

Structural use of steelwork in building —

Part 3: Design in composite construction —

Section 3.1 Code of practice for design of simple and continuous composite beams

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Summary of pages

This document comprises a front cover, an inside front cover, pages i to iv, pages 1 to 36, an inside back cover and a back cover.

Foreword

This Section of BS 5950 has been prepared under the direction of the Civil Engineering and Building Structures Standards Policy Committee. BS 5950 is a document combining codes of practice to cover the design, construction and fire resistance of steel structures and specifications for materials, workmanship and erection.

The start and finish of text introduced or altered by Amendment No. 1 2010 is indicated by tags **A1** **A1**. Minor editorial changes are not tagged.

BS 5950 comprises the following Parts:

- *Part 1: Code of practice for design in simple and continuous construction: hot rolled sections;*
- *Part 2: Specification for materials, fabrication and erection: hot rolled sections;*
- *Part 3: Design in composite construction;*
- *Section 3.1: Code of practice for design of simple and continuous composite beams;*
- A1** *Text deleted* **A1**
- *Part 4: Code of practice for design of floors with profiled steel sheeting;*
- *Part 5: Code of practice for design of cold formed sections;*
- *Part 6: Code of practice for design of light gauge sheeting, decking and cladding;*
- *Part 7: Specification for materials and workmanship: cold formed sections;*
- *Part 8: Code of practice for fire resistant design;*
- *Part 9: Code of practice for stressed skin design.*

BS 5950-3.1:1990+A1 supersedes BS 5950-3.1:1990, which is withdrawn. Section 3.1 gives recommendations for the design of simple and continuous composite beams.

NOTE BS 5950-3.1:1990 superseded CP 117-1, which was withdrawn in 1990.

The full list of organizations who have taken part in the work of the Technical Committee is given on the back cover. The Chairman of the Committee is Mr P R Brett and the following people have made a particular contribution in the drafting of the code.

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It has been assumed in the drafting of this British Standard that the execution of its provisions will be entrusted to appropriately qualified and experienced people, for whose use it has been produced.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

Section 1. General

1.0 Introduction

1.0.1 Aims of economical structural design

The aim of structural design is to provide, with due regard to economy, a structure capable of fulfilling its intended function and sustaining the design loads for its intended life. The design should facilitate fabrication, erection and future maintenance.

The structure should behave as one three-dimensional entity. The layout of its constituent parts, such as foundations, steelwork, connections and other structural components, should constitute a robust and stable structure under normal loading to ensure that, in the event of misuse or accident, damage will not be disproportionate to the cause.

To achieve this it is necessary to define clearly the basic structural anatomy by which the loads are transmitted to the foundations. Any features of the structure which have a critical influence on its overall stability can then be identified and taken account of in design.

Each part of the structure should be sufficiently robust and insensitive to the effects of minor incidental loads applied during service that the safety of other parts is not prejudiced.

While the ultimate strength recommendations within this standard are to be regarded as limiting values, the purpose in design should be to reach these limits in as many parts of the structure as possible, to adopt a layout such that maximum structural efficiency is attained and to rationalize the steel member sizes and details in order to obtain the optimum combination of material and fabrication.

1.0.2 Overall stability

The designer responsible for the overall stability of the structure should ensure the compatibility of design and details of parts and components. There should be no doubt of this responsibility for overall stability when some or all of the design and details are not made by the same designer.

1.0.3 Accuracy of calculation

For the purpose of deciding whether a particular recommendation is complied with, the final value, observed or calculated, expressing the result of a test or analysis should be rounded off. The number of significant places retained in the rounded off value should be the same as for the value given in the recommendation.

1.1 Scope

This Section of BS 5950 gives recommendations for the design of simply supported and continuous composite beams, comprising hot rolled steel sections, plate girders and hollow sections acting compositely with reinforced concrete slab, or with a composite slab complying with BS 5950-4.

This Section of BS 5950 does not cover the design of composite columns or composite frames

Text deleted.

NOTE The publications referred to in this standard are listed on the inside back cover.

1.2 Definitions

For the purposes of this Part of BS 5950, the definitions given in BS 5950-1 and BS 8110 apply, together with the following.

1.2.1

composite action

the structural interaction which occurs when two elements are inter-connected along their length, so as to modify the behaviour of the individual elements. The inter-connection may be continuous or at discrete points along the member

1.2.2

composite section

a steel beam which acts compositely with a concrete flange

1.2.3

composite slab

a slab consisting of profiled steel sheets, a concrete slab and reinforcement where necessary. The design of the slab may be composite or non-composite with the profiled sheeting

1.2.4

concrete flange

the structural concrete slab forming part of a floor or roof of the structure and acting compositely with the steel beam. The slab may be of precast, in-situ or composite construction

1.2.5

full shear connection

shear inter-connection between steel and concrete elements sufficient to produce full composite action, permitting only negligible slip at the interface and developing the full moment capacity of the composite cross section

1.2.6**global analysis**

analysis of the structure to determine the internal forces and moments in the members

1.2.7**negative moment**

bending moment causing “hogging”, i.e. moment causing compression at the bottom of a beam

1.2.8**partial shear connection**

shear inter-connection between steel and concrete elements producing less composite action than full shear connection, permitting some limited slip at the interface and developing a reduced moment capacity, less than the full moment capacity of the composite cross section

1.2.9 positive moment

bending moment causing “sagging”, i.e. moment causing tension at the bottom of a beam

1.2.10**profiled steel sheeting**

cold formed steel sheet profiled to increase its second moment of area in one direction

1.2.11**resistance**

limit of force which an element of a member can withstand

1.2.12**shear connector**

a mechanical device producing interaction between steel and concrete

1.2.13**solid slab**

a concrete flange which, at least in the zone surrounding the shear connectors, has a flat soffit and no internal voids

1.3 Major symbols

For the purposes of this Part of BS 5950, the following symbols are used.

A	Area of steel section
A_c	Area of concrete
A_{cv}	Area of concrete shear surface per unit length of beam
A_{sv}	Area of transverse reinforcement per unit length of beam
B_e	Total effective breadth of concrete flange

b_e	Effective breadth of concrete flange, one side of steel beam
b_r	Breadth of the concrete rib
D	Depth of steel section
D_p	Overall depth of profiled steel sheet
D_s	Overall depth of slab
d	Clear depth of web or Nominal shank diameter of a stud shear connector
f_{cu}	Characteristic cube strength of concrete (in N/mm^2)
f_y	Characteristic strength of reinforcement
h	Overall height of stud
I_g	Second moment of area of uncracked composite section
I_n	Second moment of area of cracked section for negative moments
I_p	Second moment of area of cracked section for positive moments
I_x	Second moment of area of steel beam about major axis
k	Reduction factor depending on profile shape
L	Length of span
L_z	Distance between points of zero moment
M	Moment
M_c	Moment capacity of composite section
M_s	Moment capacity of steel beam
N	Number of shear connectors in a group
N_a	Actual number of shear connectors between intermediate point and the adjacent support
N_i	Number of shear connectors required between intermediate point and the adjacent support
N_n	Number of shear connectors for negative moments
N_p	Number of shear connectors for positive moments
p_y	Design strength of structural steel (in N/mm^2)
Q_k	Characteristic resistance of shear connector
Q_n	Capacity of shear connector in negative moment regions
Q_p	Capacity of shear connector in positive moment regions

R_c	Resistance of concrete flange
R_f	Resistance of steel flange
R_n	Resistance of slender steel beam
R_o	Resistance of slender web
R_q	Resistance of shear connection
R_r	Resistance of reinforcement
R_s	Resistance of steel beam
R_v	Resistance of clear web depth
R_w	Resistance of overall web depth
r	Ratio of mean longitudinal stress in the web to p_y
s	Longitudinal spacing centre-to-centre of groups of shear connectors
t	Web thickness
v	Longitudinal shear per unit length
v_p	Contribution of profiled steel sheeting per unit length
v_r	Shear resistance of concrete flange per unit length
α_e	Modular ratio
δ	Deflection
ε	Constant, equal to $(275/p_y)^{1/2}$

1.4 Design procedure

The overall design procedure for steel structures incorporating composite construction should be in accordance with BS 5950-1, except as modified and supplemented by the recommendations of Part 3.

The detailed design of the structural steel components should be as recommended in BS 5950-1, modified as recommended in Part 3 when acting compositely.

In the design of composite construction in accordance with this Part of BS 5950, the recommendations of BS 5950-1 and of BS 8110 also apply, unless modified by this Part.

Reference should also be made to BS 5950-8 for recommendations concerning fire protection.

The requirements of BS 5950-2 should also be considered as applying equally to steelwork designed to act compositely as recommended in this Part. In addition guidance on additional aspects of construction is given in Appendix A. Particular attention should be paid to the need to provide temporary lateral restraint to the structure during construction, prior to the development of composite action.

Composite slabs used compositely with steel beams should be designed and constructed in accordance with BS 5950-4.

Reinforced concrete slabs, including precast slabs, used compositely with steel beams should be designed and constructed as recommended in BS 8110.

Section 2. Limit state design

2.1 General principles and design methods

2.1.1 Limit state concept

Structures should be designed by considering the limit states at which they would become unfit for their intended use, by applying appropriate factors for the ultimate limit state and the serviceability limit state.

All limit states covered in BS 5950-1 or in BS 8110 should be considered.

The recommendations given in this Part should be followed in respect of the ultimate limit states of strength and stability and the serviceability limit states of deflection, cracking and vibration.

2.1.2 Methods of design

2.1.2.1 General. The design of any structure or its parts should be carried out by one of the methods given in 2.1.2.2 to 2.1.2.5.

In all cases, the details of members and connections should be such as to realize the assumptions made in design without adversely affecting any other parts of the structure.

2.1.2.2 Simple design. This method is described in 2.1.2.2 of BS 5950-1:1985.

2.1.2.3 Rigid design. This method is described in 2.1.2.3 of BS 5950-1:1985.

2.1.2.4 Semi-rigid design. This method is described in 2.1.2.4 of BS 5950-1:1985.

2.1.2.5 Experimental verification. The recommendations given in 2.1.2.5 of BS 5950-1:1985 should also be considered as applicable to composite beams. However, although the test procedures for steel structures given in section seven of BS 5950-1:1985 are generally applicable, further consideration should also be given to the special features of composite construction.

2.1.3 Methods of analysis

2.1.3.1 General. A distinction is made between the global analysis, by which the moments and forces in the structure are determined, and the procedures for member design.

2.1.3.2 Global analysis. The moments and forces in the members of any structure should be determined by elastic or plastic global analysis. Elastic global analysis may be used without restriction but plastic global analysis should only be used in structures where the members satisfy the necessary criteria (see 5.2.4 and D.3).

2.1.3.3 Member design. The plastic moment capacity (see 4.4.2) should be used for member design provided that the compression flange is class 1 plastic or class 2 compact (see 4.5.3), otherwise the elastic moment capacity (see 4.4.3) should be used.

NOTE Plastic design of members is recommended irrespective of whether the global analysis is elastic or plastic.

2.2 Loading

2.2.1 General

All relevant loads should be considered separately and in such realistic combinations as to cause the most critical effects on the elements and the structure as a whole.

The following should be taken into account.

- a) The magnitude and frequency of fluctuating loads should be considered.
- b) Loading conditions during erection should receive particular attention.
- c) The possible adverse effects of settlement of supports may need to be taken into account.
- d) When the values of modular ratio recommended in 4.1 are adopted, it is not necessary to give further consideration to the effects of creep.
- e) It is not necessary to consider stresses due to shrinkage.
- f) When the procedures recommended in 6.1 are adopted, it is not necessary to consider the effects of shrinkage on deflection.
- g) For internal steelwork, it is not necessary to consider temperature effects within the range quoted in BS 5950-1.

2.2.2 Dead, imposed and wind loading

Reference should be made to BS 6399-1, CP 3:Chapter V-2, and BS 6399-3 for the determination of the dead, imposed and wind loads.

2.2.3 Construction loads and temporary storage loads

Construction loads should be considered in addition to the nominal weight of the wet concrete slab (see 2.3.2).

The construction load on the area supported by the beam should be taken as not less than 0.5 kN/m^2 . An alternative construction load comprising a moveable point load of not less than 4 kN should also be considered. Local effects due to this point load need not be considered.

NOTE 1 See BS 5950-4 for construction loads to be assumed in the design of composite slabs.

NOTE 2 Allowance is made within these values for construction operatives, impact and heaping of concrete during placing, hand tools, small items of equipment and materials for immediate use. The minimum values quoted are intended for use in general-purpose working areas, but will not necessarily be sufficient for excessive impact or excessive heaping of concrete, or pipeline or pumping loads.

Where excessive loads are expected, reference should be made to BS 5975.

Where materials to be stored on the structure during erection (or on a recently formed slab before it has attained sufficient strength to act compositely with the steel beam) may produce loads in excess of the construction loads, provision should be made in design for the additional loading (see 2.3.2).

2.3 Ultimate limit states

2.3.1 General

In checking the strength and stability of the structure the loads should be multiplied by the relevant γ_f factors given in BS 5950-1. The factored loads should be applied in the most unfavourable realistic combination for the part or effect under consideration.

The load capacity of each member and its connections, as determined by the relevant provisions of this standard, should be such that the factored loads would not cause failure.

2.3.2 Construction stage

Account should be taken of probable variations in dead load during construction or other temporary conditions. For the purpose of assigning γ_f factors, construction loads and temporary storage loads should be treated as imposed loads.

Strength and stability should also be checked for the construction stage where the steel beam acts non-compositely to support the dead load of the formwork and wet concrete plus construction loads or temporary storage loads (see 2.2.3).

Profiled steel sheeting which is fixed to a beam as recommended in A.2.3 should be assumed to give lateral restraint to the flange to which it is fixed, provided that the ribs run perpendicular to the beam or at an angle of at least 45° to the beam. Profiled steel sheeting with ribs running parallel to a beam, or at an angle of less than 45° to it, should not be assumed to give it lateral restraint.

Where the profiled steel sheeting is also assumed to act as a stressed skin diaphragm to provide structural stability at the construction stage, reference should be made to BS 5950-9.

NOTE A.2 gives design considerations related to construction.

2.4 Serviceability limit states

2.4.1 General

The design recommendations for serviceability given in section 6 should be followed.

The serviceability loads should be taken as the unfactored values. Dead and imposed loads should be considered as recommended in the appropriate clause. The construction loads should not be included in the serviceability loads.

2.4.2 Deflection

The deflection under serviceability loads of a building or part should not impair the strength or efficiency of the structure or its components or cause damage to the finishings.

Reference should be made to BS 5950-1 for recommendations on limiting values for deflections under unfactored imposed loads.

Deflections at the construction stage due to the dead load of the concrete flange and the steel beam may also need to be considered when unpropped construction is used.

NOTE If necessary, precambering can be used to counteract deflections due to dead loads.

2.4.3 Irreversible deformation

To prevent gross deformations under normal service conditions, irreversible deformations should be avoided in simply supported beams and cantilevers, and in the mid-span regions of continuous beams.

The stresses based on the elastic properties of the section should be calculated under serviceability loading (see 6.2). When unpropped construction is used, the stresses due to the dead load of the concrete flange and the steel beam should be based on the properties of the steel beam.

In simply supported beams and cantilevers, and in the mid-span regions of continuous beams, the stress in the extreme fibre of the steel beam should not exceed the design strength p_y and the stress in the concrete flange should not exceed $0.50 f_{cu}$.

It is not necessary to limit the stresses over the supports of continuous beams, provided that the recommendations given in 6.1.3 and 6.2 are followed.

2.4.4 Cracking of concrete

Cracking of concrete should be controlled by attention to detail as recommended in 6.3.

2.4.5 Durability

The relevant recommendations in BS 5950-1 and in BS 8110 should be followed as appropriate.

2.4.6 Vibration

To control vibration, the recommendations given in 6.4 should be followed.

Section 3. Materials

3.1 Structural steel

Structural steel complying with grades 43, 50 or WR50 of BS 4360 may be used. If other steels are used, due allowance should be made for variations in properties, including ductility.

The design strength p_y should be obtained by reference to BS 5950-1.

However, in the design of composite beams, p_y should not be taken as being more than 355 N/mm^2 .

NOTE The limit of 355 N/mm^2 is due to lack of test evidence using higher-strength steels.

3.2 Concrete

Concrete should be in accordance with the recommendations given in BS 8110.

The nominal maximum size of aggregate should not exceed 20 mm.

For normal weight concrete, the grade specified should be in the range C30 to C50.

The dry density of lightweight aggregate structural concrete should normally be not less than $1\,750 \text{ kg/m}^3$. The grade specified should be in the range C25 to C40.

Other densities can be used, but all references to lightweight concrete elsewhere in this Part of BS 5950 assume a dry density of at least $1\,750 \text{ kg/m}^3$. Where lightweight concrete of less than $1\,750 \text{ kg/m}^3$ dry density is used, due allowance should be made for variations in properties of concrete and their effect on the resistances of shear connectors.

NOTE 1 Information on the elastic modulus, creep coefficient, shrinkage coefficient and coefficient of thermal expansion for concrete may be obtained from BS 8110-2.

NOTE 2 The minimum grades are generally in line with the minimum grades recommended in BS 8110. They do not apply to existing structures.

3.3 Reinforcement

Reinforcement should comply with BS 4449, BS 4482 or BS 4483. Different types of reinforcement may be used in the same structural member.

To simplify calculation, the modulus of elasticity of reinforcement and the modulus of elasticity of structural steel may both be taken as 205 kN/mm^2 .

3.4 Shear connectors

3.4.1 Stud shear connectors

The studs should be headed, with a minimum head diameter of $1.5d$ and a minimum depth of head of $0.4d$, where d is the nominal shank diameter of the stud.

The stud material should be mild steel with minimum properties (in the cold drawn condition), when tested in accordance with BS 18, as follows:

ultimate tensile strength: 450 N/mm^2

elongation (on $5.65 \sqrt{S_0}$ gauge length, as given in BS 18): 15 %.

NOTE These material properties relate to the steel from which the studs are manufactured. It is not possible at this time to give recommendations for the properties to be expected when testing finished studs.

3.4.2 Other types of shear connector

Where other types of shear connector are used, structural steel used for fabricated shear connectors should be in accordance with the recommendations given in 3.1.

Friction grip bolts used as shear connectors should be in accordance with BS 4395-1.

Other materials may also be used for shear connectors provided that they can be demonstrated to produce shear connections possessing sufficient deformation capacity (see 5.4.2).

3.5 Profiled steel sheets

Profiled steel sheets used to form composite slabs should be in accordance with BS 5950-4.

3.6 Concrete flange

3.6.1 General

A slab acting compositely with a steel member may be designed assuming it is supported by that member and capable of free rotation about it.

Any longitudinal reinforcement required in negative moment regions of a composite beam should be provided in addition to any required to reinforce the slab for moments due to loading acting directly on it.

3.6.2 Reinforced concrete slabs

A reinforced concrete slab should be designed for the effects of loading acting directly on it in accordance with BS 8110.

3.6.3 Composite slabs

A composite slab should be designed for the effects of loading acting directly on it in accordance with BS 5950-4.

3.6.4 Precast concrete slabs

A slab constructed using precast concrete units should be designed for the effects of loading acting directly on it in accordance with BS 8110. Where precast units are designed to act compositely with in-situ concrete, the interface of the precast and in-situ components should be designed to resist horizontal shear in both the longitudinal and the transverse direction.

Sufficient clearance should be provided to facilitate the placing and compaction of in-situ concrete around the shear connectors.

Where the effective continuity of transverse reinforcement is provided by means of overlapping horizontal U-bars, these U-bars should pass around the shear connectors.

Section 4. Section Properties

4.1 Modular ratio

The elastic section properties of composite members may be expressed in terms of an equivalent steel section by dividing the contributions of the concrete components by the effective modular ratio α_e .

The effective modular ratio α_e to be used in design should be determined from the proportions of the loading which are considered to be long term and short term, using the expression:

$$\alpha_e = \alpha_s + \rho l(\alpha_l - \alpha_s)$$

where

- α_l is the modular ratio for long-term loading;
- α_s is the modular ratio for short-term loading;
- ρl is the proportion of the total loading which is long term.

For the purpose of determining the modular ratio, it should be assumed that all spans are fully loaded. Imposed loads on floors should be assumed to be two-thirds short term and one-third long term in buildings of normal usage. Storage loads and loads which are permanent in nature should be taken as long term. Imposed roof loads, wind loads and snow loads should be treated as short term.

The values of short-term and long-term modular ratios given in Table 1 may be used for all grades of concrete.

Table 1 — Modular ratio

Type of concrete	Modular ratio for short-term loading α_s	Modular ratio for long-term loading α_l
Normal weight	6	18
Lightweight (see 3.2)	10	25

4.2 Second moment of area

4.2.1 General

For composite beams three possible values of the second moment of area should be distinguished as follows:

- I_g the gross value for the uncracked section;
- I_n the cracked section value for negative moments;
- I_p the cracked section value for positive moments.

The appropriate value of the second moment of area should be determined as follows:

- a) for deflection calculations (see 6.1.3.5) using I_g ;
- b) for elastic global analysis (see 5.2.3) using:
 - 1) for the gross uncracked section method (see 5.2.3.1), I_g ;
 - 2) for the cracked section method (see D.2), I_g and I_n ;
- c) for the elastic section modulus (see 4.3) using I_g , I_p or I_n as appropriate.

4.2.2 Gross uncracked section

The gross value of the second moment area of the uncracked composite section I_g should be calculated using the mid-span effective breadth of the concrete flange (see 4.6). The concrete flange should be assumed to be uncracked, but unreinforced. The full area of concrete within the effective breadth of the concrete flange should normally be included in the effective section. Alternatively, for simplicity, the concrete within the depth of the ribs may conservatively be neglected. Any concrete beam casing should normally be neglected.

NOTE B.3.1 gives a formula for the gross value of the second moment of area of a composite beam in which the steel beam has equal flanges and any concrete within the depth of the ribs is neglected.

4.2.3 Cracked section, negative moments

For negative moments, the second moment of area of the cracked composite section should be calculated using a section comprising the steel member together with the effectively anchored reinforcement located within the effective breadth of the concrete flange (see 4.6) at the support.

NOTE A formula for the negative moment value of the second moment of area of the cracked composite section in which the steel beam has equal flanges is given in B.3.2.

4.2.4 Cracked section, positive moments

For positive moments, the second moment of area of the cracked composite section should be calculated using the mid-span effective breadth of the concrete flange (see 4.6) but neglecting any concrete in tension.

NOTE A formula for the positive moment value of the second moment of area of a cracked composite section in which the steel beam has equal flanges is given in B.3.3.

4.3 Elastic section modulus

The elastic section modulus of a composite section, required to calculate stresses at the serviceability limit state (see 6.2), should be determined from the appropriate value of the second moment of area (see 4.2).