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# Actions on structures

*Actions sur les structures*

Technical Report 6116 was drawn up by Technical Committee ISO/TC 98, *Bases for design of structures*, and approved by the majority of its members. The reason which led to the decision to publish this document in the form of a Technical Report rather than an International Standard is the impact of the revision of ISO 2394, *General principles for the verification of structures*, undertaken by TC 98. The future International Standard will be based partly on this Technical Report which will probably form an integral part of the revised text of ISO 2394.

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## 0 Introduction



This document which has been prepared as a contribution towards the revision of ISO 2394-1973, *General principles for the verification of the safety of structures*, is based on principles worked out by the Joint Committee on Structural Safety (JCSS), taking into account other relevant documents such as the CEB Model Code, CMEA Standards, etc. This document is published as a Technical Report because it covers only some of the problems which enter into the content of ISO 2394, and because the rules for establishing design values and combination values of actions given in this document are closely related to the principles of verification of structural safety currently under review. The document points out the existence of divergences in approach between regional organizations on standardization.

It is hoped to review and possibly transform this document into a standard after the agreement on the new version of ISO 2394 has been reached.

During the preparation of this document care was taken to weigh off the physical and theoretical soundness versus clarity and simplicity. The flexibility of the document which ensures its acceptability to all member bodies, is achieved by the introduction of a large number of decision parameters. These are :

— the reference period $T$ and the probability of non-exceedance $p$ for the characteristic values;

— the partial safety coefficient $\gamma_{fu}$ for the ultimate limit states;

— the coefficients $\psi_0$ and $\gamma_{fu}$ for combination values;

— the number $r_1$ of variable actions for fundamental combinations;

— the fraction $c_1$ and the coefficient $\gamma_{fs}$ for frequent values;

— the fraction $c_2$ and the coefficients $\gamma_{fu}$ and $\gamma_{fs}$ for quasi-permanent values;

— the number $r_2$ of variable actions for long-term combinations.

The adoption of these parameters and their numerical values are left to the discretion of national code committees. A proper calibration of decision parameters should be carried out for those rare situations which — for the sake of simplicity — do not appear explicity in this document (service value and some rare combinations of actions for the serviceability limit states).

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## 1 Scope and field of application

The aim of this document is to create a common basis for the determination of actions for the verification of safety and serviceability of structures.

The document concerns building and civil engineering structures whatever the nature of the material used.

## 2 Terminology

An action $F$ is :

a) an assembly of concentrated or distributed forces acting on the structure (direct actions), or

b) the cause of imposed or constrained deformations in the structure (indirect actions).

An action is considered to be *one* single action if it can be assumed as being stochastically independent, in time and space of any other action acting on the structure.

NOTE — Actions, however, often occur simultaneously and they may be stochastically dependent to some extent. For the sake of calculation, it is more convenient to treat them as single actions. The problem of stochastic dependence may be treated as a special case. To facilitate the calculation of the action effects, it may be convenient to regroup several analogous elementary actions into one composite action or to resolve certain actions into a sum or difference of several components.

Actions and their random variations should normally be established on the basis of reliable observations, tests, or from data supplied by manufacturers of material, equipment, etc.



Other sources of information, for example, judgement on the type of use, legal or physical constraints, may also be taken into account.[1].

## 3 Qualitative classification of actions



### 3.1 General considerations

Actions may be classified according to the variation of their magnitude with time and/or space, or according to the effects of the actions on the structure (static or dynamic).

NOTE — Actions may be further classified according to other criteria.

### 3.2 Classification of actions according to the variation of their magnitude with time

Actions are divided — according to their variation in time — into :

**3.2.1 Permanent actions,** $G$, which are likely to act throughout a given design situation[2] and for which variation in magnitude with time are negligible in relation to the mean value; or those for which the variation is in one sense and the actions attain some limiting values.

The permanent actions include :

a) the weight of structures themselves (except possibly certain parts of this weight during certain phases of construction);

b) the weight of superstructures when appropriate;

c) the forces applied by earth pressure, resulting from the weight of soil;

d) the deformations imposed by the mode of construction of the structure;

1) In existing documents, values obtained within this group of information are described as ''nominal values''.

2) For any structure it is generally necessary to consider several distinct design situations, for example consecutive stages of construction, normal use, changes in use, accidents etc. Separate safety checking is required for each design situation.

e) the actions resulting from shrinkage of concrete, and distortions due to welding;

f) the forces resulting from water pressure when appropriate;

g) the actions resulting from support settlements and mining subsidence;

h) prestressing forces.

**3.2.2 Variable actions,** $Q$, which are unlikely to act throughout a given design situation or for which variations in magnitude with time are not negligible in relation to the mean value.

The variable actions include :

a) loads due to use and occupancy;

b) certain parts of the weight of structures themselves during certain phases of construction;

c) erection loads;

d) all moving loads and their effects;

e) wind loads;

f) snow loads;

g) ice formation;

h) earthquakes[1];

j) the effects of variable level of water surface, when appropriate;

k) temperature changes;

m) wave loads.



For some materials it is useful to distinguish between variable actions of long and short duration, depending upon the behaviour of the structure on which they are acting.

**3.2.3 Accidental actions,** $F_a$, the occurence of which, in any given structure and with a significant value, is unlikely for a period of time under consideration.

In the total population of structures only a limited number of structures will be exposed to an accidental action.

The accidental actions include :

a) collisions;

b) explosions;

c) subsidence of subsoil;

d) tornados in regions not normally exposed to them;

e) earthquakes[1];

f) fire;

g) extreme erosion.

1) Earthquakes may be considered either as a variable action or as an accidental action.

### 3.3 Classification of actions according to their variation in space

Actions are divided — according to their variation in space — into two groups :

a) fixed actions, which have a fixed, spatial distribution over the structure, so that the magnitude of the action is unambiguously determined for the whole structure if it is given for one point;

b) free actions, which may have arbitrary spatial distribution over the structure within given limits.

Actions which cannot be defined as belonging to either of these two groups may be considered as consisting of a fixed part and a free part.

The treatment of free actions needs consideration of different load cases. A load case is determined by fixing the configuration of each of the free actions.

NOTE — In some cases it is necessary to distinguish fixed actions and actions which are movable or act in a probabilistic way at certain points or on certain parts of structures. In such cases and in the absence of a more detailed study, it is generally agreed that such actions are separated into different elementary actions; those applied to points or parts recognized, *a priori*, as the most unfavourable, and those applied to other parts.

### 3.4 Classification of actions according to the structural response

According to the way in which the structure responds to an action it is distinguished between :

a) static actions, which are applied to the structure without causing significant acceleration of the structure or structural member;

b) dynamic actions, which cause significant acceleration of the structure.



Whether or not the action is regarded as a dynamic one is thus dependent on the structure.

NOTE — For simplification, dynamic actions may be often treated as static actions, dynamic effects which depend on the behaviour of the structure, being taken into account by an appropriate increase in the magnitude of actions.



## 4 Quantitative representation of actions

### 4.1 Representative values

An action is specified by its representative value. Each action may have several representative values. The main representative value is the characteristic value of an action. Representative values may also be used to study the effects resulting from frequent or long-term application of an action (frequent and quasi-permanent values). Other representative values may be values for a combination of actions (combination values). It is also possible, in the alternative approach, instead of using these combination values, to modify the safety factors (see 4.3.4).

The characteristic value $F_k$ of an action is a value with an accepted probability $p$ of not being exceeded towards unfavourable values during some reference period, having regard to the intended life of the structure and to the duration of the design situation.

In some cases an action may have two characteristic values : upper and lower. In cases where the effect of a reduction in the action is more dangerous for the structure, the lower values should be taken as the more unfavourable.

### 4.2 Representative values of permanent action, $G$

All representative values of permanent actions, $G$, are in general assumed to be equal to the characteristic values.

a) The weight, $G_o$, of structures themselves is represented, in general, by a unique value calculated from the drawings of the project and the mean unit weight of the materials;

b) The weight of non-structural elements may be represented, where appropriate, by two values, upper and lower, assessed by taking into account all variations which are reasonably foreseeable.

NOTE — For many structures, only the maximum values of weight of non-structural elements are relevant for design.
The minimum value of the weight of certain non-structural elements is often taken as zero.

c) The actions of earth pressure are in the present state of knowledge represented in the same manner, as in b) above.

NOTE — For many structures, only the maximum value of the active earth pressure, and the minimum value of the passive earth pressure, are relevant for design.

d) The actions of pre-stress may be represented by two characteristic values, an upper and a lower; both values depend on the time elapsed since pre-stressing.

e) The deformations imposed by the mode of construction of the structure and by shrinkage, are normally represented by unique values.

NOTE — However, the shrinkage varies with time, and the action of shrinkage during a certain interval of time may be represented by taking into account the values calculated at the beginning and the end of this interval of time.

f) The actions due to settlement and mining subsidence are represented by two values, an upper and a lower which is often zero.

NOTE — Support settlement is generally a composite action representing the global effect of the settlements of various supports. Mining subsidence is generally a succession, sometimes complex, of several forces or imposed deformations. Consideration should be given to possible differential settlement which may be positive or negative.

## 4.3 Representative values of the variable actions

Representative values of the variable actions may be, in general, all those given in 4.1.

**4.3.1 Characteristic values,** $Q_k$, of variable actions are determined by the general definition given in 4.1.



NOTE — If an action satisfies certain conditions of stability, the probability $p$ of non-exceedance during the reference period (see 4.1) may be alternatively expressed by the corresponding return period (mean return period).



Various statistical procedures for determination of characteristic values may be used. One example of such a procedure is given in annex A.

For certain actions dependent on use, the characteristic values may be taken as those values which the users are expected not to exceed.



### 4.3.2 The representative frequenty value

The frequenty value $\psi_1 F_k$ of a variable action may be determined so that the total duration $T_1$ of its exceedance constitutes a small portion $c_1$[1)] of the reference period $T$;

$$T_1 = c_1 T$$

A value of an action, which has a significant number of occurences but a value of $c_1$ below the specified one, should nevertheless be taken as the frequenty value. The same applies for a value which is exceeded frequently, regardless of numerical value of the coefficient $c_1$.

### 4.3.3 The representative quasi-permanent value

The quasi-permanent value $\psi_2 F_k$ of a variable action may be determined so that the total duration $T_2$ of its exceedance constitutes a large portion $c_2$[2)] of the reference period $T$ :

$$T_2 = c_2 T$$

1) For many types of actions where the relevant data are available (for example, stationary normal processes), this is equivalent to the condition :

$$\psi_1 F_k = q_m + k_1 s_q$$

where $q_m$ and $s_q$ are the mean and standard deviation of the instantaneous values of the action, $k_1$ is a coefficient depending on the chosen value of $c_1$ (see annex B). The value of $c_1$ may be taken, for example, as 0,05.

2) For many types of actions this is equivalent to the condition :

$$\psi_2 F_k = q_m + k_2 s_q$$

Usually, the value of $c_2$ will be taken as equal to or greater than 0,5. For $c_2 > 0,5$ the coefficient $k_2$ is in most cases negative.

#### 4.3.4 The representative combination value

The combination value $\psi_0 F_k$, ($\psi_0 \leqslant 1$) takes account of the reduced probability of simultaneous appearance of more than one independent actions all at their characteristic values.

In the alternative approach (see 4.1), the combination coefficient $\psi_0$ takes account of the reduced probability of simultaneous appearance of several independent actions, each at their design value.

The numerical values of $\psi_0$ may depend on the type and number of actions being combined and may take account of past experience of design and use concerning the consequences of overloading.

### 4.4 Representative values of accidental actions $F_a$

Representative values of accidental actions $F_a$ are unique values, specified by a decision of competent authorities, determining the level of safety in terms of various criteria of a general nature (notably economic) or by a statement of the engineer that a higher value should be used to take account of the serious consequences of a gross error.

## 5 Design values of actions

### 5.1 General

Actions are introduced into calculations by their design values, which are obtained from representative values by multiplication with partial safety coefficients $\gamma_f$, according to the following table :



**Table — Design values**

| Actions | Representative values Designation | Symbol | Design values |
|---|---|---|---|
| **Permanent and variable actions** | Characteristic | $F_k$ | $\gamma_f F_k$ |
| **Variable actions** | Combination* | $\psi_0 F_k$ | $\gamma_f \psi_0 F_k$ |
| | Frequent | $\psi_1 F_k$ | $\gamma_f \psi_1 F_k$ |
| | Quasi-permanent | $\psi_2 F_k$ | $\gamma_f \psi_2 F_k$ |
| **Accidental actions** | Unique | $F_a$ | $F_a$ |



* For an alternative method of its determination, see 4.1 and 4.3.4.

Characteristic and combination design values of variable actions serve mainly for checking the ultimate limit states. Design frequent and quasi-permanent values serve mainly for checking the serviceability limit states : frequent values for short-term, and quasi-permanent values for long-term behaviour of the structure.[1] However, the specific numerical values may be dependent on the type of structure and the limit state considered.

### 5.2 The partial safety coefficients[2]

The partial safety coefficients $\gamma_f$ take account of :

a) the possibility of unfavourable deviations of the actions from their representative values;

b) the uncertainty of the loading model;

c) the possible inaccurate assessment of the effects of the action insofar as they are independent of material properties.

The numerical values of the coefficients $\gamma_f$ reflect the national economic and social policy and relevant experience. This may be achieved by introducing different safety classes for different types of structures and for different design situations.

1) The frequent and quasi-permanent values may depend on design situations. It is related to structural safety.

2) Sub-clause 5.2 is of an informative character. Formally, it belonged to the basic International Standard on structural safety.

The partial safety coefficients $\gamma_f$ depend on the limit state considered and the design situation. In particular, a set of $\gamma_{fu}$ may be chosen for the verification of ultimate limit states, and another set of $\gamma_{fs}$ for serviceability limit states.

The partial safety coefficient $\gamma_f$ may be broken down (for example, for easier estimation) into several different factors, each taking account of one or more of the aspects mentioned.

For the purpose of verification of the ultimate limit states, an accidental action should be represented by a unique value equal to its characteristic value (i.e. $\gamma_{fu}$ may be assumed to be equal to unity).

In most cases partial safety coefficients $\gamma_{fs}$ for serviceability limit states may be assumed to be equal to unity.[1)]

## 6 Combinations of actions

### 6.1 General

A combination of actions is an assembly of their design values used for the verification of the structural safety in a limit state under simultaneous influence of a set of different actions. The rules of combination apply to single actions.[2)]

Actions, which are mutually exclusive, should not enter together into the combination.

The actions should be combined so that they produce the most unfavourable effect on the structure with regard to the limit state considered.

### 6.2 Ultimate limit states



In the ultimate limit states, two types of combinations of actions should be applied : fundamental combinations and accidental combinations. Different $\psi_o$ values may be used for different types of combinations.

**6.2.1 Fundamental combinations** should include :



a) the design values $\gamma_{Gui}\, G_{ki}$ of all permanent actions;

b) the design value of one variable action $\gamma_{Qui}\, Q_{ki}$;

c) the design combination values of a chosen number $r_1$ of other variable actions $\gamma_{Qui}\, \psi_{oi}\, Q_{ki}$ $(i = 2, 3, \ldots, r_1)$;

d) the design quasi-permanent values of the appropriate remaining variable actions $\gamma_{Qui}\, \psi_{2i}\, Q_{ki}$ $(i = r_1 + 1, r_1 + 2, \ldots)$.

NOTE — The following combinations may also be taken as fundamental :

a) the design values $\gamma_{Gui}\, G_{ki}$ of all permanent actions;

b) the design combination values $\gamma_{Qui}\, \psi_{oi}\, Q_{ki}$ of all variable actions.

In this case the numerical value of $\psi_o$ should not fall below $\psi_2$.

**6.2.2 Accidental combinations** should include :

a) the design values $\gamma_{Gui}\, G_{ki}$ of all permanent actions;

b) the design value of one accidental action $F_{a1}$;

c) the design combination value of one variable action $\gamma_{Qui}\, \psi_{oi}\, Q_{ki}$;

d) the design quasi-permanent values of the appropriate remaining variable actions $\gamma_{Qui}\, \psi_{2i}\, Q_{ki}$ $(i = 2, 3, \ldots)$.

In the case of insufficient statistical information, the design combination value may be replaced by the design frequent value.

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1) The problem of possible inaccurate assessment of the effects of the action will be dealt with in the basic International Standard on structural safety.

2) Correlated actions or actions of the same type, for example loading of different floors of the same building should be analysed beforehand, and then introduced into the combination as one single action.

### 6.3 Serviceability limit states

In the serviceability limit states, two types of combinations of actions should be applied : combination for long-term effects (quasi-permanent combination), and combinations for short-term effects (frequent combination).

Other types of combinations may also be adopted when appropriate, particularly for short-term effects of the actions.

**6.3.1 Combinations for long-term effects** should include :

a) the design values $\gamma_{Gsi} G_{ki}$ of all permanent actions;

b) the design quasi-permanent values of all variable actions $\gamma_{Qsi} \psi_{2i} Q_{ki}$ ($i$ = 1, 2, . . .).

**6.3.2 Combinations for short-term effects** should include :

a) the design values $\gamma_{Gsi} G_{ki}$ of all permanent actions;

b) the design frequent values of a chosen number $r_2$ of variable actions $\gamma_{Qsi} \psi_{1i} Q_{ki}$ ($i$ = 1, 2, . . ., $r_2$);

c) the design quasi-permanent values of the appropriate remaining variable actions $\gamma_{Qsi} \psi_{2i} Q_{ki}$ ($i = r_2 + 1, r_2 + 2, . . .$).

# Annex A

## Example of a statistical procedure for determination of the characteristic value of an action

In this annex, a method is proposed for determination of characteristic values of variable static actions which can be described by one parameter and considered as stationary stochastic processes. The intensity of the action is meant as the only random parameter.

**A.1** For each type of variable action choose an appropriate time interval $t_o$ called *unit observation period.*

The length of the unit observation period should be linked in a natural way with the physical character of the action considered (for example, a year for climatic actions).

It should be long enough to consider maximum values $Q$ of the action in two successive unit observation periods as independent observations. Moreover, a large extremal value of $Q$ should be likely to occur in each unit observation period.

The unit observation period should not be chosen too long (probably not longer than a year), so that sufficient data on $Q$ could be collected in a reasonable time and with reasonable effort.

**A.2** Note the largest value $Q_i$ of the action in each of $r$ subsequent unit observation periods, constituting the *total observation period.*



$$T_o = r \cdot t_o$$

The total observation period is an interval movable along the time axis. If we decide to revise the code after, say, ten years, then (assuming that unit observation periods are in years) we should leave out the ten oldest observations and add ten new ones. In this way trends could be reflected in our forecasts. For this reason, the total observation period should not be too long, probably not longer than 30 years for climatic actions, and 20 years for other actions.

On the other hand the total observation period should not be chosen too short in order to make reliable forecasts of future loads.

If new observations reveal no trends, then they can be added to the old ones and all the data pooled together.

**A.3** Estimate the intended life time of the structure being designed.

For example, the intended life time could be 5 to 10 years for temporary structures, 30 to 40 years for industrial buildings, 60 to 80 years for dwelling houses, and 100 to 200 years for bridges and monumental buildings.

**A.4** Arrange all $r$ observations $Q_i$ in an increasing order, and plot them on a probability paper for the extremal distribution type I (see figure 1). The vertical axis should be scaled regularly for $Q$. For the $m-$th observation $Q_m$ (counting from the bottom), ascribe the coordinates :

Vertically $Q = Q_m$

Horizontally $F(Q) = \dfrac{m}{r+1}$

The observations plotted should be scattered about a straight line (see figure 2). This is the proof that there is a good fit between the theoretical and empirical distributions. The straight line may be considered as the *line of prognosis.*

In this method, $Q$ is the basic random variable, in compliance with the principle that basic random variables should be direct measurable quantities. $Q$ is an extreme value and its asymptotic distribution should be theoretically the extremal distribution type I (Gumbel) for unlimited actions, and the extremal distribution type III (Weibull) for limited actions. For Weibull distribution, the same probability paper may be used, after a logarithmic transformation.

More rigorously, the goodness of fit should be tested by the construction of control bands.