Eurocode 1: Actions on structures – Part 1-1: General actions - Densities, self-weight, imposed loads for buildings

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Use of EN 1991-1-1

- Gives design guidance and actions for the structural design of buildings and civil engineering works, including the following aspects :
  - densities of construction materials and stored materials
  - self-weight of construction elements, and
  - imposed loads for buildings
- Is intended for Clients, Designers, Contractors and Public Authorities
- Is intended to be used with EN 1990 (Basis of Structural Design), other parts of EN 1991 (Actions) and EN 1992 to EN 1999 (Materials Eurocodes) for the design of structures.

LINKS BETWEEN THE EUROCODES

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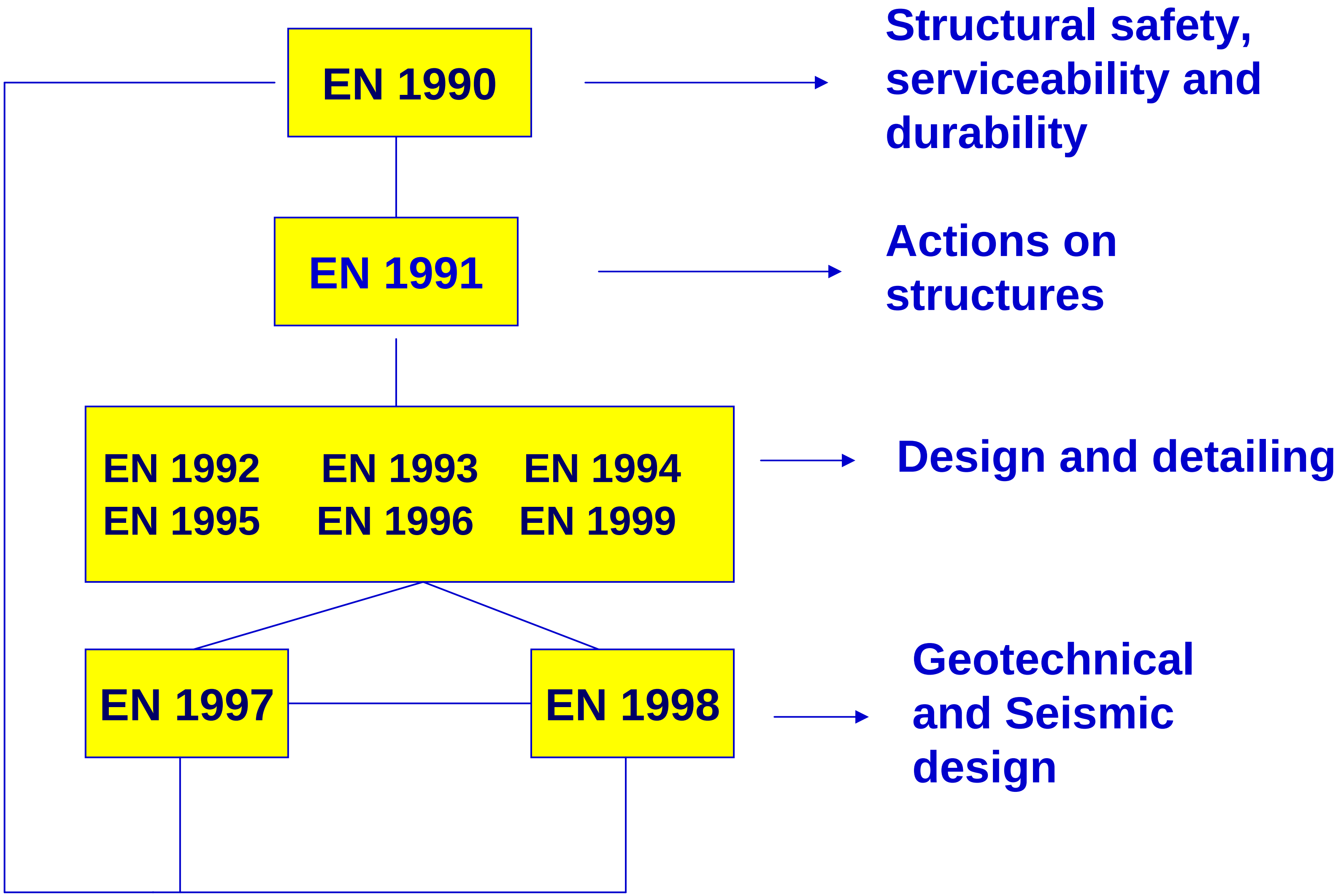

Programme of implementation of EN 1991-1-1

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- Received positive vote as EN in April 2002 ***(Supersedes ENV 1991-2-1 : 1995)***
- Published by CEN in July 2002
- Confirmed in 2007 for a further period of 5 years
- Implementation on a national level in the Member States (National Standard EN 1991-1-1 and National Annex) still in process
- Withdrawal of conflicting standards – probably by 2009/2010

Contents of EN 1991-1-1

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Scope of EN 1991-1-1

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- Design guidance and actions for the structural design of buildings and civil engineering works, including:
  - densities of construction materials, additional materials for bridges and stored materials *(Section 4 & Annex A)*,
  - self-weight of construction elements *(Section 5)*, and
  - imposed loads for building floors and roofs *(Section 6)*, according to category of use :
    - residential, social, commercial and administration areas;
    - garage and vehicle traffic areas (for gross vehicle weight < 160 kN);
    - areas for storage and industrial activity;
    - roofs;
    - helicopter landing areas.
- Actions on silos and tanks caused by water or other materials are dealt in EN 1991-4
- Snow load on roofs is dealt in EN 1991-1-3

Classification of actions

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(Reminder from EN 1990)

- Variation in time: ***Permanent, Variable or Accidental***
- Origin: ***Direct or Indirect***
- Spatial Variation: ***Fixed or Free***
- Nature and/or structural response: ***Static or Dynamic***

Classification of actions (cont.)

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- Self-weight of construction works: generally a *Permanent Fixed* action, however
- If *Variable with time* then represented by upper and lower characteristic values, and
- If *Free* (e.g. moveable partitions) then treated as an additional imposed load.
- Ballast and earth loads on roofs/terraces: *Permanent* with variations in properties (moisture content, depth) during the design life being taken into account.

Classification of actions (cont.)

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- Imposed loads (on buildings) : generally *Variable Free* actions, however loads resulting from impacts on buildings due to vehicles or accidental loads should be determined from EN 1991-1-7. Imposed loads for bridges are given in EN 1991-2. Also :
- Imposed loads generally *Quasi-static* actions and allow for limited dynamic effects in static structures, if there is no risk of resonance.
- Actions causing significant acceleration of structural members are classified as *Dynamic* and need to be considered via a dynamic analysis
- However for ***fork-lift trucks*** and ***helicopters*** additional inertial loads from hoisting and take-off/landing are accounted for through a *dynamic magnification factor* φ applied to appropriate *static* load values

Design situations – Permanent loads

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- The total self-weight of structural and non-structural members is taken as a ***single action*** when ***combinations of actions*** are being considered

- Where it is intended to add or remove structural or non-structural members after construction critical load cases need to be identified and taken into account.

- Water level is taken into account for relevant design situations, as is the source and moisture content of materials in buildings used for storage purposes.

Design situations – Imposed loads

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- Where areas are likely to be subjected to different categories of loadings, the critical load case needs to be identified and considered

- When ***imposed loads*** act simultaneously with ***other variable actions*** (e.g. wind, snow, cranes or machinery) the total of those imposed loads may be considered as a single action. However, for roofs of buildings, imposed loads should not be considered to act simultaneously with snow loads or wind actions.

Probabilistic aspects

- ***Self-weight*** may be usually determined as a product of the volume and the density, which both as random variables that may be described by ***normal distributions***, with a mean value very close to their nominal value.

- ***Imposed loads*** are usually described by ***a Gumbel distribution***, although Gamma distributions may also be used for the sustained (long-term) loads and exponential distributions for the intermittent (short-term) loads.

Densities of construction and stored materials

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- *Characteristic values* of densities of construction and stored materials should generally be used. ***(If there is a significant scatter - e.g. due to their source, water content etc. – an upper and a lower value should be used).***
- Where *only mean values are available*, they should be taken as *characteristic* values in the design.
- Mean values for a large number of different materials are given in EN 1991-1-1 Annex A.
- For materials not in Annex A either:
  - the characteristic value of density needs to be determined in the National Annex,
  - a reliable direct assessment is carried out (eventually according to EN 1990 Annex D).

Self-weight of construction works

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- Generally represented by a ***single characteristic value*** calculated from nominal dimensions, characteristic values of densities and including, where appropriate, ancillary elements, e.g. non-structural elements and fixed services, weight of earth and ballast.
- Non-structural elements include :

  - roofing;
  - surfacing and coverings;
  - partitions and linings;
  - hand rails, safety barriers, parapets and curbs;
  - wall cladding;
  - suspended ceilings;
  - thermal insulation;
  - fixed services

Self-weight of construction works (cont.)

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- Fixed services include :

  - equipments for lifts and moving stairways;

  - heating, ventilating and air conditioning equipment;

  - electrical equipment;

  - pipes without their contents;

  - cable trunking and conduits

- Loads due to movable partitions are treated as *imposed loads*, but an equivalent uniformly distributed load may be used.

Self-weight of construction works (cont.)

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Additional provisions specific for bridges :

- For ballast on railway bridges or fill above buried structures the upper and lower characteristic values of densities should be taken into account.
- The upper and lower characteristic values of the ballast depth should be considered as deviating from the nominal depth by ± 30% .
- The upper and lower characteristic values of the thickness due to waterproofing, surfacing and other coatings should be considered as deviating from the nominal value by ± 20% (if a post-execution coating is included in the nominal value) otherwise +40% and –20%, respectively.
- The upper and lower characteristic values of the self-weight of cables, pipes and service ducts should be considered as deviating from the mean value by ± 20% .

Imposed loads on buildings

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- *Characteristic values* of imposed loads for floors and roofs for the following types of occupancy and use:

  - residential, social, commercial and administration areas

  - garage and vehicle traffic

  - areas for storage and industrial activities

  - roofs

  - helicopter landing areas

  - barriers and walls having the function of barriers.

Representation of actions

- Imposed loads on buildings are those arising from occupancy and the values given include :

  - normal use by persons;

  - furniture and moveable objects;

  - vehicles;

  - rare events such as concentrations of people and furniture, or the moving or stacking of objects during times of re-organisation and refurbishment

- Floor and roof areas in buildings are sub-divided into 11 *categories* according to use; loads specified are represented by ***uniformly distributed loads (UDL), concentrated loads, line loads or combinations*** thereof. Heavy equipment (e.g. in communal kitchens, radiology or boiler rooms) are not included in EN 1991-1-1. (To be agreed with the Client and/or the relevant Authority).

Categories of use

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Main Categories of Use :

- Residential, social, commercial and administration areas
  - 4 ***categories (A, B, C and D)***
- Areas for storage and industrial activities
  - 2 ***categories (E1 and E2)***
- Garages and vehicle traffic (excluding bridges)
  - 2 ***categories (F and G)***
- Roofs
  - 3 ***categories (H, I and K)***

Residential, social, commercial and administration areas

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Table 6.1 – Categories of use

Category	Specific use	Example
A	Areas for domestic and residential activities	Rooms in residential buildings and houses; bedrooms and wards in hospitals; bedrooms in hotels and hostels kitchens and toilets.
B	Office areas	
C	Areas where people may congregate (with the exception of areas defined under category A, B and D[1])	**C1**: Areas with tables, etc e.g. areas in schools, cafes, restaurants, dining halls, reading rooms, receptions **C2**: Areas with fixed seats, e.g. areas in churches, theatres or cinemas, conference rooms, lecture halls, assembly halls, waiting rooms, railway waiting rooms. **C3**: Areas without obstacles for moving people, e.g. areas in museums, exhibition rooms, etc. and access areas in public and administration buildings, hotels, hospitals, railway station forecourts **C4**:Areas with possible physical activities, e.g. dance halls, gymnastic rooms, stages . **C5**:Areas susceptible to large crowds, e.g. in buildings for public events like concert halls, sports halls including stands, terraces and access areas and railway platforms.
D	Shopping areas	**D1:** Areas in general retail shops **D2**: Areas in department stores.

[1] Attention is drawn to 6.3.1.1(2), in particular for C4 and C5. See EN 1990 when dynamic effects need to be considered. For Category E, see Table 6.3

NOTE 1. Depending on their anticipated uses, areas likely to be categorised as C2, C3, C4 may be categorised as C5 by decision of the client and/or National annex.

Table 6.2 – Imposed loads on floors, balconies and stairs in buildings

Categories of loaded areas	**q_k [kN/m^2]**	**Q_k [kN]**
Category A		
- Floors	1,5 to 2,0	2,0 to 3,0
- Stairs	2,0 to 4,0	2,0 to 4,0
- Balconies	2,5 to 4,0	2,0 to 3,0
Category B	2,0 to 3,0	1, 5 to 4,5
Category C		
- C1	2,0 to 3,0	3,0 to 4,0
- C2	3,0 to 4,0	2,5 to 7,0 (4,0)
- C3	3,0 to 5,0	4,0 to 7,0
- C4	4,5 to 5,0	3,5 to 7,0
- C5	5,0 to 7,5	3,5 to 4,5
Category D		
-D1	4,0 to 5,0	3,5 to 7,0 (4,0)
-D2	4,0 to 5,0	3,5 to 7,0

NOTE: Where a range is given in this table, the value may be set by the National annex. The recommended values, intended for separate application, are underlined. q_k is intended for the determination of general effects and Q_k for local effects. The National annex may define different conditions of use of this Table.

Additional loading from movable partitions

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- Provided that a floor allows a lateral distribution of loads, the self-weight of movable partitions may be taken into account by a uniformly distributed load q_k which should be added to the imposed loads of floors obtained from Table 6.2 (Cat. A to D). This load depends on the self-weight of the movable partitions, as follows :

- self-weight < 1 kN/m, $q_k = 0{,}5$ kN/m²

- 1 kN/m < self-weight < 2 kN/m, $q_k = 0{,}8$ kN/m²

- 2 kN/m < self-weight < 3 kN/m, $q_k = 1{,}2$ kN/m²

Load arrangements

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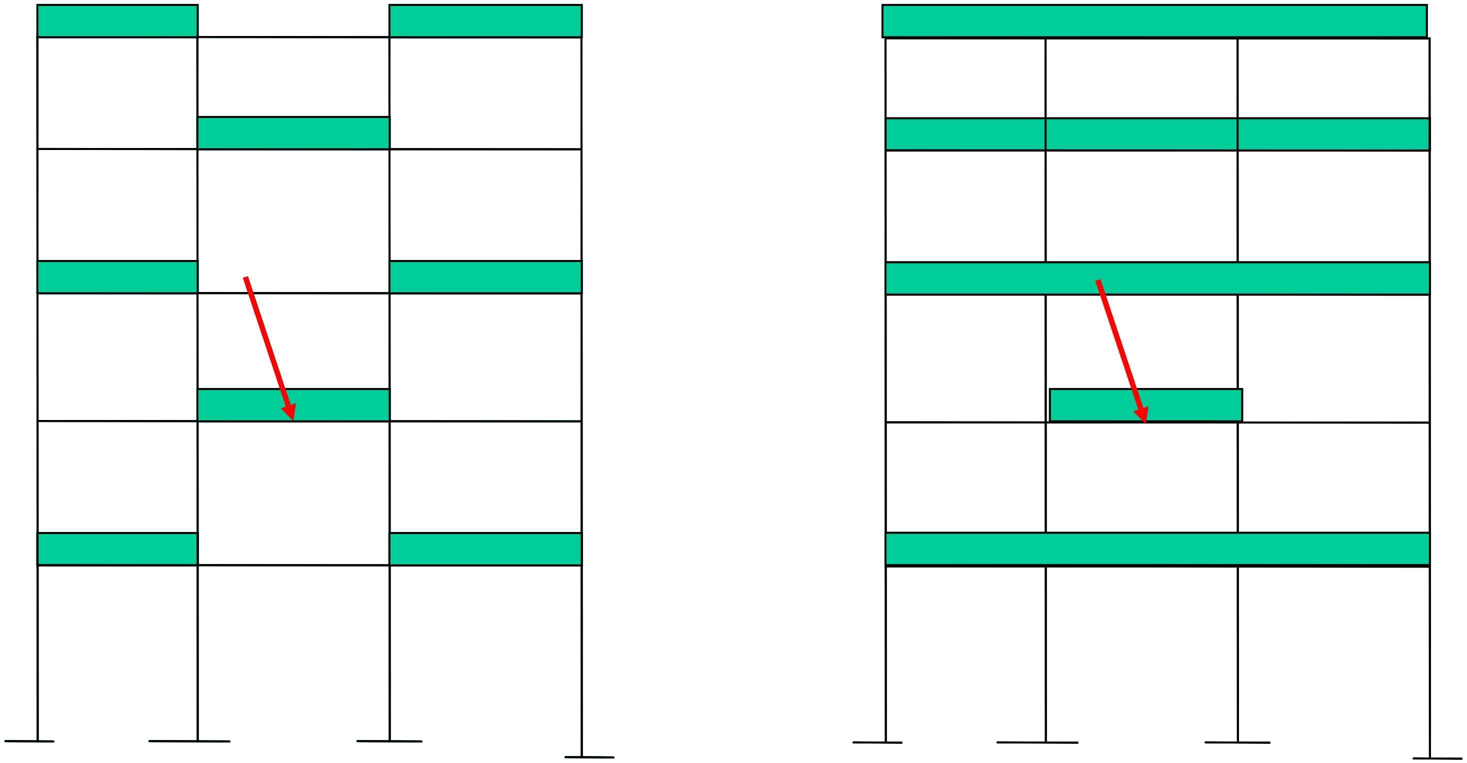
- Floors, beams and roofs

Mid span bending moment of a floor structure



Chess board arrangement Simplification in EN 1991-1-1

Load arrangements (cont.)

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- For the design of a floor structure within one storey or a roof, the imposed load shall be applied as a free action at the most unfavourable part of the influence area.
- Effect of actions that cannot exist simultaneously should not be considered together (EN 1990).
- For the design of a column loaded from several storeys, load assumed to be distributed uniformly.
- For local verification concentrated load Q_k acting alone should be considered.
- Reduction factors α_A (for floors, beams and roofs) and α_n (for columns and walls) may be applied, but factors ψ and α_n should not be considered together.

Reduction factors α_n and α_A

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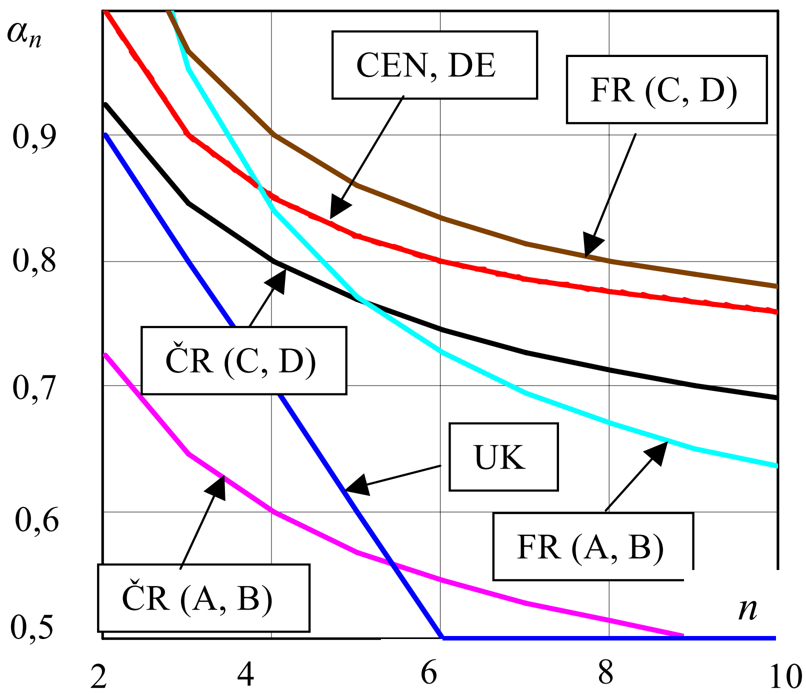
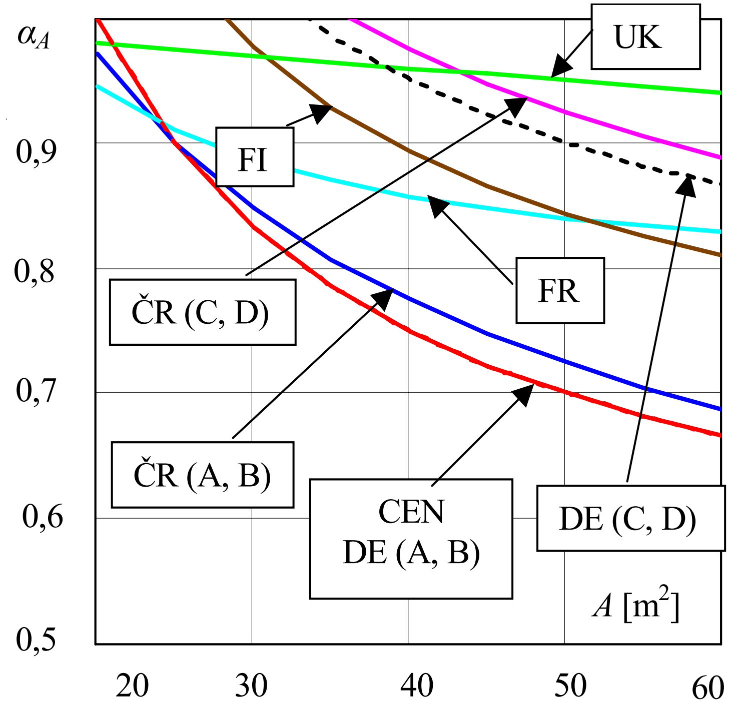
$$\alpha_n = \frac{2+(n-2)\psi_0}{n}, \quad \alpha_A = \frac{5}{7}\psi_0 + \frac{A_0}{A}$$





Factors ψ_i

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(Reminder from EN 1990)

Actions	ψ_0	ψ_1	ψ_2
Imposed Cat. A, B	0,7	0,5	0,3
Imposed Cat. C, D	0,7	0,7	0,6
Imposed Cat. E	1,0	0,9	0,8
Snow	0,5-0,7	0,2-0,5	0,0-0,2
Wind	0,6	0,2	0,0
Temperature	0,6	0,5	0,0

Reduction factor α_A for floors

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A (m^2)	α_A (EN 1991-1-1 with ψ_o = 0,7)	α_A (EN 1991-1-1 with ψ_o = 1,0)
40	0,75	0,96
80	0,63	0,84
120	0,59	0,80
160	0,56	0,78
240	0,54	0,76

Reduction factor α_n for columns

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n	α_A (EN 1991-1-1 with ψ_o = 0,7)
1	1,00
2	1,00
3	0,90
4	0,85
5	0,82
6	0,80
7	0,79
8	0,78
9	0,77
10	0,76

Imposed loads on floors due to storage

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Table 6.3 – Categories of storage and industrial use

Category	Specific Use	Example
E1	Areas susceptible to accumulation of goods, including access areas	Areas for storage use including storage of books and other documents
E2	Industrial use	

Table 6.4 – Imposed loads on floors due to storage

Categories of loaded areas	**q_k [kN/m^2]**	**Q_k [kN]**
Category E1	7,5	7,0

NOTE The values may be changed if necessary according to the usage (see Table 6.3 and Annex A) for the particular project or by the National annex. q_k is intended for the determination of general effects and Q_k for local effects. The National annex may define different conditions of use of Table 6.4.

Actions induced by forklifts

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Forklifts and transport vehicles

- Forklifts are classified into 6 ***classes*** via their hoisting capacity, which is reflected in other characteristics such as weight and plan dimensions.

- For each class, a ***static axle load*** is defined which is then increased by a ***dynamic (multiplication) factor*** φ dependent on whether the forklift has solid (φ = 2,00)or pneumatic (φ = 1,40) tyres. That factor is intended to account for the inertial effects caused by acceleration and deceleration of the hoisted load.

- Where transport vehicles move on floors, either freely or guided by rails, the actions need to be determined from the pattern of the vehicle's wheel loads. The static value of those wheel loads is determined from permanent weights and pay loads and the spectra of loads should be used to define appropriate combination factors and fatigue loads.

Actions induced by forklifts

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Table 6.5 - Dimensions of forklift according to classes FL

Class of Forklift	Net weight [kN]	Hoisting load [kN]	Width of axle a [m]	Overall width b [m]	Overall length l [m]
FL 1	21	10	0,85	1,00	2,60
FL 2	31	15	0,95	1,10	3,00
FL 3	44	25	1,00	1,20	3,30
FL 4	60	40	1,20	1,40	4,00
FL 5	90	60	1,50	1,90	4,60
FL 6	110	80	1,80	2,30	5,10

Table 6.6 - Axle loads of forklifts

Class of forklifts	Axle load Q_k [kN]
FL 1	26
FL 2	40
FL 3	63
FL 4	90
FL 5	140
FL 6	170

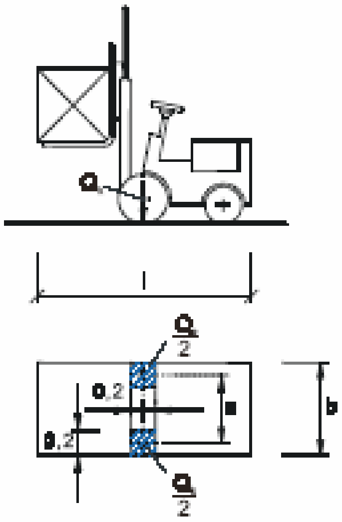

Figure 6.1 - Dimensions of forklifts

Garages and vehicle traffic areas

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Table 6.8 – Imposed loads on garages and vehicle traffic areas		
Categories of traffic areas	q_k [kN/m²]	Q_k [kN]
Category F Gross vehicle weight: ≤ 30kN	q_k	Q_k
Category G 30kN < gross vehicle weight ≤ 160 kN	5,0	Q_k
NOTE 1 For category F q_k may be selected within the range 1,5 to 2,5 kN/m² and Q_k may be selected within the range 10 to 20 kN. NOTE 2 For category G, Q_k may be selected within the range 40 to 90 kN NOTE 3 Where a range of values are given in Notes 1 & 2, the value may be set by the National annex. The recommended values are underlined.		

- Category F (e.g. garages, parking areas, parking halls)
- Category G (e.g. access routes, delivery zones, zones accessible to fire engines)

Categorization of roofs

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Categories of loaded area (of a roof) :

- *Category H* – Accessible for normal maintenance and repair only
- *Category I* – Accessible with occupancy according to categories A to G
- *Category K* – Accessible for special services e.g. helicopter landing areas

Imposed loads on roofs of Cat. H

Table 6.10 – Imposed loads on roofs of category H

Roof	q_k [kN/m^2]	Q_k [kN]
Category H	q_k	Q_k

NOTE 1 For category H q_k may be selected within the range 0,0 to 1,0 kN/m2 and Q_k may be selected within the range 0,9 to 1,5 kN. Where a range is given the values may be set by the National Annex. The recommended values are: q_k = 0,4 kN/m^2, Q_k = 1,0kN

NOTE 2 q_k may be varied by the National Annex dependent upon the roof slope

NOTE 3 q_k may be assumed to act on an area A which may be set by the National Annex. The recommended value for A is 10m^2, within the range of zero to the whole area of the roof.

NOTE 4 See also 3.3.2 (1)

- The minimum values given in Table 6.10 do not take into account uncontrolled accumulations of construction materials that may occur during maintenance
- Separate verifications to be performed for Q_k and q_k , acting independently

Imposed loads on roofs of Cat. K for helicopters

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Table 6.11 – Imposed loads on roofs of category K for helicopters

Class of Helicopter	Take-off load Q of helicopter	Take-off load Q_k	Dimension of the loaded area (m x m)
HC1	$Q \leq 20$ kN	$Q_k = 20$ kN	0,2 x 0,2
HC2	20 kN < $Q \leq 60$ kN	$Q_k = 60$ kN	0,3 x 0,3

- The *dynamic factor* φ to be applied to the take-off load Q_k **to take account of impact effects may be taken as** $\varphi = 1,40$

Table 6.12 – Horizontal loads on partition walls and parapets	
Loaded areas	**q_k [kN/m]**
Category A	q_k
Category B and C1	q_k
Categories C2 to C4 and D	q_k
Category C5	q_k
Category E	q_k
Category F	See Annex B
Category G	See Annex B

NOTE 1 For categories A,B and C1, q_k may be selected within the range 0,2 to 1,0 (<u>0,5</u>)

NOTE 2 For categories C2 to C4 and D q_k may be selected within the range 0,8 kN/m to <u>-1,0</u> kN/m

NOTE 3 For category C5, q_k may be selected within the range <u>3,0</u> kN/m to 5,0 kN/m

NOTE 4 For category E q_k may be selected within the range 0,8 kN/m to <u>2,0</u> kN/m. For areas of category E the horizontal loads depend on the occupancy. Therefore the value of q_k is defined as a minimum value and should be checked for the specific occupancy.

NOTE 5 Where a range of values is given in Notes 1, 2, 3 and 4, the value may be set by the National Annex. The recommended value is underlined.

NOTE 6 The National Annex may prescribe additional point loads Q_k and/or hard or soft body impact specification for analytical or experimental verification.

Annex A (informative) : Nominal densities and angles of repose

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- Table A.1 - Construction materials-concrete and mortar
- Table A.2 - Construction materials-masonry
- Table A.3 - Construction materials-wood
- Table A.4 - Construction materials-metals
- Table A.5 - Construction materials- other materials
- Table A.6 - Bridge materials
- Table A.7 - Stored materials - building and construction
- Table A.8 - Stored products – agricultural
- Table A.9 - Stored products - foodstuffs
- Table A.10 - Stored products - liquids
- Table A.11 - Stored products - solid fuels
- Table A.12 - Stored products - industrial and general

Annex B (informative) : Vehicle barriers and parapets for car parks

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The force in kN acting on 1,5 m of a barrier :

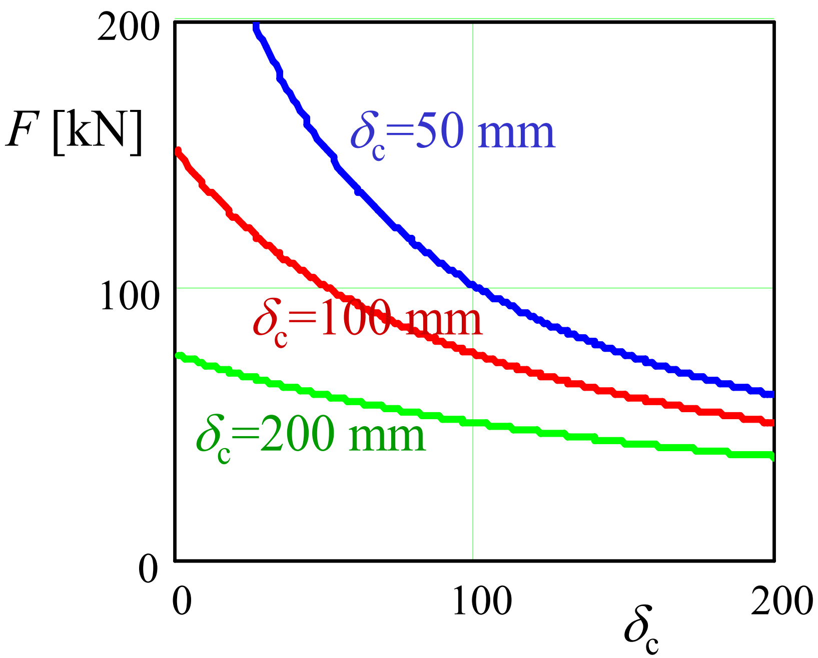
$$F = 0{,}5\, m\, v^2 / (\delta_c + \delta_b) \ \ [\mathrm{kN}]$$

δ_c the deformation of the vehicle (mm)

δ_b the deformation of the barrier (mm)

m the gross mass of the vehicle (kg)

v the velocity of the vehicle (m/s)



For vehicles < 2500 kg: m = 1500 kg, v = 4,5 m/s, δ_c = 100 mm

Backgound Documents and other supporting material

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- A more general reference to Background Documents (BD) and related supporting material has been included and presented in the Introduction to EN 1991. The BD on the imposed loads on floors and roofs is already uploaded on the relevant website.
- *Handbook 3* (Action Effects for Buildings) and *Handbook 4* (Design of Bridges) of the Leonardo Da Vinci Pilot Project for the *Development of Skills Facilitating the Implementation of Structural Eurocodes* are considerd to be an appropriate first approach for the deeper understanding of EN 1991.
- Since a few years various books are being available (e.g. the Thomas Telford collection of Guides)

Message for the near future

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Please try on a national level to finalise and issue the National Annex and upload the NDPs in the ad-hoc data base of JRC Ispra

(if not already done so)

THANK YOU FOR YOUR ATTENTION