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NATIONAL BUREAU OF STANDARDS REPORT

4286

TESTS OF PRECAST CONTINUOUS SPLICED GIRDERS

by

L. F. Skoda and J. O. Bryson

Report to
Bureau of Yards and Docks
Department of the Navy



**U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS**

U. S. DEPARTMENT OF COMMERCE

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Radio Standards. High Frequency Standards. Microwave Standards.

● Office of Basic Instrumentation

● Office of Weights and Measures

NATIONAL BUREAU OF STANDARDS REPORT

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NBS REPORT
4286

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To

Bureau of Yards and Docks
Department of the Navy

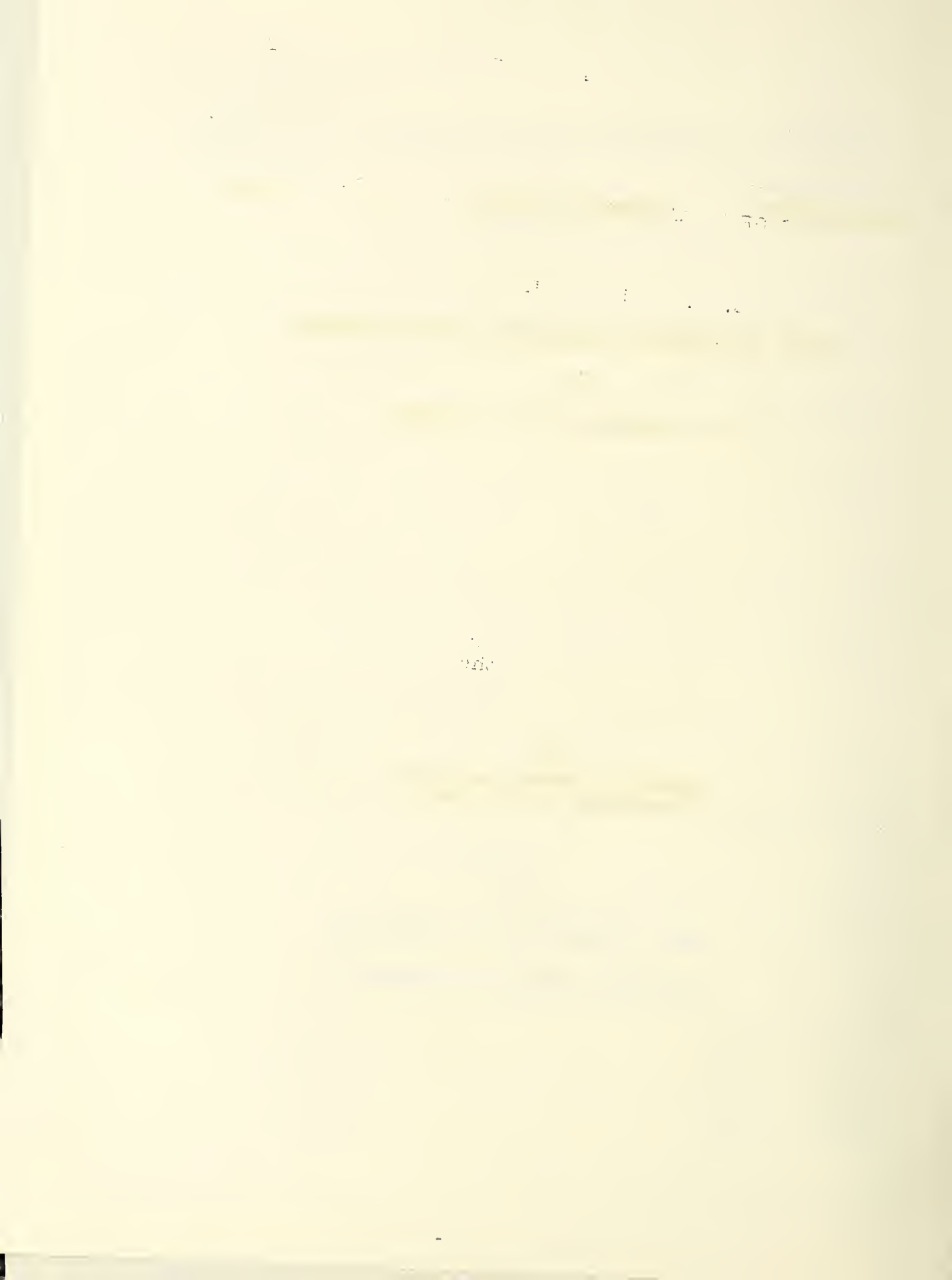


**U. S. DEPARTMENT OF COMMERCE
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TESTS OF PRECAST CONTINUOUS SPLICED GIRDERS

by

L. F. Skoda and J. O. Bryson

Abstract

The rigidity and strength of two precast girders with welded splices of two different designs were determined in tests of the girders as beams continuous over three supports. The girders consisted of three reinforced concrete box sections welded and grouted together to form a beam 1- by 2-ft in cross section and 25 ft long.

The splices located at points of inflection were formed by lap welding suitable lengths and amounts of positive and negative reinforcement projecting from the ends of adjoining sections and then grouting the pockets.

The designs of the splices of the two girders were identical, except that girder No. 2 contained an additional amount of reinforcement consisting of three inclined stirrups of No. 4 bars on each side of the splice. The addition of the inclined stirrups resulted in an increase of 67 percent in load carrying capacity of girder No. 2 as compared with girder No. 1.

1. INTRODUCTION

At the request of the Bureau of Yards and Docks, two precast continuous spliced girders were tested to evaluate the structural strength of proposed welded splices.

CHAPTER I

Introduction

1.1

The first part of the book is devoted to a study of the history of the subject. It begins with a survey of the early work of the great mathematicians of the past, and then proceeds to a more detailed examination of the work of the modern mathematicians. The author's aim is to show how the subject has developed over the years, and how it has become an integral part of the scientific world.

The second part of the book is devoted to a study of the theory of the subject. It begins with a survey of the basic principles of the theory, and then proceeds to a more detailed examination of the various branches of the theory. The author's aim is to show how the theory has developed over the years, and how it has become an integral part of the scientific world.

The third part of the book is devoted to a study of the applications of the theory. It begins with a survey of the various applications of the theory, and then proceeds to a more detailed examination of the various branches of the theory. The author's aim is to show how the theory has been applied in various fields of science and engineering, and how it has become an integral part of the scientific world.

Conclusion

1.2

The author concludes the book by summarizing the main results of the study. He shows how the theory has developed over the years, and how it has become an integral part of the scientific world. He also discusses the various applications of the theory, and how it has been used in various fields of science and engineering.

The following report presents observations and data obtained during the construction, fabrication and testing of two such girders.

2. PREPARATION OF THE SPECIMENS

2.1 Description of the specimens

Each girder consisted of three sections approximately 8 ft long joined together to form a girder 24.5 ft long. The sections were joined by lap welding suitable lengths and amounts of positive and negative reinforcement projecting from the ends of adjoining sections and then grouting the pockets. Each girder section was fabricated by welding together two channels which formed a box girder having a 1- by 2-ft cross section. The flange of the channel was 6 in. in breadth and its thickness varied from 6 in. at the base to $4 \frac{3}{4}$ in. where the channels joined. The web thickness was $2 \frac{1}{2}$ in. Each channel had three stiffening ribs, one at each end and one at the center. Steel plates, welded to bent No. 5 bars for anchorage, were embedded in the concrete at the time of casting. They were placed at the edge of the flanges, both on top and bottom, 2 ft 4 in. from the ends and 2 ft 4 in. from the center line of the joints. This provided each pair of channels with four points of attachment. Details of the girder and the reinforcement are shown in figure 1.

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2.2 Forms

The symmetrical design of the girders made it possible to construct forms for only one-half of the specimen. To keep the cost of casting at a minimum, each girder was made from two casting operations.

The forms, made at the National Bureau of Standards carpenter shop, had a base of $3/4$ in. plywood braced with 2- by 4-in. timbers. The pans were made of $3/4$ -in. plywood. The sides of the forms were made of 2- by 6-in. white pine and were removable. The heavy side pieces prevented warping. This resulted in an excellent duplication of the channels and a precise fit. The forms received three coats of waterproof spar varnish and, prior to each casting, oil and asbestine powder was applied as a separator. The forms with reinforcement in place are shown in figures 2 and 3.

2.3 Concrete

The proportions of the concrete were 1:2.48:2.02, by weight. High-early-strength cement was used to expedite-curing. The aggregates were sand and pea gravel, with a maximum size of $3/8$ in., from White Marsh, Maryland. Three batches of concrete, with slump from 3 to 4 in., were mixed for each casting operation.

The first part of the document discusses the importance of maintaining accurate records of all transactions. It emphasizes that every entry should be supported by a valid receipt or invoice. This ensures transparency and allows for easy verification of the data.

In the second section, the author outlines the various methods used to collect and analyze the data. This includes both primary and secondary data collection techniques. The primary data was gathered through direct observation and interviews with key stakeholders.

The analysis phase involved using statistical software to identify trends and correlations within the data set. It is noted that while the data shows a general upward trend, there are significant fluctuations that require further investigation.

The final section provides a summary of the findings and offers recommendations for future research. It suggests that more detailed studies should be conducted to explore the underlying causes of the observed trends.

Two 6- by 12-in. control cylinders were cast from each batch and gave the following average results:

	<u>Compressive strength</u>	<u>Tangent modulus</u>
	psi	psi
Girder No. 1	7,560	4.5 by 10 ⁶
Girder No. 2	8,130	4.4 by 10 ⁶

Stress-strain curves for the concrete in each specimen are shown in figures 4 and 5.

Both specimens were kept under damp burlap for two days and then transferred to a curing chamber where they were moist-cured for periods ranging from 1 to 4 months. The concrete was then air-dried until tested at an age of about 8 months.

2.4 Reinforcement

Reinforcement in the upper flanges of the end sections of each girder consisted of four No. 8 deformed bars. The two inner bars were completely embedded while the outer bars extended 5 in. beyond the joint end. The upper flange of the middle section was reinforced with two No. 4 deformed bars. These bars extended 5 in. from the middle section to lap the No. 8 bars from the end sections. The lower flanges were reinforced conversely: four No. 8 bars in the middle section and two No. 4 bars in the end section.

The web reinforcement in the portion near the joint was different for the two girders. In girder No. 1 there was a single, hooked No. 4 bar while girder No. 2 had a bent No. 4 bar tied to three inclined stirrups of No. 4 bars on each side of the welded splice, as shown in figure 1.

All of the deformed reinforcing bars were of intermediate grade steel. The girders were further reinforced throughout their webs and flanges with 4- by 4-in. welded wire fabric, No. 6 gage.

2.5 Assembly, welding, and grouting

After curing, the channels were dried for two days before being assembled.

Each pair of channels was welded together with 1- by 3/8- by 2-in. connector plates, centered over the embedded steel plates (2.1). Small cracks, 1-in. to 2-in. long, adjacent to and radiating from the embedded plates, resulted from the heat produced by welding. These cracks were negligible in width, however,. Another crack appeared in girder No. 1 parallel to the embedded No. 5 anchorage bar, but it seemed to have no effect on the results of the test.

The joined channels were then put in position for welding with the protruding reinforcement overlapping 4 in., (see figure 1). To reduce heat transfer to the concrete

as the lap welding was done, each weld was allowed to cool after only half of the bead was complete. All welding was done by a qualified Navy welder.

After the welding was completed, forms were constructed around the pocket at each joint and filled with concrete having the same proportions as the concrete used in the specimen. The average compressive strength of 6- by 12-in. control cylinders was 8,400 psi.

3. TESTING PROCEDURE

3.1 Test setup

To simplify the testing procedure, the girders were tested in an inverted position. A mechanical testing machine with a 600,000 lb capacity was used.

The girder was supported on three rockers, one of which was at the center and one at each end 12 ft from the center. The load was applied to the girder through a loading beam at two load points 16 ft apart on top of the inverted girder. The machine load was applied to the loading beam through a spherically seated compression block.

The load was to be so distributed that the sum of the end reactions equaled the center reaction. To insure such a distribution, it was necessary to adjust the end reactions as each increment of load was applied by the machine. This was accomplished by means of hydraulic jacks which

served as end reactions for the girder. Calibrated load cells were placed between the jacks and the girder. As each increment of load was applied, the end reactions were adjusted to equal one-fourth of the load. A diagram of the loading arrangement is shown in figure 6. Figure 7 shows a close-up of the end reaction and figure 8 shows girder No. 1 in the testing machine.

3.2 Instrumentation

The instruments employed to measure the strains of the girders were 0.001-in. dial gages and SR-4 electrical resistance strain gages.

The dial gages were placed opposite the three reactions and the two points of load application, and measured the displacements of these points relative to the platen. It was necessary, therefore, to measure also any possible deflection in the platen of the testing machine in respect to the laboratory floor. The SR-4 gages were placed on all of the reinforcing bars at the points of maximum bending moments (see figure 6). A complete set of readings was taken at each machine load increment of 20,000 lb.

The first part of the document discusses the importance of maintaining accurate records of all transactions. It emphasizes that every entry should be supported by a valid receipt or invoice. The second part outlines the procedures for handling discrepancies and errors, including the steps to be taken when a mistake is identified. The third part provides a detailed explanation of the accounting cycle, from identifying transactions to preparing financial statements. The final part of the document discusses the role of the accountant in providing financial information to management and other stakeholders.

The following table shows the results of the audit for the period ending 31st December 2023. The audit was conducted in accordance with the standards of the Institute of Chartered Accountants in England and Wales. The auditor has found that the financial statements are true and fair in all material aspects. The following table shows the results of the audit for the period ending 31st December 2023. The audit was conducted in accordance with the standards of the Institute of Chartered Accountants in England and Wales. The auditor has found that the financial statements are true and fair in all material aspects.

Particulars	2023	2022
Revenue	1,200,000	1,100,000
Cost of Sales	(800,000)	(750,000)
Gross Profit	400,000	350,000
Operating Expenses	(250,000)	(230,000)
Operating Profit	150,000	120,000
Finance Income	20,000	15,000
Finance Expenses	(10,000)	(15,000)
Profit Before Tax	160,000	110,000
Income Tax	(40,000)	(30,000)
Profit After Tax	120,000	80,000

The above table shows the results of the audit for the period ending 31st December 2023. The audit was conducted in accordance with the standards of the Institute of Chartered Accountants in England and Wales. The auditor has found that the financial statements are true and fair in all material aspects.

4. RESULTS

The girders were tested as beams continuous over three supports with the loads applied at points 4 ft from each end of the girder. This arrangement of supports and loads, shown in figures 1 and 6, was devised in order to have the welded splices at the third points coincide with points of inflection in the continuous girder.

Both girders failed by diagonal tension. Girder No. 1 failed at a total applied load of 151,000 lb and girder No. 2 at 253,500 lb. Thus, the addition of six inclined stirrups of No. 4 bars on each side of the welded splices resulted in an increase of 67 percent in resistance to shear of the girder No. 2 as compared with girder No. 1. The loads given here are the applied machine loads and do not include the weights of the specimen and the loading fixtures.

The load deflection diagrams for the two girders are given in figures 9 and 10. The values of the deflections in the diagrams are the displacements of the center and the ends of the girders with respect to a straight line passing through the points of application of load. Negative values of deflection indicate downward displacements of the girder in its actual position in the structure.

CHAPTER 10

The first part of the chapter discusses the importance of maintaining accurate records of all transactions. It emphasizes that every sale, purchase, and payment must be properly documented to ensure the integrity of the financial statements. The text also covers the various methods used to record transactions, including the double-entry system and the use of journals and ledgers.

Subsequent sections explore the different types of accounts used in accounting, such as assets, liabilities, equity, and income. It explains how these accounts interact and how they are used to calculate the net income of a business. The chapter also discusses the process of adjusting entries, which are necessary to ensure that the financial statements reflect the true financial position of the company at the end of the period.

The final part of the chapter focuses on the preparation of the financial statements, including the balance sheet, income statement, and statement of cash flows. It provides a detailed explanation of how each statement is derived from the accounting records and how they are used to provide a comprehensive overview of the company's financial performance and position.

Girder No. 1 reached a center deflection of 0.314 in. at a load of 139 kips, at which load the last deflection reading was obtained prior to failure. The end deflections at this load averaged 0.135 in.

Girder No. 2 reached a center deflection of 0.395 in. at 220 kips, the last observed deflection prior to failure. The end deflections at this load averaged 0.242 in.

The relation between the observed strain in the reinforcement and applied load is illustrated in figures 11 and 12. The strains were observed at the center of each girder and the points of application of load in both compressive and tensile reinforcement.

The strain in the reinforcement was also plotted in figures 13 and 14 to show the distribution of strain along the length of the girder and to check the theoretical location of the points of inflection. It can be seen that as the loads increased and cracks in the concrete became wider and more closely spaced, the sections of zero bending moments shifted somewhat toward the center of the girder. This was indicated, in general, by both the tensile and compressive strain measurements in the reinforcement.

Close-up views of the sections of the girders where failure occurred are shown in figures 15, 16, and 17, and the general crack pattern is shown in figure 18. It can

be seen that the shear failure in girder No. 1 was sudden and complete, as is usually the case with shear failures in reinforced concrete beams containing little or no web reinforcement. The major diagonal tension crack in girder No. 1 which ran from the point of application of load to the mid-section of the welded splice was wide enough to cause tensile failure in the 4- by 4-in. welded wire fabric of No. 6 gage which was present in the webs of the girder.

The diagonal tension crack at which failure developed in girder No. 2 was considerably steeper than that in girder No. 1. As can be seen in figures 16 and 17, the diagonal tension crack ran from the point of application of load to a section about midway between the splice and the load point. The splice itself, as seen in the close-up of figure 17, appeared to be substantially intact after the test, even though crossed by several cracks.

The distribution of cracks illustrated in figure 18 shows substantially the same crack pattern in both girders in the vicinity of supports and applied loads. However, on account of its greater load carrying capacity, girder No. 2 developed extensive tensile cracking in the vicinity of the splices which was absent in girder No. 1.

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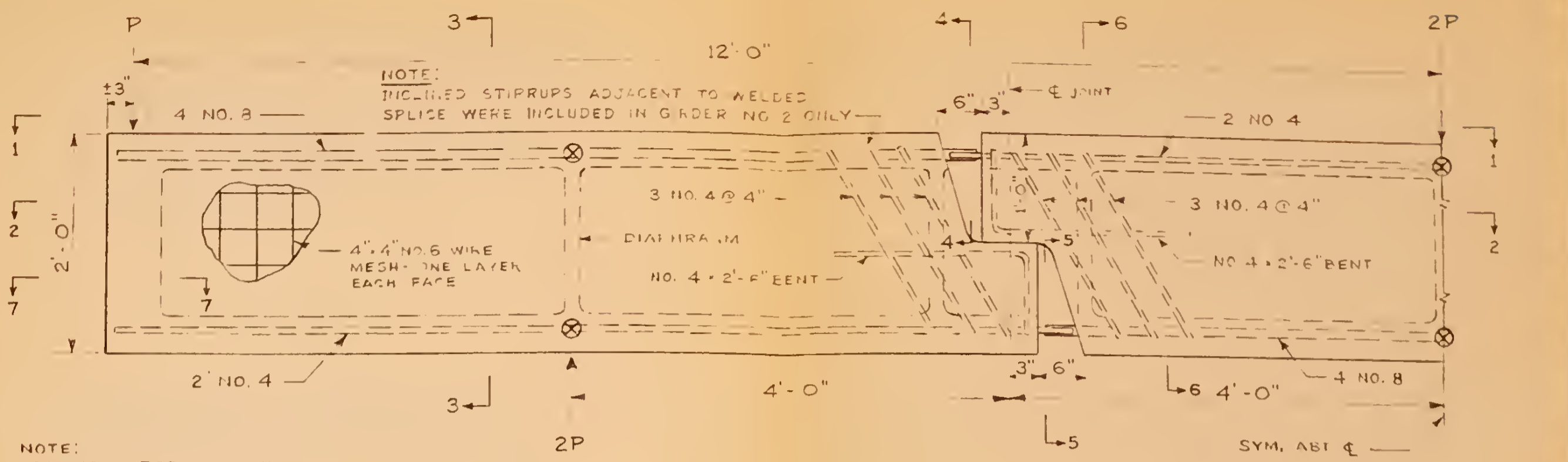
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The first part of the document discusses the importance of maintaining accurate records of all transactions. It emphasizes that every entry should be supported by a valid receipt or invoice. The text also mentions the need for regular audits to ensure the integrity of the financial data. Furthermore, it highlights the role of the accounting department in providing timely and accurate information to management for decision-making purposes.

In addition, the document outlines the procedures for handling discrepancies and errors. It states that any identified errors should be promptly investigated and corrected. The text also discusses the importance of maintaining proper documentation for all financial activities, including bank statements and tax returns. Moreover, it mentions the need for clear communication and collaboration between different departments to ensure the smooth flow of financial information.

The document concludes by reiterating the commitment to transparency and accountability in all financial matters. It encourages all employees to adhere to the established policies and procedures. Finally, it expresses confidence in the ability of the organization to maintain high standards of financial performance and reporting.



NOTE:
 INCLINED STIRRUPS ADJACENT TO WELDED
 SPLICE WERE INCLUDED IN GIRDER NO. 2 ONLY

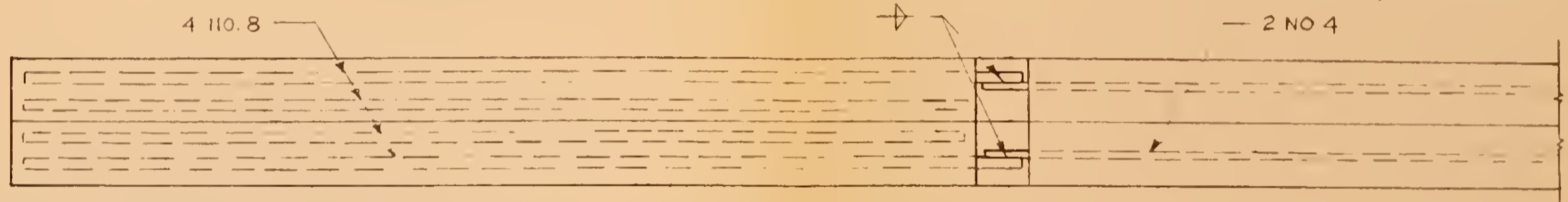
NOTE:
 LAP WELD RST AT JOINT
 TO DEVELOP FULL STRENGTH
 OF SMALLEST BAR CONNECTED.

SYM. ABT ϕ
 AFTER BARS ARE WELDED
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HALF ELEVATION OF SPLICED GIRDER

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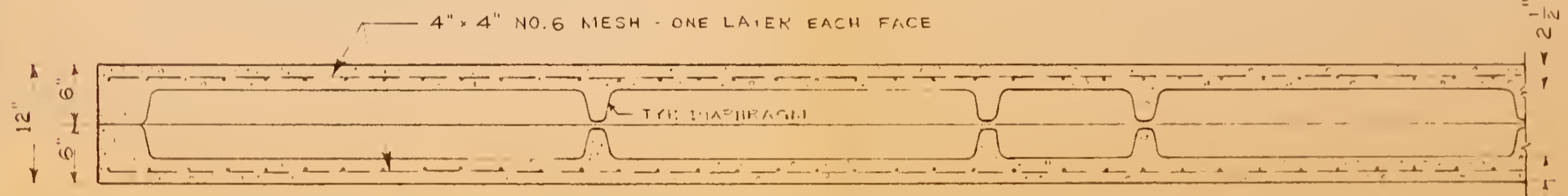
⊗ INDICATES LOCATION OF SR-4 STRAIN GAGES.



SECTION 1-1

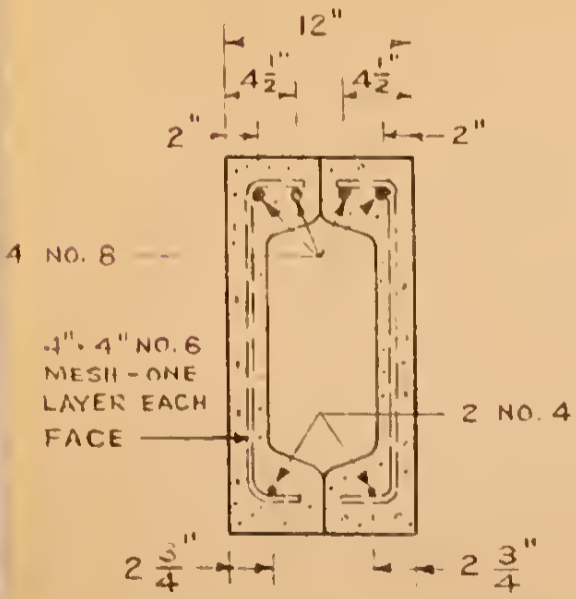
SCALE: 1" = 1'-0"

NOTE:
 FOR DETAIL OF CHANNEL
 CONNECTIONS SEE DWG. OF
 PRECAST TEE-HEAD SKETCH B-1.



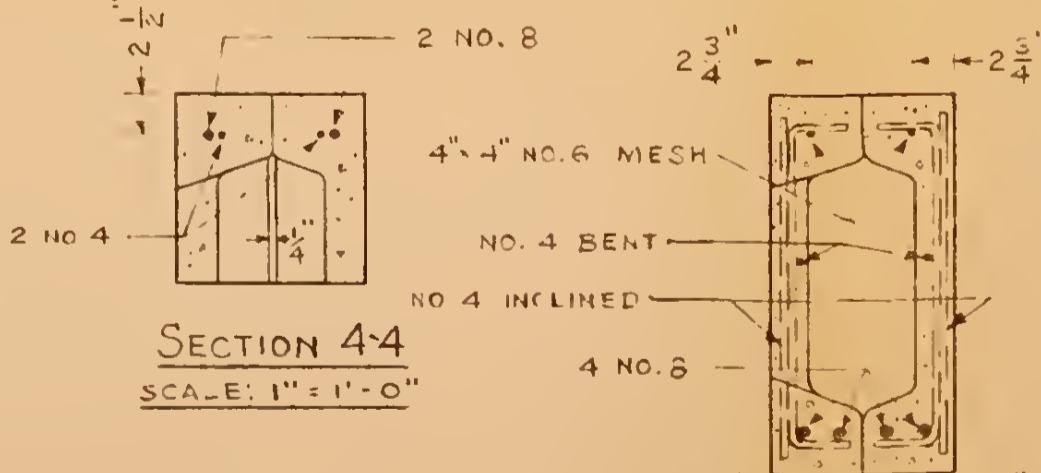
SECTION 2-2

SCALE: 1" = 1'-0"



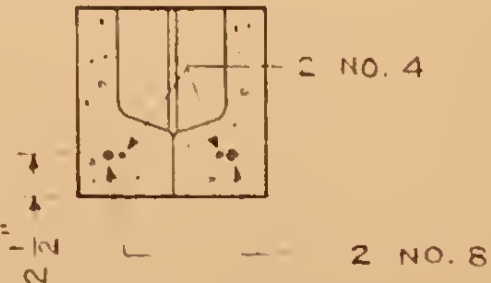
SECTION 3-3

SCALE: 1" = 1'-0"



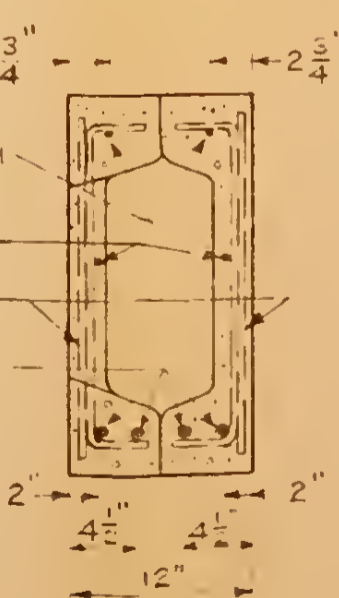
SECTION 4-4

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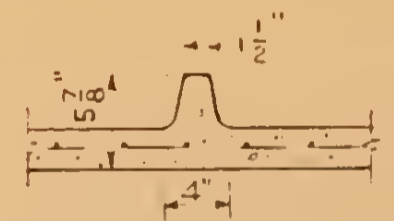
SECTION 5-5

SCALE: 1" = 1'-0"



SECTION 6-6

SCALE: 1" = 1'-0"



TYPICAL DIAPHRAGM

SCALE: 1" = 1'-0"



SECTION 7-7

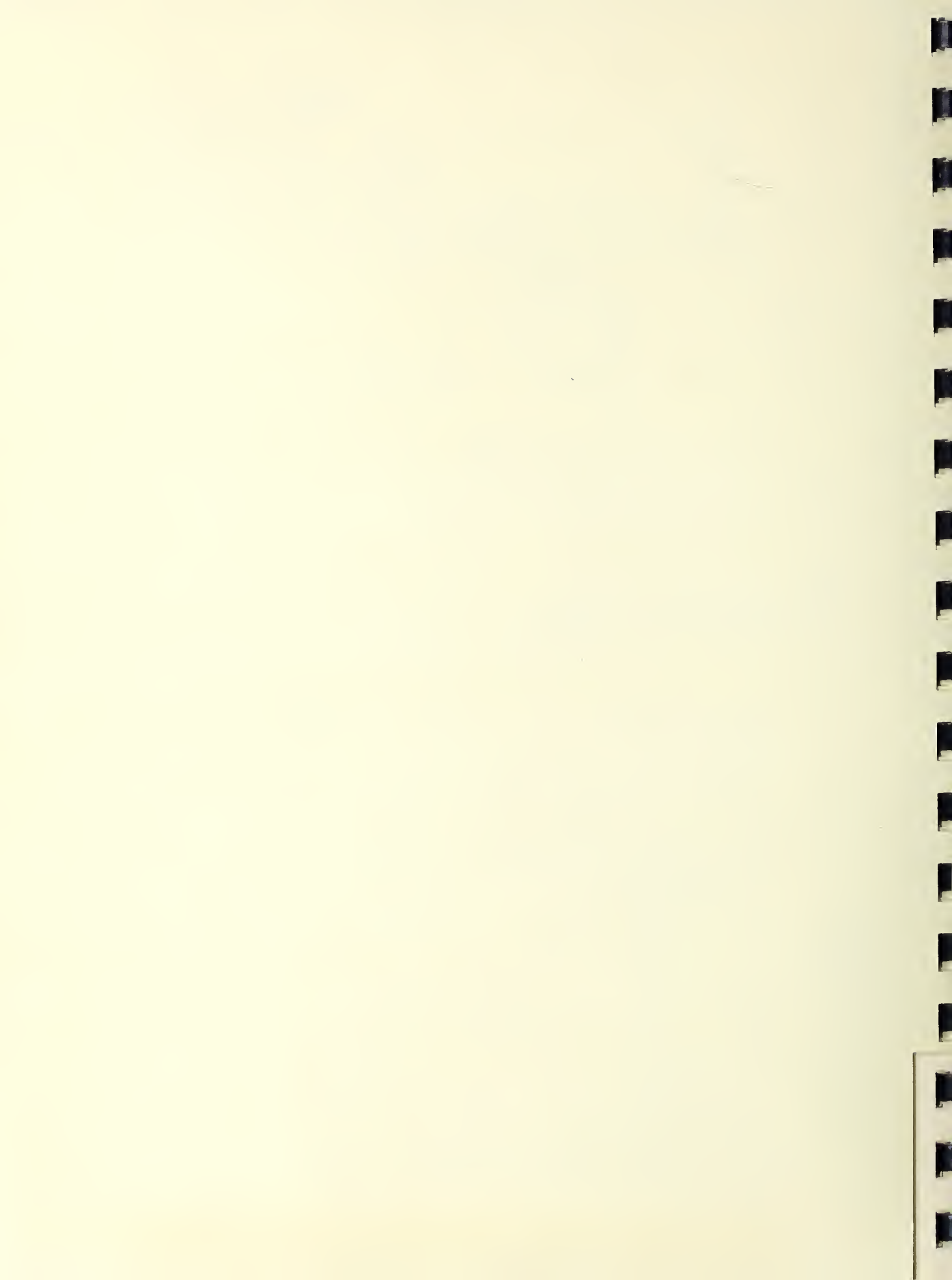
SCALE: 1" = 1'-0"

GENERAL NOTES

CONCRETE CYL. STR.	4,000 P.S.I.
CEMENT FACTOR	7 BAGS/CU. YD.
MAX. SIZE AGGREGATE	3/8 IN.
INT. GRADE REINF. STEEL	24,000 P.S.I.
WELDED WIRE MESH.	30,000 P.S.I.

**PRECAST CONTINUOUS
 SPLICED GIRDER**

DATE: 5-13-53 SKETCH B-3
 DESIGNED BY: W.C. GREEN TRACED BY: E.K.



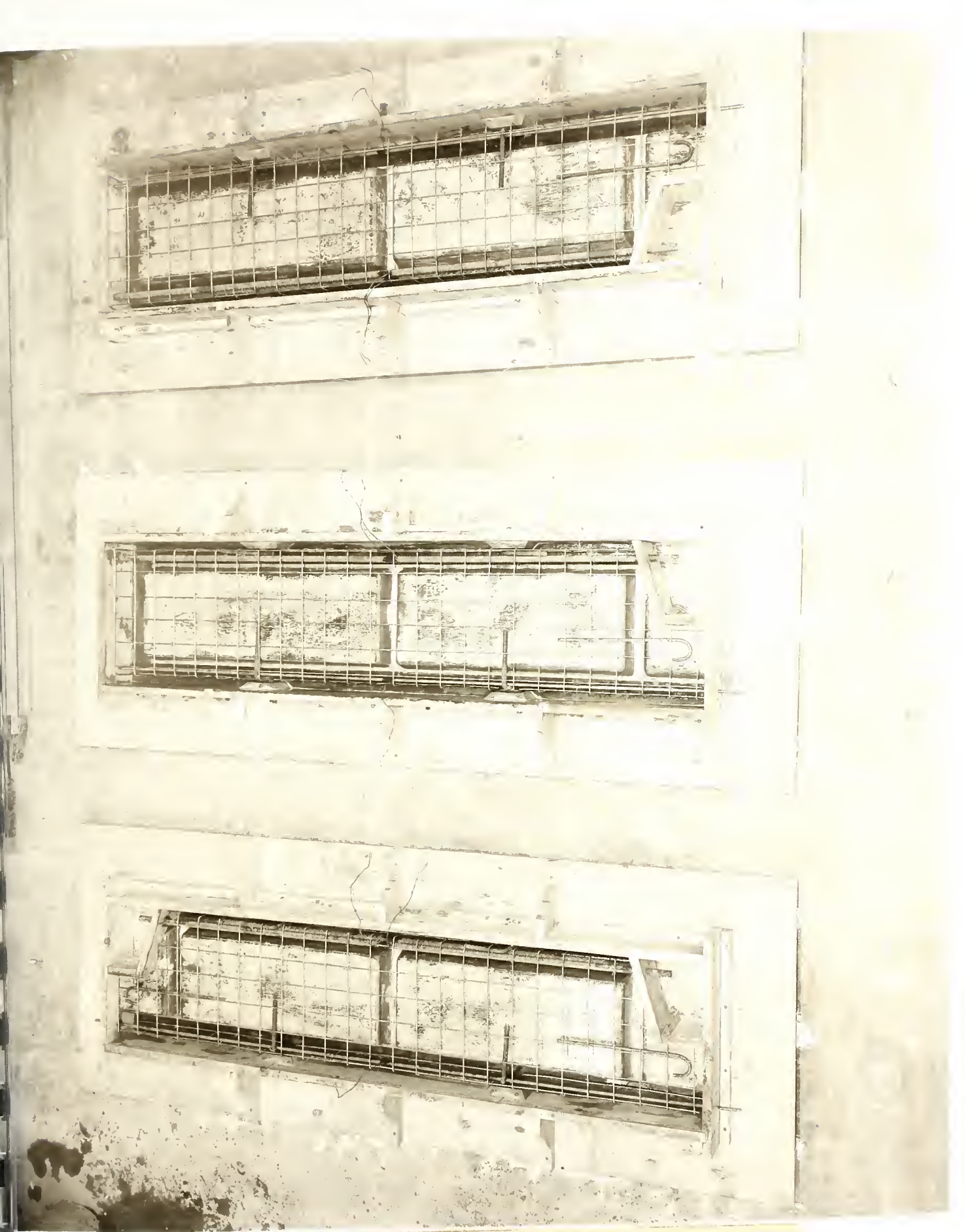


Fig. 2. Reinforcement and forms, girder No. 1.

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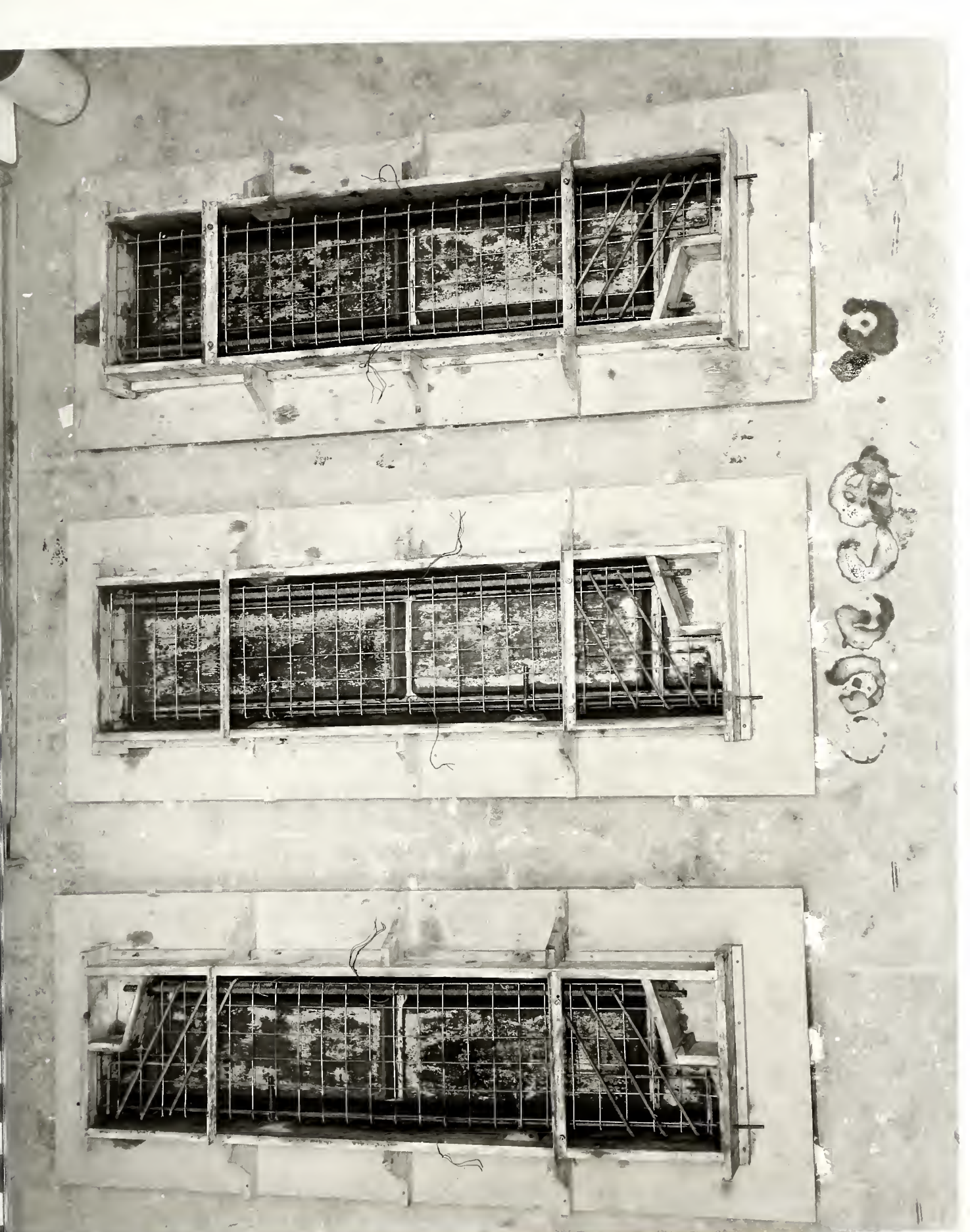


Fig. 3. Reinforcement and forms, girder No. 2.

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CONTINUOUS GIRDER NO. 1

STRESS-STRAIN CURVE OF 6"X12" CONCRETE CONTROL CYLINDER

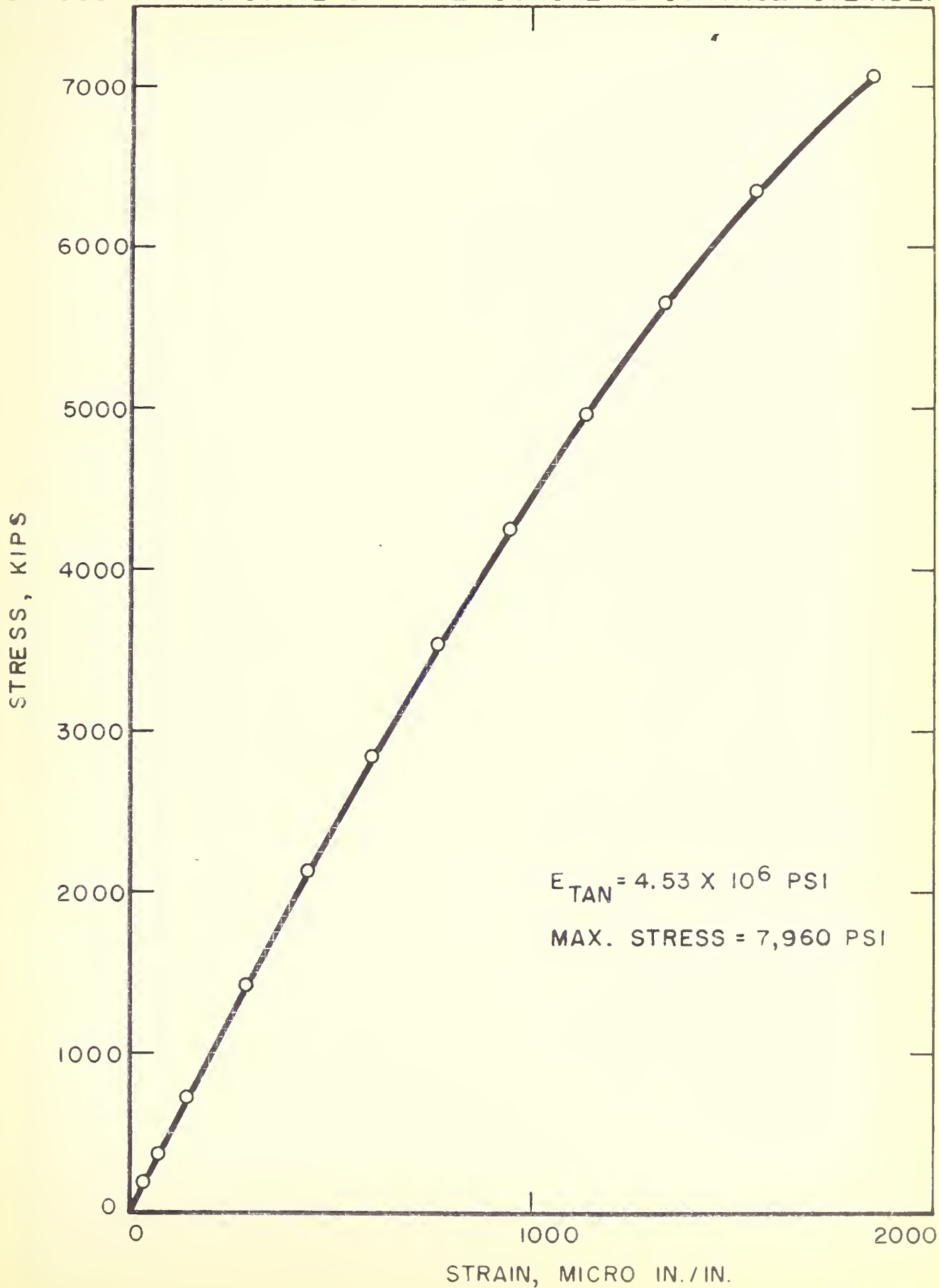
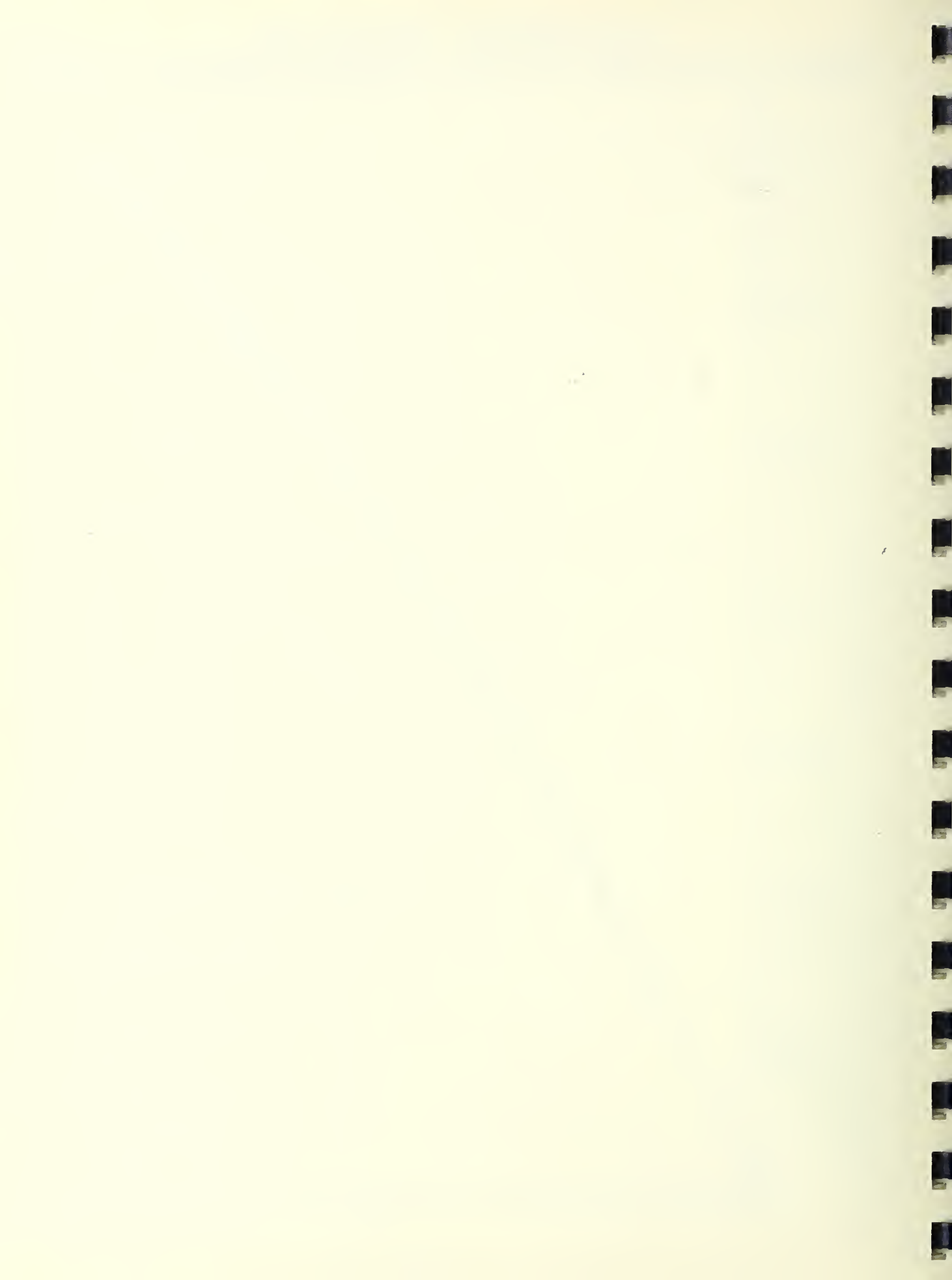


FIG. 4



CONTINUOUS GIRDER NO. 2
STRESS-STRAIN CURVE OF 6"X12" CONCRETE CONTROL CYLINDER

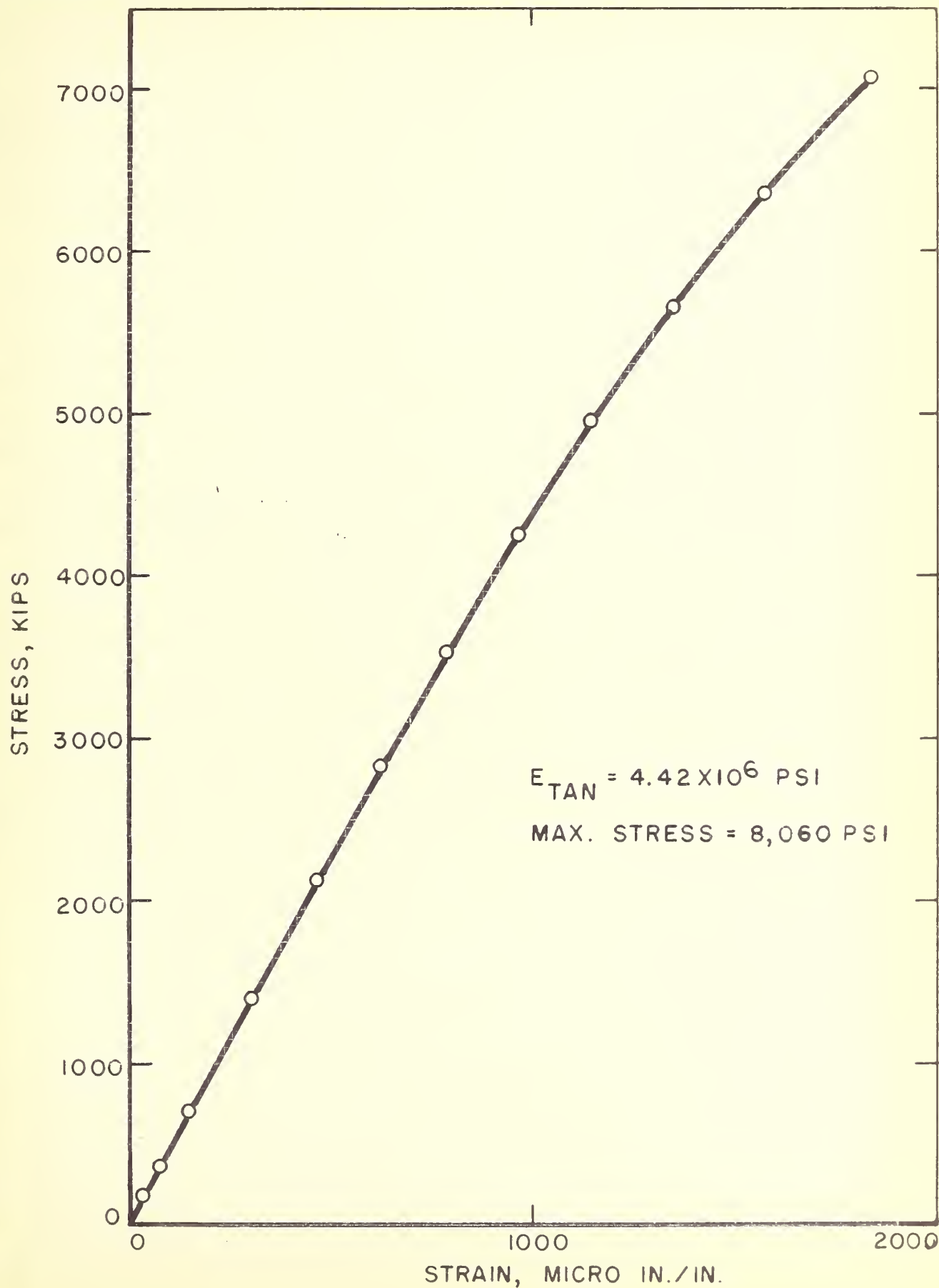
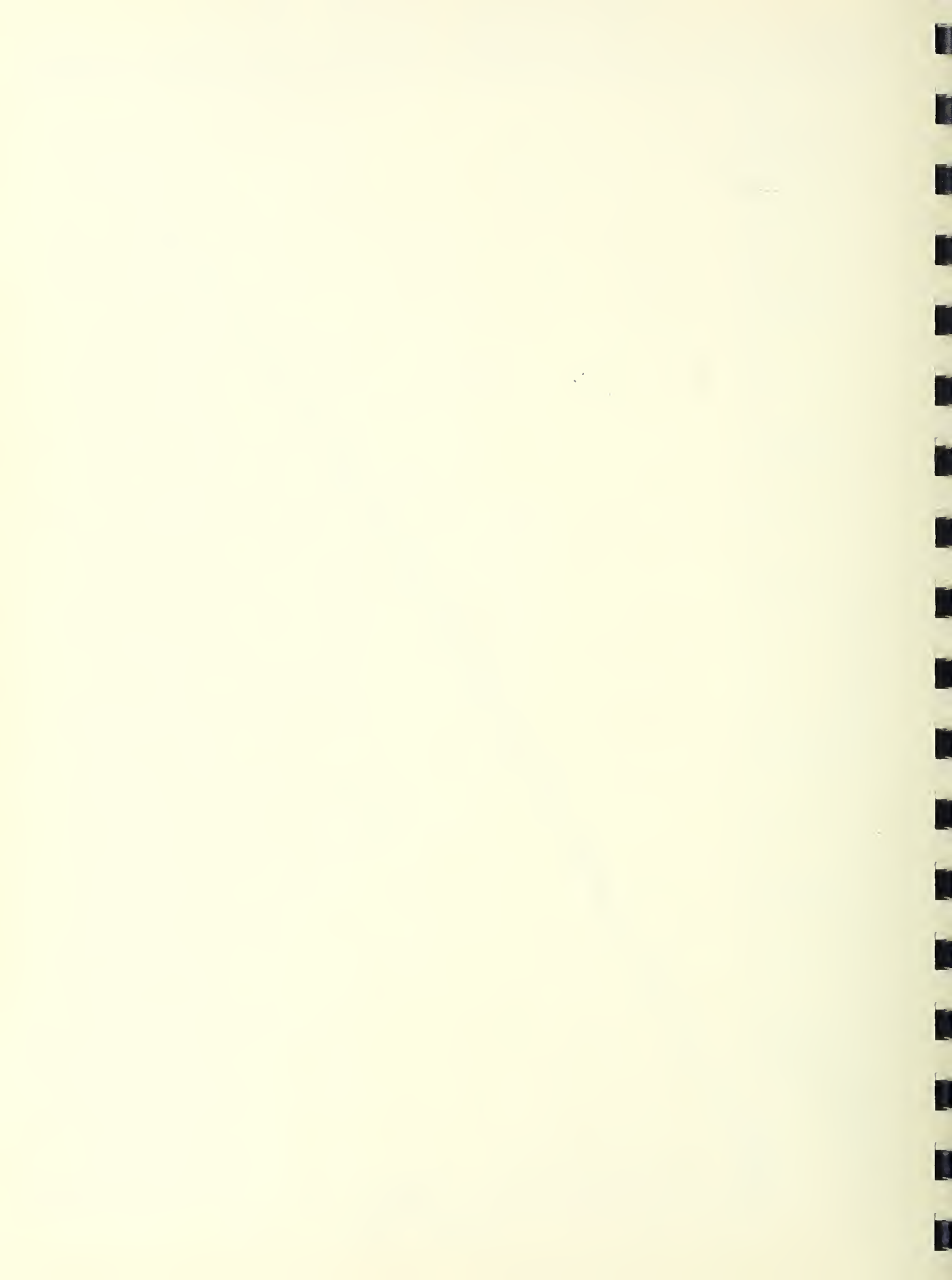
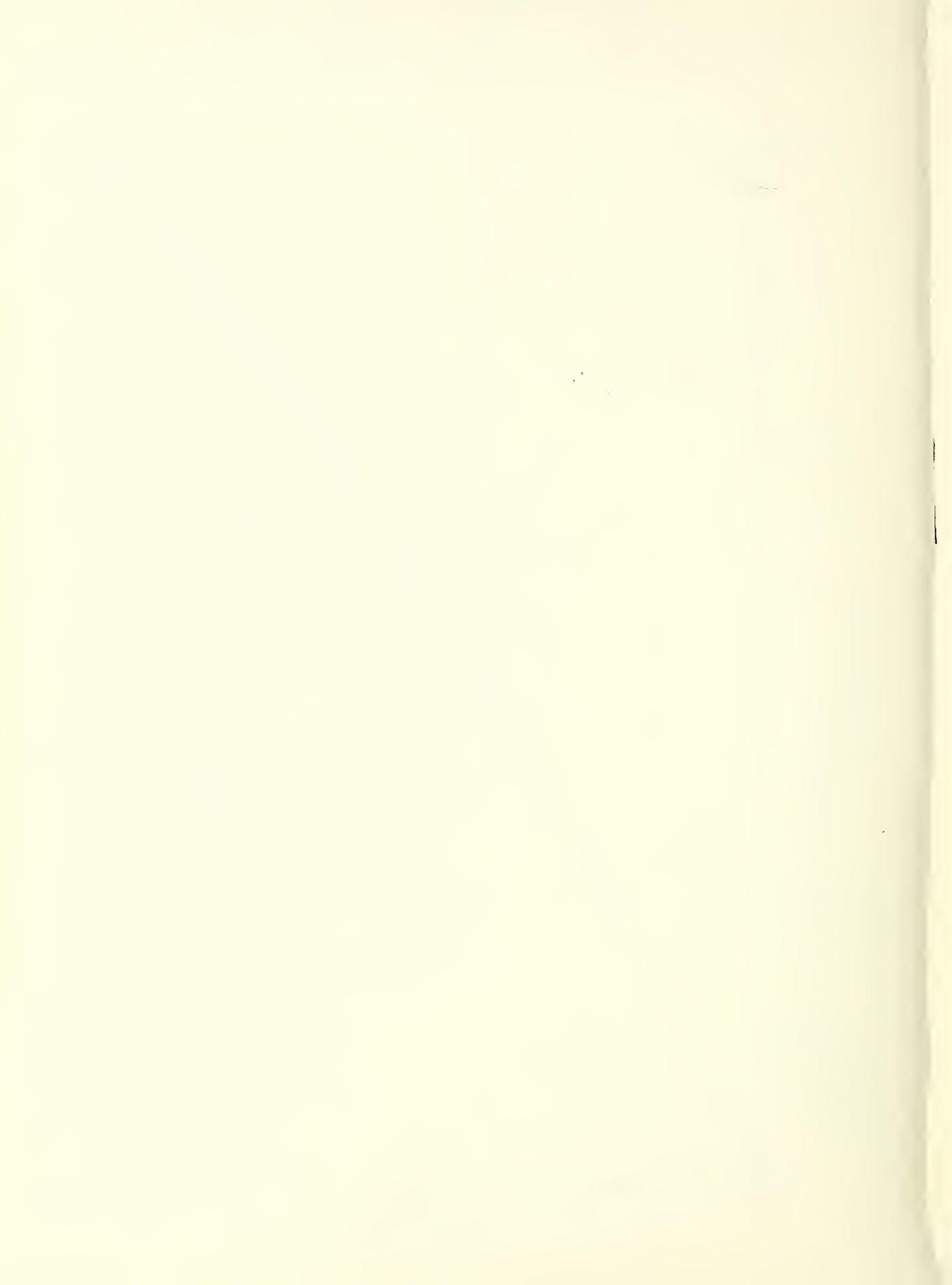


FIG. 5

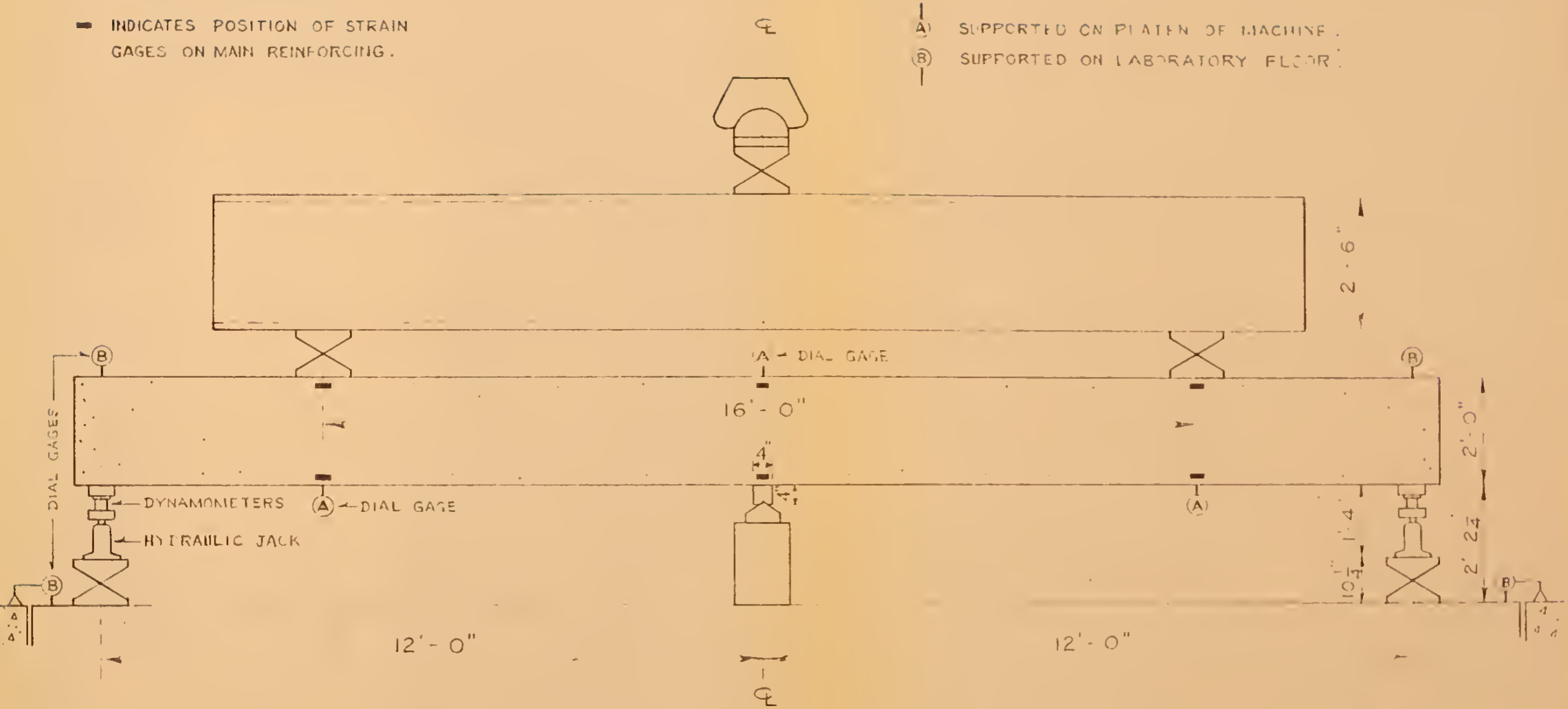






— INDICATES POSITION OF STRAIN GAGES ON MAIN REINFORCING.

(A) SUPPORTED ON PLATEN OF MACHINE.
 (B) SUPPORTED ON LABORATORY FLOOR.



LOADING ARRANGEMENT & LOCATION OF GAGES

SCALE: 1/2" = 1' - 0"



8-13-54

EK

FIG. 6

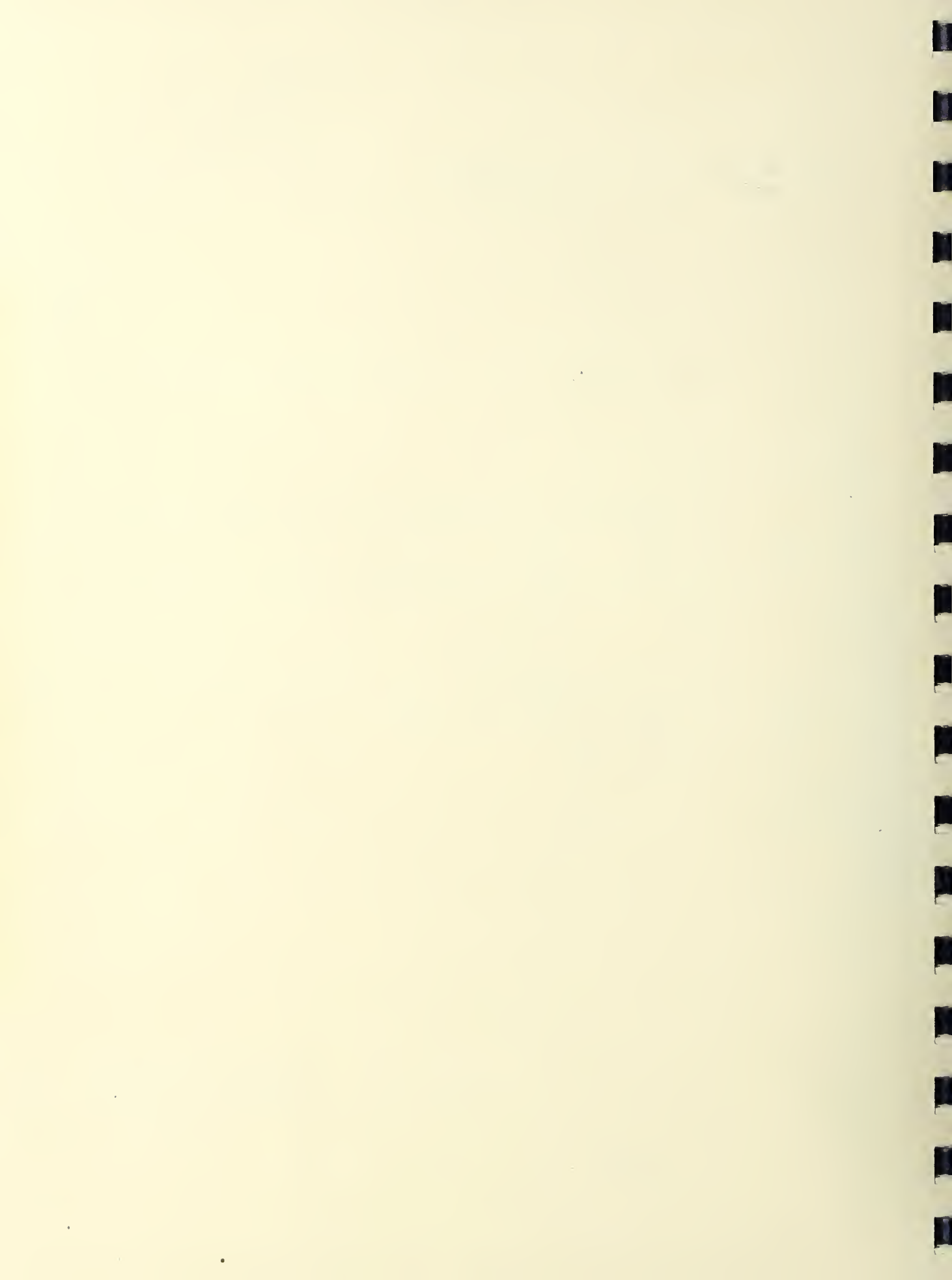




Fig. 7. Close-up of end reaction showing jack and load cell.

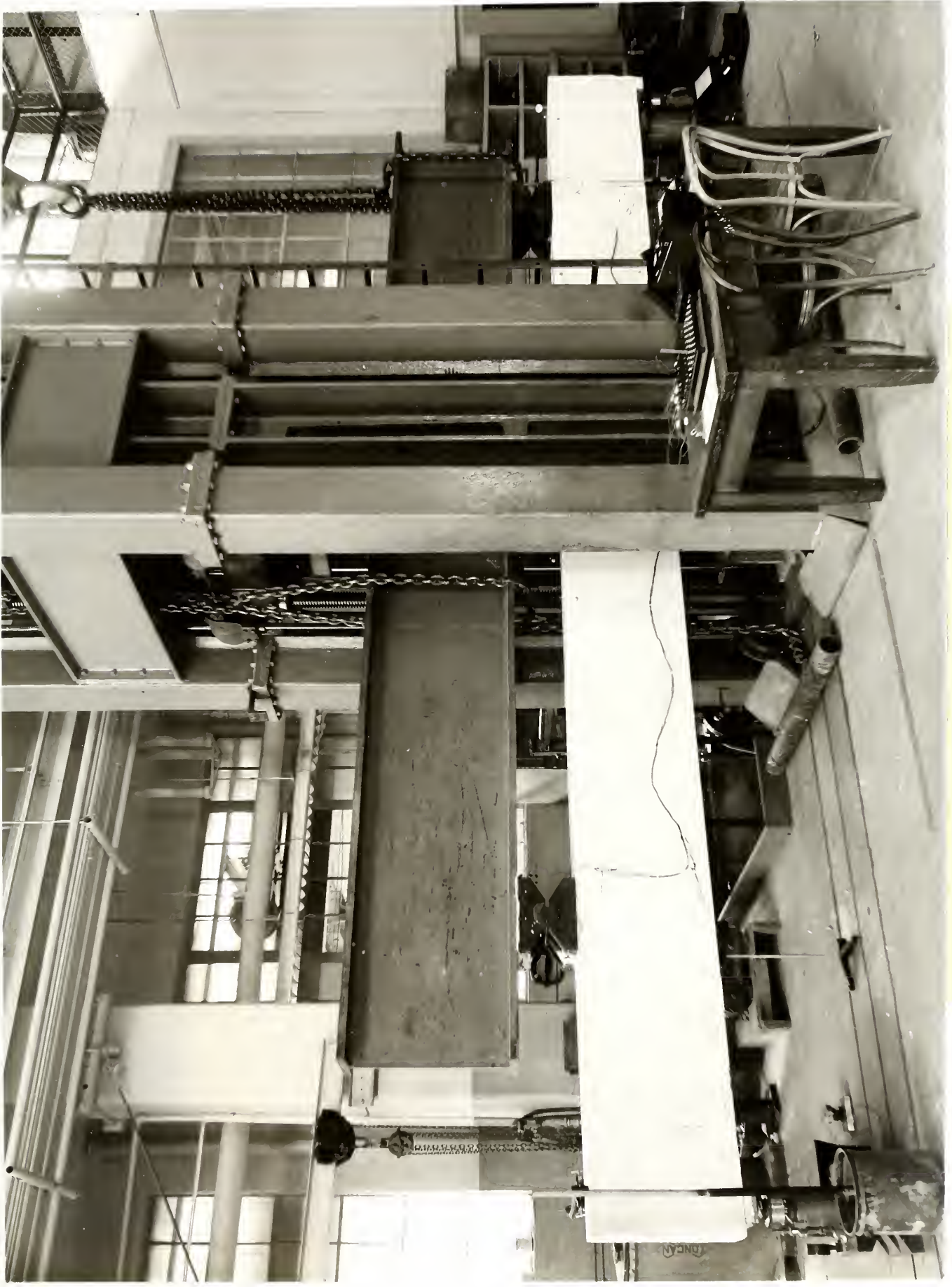


Fig. 8. Girder in 600,000 lb testing machine.

1-8 (17)

MACHINE LOAD VS. DEFLECTION C. G. NO.1

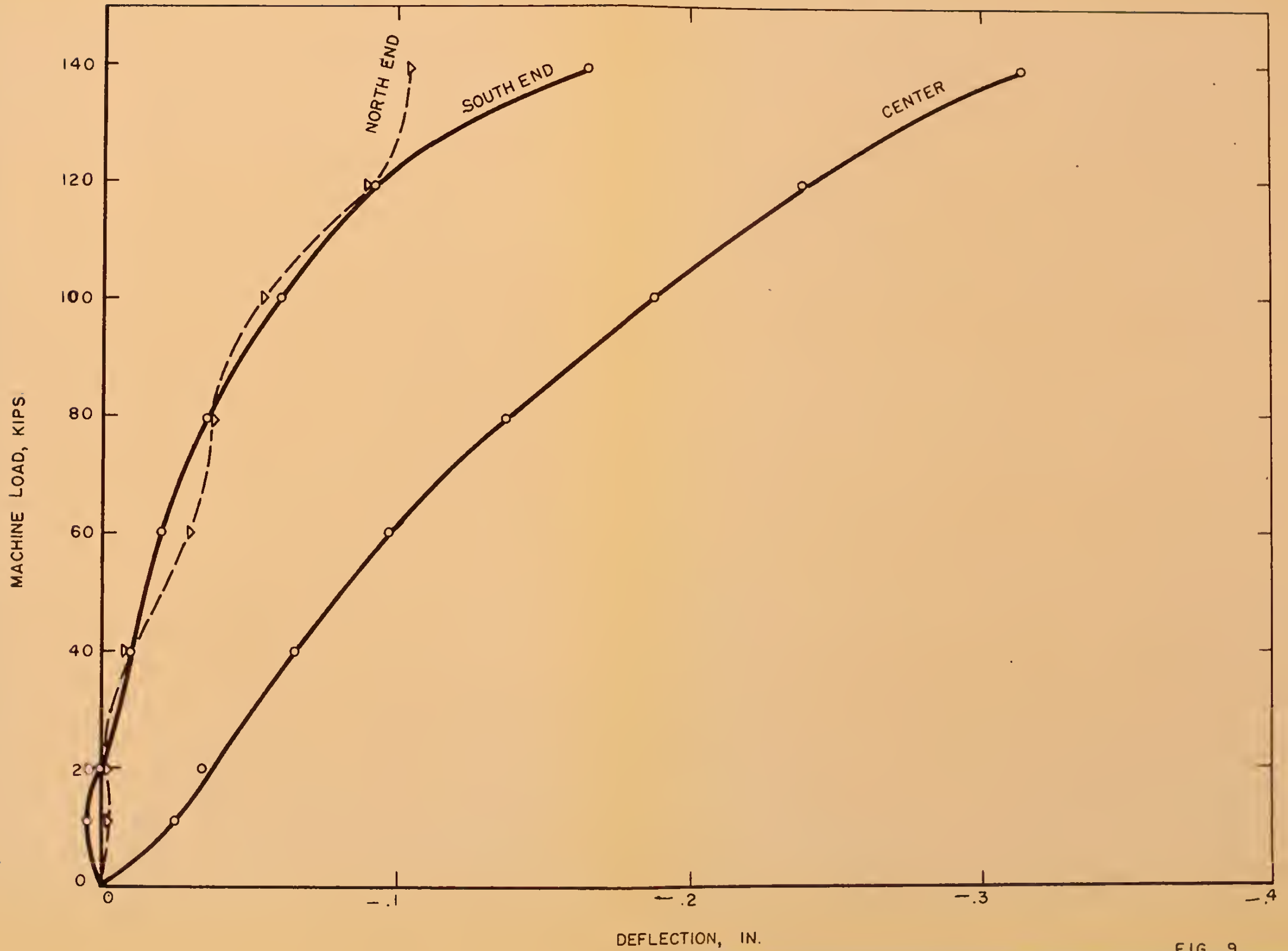
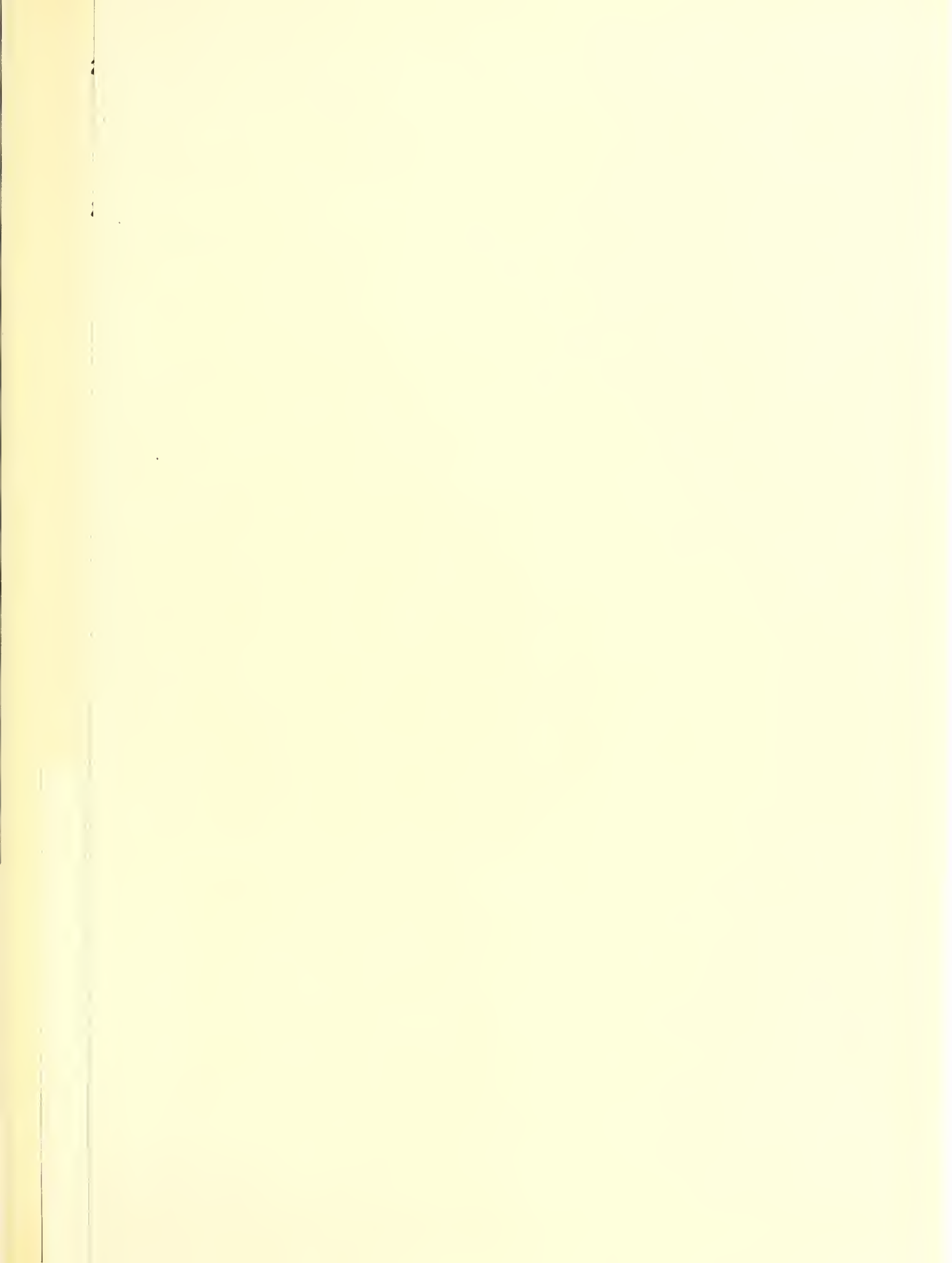
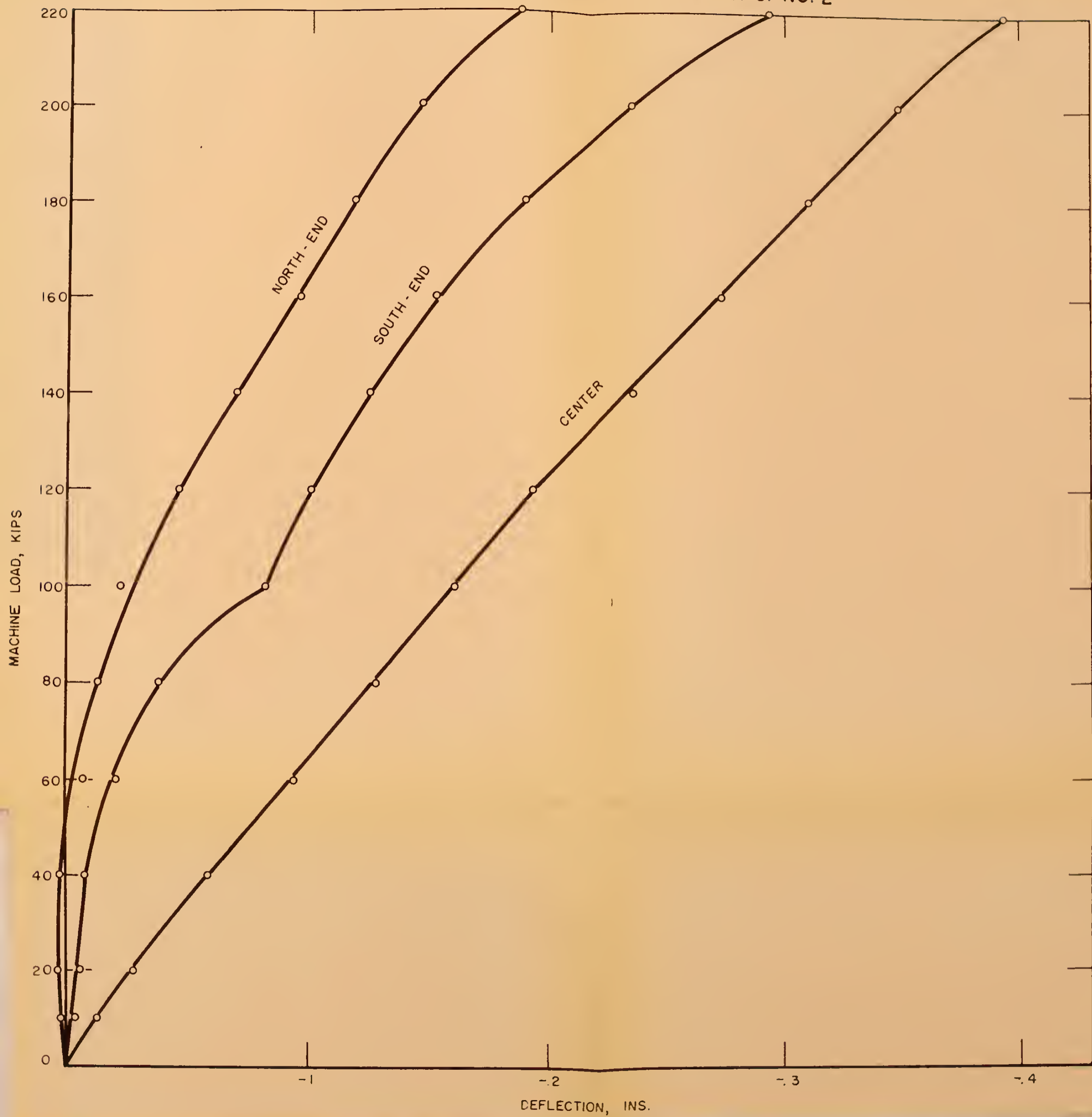


FIG. 9



MACHINE LOAD VS. DEFLECTION C. G. NO. 2



MACHINE LOAD KIPS



OBSERVED STRAIN VS. MACHINE LOAD C. G. NO. 1

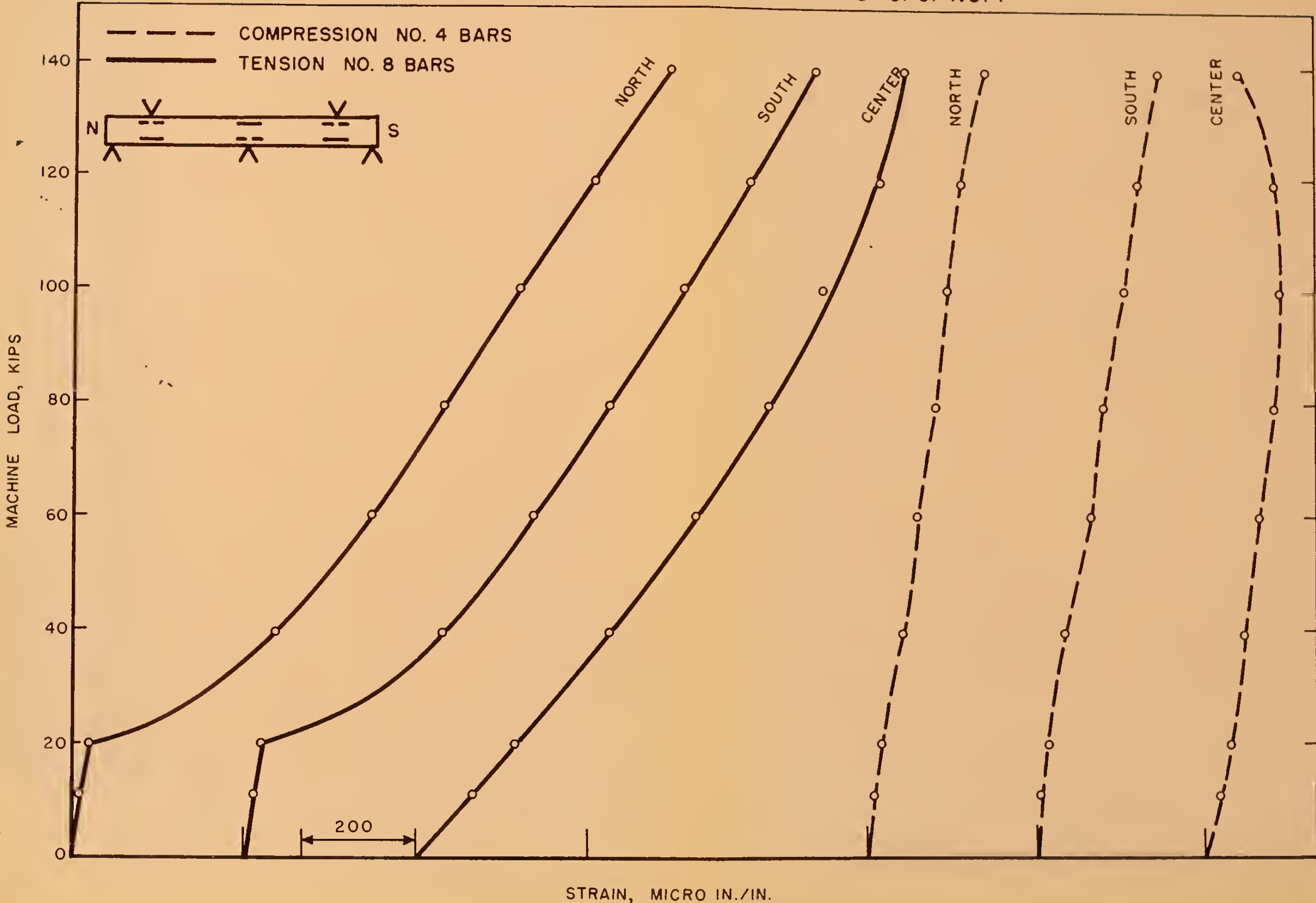


FIG. II

MACHINE LOAD, KIPS

2

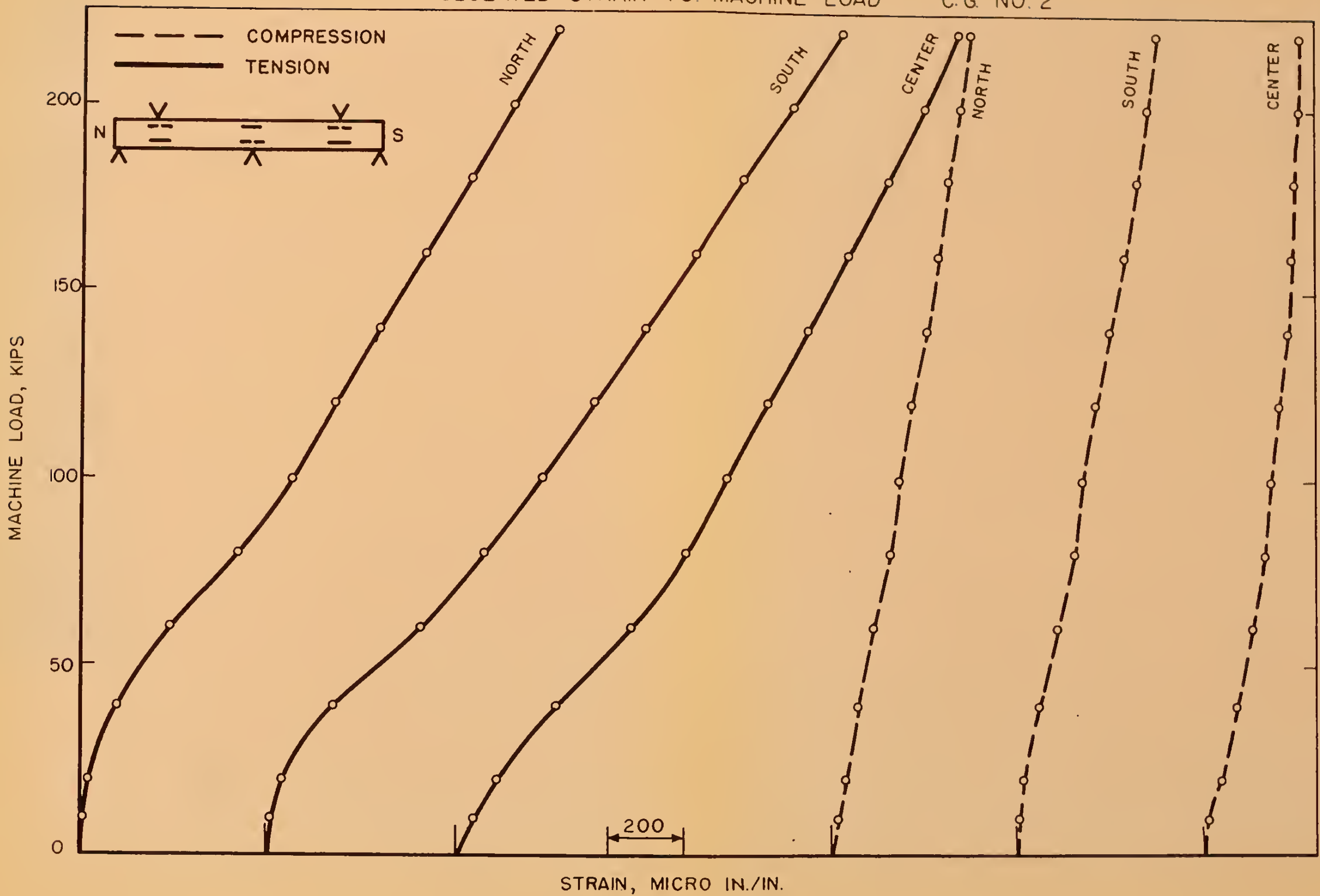
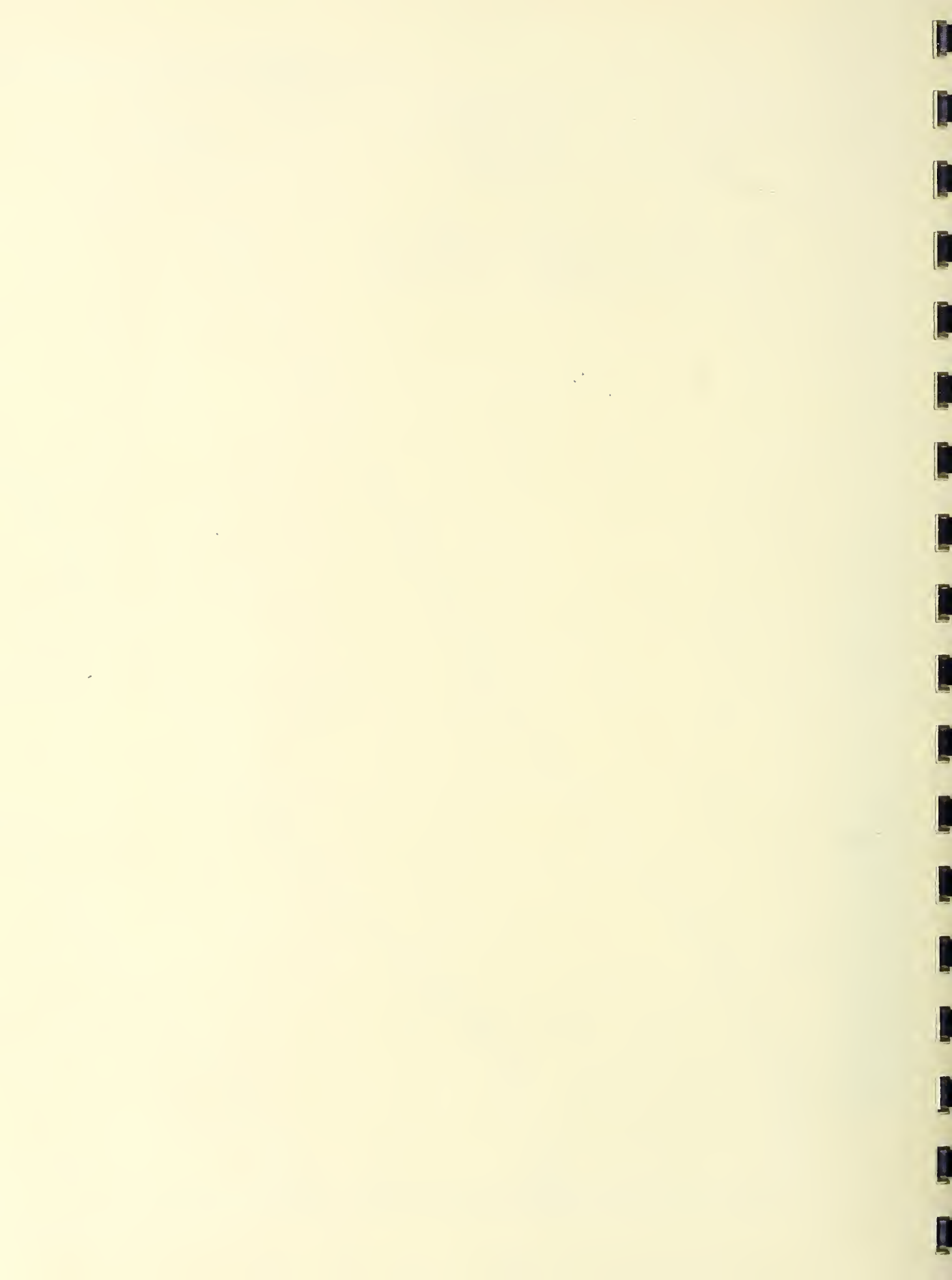


FIG. 12



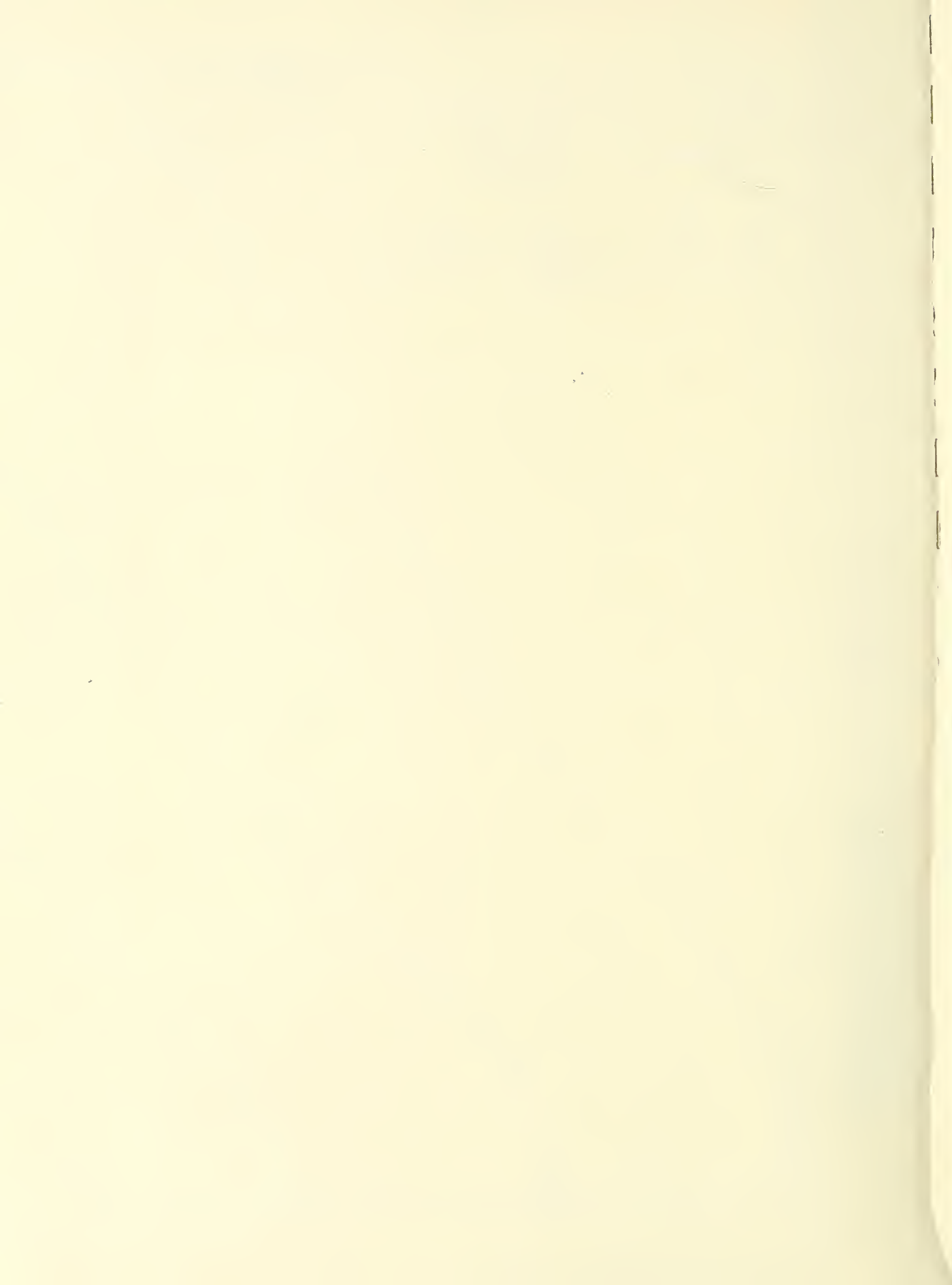
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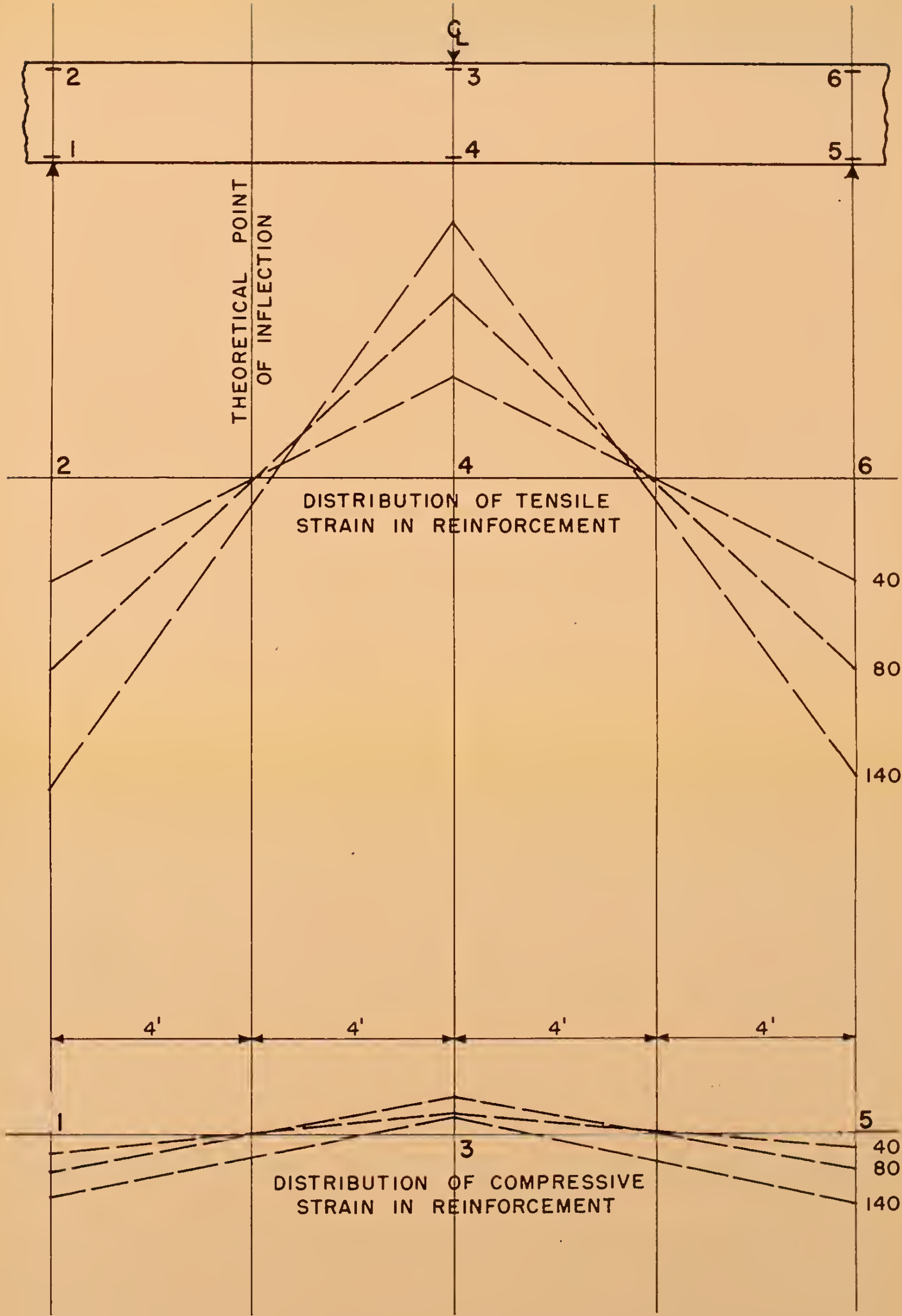
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STRAIN DISTRIBUTION IN REINFORCEMENT - C.G. NO. 1

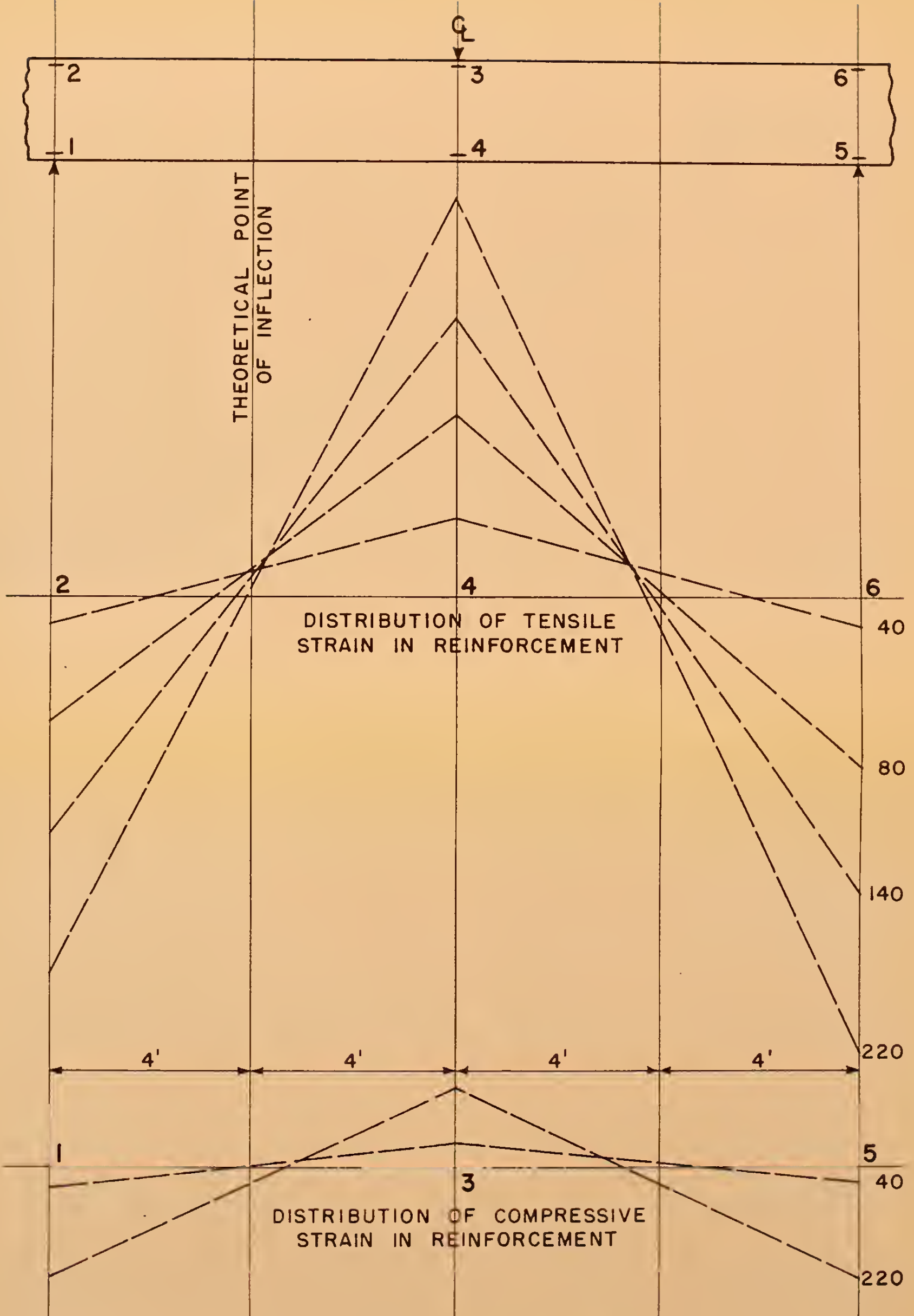
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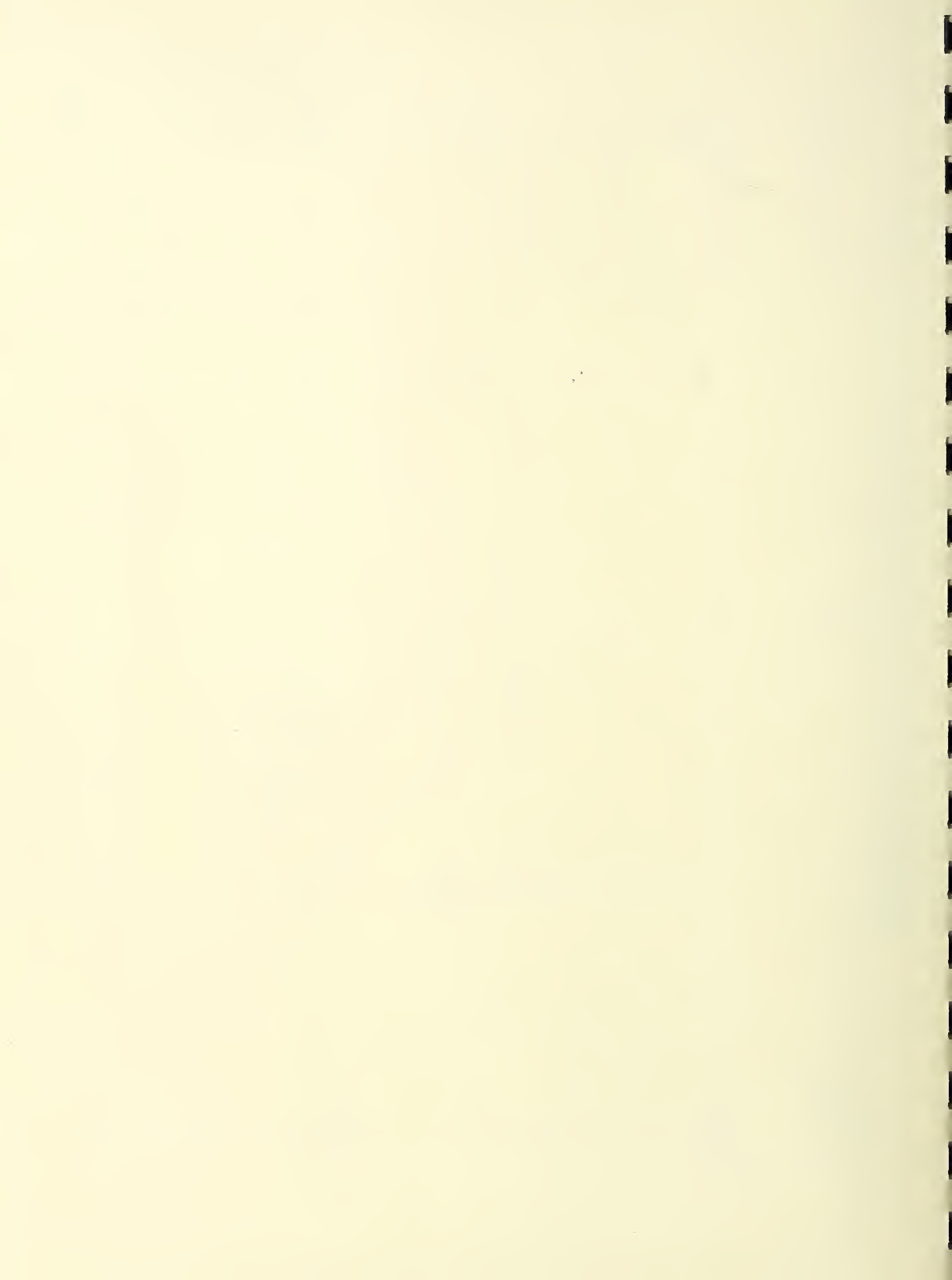
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STRAIN DISTRIBUTION IN REINFORCEMENT — C.G. NO. 2



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— 6

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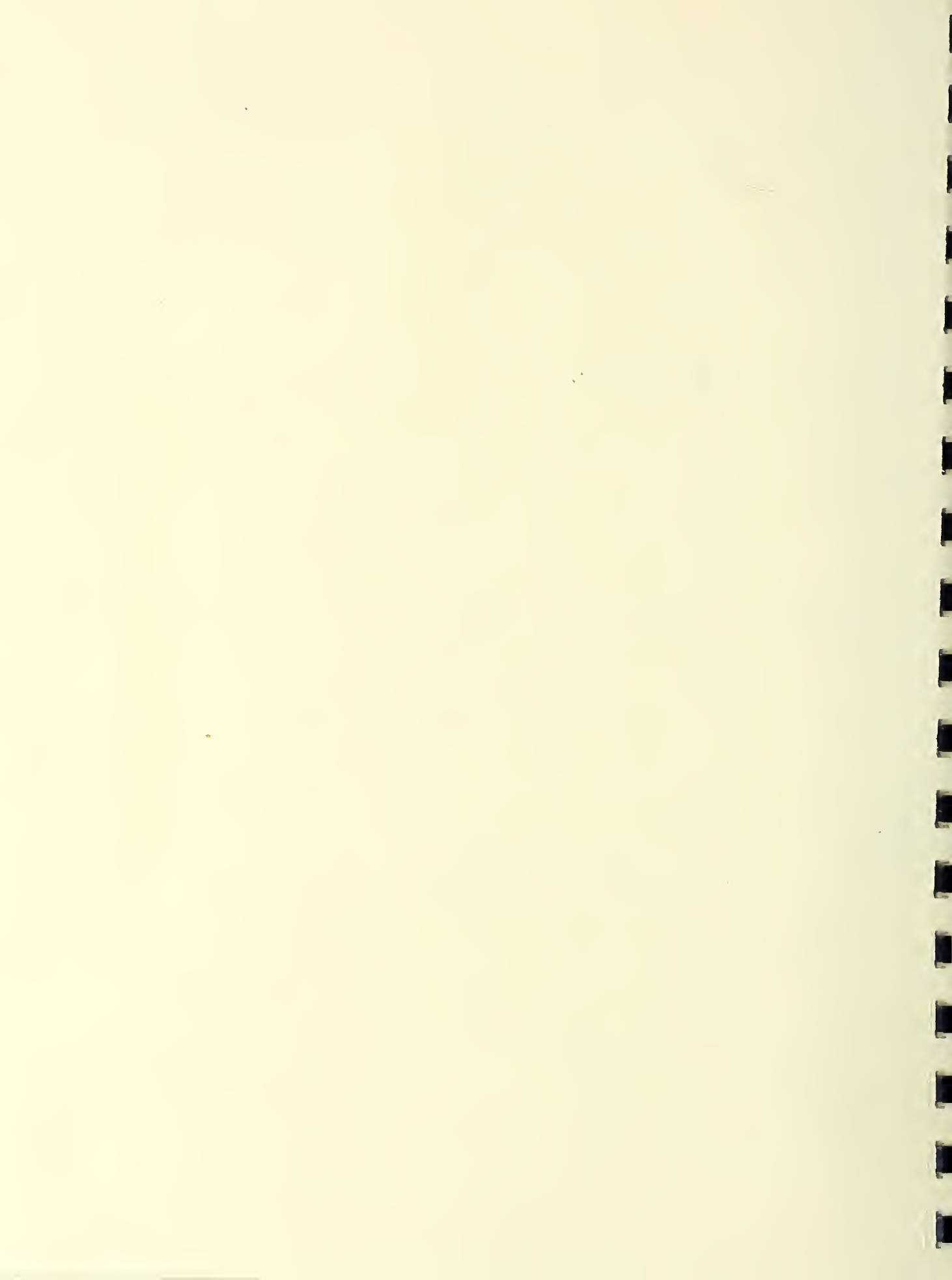




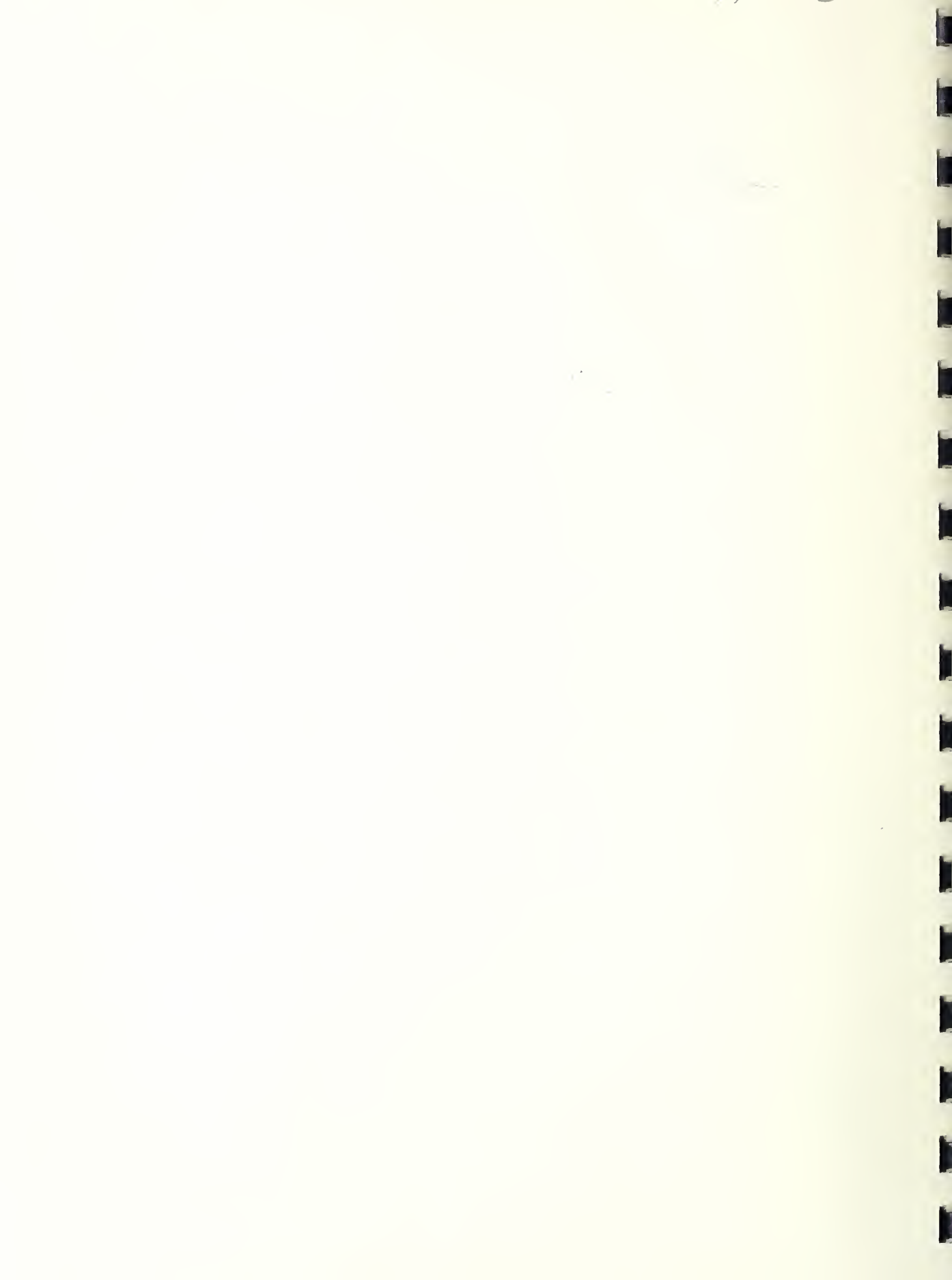
Fig. 15. Failure of girder No. 1.



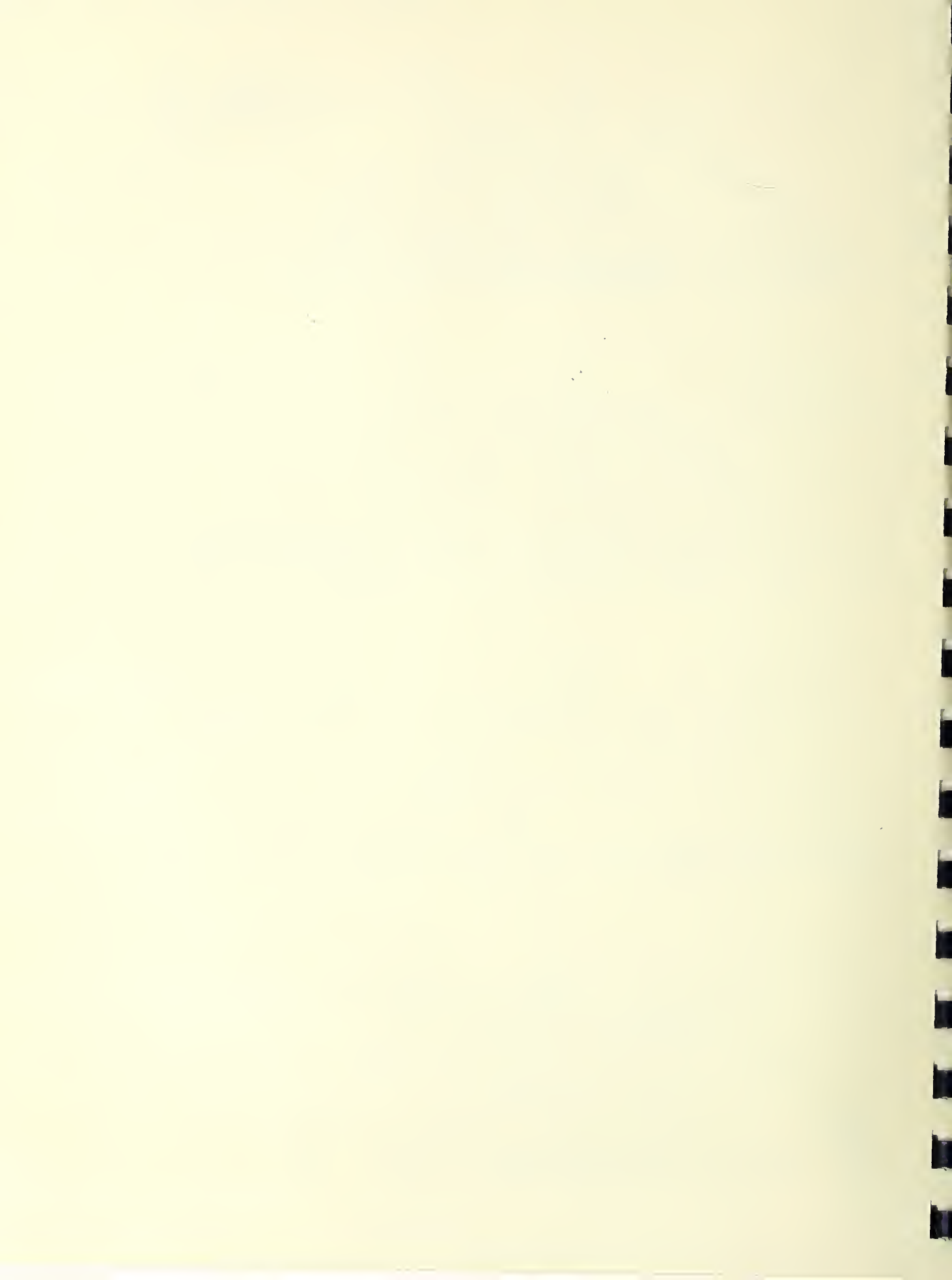
Fig. 16. Failure of girder No. 2, view of east side.



Fig. 17. Failure of girder No. 2, view of west side.







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