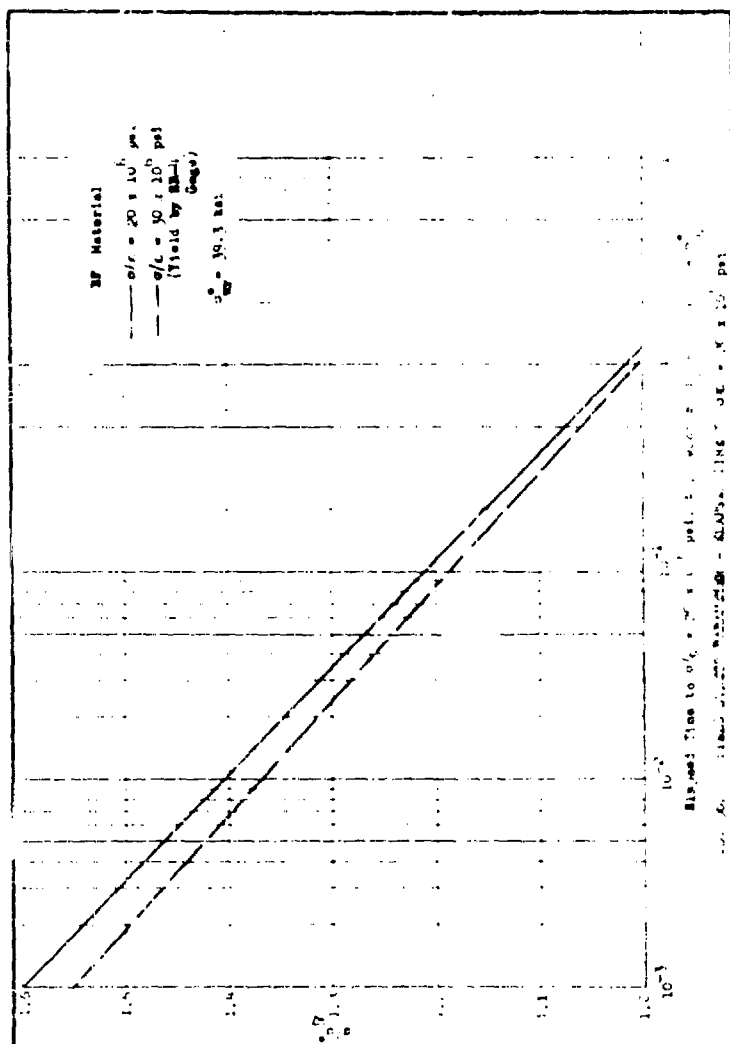
For BF Series specimens, one additional similar bridge was used.

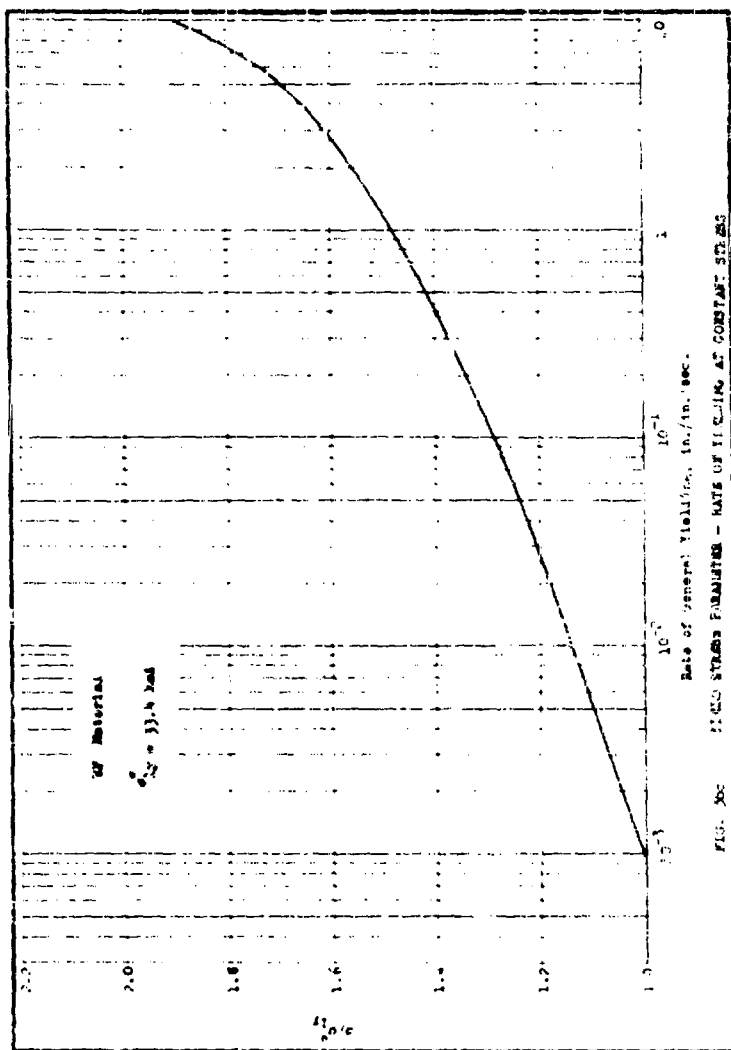
*G represents a galvanometer.

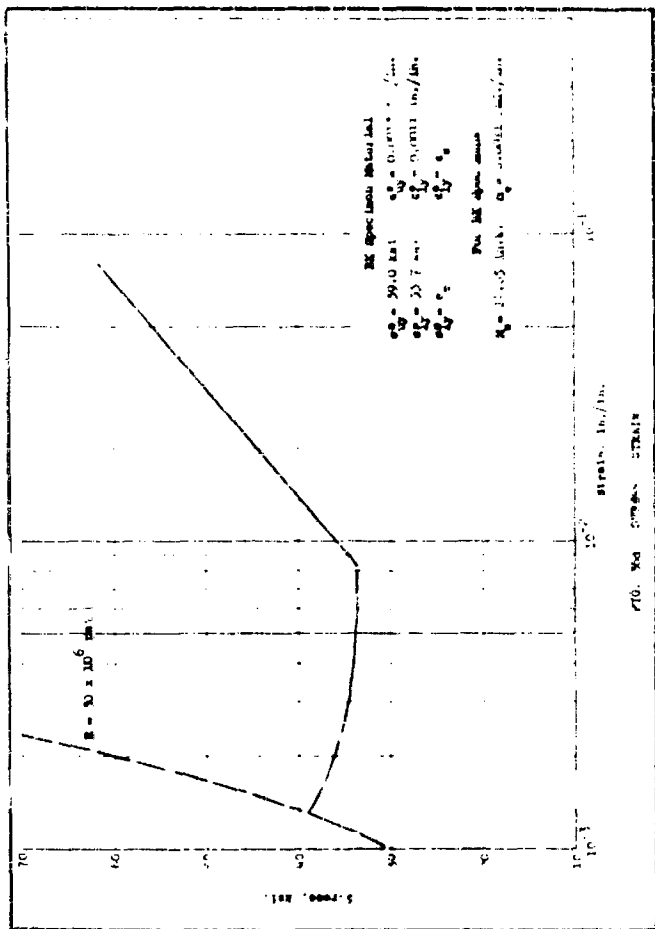
*A represents an ammeter.

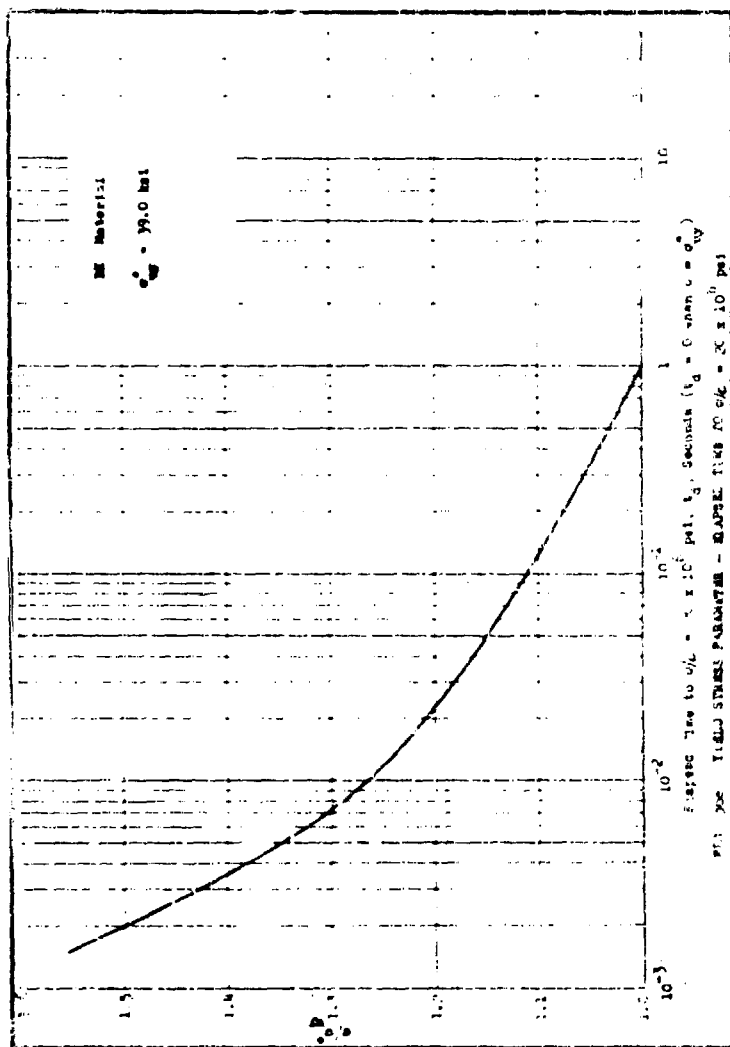
FIG. 15 DEFLECTION BRIDGE CIRCUITS

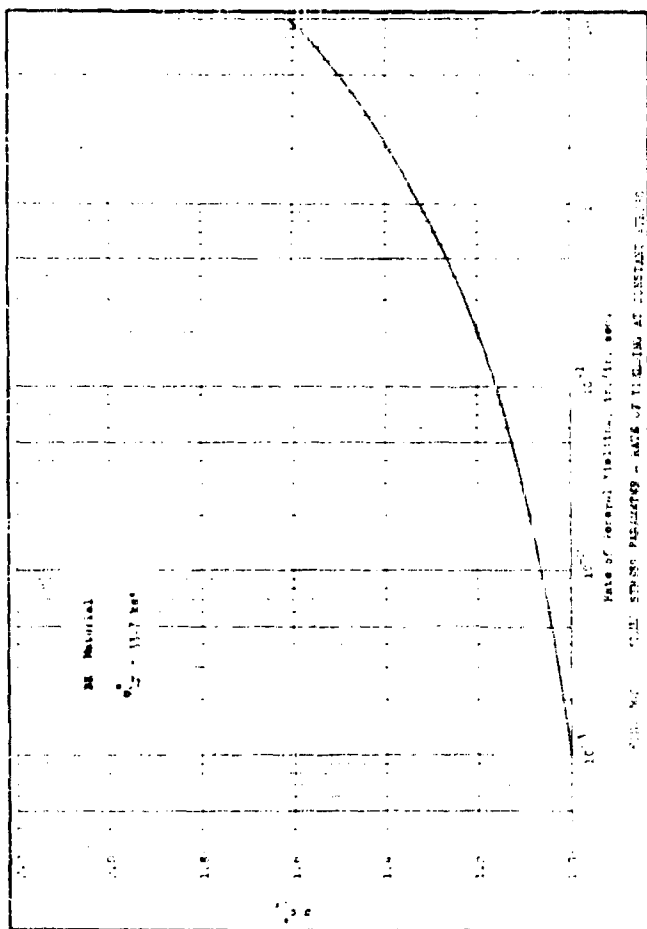






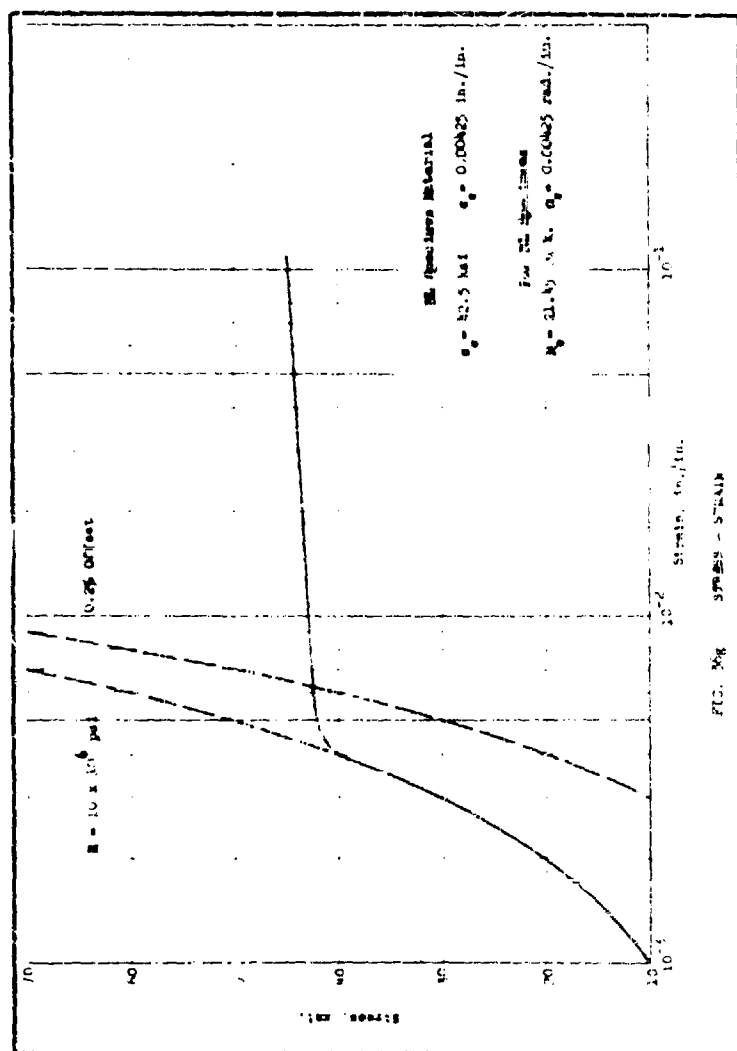






Rate of creep (in./in./hr.)

Rate of loading (in./in./hr.)



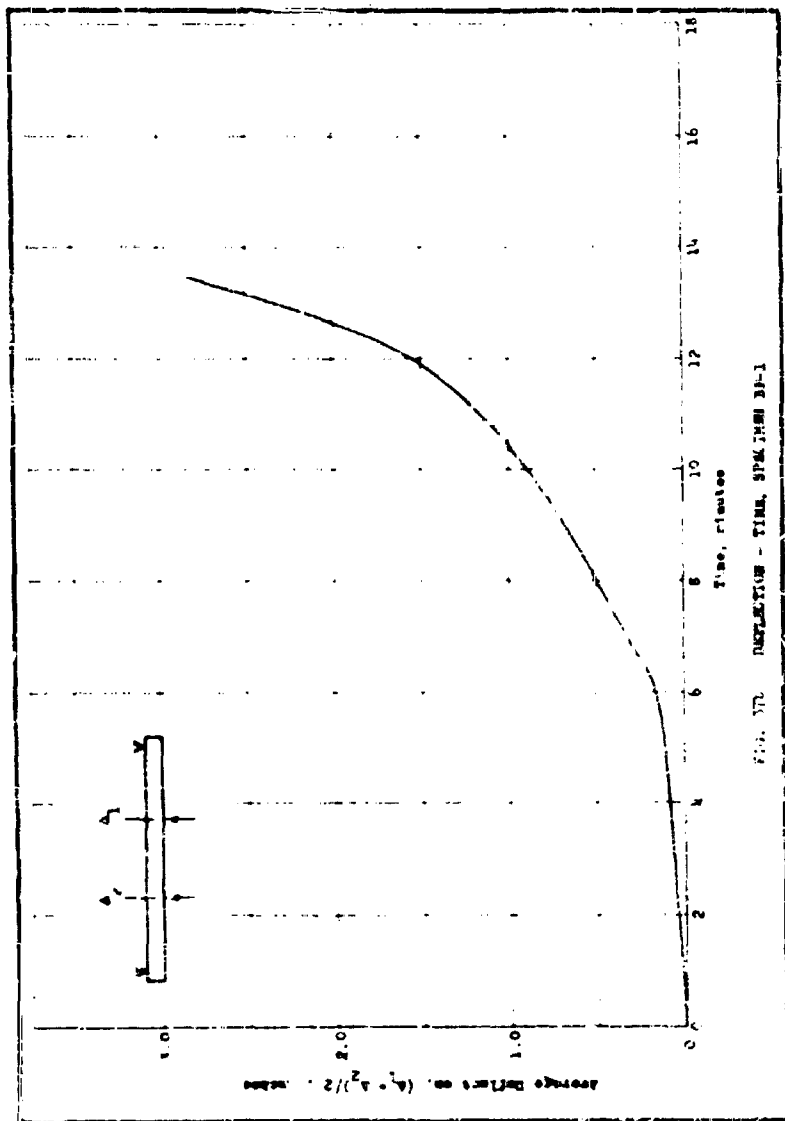
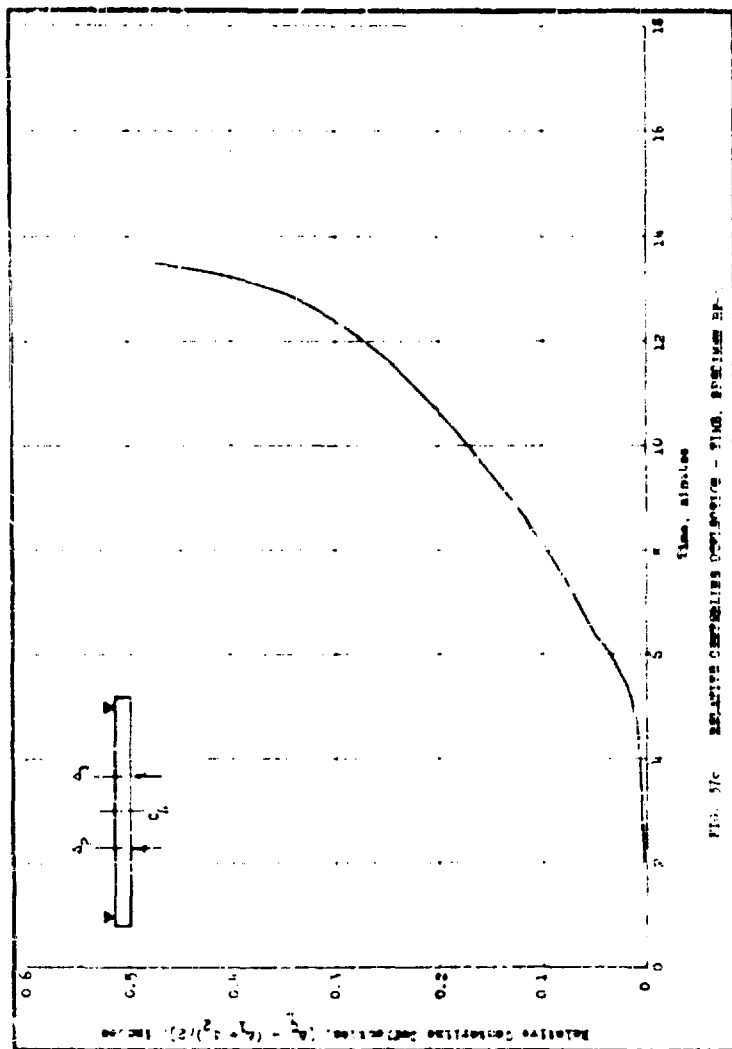
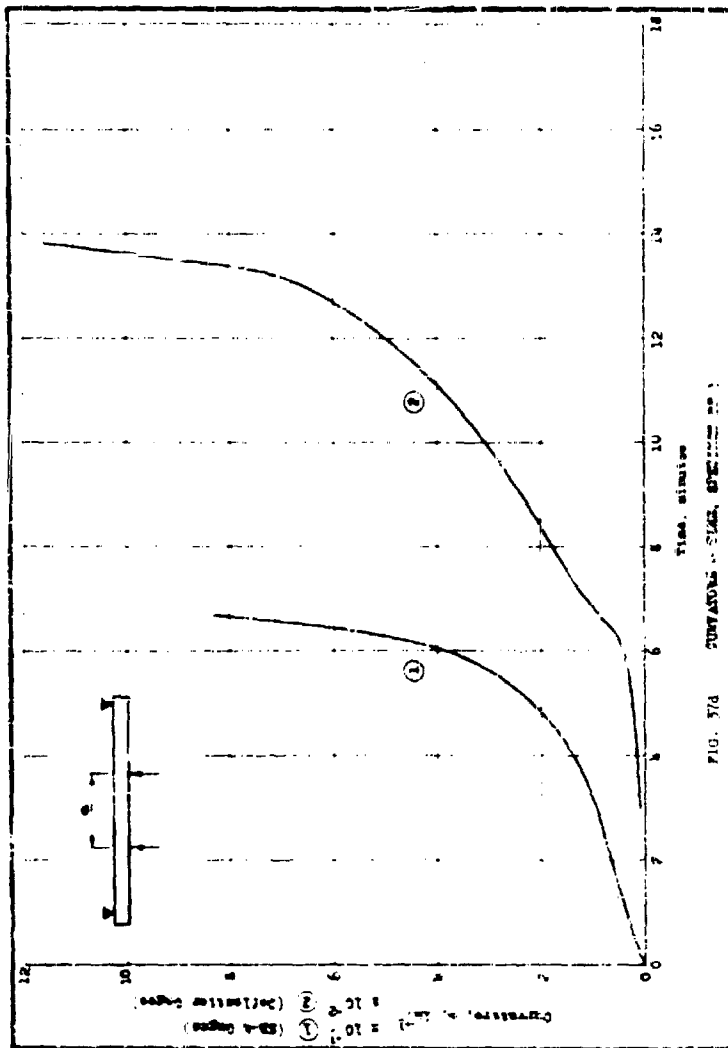


FIG. 37C DEFLECTION - TIME, SPECIMEN 3A-1





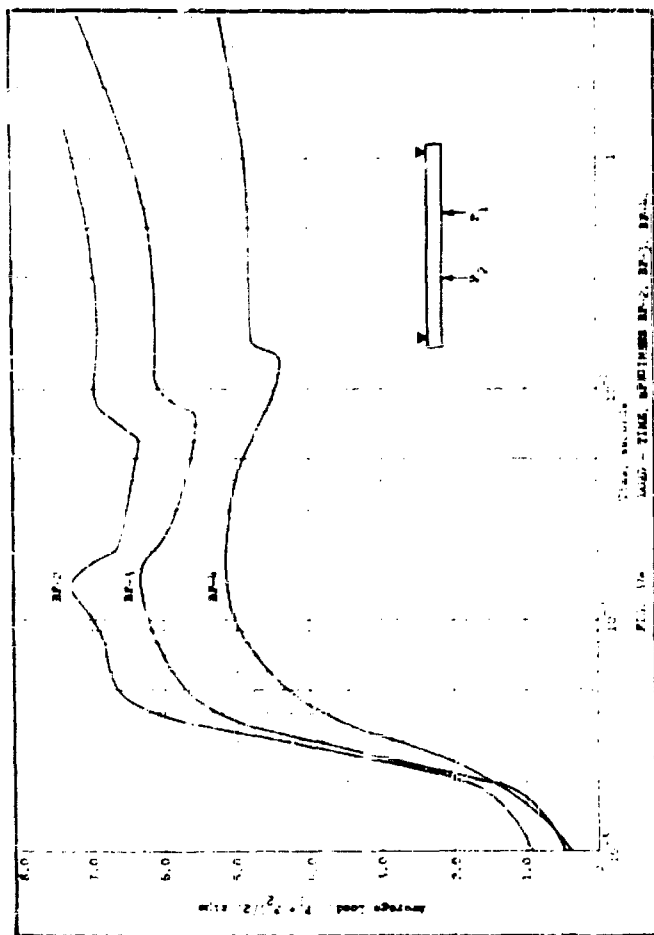
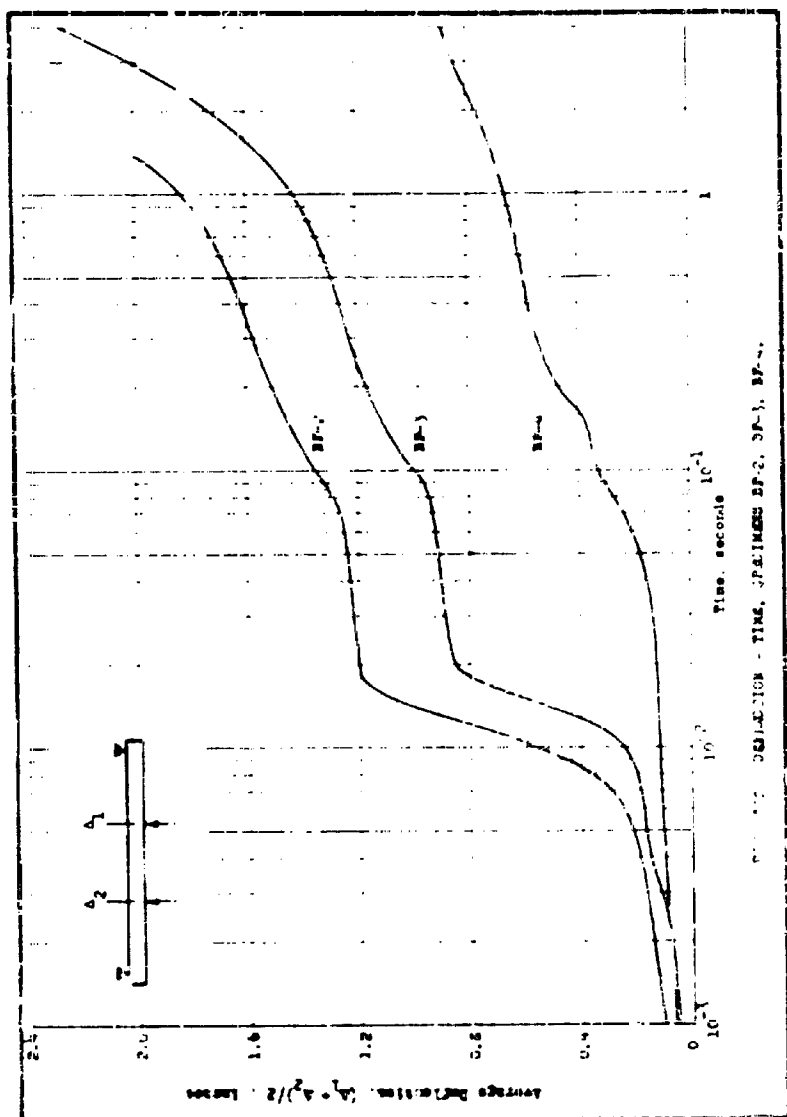


Fig. 10
Time, minutes
Load - Time, Specimens BP-2, BP-1, BP-4



UNCLASSIFIED

A
D
210240

Armed Services Technical Information Agency

ARLINGTON HALL STATION
ARLINGTON 12 VIRGINIA

FOR

MICRO CARD

CONTROL ONLY

6 OF 7

NOTICE: WHEN GOVERNMENT OR OTHER DRAWINGS, SPECIFICATIONS OR OTHER DATA ARE USED FOR ANY PURPOSE OTHER THAN IN CONNECTION WITH A DEFINITELY RELATED GOVERNMENT PROCUREMENT OPERATION, THE U. S. GOVERNMENT THEREBY INCURS NO RESPONSIBILITY, NOR ANY OBLIGATION WHATSOEVER; AND THE FACT THAT THE GOVERNMENT MAY HAVE FORMULATED, FURNISHED, OR IN ANY WAY SUPPLIED THE SAID DRAWINGS, SPECIFICATIONS, OR OTHER DATA IS NOT TO BE REGARDED BY IMPLICATION OR OTHERWISE AS IN ANY MANNER LICENSING THE HOLDER OR ANY OTHER PERSON OR CORPORATION, OR CONVEYING ANY RIGHTS OR PERMISSION TO MANUFACTURE, USE OR SELL ANY PATENTED INVENTION THAT MAY IN ANY WAY BE RELATED THERETO.

UNCLASSIFIED

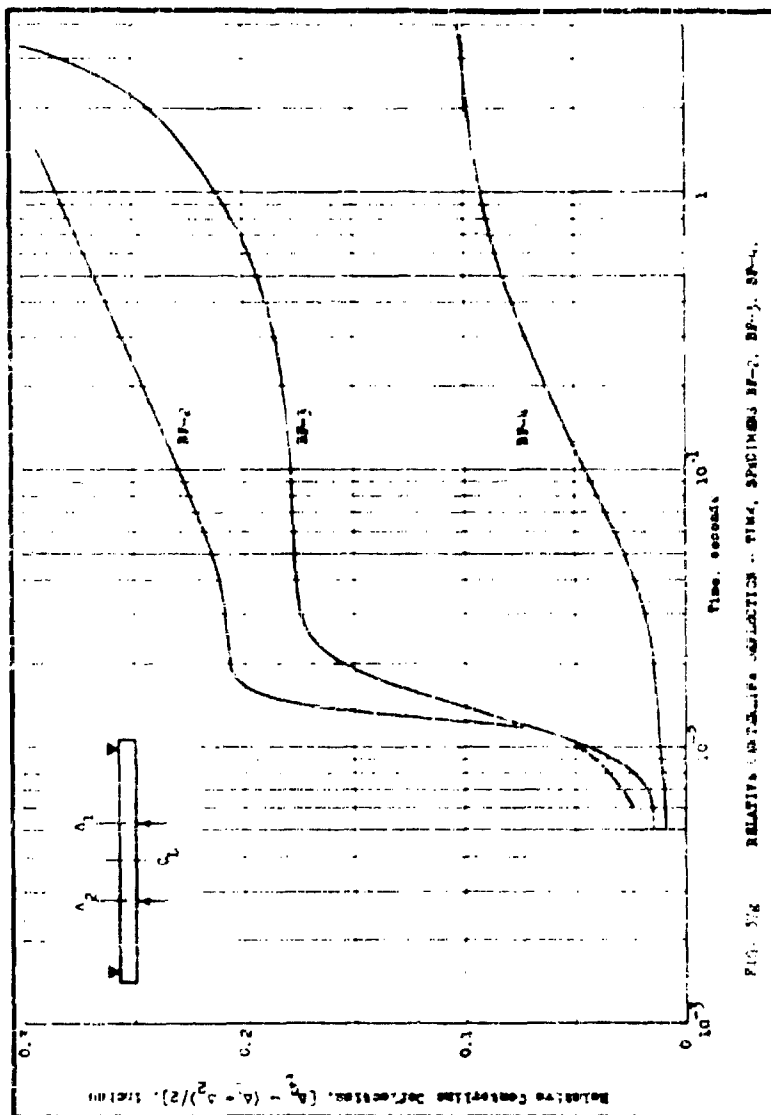
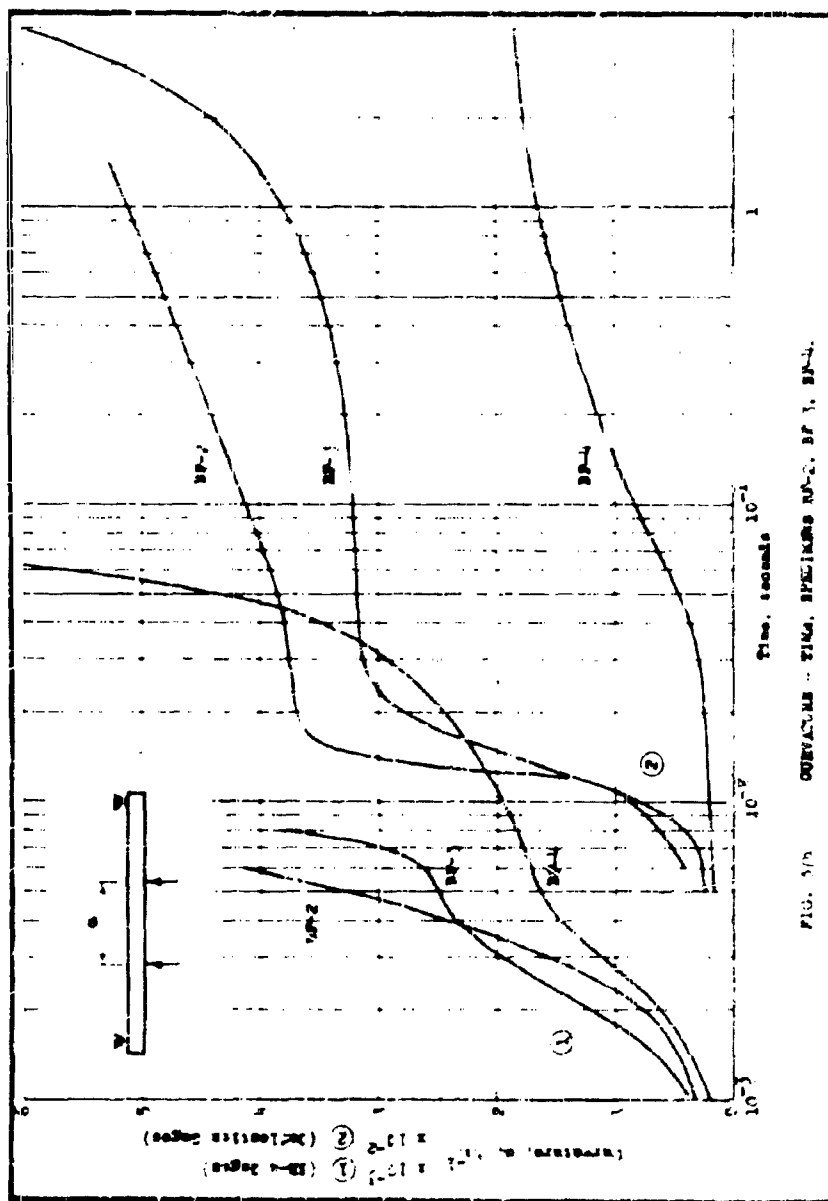
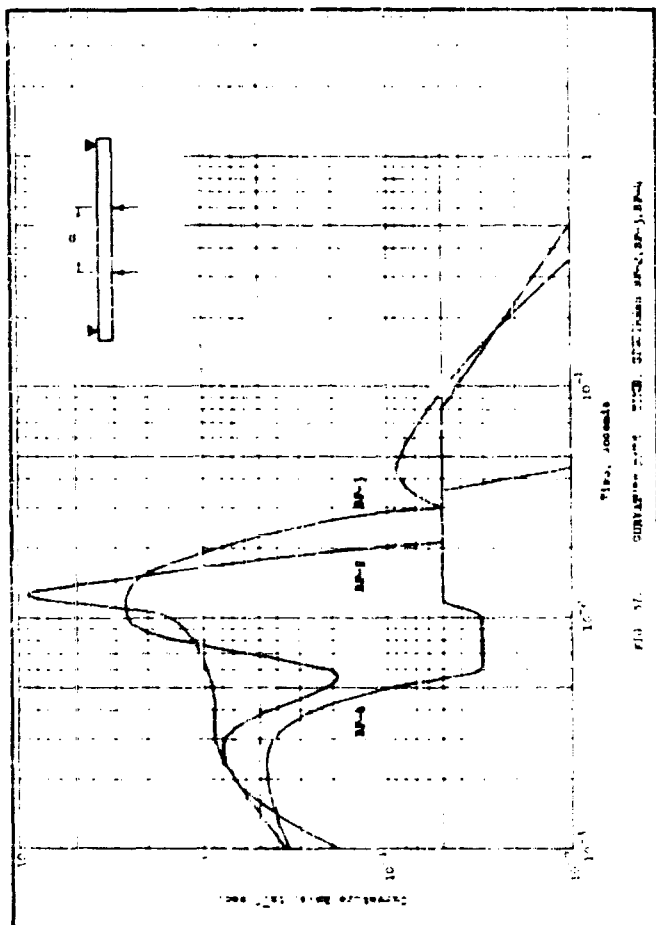
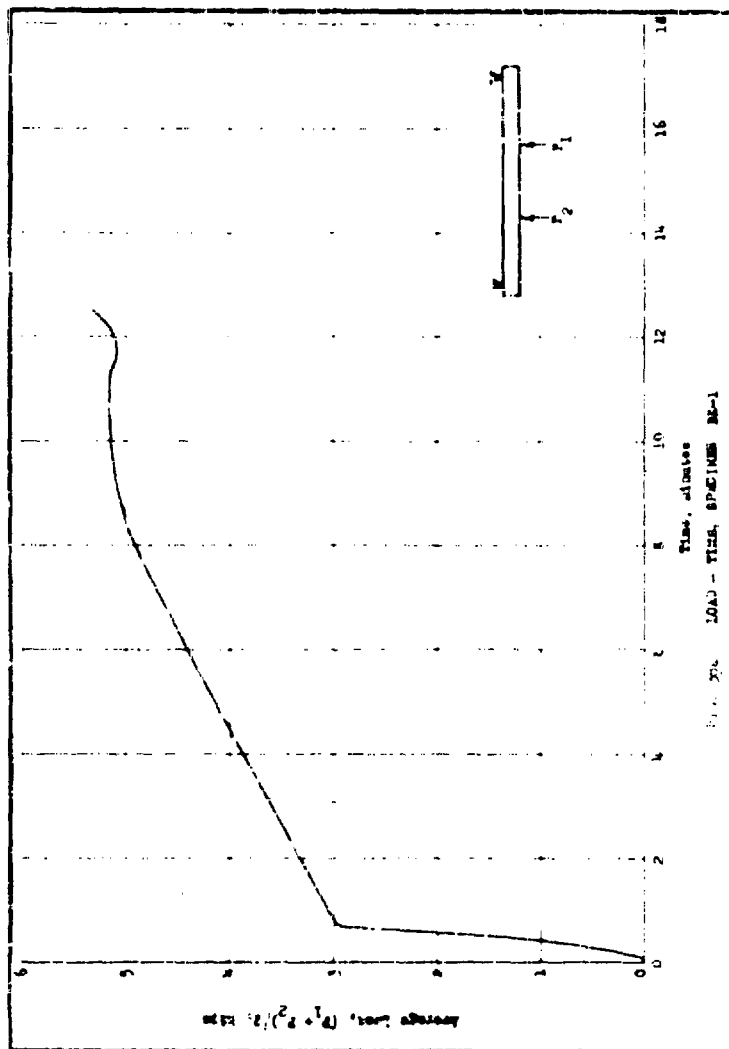


FIG. 5/2 RELATIVE ENTALPIES OF SPECIMENS BP-2, BP-3, BP-4.







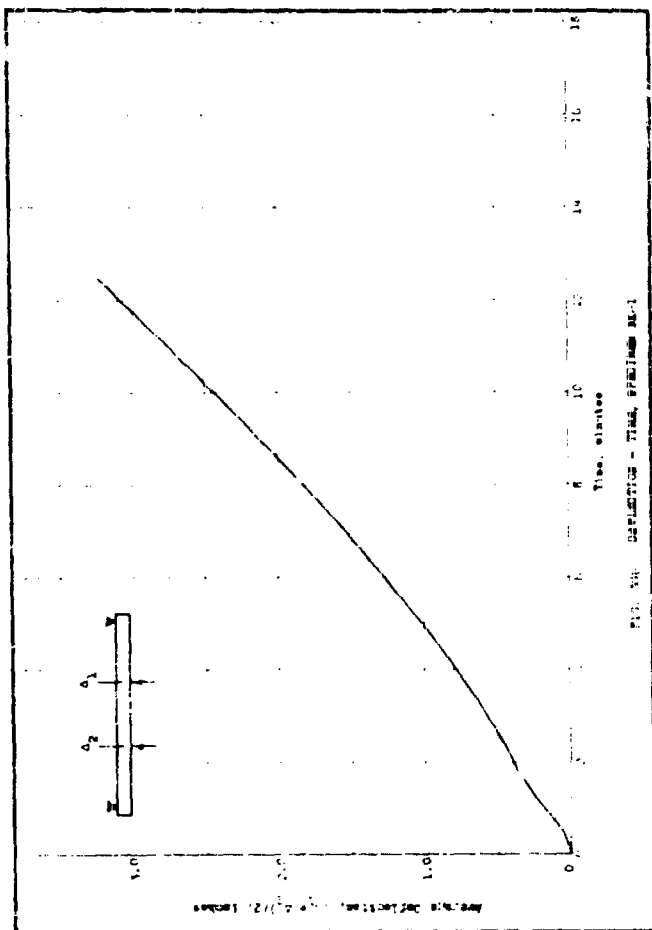
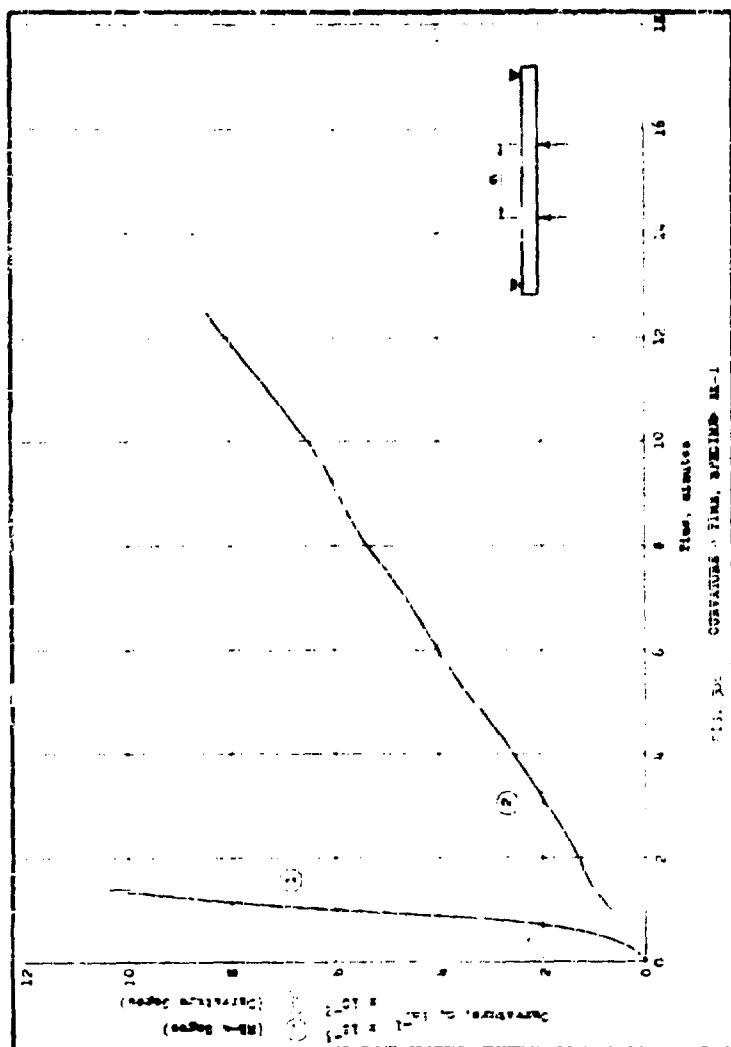
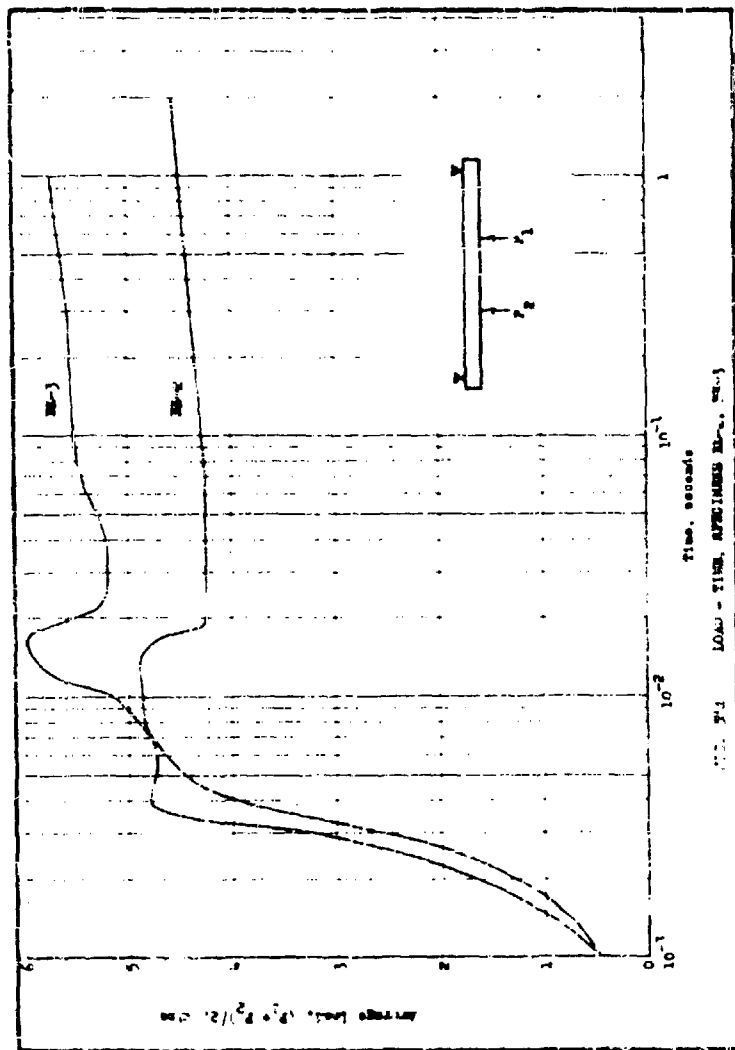
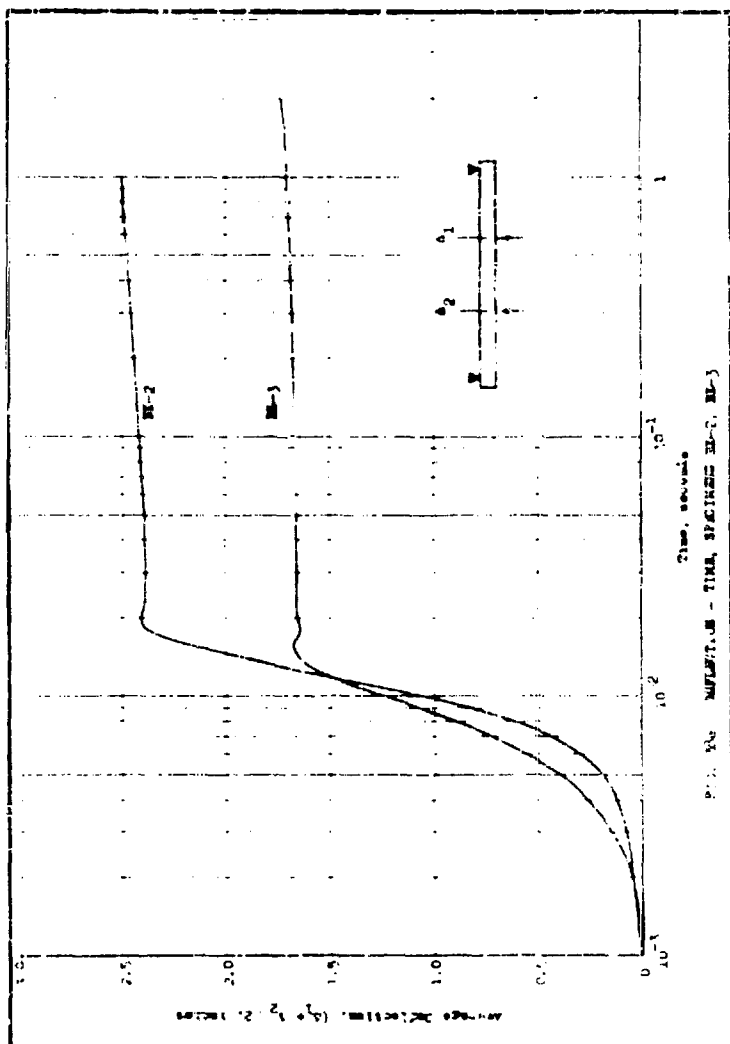


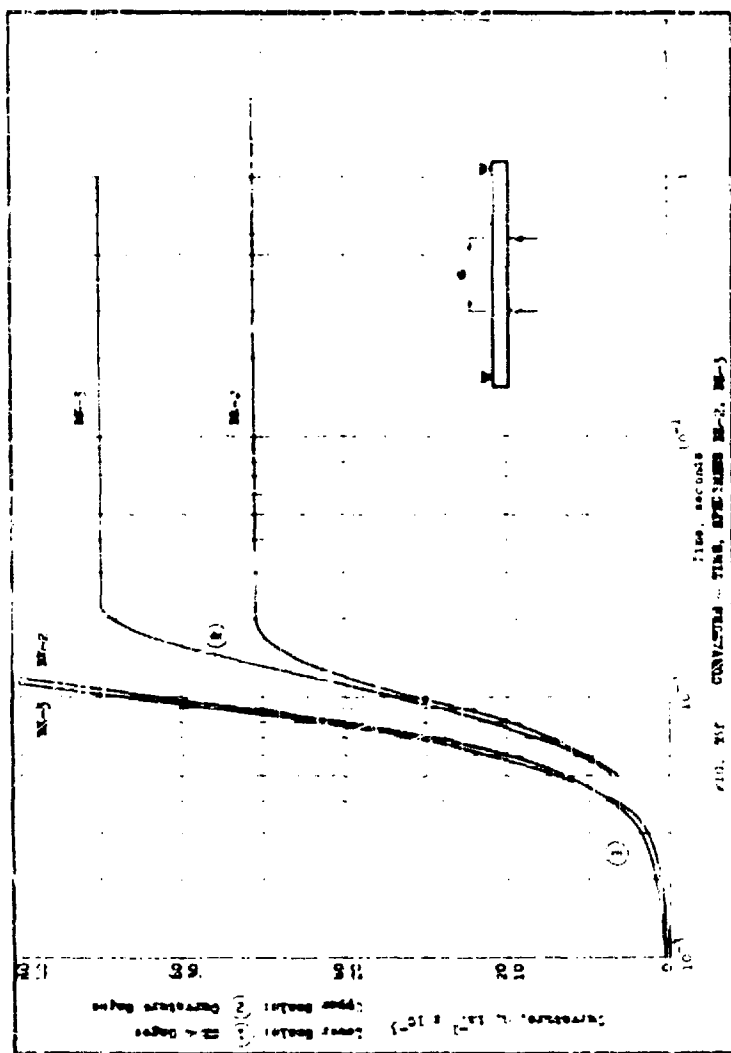
FIG. 14. DEFLECTION - TIME, SPECIMEN NO. 1







P. 1. V. M. MURPHY - TIME, SPECIES M-1, M-2, M-3



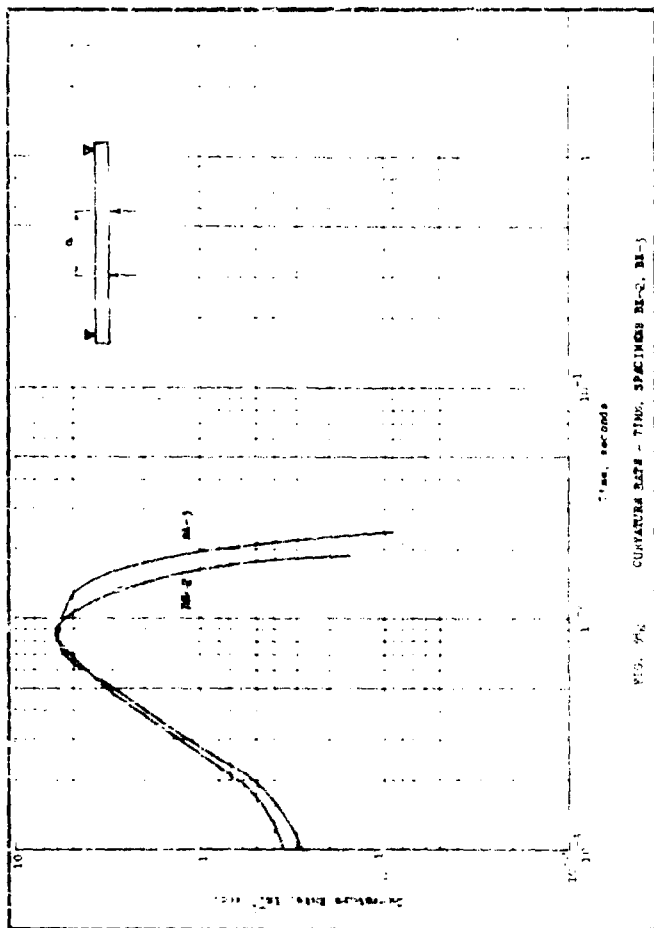
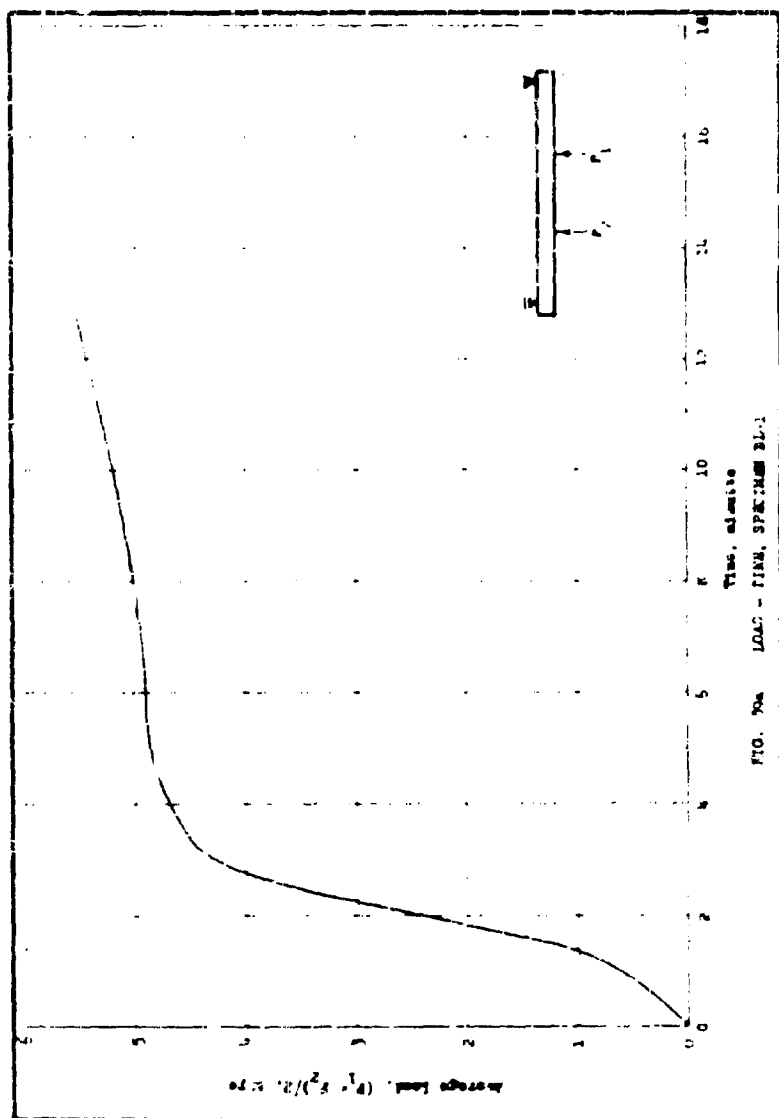
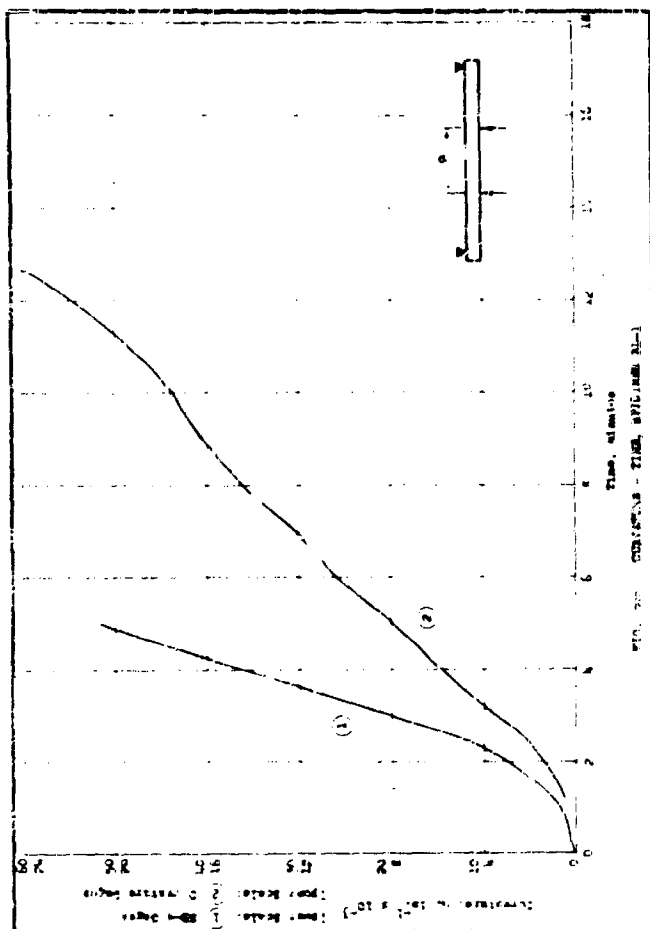


FIG. 7. CURVATURE RATE - TIME, SPACINGS M-2, M-3





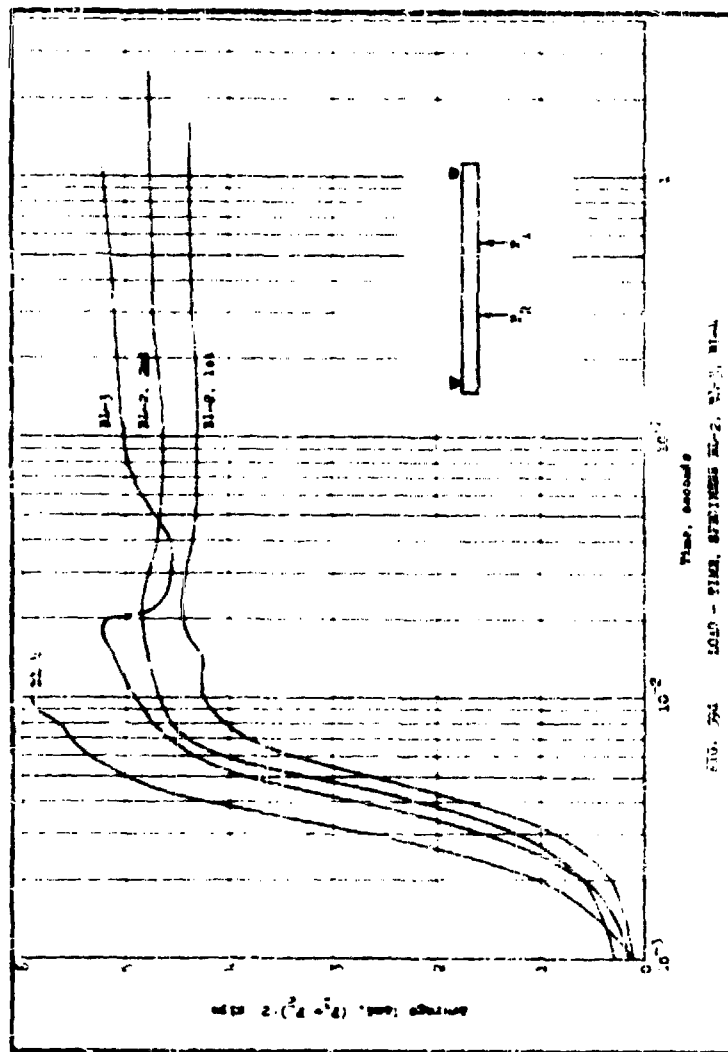


FIG. 294. 1010 - TIME, STRESSING NO. 2, 21-1, 21-2, 21-3.

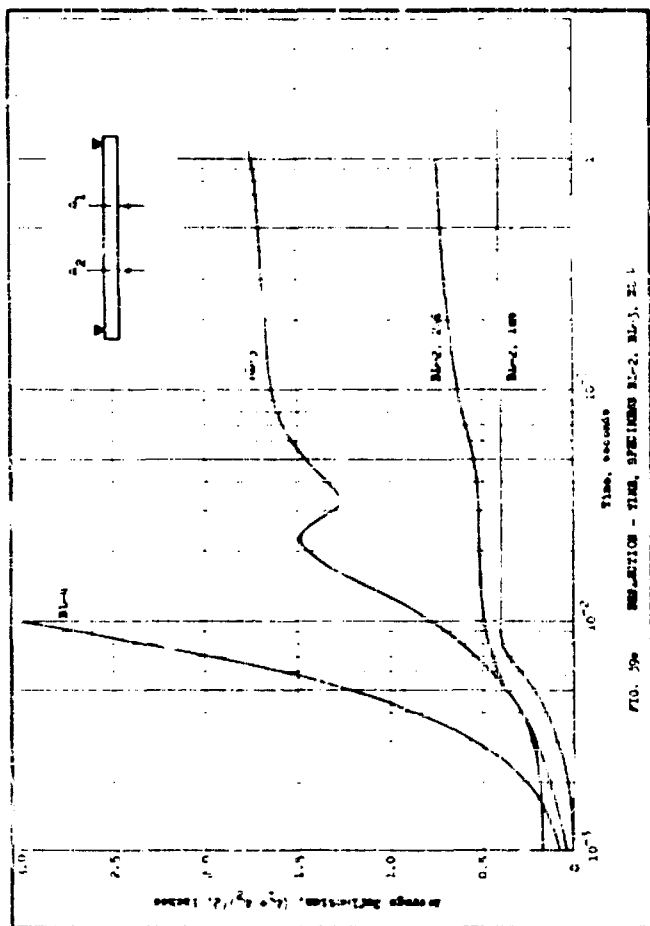


FIG. 59a. BEAM LENGTH - TIME, DEFLECTION BL-1, BL-2, BL-3.

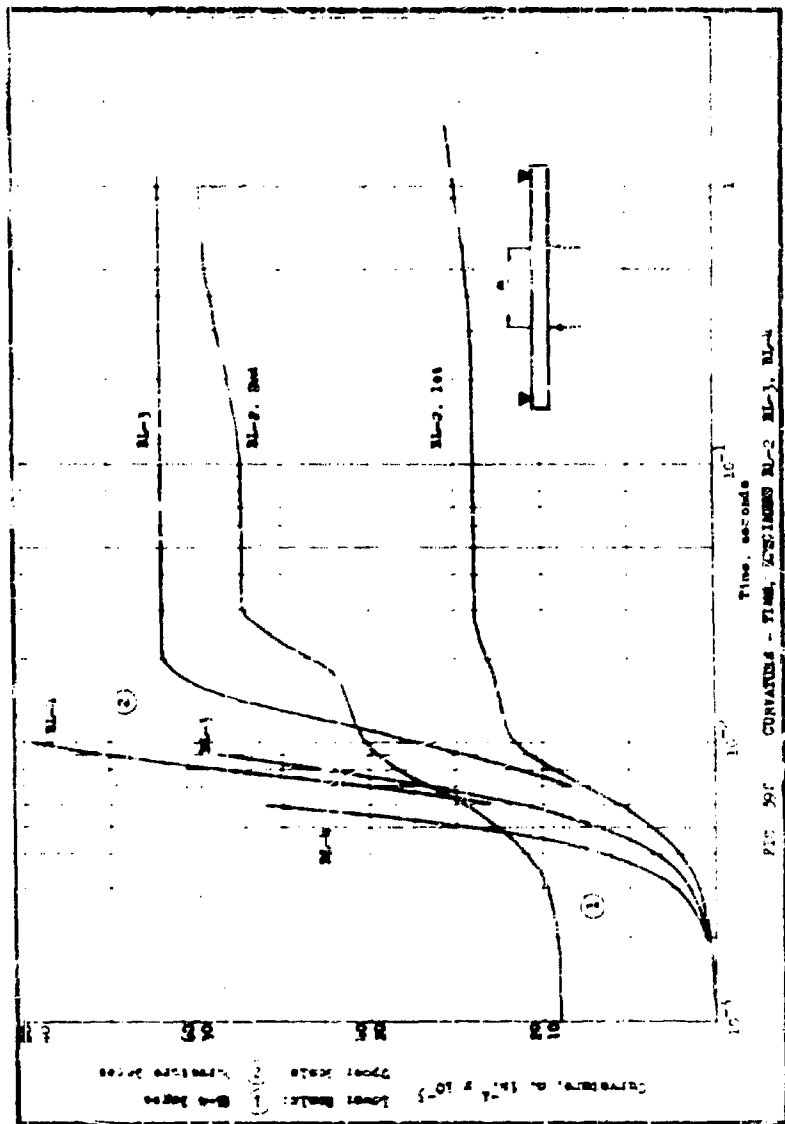


FIG. 90. CURVES OF TEMPERATURE, PRESSURE, AND TIME FOR SPECIMENS BL-1, BL-2, BL-3, AND BL-4

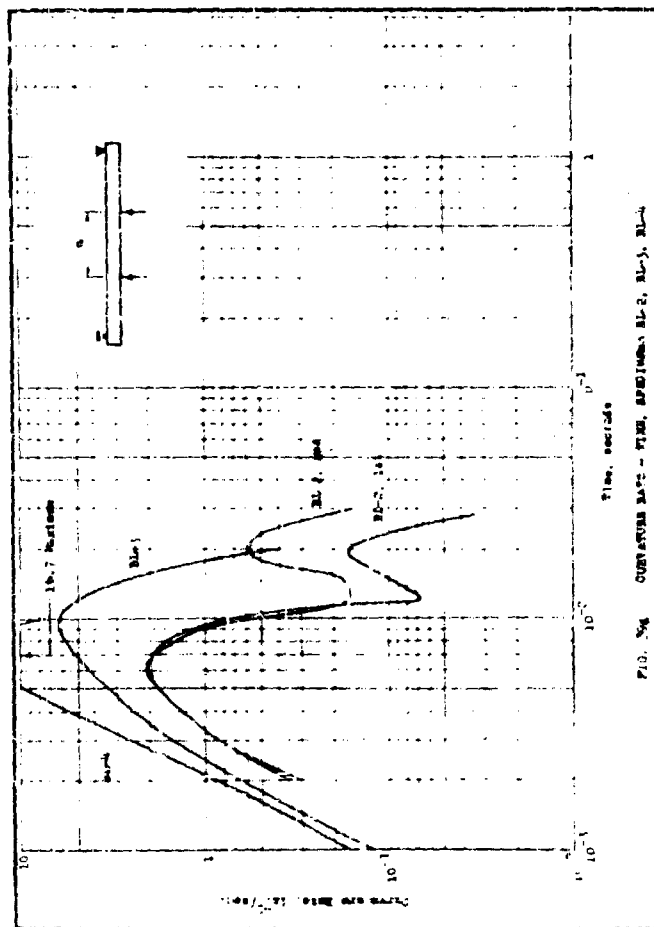
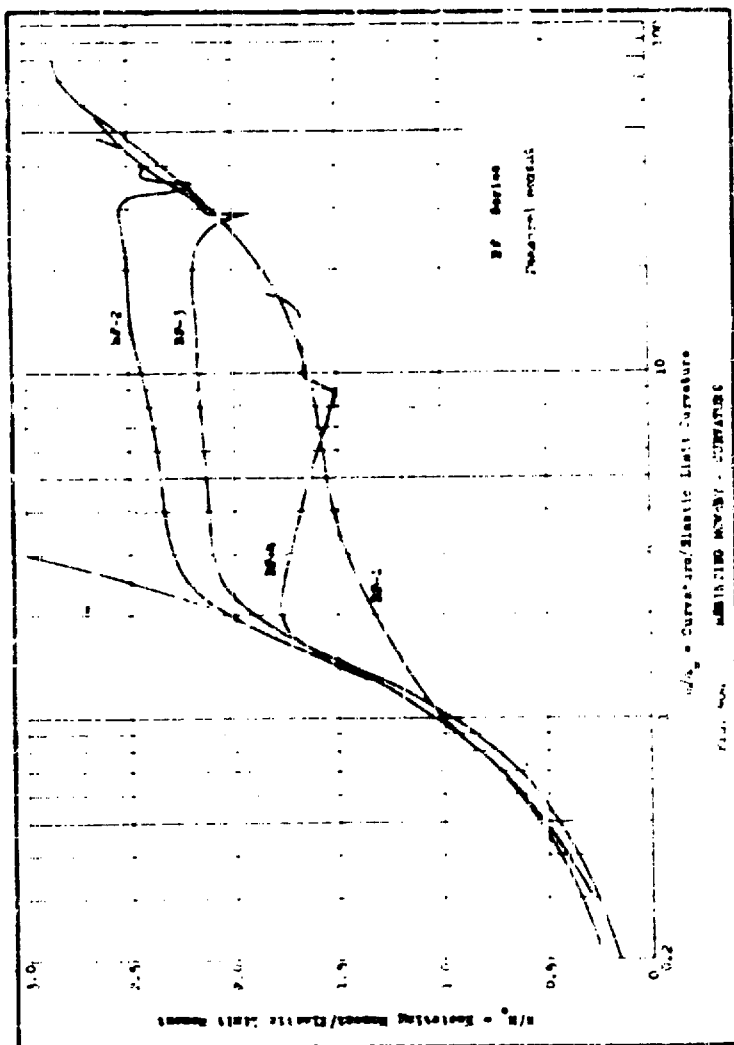
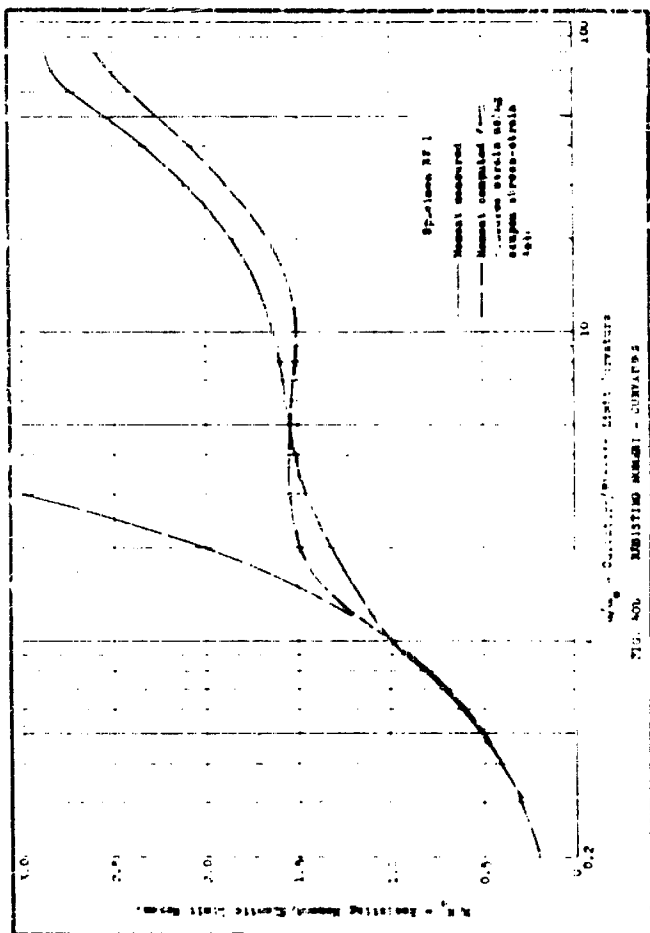
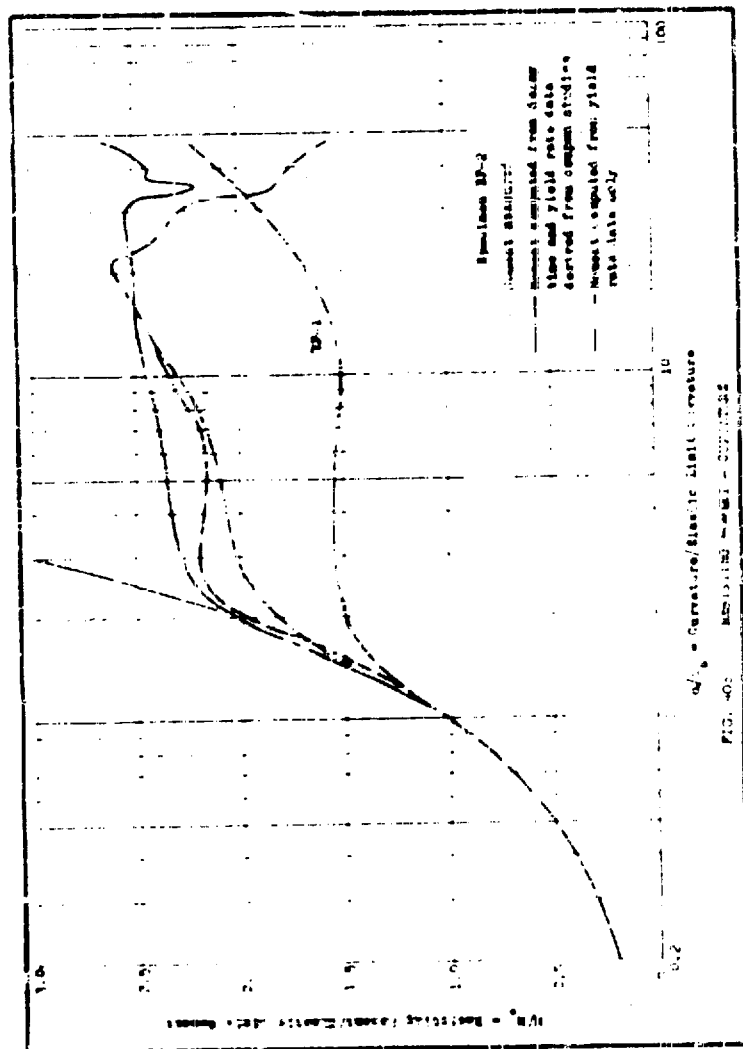
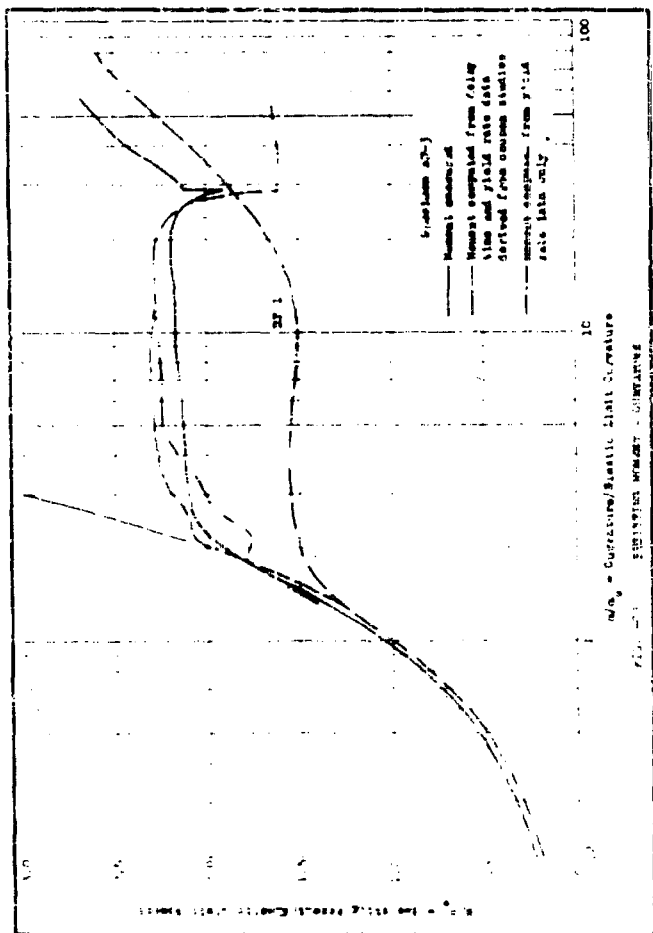


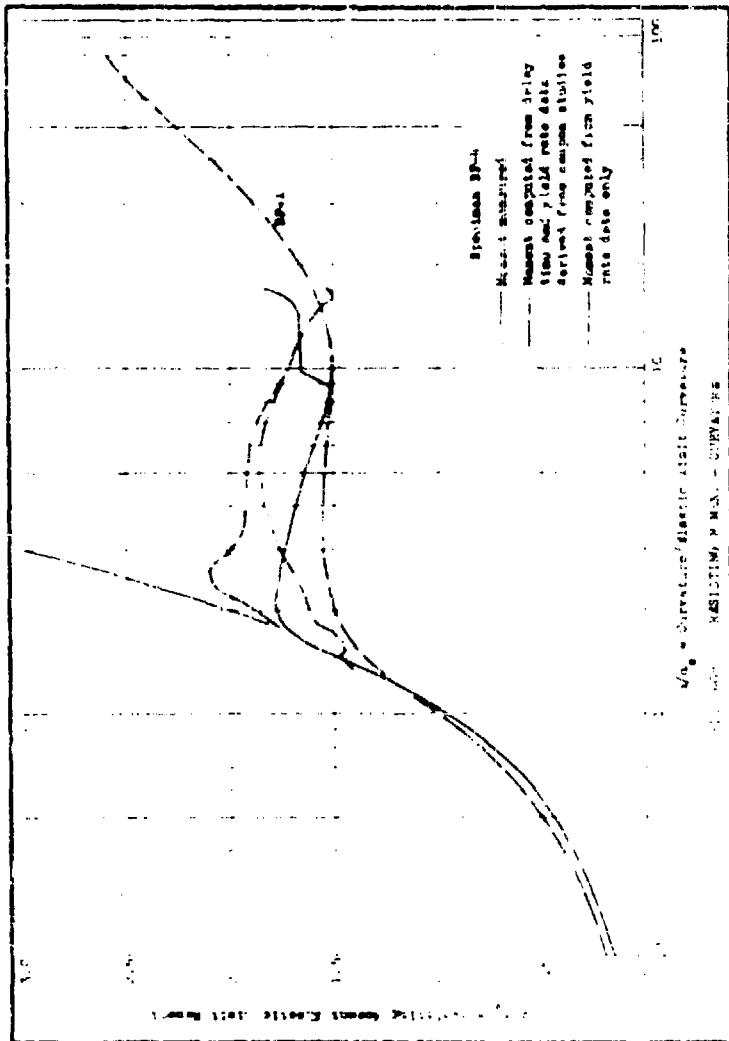
FIG. 5. CURVATURE RATE - TIME, SPECIMENS BL-2, BL-3, BL-4











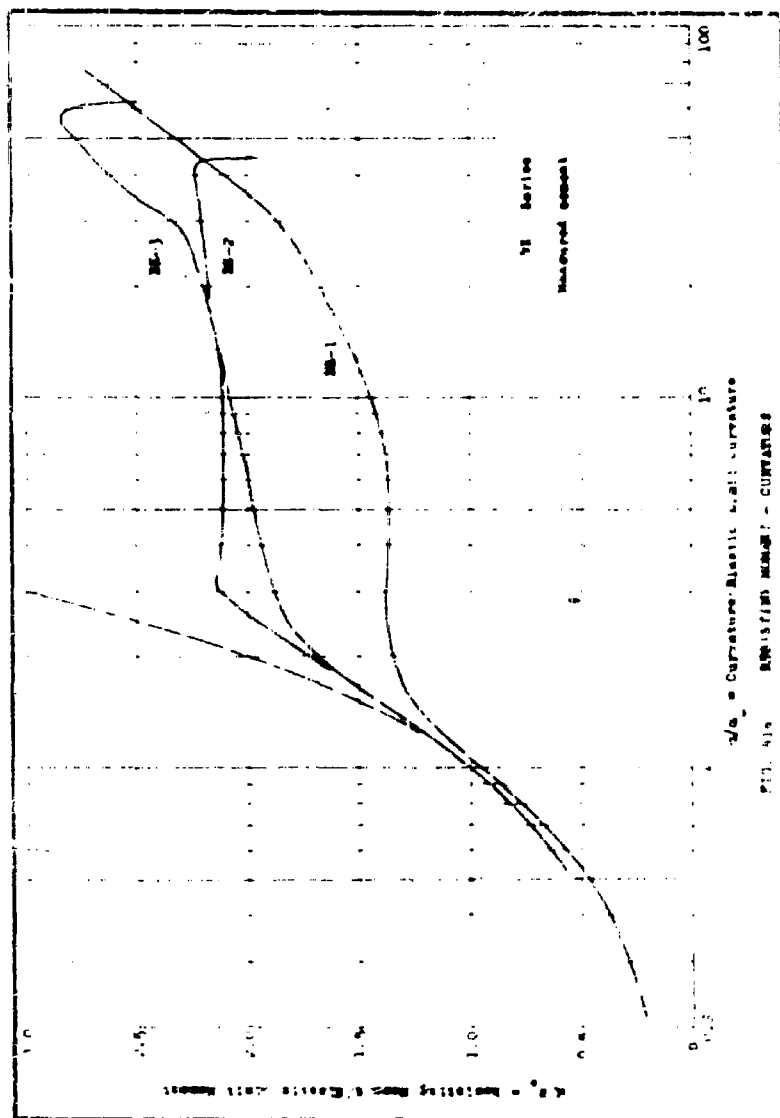
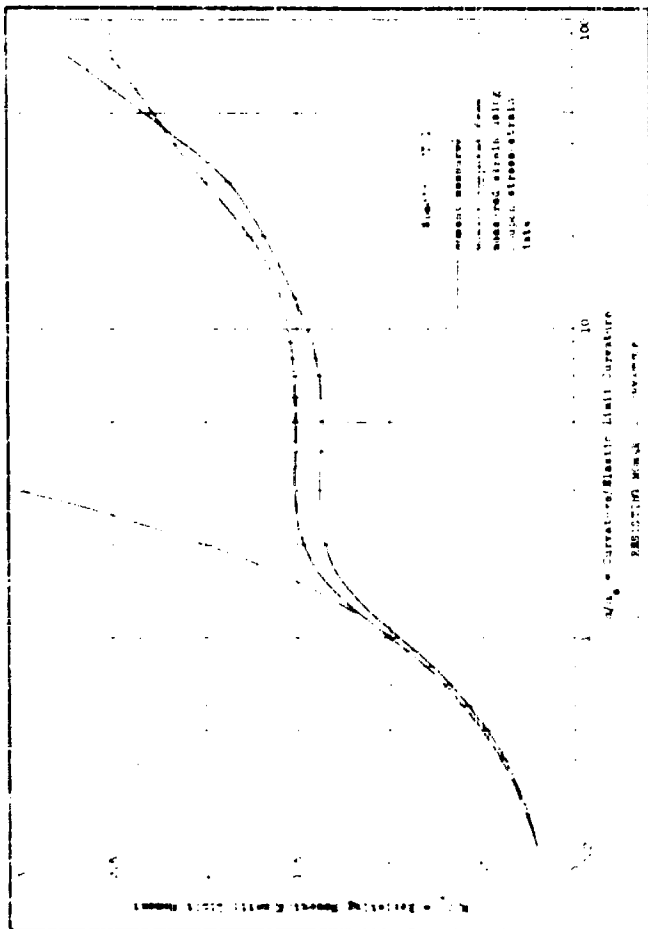
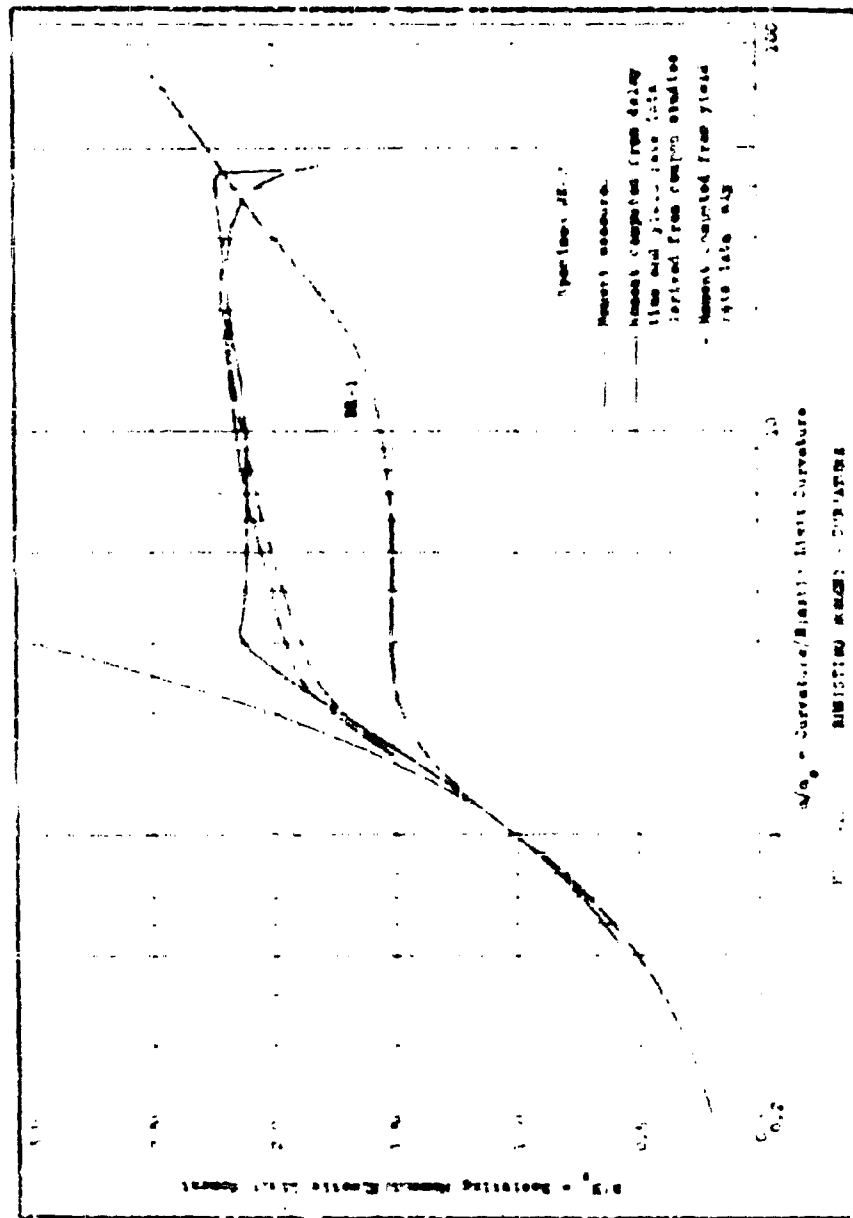
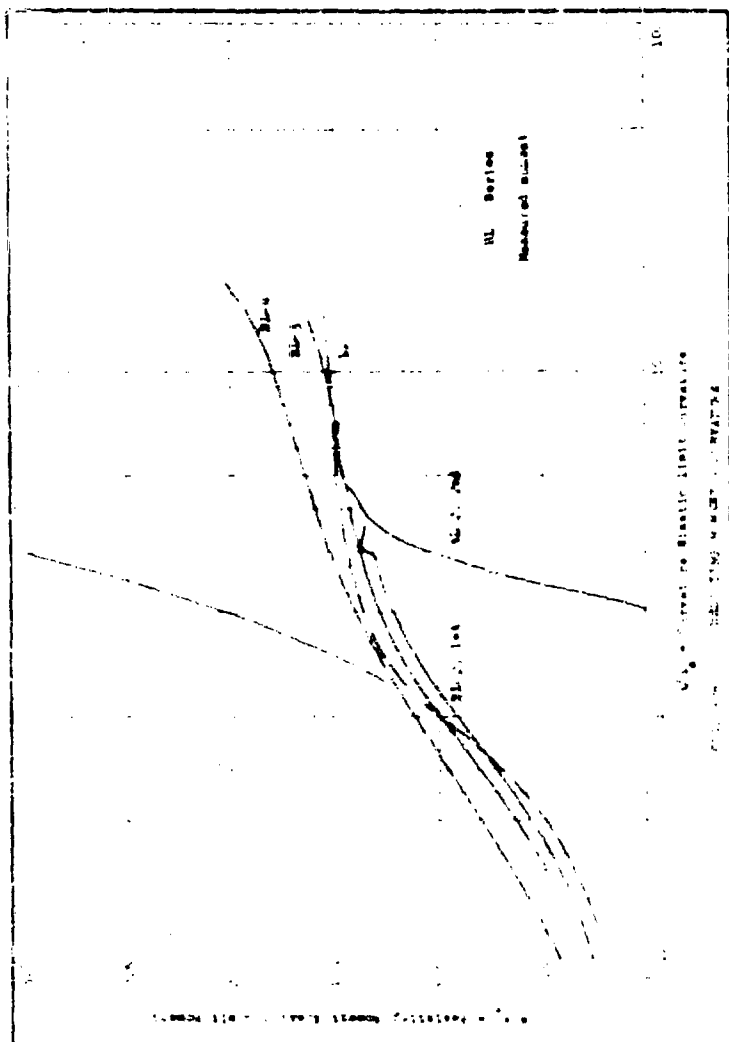
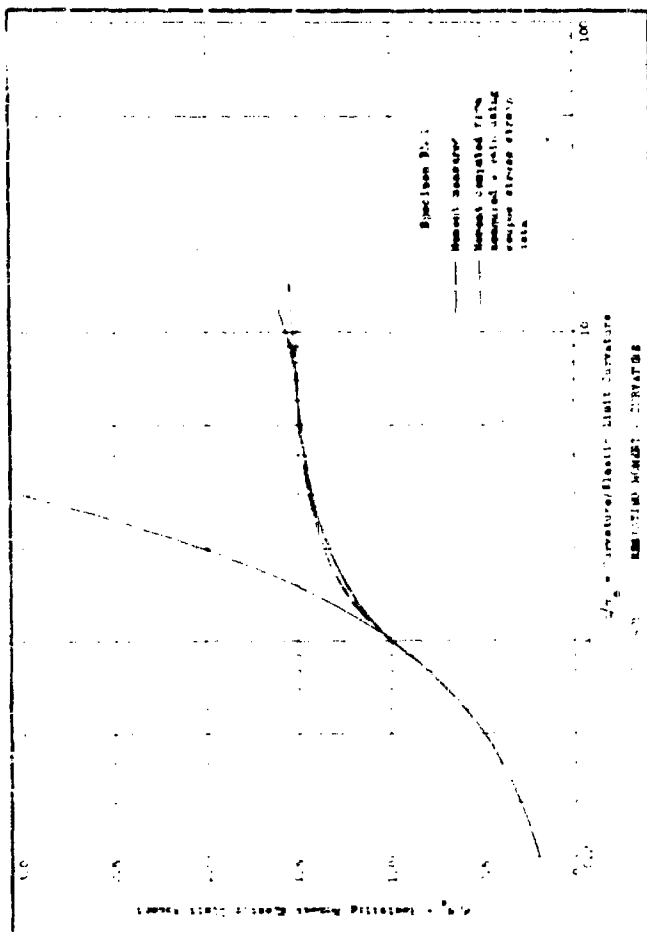


FIG. 416. STRESS/TIME MODEL - CURVATURE









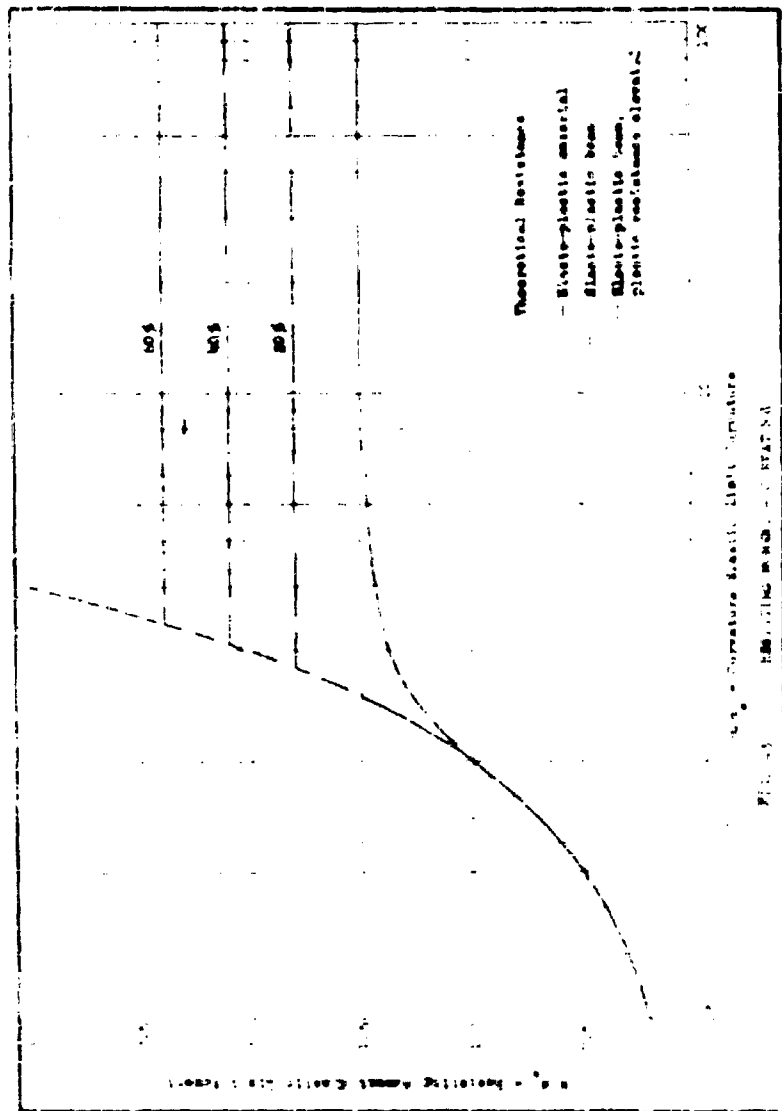


Fig. 3. Modulus vs. Temperature

UNCLASSIFIED

A
D
210240

Armed Services Technical Information Agency

ARLINGTON HALL STATION
ARLINGTON 12 VIRGINIA

FORM

MICRO-CARD

CONTROL ONLY

7 OF 7

NOTICE: WHEN GOVERNMENT OR OTHER DRAWINGS, SPECIFICATIONS OR OTHER DATA ARE USED FOR ANY PURPOSE OTHER THAN IN CONNECTION WITH A DEFINITELY RELATED GOVERNMENT PROCUREMENT OPERATION, THE U. S. GOVERNMENT THEREBY INCURS NO RESPONSIBILITY, NOR ANY OBLIGATION WHATSOEVER; AND THE FACT THAT THE GOVERNMENT MAY HAVE FORMULATED, FURNISHED, OR IN ANY WAY SUPPLIED THE SAID DRAWINGS, SPECIFICATIONS, OR OTHER DATA IS NOT TO BE REGARDED BY IMPLICATION OR OTHERWISE AS IN ANY MANNER LIMITING THE HOLDER OR ANY OTHER PERSON OR CORPORATION, OR CONVEYING ANY RIGHTS OR PERMISSION TO MANUFACTURE, USE OR SELL ANY PATENTED INVENTION THAT MAY IN ANY WAY BE RELATED THERETO.

UNCLASSIFIED

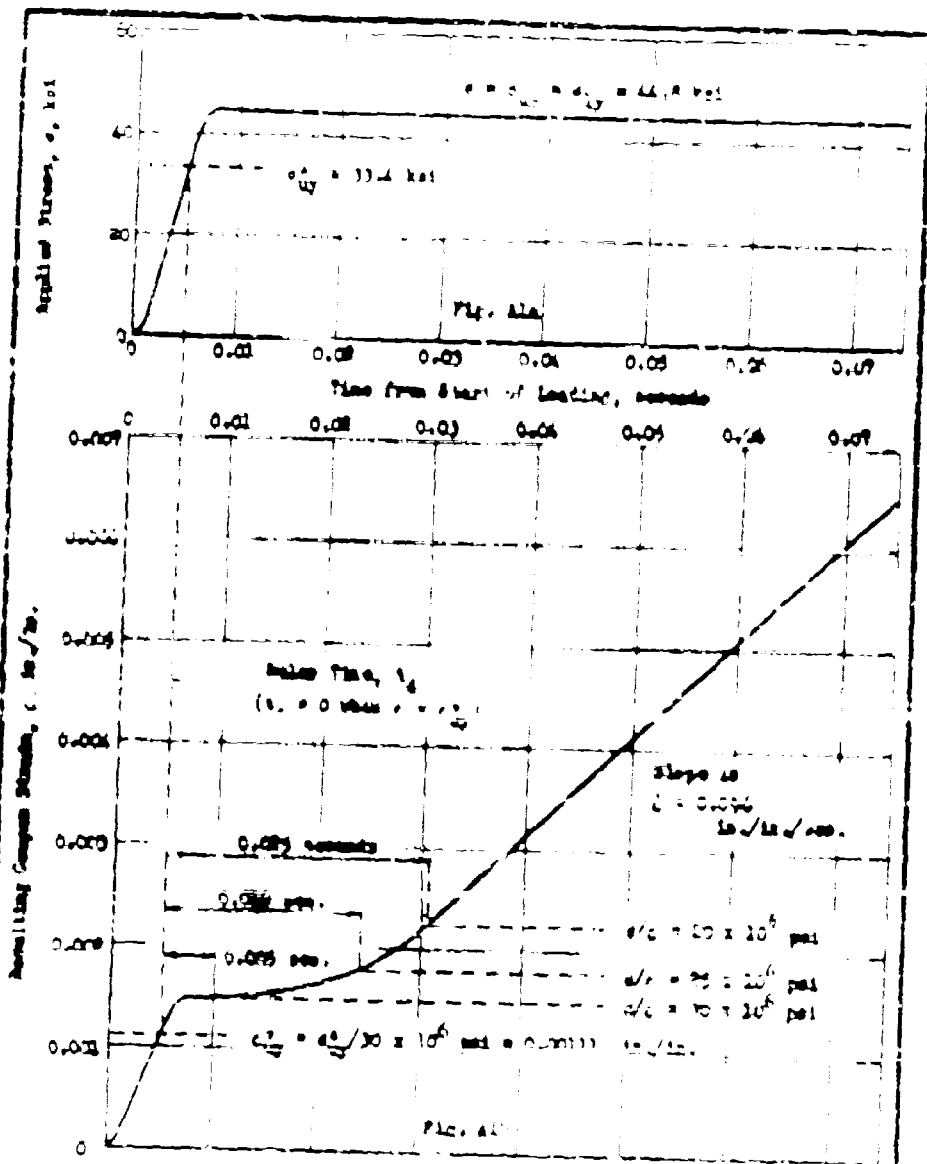
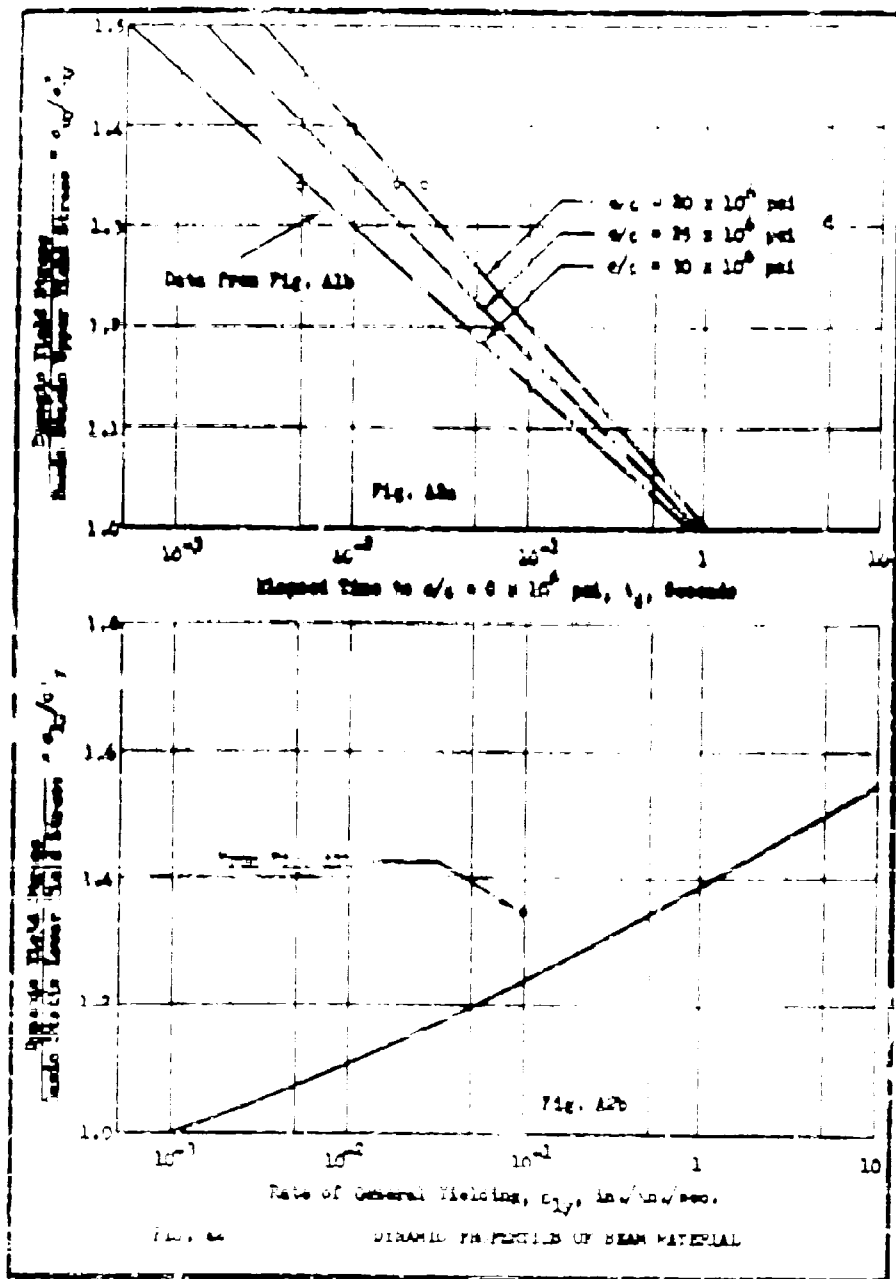


FIG. A1 TYPICAL RAPID COUPON TEST; APPLIED STRESS, RESULTING STRAIN



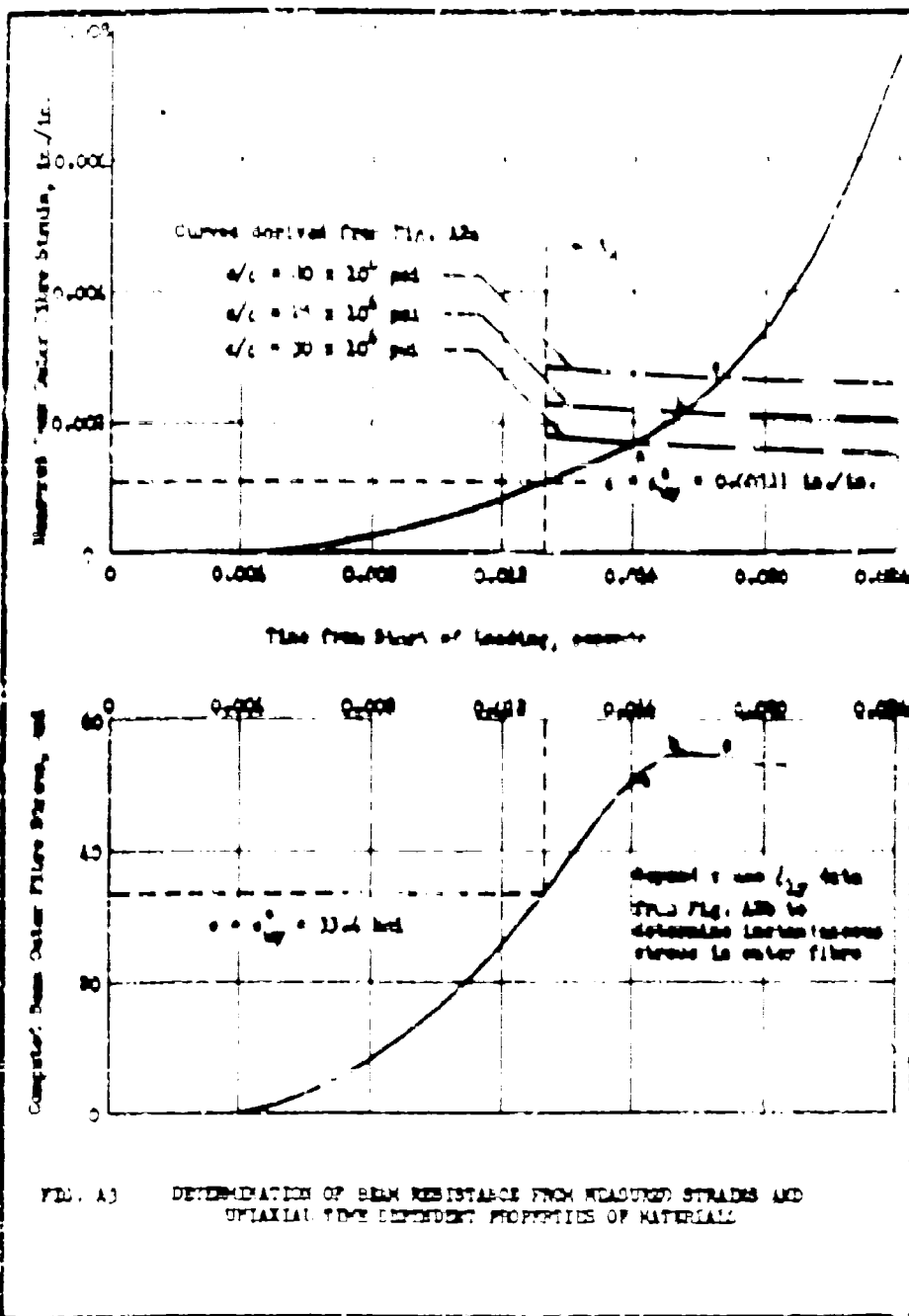


FIG. A3 DETERMINATION OF BEAM RESISTANCE FROM MEASURED STRAINS AND UNIAxIAL TIME DEPENDENT PROPERTIES OF MATERIAL

UNCLASSIFIED

A
D
211240

Armed Services Technical Information Agency

ARLINGTON HALL STATION
ARLINGTON 12 VIRGINIA

FOR
MICROFILM
CONTROL ONLY

7 OF 7

NOTICE: WHEN OBTAINING OR OTHER DRAWING, COPY-
RIGHT FOR ANY DRAWING OTHER THAN IN CONNECTION
GOVERNMENT POLICE/INVESTIGATION OPERATION, THE U. S. GOVERN-
MENT RESERVES THE RIGHT TO REPRODUCE AND TO TRANSMIT IN ANY
MANNER AND BY ANY MEANS, AND TO MAKE ANY OTHER
DRAWING, SPECIFICATIONS, OR OTHER DATA WHICH TO BE
PUBLISHED OR OTHERWISE AS IN ANY MANNER LATERING TO
THE GOVERNMENT OR CONSPIRACY, OR CONTAINING ANY RIGHTS OR PAT-
ENT OR SELL ANY PATENTED INVENTION THAT MAY IN ANY WAY

THIS DRAWING IS A
COPYRIGHTED DRAWING
OF THE U. S. GOVERNMENT
AND IS NOT TO BE
REPRODUCED OR
TRANSMITTED IN ANY
MANNER OR BY ANY
MEANS, OR TO BE
PUBLISHED OR
OTHERWISE AS IN
ANY MANNER LATERING
TO THE GOVERNMENT
OR CONSPIRACY, OR
CONTAINING ANY
RIGHTS OR PATENT
OR SELL ANY
PATENTED INVENTION
THAT MAY IN ANY
WAY

UNCLASSIFIED