Instruments for measurement of dynamic stresses (or strains) in temporary steel structures

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BUILDING NOTE

INSTRUMENTS FOR

MEASUREMENT OF DYNAMIC STRESSES (OR STRAINS)

IN TEMPORARY STEEL STRUCTURES

by

W. R. Schriever

Abstract

Measurement of stresses in temporary steel structures, such as girders, struts and piles, used during construction of the Yonge Street Subway are being made in co-operation with the Toronto Transportation Commission. While stresses due to dead load and earth pressure are static, it is necessary to obtain a continuous strain record by means of an oscillograph to determine the additional dynamic stresses due to live load. The objective is to ascertain the maximum stresses and the frequency of their occurrence in order to compute the maximum loads and their distribution to determine whether the design loads used at present are too conservative. Suitable instruments which could be used for such an investigation are described and relative merits of the equipment are discussed. Lists of manufacturers of strain gauges and amplifying and recording equipment are included.

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INSTRUMENTS FOR MEASUREMENT OF DYNAMIC STRESSES (OR STRAIN) IN THE TEMPORARY STEEL STRUCTURES

by

W. R. Schriever

Introduction

The construction of the Yonge Street Subway by the Toronto Transportation Commission provides an unusual opportunity to investigate soil and foundation conditions in the Toronto area and to study some related design and construction problems. A programme of co-operative work was therefore suggested by the National Research Council and the Toronto Transportation Commission, the results of which will contribute to the knowledge in this field of engineering in general and will be of value to the construction industry of Canada as well as to the Toronto Transportation Commission.

Among the list of investigations is the measurement of stresses in the temporary structures, such as girders, struts and piles used in the cut-and-cover method. Measurement of stresses in these members is being carried out for two purposes:

(1) As a check of the design of the temporary structures, i.e. in order to compare actual stresses with allowable stresses.

(2) In order to determine the earth pressure acting on the sides of the subway excavation under various conditions.

While the stresses due to dead load and earth pressure are static, the stresses due to live load (streetcar and motor traffic) are transient and also, to a certain extent, oscillating, depending on shock effects of the traffic and the vibration characteristics of the deck. Therefore, while it is sufficient to measure the static stresses periodically by means of a mechanical strain gauge, it is necessary to obtain a continuous strain record by means of an oscillograph to determine the additional dynamic stresses due to live load with the aim of finding the maximum stresses occurring and the frequency of their occurrence. Only in this way is it possible to compute, from the determined maximum stresses, the maximum loads and their distribution and thus to find out whether the design loads used at present are too conservative.

For the measurement of the <u>static</u> strains, an 8-inch mechanical strain gauge (or extensometer) of the Berry type is being used which measures the distance, or change of distance, of two small holes drilled into the steel. For the measurement of the dynamic strains, it is intended to use electrical gauges; either magnetic or resistance strain gauges. Magnetic (or inductance) strain gauges and also unbonded wire resistance strain gauges have a better long life stability and are more rugged than bonded wire resistance strain gauges, although the latter are much lower in cost. The output of the gauges (or balancing bridge circuit) is usually amplified and can then be fed into an oscillograph recorder, of which there are a great variety of types.

The question of the most suitable equipment for the present investigation is a very important one. Much helpful information has been received by correspondence and during discussions of this problem. Considerable time has been spent on a thorough study of this information, which is believed to be of such value, not only in the present work but also for future reference, that it was decided to prepare a summary, which is now presented in this Building Note.

In view of the large expenditure involved in the purchase of this equipment (as a multichannel instrument is required) and the importance of the instruments, not only for the present work but also for other uses in the Division of Building Research later on, this Note is sent to all those who contributed to this information and to other interested persons. Comments and suggestions are welcomed from readers, as they will facilitate the decision on the equipment best suited for this work. In the meantime, while this Note is under consideration, it is hoped that it will be possible to carry out a preliminary test with borrowed instruments, so that on the basis of the comments received and the results of the preliminary test, a well-founded decision will be possible.

Acknowledgements

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and a number of agents of manufacturers of strain measuring and recording equipment.

Measurement of Stresses in Beams and Trusses of the Temporary Decking

Fig. 1 shows typical cross-sections of the two main types of the temporary street decking used during subway construction.

Procedure

For the strain measurements on the beams, the procedure is as follows (a similar procedure being followed for the trusses):

(1) Before the beam is stressed, gauge holes are drilled for the measurements with the mechanical gauge in several (usually three) cross-sections and zero readings are taken. In order to differentiate between bending and compression, at least two strain measurements must be obtained in every cross-section, one near the top and the other near the bottom of the beam in which the stresses are to be determined. For reasons of accessibility, the readings are taken on the web, near the flanges.

(2) After the beam is set in place, strain readings are taken at various stages of construction, yielding bending stresses due to dead weight of decking and compression stresses due to the earth pressure, which increases as excavation is carried deeper.

(3) At a convenient time, the electrical gauges for the measurement of the additional stresses due to transient loads (traffic) are attached to the beam next to the gauge holes for the mechanical gauge. Readings with the mechanical gauge are continued periodically at times of no traffic. In this way, a continuous comparison of the electrical and the mechanical gauges is possible, and the "zero drift" of resistance wire strain gauges, should this type of electrical gauge be used, can practically be eliminated.

Static Stresses

As already mentioned, a mechanical strain gauge (or extensometer) of the Berry type (made by F.F.Metzger & Son, Philadelphia, Pa.) is being used for the measurement of static stresses. One division on the dial of this gauge, which has a base of 8 inches, corresponds to a strain of 12.5 micro-inches per inch, or 375 lb. per square inch stress in steel. For temperature compensation, with every reading a second reading is taken on a mild steel reference bar, which is put on the structural member so that it will assume the same temperature as the member.

Stresses due to Traffic Load

An important question in the selection of the recording equipment is the type of stresses to be recorded, i.e. their variation with time.

The nature of the stresses caused by streetcar and motor traffic is similar to the stresses due to live load in railway and highway bridges. A wheel of either a streetcar or an automobile passing over a beam of the decking causes strains which consist of a "static" part, caused by the static load of the wheel coming on (and off) and a superimposed part due to the vibration of the beam when excited by shock effects resulting from the roughness of the surface on which the wheel travels. As an example, a figure from a paper entitled "Description and Analysis of the Bridge Impact Tests made by the Pennsylvania Railroad at Chester, Pa." (Proceedings of the American Railway Engineering Association, 1941, page 432) is reproduced as Fig. 2 in this Note, showing strains in a plate girder of 55 feet 10 inches span measured in the middle of the span by means of magnetic strain gauges (instruments No. 1, 2, 3, and 4) and also vertical and lateral deflections measured by instruments of a different principle (instruments No. 5 and 6). These strains resulted from the transient load of a steam locomotive travelling at a speed of 46 miles per hour.

For the beams of the temporary subway decking, it is not quite clear, at the present stage of construction, how important, i.e. how large, the superimposed vibrational part of the stress is compared with the mean stress as illustrated in Fig. 2. In view of the high cost of oscillograph equipment, one must ask, of course, whether the vibrational part of the stress is of a magnitude which would justify more expensive equipment than would be required to measure the mean stress. However, it seems that oscillographs with a low frequency response (e.g. Esterline Angus Recording Milliameters, response time 0.5 -1 second) are not much lower in cost than direct-writing oscillographs with a medium frequency response (e.g. Brush Oscillograph, frequency response claimed up to 120 cycles per second). Therefore, especially with regard to other uses of the strain recording equipment later on, a type of instrument covering medium frequencies often occurring in structural work would be much preferable.

An idea of the frequencies to be expected in the beams of the temporary subway decking was obtained by recording the vibration of one of the beams under traffic by means of a portable Leet Seismograph. The result was a natural frequency of approximately 45 cycles per second.

Magnitude of Traffic Loads

It has already been mentioned that the strains are being measured in several cross-sections of a beam. This is done because it is intended not only to find the maximum stresses but also to determine from these stresses the maximum traffic loads that occur and their distribution. In this way it will be possible to ascertain whether the design loads used at present have been reached or not, i.e. whether they should be retained or reduced in future design.

The distribution of a load acting upon a decking beam can be determined from the bending moment diagram, found from stresses. As this can be done with reasonable accuracy only if the stresses are known in a number of cross-sections, the stresses are measured at the center and at the quarter points of the beam. This means a minimum of six gauge lines for a beam in which the strains must be recorded in order to find simultaneous stress peaks. Therefore a mechanical oscillograph recorder is required. As each channel is a practically separate unit composed of the active gauge, the dummy gauge, the balancing bridge and its power supply (sometimes contained in the amplifier box), the amplifier and the oscillograph recorder, the high cost of a six channel installation is understandable.

Instruments

On the following pages are lists of appropriate instruments (gauges and recorders) produced by manufacturers of strain gauges and amplifying and recording equipment. Also set out are references on the subject matter. These lists and references have been compiled on the basis of information kindly submitted by a number of those interested in the problem (see acknowledgements) with a view to giving complete information regarding the various available instruments.

No complete information can be given regarding the comparative cost of various makes of instruments, as the cost of only a few of them is known to the writer. The cost of a six channel installation with 6 magnetic and 6 balancing gauges, (calibrating stand extra) in Canadian funds, sales tax and transportation extra, is as follows:

Hathaway (photographic record)	Approximately -	$ 6,100.00
General Electric (photo. record)	" -	8,600.00
* Brush (direct-writing record)	" -	8,300.00

* using Hathaway magnetic strain gauges.

Conclusion

Assuming that the measurement of the vibration part of the transient stresses is desirable, it is thought at the present time that magnetic strain gauges and an oscillograph using a direct writing recorder with a frequency response of somewhat more than 50 cycles per second would be the most suitable for the investigations described in this Note.

INSTRUMENTS

Purpose	Instrument	Examples & Remarks
To record peak strains only	(1) Scratch gauge	Example: De Forest
	(2) Indentor type load cell	No commercial make - Suited only to measure reactions.
To pick up strains continuously	(1) Bonded wire resistance gauges	Where no long stability required. Example: SR-4 gauge.
	(2) Unbonded wire resistance gauges	Where long time stability required. Example: Carlson Strainmeter.
	(3) Magnetic or inductance strain gauges	Where ruggedness and longtime stability required.
To amplify and record strain gauge out-put	Bridge, amplifier plus	
	(1) Direct writing recorders and oscillographs	Examples: Esterline Angus, Brush.
	(2) Galvanometer oscillographs with photographic recording.	
	(3) Cathode ray oscillograph	

MANUFACTURERS OF STRAIN GAUGES

De Forest Scratch Gauge:	Baldwin Southwark Division, Baldwin Locomotive Works, Philadelphia 42, Penn.
Indentor Type Load Cell:	No commercial make.
Bonded Wire Resistance Gauge:	SR-4 Gauge - Baldwin Southwark (see above)
	Ruge-de Forest Inc., 76 Massachusetts Ave., Cambridge, Mass.
	DeHaviland Propellers Ltd., Hatfield Airodrome, Hartfordshire, England.
Unbonded Wire Resistance Gauge:	Dr. Roy W. Carlson, Engineering Material Laboratory, University of California, Berkeley, California.
	Statham Laboratories, 9823 Santa Monica Blvd., Beverly Hills, California.
Magnetic Strain Gauge:	Hathaway Instrument Co., 1315 South Clarkson St., Denver, Colorado.
	Westinghouse Electric Company, Pittsburgh, Penn.
	General Electric Company, Apparatus Dept., Schenectedy, New York.

MANUFACTURERS OF AMPLIFYING AND RECORDING EQUIPMENT

Equipment with pen-and-ink recorders:

Brush Development Co., 3405 Perkins Ave., Cleveland 14, Ohio.
Henry Hughes and Son Ltd., 2 Claxton St., London SW. 1. England.

Equipment with galvanometer oscillographs:

Hathaway Instrument Co., 1315 South Clarkson St., Denver, Col.
Savage and Parsons Ltd., Watford Bypass, Herts., Eng. (up to 1000 c/s)
William Miller Co., Pasadena, California.
Consolidated Engineering Corp., 620 North Lake Ave., Pasadena 4, California.
Heiland Instrument Co., Denver, Colorado.
General Electric Company, Apparatus Dept., Schenectady, N. Y.
Westinghouse Electric Company, Pittsburgh, Penn.

Equipment with cathode ray oscillographs:

Avimo Ltd., Taunton, Somerset, England. (15 channel instrument)
Southern Instruments Ltd., Fernhill, Hawley, Camberley, Surrey, England.
Mullard Electronic Products, Century House, Shaftesbury Avenue, London W.C.2, England.
Furzehill Laboratories Ltd., Borcham Wood, Herts., England.

Not Specified:

DeHaviland Propellers Ltd., Hatfield Aerodrome, Hertfordshire, Eng.
Trimount Instrument Co., 37 W. Van Buren St., Chicago 5, Illinois (amplifiers only)

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American Railway Engineering Association, "Description and Analysis of the Bridge Impact Tests made by the Pennsylvania Railroad of Chester, Pa. "Proceedings, Vol. 42, pp. 393-483, 1941. (Instruments described on pp. 402-408)

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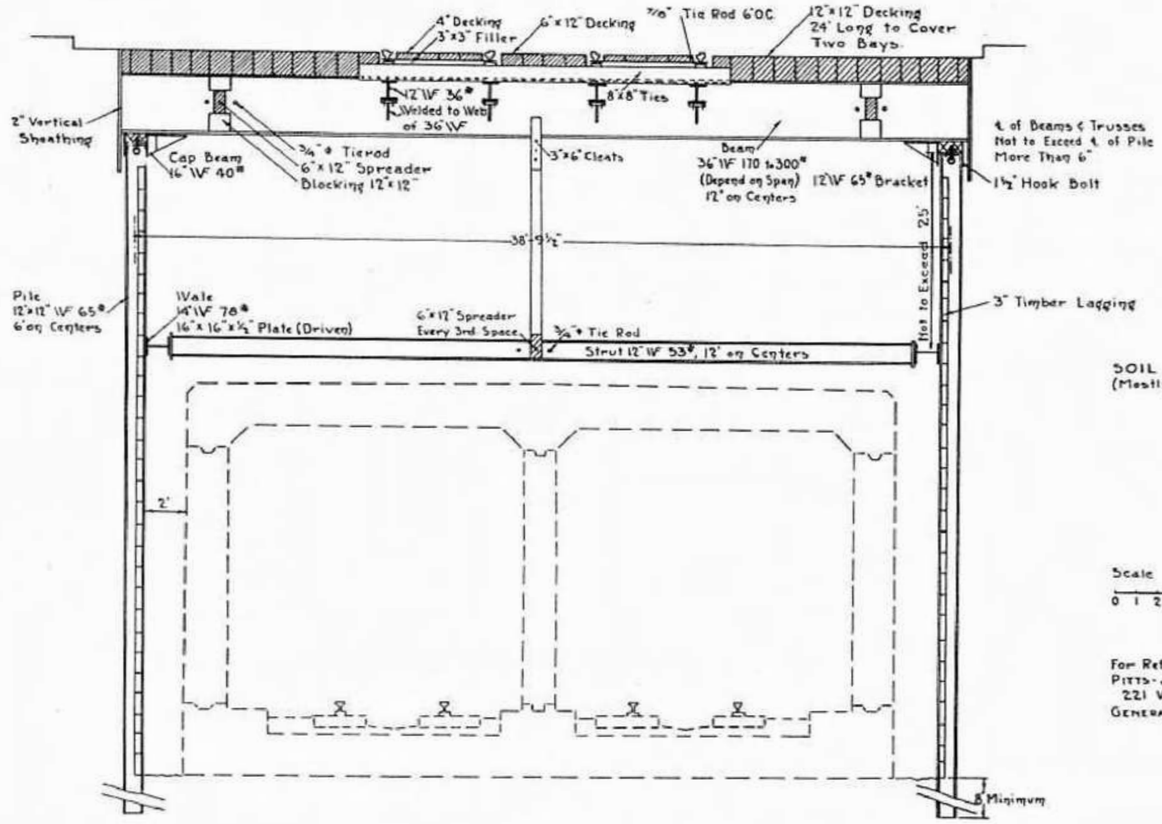
TORONTO TRANSPORTATION COMMISSION – RAPID TRANSIT DEPARTMENT

BEAM CONSTRUCTION

For Box Sections



SOIL
(Mostly Stiff Clayey till)

Scale

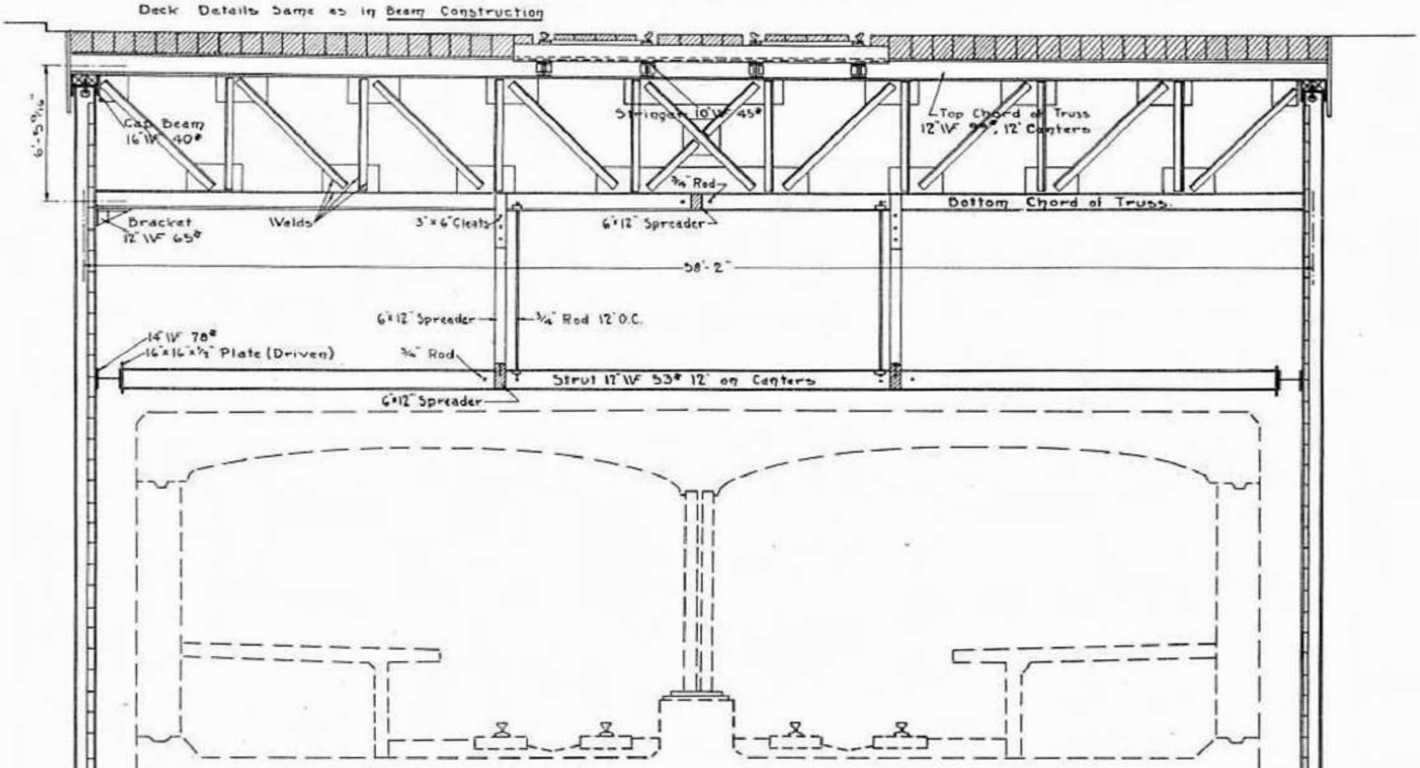
0 1 2 3 4 5 Ft.

For Reference See Drawing T.S 12
PITTS - JOHNSON - DRAKE & PERINI
221 VICTORIA ST. TORONTO
GENERAL CONTRACTORS (CONTS 5-1 & 5-2)

TRUSS CONSTRUCTION

For Station Sections

Deck Details Same as in Beam Construction



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