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BRANZ

THE RESOURCE CENTRE FOR BUILDING EXCELLENCE

EVALUATION METHOD

No. 1 (1999)

Structural Joints – Strength and Stiffness Evaluation

The development of the method outlined here was funded by the Building Research Levy.

BRANZ Evaluation and Test Method

EM1: Structural joints - strength and stiffness evaluation

1. Scope (Scope of ISO 7162)

This test procedure may be used to determine strength and stiffness parameters of joints, or individual fasteners used to connect structural elements, either to each other, or to sheet material. The parameters may be used for design of joints used in gravity, cyclonic wind, or seismic loading applications.

The procedure is written to be general in nature and material independent, so that it can be applied to a variety of joint or fastener configurations and loading directions.

2. Referenced Documents (References)

NZS 3603:1993	Timber Structures Standard
NZS 4203:1992	The Loading Standard
AS 1107.2-1989	SAA Loading Code. Part 2 Wind loads
AS 1649-1998	Methods of test for mechanical fasteners and connectors - Basic working loads and characteristic strengths
AS/NZS 1080.1:1997	Timber - methods of test. Part 1 Moisture content

3. Definitions (Definitions)

Capacity design: The design method in which elements of the primary lateral earthquake force-resisting system are chosen and suitably designed and detailed for energy dissipation under severe deformations. All other structural elements are then provided with sufficient strength so the chosen means of energy dissipation can be maintained.

Characteristic strength: The strength of a joint or fastener as determined by the tests prescribed by this document. It is based on the 5^{th} percentile value with 75% confidence.

Cyclonic test: A test designed to reproduce the load environment experienced by a component acted upon by repetitive cyclonic wind loads. The regime is described in detail in Section 9.

Dependable strength: The characteristic strength, multiplied by the strength reduction factor, and the relevant modification factors for the service conditions, as prescribed by the appropriate material standard (equivalent to the **design strength** of NZS 3603).

Ductility: The ability of a structural element to sustain its load carrying capacity when it is subjected to cyclic inelastic displacements during an earthquake.

Earthquake test: A test designed to reproduce the load environment experienced by a component required to resist loads caused by seismic actions. The regime is described in detail in Section 9.

Fastener: The component used to introduce forces into or out of the timber member or joint substrate.

Gravity test: A test designed to reproduce the load environment experienced by a component acted upon only by gravity loads. The regime is described in detail in Section 9.

Joint: The whole connector or assembly which transfers forces from one structural member to another.

Monotonic test: A test where the applied load is gradually increased until specimen failure, or a predetermined limit, is reached.

Overstrength factor: The factor to be applied to the characteristic residual strength to estimate the maximum probable strength of a joint or fastener, where required for capacity design.

Residual load: The load resisted by a specimen after several cycles of displacement applied during an earthquake test as prescribed in Section 9.

4. Notation (Not included)

k_p the preliminary stiffness (kN/mm)
k_s the serviceability stiffness (kN/mm)
k_k the characteristic stiffness (kN/mm)
P the applied load (kN)
P_c the peak load obtained during the monotonic portion of a cyclonic test (kN)
P_e the residual load obtained during the earthquake test (kN)
P_{est} the estimated peak load, obtained from a preliminary test, by calculation, or known from experience (kN)
P_u the peak load obtained during a gravity test (kN)
R_{ek} the characteristic strength obtained from an earthquake test (kN)
R_k the characteristic strength obtained from a gravity test (kN)
R_o the overstrength factor
δ_y the displacement at yield, or at the onset of inelastic behaviour, determined from the gravity test (see Section 10).

5. Principle (Principle)

Construct a number of test specimens to represent the actual in-situ joint or fastener configuration under investigation, and condition them to simulate the expected in-service environment up to the time of loading.

For each direction under investigation, subject each specimen to one of the following loading regimes, to simulate either gravity, cyclonic, or seismic loading:
Gravity sequence only, for joints designed to resist dead, live, snow or non-cyclonic wind loads.
Gravity and cyclonic sequences, for joints designed to resist cyclonic loads (e.g. as prescribed in AS 1107.2).
Gravity and earthquake sequences, for joints designed to resist loads caused by seismic actions (e.g. as prescribed in NZS 4203).

6. Equipment (Equipment)

The following equipment is required to conduct this test:

1. An actuator of sufficient capacity to fail the specimen under the intended action, at the prescribed loading rate. It shall be controlled (manually or automatically) to follow the nominated test sequences within an error of $\pm 1\%$ of the peak load.

2. A test rig to enable the actuator load to be applied to the specimen, while providing restraint against unwanted displacements.

3. A load cell with an accuracy of $\pm 1\%$ of peak load to measure the applied load. Load shall be measured and recorded at least 20 times per load cycle.

4. A means to measure the displacement between the individual members (slip planes) of the joint. Displacement shall be measured with an accuracy of ± 0.1mm.

   Commentary: Where secondary displacements of the joint components are eliminated by the test set-up, it may be possible to use only one displacement gauge. Where this is not possible, slip shall be recorded as the average of the readings of two gauges.

5. Equipment to record the measured data in a form suitable for analysis.

7. Sampling (Not included)

Ten is the number of replicate test specimens which normally constitutes a test series for any of the test procedures described in Section 9.

Materials shall be representative, with respect to grade, strength, moisture content and density, of those intended to be used in the joint in practice. Where generic materials, such as nails or timber, are to be supplied by the testing agency, they shall be sampled at random from packages or stacks of materials.

Fasteners, accessories and sheet materials shall be in accordance with the manufacturer's standard specifications.

8. Test Specimens (Condition of test pieces)

The test specimens shall be constructed to simulate as closely as practicable their configuration in practice. The actual construction details shall be described in the test report. *Examples of specimen construction details for typical joint configurations are given in the papers referred to in Appendix A.*

Specimens shall be constructed (and subsequently conditioned if required) with all their components in a state which simulates the least advantageous condition (with respect to weathering or moisture content) reasonably expected at the time of construction or service. They shall then be conditioned before testing to a state which reasonably simulates their condition at the time of loading.

Commentary: Timber members will generally require testing at a moisture content between 10% and 16%. Further information on specimen conditioning is contained in Appendix A.

9. Test Procedure (Procedure)

1. General

The following test procedures require an estimate of the peak load of the specimen (P_{est}). This may be determined from a preliminary monotonic test, by calculation, or from experience.

Loading rates shall be between 0.2 P_{est}/min, and 0.4 P_{est}/min. for the portion of the gravity sequence up to 0.7 P_{est}, and between 0.1mm/sec and 1.5mm/sec for the remainder of the gravity sequence, and the earthquake test.

Where differential movements would normally be expected in service between the components of the joint (e.g. from the effects of moisture or thermal movement, shrinkage or creep) then an assessment of this movement shall be made, and appropriate displacements applied to the test specimens before the following load sequences are applied.

The moisture content of each timber component shall be determined immediately after testing by an electric resistance moisture meter, or by one of the methods specified by AS/NZS 1080.

2. Gravity

Load shall be applied to the specimen in order to achieve the loading sequence shown in Figure 1. The test equipment may be operated under either load or displacement control, as long as the loading sequence defined above is achieved. For safety, displacement control is preferred where indicated in Figure 1.

Commentary: If, during the execution of the test, the mean value of the peak loads, P_u, of the specimens already tested deviates by more than 20% of P_{est}, then P_{est} should be adjusted correspondingly for subsequent tests. The values of peak load already determined may be accepted without adjustments as part of the final results but the stiffness calculations for the specimens already tested should be revised using the new value of P_{est}.

3. Cyclonic

This procedure requires knowledge of the characteristic strength of the joint (R_k) which, if not known already, may be obtained using results from the gravity load test, and calculated using equation (2). Load shall be applied to the specimen in order to achieve the loading sequence shown in Figure 2. The test equipment may be operated under either load or displacement control, as long as the loading sequence defined above is achieved. For safety, displacement control is preferred where indicated in Figure 2.

4. Earthquake

This procedure requires an estimate of the displacement δ_y. This may be obtained using the mean value of the results from the gravity load test. δ_y for each specimen is defined as the displacement measured at 0.5 x P_u.

Load shall be applied to the specimen to achieve the loading sequence shown in Figure 3.
The test may be terminated when the peak load measured at the third of a series of cycles is less than 90% of that measured at the previous third cycle.

10. Data Analysis and Interpretation (Presentation & interpretation of results)

1. Stiffness

The preliminary stiffness k_p, and serviceability stiffness k_s, of the individual specimens are defined with reference to Figure 4, and are given by:

$$k_p = \frac{0.3P_{est}}{\delta_c - \delta_a}$$

$$k_p = \frac{0.3P_{est}}{\delta_d - \delta_b}.$$

The characteristic stiffness values, k_k, are given by:

$$k_k = \left(1 - \frac{0.7v}{\sqrt{n}}\right)k_{mean} \quad \text{.................................equation (1)}$$

where: k_{mean} and v are the mean and coefficient of variation of the individual values respectively, and n is the number of specimens in the sample.

2. Strength

2.1 Peak load (gravity test)

The peak load of each specimen, P_u, is the maximum load resisted during the gravity test.

The characteristic strength for a sample of 10 or more specimens, R_k, is given by:

$$R_k = \left(1 - \frac{2.7v}{\sqrt{n}}\right)P_{0.05} \quad \text{.................................equation (2)}$$

For a sample of less than 10 specimens:

$$R_k = P_{(min)}\left(\frac{n}{27}\right)^v \quad \text{.................................equation (2a)}$$

where: v is the coefficient of variation of the individual values

n is the number of specimens in the sample

$P_{0.05}$ = 5th percentile of the measured data (P_u values)

= mean - 1.65 x std deviation.

$P_{(min)}$ = minimum value of P_u

2.2 Peak load (cyclonic test)

The peak load of each specimen, P_c, is the maximum load resisted during the cyclonic test.

2.3 Residual load (earthquake test)

The residual earthquake load of each specimen, P_e, is determined from the maximum of the peak loads resisted during the third of each of the displacement cycles. It is taken as the mean of the +ve and -ve (absolute) values.

The characteristic residual strength for a sample of 10 or more specimens, R_{ek}, is given by:

$$R_{ek} = \left(1 - \frac{2.7v}{\sqrt{n}}\right)P_{0.05} \quad \text{.................................equation (2)}$$

For a sample of less than 10 specimens:

$$R_{ek} = P_{(min)}\left(\frac{n}{27}\right)^{v} \qquad \text{.................................equation (2a)}$$

where: v is the coefficient of variation of the individual values,

n is the number of specimens in the sample

$P_{0.05}$ = 5th percentile of the measured data (P_e values)

= mean - 1.65 x std deviation.

$P_{(min)}$ = minimum value of P_e

2.4 Overstrength (earthquake test)

Where required for capacity design procedures in seismic applications the overstrength factor, R_o, may be determined from:

$$R_o = \frac{\left(1+\frac{2.7v}{\sqrt{n}}\right)P_{0.95}}{\left(1-\frac{2.7v}{\sqrt{n}}\right)P_{0.05}} \qquad \text{.................................equation (3)}$$

2.5 Ductility (earthquake test)

The ductility factor is defined as:

$$\mu = \frac{\delta_{ult}}{\delta_y} \qquad \text{.................................equation (4)}$$

where: $\delta_{ult.}$ is the displacement where the resistance begins to degrade after several cycles of reversing load, determined from the earthquake test. It is defined, with reference to Figure 5, as the displacement at the 3rd cycle peak immediately prior to the curve through the 3rd cycle peaks becoming negative.

and δ_y is the displacement at yield, or where inelastic behaviour begins, determined from the gravity test. It is defined as the value of displacement at half the peak load (i.e. at 0.5 P_u).

11. Reporting (Not included)

Depending on the information required from the tests, some or all of the following information shall be included in the report:

1. Reference to this document.
2. Identification of the joint type and configuration.
3. Description of the mechanical fasteners used (including surface finish).
4. Description and specification of the joint materials used. (the grade, density and moisture content).
5. A drawing showing the specimen configuration in sufficient detail to enable reproduction of nominally identical specimens.
6. Sample size.
7. Location or placement of measuring devices, the load configuration and the loading regime used.
8. Representative load-deformation diagrams and tabulated data.
9. All individual results.

10. The number of cycles to failure, or peak load reached (cyclonic test).
11. Characteristic preliminary and serviceability stiffness, characteristic strength (gravity test), characteristic residual strength (earthquake test), overstrength factor, ductility factor.
12. Any departures from this standard test, relevant information regarding data adjustments (if any) and descriptions of the modes of failure.

Appendix A.

1. Engineering rationale

The rationale and background relevant to this test method are contained in the following two papers:

Timber fastener capacities - a limit state approach by B. L. Deam, A.B. King and Button, presented at IWEC, New Orleans, 1996, and

Limit state fasteners, the development of a test method by R.H Shelton, presented at PTEC, Rotorua, 1999.

2. Conditioning

It has been shown that changes in the moisture content of timber based products in the period between construction and loading can have a significant influence on structural design parameters.

The testing agency should ensure that the condition of the test specimens during their construction, and up to the time of testing, accurately represents the environment appropriate for the intended end use application. NZS 3603 provides some guidance on suitable conditions.

For specimens that are to be **tested dry**, the timber components should be stored in a way that will ensure uniformity of moisture content within the range 10% to 16%.

For specimens that are to be **constructed and tested green**, the timber components should be maintained at a moisture content of at least 30% before and after joint assembly, until they are tested.

Specimens that are to be **constructed green and tested dry** should be constructed from timber that has a moisture content of at least 30%. They should then be stored to attain a moisture content within the range 10% to 16% by the time of testing. It may be necessary to coat the end grain surfaces of such specimens with a sealer to reduce the incidence of end splitting.

Specimens representing types of construction expected to be **exposed to the weather** during construction or in service should be subjected to conditioning that closely simulates such exposure. For example, particleboard flooring specimens should be exposed to representative weather conditions after construction and before testing. The duration of such exposure should be the maximum period nominated by the manufacturer in between construction and closing in by the building envelope (normally two to three months).

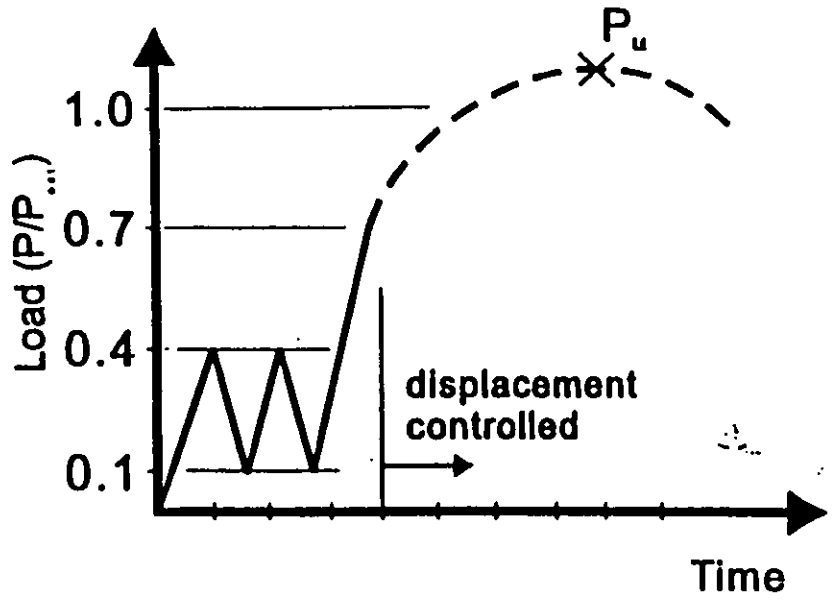
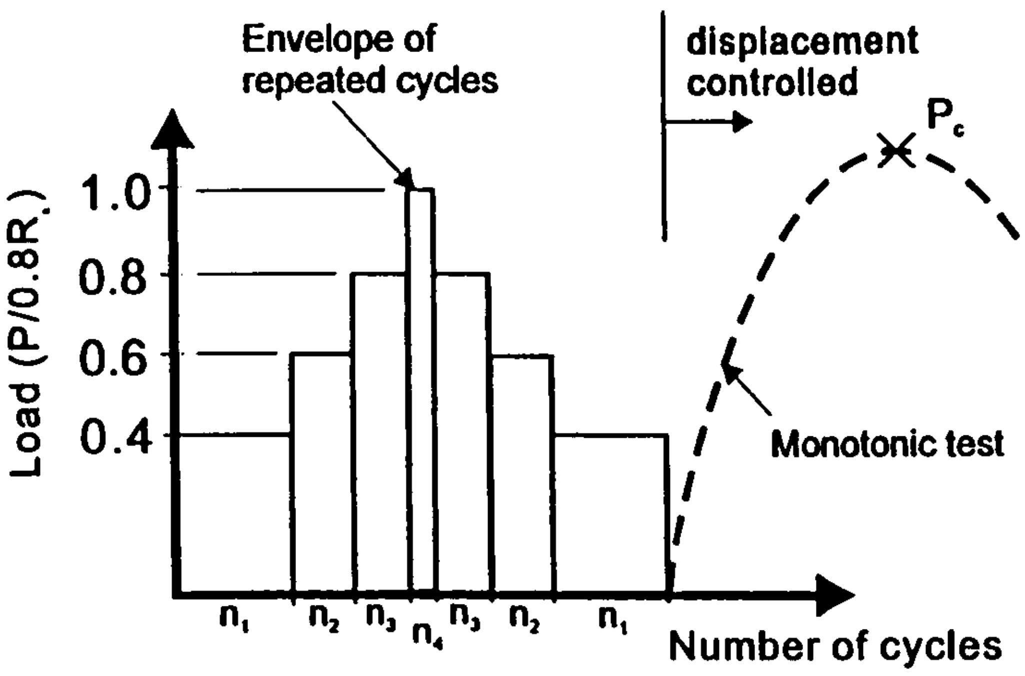


Figure 1. Gravity test sequence



	Cladding & fixings	Roof framing	Wall framing
n_1	5000	2500	500
n_2	625	300	60
n_3	70	35	7
n_4	10	5	2

Figure 2. Cyclonic test sequence

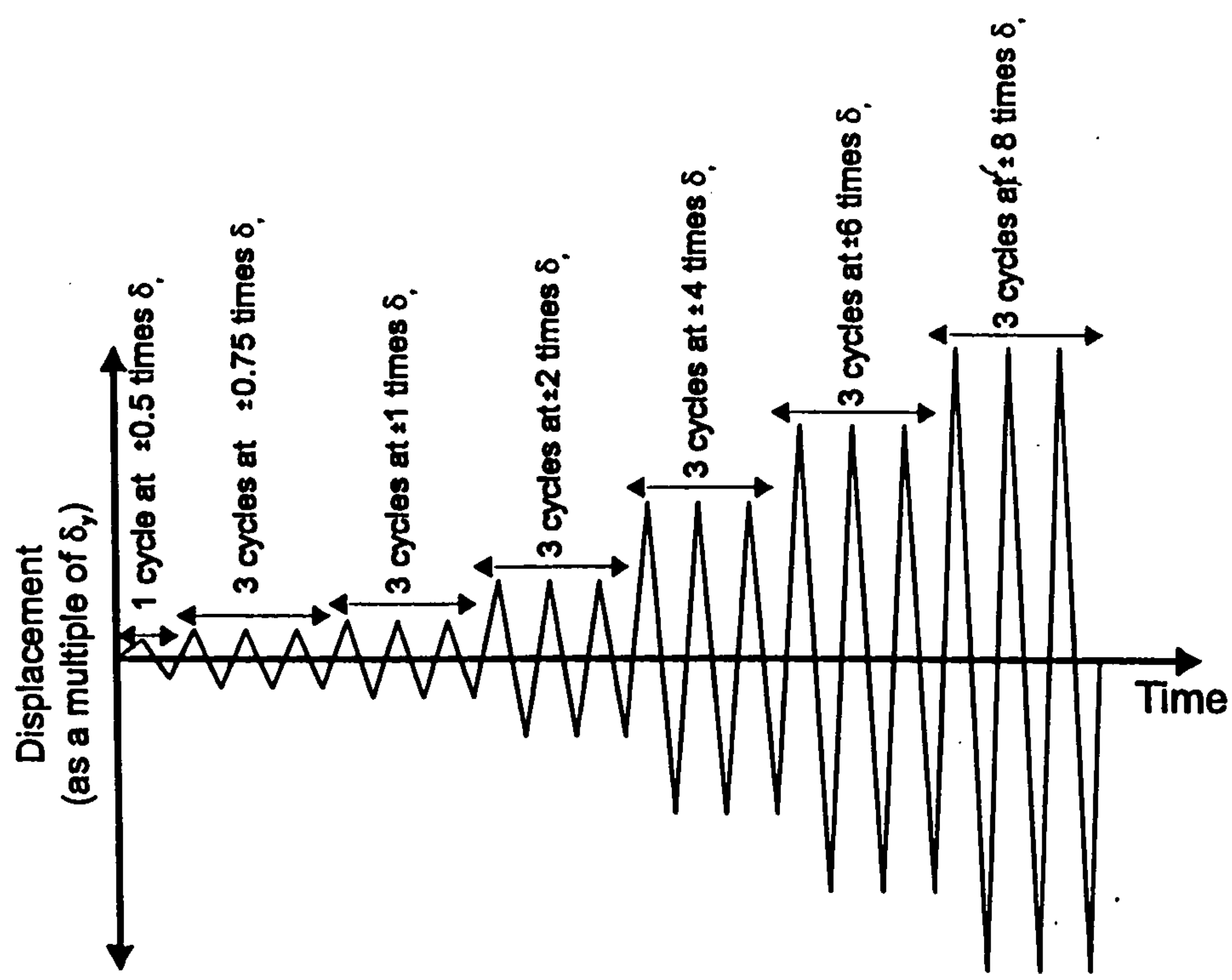


Figure 3. Earthquake test sequence

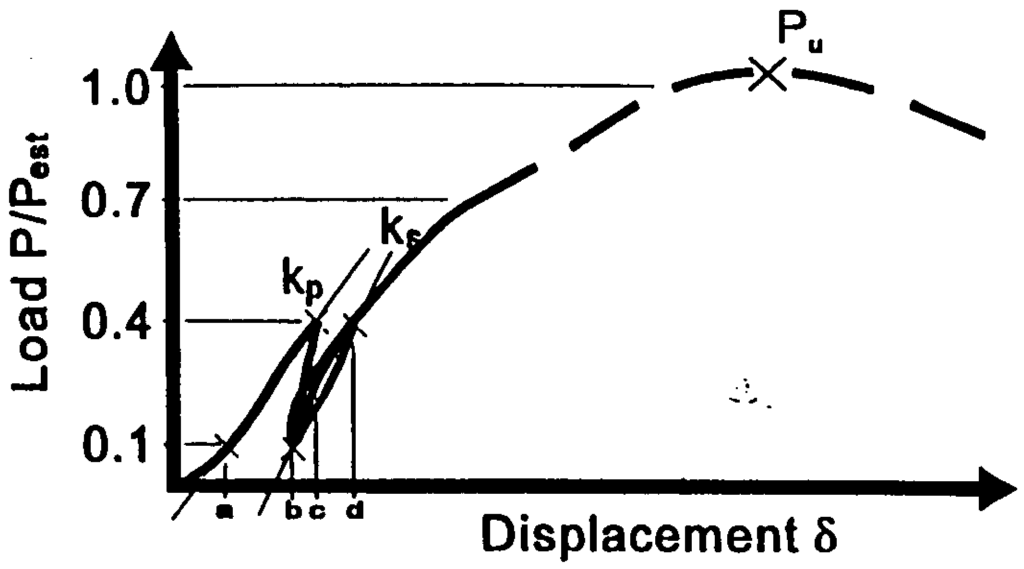


Figure 4. Stiffness parameters

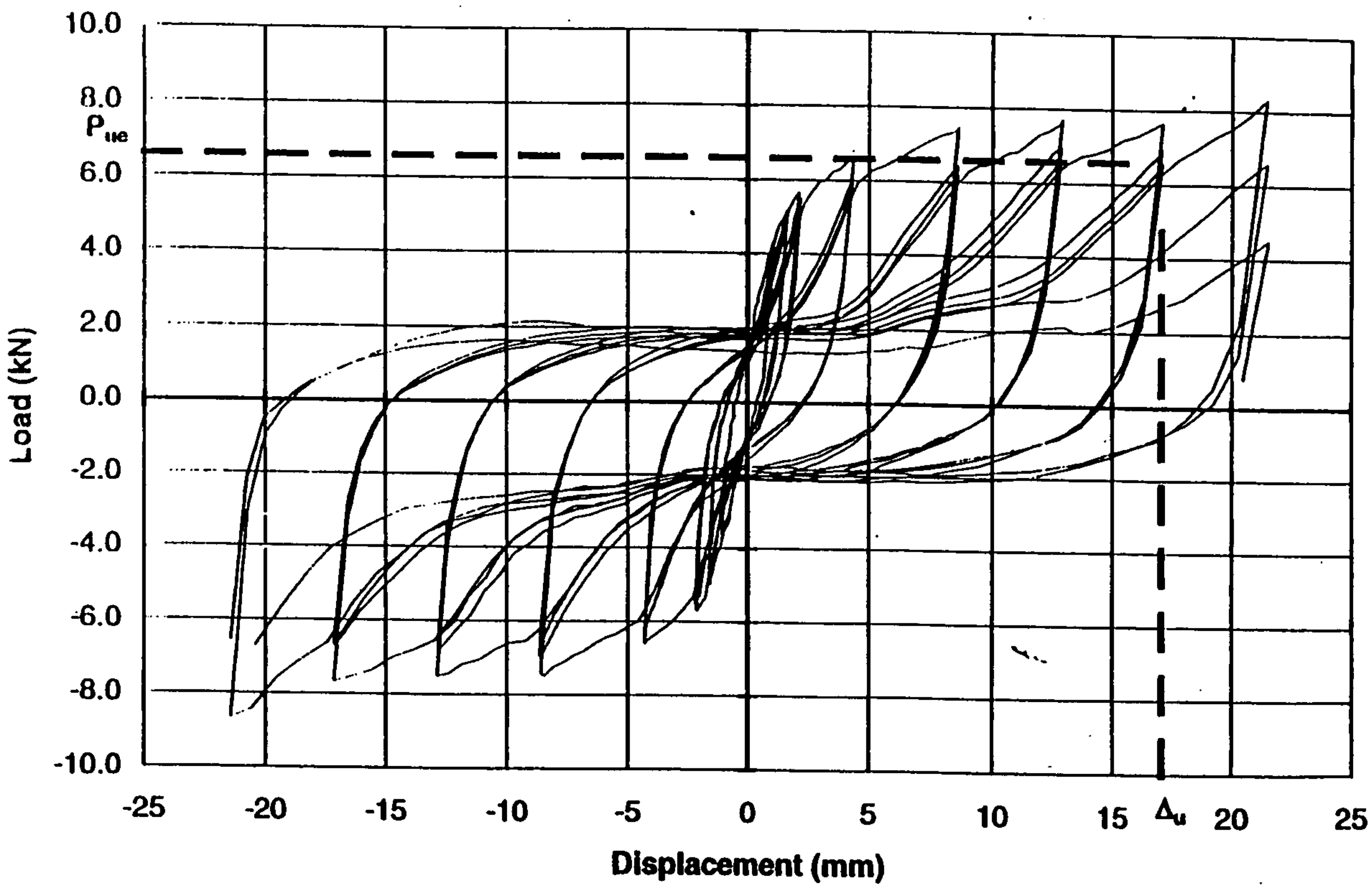


Figure 5. Ductility parameters

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MISSION

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