IR. P. VERMEYDEN

A LOADING PROCEDURE FOR TESTING TIMBER JOINTS

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As a first step on the way to a standard method for testing timber joints, a study was made of the loading procedure. After discussing the factors associated with this procedure, conclusions are drawn and some proposals put forward. By way of example a short description is given of the method as applied in the Stevin-laboratory.

1 Purpose

Although numerous laboratory tests on timber joints have been performed in various countries in the past twenty-five years, there is no uniformity yet in the testing procedure. Consequently, it is very difficult to compare data from different sources with each other.

One of the principal factors influencing test results is the procedure adhered to in the loading process. The present paper, after giving a brief survey of a number of testing methods as published in technical literature, comprises a study of the factors associated with the loading procedure, resulting in some proposals being put forward for the sake of standardization.

In the preparation of these proposals consideration has been given both to the desirability of adopting a method which would eventually yield results comparable to and in reasonable accordance with the test results already published, and to the necessity of avoiding differences originating from the time-effect of the loading. As is generally known, the duration of this loading as well as the speed of testing have an influence upon the resulting ultimate strength figure of timber itself, and, by inference, on the ultimate carrying capacity of timber joints as well.

In order to substantially circumvent this time-effect, one should have at one's disposal a standard testing method giving an ultimate load figure almost unaffected by that influence; *viz.* all kinds of timber joints in compression or in tension would be affected then by this time-effect to the same, lowest possible degree and should therefore give the best comparable results.

2 Review of some published loading procedures

The influence of the rate of loading on the ultimate load carried by bolted timber joints is recorded by F. KOLLMANN [6].[1]) He describes some tests performed by TEICHMANN and BORKMANN, who found a reduction of the ultimate

[1]) Numbers in parentheses refer to the list of references at the end of this paper.

load by 4 per cent. at a rate of loading of 20 kg/cm² per minute, as compared to that resulting from a rate of loading of 200 to 300 kg/cm² per minute. Some tests performed in the Stevin-laboratory show also such an influence.

K. Egner [4] gives directives for the testing of wood joints: the load has to be increased stepwise in such a way as to reach the working load in 3 or 4 steps. After each increment the load is kept constant during 2 minutes, after which the deformation is measured. The working load having been reached for the first time, Egner recommends decreasing the load to a predetermined low level, and to load again up to the working load. This cycle is to be repeated twelve times. Finally, the specimen should be loaded further, stepwise or continuously, until failure occurs.

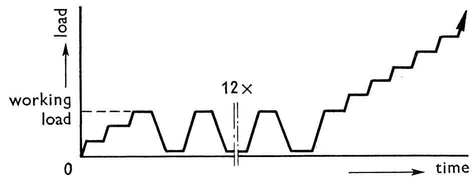

Fig. 1. Load as a function of time (Egner).

E. Staudacher [11] distinguishes the so-called „creep-limit". The latter is defined as the load causing observable creep (*e.g.* 0.01 cm) within 2 minutes' time, the creep reaching an asymptotic value after some time. Below this creep-limit the load is augmented and reduced stepwise; beyond, either the load is kept constant during 10 minutes at a level just above the creep-limit, in order to give an impression of the creep, whereafter the load is increased furthermore in the same stepwise way as described, or the test is continued with continuously increasing load, until failure.

J. A. Scholten [10] has tested numerous timber-connector joints. The load was applied under continuous increase in such a way that the rate of travel of the movable head of the testing machine was kept constant. The ultimate loads are the highest ones observed within or at an amount of slip in the joint of 0.60 inch. The tests were not continued beyond this latter stage.

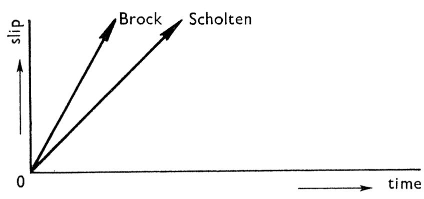

Fig. 2. Slip as a function of time.

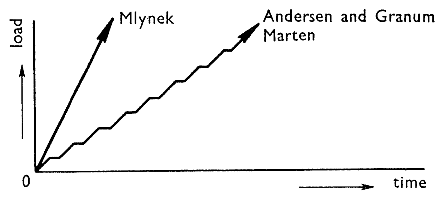

Fig. 3. Load as a function of time.

G. R. Brock [2], in testing toothed-plate timber connector joints, applied a constant rate of strain of 0.1 in./minute. Loading was continued until failure of the joint, or until a slip of 0.600 in. was reached. With tests on nailed joints [3] the rate of travel of the loading crosshead of the testing machine was kept constant.

A. ANDERSEN and H. GRANUM [1] tested joints made with various kinds of connectors. The loading went at a constant rate of increase until the rate of deformation was 0.80 mm/minute; from that stage onward the rate of descent of the movable head of the testing machine was kept constant. The authors mentioned found an influence of the rate of loading upon the value of slip in the joint, especially in case of not too small loads.

W. STOY and F. MLYNEK [12] describe some compression tests on nailed joints, performed by MLYNEK. During these tests the rate of loading was a uniform 600 kg/minute. The ultimate load on the joints was in the range of 1800 to 3600 kg; hence the duration of those tests was between 3 and 6 minutes.

A. MEYER [8] reports some loading procedures applied in the determination of the "strength on face of hole" of nailed joints. G. MARTEN for instance, increased the load stepwise (10 to 15 steps in total). After each increment the load was kept constant during 2 minutes, at the beginning and at the end of which period the necessary measurements were taken. T. MÖLLER adhered to a constant rate of deformation of 0.2 mm/minute. When comparing the ultimate loads thus obtained, with those reached under a constant rate of deformation of 1 mm/minute, the latter loads showed to be abt. 15 per cent. in excess.

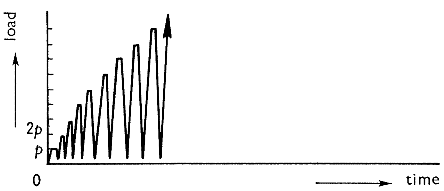

Fig. 4. Loading procedure adopted by Meyer.

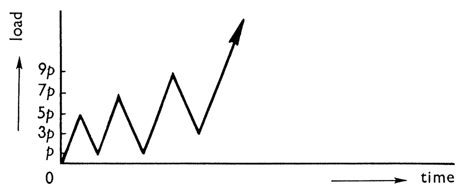

Fig. 5. Load as a function of time.

In his own tests on nailed joints, MEYER increased the load (in about 10 equal steps) until failure occurred. The rate of loading was such as to reach the first step in 3 seconds, and so on, hence the n^{th} step in 3n seconds. At every step the load was kept constant for 30 seconds, after which followed rapid removal of the load. Tests ended when the highest load was reached or when the slip in the joint amounted to 15 mm.

The influence of the duration of load on the test results was also investigated by MEYER. He did not find appreciable differences between continuous and stepwise loading, nor between duration of load of 30 seconds and of 2 minutes.

J. KUIPERS [7] has performed numerous tests on split-ring connectors. He applied a constant rate of loading, differing from type to type of joint, to obtain a constant duration of each complete test (20 to 25 minutes). The load was increased and decreased several times during a test, allowing data to be gathered concerning the elastic behaviour of the timber joint.

3 Factors associated with the loading procedure

a. Rate of loading vs. rate of deformation

The loading procedures mentioned in the previous paragraph may be divided into two groups:

those performed under a prescribed rate of *loading*, and
those performed under a prescribed rate of *deformation*.

B. Norén [9] extensively discusses these matters for *timber* as a material, and comes to the conclusion that a prescribed rate of deformation is to be preferred. The most serious disadvantage of testing timber at a constant rate of loading lies in the fact that determination of the ultimate load is very often subjective, for, after a certain amount of load is reached, it is in most cases nearly impossible to continue the test at the predetermined rate of load-increase. As laboratory tests have shown, the same reasoning holds for timber *joints*, where the above-mentioned load appears to be about 75 to 100 per cent. of the ultimate load. There are cases in which a constant rate of deformation establishes itself, nearly independently of the load on the joint.

On the other hand, Norén also indicates a difficulty: above a certain limit there is no longer a definite relation between the movement of the testing machine's head and the deformation within that part of the specimen in which failure sets in. This error can be eliminated by controlling the speed of testing by the last-mentioned deformation, *viz.* the slip-rate of the joint. As the major part of the deformation in a timber joint undoubtedly occurs in the joint proper, no great error is made when the difference between the rate of deformation and the speed of the machine's head is neglected.

The first Conference on Mechanical Wood Technology of the Food and Agricultural Organization (F.A.O.) of the United Nations, held at Geneva in 1949 [5] recommends "that all static tests on small clear specimens of wood be made at a constant rate of movement of the movable head of the testing machine". In connection with the arguments stated earlier, this recommendation should most likely be applied in testing timber *joints* as well, at least with loads surpassing 75 per cent. of the ultimate load which the joint is able to carry.

b. Duration of test

As for the speed of testing it would, of course, be very easy to prescribe a constant rate of movement of the machine's head for all kinds of timber joints to be tested. This, however, could entail a divergency in the duration of the test, and hence a difference in the influence of the duration of load, affecting the value of the ultimate load the test piece will bear. The *duration* of load being of more influence upon the strength of wood than are differences in the *rate* of loading, it seems recommendable to aim at an almost constant duration of the tests. This is in the same vein as the F.A.O.-conference recommendation for the testing of specimens of wood.

Now the question may arise: What is meant by "duration of test"? When a specimen fails quite suddenly whilst the load is being increased, the answer should be of course: the total duration of the test up to that moment. But when a specimen deforms under a certain load and this goes on for several minutes, two periods are to be distinguished in this case:

a. the time required in increasing the load, which is called the "duration of load increase";
b. the time during which the specimen deforms at that (nearly constant) load.

In order to avoid differences in the effect of time in the loading of different specimens, only the period defined under a) ought to be taken into consideration.

The practical application of this recommendation, however, is difficult when the load, approaching its maximum, is increasing very slowly. Therefore it may be proposed to limit the duration of load-increase to the time that is required to obtain a value of *e.g.* 90 per cent of the maximum load.

From the different loading procedures described in par. 2, the fact does stand out that the duration of test is a function of the speed of testing *and* of the way in which the load is a function of time (spent in increasing, decreasing, and keeping constant the load). Both features will be presently discussed.

c. Speed of testing

Since some investigators use a constant rate of loading and others a constant rate of deformation, comparison of testing speeds is difficult. On the one hand there are STAUDACHER and KUIPERS, who, in their respective tests, maintain nearly the same rate of load-increase (about 15 per cent. of the ultimate load, per minute), whilst ANDERSEN and GRANUM apply the load at a rate half as low, and MLYNEK at a rate twice as high. Only MEYER's rate of loading deviates considerably from those just mentioned.

On the other hand we have SCHOLTEN working with a rate of deformation of 0.8 mm/min as an average, BROCK with 1.5 mm/min and MÖLLER with 0.2 mm/min. Calculations show that the average rate of deformation under small loads (below 60 per cent. of the ultimate load) in the tests performed by KUIPERS was about 0.3 to 0.4 mm/minute.

These figures might indicate the range in which the rate should be kept. Too great a speed is not desirable because of the measurements to be taken during the test and of the need to keep the speed constant as accurately as possible.

d. Increasing, decreasing and constant load

A constant, uninterrupted rate of movement of the head of the testing machine, up to the moment of failure of the specimen, gives the ultimate load only, besides some data concerning the total deformation. Nothing becomes known about the elastic and plastic (creep) behaviour of the specimen. For the determination of the elasticity (stiffness) of the joint, intermediate removal of the load is a requisite, and, in order to gain some impression about the creep a constant load during some time is essential.

In paragraph 1 it has been pointed out that this testing method is meant for the determination of an ultimate load, possibly least affected by time-dependent phenomena which play their part in "duration of load"," creep", etc. In tests intended to establish the "ultimate load" though, any attempt to investigate such time-effects should be left out. This does not imply that an investigation of that kind would not be of importance: on the contrary, a more profound understanding of the behaviour of timber joints under prolonged loading is very important indeed, and further research as to this matter is to be recommended.

The elastic behaviour of a specimen is of interest especially within the range of loading to be expected in practice, *viz.* under loads remaining below the accepted working load. As a rule, the latter never exceeds 40 per cent. of the ultimate load. It is therefore desirable to remove the testing load at reaching 40 per cent. of the ultimate figure expected. The question is: does this load-decrease and subsequent increase affect the ultimate strength and/or the load/slip diagram? Investigations have shown for that matter that removal of the load, followed by load-increase has no influence on the test results if this process is performed below a certain upper limit. For timber this limit appears to coincide with the proportional limit, which in most cases is situated above 60 per cent. (and very seldom below 40 per cent.) of the ultimate strength. As for wood *joints*, a comparable "proportional limit" would be hard to determine. However, a large number of tests have shown that the load/slip diagram is almost unaffected by removal of the load, when the latter stays below about 50–60 per cent. of the ultimate load. This means to say that in the domain below 40 per cent. of the ultimate load, an alternation as put forward will not introduce any appreciable time-effect, and consequently will leave the ultimate load unimpaired.

e. Ending of test

As some types of joints do fail only after considerable deformations have been induced, which take a long time to develop, whilst the load remains almost constant, it seems recommendable to limit the duration of each test. A generally accepted criterion for this limit appears to be the moment when the amount of deformation has reached 15 mm (0.6 in).

f. Ultimate load

A definition of the concept "ultimate load" is necessary, because this value can be considered from various viewpoints, namely as:

1. to be represented by the maximum load attained;

2. to be represented by the maximum load reached below or at a given value of deformation;
3. to be represented by the load under which failure occurs, or the load at which deformation continues to increase with hardly any increase of the load;
4. to be represented by the load reached just prior to the first drop of its value.

The first-listed possibility should be rejected, since we definitely propose to end the test at a limit of deformation. In the third case determination of the ultimate load will be too subjective sometimes. As for the fourth characteristic: with some types of joints a drop in load may occur at a rather low amount of loading; hence this way of definition should not be adhered to either.

Therefore only the second characterization of "ultimate load", as having no undesirable side-effects, would give reliable information in practice, hence be most suitable for our purpose.

4 Conclusions and proposals

Keeping in mind all factors discussed in the preceding paragraph, the *conclusions* arrived at with regard to testing of timber joints may be listed as follows:

1. Since in those tests any attempt to investigate time-effects should be abandoned, the load should never be kept constant during any part of the duration of the test.
2. The duration of load-increase (*i.e.* the time required in increasing the load from zero to about 90 per cent. of the expected ultimate load) should be the same for all types of test-specimens.
3. For the determination of the elastic behaviour of the test-specimen one decrease of load and one subsequent increase, within the range below 40 per cent. of the ultimate load, are permitted;
4. The speed of testing can be determined in two ways: by the rate of loading, or by the rate of deformation (the latter assumed to be equal to the rate of displacement of the movable head of the testing machine).
   For the first part of the test, from its start up to a load not exceeding 75 per cent. of the ultimate load, either method may be applied. For the remaining part of the test a constant rate of movement of the travelling head of the testing machine stays indicated. The overall speed, which should be constant during the several parts of the test, follows from conclusion 2.
5. The test should be terminated when the specimen has been brought to complete failure (the deformation at this stage being less than 15 mm), or when deformation has reached the 15 mm limit, no failure having occurred yet.
6. The load to be recorded as "ultimate load" is the maximum value ob-

tained during the test, hence before reaching or at the limit-deformation indicated in 5.

In connection with these conclusions the following *proposals* may be stated:

1. Tests on timber joints should be performed along lines as pointed out in the preceding 6 Conclusions.
   One alternation of loading as mentioned in conclusion 3 is optional, but recommended as a means in determining the elastic behaviour of the test-piece.
2. When the just-mentioned alternation of loading is to be included the following procedure is recommended:
   Immediately after reaching 40 per cent. of the expected ultimate load, the acting load should be decreased to a value of about 10 per cent. of the ultimate load. Then, without delay, the load should be increased again to its previous level.
   Since it is desirable to take readings of the deformations, this alternation of load (40–10–40 per cent. of ult. load) should cover about 2 to 3 minutes' time.
3. As regards the time mentioned in conclusion 2, it is proposed that the specific duration of load-increase should not be under 5 nor over 10 minutes, all the same whether the alternation of load, referred to in conclusion 3 is being included or not. This duration of load-increase, from which follows the speed of testing, is chosen as such for two reasons. In the first place there is a close relationship to most of the speeds used by the other investigators, and secondly, it sufficiently allows reading of measuring instruments.

5 Description of a loading procedure according to the preceding proposals, as already adopted in the Stevin-laboratory

By way of example the loading procedure and the accessory measurements as adopted in the Stevin-laboratory will be described here.

a. Loading procedure (see fig. 6)
The presumed ultimate load, estimated from previous tests or otherwise, is divided into 10 equal parts p. At a constant rate of load-increase (1 step p every 30 seconds) and without interruption, the load is brought up to a level of $4\,p$ (*i.e.* 40 per cent. of the ult. load). Then removal of the load is effectuated at the same rate, until the level of p is arrived at, and followed by a renewed continual increase at the intended rate as before, until failure occurs or until the amount of slip in the joint reaches 15 mm (0.6 inch). The rate of oil flow in the machine is to be kept constant after the load has reached a value of $7p$. [1])

[1]) The hydraulic testing machines of the Stevin-laboratory not being capable for the present to secure a constant rate of displacement of the movable upper head as prescribed in concl. 4, this approximation seems acceptable.

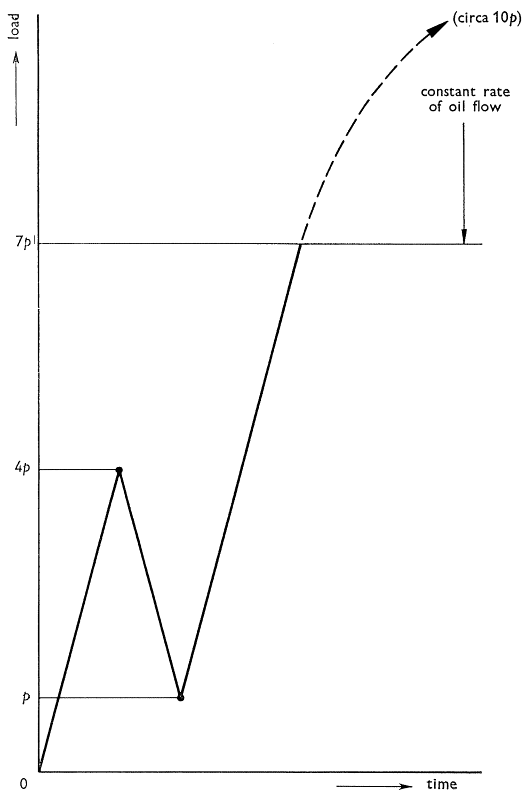

Fig. 6. Loading procedure at the Stevin-Laboratory.

b. Measurements [1])

Recordings to be made during all tests are: the load/slip diagram, the value of the ultimate load, and the duration of load-increase. In testing, measurements of the amount of slip in the joint are taken at every tenth part of the expected ult. load, hence at p, $2p$, . . ., $9p$, $(10p)$.

To obtain an impression of the behaviour of the joint, without having to take recourse to the entire load/slip diagram, some values are readily calculated from the series of measurements. They are:

$v_{0.4}$ = the total (instantaneous) slip at loading to 40 per cent. of the ult. load, apart from any earlier deformations possibly occurred at the start of the loading;

$e_{0.4}$ = the elastic slip at a load equal to 40 per cent. of the ult. load.

These two data describe the behaviour of a specimen in the range of practical application, *i.e.* below the working load. As is generally known there is a greater

[1]) Factors associated with the loading procedure are discussed only; necessary other measurements, *e.g.* of moisture content, are not dealt with in this paper.

slip in a timber joint when it is loaded for the first time than when loaded a second, third etc. time (elastic slip). Now $v_{0.4}$ gives an indication of the first-mentioned slip, and $e_{0.4}$ does so for the elastic slip, *viz.* stiffness. Because of some disturbances that may occur at the beginning of the test and may be a function of the assembly of the joint, these deformations are not comprised in $v_{0.4}$.

The two quantities are calculated as follows:

$$v_{0.4} = \frac{4}{3}\,[(4)-(1)];$$

$$e_{0.4} = \frac{4}{3}\left[\frac{(4)+(4'')}{2} - (1')\right].$$

The numbers in parentheses correspond with those inscribed along the diagram plotted in fig. 7.

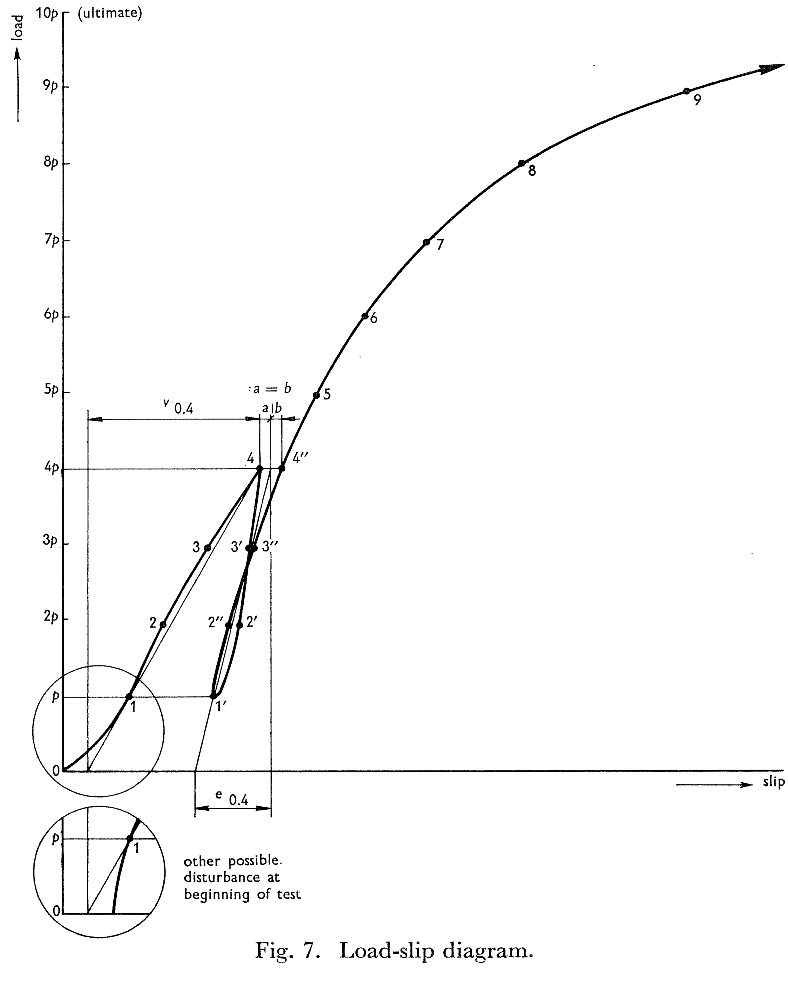

Fig. 7. Load-slip diagram.

In the same way as before, similar values can be defined that describe the behaviour of a joint under loads in excess of the working load. Such values can indicate excessive deformations at a certain load as compared with other specimens of the same type.

At the Stevin-laboratory, for example, $v_{0.6}$ and $v_{0.8}$ are determined:

$v_{0.6}$ = the total slip at loading up to 60 per cent. of the ult. load, apart from earlier deformations possibly occurring at the beginning of loading;

$v_{0.8}$ = ditto at 80 per cent. of the ult. load.

They are calculated according to the formulas:

$v_{0.6} = v_{0.4} + (6) - (4)$;

$v_{0.8} = v_{0.4} + (8) - (4)$.

These data are useful also for the sake of comparison with measurements obtained in sustained loading tests. This is one of the reasons why readings of the amount of slip at a given load are to be preferred to readings of the load at a given amount of slip.

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