1974

Field study on the president costa e silva bridge (steel structure), Progress Report No. 2, October 1974

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397.4

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PROGRESS REPORT No. 2

(Period from May 1, 1974 to August 31, 1974)

FIELD STUDY ON THE PRESIDENT COSTA E SILVA BRIDGE

(STEEL STRUCTURE)

by

A. Ostapenko, B. T. Yen, J. H. Daniels and J. W. Fisher

Fritz Engineering Laboratory Report No. 397.4

October 1974

LEHIGH UNIVERSITY
BETHLEHEM, PENNSYLVANIA 18015

DEPARTMENT OF CIVIL ENGINEERING
FRITZ ENGINEERING LABORATORY

October 16, 1974

Ilmo Sr.
Dr. Jose Paz Ferreira
Diretor Tecnico da ECEX
S.A. EMPRESA DE ENGENHARIA E CONSTRUCAO
DE OBRAS ESPECIAIS - ECEX
Cidade Universitaria, Ilha do Fundao
Rio de Janeiro, Guanabara (20000)
Brasil

Subject: Instrumentation Program of Steel Structure -- Progress Report No. 2

Dear Sir:

Enclosed are two (2) copies of "PROGRESS REPORT No. 2 -- FIELD STUDY ON THE PRESIDENT COSTA E SILVA BRIDGE (STEEL STRUCTURE)" by A. Ostapenko, B. Y. Yen, J. H. Daniels and J. W. Fisher. Two more copies will be sent by second mailing. Should you need more copies, please let us know.

This report summarizes the project activities from May 1 to September 30, 1974. The period was primarily spent on the reduction and initial analysis of the field data and also included a trip to Rio de Janeiro by three Lehigh University researchers. Some of the results of this study are briefly discussed to indicate the direction in which the work is proceeding. We hope that this form of reporting our research progress meets with your approval.

We deeply appreciate your support of this project and remain,

Sincerely yours,

John W. Fisher
Project Director

AO:JWF:dz

Enclosure

P.S. We assume you will forward a copy of the report to Mr. E. P. Rausa of HNTB.

PROGRESS REPORT NO. 2

(Period from 1 April 1974 to 30 September 1974)

FIELD STUDY OF THE PRESIDENTE COSTA E SILVA BRIDGE (STEEL STRUCTURE)

by A. Ostapenko, B. T. Yen, J. H. Daniels and J. W. Fisher

This report briefly describes the general activities on the project from 1 April to 30 September 1974 and presents some sample results and interpretations to illustrate the level of research progress.

1. GENERAL SUMMARY

The time covered by this progress report (No. 2), from 1 April to 30 September 1974, can be subdivided into three periods each characterized by some principal activities. The key period is the time of the May-June trip to Rio by the Lehigh University researchers.

Period 1: 1 April to 26 May 1974 - Reduction of Data and Preparation for Field Measurements in Rio de Janeiro

Much of this period was spent on the preparations for making the field studies in the forthcoming trip to Rio. These preparations included working out the details of the stress history measurements and modification and fabrication of some components needed for the oscillograph which was to be taken to Rio. The logistics of the operation and the needed number of readings were established. The temperature readings projected for this trip required the devising of a switching scheme so that all the temperature gages and the most important strain gages could be read with a minimum of switching operations by soldering. The scratch gage arrangement and the conditions for storage of instrumentation were established to facilitate future use.

Concurrently with the trip preparations, other members of the research team continued the reduction of the previously acquired field data. This involved the development of several computer programs. The programs for the reduction of strain and temperature readings and for the analysis of principal stresses were completed. Analysis of some of the reduced data was initiated.

As shown in the Project Progress Schedule of Fig. 1, the activities of this period bring to completion Phase II.A — Planning & Preparation (Item 1 of Exhibit A of the Proposal) and portions of Phases III.A and III.B — Data Reduction* and Analysis** (Items 7 and 8 of Exhibit A of the Proposal).

Period 2: 26 May to 13 June 1974 — Trip to Rio de Janeiro

On 26 May, Professors J. H. Daniels and B. T. Yen and Mr. H. T. Sutherland went to Rio to conduct the planned field studies on the completed bridge under normal traffic conditions and under variable temperature. All the intended studies for the stress history portion, that is, of the orthotropic deck gages, were successfully completed. An oscillograph was used to record the readings of the seventeen most significant strain gages in the orthotropic deck. The dynamic stresses were produced by a single control truck or by the normal traffic flow. The temperature studies were hampered by the very small variation in temperature during this period, and the readings were limited to the minimum expected to give a qualitative picture of the thermal conditions in the bridge.

In addition to the electrical strain and temperature readings, the targets of the scratch gages were replaced, and an additional set of the mechanical gage readings was taken.

*The term Data Reduction signifies conversion of the numerical readings obtained in the field to strains and temperature and then to stresses and cross-sectional forces. The original readings are in the form of hand filled tables, perforated tape, light-sensitive tape, and traces on the scratch gage targets. Their conversion involves the development of suitable computer programs for the numerical and analytical operations involved, error studies, manual and/or automatic plotting of the principal or other stresses in a cross section, photographing the scratch gage targets in the electron microscope and subsequent interpretation of the traces, statistical analysis of the deck gage readings, etc. In summary, the term data reduction covers all the operations needed to prepare the data accumulated in the field for the subsequent analysis.

**The term Analysis indicates the work which follows after the data is reduced. This means: determination of the reasons for a specific stress variation in a cross section, Meanwhile, most of the previous readings were reduced at Lehigh University.

On 13 June, Professors Daniels and Yen and Mr. Sutherland returned from Rio.

In Figure 1 this period is marked by the completion of a large portion of Phase II.C.2 — Stress Measurements on Completed Bridge under Normal Traffic (Item 6 of Exhibit A of Proposal), and by some work on Phases III.A and III.B — Data Reduction and Analysis. Some progress was also made on the completion of Phase II.B — Instrumentation, as the switching system was partially modified for the limited temperature readings.

Period 3: 14 June to 30 September 1974 -- Data Reduction and Analysis

The major effort after the field trip to Rio was the reduction of the readings and analysis of the new and previous data (Phases III.A, and B of Fig. 1). All the available temperature and strain readings have been reduced. The data was smoothened by appropriate error studies and some has been analyzed to determine the significance of various influences on the bridge behavior. Computer programs were developed for plotting and curve-fitting the observed strain and temperature changes with respect to time and for performing a complete thermal stress analysis of the bridge structure. Information supplied by the Supervision (HNTB) from Rio on the weather and loading conditions before the opening of the bridge to traffic was a key in explaining some puzzling scratch gage data. The stress history and fatigue studies were continued by analyzing the statistical samples obtained during the field trip in May-June. This information will later be combined with the information supplied from Rio by DNER on the traffic conditions and monthly vehicle counts.

Summary

A summary comparison of the work done during the report period from 1 April to 30 September with the estimated Project Progress Schedule of Fig. 1 shows a good agreement since the lack of full temperature readings in May-June has been compensated by a substantially faster progress on the data reduction. Analysis of the limited temperature data from the May-June trip indicates that the originally intended scope of the temperature studies on the bridge can still be met by an additional set of field readings.

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and for the deviations from the theoretically established stress distributions, and an explanation of any inconsistencies found in the field. This phase also involves preparation of recommendations for the modification of design procedures in the light of the actual behavior of the structure, for example, the true distribution of temperature in the bridge. It will also give recommendations on the inspection of the bridge deck for the appearance of fatigue cracks if the analysis of the stress history data should indicate such possibility.

A request for another trip to Rio in January 1975 has been made and the Project Progress Schedule (Fig. 1) correspondingly adjusted.

2. SAMPLE RESEARCH RESULTS

Some of the reduced data have been analyzed and representative samples of the results and/or observations are given below.

(1) Strain, Mechanical and Scratch Gages

The scratch gage trace shown in Fig. 6 of Progress Report No. 1 contains a long portion of small amplitude (abt. 300 kg/cm^2) which follows the connection of the center bridge section to the side spans. This trace portion is reproduced as the left continuous segment in Fig. 2 of the present report. Previously, no conclusive explanation could be offered. Now, after a detailed analysis of the temperature distribution patterns measured in February, of the additional information on construction loads obtained from the Supervision (HNTB), and of the scratch gages retrieved during the May-June trip to Rio, a conclusion has been reached that these stress changes were produced by day-night fluctuations of temperature in the bridge. The new scratch gage trace covering the period from 25 February to 6 June 1974 is added in Fig. 2 on the right side. The expected stress variation produced by the construction of the parapet and median is given below the scratch gage trace to the same stress scale. Both stress changes are plotted against the time of construction progress. However, at certain points, the time scale had to be contracted to allow for the periods when the stress changes were too small to advance the scratch gage target and polished blobs were produced on the target -- for instance, around 31 January, 20 February, and some extended periods between February and June. A direct correlation is seen to exist between the two overall stress variations. For example, an expected stress change of 176 kg/cm^2 was computed for the seven days from 15 to 21 January and this corresponds to an overall stress change on the trace also of about 176 kg/cm^2 occurring over 7 zigs (days).

Analysis of the strain data obtained during the construction phases and on the completed structure indicates that the measured stresses in the top and bottom flanges of the bridge are in somewhat different ratios along the girder than the ratios computed from the design dimensions. The resulting shift of the centroidal axis of the bridge cross section can be tentatively attributed to the possibility that the actual thickness of the top and/or bottom plate is greater than the design thickness. Although the deviation is under 10%, and thus should be no cause for alarm, it indicates that such deviations between the design and as-built values should be taken into account in a more refined analysis of the bridge behavior and in establishing the coefficients of variation.

An observation which was made for the first time is the considerable effect of the state of temperature and longitudinal stress in the flanges and web upon the secondary bending in the stiffening and framing members. This is of particular importance for the floor beam components of the cross frames. The field data indicates stress changes due to dead load of the order of 500 kg/cm^2 (7 ksi), that is, of sufficient magnitude not to be neglected in the analysis of floor beams subjected to truck loads, although the stress changes may be secondary for other transverse stiffening components. There should, however, be no serious concern for the Rio-Niteroi bridge since at the locations where such stress changes were observed (or may be expected), the live load stresses should be relatively small. A computer program is being developed for analyzing this phenomenon as well as establishing the actual effective width of the plating participating in the bending of transverse members.

Other analytical work has been concerned with finding a qualitative/quantitative explanation for the non-linear stress distribution observed on the bridge and defining a continuous correlation between the stress changes at various stages of bridge construction and use.

(2) <u>Temperature Studies</u>

A computer program was developed for the thermal stress analysis of the bridge and some sample cases have been run to check the program. The readings made in February will be analyzed next.

Two samples of the readings made in June are given in Figs. 3 and 4. Figure 3 shows the temperature variation during 10 June in the cross section at Pier 100 (FB57). The air temperature varied only 5.5°C whereas the bridge temperature varied about 15°C. The strain variation in the deck plate during the day is plotted in Fig. 4 for a representative point. The overall variation of the strain is seen to correspond to the changes in temperature as given in Fig. 3. This is the type of data, but with a greater amplitude and over the whole bridge, that is expected to be obtained during the proposed trip to Rio in January 1975. Then, a complete thermo-elastic analysis can be made which can be used as a basis for formulating design guidelines.

(3) Stress History Studies Under Traffic Loading

Strains were measured under both controlled vehicle loading and under random truck traffic. The recording of stresses under truck traffic was taken over a sufficient period of time to include such effects as variation in loading, vehicle speed, and vehicle position. All of these stress history readings were made at a location adjacent to FB17 (over Pier 99) where the plate thickness is 10 mm; preliminary readings made during the previous field study in February 1974 indicated that readings adjacent to FB42 (plate thickness is 16 mm) would not be so critical.

The typical response of several gages as recorded with the oscillograph is shown in Fig. 5. The frequency distribution (histogram of stress range spectra) of the stress range acquired at gage No. 8 is shown in Fig. 6. This frequency distribution is of a skewed distribution that is characteristic of most bridges.

3. FUTURE WORK

The work planned for the next six months (till the next scheduled progress report) shall consist primarily of the analysis of the available data and the preparation of an initial draft of some portions of the final report, particularly on the phases dealing with the description of the instrumentation and acquisition of the field readings (Phase III.B, Items 7 and 8, in Fig. 1).

The proposed trip to Rio in January 1975 constitutes a portion of Phase II.C.2 (Item 6) in Fig. 1 and is needed to obtain comprehensive temperature readings mandatory for meeting the objectives of the temperature study. It will require no technical preparations since they were completed before the May-June trip. Only the organizational matters would have to be worked out in accordance with the then prevailing working conditions.

Some specific items planned for the next six months include the following:

- Completion of the computer program for the cross-bending analysis (secondary stresses in transverse members and effective plate width). Use of this program for studying the data available and preparation of initial conclusions and tentative recommendations related to this topic.

- Streamlining and proper documentation of the computer programs for the reduction of the strain and temperature readings and for the thermal stress analysis of the bridge.
- Completion of the thermal stress analysis using the February readings and preparation of a report on the method and results. This work will be later made complete by analyzing the January 1975 readings and preparing recommendations.
- Continuation of the search for a quantitative explanation of the stress non-linearity in the haunched flange at the channel pier.
- Continuation of the stress history and fatigue studies by performing statistical analysis of the incoming monthly traffic counts supplied by DNER from Rio.

Progress to
September 30, 1974

Fig. 1 PROJECT PROGRESS SCHEDULE

RESEARCH PHASE	ITEM *	1973 A	S	O	N	D	1974 J	F	M	A	M	J	J	A	S	O	N	D	1975 J	F	M	A	M	J	J	A	Est. % Compl.
I ERECTION STRESSES A. PLANNING & PREP.	1	100																									100
B. INSTRUMENTATION & MEASUREMENTS	2, 3 & 4				100																						100
II COMPLETED BRIDGE A. PLANNING & PREP.	1				80				90		100																100
B. INSTRUMENTATION	2, 3 4, 5				80								(100)						100								92
C. STRESS MEAS.																											
1. Controlled Load, Temp.	5						100																				100
2. Normal Traffic & Temp.	6												(100)						100								70
III A. DATA REDUCTION	7					4			10		20		35		55		80	90	100								75
B. ANALYSIS	7, 8								5		10		25		40		60		80		90		100				35
C. REPORT PREPARATION	8								5	P		10			P 20		35		50		P 65		80			F 100	15
OVERALL COMPLETION		3	8	11	16	19	22	28	32	36	40	45	50	55	60	65	70	75	80	84	88	92	94	96	98	100	60

* Items in Exhibit A of Proposal

Actual Effort (hatched bar)

Planned (line)

(100) Planned Initially, but Revised

P = Progress Report

F = Final Report

OVERALL STRESS CHANGE - 42B

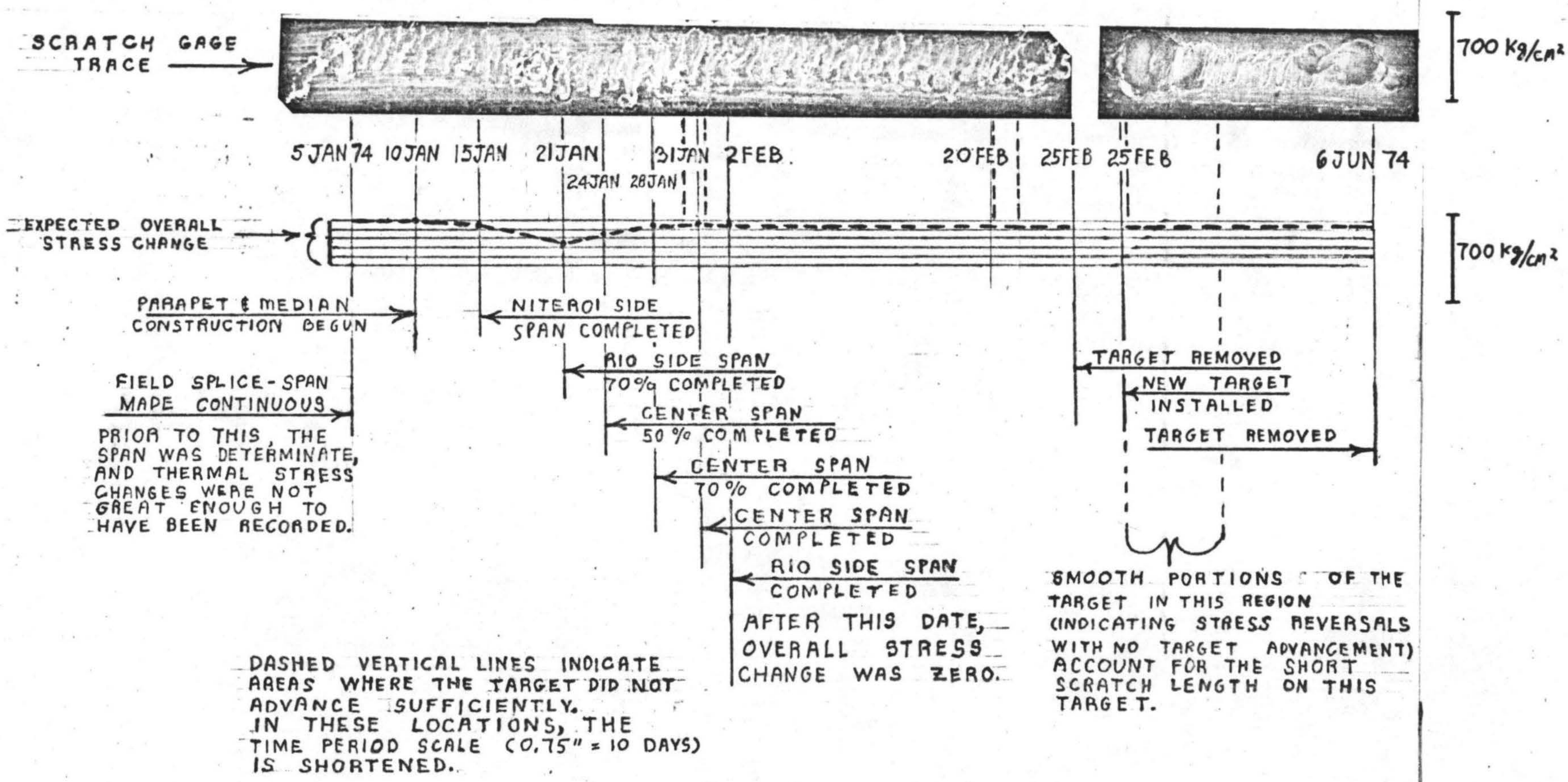

FIGURE 2

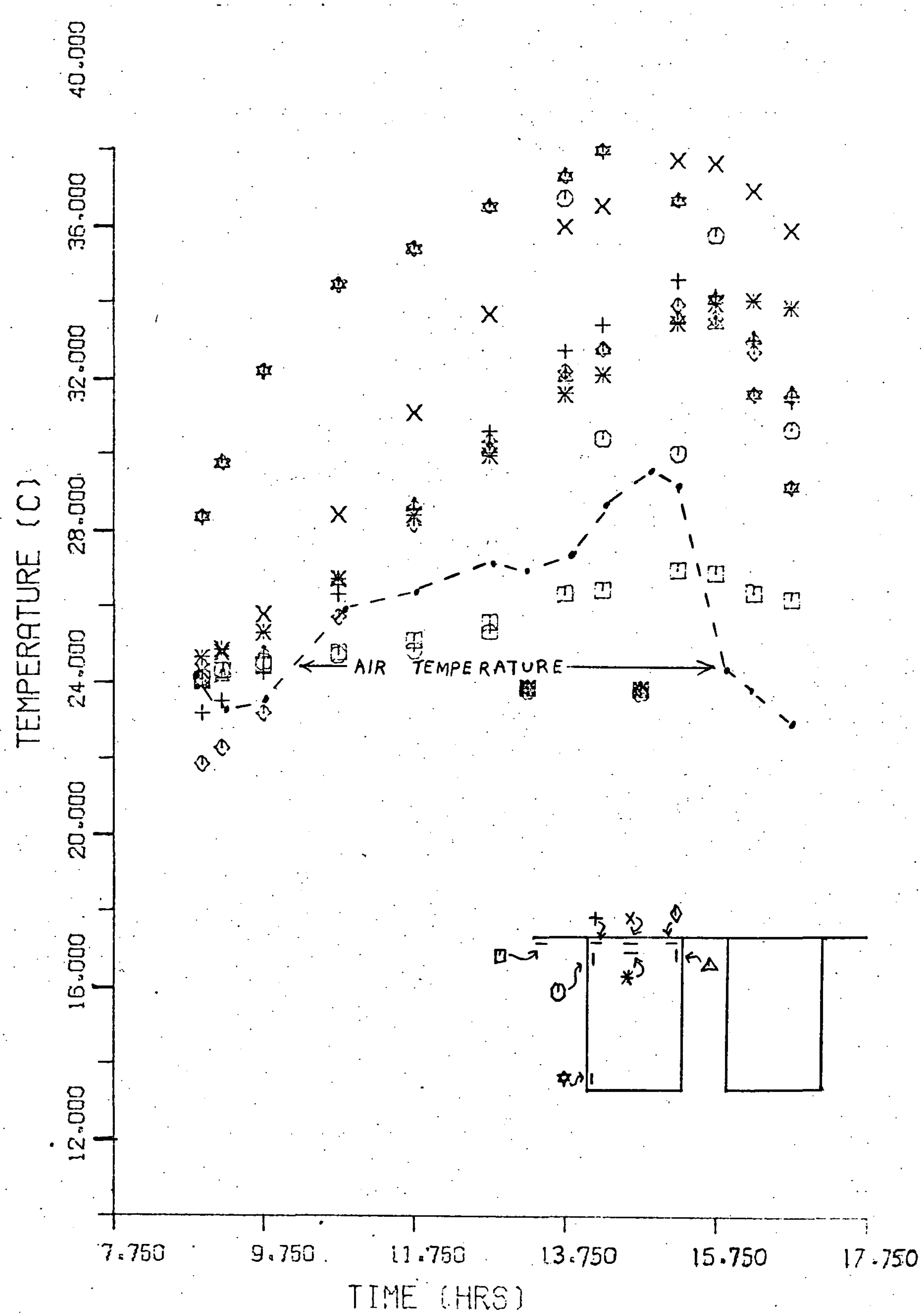

Fig. 3 FB57 TEMPERATURE 10/JUN/74

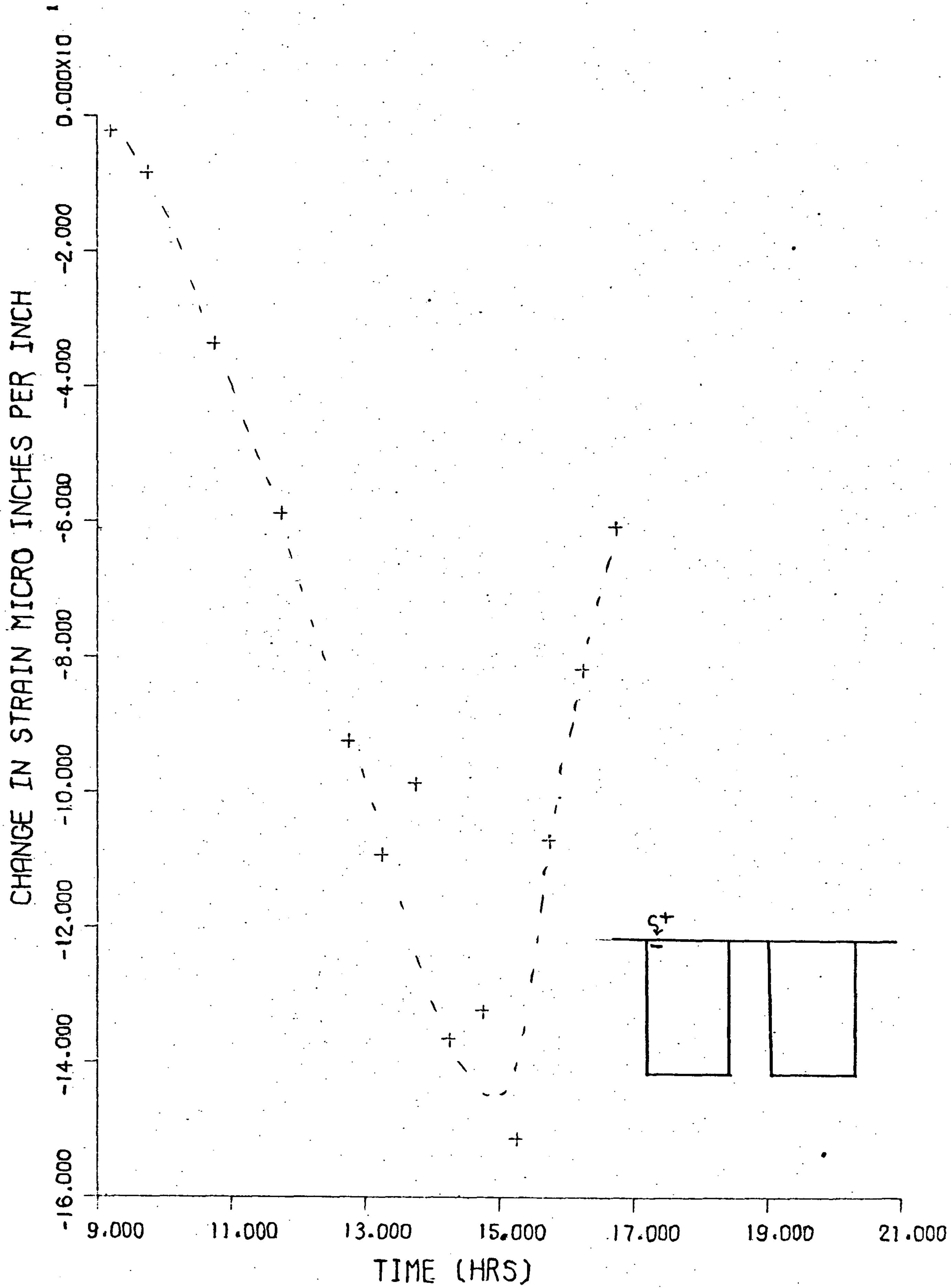

Fig.4 GAGE 18A AT FB57 JUNE 10, 1974

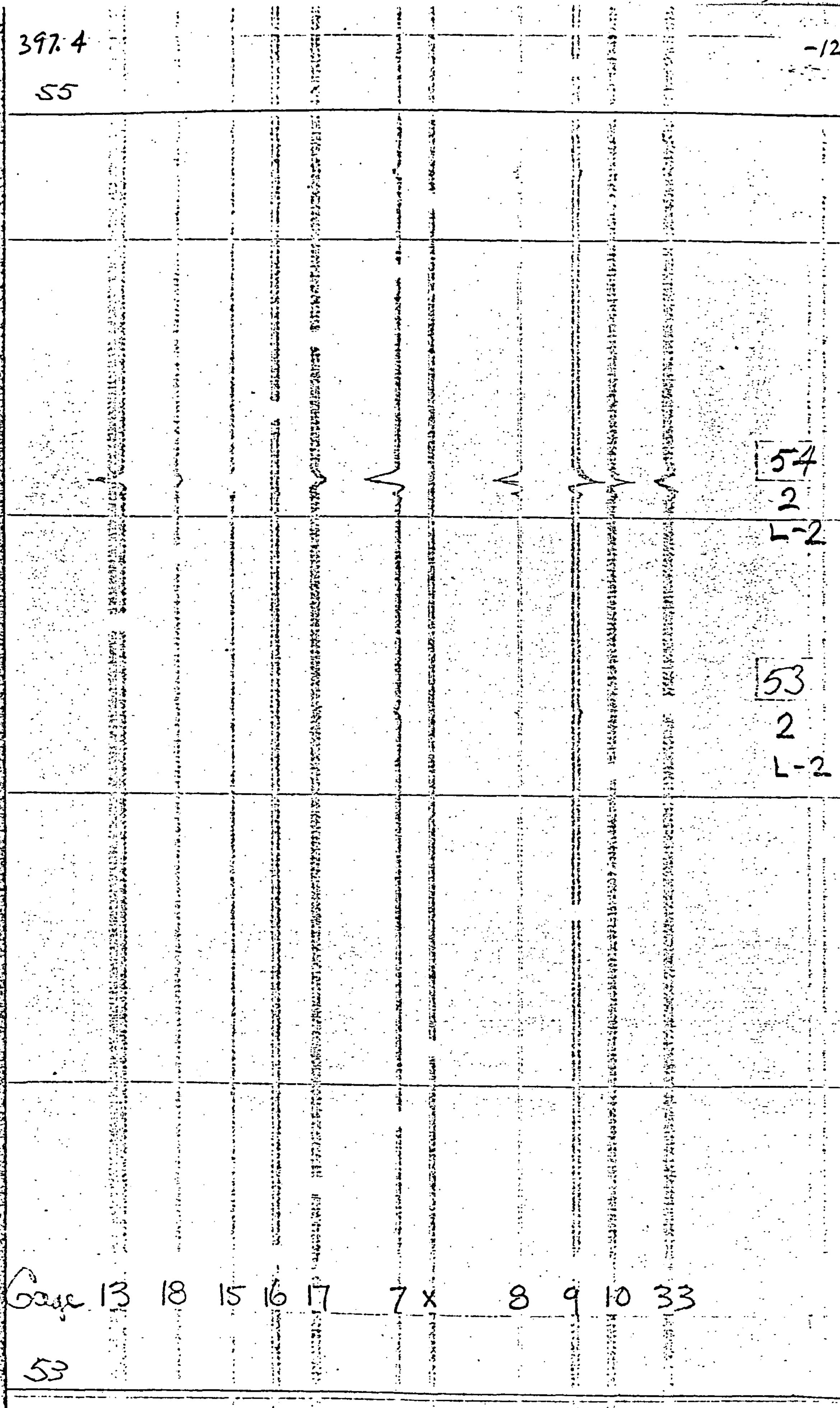

FIG 5 RESPONSE OF SEVERAL GAGES

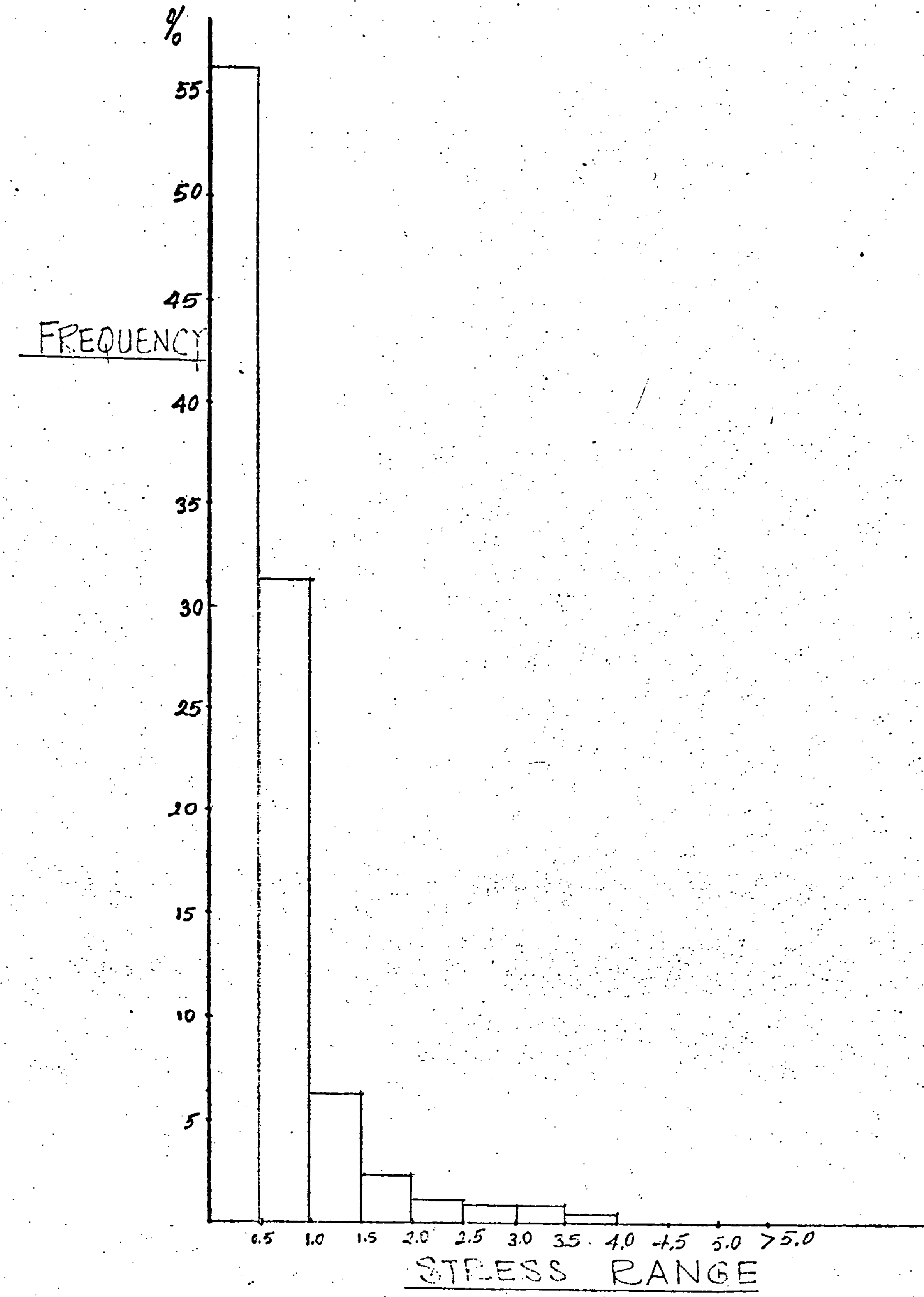

FIG 6 - FREQUENCY DISTRIBUTION OF STRESS RANGE AT GAGE NO. 8