METHODS FOR MEASURING ELASTIC AND PLASTIC DEFORMATIONS AND DISTENSIONS OF STEEL WELDS

Commun cation of M. CAMPUS

Directeur du Laboratoire d'Essais des Constructions du Génie Civil et d'Hydraulique Fluviale de l'Université de Liège.

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In bulletin n° 3 of R.I.L.E.M dated 3 June 1951, a communication by Mr. R. GUNNERT, having the same title as above discussed a method for measuring residual tensions to which he attributes my name. I have sent a letter dated 26 May 1950, on this subject to Mr. R. GUNNERT which he seems to have disregarded. For this reason I deem it advisable to have this communication follow his. It lays no claim to priority ; on the contrary, it attempts to show the in-expediency of attaching names of individuals to methods which I am proposing to qualify, instead, by their nature. But it mains purpose is to deepen the discussion of testing methods and of circumstances under which they may be applied. In order not to take up too many pages of the bulletin, I am refering to the following publications in which I have trested this subject.

1) Research, studies and considerations on Welded structures. Edition sciences and letters - Liege - 1946.
2) Fundamental questions concerning Welded structures - Bulletin CERES - Vol. 11 - Liege - 1947.
3) Mechanical instruments for the measurement of deformations. Publication Ce Be Re Na. S I/I of the Belgian Center for Naval Research - Brussels - 1949.

These publications will be henceforth designated as : Research, Questions, Instruments.

For the very numerous measurements of deformations and residual tensions of plates welded in the laboratory, various instruments have been employed successively since 1937 : precision sliding calibers : Zeiss measuring microscope ; " deformeter " with conical plunger accurate to 1/1000 mm and using a gauge line fo 20 mm (Research PP. II-I3).

Using this last instrument as the point of departure, a direct-reading " deformeter " has been developed. It is accurate to 1/1000 mm and has adjustable gauge lines of 12, 20, 40, 80 and 100 mm. (fig. I) (Instruments PP. 9-10). It enables measurements to be made in all positions. In this instrument, as in the preceding, from which it is derived, a significant improvement over similar commercial instruments has been effected in 1942. The conical measuring points have been replaced by calibrated steel balls. Experience shaws thats conical points engender a certain inaccuracy of measurement, even when no angular deviation of the conical reference points takes place. However, angular deviation does occur in the neighborhood of the welds in welded plates. Because of this, the conical points of the measuring apparatus can no longer be fitted to the conical reference holes. Besides, the drilling of conical reference holes is a delicate affair.

Since 1942, the conical points of the instruments made in my laboratories have been replaced by set, calibrated balls. The reference marks are made by drilling a small, shallow, cylindrical hole of a diameter smaller than that of the ball. A calibrated ball of the same diameter as the hole is then pressed into it, producing a hemispherical indentation. Thus, the ball of the measuring instrument is always superposable, even in the case of angular deviation. The results have been excellent. The reference marks are easier to make and more exact ; the readings are facilitated and are more accurate. Until now, the balls used have been 2 mm in diameter. An instrument according to the same principle is going to be constructed out of light metals. It will have a gauge line as short as 10 mm or less and, eventually, will use balls 1 mm in diameter. The instrument is very rugged and easy to handle. Its accuracy is as satisfactory as its sensitiveness, which has the additional advantage of not being superior to the accuracy.

It is not possible to describe here the measurements of shrinkage and deformations performed in considerable number both in the laboratory and in the field (Research PP. 7-70 ; Questions PP. I89-222). I shall limit myself to the methods of measuring residual tensions.

In order to examine the state of tension of the test plates in the laboratory, I used the method of cutting up the plates into fragments. Squares 25 mm long on each side were traced on the plates ; four 20 mm, gauge lines, inclined at 45 deg. to each other were marked, giving, in all, eight reference points. The initial measurements were made ; then the square fragments were cut up, and the final readings taken. Admittedly, the tensions are annulled by the cutting up process. Thus the principal tensions on the two faces are determined both in direction and in magnitude. Note that these operations are quite fastidious, and that it is worthwhile to facilitate them by means of easily established diagrams.

It is to this method, which I prefer calling the cutting up method, that Mr. R. GUNNERT attaches my name. I do not believe myself to have been the first to use it. I believe that Professor ROS, in particular, has used it before me. This method has given satisfactory results in the laboratory. Mr. GUNNERT finds fault in the use of an insufficiently accurate instrument and in the too large size of fragments. This is a matter of opinion, and I do not share that of Mr. GUNNERT. The accuracy of the extensometer used is quite sufficient. The dimensions adopted for gauge lines (20mm) have determined those of the fragments (25mm). The measurements were performed in a systematic manner in accordance with the checkered networks of reference marks, corresponding to the 20 mm gauge lines. Considering the rather large dimensions of the test specimens, these gauge lines were appropriate but required truly fastidious measuring work, fatiguing the operators rather quickly.

That is why it was necessary to devise a truly simple, rugged and practically fool-proof instrument, but having the same accuracy and sensitiveness as a fine instrument like the Huggenberger extensometer. In my opinion, both the instrument and the method are highly suited for systematic routine tests performed in rather large numbers. In such a case, it is very simple and sufficiently accurate. These conditions are essential to the value of measurements done by professional operators.

If it is the question of making a small number of isolated measurements, a greater accuracy would be sought. This is the reason why a more perfected instrument is projected at the laboratory, while trying as much as possible to conserve the great ease of manipulation and the ruggedness.

This is in order not to render the accuracy of the instrument illusory by making it too delicate. In the meantime, it may well be asked whether such great accuracy has any real significance in the measurement of residual tensions, which are all specific cases, and even whether it is not illusory in principle. In effect, the laws of distribution of tensions about a point are used as the basis for working on average tensions, actually measured along a base of definite length.

There exists thus, a systematic discrepancy, which the possible differences in the length of gauge lines do not seem to influence much, when the order of ± 10 mm is attained.

The cutting up method is entirely destructive. It is practicable in the laboratory, but not on an actual structure in the field. The problem of trying to measure actual tensions in existing structures has been posed in Belgium in 1938 by one of my scientific collaborators, Mr H. LOUIS.

At his suggestion a change has been made in the laboratory in the Schmuckler apparatus used for controlled milling of welds. A special hollow drill-press has been adapted, by means of a flexible shaft, to permit the extraction from structures of cylindrical disks 27 mm in diameter and up to 30 mm thick. The measurements are taken on the two faces of these disks along 20 mm, gauge lines, just like in the cutting up method. Originally they were taken with a measuring microscope ; at the present time with an instrument of the shape deformation type. This instrument posesses the advantage of being able to operate in all directions, depending on the position of the element of the structure. In addition, the 12 mm gauge line permits it to work on disks of smaller diameter, e.g. 18mm. However, an 18 mm, drill-press has not yet been used.

This is the chiselling method. It is identical in principle to the one attributed by Mr. GUNNERT to MERIAM-GARMO-JONASSEN, but superior to it in chiselling technique. This method has been used on structures on several separate occasions with satisfactory results.

But, in the meantime, the chiselling proved, to be somewhat complicated when applied to an actual structure.

Finally, this semi-destructive method is more convenient to use in the laboratory than in the field. But in the laboratory it does not really offer any advantage of principle over that of cutting up method, when it is a question of systematic research. It is, above all, appropriate for isolated measurements, e.g. without total detachment of the disk, as in indicated by Mr. GUNNERT. In this case, great accuracy is not always required.

These tests and the experience acquired from them led me to adopt the principle of MATHAR instrument for outdoor use. Before 1938 this instrument was submitted in my laboratories to a control and calibration test which established its imperfections (Research P.7I - Questions, P. 224).

All calibration was found to be impossible. The instrument has two major defects. One is structural, in that the extensometer is affected by drilling vibrations ; the other is of principle, in that measurement is performed by a single extensometer in one direction only. However, these imperfections do not affect the principle of modification of the elastic field by the drilling of a hole, permitting theoretically the measurement of the initial field.

This method seemed more convenient for the measurement of actual structures, since the hole drilling may be done by an ordinary portable drill-press without undue difficulties.

This drilling method (Research, PP. I03-I09 - Questions, P. 226) has been first used during the war. A hole 10 mm in diameter was drilled and stradded by four diametrical gauge lines 20 mm long, whose mid-points coincided with the center of the hole. This arrangement of gauge lines astride the hole promotes an increase in the method's sensitiveness, which is inferior to that of the two preceding methods. The shape " deformeter " gives sufficient accuracy under these conditions.

After the war, Mr. SOETE returned to the same principle. He utilized the ohmic strain-gauges introduced in Europe recently. These compensate the reduced sensitiveness implicit in the method's principle by the greater sensitiveness of extensometers per drilling (three on each of the two faces) are needed, it is rather costly. The mechanical instrument, placed astride the hole, allows eight measurements per point, i.e. two measurements of control, without large expense.

At the present time, a 12 mm gauge line straddling a 6 mm hole is employed in connection with the shape " deformeter ". This method has been used successfully during the winter of 49-50 to effect a very large number of measurements on two large welded boats (an oil tanker and a cargo boat) at the works of JOHN COCKERILL Inc. (HOBOKEN, Belgium).

The main difficulties were caused by very bad weather (rain, snow and frost), the feverish activity of the yards, the difficulty of access to hull bottoms, the inconvenient positions and the long duration of the tests, particularly the long intervals between measurements.

The results obtained by the indicated method have been clearly superior to those of the strain-gauge method, whose functioning has been often impeded or made precarious by the conditions described above.

The drilling method, as defined above, thus posesses advantages of efficiency and convenience in cases where the measurement of actual structures is difficult but desirable. Its accuracy is variable and, in principle, rather moderate. Theoretically, if the tensions to be measured are high, the drilling of the hole causes permanent deformations which should affect the measurement. I do not consider it to be of great importance. Nevertheless, high tensions do seem to be affected by a systematic error, while small tensions are susceptible to accidental errors. The method discloses an order of magnitude.

It is understood that if the deformations undergone by the structure are below the elastic limit, the measurements taken before and after welding, without cutting up, chiselling or drilling, permit the determination of tensions directly from the deformations.

In conclusion, the drilling method appears to be suitable for actual structures, above all in connection with mechanical measuring devices which are rugged, fool-proof, convenient and as accurate and sensitive as these necessities permit. The accuracy is moderate.

The cutting up method and the chiselling method are, on the whole, identical in principle. The use of the one or the other depends on the specific case.

Here, too, the search for great accuracy should be limited by considerations of convenience and safety, as well as by the theoretical imperfection of the methods. However, it is desirable to obtain as great accuracy and sensitiveness as possible. This is always interesting in itself, from the metrological point of view, even if doubtful for certain applications. This is the reason inducing me to try, but lighter, more compact and having a shorter minimum gauge line, as well as a measuring instrument more sensitive than the dial micrometer to one thousandth of a millimeter. This last might be a microcator or any device serving the same purposes.