16 LOADING TESTS

16.1 GENERAL

16.1.1 Scope

Load tests may be used to establish the capacity of an existing structure or component or to verify design or construction that is not entirely in accordance with the design requirements of the Code.

Design may not be in accordance with the rest of the Code if sufficient and accurate calculations/models are not available or where the design loading capacity is to be established directly from knowledge of the failure capacity. However, testing must not be used to reduce levels of safety below those assumed in the remainder of the Code.

The loading tests described in this section are to verify or establish the design strength of a structure or component. They are proof, strength and failure tests. Tests may also be undertaken to establish design data to be used in a calculation model. These latter tests are not covered in detail in this section, and test plans must be established for each particular case taking into account the advice in this section.

Strength tests may be carried out on one or more prototypes where it is intended to construct a number of similar structures.

The tests described in this section are not applicable to the testing of scale models or of items subject to fluctuating loads where fatigue may govern the design.

For composite slabs with profiled steel sheets, both dynamic and static tests are required to demonstrate structural adequacy against shear-bond failure between the concrete and the profiled steel sheets. Refer to clause 16.4 for details of the test set-up, the testing procedures and the interpretation of the test results.

16.1.2 Requirement for testing

Where the structures and its parts have been designed in accordance with sections 1 to 13 of the Code, there is no requirement for testing.

16.1.3 Recommendations for conduct of tests

The following recommendations should be taken into account when deciding on a test and in the test preparation, execution and reporting.

Testing should only be carried out when the objectives have been clearly identified and there is sufficient confidence that they can be achieved. This should be based on calculation models and/or pilot tests. The objectives should include, where appropriate, the ability to incorporate the results in the design.

A test plan should be developed and should be agreed by all concerned before commencement of the test. The test plan should include the following as appropriate:

(a) Aim of the test including the number of specimens.

(b) Description of the test specimen/structural model together with the loading to be applied with particular attention to parameters and tolerances in dimensions and materials during fabrication and erection that might affect the performance.

(c) Possible modes of failure.

(d) Details of material and dimensional tests to be carried out on the specimens.

(e) Testing arrangements including measures taken to ensure adequate strength and stiffness for any supporting rig as well as sufficient clearance to allow for deflections. This must take into account all possible failure mechanisms.

(f) Details of loading and restraints and how the load will be controlled, i.e. either stress or strain control.

(g) Details of what measurements are to be taken and frequency of measurements.

(h) Accuracy of measurements.

The test plan should take into account the knowledge and experience of those carrying out the tests as well as the facilities and equipment being used.

When testing an existing structure a careful assessment of structural conditions before execution is a fundamental requirement. A support framework in proximity to the structure should be considered to avoid less than expected performance leading to failure.

16.2 PROOF, STRENGTH AND FAILURE TESTS

16.2.1 Proof and strength tests

16.2.1.1 General

Proof and strength tests are where the structure or component is tested to a particular level of load. A proof test may confirm that the structure performs adequately; a strength test may confirm that it can sustain a particular design load and can be used to accept similar items (see clause 16.3.6). A structure to be strength tested should first undergo a proof test and it is recommended that a failure test should follow the strength test, if appropriate.

Although a proof test is a non-destructive test, there may be permanent local distortions. The effect of these on future use of the structure should be considered before testing. Any departure from linear behaviour during the proof test should be noted and reasons for such behaviour should be explored. A strength test is likely to create significant residual deflection.

The loading steps for both tests are similar. To detect possible creep, the test load should be maintained at as constant value as possible to allow repeated measurements. The loads and deflections should be measured at regular intervals. The intervals should be at least 5 minutes. The loading should be maintained at the proof test load until there is no significant increase in deflection during at least three intervals after the attainment of the test load.

16.2.1.2 Test loads

The test load for a proof test should be taken as equal to the sum of:

1.0 x (actual dead load present during the test);

and one of the following as appropriate:

a) 1.25 x (imposed load) plus 1.15 x (remainder of dead load);
b) 1.15 x (remainder of dead load) plus 1.2 x (wind load);
c) 1.2 x (wind uplift) minus 1.0 x (remainder of dead load);
d) 1.15 x (remainder of dead load) plus 1.0 x (imposed load and wind load).

The test load for a strength test is the factored design load (from section 4) multiplied by a relative strength coefficient (see Annex B).

16.2.1.3 Test criteria

The criteria for a successful proof test are:

(a) Substantially linear behaviour under the proof test load;
(b) No creep under the proof test load for a period of at least 15 minutes; and
(c) On removal of the test load a residual deflection not exceeding 20% of the maximum deflection recorded during the test.

If the proof test is not successful it may be repeated once only. For this repeated test the deflection criteria is reduced to 10% of the maximum recorded during the test.

For a successful strength test the residual deflection on removal of the test load shall not exceed 80% of the maximum deflection recorded during the test and there is no buckling or rupture of any part of the structure.

16.2.2 Failure test

16.2.2.1 General

In a failure test the mode of failure and the ultimate load carrying capacity of a structure or component are to be determined. Gross permanent deformation is likely to occur during the test.

Before carrying out a failure test, a proof test and a strength test should be carried out. The loads for these tests will need to be based on estimates of the design capacity. This could then be adjusted following the strength test.

The loading in a failure test should initially be that of a strength test. After the strength test load has been reached subsequent increments should be based on an examination of a plot of the principal deflections.

The failure load is the maximum test load that the specimen can sustain.

The design capacity of an item similar to that being tested may be determined from the results of a failure test in accordance with the method given in Annex B of the Code.

16.2.2.2 Failure criteria

Failure of a test specimen should be considered to have occurred

(a) if there is collapse or fracture;

(b) if a crack begins to propagate spread in a vital part of the test specimen; or

(c) if the displacement becomes grossly excessive.

16.3 TEST CONDITIONS, METHODS AND PROCEDURES

16.3.1 Test conditions

The test rig should have sufficient strength and stiffness so that the tests can simulate the behaviour of the structure or component in service. Adequate clearance should be provided for the expected deflections. Any restraint to deformation of the specimen provided by the rig should not be more than that which would be available in service.

The specimen, the loads and the restraints should be similar in all aspects to the structure or component that is to be represented. Loading devices should reproduce the magnitude and distribution of loads and avoid unintended eccentricities. Supports and restraints should represent the actual conditions in service.

Safety must be considered in the layout and design of the test. The test rig should be designed so that it remains stable even if there is failure of the test specimen.

16.3.2 Loading and unloading

Before the commencement of the test an initial load may be applied and removed to secure the test specimen onto the test rig. This should not exceed the unfactored value of the relevant loads.

The test loads must take into account the difference between the self-weight of the specimen and the actual dead load in service. When several loads are applied to the specimen, the load increments should be applied proportionally to each loading point.

There shall be at least five load increments in the test. The actual number should be such that there is a full record of the behaviour of the test specimen. They should be based on the expected load-deformation behaviour. The principal deflections should be monitored throughout the test and if they indicate significant non-linearity the load increments should be reduced. Unloading should be completed in regular decrements.

The rate of loading should be such that it can be considered to be quasi-static and after each load increment enough time must be allowed for the structure to reach stationary equilibrium.

Deflections and strains should be measured at each increment or decrement of the loading and after unloading is completed. Readings should not be taken until the structure has completely stabilized. Where it is possible and safe, the structure should be examined after each load increment for signs of rupture, yielding or overall buckling.

16.3.3 Measurements

The anticipated magnitudes of the deflections should be estimated in advance, with generous allowances for movement beyond the elastic range. Sufficient measurement points should be used such that the maximum deflection of the test specimen can be determined.

16.3.4 Material properties

In order to use and compare the test results the properties of the steel used in the specimen should be established by means of coupon tests.

The coupons should be cut from the same sections or plates as the test specimens or recovered from unyielded areas of the test specimens after the completion of testing.

The yield strength and tensile strength of the steel should be determined by tensile testing in accordance with recognised standards.

A set of coupon tests should be taken from each component. The mean of each set may be taken as the material properties of the component.

Where material properties are required to determine the test load for a strength test or for other reasons, a single coupon test from each lot of material for the components of an individual test specimen may be used to obtain a weighted mean yield strength for the whole assembly.

16.3.5 Relative strength coefficient

Test results should be adjusted using a relative strength coefficient unless the design is based on the properties obtained from the test. This takes into account the effect of variations of the geometry or material properties of the test specimens, as compared with their nominal values. The coefficient should be used to predetermine the test load for strength tests and/or to determine the design capacity from a failure test. Annex B of the Code describes how the relative strength coefficient may be calculated for strength and failure tests.

16.3.6 Quality control of load testing

Components or parts of a structure can only be accepted on the basis of strength or failure tests if there is quality control during production to confirm consistency.

Unless justified by other means at least two samples should be selected at random from each production batch. Each batch should be taken as 20 tonne weight or less of the same section group with identical nominal serial size. Examination of the samples should establish that they are similar in all relevant respects to the prototype tested. Particular attention should be given to the dimensions of components and connections, to the tolerances and workmanship and to the quality of steel used (checked by reference to mill certificates).

If, after careful examination, the variations or the effect of variations compared to the prototype cannot be determined, a proof test should be carried out with measurements of deflections at the same positions as in the initial proof test on the prototype. The maximum measured deflection should not exceed 120 % of the deflection recorded during the proof test on the prototype and the residual deflection should not be more than 105 % of that recorded for the prototype.

16.3.7 Contents of test report

The test report should record the circumstances of the test and include all measurements and observations taken. The list below identifies possible items.

(a) Circumstances of the test i.e. test plan, date, location, list of witnesses and attendees;

(b) Qualifications and experience of test consultant and accreditation status such as a HOKLAS accredited laboratory;

(c) Dimensions and arrangement of the test rig including the positions of loading points and measuring devices;

(d) Actual dimensional measurements of the test specimen;

(e) Details of the loading method and testing procedure;

(f) All test results necessary for the test evaluation;

(g) A record including data and photographs of all other observations from the test.

As far as is possible tested samples should be retained. If not, then photographs of the samples after testing should be kept.

16.4 TESTING OF COMPOSITE SLABS

For composite slabs with profiled steel sheets, it is essential to perform full-scale dynamic and static tests to demonstrate structural adequacy against shear-bond failure between the concrete and the profiled steel sheets.

16.4.1 General

The tests described in this section are of two types.

(1) Specific tests
These are full-scale tests of a composite slab with a particular member configuration, using actual loading or a close approximation to it. The purpose is to determine the load carrying capacity of a slab directly by testing. The results obtained should be applied only to the particular case of span, profiled steel sheets and concrete grade and thickness tested.

(2) Parametric tests
These are a series of full-scale tests of a proposed type of composite slab, over a range of parameters covering loading, profiled steel sheet thickness, concrete thickness and spans. The purpose of these tests is to obtain data to enable the values of the empirical parameters k_r and m_r to be established, which are then used to determine the shear-bond capacity V_s (see clause 10.4.5.3(2)a).

All testing should be carried out by established testing organizations with suitable qualifications and relevant experience such as a HOKLAS accredited laboratory or equivalent.

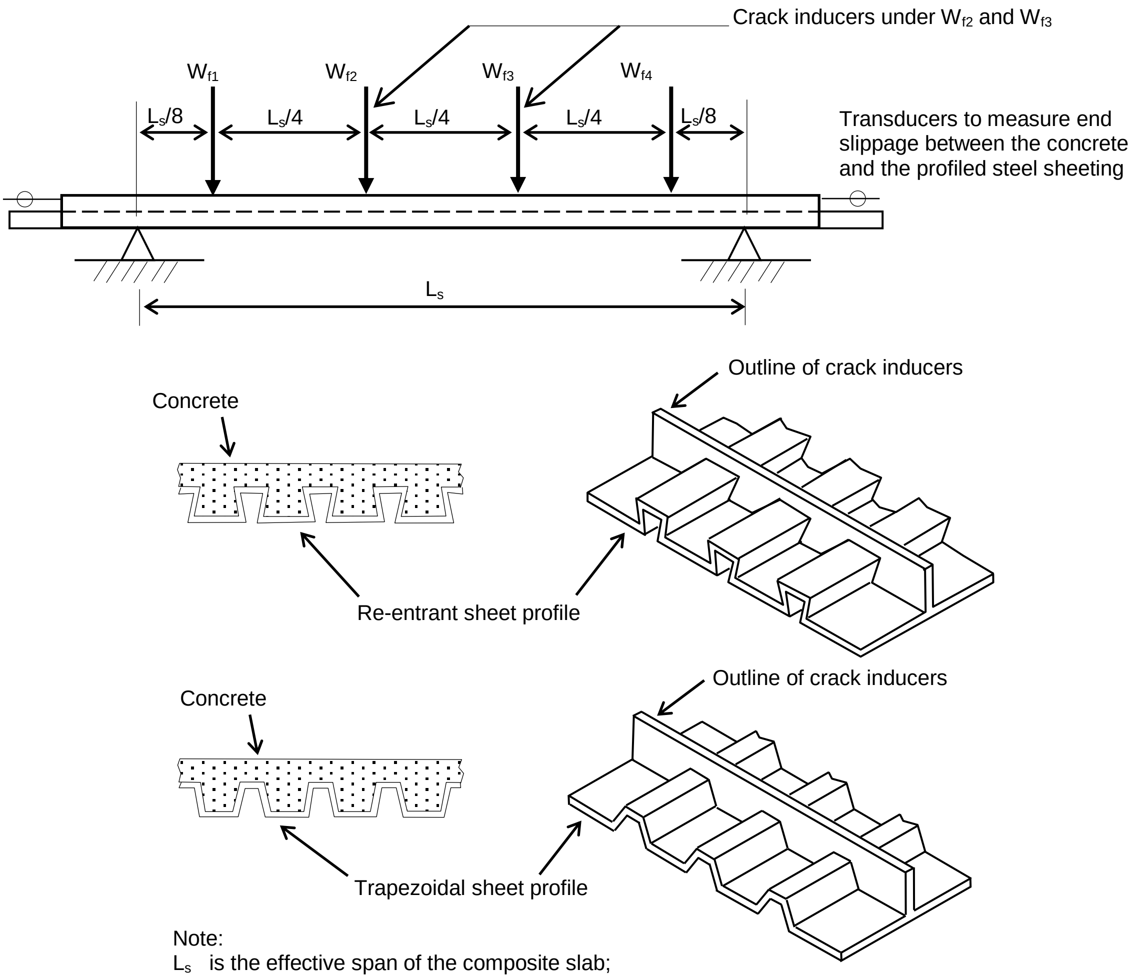
16.4.2 Specific tests

(1) Test arrangement
A minimum of three full-scale tests should be carried out on representative samples of the proposed slab construction using actual loadings or, in the case of uniformly distributed loads, a close simulation of the loading as shown in Figure 16.1. In the case of continuous spans, the tests should either be on multiple spans or be on a single span with simulated support moments.

The width of the test slabs should not be less than the largest of the following:

- three times the overall depth, $3D_s$;
- 600 mm;
- the width of the profiled steel sheet.

Thin sheet steel crack inducers extending to the full depth of the slab and coated with a debonding agent should be placed across the full width of the test slab to ensure that the cracks form in the tensile zone of the slab. In the case of four-point loading, the crack inducers should be positioned under the two more central loads, as shown in Figure 16.1. For non-uniform or asymmetrical loading arrangements, the crack inducers should be positioned at the points of maximum bending moment.



Note:
L_s is the effective span of the composite slab;
W_{f1} to W_{f4} are concentrated loads.

Figure 16.1 - Test details

The surface of the profiled steel sheets should be in the "as-rolled" condition, no attempt being made to improve the bond by degreasing the surface. A minimum of four concrete test cubes should be prepared at the time of casting the test slabs. The cubes should be cured under the same conditions as the slabs and tested at the time of loading the slab. The ultimate tensile strength and yield strength of the profiled steel sheets should be obtained from standard coupon test with test specimens cut from samples of each of the sheets used to form the composite test slabs.

(2) Test load procedure

a) General

The load carrying capacity of the proposed composite slab construction should be determined from tests representing the effects of loading applied over a period of time. The testing procedure should consist of the following two parts:

- an initial dynamic test in which the slab is subjected to a cyclic load;
- a static test in which the applied load is increased until the slab fails.

It is important to set up the target values of the applied loading capacities of the proposed composite slab construction, W_c, which is equal to the anticipated value of the applied load W_w (at γ_f = 1.0) excluding the weight of the composite slab.

b) Initial dynamic tests
A test slab representative of the proposed composite slab should first be subjected to an applied cyclic load which varies between a lower value not greater than 0.5 W_w and an upper value not less than 1.5 W_w. This loading should be applied for 10000 cycles in a time of not less than 3*h*. Both the mid-span deflection and the end slippage should be recorded at regular intervals during the test. The slab should be deemed to have satisfactorily completed this initial dynamic test if the maximum deflection does not exceed L_s / 50, where L_s is the effective span of the composite slab. The dynamic tests aim to destroy any chemical bond between the concrete and the profiled steel sheet for subsequent examination. Moreover, the shear bond capacity through the mechanical interlocking and friction will be fully mobilized.

c) Static test
After satisfactory completion of the initial dynamic test, the same slab should be subjected to a static test in which the applied load is increased progressively until failure occurs. The failure load applied to the test slab, the mid-span deflection and the load at which the mid-span deflection reaches L_s / 50 should be recorded.

d) Applied loading capacity
The loading capacity W_c (at γ_f = 1.0) for the load applied to the slab should, for design purposes, be taken as the lowest of the following:

i) 0.75 of the average applied static load (for a minimum of three tests) at a deflection of L_s / 50, the slab not having failed;

ii) 0.5 of the average applied static load at failure W_{st}, when the slab fails with sudden and excessive end slip (i.e. when only partial horizontal shear connection is present between the concrete and the profiled steel sheets);

iii) 0.75 of the average applied static load at failure W_{st}, when the slab fails without sudden and excessive end slip (i.e. when full horizontal shear connection is present between the concrete and the profiled steel sheet);

iv) the upper value of the applied load used for the dynamic test.

If the applied load in the static test has reached twice of W_w but has not caused failure in the slab under i), ii) or iii), then the static test may be stopped, and both the dynamic and static tests may be repeated at higher values of W_w. Hence, the target values of the applied load capacity of the proposed composite slab construction will be increased accordingly.

(3) Reporting of test results
The following information should be included in the report for each slab tested:

- anticipated value of the applied load W_w (at γ_f = 1.0) for which the slab was tested;
- thickness and overall depth of profiled steel sheets;
- dimensions and spacing of shear transfer devices;
- ultimate yield strength and tensile strength of profiled steel sheets;
- dimensions of composite slab;
- observed values of concrete cube strengths f_{cm};
- load ranges during the dynamic test, e.g. 0.5 W_w to 1.5 W_w;
- load deflection and load end slippage graphs for both the dynamic test and the static test;
- static load at failure W_{st};
- mode of failure of composite slab (flexure, longitudinal slip or vertical shear) and type of failure (ductile or brittle);

- applied loading capacity W_c;
- dead weight of composite slab;
- the total load carrying capacity of the slab (i.e. W_c plus dead weight of slab).

16.4.3 Parametric tests

(1) General

Separate series of tests should be carried out for different thicknesses, grades and types of profiled steel sheets and for different grades of concrete and slab thickness. The variable in a series of tests should be the shear span L_v (see clause 10.4.5.3(2b)).

The tests should encompass the full range of spans required for use in practice. No extrapolation should be made outside this range of spans.

Where shear studs are used to connect the composite slab to the supporting beams, these should be omitted from the test specimens. Their effects as end anchorages should then be covered separately (see clause 10.4.5.3(3)).

The mode of failure should be recorded, distinguishing between flexural failure, longitudinal slip and vertical shear failure. Relative movement (end slip) between the sheets and the concrete at the ends of the test slab should be considered as indicating longitudinal slip. The absence of end slip at failure should be considered as indicating flexural failure with full shear connection.

If the failure mode is vertical shear, the results should not be used for determining values of the empirical parameters m_r and k_r.

(2) Testing arrangement and procedure

At least two sets of slabs should be tested, each comprising not less than three samples. Testing should be carried out in accordance with clauses 16.4.2(1) & (2) while at least two sets of four concrete cubes will be required. The same nominal compressive cube strength grade of concrete should be used for all tests.

Both shape and the shear transfer device such as embossment of the profiled steel sheets should accurately represent those to be used in practice. Tolerances of 5% on spacing of embossments and 10% on size and depth of embossments should be applied as limits.

(3) Test results

To establish the design relationship for shear-bond capacity, tests should be carried out on specimens in regions A and B indicated in Figure 16.2. The maximum experimental shear force V_E should be taken as half of the value of the failure load W_{st} as defined in clause 16.4.2(2c) for each test. Only values from tests which resulted in shear-bond failure should be included.

The variables used for the tests should have values such that the parameters $V_E / \left(B_s d_s \sqrt{f_{cm}}\right)$ and $A_p / \left(B_s L_v \sqrt{f_{cm}}\right)$ for A and B regions:

- lie within the complete range of values for which a shear-bond type of failure is expected to occur; and
- encompass the actual range of values which are required for use in practice.

For specimens in region A the shear span should be as long as practicable, whilst still producing a shear-bond type of failure. For specimens in region B the shear span should be as short as practicable, whilst still producing a shear-bond type of failure. However, shear spans less than 450 mm should not be used.

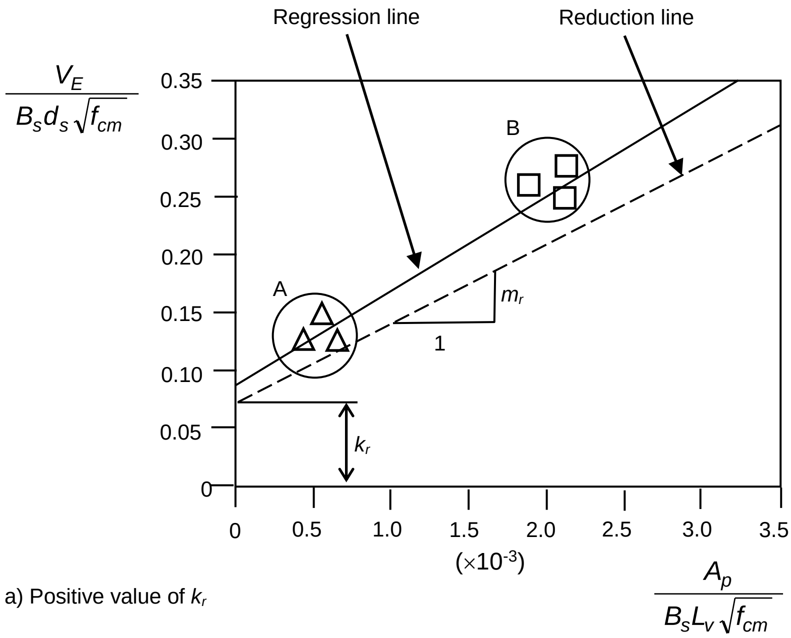
The nominal shape and thickness of the profiled steel sheets used for the tests should be the same as those to be used in practice and the value of A_p should not vary by more than ±10% between the test specimens. The nominal strength grade of the profiled steel sheets should also be the same as that to be used in practice.

The minimum cube strength f_{cm} of the concrete for the specimens should not be less than 25 N/mm^2 and the variation between the mean cube strengths of the concrete for the specimens in regions A and B should preferably not exceed 5 N/mm^2. Where the variation is greater, the mean cube strength for all the specimens should be used when plotting the test results.

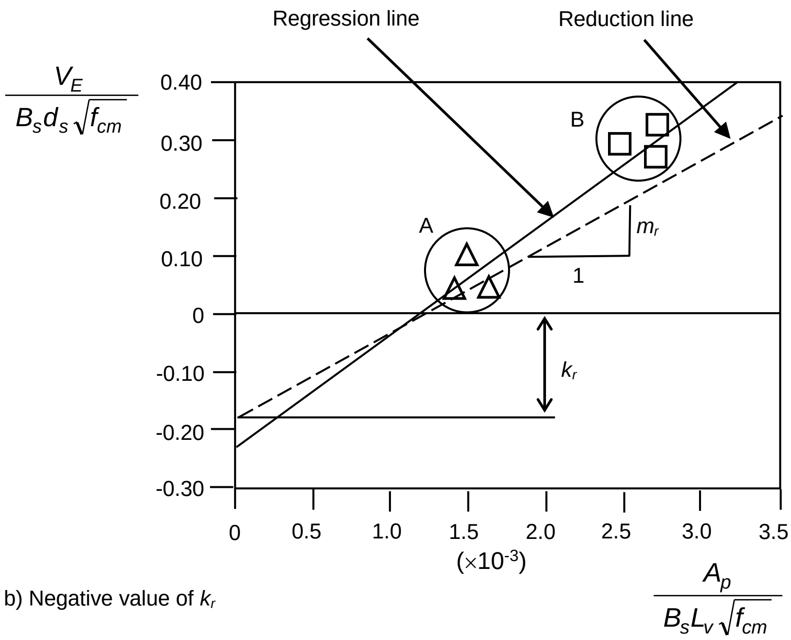
From the tests a regression line should be plotted as shown in Figure 16.2. The regression line should be taken as the best straight line between the test results in region A and those in region B.

There should be a minimum of three tests in each region, provided that the variation from the mean of the three results is not greater than ±7.5%. When the variation is greater than ±7.5%, three further tests should be carried out and the six test results should be used to obtain the regression line. In order that the experimental values will generally lie above the line used for design, the values of the empirical parameters m_r and k_r for use in design (see clause 10.4.5.3(2)a) should be determined on the basis of a reduction line, as indicated in Figure 16.2. Generally, the reduction line should be 15% below the regression line, except that, when eight or more tests are carried out, the reduction line should be taken as 10% below the regression line.

In the event that the value of the empirical parameter k_r from the reduction line is negative (see Figure 16.2b), the application of the test results to design should be restricted as described in clause 10.4.5.3(2a).



a) Positive value of k_r



b) Negative value of k_r

Note:

A_p is the cross-sectional area of the profiled steel sheeting (in mm^2);
B_s is the width of the composite slab (in mm);
d_s is the effective depth of slab to the centroid of the profiled steel sheetings (in mm);
f_{cm} is the observed concrete cube strength (in N/mm^2);
k_r is an empirical parameter (in $\sqrt{N/mm^2}$);
L_v is the shear span of the composite slab (in mm), determined in accordance with clause 10.4.5.3(2);
m_r is an empirical parameter (in N/mm^2); and
V_E is the maximum experimental shear force (in N).

Figure 16.2 - Shear bond failure