THE TESTING OF BRIDGES.

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PRELIMINARY.

There are four well defined methods by which the strength and condition of a steel structure subjected to stresses under a rolling load can be investigated—

(1). By direct calculation of the induced stresses by the principles of statics, and to a limited extent by the principle of least work enunciated by Castigliano, the great Italian mathematician.

(2). By the determination of the stresses experimentally with the aid of instruments, which measure the alteration in length of a bridge member between two fixed points.

(3). By an examination of the behaviour of the structure in regard to the external movements caused by the action of the live load.

(4). By an examination of the condition of the structure after a large number of repetitions of the live load.

Any of these four methods may, however, under certain conditions, fail to give the complete information wanted in some important particulars and recource must then be had to one or more of the remaining three.

It is not proposed to discuss the investigation of bridge structures by analytical methods, as this branch of the subject is fairly well-known to most engineers and attention will be confined to the second, third and fourth methods of investigating steel structures. It is necessary, however, in the first place to explain why a bridge cannot always be completely investigated by analytical methods, in other words, why a stress sheet will not always furnish complete information about the structure and why, in consequence, other methods of investigation, have sometimes to be adopted.

The reasons are as follows :—

A span as actually constructed does not altogether comply with the theoretical conditions necessary for a correct determination of the stresses by calculation. Ordinary statics assume that the structure is articulated, that is, the joints are pin joints. It is necessary, however, to point out that a girder, whose members are rivetted together at the joints, is stronger than another whose members are connected together by pins, but the additional strength in the members resulting from the more rigid form of connection, is an uncertain quantity. Sometimes the attempt is made to solve the problem by the principle of least work, but the calculations are so complicated, and involve so many assumptions, that generally little reliance can be placed on them. Theory is obliged to assume that cross girder ends are free, because, until the conditions are investigated actually with the aid of instruments, it cannot be ascertained to what extent they are fixed. The difference in strength between a cross girder which is free at the ends, and one which is fixed, or only partially fixed, is, of course, great. Again, in calculating the stresses induced in a span, the axle loads have either to be treated directly as concentrated, or the effect of such concentrations has to be worked out by some other method of calculating the uniform distributed load, theoretically equivalent to those concentrations. The interposition of rails and rail girders (in spans where there are rail girders) has an important effect in distributing the axle concentrations, and thus reducing to some extent the stresses in the main members. The extent to which the theoretical stresses are reduced by these mitigating conditions cannot however be ascertained by calculation.

Constructional defects, often unavoidable, are the cause of stresses greatly in excess of those dictated by theory. For instance a web tension member may be stressed to three tons per square inch on one edge, and five tons per square inch on the other. Owing to the deflection of the cross girders the inner members of the web system are often stressed more than the outer members of the web system. The extent of this overstress in the inner web tension bars of the Nerbudda bridge at Broach on the Bombay, Baroda and Central India Railway was thirteen per cent. The constructional defect in this case was in the method of attachment of the cross girders to the vertical web members. Columns, which in design are regarded as fixed, being rivetted at their ends, may be secured to other members by a group of rivets, whose centre of gravity does not coincide with the centre of gravity of the column ; or through some of the rivets having become loose, their centre of gravity, originally coincident with the centre of gravity of the column, may afterwards become eccentric with that centre. Owing to these defective conditions, the column (originally supposed to be fixed) may in reality be no better (it might be worse) than a column hinged at the ends. The condition of the column, whether fixed or hinged, cannot be ascertained by theory, but the case can be investigated, within limitations, by experiment.

Certain members may be subjected, in addition to the direct stress, which alone, under ordinary assumptions, they have to carry, to an excess stress due to bending. Cross girders secured to verticals may induce in the latter bending moments for which these members were not designed. The bending moment is generally due to the condition of the cross girders being partially fixed at their ends, and, as previously stated, the extent of fixture cannot be ascertained theoretically. Similarly, the secondary stress induced in compression chords is due, in certain types of spans, to these members acting as beams to take cross girder end reactions, in addition to the direct load which they were originally designed to carry. If the chords were pivoted at the ends, the secondary stress could easily be computed, but here again the nature of the fixture at the ends is uncertain. Again, the intersection of the centre lines of the web members may not lie in the line of the neutral axis of the chords, and the latter may be subjected to additional bending action, which cannot always be accurately estimated by the methods of statics.

Reversals of stresses sometimes occur in members where they are never expected. The causes for this abnormal action are very obscure, but can sometimes be understood to a limited extent, by exhaustive tests with the extensometer.

It is scarcely necessary to mention that the strength of a structure can be completely investigated under any given system of loading, if it is known how, and to what extent, each of its several parts deforms. This principle, as is well known, forms the basis of all analytical methods of computing stresses either by statics or by the principle of least work. The structure is, in fact, elastic ; it may stretch ; it may compress ; it may twist ; or it may bend. The movements may be simple, or they may be very complex. However, all movements may, for purposes of investigation, be included in one or the other of two main divisions, which, for want of better names, may be called, external movements and internal movements.

An external movement may be regarded as the movement of a member as a whole ; the movement may be in relation to some fixed point, or it may be in relation to some point which has itself moved. When a girder oscillates, a point, say in the compression flange, moves in regard to a fixed point, say on a post erected in the river bed, or the same point in the compression flange may move relatively to some other point in the tension flange. When a girder deflects, the centre of the bottom boom has moved vertically downwards in relation to a fixed point on the abutment, or the centre of the bottom boom may have moved vertically downwards in relation to a point, say, at a quarter of the span, this point having itself moved in relation to some fixed point.

Internal movements may be described as the alteration in length of the fibres of the material which may be either extended or compressed.

The author realises that the colloquial terms which he has used to explain his meaning may not be altogether scientific, nevertheless he hopes that the principles involved will be more clearly understood with the aid of the diagrams and he will now describe the method of measuring these two kinds of movements by some of the instruments he has used for the purpose.

EXTERNAL MOVEMENT.

Method of measuring Deflections.

The simplest method of measuring external movements is by an arrangement with which every one is familiar. Plate 1, Fig. 1 shews a post erected in a river bed under a girder. On the post is pinned a card which is divided by vertical and horizontal lines spaced at intervals of one-tenth of an inch so that the diagrams can be easily and quickly read. To the girder is fixed a clamp which is provided at the other end with a pencil working in a socket, while a spring in the socket provides for an even and constant pressure of the pencil on the paper.

This bit of simple apparatus is in use all over the world ; in fact it was, until a few years ago, the principal means we possessed for measuring external movements. It answered its purpose fairly well, because both deflections and oscillations could be read off the card at the same time. (*Vide* Plate 2, Fig. 1).

The arrangement, however, is open to several objections. In the first place the deflection as measured by the diagram is the total downward movement of the girder plus any downward and upward movement of the girder on the bearings; and in the case of small spans, the ratio of this latter error to the total result may be considerable. A timber bed block may be elastic, or the girder, through improper bedding, may jump about. Another objection is the frequent want of rigidity of the pencil itself, which in badly fitted pencil attachments wobbles about thus vitiating the results. Also the pencil point is frequently broken, when the test has to be repeated.

Frankel's Deflectometer.

When more accurate observations are required the self-recording deflectometer is used. This instrument is the invention of Mr. Frankel, and is manufactured by Oscar Leuner of Dresden. A description of the mechanism is given separately in Appendix A. The method of applying the instrument is shown by two diagrams Plate 1, Figs. 2 and 3. The instrument is firmly attached by the clamping screws to the centre of the span, generally on the bottom boom, though it may, if necessary, be attached to the top boom. The weight *p* (Plate 1, Fig. 3) is lowered by a wire and allowed to rest on the ground, care being taken to get as even a bed as possible. When in position, the wire is pulled up taut, and the upper end secured to a steel tape which is slipped over a pin on one of the discs, the disc selected being the one which will give the required ratio to the instrument and consequently to the diagram. As the girder deflects these discs rotate and exert a torque in a clockwise direction (facing the instrument) the motion being limited by stops.

It is, therefore, necessary to attach the wire at a point such that the disc is free to rotate either way from its mid position. The torque is constant, and is produced by the energy of a spiral spring which is wound up by a handle provided for the purpose. The circular motion of the discs is then converted by suitable mechanism into the rectilinear motion of the pencil.* The weight being fixed, as well as the wire attaching it to the instrument, the discs will rotate as the span deflects, the motion of the former corresponding to the deflection of the girder.

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* For fuller details see Appendix A on page 24.

The recording mechanism is independent of the machine proper as described above. It is worked either by hand as illustrated on Plate 10 and described in the appendix, or in the more elaborate type of machine by clockwork which, in conjunction with an air valve, ensures the drums revolving at a more constant speed. In the latter type the paper is fed from one roller on to another, while an intermediate one serves the purpose of keeping the paper taut and in position. There is also a lever for starting and stopping the mechanism.

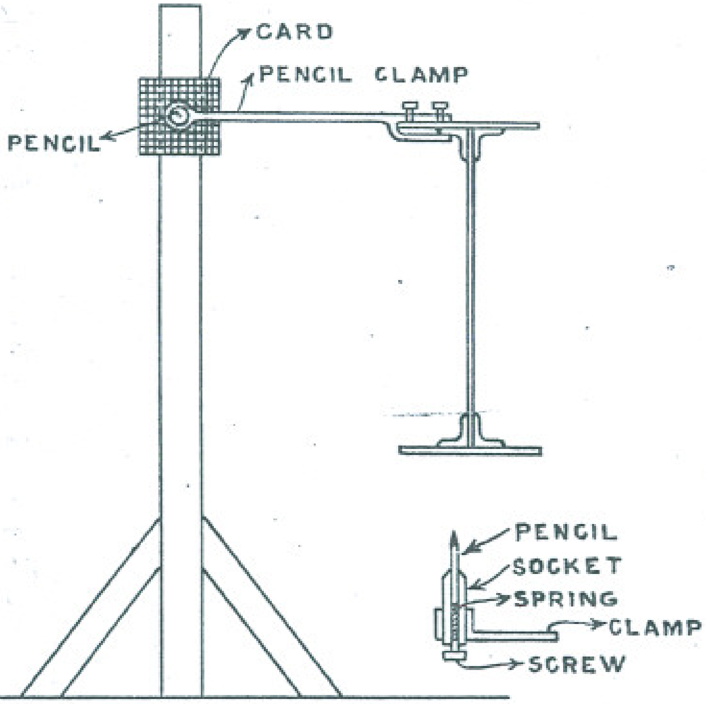
Owing to the torque exerted by the discs being constant, the tension in the wire is also constant, hence it follows that the upper end of the wire does not move in relation to the weight at the bottom. Where the length of the wire is so great as to be affected by wind or by flowing water in the river, the weight should not be allowed to rest on the river bed as shewn in Fig. 3, Plate 1, but should be carried by diagonal wires fastened to the ends of the spans as shewn in Fig. 2. These perform the same service as the river bed, namely to support the weight and keep it fixed in position. The arrangement, however, is not quite so good as the one previously described owing to the slight error introduced by the drawing out of the upper ends of the wires caused by the lengthening of the lower boom during the deflection of the girder, and it might be better to attach the ends of the wires to points at the ends of the girders midway between the upper and lower booms, but the author has never tried this arrangement, and cannot say whether inaccuracies are entirely avoided by it.

Method of measuring Oscillation.

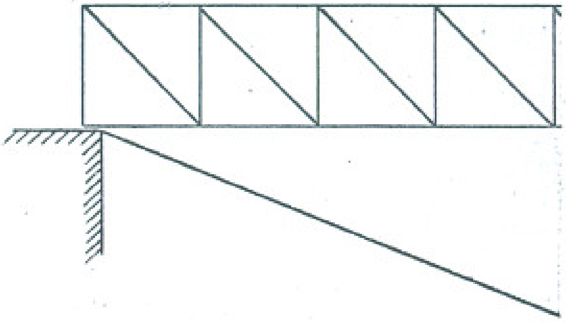
The simplest form of apparatus for measuring the oscillation of a girder is that previously described for measuring the deflection, *viz.*, the post and card, Plate, 1, Fig. 1. Referring to the typical card diagram drawn in Fig 1, Plate 2, it will be seen that there is a sensible thickness or width of the lines and the measure of the width of these lines, or rather the width between the vertical lines bounding the areas, is the oscillation of the girder. By using two clamps (sometimes called pointers) and two cards, on one post, simultaneous oscillations can be taken for both top and bottom. This test is sometimes very useful, and by taking the differences in oscillation, it indicates which of the two sets of booms (top or bottom) requires extra stiffening in the form of lateral bracing.

DIAGRAMS SHOWING

FIG I



POST & CARD METHOD OF TAKING DEFLECTIONS



METHOD OF TAKING
WHEN RUNNING WATE
IN FIG 3 BEING ADO

Oscillations may also be measured by the deflectometer previously described. The instrument is fixed to the girder while the other end of the wire is secured to a post or other fixed point, but this arrangement is seldom adopted as the vertical vibration of the wire gives rise to errors which can be avoided by the use of the seismograph.

The Seismograph.

For measuring oscillations in places where, owing to the height of the span, or for other reasons, a post cannot be used or a fixed point readily obtained, the instrument known as the seismograph is employed. The author has been informed by meteorological experts that the mathematical theory of the seismograph is abstruse, and that differential equations enter into the theory of some of the more complicated instruments, though these are chiefly concerned with the error. Since however with one type of instrument at least the error itself can be obtained experimentally, the author proposes, in the limited space at his disposal, to discuss this instrument from the point of view of its practical application.

As regards seismographs generally, it seems hardly necessary to mention that the principle, on which they depend for their action, lies in the fact that a mass or weight, if suitably suspended, will remain still in space (without sensible error) when the frame containing the weight and mechanism is vibrated round it. There are two varieties of the instrument—one designed to record horizontal vibrations in any direction, while the other only records vertical vibrations, but for the purpose of measuring oscillations we are concerned only with the horizontal seismograph.

The application of the principle of the seismograph can most easily be explained by a description of an instrument of simple construction. The seismograph shown by Fig. 2, Plate 2, was designed by the author for measuring the oscillation of the Khushalgarh Bridge. It consists essentially of a pendulum supported on a timber frame, on which it is free to swing. The weight is carried by a thin iron rod secured at its upper end by a nut and lock nut to a cross-bar, which is provided with two steel screws, whose points are hardened and bear in steel cups, also hardened. The pendulum, therefore, swings on the points of the set screws. It will be found on setting the instrument level, that it can be vibrated in a direction at right angles to the centre line of the cross-bar, without appreciably moving the centre of the weight. As the rapidity of the vibration is increased, the proportionate error will become less ; but, as in all instruments of this kind, the oscillation of the set screws in the steel cups must be practically frictionless. To effect this the steel set screws are hardened and ground to an angle of ninety degrees, and the cups, after hardening, are ground and highly polished.

The recording mechanism is only shown in outline, the arrangement being quite simple. As the frame vibrates a finger attached to the weight by a small set screw moves the pencil attachment, which consists of a small carriage provided with wheels which roll between two parallel bars.

It is only necessary, when carrying out tests, to set the frame level and secure it to the girder by clamps or other means.

The diagram recorded by the instrument is interesting. (Plate 2, Fig. 3). It consists of two parts ; the first an irregular line which may be called the vibration line, and the second, the right end of the diagram, a regular sinuous line, due to the residual motion of the pendulum. Needless to say, the first part of the line is due to the oscillation of the bridge, and the second, which has been exaggerated for the sake of clearness, that due to the pendulum.

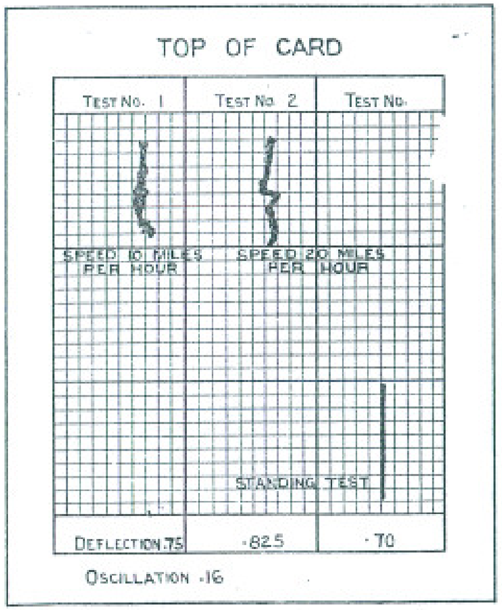
The latter represents in amplitude an error which may be plus or minus, so that it is safer in measuring the oscillation of the bridge to assume that the oscillation equals $A \pm (B+C)$ as shown by the diagram (Plate 2, Fig. 3).

A more elaborate form of seismograph is shown on Plate 3. This instrument is the invention of Oscar Leuner and is made by the firm of that name in Dresden. In this case the weight is placed horizontally, the pendulum action being obtained by setting the instrument with the aid of the three adjusting screws s_1 s_2 and s_3, so that the centre line of the rod is inclined upwards, the weight being in the lowest position. When an impulse is given to the weight, it swings with a slow period of vibration, and returns finally to its original position. The weight g is itself provided with a steel plate p_4 which corresponds with a precisely similar plate fixed in the casting of the instrument. Steel balls k_2 are placed between the two plates for the purpose of reducing friction, and elaborate arrangements are provided for keeping these balls in their correct position. They consist of a cast iron frame o and two curved metal plates, o_1. o_2., which are withdrawn after the

DIAGRAMS SHEWING METHODS OF TAKING OSCILLATIONS

FIG I

DEFLECTION CARD



FIG

SALES HORIZONTA SEISMOGRAPH

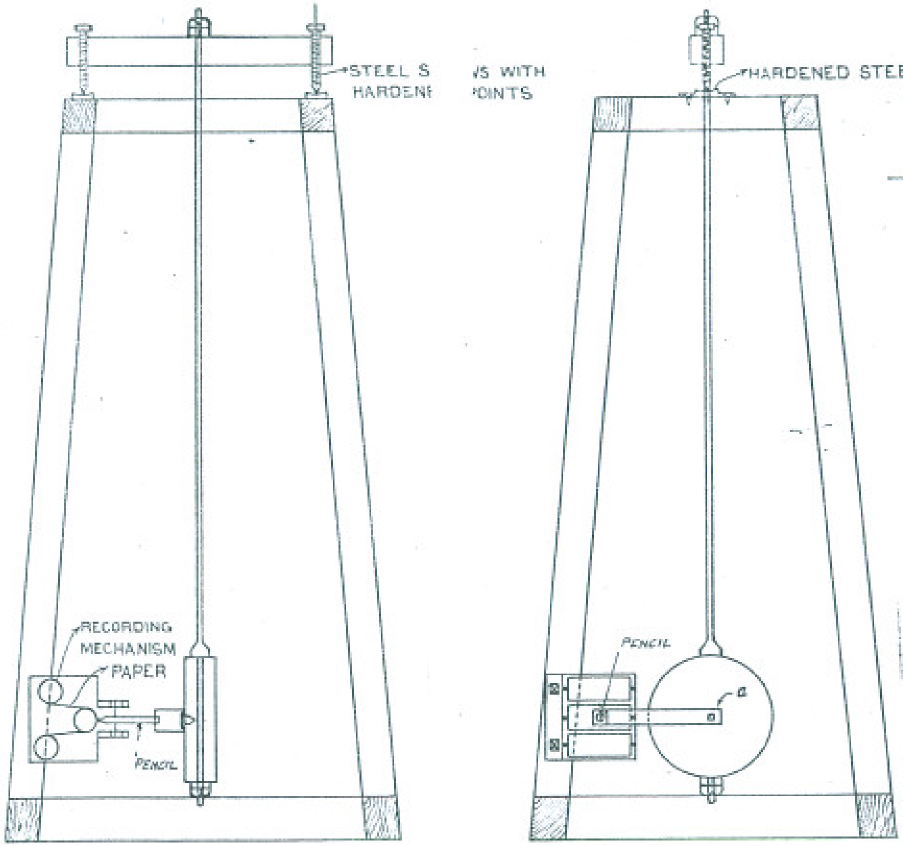
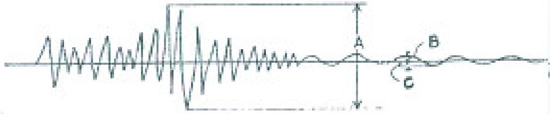


FIG 3

DIAGRAM RECORDED BY SEIS



TOTAL MOVEMENT = A

ERROR = B + C

OSCILLATION = A ± (B + C)

instrument has been set. The upper end of the bar is provided with a steel stud *p* pointed at the ends which work in socket screws *t* and p_1 as shown.

There is a self-recording mechanism, which it is unnecessary to explain in detail, as a full account of similar mechanism is given under the heading of the extensometer.

Other details are self-explanatory and can best be understood by a reference to Plate 3.

In actual working this machine has not proved to be satisfactory. Owing to the vibration to which most spans are subjected, the steel balls become displaced, and, as might be expected, the instrument, when once out of adjustment, gives very extraordinary and unexpected results.

A *sine qua non* in all instruments of the kind described is that the pencil should, after the test, return to the original datum from which it started. If it does not, then reliance cannot be placed on the results.

Occasionally apparatus is required for measuring the relative oscillation of two principal members, or more usually of two girders which are paired together to form a span, and a properly conducted investigation of this kind will furnish, in some cases, information of the utmost value in regard to those members, such as lateral bracing, which have to resist unknown forces induced by the swing of a locomotive, etc. This lateral bracing can, at best, only be designed approximately either from standard practice, or from the bracing of bridges, where the conditions are similar. Hence it follows that, when a girder oscillates, or there is reason to believe that the adequacy of the laterals is insufficient, recourse must be had to experiments. Two seismographs might, for example, be simultaneously employed, one on each girder, and by the aid of the electrical apparatus usually attached to the recording instrument, indicate by a succession of dots on a diagram, the amplitude of the two vibrations at any precise moment. By comparing the diagrams it could then easily be ascertained whether the one girder had moved relatively to the other.

A simpler method would be to fix a horizontal piece of wood o one girder, and allow it to slide on the other, when readings could be obtained in the ordinary way by a pencil and card,

INTERNAL MOVEMENT.

Method of Measurement.

Various instruments have been designed, from time to time, for measuring alterations in length of the fibre of metal under stress. Their number is legion, and they are usually designated by such names as strain meter, strain gauge, extensometer, etc. It is not proposed to describe the construction and action of the earlier types, since it was only with the introduction of the Frankel Extensometer, so far as the author is aware, that a reliable machine came on the market.

A reliable extensometer should embody the following essential features ; it must be self-recording ; the inertia of the moving parts must be a minimum ; the gearing must be absolute, or, in other words, there must not be any transmission of motion which depends on frictional arrangements; there must be no backlash ; the clamps must be perfectly rigid ; and at one end of the bar, there must be a universal joint which permits of angular adjustment without detriment to absolute accuracy in transmitting movements. The function of the extensometer is to record, on a given length of bar, the actual extension or compression in fractions of an inch. The extension might be only a five hundredth part of an inch, so that it follows that without mechanism for multiplying this movement, the diagram could not be read. This mechanism includes the transformation of the rectilinear motion of the member into circular motion through some sort of gearing in order to multiply it, and subsequently the conversion of this circular motion back into the rectilinear motion of the pencil ; while this gearing has to be designed so that not even one thousandth part of an inch of the motion is lost, consequently any gearing in the form of a wheel and pinion would be worthless, as there would be loss of motion between the teeth.

Again, the axles on which the wheels are mounted must not shake about in their bearings, as this also would result in a loss of motion.

Frankel's Extensometer.

The instrument shown in Plate 11 is interesting as a study in mechanism. There are two fixed clamps, L_1 and M_1 and the movement between the two fixed points, l_1 and m_2, takes place by the sliding of the bar n_1 in the socket of the instrument, one end of the bar—the one to the right—being fixed. At the point where the straight motion has to be transformed into circular motion, the end of the sliding bar is secured to the end of a thin steel strap r (Fig. 3), the other end of the strap being secured to a circular sector r_1. On the same axle as this sector is secured a lever R or, more correctly, a sector of a disc to which also is attached a steel strap s of which the other end is attached to a disc s_1 on the second and last axle, to which is also fixed the sector S with steel ribbons $t\ t_2$ attached for converting the [illegible]lar motion into the straight motion of the pencil. If, at the [illegible]nd of this mechanism, that is on the last axle, a constant [illegible] is induced, the whole mechanism is strained equally in [illegible] direction, the steel straps are tight, and the pivots of the axles bear always on one side of the bearing. This is accomplished by the lever s_1 and the spiral spring shown to the left of Fig. 3.

The recording mechanism is fully described in Appendix B. Enough has been said to describe the method by which the principal mechanical difficulties have been overcome, and for a complete description of the instrument the reader is referred to the appendix.

The method of attachment of the instrument is important—the accuracy of the results depending on the care taken in fixing it. It will be observed on referring to Plate 11, that of the four attachment screws, the two extreme ones, *viz*., l_1 and m_2, are fixed with regard to their respective frames. The bar n is first screwed into the socket p, and the lock nut tightened. All screws l_1, l_2, m_1, and m_2 are then eased off, and the machine is placed in position on the bar to be tested.

In placing the instrument in position the two brackets, L_1 and M_1 are pulled out by hand to remove, as far as possible, all slack in the socket. After tightening the screws temporarily to make marks on the bar to be tested, the instrument is removed, and the marks made by the screws, together with the steel points opposite to them, are punched. The instrument is then placed in position with the screw points and steel points opposite coinciding with the centre punched holes. After tightening up the main screws the bar n is tightened, by turning the socket screw p until the pencil v (Figs. 1 and 2) is in mid position. Having well tightened the extreme screws l_1 and m_2, the intermediate screws l_2 and m_1 are tightened till they easily rotate but without any looseness. It will be observed that the attachments holding the screws l_2 and m_1 are free to rotate on each frame, for the simple reason that the bar to be tested extends or compresses, as the case may be, between l_1 and l_2 and between

m_1 and m_2. Hence it follows that the brackets *b* and *a* cannot be rigid with their main frames and thus render necessary the pivots c_2, d_2, c_1 and d_1 (Fig. 1). The points of all fixing screws should be well oiled.

As to the records, and the method of interpreting them, a typical [illegible]es is shewn by Figs. 1 to 3 on Plate 4. Fig. 1 is a recor[illegible]n of a bar in tension (extension), Fig. 2 that of a bar [illegible]pression (compressed), and Fig. 3 that of a bar which is alternately extended and compressed (reversal). The datum lines *a b* are those drawn by the pencil after the instrument has been adjusted; they indicate the positions of neutral stress in bars, which are not already subjected to stress, while in bars, which are already subjected to a constant dead load stress, they indicate the starting point from which alteration in stress (in other words extension or compression) begins, as illustrated in Fig 4, Plate 4. It must be remembered that the constant stress to which a bar is subjected by the dead load of a bridge cannot be measured by the extensometer, but only the variable stress commencing from zero and reaching a maximum during the passage of a live load. The height of the diagram from datum measures the maximum extension, and the depth below datum the maximum compression.

In taking a diagram, the pencil makes some hundreds of vibrations, so that under normal conditions it should at the end of its travel return to datum, the bar then being in the same condition as it was at the beginning, before the test. If, on the other hand, the pencil does not return to datum as illustrated at Fig. 5 (Plate 4), some displacement has occurred which will generally be found to be due to the instrument having been improperly secured to the member, and in such cases the test should be regarded as unsatisfactory, and the diagram should be discarded and the test repeated.

COMBINED INTERNAL AND EXTERNAL MOVEMENTS.

Method of Measurement.

Since a metallic structure under the influence of stress will deform externally, it obviously follows that external movements are always the result of internal movements. These two kinds of movements occur at precisely the same moment, a circumstance which is of considerable value in certain classes of experimental investigations.

TYPICAL EXTENSOMETER DIAGRAMS WITH METHODS OF INTERPRETING RESULTS

PLATE 4

FIG 1

TENSION

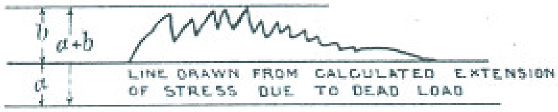
FIG 2

COMPRESSION

FIG 3

REVERSAL

FIG 4



a = STRESS DUE TO DEAD LOAD (TO SCALE 1 INCH = 2·58 TONS PER SQUARE INCH.

b = STRESS DUE TO LIVE LOAD OBTAINED FROM READINGS.

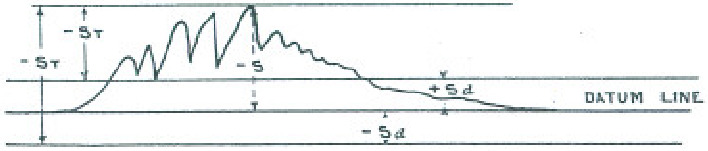
$a+b$ = TOTAL STRESS.

FIG 5

BAD DIAGRAM

a INDICATES THE DISPLACEMENT DUE TO INCORRECT FIXING

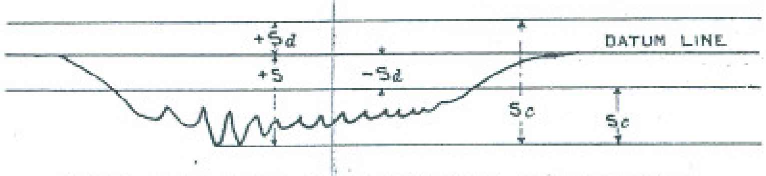
FIG 6



CASE 1 $-S_T = -S - S_d$ WHEN DEAD LOAD IS TENSION

CASE 2 $-S_T = -S + S_d$ " " " IS COMPRESSION

FIG 7



CASE 1 $S_c = +S + S_d$ WHEN DEAD LOAD IS COMPRESSION

CASE 2 $S_c = +S - S_d$ " " " IS TENSION

Hitherto each kind of movement has been considered separately. Internal movements, as measured by the extensometer, corresponding with fibre stresses induced in the material of the members under the influence of definite loads, while external movements as measured by seismographs, deflectometers, and the like, are the deformations of a structure, the members of which are subjected to fibre stresses. To put the case concisely, it may be said that the strength of a structure is largely determined from the results obtained by measuring internal movements, and constructional efficiency from the determination of its external movements or deformations.

The experimental investigation of metallic structures, however, is not complete unless practical methods can be devised for obtaining simultaneous records of both kinds of movements. There are, for instance, certain external movements which can be predetermined from the dimensions of the girders, and the loads they have to carry, as, for example, the deflection, which depends on the loads, the type of truss, the fibre stresses induced in the various members of the truss, and the lengths of the members subjected to stress. The amount of this deflection can also be obtained experimentally, and compared with the figure computed under the above conditions. If the deflection of a girder is greater than it should be, the design and workmanship should be scrutinised, the defects discovered, and remedial measures carried out.

In the case of such external movements, however, as do not depend on known conditions similar to those just described, the resistance of certain portions of the structure has to be determined, of which the design is largely a matter of experience, judgment, and sometimes conjecture. In other words, although the distortion is known, the resistance of such portions of the structure as are designed to prevent it, or at least reduce it within efficient limits cannot be fully determined by theoretical computations, and the problem must then be solved experimentally (within certain limits) by a combination of the two methods described for the measurement of external and internal movements respectively.

Plate 5 illustrate the principles involved in this method of investigation. A well designed girder span of the ordinary open deck type is shown in side elevation, plan, and cross section, and ordinarily there would be little or no side oscillation in the direction of the arrow. The writer had not time to draw a defective span, and the diagram is to be taken as merely illustrating the process, and not as showing girderwork which would require testing. A horizontal pendulum seismograph *A* is secured to a long timber firmly attached to the top booms, while four extensometers *B* are clamped to the cross and lateral bracings. The five instruments are electrically connected together in series, the contact arrangements being shown diagramatically by the star wheel and handle at *C* and *D*. If the clockwork of all the instruments is set in motion when a train crosses the bridge, a diagram will be obtained from instrument *A* showing the side oscillation of the top boom, together with four other diagrams, two from the cross bracing and two from the lateral bracing, indicating the extensions or compressions or fibre stresses induced in these members. Also if, during the passage of the train, a quick succession of electrical contacts is produced by drawing the handle *B* over the teeth of the star wheel *C*, a simultaneous series of dots or pencil marks will be given by the magnet apparatus on all five diagrams. At any point on this diagram obtained for the seismograph, or at any moment during the passage of the train, the corresponding resistance of the members designed to prevent this movement, *i.e.*, the bars of the cross or lateral bracing, can be obtained, and the investigator is thus in a position to determine, in the case of a girder which has little or no oscillation, the constraining forces which have kept the girders rigid, or alternatively the absence, or the smallness of the constraining forces which have resulted in abnormal oscillation. It could also be decided in any given case whether the deficiency existed in the cross bracing or in the lateral bracing, by ascertaining which set came into action ; or, if there was time to carry out a large number of observations, a series of results might be tabulated showing the increments in the constraining forces necessary for definite reductions in the oscillations,

The positions of the instruments, as shown in the diagrams in Plate 5, have not been specially selected, and, in making an investigation, it might be necessary to place them successively in various positions commencing, say, from the centre of the span.

DETERMINATION OF FIBRE STRESS FROM EXTENSOMETER DIAGRAMS.

As already mentioned, the extensometer cannot be applied to the investigation of the constant stress due to the dead load of a structure. We are, therefore, only concerned with the stress due to live load, and its determination from the diagrams. Let *L* equal the length between the outer screws, centre to centre,

e the maximum extension or compression in inches as measured from the diagram, r the ratio of the instrument usually 134, M the modulus of elasticity of the metal in tons, S the stress per square inch.

$$\text{Then } S = \frac{e\,M}{r\,l} = \frac{e\,M}{39{\cdot}375 \times 134}$$

$$= \frac{e\,M}{5276{\cdot}25}$$

when the metric bar is used. If the value of M is taken as 3,650 tons

$$S = e\left(\frac{13650}{134 \times 39{\cdot}375}\right) = 2{\cdot}58 \text{ tons}$$

that is for every inch height of diagram, the stress per square inch is equal to 2·58 tons. This applies to both tension and compression, e being measured from datum line upwards, or downwards, see Fig. 3, Plate 4.

Let $S =$ the total fibre stress due to live and dead load.

$- S =$ the live load fibre stress in tension.

$+ S =$ the live load fibre stress in compression.

$- S_d =$ the dead load fibre stress in tension.

$+ S_d =$ the dead load fibre stress in compression.

Then if the stress recorded by the diagram is tension (Fig. 6, Plate 4).

$- S_T = -S \mp S_d$ according as the dead load stress is in tension or compression.

If the stress recorded by the diagram is compression

$S_C = + S \pm S_d$ according as the dead load stress is in compression or tension (Fig. 7, Plate 4).

Special provision has to be made for reversals of stress. The Government of India Bridge Rule to cover this condition is as follows :—

" Members and connections subject to alternating stresses, are to be proportioned for tension and compression separately, and half the smaller area is to be added to the larger area to give the total section."

It follows that if the total stress S_T is in tension, and there is a dead load stress of S_d in compression, the total effective stress $S_{\text{effective}} = -S_T - \frac{S_d}{2}$. The member must, therefore, be of sufficient cross section to carry $S_{\text{effective}}$ in tension, and it must be stiff enough as a column to carry a compressive stress of S_d. If the total stress S_T is in compression and we have a dead load stress of S_d in tension the total effective stress is given by the formula

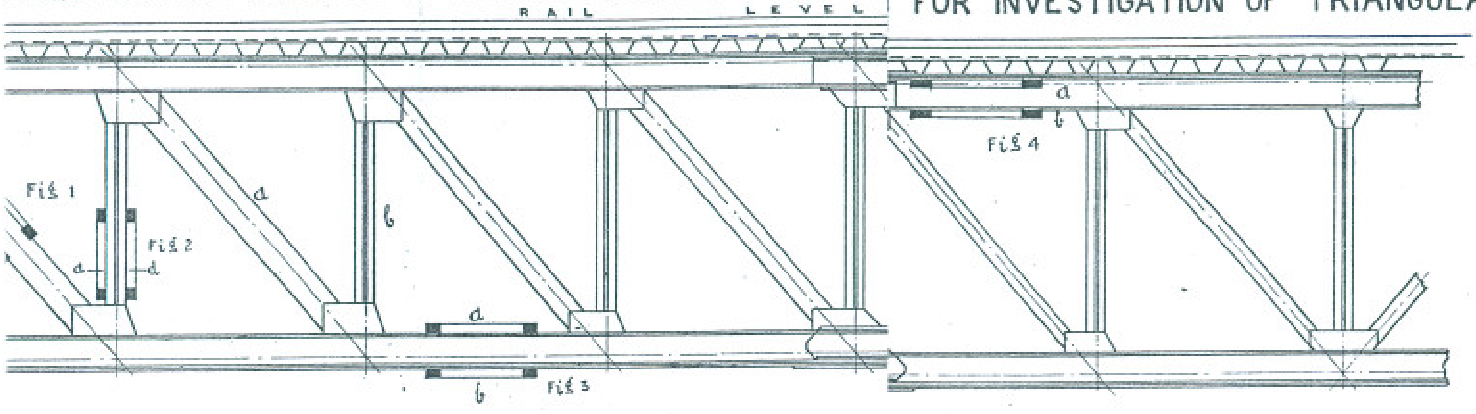
$$S_{\text{effective}} = + S_T + \frac{S_d}{2}$$

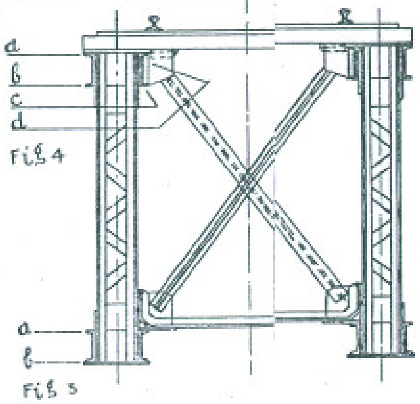
The member must therefore be of sufficient cross section and be of sufficient stiffness as a column to carry $S_{\text{effective}}$ in compression.

Since, as has previously been shown, the fibre stress may vary considerably across the same section, care must be taken, wherever possible, to attach extensometers to as many edges of the member as possible. For plain bars it will generally suffice if readings are taken on the two edges as shown in Fig. 1, Plate 6. For web verticals, where the fibre stress varies considerably over the section, readings should preferably be taken at the four points, *a*, *b*, *c*, *d* (Fig. 2). For chords in tension it is usually unnecessary to take readings at more than two positions *a* and *b*, Fig. 3. For chords in compression four positions *a*, *b*, *c*, *d*, should be chosen as for web verticals, *vide* Fig. 4. If the experimenter wishes to investigate for fibre stress only, he should, in addition to testing as many edges of the same member as possible, also test as many members of the same kind as possible. Thus in a span of the kind shown on Plate 6 there are eight tension bars of the kind *a*, four web verticals of the kind *b*, four compression chord members of the kind *c* and so on. It thus follows that as many as sixteen tests are required in order to test thoroughly, say, a top chord member. Of course, if four instruments are available the work is reduced correspondingly.

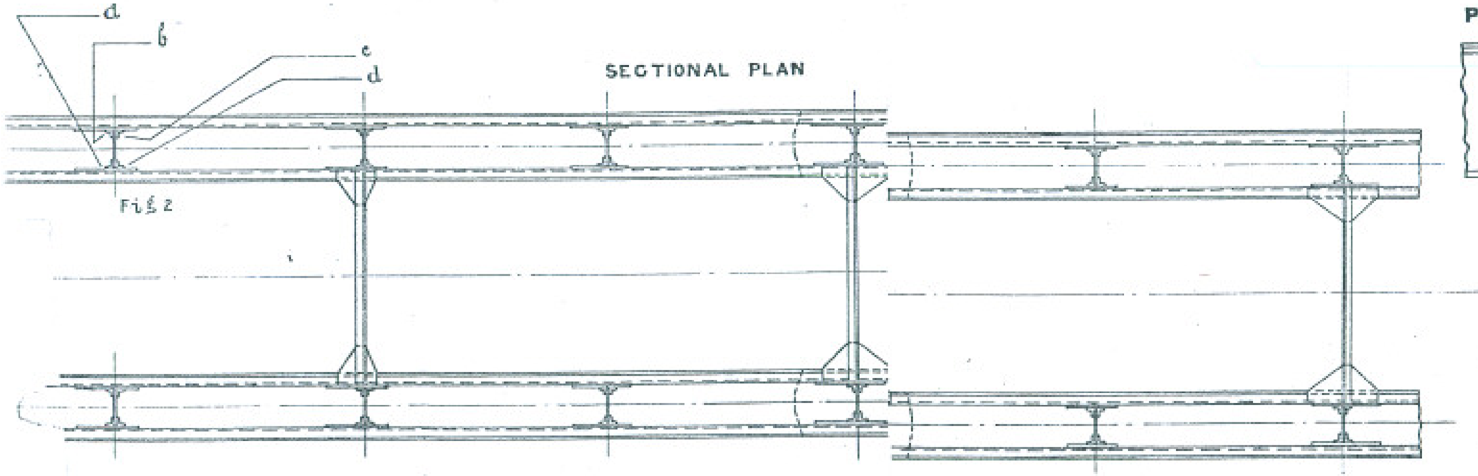
These tests may be regarded as taken with the rolling load crossing the span dead slow, because for stress comparisons we are not concerned with the question of the effect of impact at speed which can be more conveniently discussed separately. Having obtained, say, sixteen diagrams for the same kind of member, the maximum reading should be noted and the fibre stress calculated from it. This figure should then be compared with

RAMS SHOWING METHOD OF APPLYING EXTENSOMETERS FOR INVESTIGATION OF TRIANGULATED GIRDER





CROSS SECTION



SECTIONAL PLAN

SKETCH SHOWING METHOD OF TESTING PERMANENT DISTORTION OF JOINTS

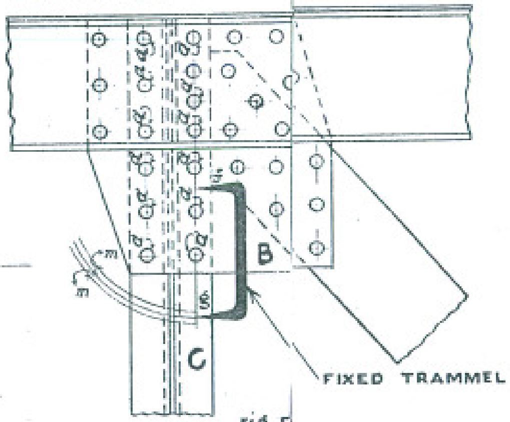


Fig 5

that obtained by analytical methods. We should next calculate the difference in stress in two planes at right angles to each other, and diagnose the cause of this difference by an examination of the peculiarities in the design and construction of the girder.

By repeating this process for various members the investigator will not only gain an insight into the strength and condition of the span, but will add considerably to his knowledge in regard to the conditions which should govern the design of steel work generally. Needless to mention, however, the train loads must be the same in carrying out the experiments as are used in the calculations.

The extensometer cannot be applied with the same readiness for determining stresses which vary along a given length, as, for instance, those due to bending movement. Stresses vary in the flanges of some members even over a short length, as, for instance, in rail girders, and in cross girders between the point of support of the rail girders and the end of the girders. A position should be selected where the bending moment is constant, or if the bending moment is not constant in the length of the beam, then in that position where it is most uniform, but for most cross girders the bending moment between the two rail girders is constant for all practical purposes. In rail girders and flanges of plate girders generally, the best position to fix the instrument is in the centre of the girder. The distance, using the meter bar, between the centre of the girder and the extreme screw is only $\frac{39{\cdot}375}{2} = 19{\cdot}68$ inches and the actual variation in fibre stress within this distance may be only two or three per cent.

Having fixed the instrument and taken a diagram, the maximum fibre stress is worked out in the ordinary way. The figure is then multiplied by the ratio $\frac{S \text{ max}}{S \text{ mean}}$

S max = the maximum stress on the length measured.

S mean = the mean stress on the length measured.

Without actually ascertaining the values of S max ana S mean we can easily obtain the ratio graphically from the curve of bending moments, or by roughly dividing the sum of the maximum and minimum bending moments by two, and in most cases this will be accurate enough for all practical purposes. The stress, thus found, is further increased in the ratio o $\frac{d_1}{d_2}$.

where d_1 is the distance from the neutral axis of the beam to the extreme fibre, and d_2 the distance of the neutral axis to the centre of the flange to which the extensometer is clamped.

Occasionally, we require to know the stress due to bending where the section is subjected to both thrust and bending moment.

Let S_t = Stress per square inch due to thrust.

S_b = Stress per square inch due to bending moment only.

We require to know the value of S_b from stresses obtained from diagrams taken for the top and bottom flanges. Let the stress as ascertained for the top flange be a compression of eight tons per sq. inch, and that of the bottom flange be a tension of six tons per sq. inch.

Then we have

$$S_t + S_b = 8$$
$$S_t - S_b = 6$$
$$\therefore \quad S_t = 7 \quad \text{and} \quad S_b = 1$$

That is, the stress due to bending is one ton per square inch.

DETERMINATION OF IMPACT CO-EFFICIENTS FROM EXTENSOMETER READINGS.

So far, we have considered only the extensometer diagram as furnishing information from which we can calculate fibre stress. Live load has been considered as dead load, and the test train for the purpose of computing fibre stress only, has been regarded as crossing the bridge at a very slow speed. We will now consider whether further use can be made of the extensometer diagrams. If we attach and adjust an extensometer to some member of a bridge, and make a series of tests commencing with a speed of two miles an hour, and increasing it by, say ten miles an hour, until a speed of sixty miles an hour has been reached, we find, on comparing the diagrams, that there is a marked difference in the character of the curves. As the speed increases the curve, which at dead slow is a plain line, becomes a succession of jigs due to the vibration of the member, or more correctly due to vibration in extensions or compressions of the metal between the extreme screws of the instrument. Also in measuring the heights of the diagram we find that the maximum ordinates are greater at higher speeds than at slow, and this difference in height is a measure in tons per square inch of the immediate effect of the live load at a high speed. The action is perfectly simple to understand. As an illustration, take the case of a piece of elastic, to which is attached a small weight. If we gradually allow the weight to fall, we find that the elastic has lengthened by an amount which we will call a, if we allow the weight to suddenly drop the elastic will lengthen by an amount $a+b$, b being, so to speak, the measure and effect of impact.

There are many causes which contribute to an excess in the stress when the rolling load crosses a bridge at speed. In the first place the rolling load does not move in a perfectly straight line, it moves up and down, oscillates sideways, and rocks, due to inequalities of the track. Then again, the whole engine falls a distance due to the deflection of the girder. At high speeds the vertical force on the driving wheels varies considerably due to the vertical component of the thrust of the connecting rod, and in certain positions of the cranks the vertical force on the wheels is double what it is in other positions.

Two methods of computing impact co-efficients are illustrated on Plate 7. Professor Turneaure some years ago carried out a series of tests on a large number of bridges in America. He applied his instrument,—an ordinary Frankel extensometer—to various members which he regarded as critical, in the sense that the greatest effect due to impact would be likely to be observed on these members. His observations were made with trains under ordinary normal traffic conditions, no special test trains being available for his purpose, owing to the congestion in traffic on some of the sections on which many of the more important bridges were located. For this reason the tests were obviously restricted to the speeds of the passing trains, and were consequently only carried out under one set of conditions, from which it follows that only one diagram was taken for one test. Professor Turneaure on each of his diagrams drew a mean line midway between the limits of the vibration, as shown on Fig. 2 (Plate 7). The maximum impact was then measured by the ordinate of the greatest distance from this mean line to the extreme vibration. In other words, if the secondary vibrations are regarded as lying in a zone of their own, then the maximum impact is half the vertical height of the zone. The co-efficient for impact is calculated from the fraction

$$\frac{\text{Greatest height of diagram}-\text{greatest height of mean line}}{\text{Greatest height of mean line}}$$

The author's method of computing impact co-efficients is illustrated at Fig. 3 (Plate 7), and was framed to obviate the inaccuracies which, in his opinion, might result from certain assumptions made in the method first described. These are as follows :—

(1) The greatest co-efficient for impact might occur at any speed not necessarily the highest.

(2) The mean line might not be the true one as recorded, say for a train crossing the bridge at the lowest speed it was possible to run it, say one or two miles per hour.

(3) The train should at least be as heavy as the one assumed in designing the bridge.

In order to conform to these conditions the author carried out his tests with a special test train, having the same axle loads and wheel spacings as were used in calculating the stresses of the bridge under investigation. A series of tests were then taken with the extensometer fixed in one position on the member, commencing at the lowest speed at which it was possible to run the train over the bridge, and increasing it by increments of ten miles per hour, finally reaching the maximum speed at which trains would ever cross the bridge under normal traffic conditions. It was found on comparing several sets of diagrams that the maximum impact was not usually recorded at the highest speed, but at some intermediate one, generally about twenty-five miles per hour. This information, subsequently proved of considerable value in determining the conditions under which trains had to be restricted in speed in the case of overstressed bridges. Formerly it was considered that considerable relief would be effected in the stresses induced in the various members of a structure by limiting trains to a speed ranging from ten to twenty-five miles per hour, but since these experiments were carried out, the limit for overstressed bridges has been fixed at five miles per hour.

Referring again to Plate 7, we find that the maximum co-efficient for impact is determined by the formula—

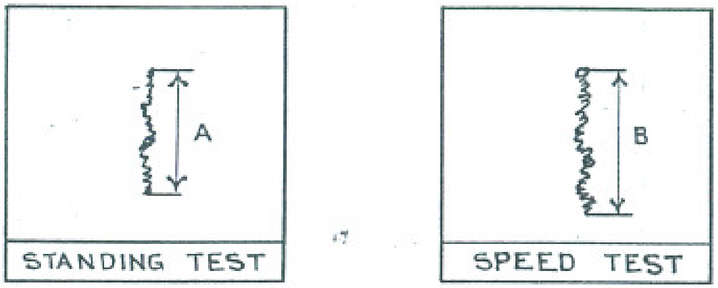
$$\text{Co-efficient}=\frac{(\text{greatest of } B_1\ B_2\ B_3,\ \text{etc.})-A}{A}$$

PLATE 7

GRAMS SHOWING METHODS OF INTERPRETING RECORDS FOR CALCULATING COEFFICIENTS FOR IMPACT

FIG. 1

ORDINARY TEST CARD METHOD

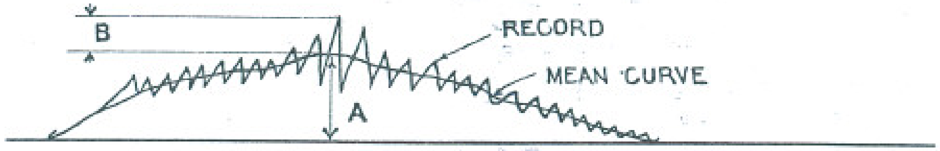


COEFFICIENT = $\frac{B-A}{A}$

FIG. 2

PROFESSOR TURNEAURE'S METHOD

DEFLECTOMETERS AND EXTENSOMETERS



NO SPECIAL TEST TRAIN IS USED – ONE DIAGRAM ONLY IS TAKEN FOR ONE TEST

COEFFICIENT = $\frac{B}{A}$

FIG. 3

SALES' METHOD — DEFLECTOMETERS AND EXTENSOMETERS

DEAD SLOW   10 MILES PER HOUR   20 MILES PER HOUR

COEFFICIENT = $\frac{(\text{GREATEST OF } B_1 \, B_2 \, B_3 \text{ ETC}) - A}{A}$

IAL TEST TRAIN OF KNOWN WEIGHT IS USED – ALL DIAGRAMS ARE TAKEN WITH THE SAME TEST TRAIN

APPENDIX B.

Description of Frankel's Recording Extensometer, with directions for its use.

The object of the extensometer is the production of diagrams which will show the whole range of the extension of a member of a structure for any desired load, during an optionally long or short time, in such a way that the abscissæ represent the time, and the ordinates the changes in length. By extension, however, is to be understood both positive extension (lengthening) and negative extension (shortening).

The ratio of movement must be ascertained separately for each apparatus. This amounts to about 1 to 175.

The advantages of such an instrument are obvious. Not only is the whole range of alteration of the extension represented in the diagrams, but the exact moment is also established in which the greatest extension of a structural part actually takes place, and this moment does not always coincide with that which, according to the usual calculations, might be expected to be the most unfavourable. Also, owing to the recording arrangements with which all these instruments are fitted, there is no danger of regarding any measured extension as the maximum, when in reality it is not so.

By using several of these instruments together, simultaneous extension diagrams of different members of a structure can be obtained, as also diagrams of adjacent portions of the same member. This arrangement will give a far clearer idea of the play of the forces than is possible from single readings. These diagrams constitute documentary evidence, which can be studied at leisure as a part of the life history of the portion of the structure concerned.

Figures 1 and 2 on Plate 4 show the instrument in plan and elevation to half size. The extensometer is depicted as if made fast to k, the portion of the structure to be examined. The ends of the length to be measured are fixed by the two clamp screws l_1 and m_2 while the screws l_2 and m_1, which hang from the axles c and d respectively, serve only for security against the distortion of the frames l and m of which the first forms the frame for the actual extensometer, while the second carries the end of the rod n.

The apparatus rod is shown by n , one end terminates in a ball joint p and c and the other end n_2 is secured by the steel strap r to the short arm of the double-armed lever $R\,r_1$. The main rod n is connected to the end n_1 of the apparatus rod N_1, by a screw socket p and locknut o, and at the other end direct to the bracket m by the small screw n_3. The locknut c and the screwed end of the rod n serve in altering the length of the rod for the purpose of adjusting the apparatus and bringing the pencil to its normal position.

The long arm R of the double armed lever $R\,r_1$, transfers its movement by means of a steel strap, to the arm s_1 of the double lever s_1S which is of the lightest possible construction. The circular movement of the end of the levers is changed by the steel ribbons t_1 and t_2 into the rectilinear movement of the scriber V_1.

In order that the ball p may always be in contact with the socket and thus induce constant tension in n, a spring q works on a short arm of the double lever s_1S. Every change of length of the given distance between the centres of l_1 and m_2, attached to the member of the structure to be tested, will then be followed by a movement of the scriber V_1 parallel to the axle of the barrel x, and indeed the movements of the pencil are proportional to those changes of length, even to imperceptible defects, as direct micrometer measurements have proved. The scriber H is guided by means of little rollers between the guiding bands z_1 and z_2 and pressed against the paper by a spring placed in the holder of the scriber V_1.

The paper which is wound on the store barrel y in the manner shown in Fig. 4 revolves round the diagram roller x, and receives its tension through the latter. To move the paper the clockwork in the barrel x is used. This can be wound up by means of a key o. The paper on which the diagrams are depicted is finally wound on the roller w. The roller w is driven by a steel strap z from the roller x.

The scriber V (Fig. 3) gives a datum line parallel to the zero for the extension diagrams drawn by the moveable scriber V_1.

In order to set the clockwork of the extensometer going, the handle must be turned in the direction of the arrow. To stop the clock work the handle P must be turned in the reverse direction.

If, during the working of the apparatus short and frequent pressures are given to the handle P points are simultaneously marked on the paper by the arm V.

Instead of setting the extensometer in motion directly by hand, the electro-magnets TT can be used. For this purpose the wires of a galvanic battery are attached to the terminals u_1 and u_2. By completing the circuit the armature K is drawn down and the clockwork released. With repeated brief closings of the current the arm v makes corresponding marks on the paper. In this way it is possible, with several extensometers applied to a bridge or to a machine, to produce the diagram ordinates corresponding to certain moments of time.

If it is required to note down the points of the diagram corresponding to certain positions of a locomotive moving over a bridge, this can be done automatically by the help of an arrangement of rail contacts applied to the particular places on the bridge roadway.

In order to measure the alteration by extension of any part of a structure, or machine, the apparatus is fastened, by the double clamp L to that part of the structure which is to be examined, by tightening both the pinch screws l_1 and l_2. The hanging screws c_2 and d_1 of the axles b and a serve only as security against the distortion of the clamps l and m. On the double clamp L is placed the rod N, by screwing the end of it into the ball socket p and securing it by the locknut o. The screw n_3 is then removed, the clamp m attached to the structure, the rod n placed in the jaw, and the screw n_1 replaced. The clamp M should be pulled outwards until the scriber V_1 is as nearly as possible in the mid position. Travel adjustment is made by the screw p, which must be so adjusted, that it has sufficient room to draw the required diagram—special care being taken to see that the scriber does not touch the limits of the space in which it works.

When the length of the rod n is thus fixed, the pinch-screws l_1, l_2, m_1, and m_2, are finally tightened.

To set the apparatus going, the clockwork at o is wound up and the handle p moved down. The fixed scriber then describes the zero line, while the moveable scriber V_1 draws the diagrams of extension in the ratio separately ascertained for the apparatus. To stop the apparatus the handle p is moved back to its original position. If during the working of the apparatus the handle p is moved backwards and forwards marks will be made on the diagram by the scriber at V_1.

Instead of setting the extensometer in motion by hand, the electro-magnet TT can be used for the purpose by attaching the wires of a galvanic battery to the terminals u_1, u_2. Closing the current releases a stop which starts the clockwork, while repeated short closings of the current causes the arm V to mark corresponding points on the paper.

One battery will serve at the same time for several extensometers, while by means of special automatic rail contract, attached in certain positions, for instance, on a railway bridge, repeated brief closings of the current can be produced by the front wheels of the locomotive as it moves along over one of these contact arrangements The marking point will then simultaneously record certain positions of the rolling load on all the extensometer diagrams.

Care must be taken to stretch the paper evenly, and in order to wind on new paper the axle of the paper carrying roller Y can be drawn out and the cylinder removed from the frame.

The following points are to be noted when using the extensometer :—

1. After the apparatus is screwed to the trial bar, the clockwork should be set going for a short time in order to make certain by slight taps with the hand on the apparatus rod that the pencil does not move, or only makes slight oscillations, and on the cessation of the taps remains always at the same place. A similar tapping is recommended after the diagram has been recorded in those cases in which the apparatus has received only very trifling concussion, but in the examination of bridges, the movement of the locomotive over the structure supplies sufficient vibration. It is also advisable to reject the first diagram, in the event of the extensometer not having been well shaken.

2. If much time has elapsed after an experiment with the apparatus screwed in position it is well not to begin again without repeating the original precautions as the bridge meanwhile may have altered its conditions of extension.

3. In long experiments possible changes in the temperature of the air must be taken into consideration, especially if the sun has been shining on the bridge.

4. Both the fixed clamps of the apparatus must be carefully screwed on to the member of the structure to be examined.

5. In cases where only extension or only compression is to be expected, the scriber V_1 must be set more to the one side or to the other of the paper, so that it may not touch the limits of the space in which it moves in recording great extensions, otherwise the lever gear would be injured. It is equally requisite to use the short rods when great extensions are to be expected.

6. The scriber V_1 should be fixed in its holder in such a way that it does not press too firmly on the paper, whereby elastic deformation of the lever will be avoided.

would give precise values for the effect of impact. The methods described for the measurement of impact were of value in deciding as to whether a bridgel was really strong enough under any given system of loads; while the procedure indicated for measuring the fibre stresses induced in various parts of a structure, of which the theoretical investigation was difficult, would enable an engineer to decide which portions of a structure were weak and which sufficiently strong under the given sets of conditions he had to consider. In conclusion the speaker said that the paper was anything but a treatise on the subject, and it should be regarded more in the light of an introduction to a branch of experimental science. The subject was in its infancy and was capable of extensive development; nevertheless he hoped that he had succeeded in framing a system, which, with the detailed explanations, would be capable of further development. The two or three pages on the method of measuring permanent deformations would suffice to indicate the lines on which this portion of the subject might be profitably studied, but beyond this it did not cover much ground.

MR. PAVRY, in reference to the subject of oscillation, was recently standing on a forty foot girder bridge when a train passed over it, and with the naked eye noticed that the lateral oscillation was excessive. The card test, however, showed the oscillation to be within prescribed limits. He would like some explanation of this. It had occurred in the morning, and not after dinner, so the speaker could vouch for what he said.

MR. HARFORD said he remembered a case similar to the ne described by Mr. Pavry. The oscillation in this case had en due to the bad setting of the girders, and the action was ther accentuated by the absence of a portion of the strip of lead under the bed plate, which had been stolen.

MR. DORMAN said he would like to see the instruments at work, and as Mr. Sales had some with him perhaps he would give a short practical demonstration. Apparently all Mr. Sales' instruments were of German design and manufacture—were none made in England?

MR. ASHFORD remarked that the whole science of engineering was built up on a system of measurement. Before bridges and such like structures could be built a measure of the stress that the material would stand had to be obtained. With that as a basis the engineer could proceed to design his structure, but there was so often an element of uncertainty in his work, due to the type of joints he had to use, together with the elasticity and flexibility of the structure, that uncertainty caused him to introduce factors of safety into his calculations. When designing the joints of his structure he knew that his calculations might be discounted by errors in construction or workmanship, as well as by flexure which might introduce compound stress in a member and thus displace the centre of stress from the centre of the section. It was only by the actual measurement of the strain, and thereby of the stress in the various parts of the members of a structure, as described by the author, that the actual stresses could be compared with those calculated. He wished to express his appreciation of the author's excellent and practical paper.

MR. SALES in reply said that it was an unfortunate fact that all his instruments had been made in Germany ; but English enterprise was coming to the front, and for one thing, a new pattern of hydraulic extensometer, embodying several interesting features, had been devised by an English firm. It was the simplest extensometer that had been produced, and it had the advantage that there were no defects due to inertia of the moving parts.

A point of special interest was that which had to do with deformations that were not elastic but were due to deterioration, and this was a matter with which inspectors in the field were chiefly concerned. In steel structures the premonitory signs of failure were the loosening of rivets. During the passage of a train over a bridge certain joints might be noticed to be loose which were tight at other times. A simple method of detecting this was to paste pieces of paper on two members at a joint and if there was any considerable movement, the paper would break. Other movements again were so great as to be apparent to the naked eye. As regards the oscillation Mr. Pavry had mentioned, there were over fifty miles of steel bridge work on the North-Western Railway, and he could not call to mind the particular instance. He had known cases of considerable oscillation in new bridges. On a cantilever bridge the oscillation was bound to be very much greater than in the open deck span type, and yet there seemed to be no objection to this oscillation, which in many cases, indeed, there were no means of preventing. The remedy in the case of open deck spans was to give greater lateral resistance by remodelling the bracings.

DISCUSSION.

MR. A. E. ORR. (Vice-President) in opening the proceedings on behalf of the President, who was unavoidably absent, said, that Colonel Craster would address the Congress the next day (Tuesday), when His Honour the Lieutenant-Governor would also be present. As this would be the first visit of His Honour to the Congress, he hoped everyone would make a point of being present.

MR. SALES, in introducing his paper, said that his principal purpose was to indicate the broad lines on which steel bridge work could be investigated from a practical point of view. This branch of engineering had hitherto been considered almost wholly in theory without any reference to the behaviour of steel work under rolling loads; but it had to be borne in mind that the investigation of metallic structures was incomplete without some reference to what occurred in practice. A bridge might have only a very few years of useful life owing to inherent defects, though theoretically it might be up to standard; on the other hand a bridge might be theoretically overstressed, but in practice perfect. The paper was the result of an attempt to apply the principles underlying the temporary deformation of a structure to its investigation by methods, which, so far as the speaker was aware, were not in systematic use. It was more or less an attempt to extend the principles of statics to instrumental research, where pure theory failed, owing to the complexities of the assumptions involved.

A designer might succeed in producing steel bridge work which fulfilled necessary requirements; but nevertheless designs frequently failed to give satisfaction in important details. The reason for this was that most designs were often the result of such experience as was obtainable in the drawing office. Defects in the field are only known to the maintenance engineer, and the result in many cases was that the designer in the drawing office was frequently unacquainted with the efficiency of his own designs. Thus errors of judgment might be perpetuated for long periods in the drawing office; and it was not often that designers were placed in the position of being able to maintain the bridges they themselves had designed. In India, however, conditions were much more satisfactory. Large railways had a bridge engineer, and the design of steel work and its maintenance went hand in hand, The speaker felt that some attempt should be made by bridge engineers to communicate their experience of steel structural work in service for the guidance of designers and draftsmen generally, though hitherto this had only been possible to a very limited extent. Moreover, such knowledge as existed in regard to the behaviour of bridges under traffic was for the most part only fragmentary, and such isolated instances as existed did not help to convey any substantial idea as to their correct interpretation. He had, accordingly, endeavoured to indicate the broad lines on which the subject should be studied, so that engineers might develop certain principles according to the means and time at their disposal.

At first sight the paper might be taken to be a description of the various instruments used in this phase of engineering, but a perusal of the text would prove that the more important matter consisted of the methods by which the instruments could be used to make a bridge tell its own story. No progress could be made in engineering or in physical science without the aid of accurate measuring instruments; hence it had been found necessary to describe somewhat in detail the construction and the working of apparatus, which was seldom used except perhaps by professors entrusted with certain specific investigations. Much of this description had, therefore, been printed as appendices, with the object of separating it from the other matter which dealt with methods.

A large part of a bridge engineer's work consisted in the investigation of bridge work, which was considered to be unsafe according to mathematical methods for the loads it had to carry. If such bridge work had to be scrapped because of mathematics, considerable expenditure would be involved. In some cases steel bridge work fell short of theoretical requirements due to defects in design; in other cases, owing to precise knowledge as to the theory itself—a knowledge which could be obtained by experimental research—bridge work was much stronger than conventional computation indicated. There were the unknown factors of fatigue and impact for which allowance was generally made in the factor of safety, but it was impossible to formulate factors which would allow for fatigue which was one of the unknowns in bridge work. On the other hand, it was easy by the methods described in the paper to obtain in any particular case co-efficients which