# INTERNATIONAL STANDARD ISO 4356

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## Bases for the design of structures — Deformations of buildings at the serviceability limit states

*Bases du calcul des constructions — Déformations des bâtiments à l'état limite d'utilisation*

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## FOREWORD

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International Standard ISO 4356 was developed by Technical Committee ISO/TC 98, *Bases for design of structures*, and was circulated to the member bodies in July 1976.



It has been approved by the member bodies of the following countries :

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# Bases for the design of structures — Deformations of buildings at the serviceability limit states

## 0 INTRODUCTION

Deformations call for much thought on the part of the designer, and there is more than one way of dealing with some of them.

The underlying aim of the document is to assist the designer to identify those aspects of deformation that affect the suitability of a building for the purposes for which it was intended, and to set up certain criteria by which the performance of the building in this respect can be assessed. In addition, numerical values for some of these criteria are suggested in order to give some guidance where this might be desired. National standards may adopt different numerical values if conditions so require.

The recommendations for criteria of deformation, and the suggestions for limiting values are presented in annex D (tables 1 and 2).

The methods used by the designer to try to ensure that the building complies with these criteria are not, in themselves, a matter for this International Standard. Nevertheless, in view of the wide range of acceptable values of some of the criteria, and in view also of the difficulties in estimating deformations, it is believed that both the designer and the controlling authority would welcome some guidance towards uniformity in specification and in the required degree of compliance, particularly as the economics of modern building designs are increasingly controlled by deformation and maintenance during use with the designer's overall responsibility being precisely defined. Some proposals are therefore made in regard to the methods that national standards should lay down for controlling the assessment of deformations.

## 1 SCOPE

This International Standard establishes the basic principles that should be adopted when setting up national standards, regulations and recommendations for the deformation of buildings at the limit states of serviceability.

## 2 FIELD OF APPLICATION

### 2.1 Types of building considered

This International Standard refers to the deformations at the serviceability limit states of buildings such as dwellings, offices, public buildings, and factories.

It does not refer to the deformations of bridges, roads, masts, underground works, non-residential farm buildings, or special-purpose buildings such as atomic power stations or industrial plant. Some of the general principles on which this International Standard is based may nevertheless serve as a guide when the deformations of such other structures are being considered.

### 2.2 Adjacent buildings

Whilst it is undesirable that the deformations of a building should damage adjacent buildings, or inconvenience their occupants or other members of the public, such matters are normally the subject of legislation and are not appropriate to this International Standard. Nevertheless, attention may here be drawn to the fact that the provision of movement joints between adjacent buildings and the avoidance of interference with neighbouring foundations are normal good building practice.



## 3 CAUSES OF DEFORMATIONS

Deformations are caused by major ground movements, by differential settlement of foundations, by environmental and occupational loads, by pre-stressing forces and by movements of building materials due to creep and change in temperature, moisture content and chemical composition.

## 4 DEFORMATIONS — EFFECTS AND REMEDIES

Besides possibly affecting the strength or stability of a structure, deformations may affect serviceability by causing damage to adjacent parts of the building, by disturbing or harming personnel, or by preventing proper use of the building.

In many such cases the designer may be able to avoid troublesome effects either by removing the original cause, or by taking suitable precautions in the processes of design and construction to permit some or all of the deformation to occur freely, before or after completion of the building, masking the remainder by suitable constructional or decorative treatment. This course of action has the advantage that it avoids the problem of precisely estimating the magnitudes of causes and their effects. It can be adopted when the deformations, and the constructional measures taken, do not conflict with other requirements of the design. Some troubles that may be dealt with in this way are listed in annex A.

Camber can be used to reduce the final value of deflections. The normal use of camber is to reduce the contribution to deformations that is caused by self-weight and other permanent or long-term temporary action.

In other cases the designer may have no option but to provide sufficient stiffness to limit the deformations and thus reduce their effects to acceptable levels; this will inevitably increase the first cost of a structure. Indeed he may choose to do so, or to combine both approaches. Where such limits are to be set, the following clauses apply.

## 5 KINDS OF LIMITATION REQUIRED

Limitations may need to be applied to vertical or horizontal deflections or deviations, to inclinations, to curvatures, to the widths of cracks, or to the effects of vibrations.

NOTE — The limitation of beam or slab deformations may be basically a matter of deflection, rotation, or curvature. However, these requirements are specified throughout this document in terms of deflection, or of deflection in relation to span, since this is the most easily observable parameter. For simply supported spans under uniformly distributed loading the slope at the ends may be taken as equal to three times the ratio of medial deflection to span, and the radius of curvature at the middle as equal to the span divided by ten times the deflection/span ration. National codes may specify limitations in terms of equivalent rotation or curvature if so desired.



## 6 LEVELS OF MAGNITUDE OF DISTURBING ACTIONS

When specifying limitations it is necessary to consider the levels of magnitude at which the actions that cause deformations should be assumed to occur. A knowledge of these is essential if designers and controlling authorities are to find a common basis for assessing and controlling deformations.

Some of the factors that enter into this consideration are :

a) the extent to which information is available about the actions or properties involved, and the degree of accuracy of any estimates of the effects likely to be produced;

b) the possible response of the building or member, in view of the duration of the action in question;

c) the probability of the simultaneous occurrence of several actions contributing to a given kind of deformation;

d) the consequent levels of dissatisfaction.

In connection with c) it will be noted that both spatial and chronological variations of disturbing actions are involved and also that, given the necessary data, an estimate of the combined probability might be made. In the absence of sufficient data it becomes necessary to adopt other means of expressing the reduced magnitudes of several actions that should be assumed to be present simultaneously.

In connection with d) it will be noted that the sharp limit to acceptability that is exceeded at the ultimate limit state does not, in general, exist with serviceability limit states and there is usually a wide range of acceptable levels of deformation, depending on the properties of contiguous materials, the reactions of individual persons, and the possibilities and economics of repair. In this connection it is to be noted that in the case of widespread natural actions such as wind, snow and earthquake, whose characteristic values are based on temporal rather than spatial probabilities, the acceptable level of troubles due to deformation depends on the number of buildings simultaneously at risk and on the acceptability of some results of a natural calamity.

With these matters in mind, it is recommended that national codes should base their requirements on the following :

1) the actions to be taken into account when specifying or checking deformations should be those having a duration that is appropriate to the response of the building or member affected;

2) for permanent actions, for long-term temporary actions, and for short-term temporary actions affecting many buildings in the course of a single year the levels of magnitude of these actions should be the characteristic values;

3) a lower value than the characteristic may be specified when two or more of the above actions occur simultaneously, or when a short-term action is not likely to affect many buildings in the course of a single year.

## 7 DEFORMATIONS AFFECTING STRENGTH AND STABILITY — A REMINDER

Deformations affecting the strength and stability of a building, or of its parts, are taken into account in the process of structural design for the ultimate limit state and are not, in general, a matter for this International Standard. Nevertheless, designers may like to be reminded of certain cases involving static or dynamic instability where the conditions existing during normal use of the building may have considerable effect on the ultimate limit state.

### 7.1 Eccentric loading of walls and columns

Eccentric loadings of walls and columns may occur as a result of excessive constructional deviations, through inclination of these members or through deflections of floors or roof members. In both cases the effects may be progressive and lead to collapse.

#### 7.1.1 *Eccentric loading due to inclinations*

Inclination of vertical members may be due to constructional deviations or to the effects of wind load, or of permanent and imposed and snow loads acting eccentrically or causing differential settlement. The presence of properly designed stiffening elements such as shear walls, central service cores, enclosed liftwells or stairwells will usually improve stability.

**7.1.2** *Eccentric loading due to rotation of floors or roof members*

Change of slope of floors or of roof members at junctions with supporting walls or columns, taking place after construction, may produce loading of the latter that is both eccentric and inclined. Such changes of slope may be due to the effects of permanent and imposed and snow loads on the floors or roof members, the permanent load causing creep deflection and the imposed and snow loads causing elastic and possibly creep deflection.

It is difficult for the designer to assess the problem if he is not aware of the probable deformation of the floor or roof member, as may be the case if the latter is not designed by him.

(The designer will also wish to take into account differential settlement under all dead (self-weight) and imposed loads.)

### 7.2 Resonance

Near-coincidence of forcing and natural vibrations may produce resonance of any building element. The degree of resonance may be reduced by appropriate adjustment of either of the two frequencies, or by the provision of vibration insulation or adequate damping. The problem arises mainly where the disturbing force is of large magnitude, i.e. with auditoria, dance halls, sports stands, and in buildings having long-span suspended floors with a natural frequency of about 1 to 5 Hz, or containing machines with large unbalanced forces.



## 8 DEFORMATIONS AFFECTING SERVICEABILITY

Deformations, although possibly not affecting the strength or stability of a building, may cause damage to members (load-bearing or otherwise) and to finishes and claddings. They may produce unpleasant psychological effects, even to the extent of causing alarm. Finally, they may be physically such as to effectively prevent the use of the building for its intended purpose or to impair the health of personnel. Some deformations may produce more than one kind of effect.

### 8.1 Deformations causing damage to adjacent parts of the building

**8.1.1** *Cracking and spalling of walls at points of support of floors and roofs*

Change of slope of floors and roofs at junctions with supporting walls and lifting of the insufficiently restrained corners of torsionally stiff floor slabs may cause horizontal cracking (particularly undesirable where floors are carried through to the face of the external wall) and also spalling of internal or external finishes. The actions involved are permanent load causing creep deflection and the imposed floor load and snow load causing elastic deflection and creep deflection.

Differential settlement and wind forces may also cause such cracking and spalling. Thermal and moisture movements in finishes are also involved. More severe limitation may be necessary if deep edge stiffening beams are incorporated into the wall.

**8.1.2** *Cracking and spalling of ceilings*

Curvature of the floor or roof may cause cracking in decoration on the underside of concrete slabs. Curvature subsequent to plastering may cause cracking of the plaster in the span and spalling in regions of negative curvature. The actions involved are the permanent load of the floor or roofs causing creep deflection and the imposed load and snow load causing deflection and possibly creep deflection. Repeated thermal and moisture movements in the plaster may be also be involved. Good extensibility of the plaster and good distribution of concentrated loads are ameliorating factors as is also the fact that cracks may be covered by redecoration. The permissible degree of cracking is largely subjective but depends on the use of the building.

**8.1.3** *Cracking and spalling of brittle partitions and non-loadbearing walls*

Apart from cracking, spalling and local bulging due to thermal and moisture movements of the partitions themselves, or of the supporting structure, damage to brittle partitions may arise as a result of differential settlement of foundations, deflections of floors or roofs, or lateral movements of the building.

Estimation of this damage depends on a determination of the total tensile or compressive effects arising from all causes, together with information about the limiting tensile and compressive properties of the partitions, the effects on the number and width of cracks of any restraints to movement, and the degree of cracking that can be tolerated for the given type of surface finish and the given use of the building. Such a procedure is not yet sufficiently developed and it is meanwhile recommended that the deformation arising from various causes be dealt with separately. The suggested limiting values may permit a certain amount of cracking. Where this cannot be accepted a more severe limitation, or more tolerant partitions, may be called for.

**8.1.3.1** Differential settlement of foundations subsequent to the erection of partitions may produce diagonal cracking across the body of the latter. The actions involved are the dead (self-weight) load, including that of the partitions, and all long-term temporary actions capable of influencing settlement.

**8.1.3.2** Deflections of floors or roofs may damage partitions in a number of ways. In all cases the effects involved are those occurring after the erection of partitions, i.e. the dead (self-weight) load of the floor or roof, and in some cases that of the partitions, together with any pre-stress, causing creep deflections; the imposed floor or roof load (including snow load and any dead loads such as screeds and floor finishes applied after erection of partitions) causing elastic deflection and creep deflection; also curvature and other movements of the floor due to possible unrestrained moisture movements. In general, the greater the rigidity of the floor transverse to the span the worse the effects of its deformations. Three main types of behaviour are known :

a) With the first, a partition parallel to the span deforms in its own plane to follow the deformations of the floor below it, possibly producing vertical cracks in the bending tension zone, diagonal shear cracks, or a gap above the partition. This type of behaviour is most likely to occur where the partition is of relatively long span (length/height greater than 3,5 approximately for non-cantilevered spans); or is not longitudinally restrained by the structure or by contiguous partitions or contains many openings; or is of low rigidity. In this case, besides the weight of the partition concerned, one of the actions involved is part of the weight of partitions on the floor or floors above, if this can be transmitted to the partition in question.

In the case of a cantilevered span there is greater possible cracking in the upper part of the partition and possible damage to fascias due to non-uniform deflection of supporting cantilevers.

b) With the second type of behaviour, a partition parallel (or in some cases transverse) to the span tends to support itself by arching horizontally or diagonally. This is most likely to occur where the partition has a high compressive strength and limit of deformability; where the ratio of length to height lies in the range 1,5 to 3,5 approximately; where the partition is longitudinally restrained by the structure or by contiguous walls or partitions; and where there are few openings or continuous vertical sliding joints to interfere with the arching.

If, in such a case, the floor below the partition deflects more than the partition (possibly due to the absence of a partition, a stiffening beam, or other support beneath) a horizontal crack may be formed along the base of the partition, or a horizontal or arc-shaped crack may be formed in the lower portion of the partition, together with diagonal cracks across the upper corners due to extension of the under surface of the floor above. (If such horizontal cracks are likely to occur, their formation may be limited to the floor level where they can subsequently be masked by providing a chase or a separating layer; the crack can then be masked by a skirting board fixed to the floor.)

If, on the other hand, the floor or roof above the partition deflects more than the partition and there is no compressible packing at the head of the partition, the latter tends to be crushed and there may be vertical cracks in the lower portion and diagonal cracks across the upper corners.

c) With the third type of behaviour, the partition is loaded by the upper floor and carries these loads by strut-action to the ends of the span of the lower floor. This is most likely to happen when the ratio of the length to height of the partition is less than 1,5 approximately. The type of damage is the same as in the immediately preceding case.

When openings occur in partitions a combination of some of the above phenomena is likely to occur or there may be simple rotation of the portions of the partition. Diagonal cracks radiating from the corners of these openings may also be produced. Some horizontal or inclined reinforcement at such places is therefore advisable where it is not possible to break the continuity of the partition above or below the opening.

**8.1.3.3** Lateral deflection of a building as a result of wind forces may cause diagonal cracking across a partition. The action involved is the wind gust having a duration of sufficient length to produce the necessary deflection. Low-cycle fatigue damage may occur. Strong shear walls, central core zones or enclosed staircases have an ameliorating effect.



**8.1.4** *Damage to roof coverings, cladding and glazing*

Deflections of roofs may cause damage to felt or metal roof coverings, to roof sheeting, or to roof glazing or tiling and may produce ponding of rainwater. The actions involved are permanent load producing creep deflections, any imposed loads, and snow loading and wind gusts of appropriate duration producing elastic deflections.

The cladding fixing should be designed so that structural loads are not transferred to cladding panels when the structural frame deforms.

The limitations of deflection may need to be more restrictive for roofs covered with sheet materials that become brittle with age.

## 8.2 Deformations affecting appearance

**8.2.1** *Visible sag of floors and ceilings*

Visible deviations of floors and ceilings from the straight line or plane (unless obviously intentional) cause subjective feelings that are unpleasant and possibly alarming. The actions involved are the permanent load and the imposed loads, producing deflections and possibly creep deflections and also constructional deviations and thermal and moisture movements and, in the case of cantilevers, differential settlement. The provision of a camber or of a false ceiling can improve matters.

Subjective appraisal depends on the type of roof or floor (whether flat soffit, beam and slab, trough, or ribbed construction), the area of it that is visible, its height and its relationship to other elements of the construction (particularly elements that are horizontal or in a horizontal plane) and the lighting conditions.

**8.2.2** *Visible leaning of walls and columns*

Visible deviation of vertical members from the vertical (unless obviously intentional) is also a source of subjective unrest. The actions involved are the dead (self-weight) loads and imposed loads causing differential settlement, but constructional deviations and the overturning effects of eccentric and inclined loads on walls and columns may be contributing factors. Persons vary in their appraisal of lean but are often guided by neighbouring vertical elements.

### 8.3 Deformations affecting use

**8.3.1** *Curvature of floors*

Curvature of floors and the inclinations that it produces may cause stumbling or slipping of persons, movement of trolleys, tilt or rocking of furniture and equipment and spread of spilt liquids. Curvature may be due to constructional deviations, to elastic deflections and creep deflections (possibly upward) under permanent load alone or under permanent load and imposed floor loads or to thermal or moisture movements. The provisions of screeds, or a camber, may be appropriate.

**8.3.2** *Non-horizontality of floor supports*



Unintentional lack of horizontality of floor supports causes many of the effects referred to in 8.3.1. It may be due to constructional deviations or to differential settlement under dead (self-weight) loads and imposed floor loads (rotation of the point of support in the case of cantilevers).



**8.3.3** *Oscillations generated within the building or by wind forces*

Apart from man-made external sources of vibration, such as nearby industrial activities and transport facilities, whose effects are not a matter for this International Standard, the main sources of oscillations in buildings are foot traffic and machinery, within the building, together with wind gusts. (Earthquake is dealt with in 8.4.2.) The acceptable magnitudes of such oscillations, which may cause unpleasant sensations, including alarm, or prevent the carrying-on of required activities, depend on human sensitivity, on the activity to be pursued, on the degree of damping present, on the duration of the impulses and the interval between them.

Recommendations for limitation of oscillations of frequency $> 1$ Hz are given by ISO/TC 108 in a draft Application Guide [ISO/TC 108/SC 4/WG2 (Split-1) 20] based on ISO 2631. This committee is also studying the limitation of oscillations of lower frequency appropriate to horizontal oscillations of buildings.

**8.3.4** *Deformations affecting special requirements in use*

The foregoing sub-clause 8.3 refers to deformations affecting the use of the generality of buildings within the scope of this International Standard. However, in certain types of building there may be special requirements in connection with, for example, particular activities of personnel, or the use of machinery or precision apparatus. Some such requirements are :

**8.3.4.1** DEFLECTIONS OF OVERHEAD CRANE RUNWAY GIRDERS

Traversing cranes produce

a) vertical or horizontal deflections of the runway girders (and of supporting brackets in some cases) due to their own weight and that of the load carried, and

b) horizontal lateral and longitudinal deflections of the supporting columns due to the forces of acceleration and braking. (It is assumed herein that the effects of constructional deviations and any subsequent movements of supports have been negated by levelling and lining-up the crane rails. Any upward deflection due to pre-stress may be taken into account.)

In the case of vertical deflections of the runway girders there may be a problem of clearances. The principal problems, however, are the overloading of the means of propulsion due to the slope of the runway girders when under load and the maintenance of steady motion over the point of support.

In the case of horizontal deflections of the columns it is necessary to limit the transverse deflection to prevent the crane gantry itself rotating excessively about the vertical (slewing) or becoming dislodged, and also to limit both transverse and longitudinal deflections to prevent excessive deformations of the supporting columns leading to damage to cladding and fixings (or to instability, see 8.1).

**8.3.4.2** OTHER SPECIAL REQUIREMENTS

These requirements should be agreed in advance of design and construction in consultation with the client and the suppliers of any equipment involved. (See clause 11.) Examples of problems that may arise are :

- vibrations of weighing and measuring apparatus;
- damage to impermeable membranes used for isolation of, or protection from liquids and gases;
- twist of floors carrying machines operating on sheet materials;
- inclinations affecting co-linearity of apparatus or levels of liquids;
- interference with fine manual movements.

### 8.4 Deformations requiring general overall control

**8.4.1** *Cracking*

Cracks in building elements may damage coverings, permit corrosion of reinforcing elements, or allow penetration of liquids, gases, or radiation (thus, for example, reducing thermal or air-borne sound insulation, or admitting rain, dust, or light). They may also constitute disfigurement or cause alarm. (They are unlikely to cause structural collapse unless extremely wide and extensive, but they are early evidence of excessive action.)

In many cases cracks may be avoided, or located in one or more convenient places, or hidden, by appropriate initial design and construction measures. In other cases the requirements of standards for other types of deformation may prevent the formation of cracks.

However, bearing in mind that these two measures may be only partially successful in controlling cracking and that in any event cracks may occur in circumstances other than those provided for in standards, it is necessary to impose a general overall limitation on the widths of cracks.

In laying down limitations, national standards should have regard to the building materials involved, whether the cracks are though-cracks or surface cracks, whether they are likely to open further, or close, whether they are repairable or capable of being covered by decoration, whether penetration of liquids etc., is a factor, and the probable attitude of persons affected, in view of the intended use of the building.

In the case of possible corrosion of reinforcement the permissible width of cracks should be laid down in design standards for the respective materials. Where corrosion of reinforcement is not in question it is suggested :

- that through-cracks should not be permitted at positions where the transfer of water (by gravity, wind pressure, or capillarity for example) to the inside surfaces of rooms could occur;
- that cracks should individually not exceed an average width of 0,2 mm if it is intended that they should be coverable by re-decoration;
- that, if likely to be premanent, neither through-cracks nor surface cracks should individually exceed an average width of 2 mm, or such lower figures as may be required in particular circumstances (for example in the presence of a corrosive or humid atmosphere).

The widths of cracks and any resulting out-of-plane dislocations may be controlled by pre-stressed, or other, reinforcement.

**8.4.2** *Deformations from earthquake*

Apart from the hammering of adjacent buildings due to insufficient clearance, referred to in annex A, the oscillations during earthquake may cause considerable damage. Methods of predicting and assessing the damage are still the subject of disagreement between experts and of further research. It is therefore not possible at present to make any recommendation regarding limitation of deformation during earthquakes.

## 9 METHODS OF ASSESSING PROBABLE DEFORMATIONS

The method used to assess or control the probable deformation is a matter for the structural designer. For example, he may determine deformations by calculation or by model or prototype testing; alternatively, he may control them by the adoption of limiting span/depth ratios or other measures. Whatever the method used it should be such that it gives an acceptable probability of satisfying this International Standard and national standards should specify accordingly the details of methods to be used. A probability of not exceeding limits of 97 % is suggested as a desirable minimum.

When deformations are determined by calculation the latter should be based on the characteristic values of actions (loads, moisture movements, thermal movements) and of properties of members (elastic properties, creep and thermal coefficients of materials, and dimensions) making due allowance as provided for in c) of clause 6 for any appropriate combinations of particular parameters.

The calculations should take into account constructional deviations, thermal effects, moisture movements, cracking of reinforced materials, and creep of materials under permanent, and long-term temporary, loads. In addition the assistance received from various sources (for example partial fixity at ends of beams and slabs, partial support from partitions), which cannot be sufficiently relied upon when assessing strength properties, may be taken into account.



In calculating any required camber, it is suggested that the magnitude of the action involved be the mean value.

The deformation limitation to be met is the most severe of the values given in the national standard for any particular criterion.



## 10 RESPONSIBILITY OF DESIGNER

Where legislation does not do so, a national standard may specify the extent to which the structural designer is bound by that standard and the extent to which he is free to satisfy himself that deformations are not excessive, having regard to the circumstances of any particular case and bearing in mind the inability of a standard to deal with all such circumstances.

## 11 EXCEPTIONS

Where a numerical limiting value is given in a national standard for any criterion recommended in this International Standard, it shall be permissible for that numerical value to be varied only with the concerted agreement of the controlling authority, the client, the architect, the structural designer and the constructor. Such a variation may be particularly appropriate for temporary buildings, for monumental buildings, for buildings having to satisfy special requirements, and for buildings of unusual type or constructed of unusual materials.

ANNEX A

## SOME TROUBLES THAT MAY BE AVOIDED BY SUITABLE MEASURES

**A.1** Damage by mining subsidence or by movements of moisture-reactive soils (where movements are usually so great that special constructional measures are required).

**A.2** Relative movement between contiguous buildings, or at the point of entry or exit of services, due to differential settlement.

**A.3** Nipping of walls, partitions and services on a ground-bearing floor slab due to differential settlement.

**A.4** Hammering of inadequately spaced buildings during earthquake.

**A.5** Ponding on roofs.

**A.6** Vibrations of cladding, and noises due to oscillations produced by wind.

**A.7** Nipping of windows and doors and jamming or demounting of sliding doors.

**A.8** Thermal expansion, particularly of roofs and exposed columns, and differential thermal expansion of different building materials or of thin exposed members such as cladding.



**A.9** Differential shrinkage of different building materials or of different qualities of the same material, possibly at different stages in their moisture movement.

**A.10** Long term expansion of clay products, particularly in parapets, fascia and floor coverings.



**A.11** Chemical deterioration e.g. formation of sulpho-aluminates, or of rust or other corrosion products.

**A.12** Upward creep deflection of unrestrained pre-stressed roof members.

**A.13** Some types of damage to partitions.