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A Report on Designing and Building A Testing Machine and Performing Tests to Investigate Fatigue Behavior and Determine Endurance Limit of Manganese Vanadium Steel for

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16. ABSTRACT

Synopsis

By letter of October 23, 1953, Mr. N.C. Raab, Projects Engineer, Division of San Francisco Bay Toll Crossings, requested the Materials and Research Department to conduct fatigue tests on a sample of the manganese-vanadium steel specified for use on Richmond-San Rafael Bridge.

As this structural steel was specified for use and at that was being produced in eastern mills for this project, immediate indicative results were requested to be furnished by telephone. This was done. It was intended to follow up this telephone information immediately with a formal report. Unfortunately, a disastrous fire, which occurred in our laboratory early in March 1954, destroyed the first draft as well as the original data for the report. The following report is therefore based on telephone memorandum and the immediate recollection of the personnel who conducted the test. Any data contained herein has been substantiated by agreement between two or more participants.

The test results are shown in the appendix on Table I.

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STATE OF CALIFORNIA
Department of Public Works
DIVISION OF HIGHWAYS
Materials & Research Department

March 1, 1955

San Rafael Richmond Bridge
Laboratory Order No. 6004

Mr. N. C. Raab
Division of San Francisco Bay Toll Crossings
2054 University Avenue
Berkeley 4, California

Dear Sir:

Submitted for your consideration is:

A REPORT ON
DESIGNING AND BUILDING A TESTING MACHINE AND PERFORMING TESTS TO INVESTIGATE FATIGUE BEHAVIOR AND DETERMINE ENDURANCE LIMIT OF MANGANESE VANADIUM STEEL FOR SAN RAFAEL-RICHMOND BRIDGE.

Study made by ------------------ Structural Materials Section
Under General Direction of ------ J. L. Beaton
Work Supervised by -------------- H. F. Kuhlman
Report prepared by -------------- V. M. Sayers

Very truly yours,

F. N. Hveem
Materials & Research Engineer

cc: E. Withycombe
F. W. Panhorst

SYNOPSIS

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I. INTRODUCTION

The purpose of the investigation discussed in this report was to establish test procedures and perform tests in order to obtain the following information:

1. An evaluation of the fatigue behavior of the structural manganese-vanadium steel (specifications in Table II) specified for use in the Richmond-San Rafael Bridge particularly to determine the ability to withstand the vibration conditions which may occur in certain critical tension members.

2. An approximate value for the endurance limit (i.e. to determine the reversing stress which can be imposed with unlimited number of repetitions) for this kind of steel while under normal constant tension.

The objective of the tests was to determine the above information generally for the type of steel proposed for use. It was not the purpose to determine uniformity of the material in terms of variations between heats. A selected typical and representative sample of the alloy was therefore used.

It is well known that most structural assemblages are subjected to variations in applied loads, causing stress fluctuations in the component parts. If the fluctuating stresses are large enough and are applied a sufficient number of times, failure may occur, even though the maximum applied stress may be considerably less than the static strength of the material. Such failures are called "fatigue failures".

In the past it has been considered that stress fluctuations in most bridges and buildings are not large enough and ordinarily do not occur often enough to produce this type of failure.

However, consideration of the vibratory stresses that might conceivably occur in certain members of the Richmond-San Rafael Bridge as a result of wind and traffic loadings appeared to warrant a study of the behavior of the steel under simulated vibration conditions involving a constant axial tension loading and a reversing load in bending.

Therefore, in October 1953, the Materials & Research Dept. was requested by Mr. N. C. Raab, Project Engineer for the Division of San Francisco Bay Toll Crossings, to initiate a project designed to develop a test method and perform a series of tests on specimens of the steel specified for use in the structure.

The project was assigned to the Structural Materials Section, and the first step of selecting and/or designing and building a suitable testing machine was started. A detailed description of the development and the problems encountered is given under the next topic.

II. SOLUTION

A. For reasons of economy and because the exact type of machine to produce the combined stresses required did not appear to be commercially available at the time, it was decided to design and build the machine in the shop of the Materials and Research Department. The machine finally developed embodied the following basic features:

1. Constant axial load could be applied by means of calibrated springs.

2. Bending moment could be applied by means of an eccentric cam and walking beam device (detailed description appears later).

B. Tests were performed as follows:

1. A specimen 1/8" x 1" x 16" machined to a "critical zone" 2" in length with a clear span of 10" was used (Plate V).

2. A series of tests were performed using a constant axial load and variable reversing bending stress (approximately 12,000,000 cycles or until failure occurred, with each combination).

C. The final tabulation of results indicated an endurance limit of 57,200 psi (19,200 psi axial stress and 38,000 psi bending stress) and an endurance ratio (ratio of endurance limit to static tensile strength) of 0.56. Despite certain limitations of the testing machine, these values are considered to be reasonably representative and in accord with what might be expected of the alloy tested.

III. TEST EQUIPMENT AND OPERATION

A. The essential features and operation of the machine finally built are as listed below and as shown in the accompanying photographs:

1. The machine was powered by a variable speed, 3/4 HP electric motor with 1850 rpm maximum speed (Plate I).

2. The flat fatigue specimen was bolted rigidly on one end. The other end was bolted into a movable grip, which in turn was connected through four calibrated compression springs to the machine frame (Plates I, II, and III). The 19,200 psi axial load was applied by means of these springs.

3. The reversing load in bending was applied as follows:

   An eccentric cam on the motor shaft actuated a walking beam over an adjustable trunnion pivot (thus permitting adjustment of the stroke to any length desired) (Plates I and II). The walking beam in turn actuated the brass bending fixture (Plate III).

The brass fixture came into contact with the specimen at points 1/2" on each side of the mid-point (point of theoretical maximum moment). This left room for a strain gage on each side of the specimen.

4. Strain gages were applied to the specimen at the point of theoretical maximum moment and were used in adjusting the machine to obtain the desired stress in the specimen.

   Dynamic strain readings were also recorded on a Brush Magnetic Oscillograph, and dynamic reflection records were obtained by using G. E. electric gages and oscillograph. (Plates I and II).

5. Asbestos packing was used to reduce the notch effect under the vise jaws.

   The grips used to apply the reversing bending moment were also insulated to reduce work hardening of the specimen at the point of contact.

6. Instrumentation was as follows:

Measurement and adjustment of axial stress (19,200 psi)	- - -	SR-4 gages
Transverse (moment) loading, fiber stress measurement	- - -	SR-4 gages
Number of repetitions (1850 cycles per min.)	- - -	Berkeley Electronic Counter
Dynamic strain readings	- - -	Brush Magnetic ~~Counter~~ Oscillograph
Dynamic deflection recording	- - -	General Electric electric gages and oscillograph.

IV. TEST PROCEDURE

A. The test specimens were machined to nominal size (Plate V) tolerances with all parallel surfaces ground as nearly as possible to true planes. The surfaces were then hand honed to obtain the smoothest possible surface finish. All machining and grinding were done in the longitudinal direction of the specimen. Static tension and bend tests were also performed on the steel.

In order to determine the most suitable shape and dimensions for the specimens, several preliminary trial specimens were made up and subjected to the action of the machine before the actual testing was performed. The type of specimen shown in Plate VI was the one used in the actual tests.

Plate IV-D shows how the tensile, bend, and fatigue specimens were located in the sample plate.

B. Test specimens and strain gages were calibrated in static tension prior to the tests.

The modulus of elasticity of the steel was determined for use in calculating the applied loads (from the strain gage readings).

C. With the specimen firmly bolted in place, the axial tension was adjusted (by loading the calibrated springs uniformly) to obtain the desired stress. The bending load assembly was adjusted to produce the required fiber stress in bending (as indicated by SR-4 gages), and the series of load repetitions was begun. The repetitions were continued until the desired number had been reached, or until failure occurred.

D. A test was considered complete after 12,000,000 cycles had been reached or failure had occurred (whichever happened first).

Unfortunately, the detailed test records were lost in a fire of March 2, 1954, which destroyed most of the Structural Materials Section. However, the attached tabulation (Table I) summarizes the over-all results of the tests performed. Each series of tests utilized a constant axial loading (19,200 psi) and successive increments of bending stress, as summarized in the table.

V. TEST RESULTS

A. The test results are summarized on Table I. The static tension test resulted in values of 68,000 psi for yield point, 100,240 psi for ultimate tensile strength, 24% elongation, and 52% reduction of area.

B. The fatigue results indicated an endurance limit of 57,200 psi and an endurance ratio of 0.56 for the typical average rolled plate specimen of the steel.

VI. DISCUSSION

A. In designing and constructing the testing machine, care was exercised to eliminate, as far as possible, the effects of eccentricity, secondary vibrations, and localized effects, such as work hardening, notch effects, etc. (Use of asbestos packing on the specimen grips has already been mentioned).

However, within the limitations of time, equipment, and material, it was extremely difficult to eliminate all of the above-mentioned sources of error.

For example, it was difficult to avoid eccentricity in the process of applying the axial load. Also the location of the fracture indicated that local effects at the points of contact of specimen and bending fixture were not completely eliminated.

Use of a longer machine and specimen would have helped to dissipate localized stresses.

B. Based on the experience gained from this project, the following improvements in design and procedure (for any future fatigue investigations) might well be considered:

1. Vise grips holding specimens should be mounted in trunnions.

2. Drive motor should be mounted separately from the bending fixture and driven through a flexible coupling to eliminate vibrations caused by the motor.

3. The unsupported span should be longer (18" or more).

4. With reference to the axial loading, the possibility of eccentricity and other secondary effects should be reduced, possibly by utilizing a single spring or other actuating mechanism of sufficient capacity to provide free adjustment without being overstressed.

5. A method of applying the bending stress that would reduce the work hardening and notch effects might be devised. The use of trunnions or application of the load at the third points of the specimen might serve this purpose.

C. Despite the limitations of the machine and the procedure, it is believed that the results are sufficiently consistent and in accord with available data on similar steels to be considered as usable indications of the fatigue behavior of the given type of steel.

Referring to the A. S. M. E. Handbook, "Metals Engineering Design", page 95, we find listed several manganese steels with "Fatigue Strengths" ranging from 56,000 psi to 59,000 psi, and endurance ratios ranging from 0.48 to 0.58. The test values obtained in the project compare well with above figures, and with other available data on similar steels.

The range and the types of stresses applied were in accord with the requirements set forth and are believed to closely simulate the vibratory conditions likely to develop in the structure.

VII. SUMMARY AND CONCLUSIONS

A. As stated previously, the procedure, using a machine which applied a constant axial tensile loading by means of calibrated springs, and various reversing loads in bending by means of a bending fixture actuated by a walking beam and trunnion device, was designed to simulate as closely as possible anticipated vibration conditions in the structure.

B. Despite its limitations, the test method gave consistent and reasonable values which indicate that the type of steel tested should be satisfactory for resisting vibratory stress variations involving combined axial stress and reversing stresses in bending up to a combined total of about 57,000 psi.

The fire (previously mentioned), which destroyed a portion of the Laboratory of the Materials and Research Department, unfortunately resulted in the loss of most of the test data and many of the pictures (including some pictures of the specimens) collected during this study; however, the data herewith included has been authenticated and is sufficient for the purpose intended.

The foregoing has been as thorough a reconstruction and summarization of the data and the procedure as could be obtained from the salvaged records and the memories of the participants.

TABLE I

TABULATION OF TEST RESULTS

Test No.	Area (Sq.in.)	Total Axial Load	Axial Unit Stress	Unit Stress Extreme Fiber	Combined Unit Stress	Failure at(cycles)	Total Cycles
1	0.125	2400#	19,200 psi	32,500 psi	51,700	None	12,000,000
2	0.125	2400#	19,200 psi	35,250 psi	54,450	None	12,000,000
3	0.125	2400#	19,200 psi	38,000 psi	57,200	None	12,000,000
4	0.125	2400#	19,200 psi	42,000 psi	61,200	400,000	400,000

Endurance Limit: 57,200 psi

Endurance Ratio: 0.56

Additional Data:

(a) Specimen 1" x 1/8" at critical section, tested on 10" clear span.

(b) Location of specimen as shown in photograph, Plate IV, taken near rolled edge.

(c) Critical section area, 0.125 square inches.

(d) Reversing load fiber unit stress determined by SR-4 strain gages.

(e) Cycles per minute, 1850.

(f) Elapsed time, approx. 6500 minutes, or 108 hours, for tests 1, 2 and 3. For test No. 4, 216 minutes, or 3 hours 36 minutes.

(g) All fractures occurred at driving point (bending fixture), 1/2 inch from point of theoretical maximum moment. May have been due in part to work hardening.

(h) Static tensile test results: Yield Point, 68,000 psi
Ultimate, 100,240 psi
Elongation, 24%
Red. of Area, 52%

TABLE II

SPECIFICATIONS

STRUCTURAL MANGANESE-VANADIUM STEEL

SAN RAFAEL-RICHMOND BRIDGE

FATIGUE TEST

Structural manganese-vanadium steel shall conform to the requirements of the following specifications:

Chemical Composition: The steel shall conform to the following requirements as to chemical composition:

Carbon, Maximum %	0.35
Manganese, Maximum %	1.45
Phosphorous, Maximum %	0.04
Sulfur, Maximum %	0.05
Silicon, %	0.15 to 0.30
Vanadium, %	0.08 to 0.14

Tensile Properties: The material shall conform to the following requirements as to tensile properties:

Tensile strength, psi	90,000 to 115,000
Yield point, minimum psi	0.5 tensile strength
but in no case less than	55,000*
Elongation in 8", minimum %	1,600,000** / Tensile Strength
Reduction of area, minimum %	30***

* The yield point shall be determined by the drop of the beam or halt in the gage of the testing machine.

** For material over three-fourths inch (3/4") in thickness or diameter, a deduction from the percentage of elongation in eight inches (8"), specified above, of twenty-five hundredths percent (0.25%) shall be made for each increase of one-sixteenth inch (1/16") of the specified thickness or diameter above three-fourths inch (3/4") to a minimum of fourteen percent (14%).

** For material under five-sixteenths inch (5/16") in thickness or diameter, a deduction from the percentage of elongation in eight inches (8") specified above of one and twenty-five hundredths percent (1.25%) shall be made for each decrease of one thirty-second inch (1/32") of the specified thickness or diameter below five-sixteenths inch (5/16").

*** For material over three-fourths inch (3/4") in thickness or diameter, a deduction from the percentage reduction of area specified above, of fifty one-hundredths percent (0.50%) shall be made for each increase of one-sixteenth inch (1/16") of the specified thickness or diameter over three-fourths inch (3/4").

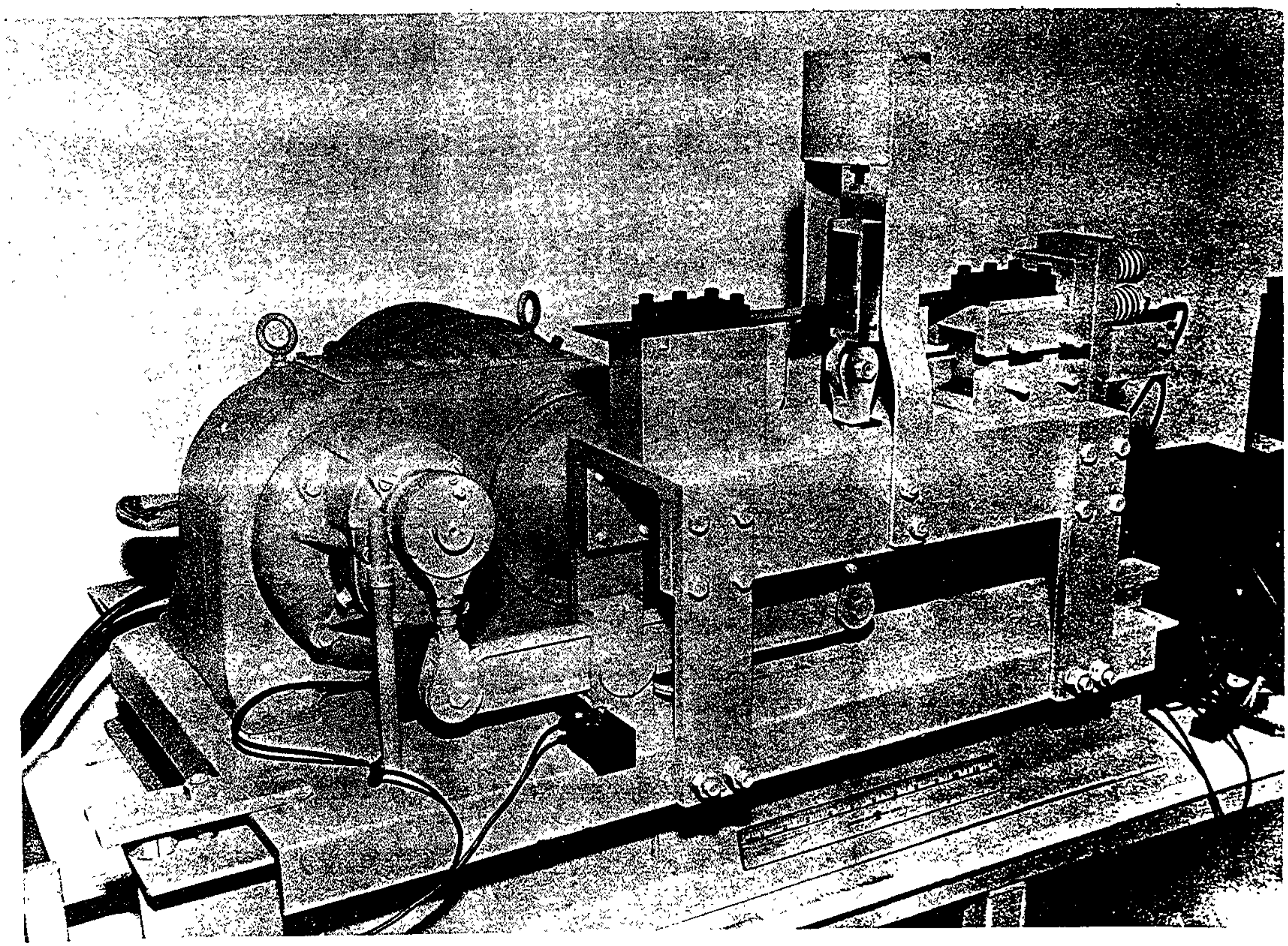

Plate I

Over-all View of Fatigue Machine with Specimen in Place

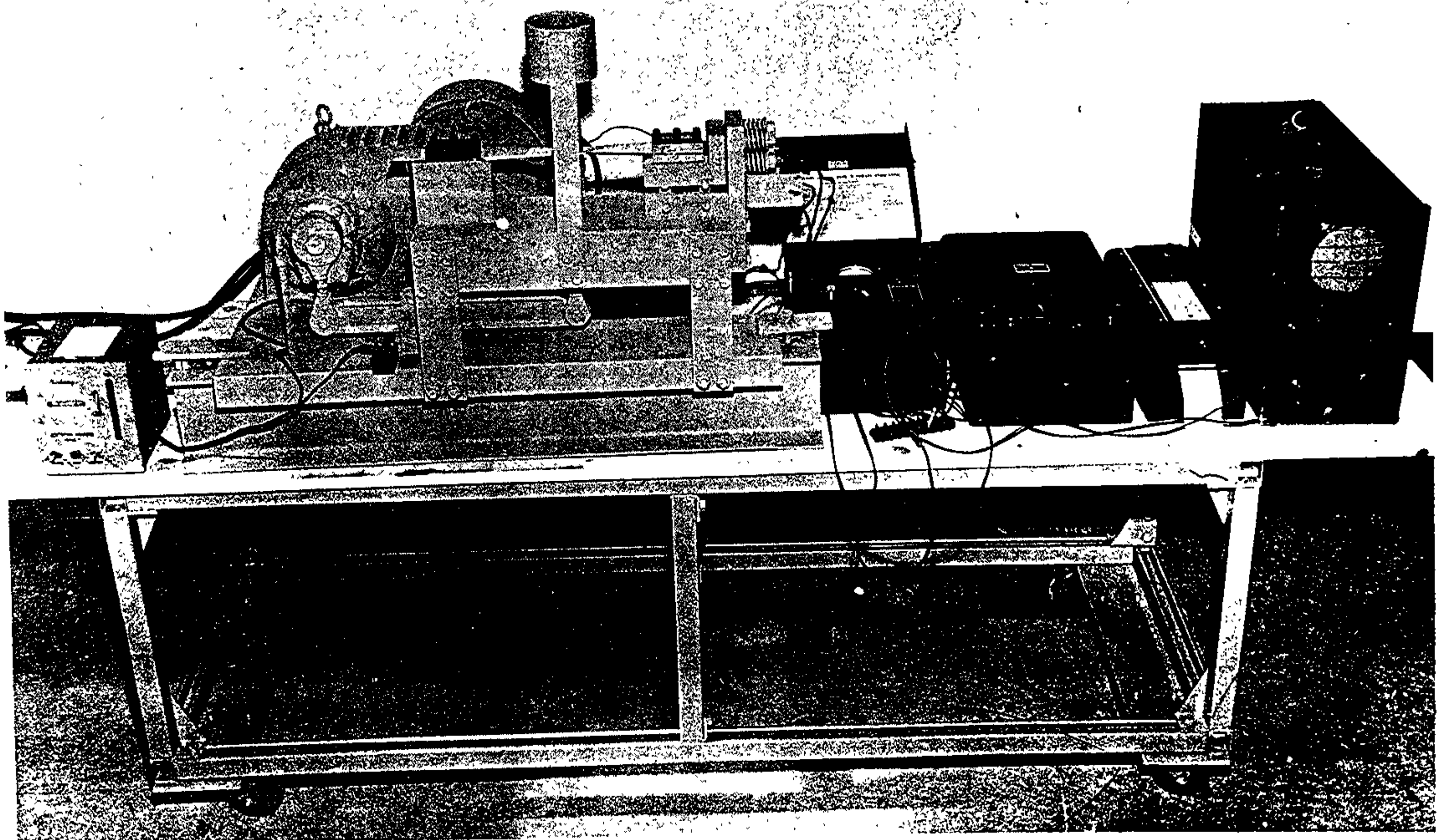

Plate 11

Fatigue Machine & Recording Equipment

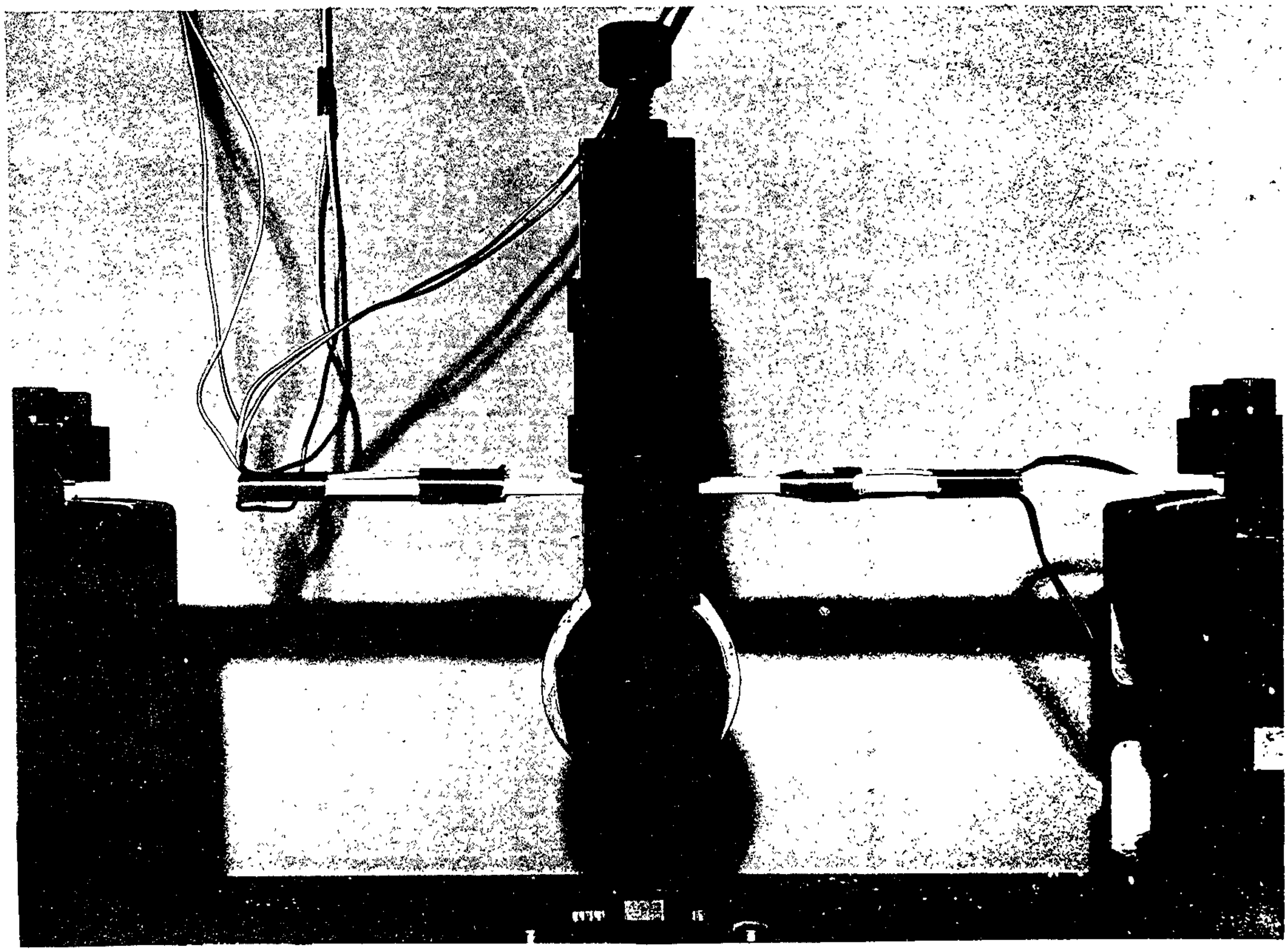

Plate III
Bending Fixture & Specimen with Strain Gages in Place

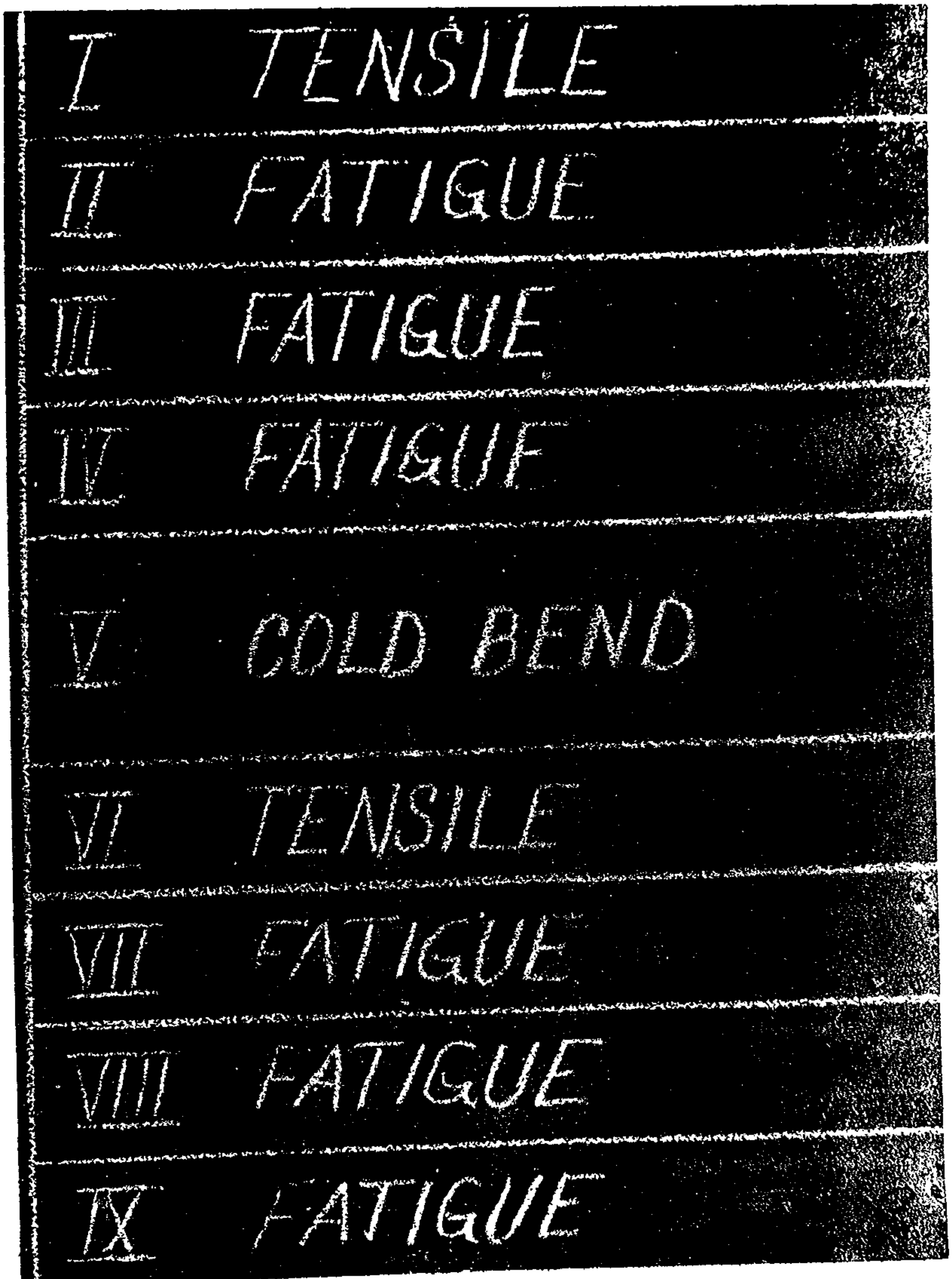

Plate IV
Steel Plate Sample Showing Location of Specimens

FATIGUE TEST SPECIMEN

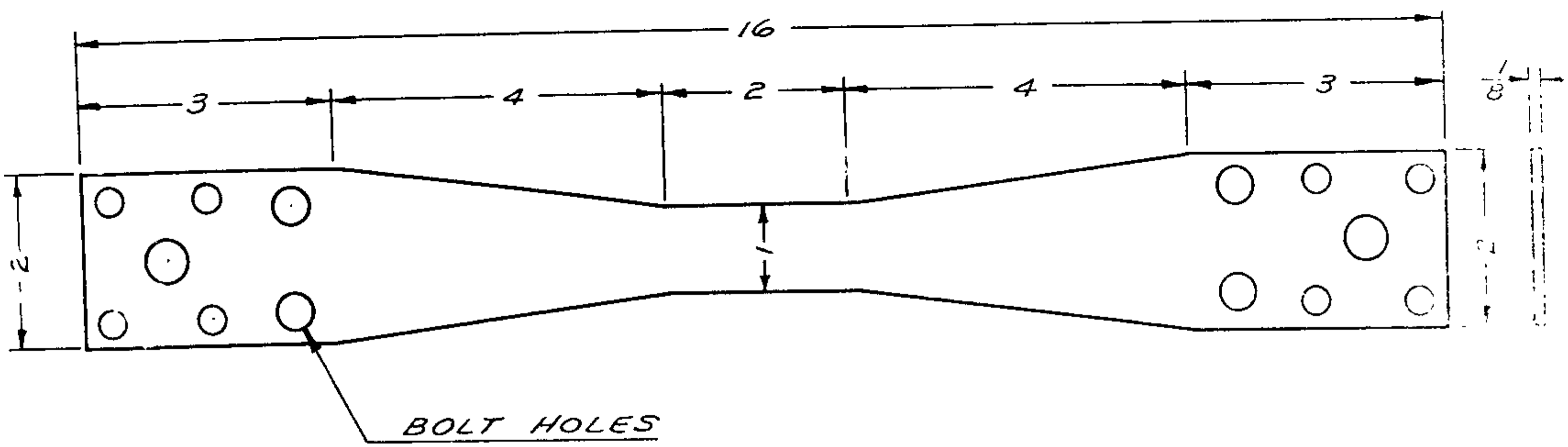

Plate V