# EN 1991 – Eurocode 1: Actions on structures
# Part 1-6 General actions
# Actions during execution

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# EN 1991-1-6: Scope



EN 1991-1-6 gives principles and general rules for the determination of **actions to be taken into account during the execution of buildings and civil engineering works**.

It may also be used as guidance for the determination of actions to be taken into account during:
- structural alterations
- reconstruction
- partial or full demolition.

It also gives rules for the determination of actions to be used for the design of auxiliary construction works (*falsework, scaffolding, propping systems, cofferdam, bracing…*), needed for the execution phases.

# EN 1991-1-6: Design Situations and limit states



During execution the following design situations will be taken into account as appropriate:

**Transient**

**Accidental**

**Seismic**

Any selected design situation will be in accordance with the execution process anticipated in the design, and with any revision occurred.

# EN 1991-1-6: Design Situations and limit states



Any selected **transient** design situation be associated with a **nominal duration equal to, or greater than the anticipated duration of the stage of execution under consideration**.

The design situations should take into account the likelihood for any corresponding return periods of variable actions (e.g. climatic actions).

The return periods for the assessment of characteristic values of variable actions during execution may be defined in the **National Annex** or for the individual project.

Recommended return periods of climatic actions are given, depending on the nominal duration of the relevant design situation.

# EN 1991-1-6: Design Situations and limit states



Table 3.1 Recommended return periods for the determination of the characteristic values of climatic actions

| Nominal duration of the execution phase | Return period (years) |
|---|---|
| ≤ 3 days | 2 [a] |
| ≤ 3 months (but > 3 days) | 5 [b] |
| ≤ 1 year (but > 3 months) | 10 |
| > 1 year | 50 |

[a] A nominal duration of three days, to be chosen for short execution phases, corresponds to the extent in time of reliable meteorological predictions for the location of the site. This choice may be kept for a slightly longer execution phase if appropriate organizational measures are taken. The concept of mean return period is generally not appropriate for short term duration.

[b] For a nominal duration of up to three months actions may be determined taking into account appropriate seasonal and shorter term meteorological climatic variations. For example, the flood magnitude of a river depends on the period of the year under consideration.

A minimum wind velocity during execution may be defined in the National Annex or for the individual project. The recommended basic value for durations of up to 3 months is **20m/s** in accordance with EN 1991-1-4: Wind Actions.

Relationships between characteristic values and return period for climatic actions are given in the appropriate Parts of EN 1991.

# Example: Snow loads according to return period [Annex D of EN 1991-1-3]

If the available data show that the annual maximum snow load can be assumed to follow a Gumbel probability distribution, then the relationship between the *characteristic value of the snow load on the ground* and the *snow load on the ground for a mean recurrence interval of n years* is given by:

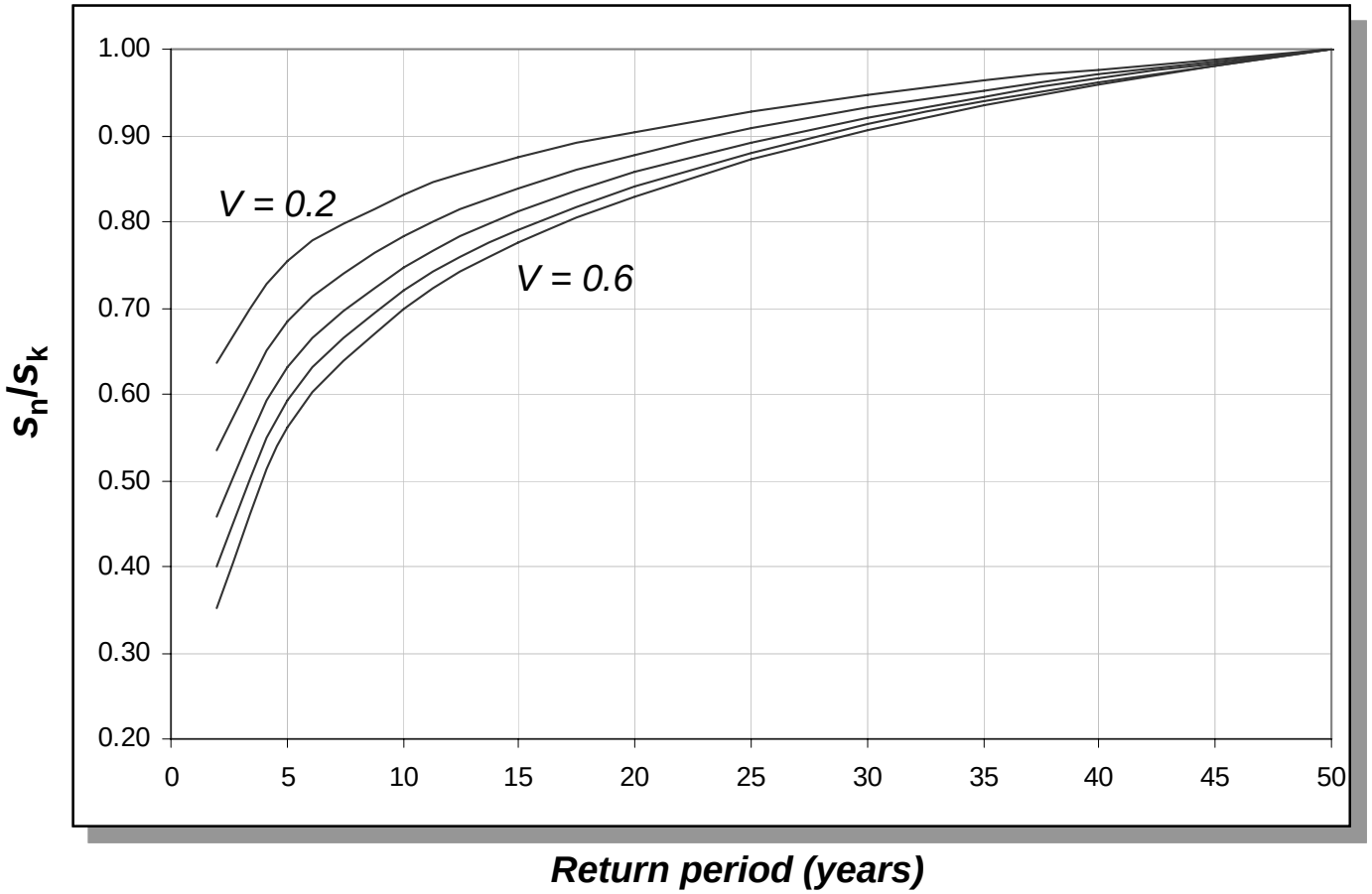
$$s_n = s_k \left\{ \frac{1 - V\frac{\sqrt{6}}{\pi}\left[\ln(-\ln(1-P_n)) + 0{,}57722\right]}{(1 + 2{,}5923V)} \right\}$$

$s_k$ is the characteristic snow load on the ground (with a return period of 50 years)

$P_n$ is the annual probability of exceedence (approx. = *1/n*)

$V$ is the coefficient of variation of annual max. snow loads

# Snow loads according to return period [EN 1991-1-3]



# EN 1991-1-6: Ultimate Limit States



Ultimate limit states need to be verified for all selected *transient*, *accidental* and *seismic* design situations as appropriate during execution in accordance with EN 1990.

The combinations of actions for *accidental design situations* can either include the accidental action explicitly or refer to a situation after an accidental event.

Generally, *accidental design situations* refer to exceptional conditions applicable to the structure or its exposure, such as:

- impact, local failure and subsequent progressive collapse,
- fall of structural or non-structural parts, and,
- in the case of buildings, abnormal concentrations of building equipment and/or building materials, water accumulation on steel roofs, fire, etc.

# EN 1991-1-6: Ultimate Limit States



The verifications of the structure should take into account the appropriate **geometry** and **resistance** of the partially completed structure corresponding to the selected design situations.

Geometry of the partially completed resisting structure

Resistance of the lower floor, which has not necessarily attained its full strength.

# EN 1991-1-6: Ultimate Limit States



## geometry

1987 – Bridgeport Connecticut (US)
Inadequate temporary connections + instability of steel members *(*)*

## resistance

1973 - Bailey's Crossroad – Fairfax (US)
Construction of a 26-story building.
Concrete was being placed at the 24$^{th}$ floor and shoring was simultaneously being removed at the 22$^{nd}$ floor cast two weeks before.
Insufficient shear resistance of concrete slabs caused progressive collapse *(*)*

*(*) K. Carper "Beware of vulnerabilities during construction" - Construction and equipment, 3/2004*

## Ultimate limit states of STR/GEO - Fundamental combination for **transient** design situations.

*Expression (6.10) EN 1990*

$$\sum_{j\geq 1}\gamma_{G,j}G_{k,j}\,"+"\,\gamma_P P"+"\,\gamma_{Q,1}Q_{k,1}\,"+"\sum_{i>1}\gamma_{Q,i}\psi_{0,i}Q_{k,i}$$

*Expressions (6.10a) and (6.10b) EN 1990*

$$\begin{cases}\sum_{j\geq 1}\gamma_{G,j}G_{k,j}\,"+"\,\gamma_P P"+"\sum_{i\geq 1}\gamma_{Q,i}\psi_{0,i}Q_{k,i}\\ \sum_{j\geq 1}\xi_j\gamma_{G,j}G_{k,j}\,"+"\,\gamma_P P"+"\,\gamma_{Q,1}Q_{k,1}\,"+"\sum_{i>1}\gamma_{Q,i}\psi_{0,i}Q_{k,i}\end{cases}$$

$$0{,}85 \leq \xi \leq 1{,}00$$

# EN 1991-1-6: Ultimate Limit States



## **Accidental** design situation

*Expression (6.11b) EN 1990*

$$\sum_{j\geq 1} G_{k,j} "+" P "+" A_d "+" (\psi_{1,1} \text{ or } \psi_{2,1}) Q_{k,1} "+" \sum_{i>1} \psi_{2,i} Q_{k,i}$$

## **Seismic** design situation

*Expression (6.12b) EN 1990*

$$\sum_{j\geq 1} G_{k,j} "+" P "+" A_{Ed} "+" \sum_{i>1} \psi_{2,i} Q_{k,i}$$

# EN 1991-1-6: Serviceability Limit States



- The **SLS** for the selected design situations during execution needs to be verified, as appropriate, in accordance with EN 1990.
- The criteria associated with the **SLS** during execution should take into account the ***requirements for the completed structure***.
- Operations which can cause *excessive cracking* and/or *early deflection during execution* and which may adversely affect the durability, fitness for use and/or aesthetic appearance in the final stage has to be avoided.

# EN 1991-1-6: Serviceability Limit States



The combinations of actions should be established in accordance with EN 1990. In general, the relevant combinations of actions for transient design situations during execution are:

- the **characteristic** combination
- the **quasi-permanent** combination

# EN 1991-1-6: Serviceability Limit States



## **SLS**: combinations of actions.

*Characteristic combination (irreversible SLS)*

$$\sum_{j\geq 1} G_{k,j} \text{"+"} P \text{"+"} Q_{k,1} \text{"+"} \sum_{i>1} \psi_{0,i} Q_{k,i}$$

*Quasi-permanent combination (reversible SLS)*

$$\sum_{j\geq 1} G_{k,j} \text{"+"} P \text{"+"} \sum_{i\geq 1} \psi_{2,i} Q_{k,i}$$

# Classification & representation of actions



Actions during execution are classified in accordance with EN 1990, and may include:

- those **actions that are not construction loads**; and
- **construction loads**

Both types of actions are classified (tables 2.1 and 2.2) depending on:

- Variation in time (*permanent, variable, accidental*)
- Origin (*direct, indirect*)
- Spatial variation (*fixed, free*)
- Nature (*static, dynamic*)

# Classification & representation of actions



**Table 2.1 Classification of actions (other than construction loads) during execution stages.**

| Related clause in this standard | Action | Classification | | | | Remarks | Source |
|---|---|---|---|---|---|---|---|
| | | Variation in time | Classification / Origin | Spatial variation | Nature (static/dynamic) | | |
| 4.2 | Self weight | Permanent | Direct | Fixed with tolerance / free | Static | Free during transportation / storage. Dynamic if dropped. | EN 1991-1-1 |
| 4.3 | Soil movement | Permanent | Indirect | Free | Static | | EN 1997 |
| 4.3 | Earth pressure | Permanent / variable | Direct | Free | Static | | EN 1997 |
| 4.4 | Prestressing | Permanent / variable | Direct | Fixed | Static | Variable for local design (anchorage). | EN 1990, EN 1992 to EN 1999 |
| 4.5 | Pre-deformations | Permanent / variable | Indirect | Free | Static | | EN 1990 |
| 4.6 | Temperature | Variable | Indirect | Free | Static | | EN 1991-1.5 |
| 4.6 | Shrinkage/hydration effects | Permanent / variable | Indirect | Free | Static | | EN 1992, EN 1993, EN1994 |
| 4.7 | Wind actions | Variable / accidental | Direct | Fixed/free | Static / dynamic | (*) | EN 1991-1-4 |
| 4.8 | Snow loads | Variable/accidental | Direct | Fixed/free | Static / dynamic | (*) | EN 1991-1-3 |
| 4.9 | Actions due to water | Permanent / variable/accidental | Direct | Fixed/free | Static / dynamic | Permanent / variable according to project specifications. Dynamic for water currents if relevant | EN 1990 |
| 4.10 | Atmospheric ice loads | Variable | Direct | Free | Static / dynamic | (*) | ISO 12494 |
| 4.12 | Accidental | Accidental | Direct/indirect | Free | Static/dynamic | (*) | EN 1990, EN 1991-1-7 |
| 4.13 | Seismic | Variable / accidental | Direct | Free | Dynamic | (*) | EN 1990 (4.1), EN1998 |

(*): The source documents need to be examined with the National Annexes in which additional relevant information may be provided.

# Construction Loads



***Construction loads $Q_c$*** may be represented in the appropriate design situations (see EN 1990), either, as one single variable action, or where appropriate different types of construction loads may be grouped and applied as a single variable action. Single and/or a grouping of construction loads should be considered to act simultaneously with non construction loads as appropriate.

$Q_{ca}$
$Q_{cb}$
$Q_{cc}$
$Q_{cd}$
$Q_{ce}$
$Q_{cf}$

**6 different sources**

# Classification of Construction Loads



## *Construction loads $Q_c$* are classified as variable actions

Table 2.2 Classification of construction loads.

| Constr. Load | Action (short descrip-tion) | Classification | | | | Remarks | Source |
|---|---|---|---|---|---|---|---|
| | | Variation in time | Classification / Origin | Spatial variation | Nature (static/dynamic) | | |
| $Q_{ca}$ | Personnel and hand tools | Variable | Direct | Free | Static | | |
| $Q_{cb}$ | Storage movable items | Variable | Direct | Free | Static / dynamic | Dynamic in case of dropped loads | EN 1991-1-1 |
| $Q_{cc}$ | Non-permanent equipment | Variable | Direct | Fixed / free | Static / dynamic | | EN 1991-3 |
| $Q_{cd}$ | Movable heavy machinery and equipment | Variable | Direct | Free | Static / dynamic | | EN 1991-2, EN 1991-3 |
| $Q_{ce}$ | Accumulation of waste materials | Variable | Direct | Free | Static / dynamic | Can impose loads on e.g. vertical surfaces also | EN 1991-1-1 |
| $Q_{cf}$ | Loads from parts of structure in temporary states | Variable | Direct | Free | Static | Dynamic effects are excluded | EN 1991-1-1 |

Where Construction Loads are classified as **fixed**, they should be defined tolerances for possible deviation from the theoretical position.

Where Construction Loads are classified as **free**, they should be defined limits of the area where they should be moved or positioned.

## *Construction loads $Q_{ca}$ Personnel and hand tools*

**Working personnel, staff and visitors, possibly with hand tools or other small site equipment.**

Modelled as a uniformly distributed load $q_{ca}$ and applied as to obtain the most unfavourable effects.

The recommended value is : $\boldsymbol{q_{ca,k} = 1{,}0\ kN/m^2}$

# Representation of Construction Loads



## *Construction loads $Q_{ca}$ Personnel and hand tools*

The recommended value has been derived from investigations on construction sites(*), with regard to the following stages of construction:

1. before pouring of concrete slab;

2. after pouring of concrete slab, during the preparation of the next floor.

| Measurement grid size [m²] | Mean Load [kN/m²] | 10% fractile Load [kN/m²] | 1% fractile Load [kN/m²] | 0,5% fractile Load [kN/m²] |
|---|---|---|---|---|
| 2,32 | 0,31 | 1,08 | 2,93 | 3,34 |
| 5,95 | 0,30 | 0,92 | 2,00 | 2,39 |
| 9,25 | 0,29 | 0,80 | 2,18 | 2,68 |
| 20,90 | 0,30 | 0,73 | 1,58 | 1,94 |
| 37,16 | 0,28 | 0,72 | 1,43 | 1,46 |

As an example: the 5% fractile value for the 9,25 m², is 1,23 kN/m² (*Gumbel distribution of the random variable is assumed*).

*(*) "Cast-in-place Concrete in Tall Building Design and Construction" – Council on Tall Buildings and Urban Habitat Committee 21 D. Mc Graw-Hill Inc. – 1991 – Chapter 2: Construction loads.*

# Representation of Construction Loads



## *Construction loads $Q_{cb}$ Storage of movable items e.g.:*

1. Building and construction materials, precast elements;
2. Equipment.

Modelled as a free action and represented by a UDL $q_{cb}$ and a concentrated load $F_{cb}$

For bridges, the following values are recommended minimum values:

$q_{cb,k} = 0{,}2$ kN/m$^2$

$F_{cb,k} = 100$ kN

# Representation of Construction Loads



## *Construction loads $Q_{cc}$ Non-permanent equipment in position for use:*

- Static (*e.g. formwork panels, scaffolding, falsework, machinery, containers*)
- During movement (*e.g. travelling forms launching griders and nose, counterweights*)



Unless more accurate information is available, they may be modelled by a uniformly distributed load with a recommended minimum characteristic value of $q_{cc,k}$ = **0,5 kN/m²**

# Representation of Construction Loads



***Construction loads $Q_{cd}$ Movable heavy machinery and equipment usually wheeled or tracked e.g.:***

Cranes, lifts, vehicles, lift trucks, power installations, jacks, heavy lifting devices.

When not defined in the project specification, information for the determination of actions may be found in:

- EN 1991-2 for actions due to vehicles
- EN 1991-3 for actions due to cranes.

# Representation of Construction Loads



***Construction loads $Q_{ce}$ Accumulation of waste materials e.g.:***

surplus construction materials excavated soil or demolition materials.

These loads are taken into account by considering possible mass effects on horizontal, inclined and vertical elements (such as walls).
These loads may vary significantly, and over short time periods, depending on types of materials, climatic conditions, build-up and clearance rates.

# Representation of Construction Loads



***Construction loads $Q_{cf}$ Loads from part of structure in a temporary state*** before the final design actions take effect e.g. loads from lifting operations.

Taken into account and modelled according to the planned execution sequences, including the consequences of those sequences (e.g. loads and reverse load effects due to particular processes of construction, such as assemblage).

# Representation of Construction Loads



## *Construction loads during the casting of concrete (4.11.2)*

Actions to be taken into account simultaneously during the casting of concrete may include:

- working personnel with small site equipment ($Q_{ca}$);
- formwork and load-bearing members ($Q_{cc}$);
- the weight of fresh concrete (which is one example of $Q_{cf}$), as appropriate.

# Representation of Construction Loads

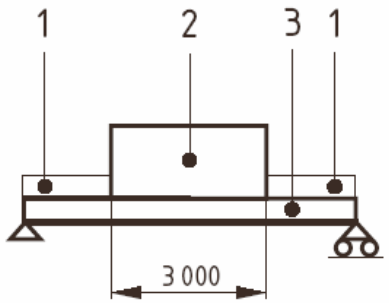


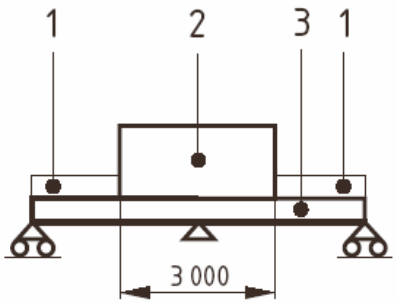
$Q_{ca}$, $Q_{cc}$ and $Q_{cf}$ may be given in the National Annex.

Recommended values for fresh concrete ($Q_{cf}$) may be taken from Table 4.2 and EN 1991-1-1, Table A.1. Other values may have to be defined, for example, when using self-levelling concrete or pre-cast products.

**Table 4.2 : Recommended characteristic values of actions due to construction loads during casting of concrete**

| Action | Loaded area | Load in kN/m$^2$ |
|---|---|---|
| (1) | Outside the working area | 0,75 covering $Q_{ca}$ |
| (2) | Inside the working area 3 m x 3 m (or the span length if less) | 10 % of the self-weight of the concrete but not less than 0,75 and not more than 1,5 Includes $Q_{ca}$ and $Q_{cf}$ |
| (3) | Actual area | Self-weight of the formwork, load-bearing element ($Q_{cc}$) and the weight of the fresh concrete for the design thickness ($Q_{cf}$) |



# EN 1991-1-6: Accidental Actions



**Accidental actions** such as impact from construction vehicles, cranes, building equipment or materials in transit (e.g. skip of fresh concrete), and/or local failure of final or temporary supports, including dynamic effects, that may result in collapse of load-bearing structural members, shall be taken into account, where relevant.

Abnormal concentrations of building equipment and/or building materials on load-bearing structural members should also be taken into account

**Dynamic effects** may be defined in the National Annex or for the individual project. The recommended value of the dynamic amplification factor is 2. In specific cases a dynamic analysis is needed.

# EN 1991-1-6: Seismic Actions



**Seismic actions** should be determined according to **EN 1998**, taking into account the reference period of the considered transient situation.

The design values of ground acceleration and the importance factor $\gamma_I$ may be defined in the National Annex or for the individual project.

# EN 1991-1-6: Annex A1 (normative)



## *Supplementary rules for buildings*

Representative values of the variable action due to **construction loads** may be set by the National Annex, within a recommended range of $\psi_0$ **= 0,6 to 1,0**.

The recommended value of $\psi_0$ is 1,0.

The minimum recommended value of $\psi_2$ is **0,2** and it is further recommended that values below 0,2 are not selected

For the verification of serviceability limit states, the combinations of actions to be taken into account should be the **characteristic** and the **quasi-permanent** combinations.

# EN 1991-1-6: Annex A2 (normative)



## *Supplementary rules for bridges*

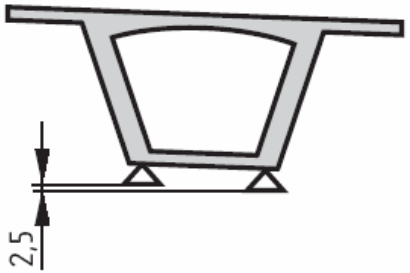
For the incremental launching of bridges the design values for vertical deflections may be found in the National Annex.

The recommended values are:

a) ± 10 mm longitudinally for one bearing, the other bearings being assumed to be at the theoretical level;

b) ± 2,5 mm in the transverse direction for one bearing, the other bearings being assumed to be at the theoretical level.


a) Longitudinal deflection




b) Differential deflection in the transverse direction

## *Supplementary rules for bridges – Construction Loads*

For the incremental launching of bridges horizontal forces due to friction effects should be determined, and applied between the bridge structure, the bearings and the supporting structures, with dynamic action effects taken into account where appropriate.

It is recommended that the design value of the total horizontal friction forces should be not less than 10 % of the vertical loads, and should be determined to give the least favourable effects.

The horizontal friction forces at every pier should be determined with the appropriate friction coefficients, $\mu_{min}$ and $\mu_{max}$ (defined in the National Annex).

Unless more accurate values are available from tests for movements on very low friction surfaces (e.g. PTFE) the recommended values are :

$\mu_{min} = 0$

$\mu_{max} = 0{,}04$

# EN 1991-1-6: Annex B (informative)



## *Actions on structures during alteration, reconstruction or demolition*

The actual performance of structures affected by deterioration should be taken into account in the verification of the stages for reconstruction or demolition. The investigation of structural conditions to enable the identification of the load-bearing capacity of the structure and to prevent unpredictable behaviour during reconstruction or demolition should be undertaken.

The reliability for the remaining structure or parts of the structure under reconstruction, partial or full demolition should be consistent with that considered in the Eurocodes for completed structures or parts of structures.

# Thank you for your attention