Actions=Loads

Design situations

❑-There are four types of design situation:

- **persistent**, corresponding to normal use;
- **transient,** temporary conditions e.g. during construction, refurbishment or repair
- **accidental**, exceptional conditions such as fire, explosion or earthquake.
- **Seismic**: conditions that are applicable to the structure during a seismic event.

TYPES OF ACTIONS:

ACTIONS = LOADS

❑- ***Direct action***

A force (load) applied to a structure.

- ✓ - *permanent action*
- ✓ -*variable action*
- ✓ -*accidental action*

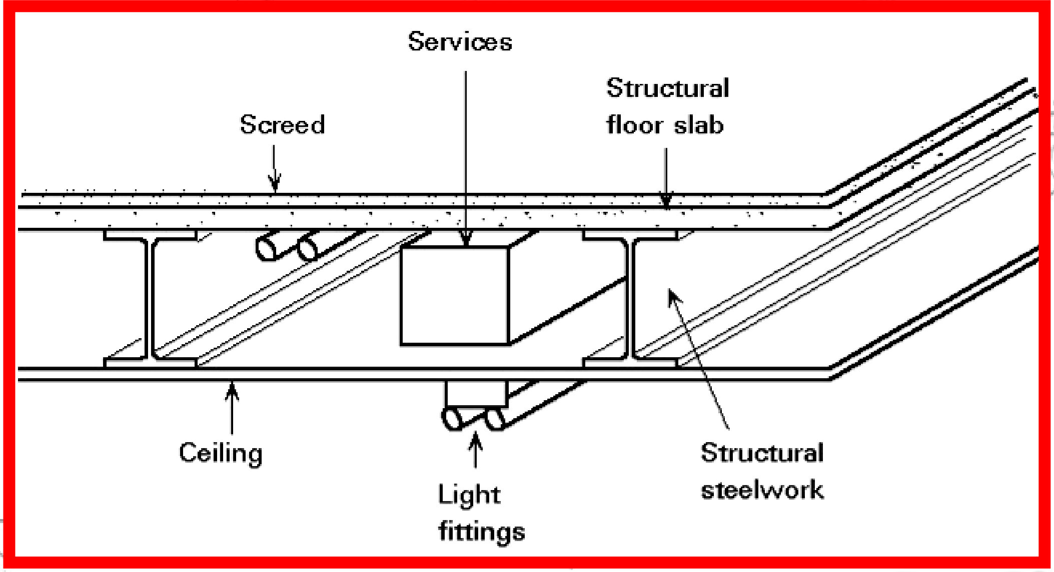
❑-***Indirect action***

An imposed deformation; such as temperature effects, settlement or shrinkage of concrete.

TYPES OF ACTIONS

✓- ***Permanent actions* (G, g): (Dead loads)** (EN1991- 1-1)

- The self-weight of the structural and non-structural elements. (weights of floor slabs, roofs, walls, ceilings, partitions, finishes, services and self-weight of steel).
- Loads due to prestressing, shrinkage of concrete



TYPES OF ACTIONS

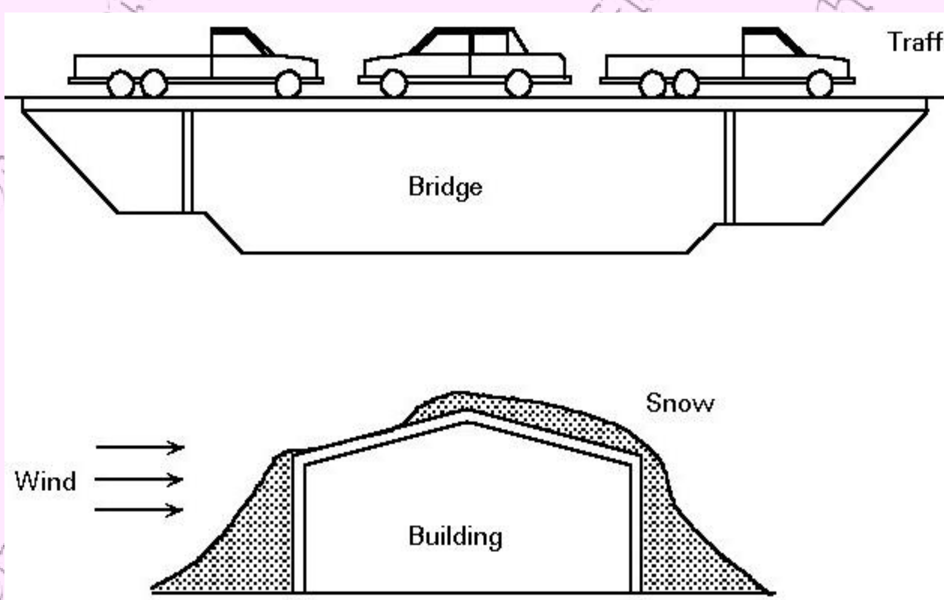
Permanent actions are represented (and specified) by a characteristic value, G_k.

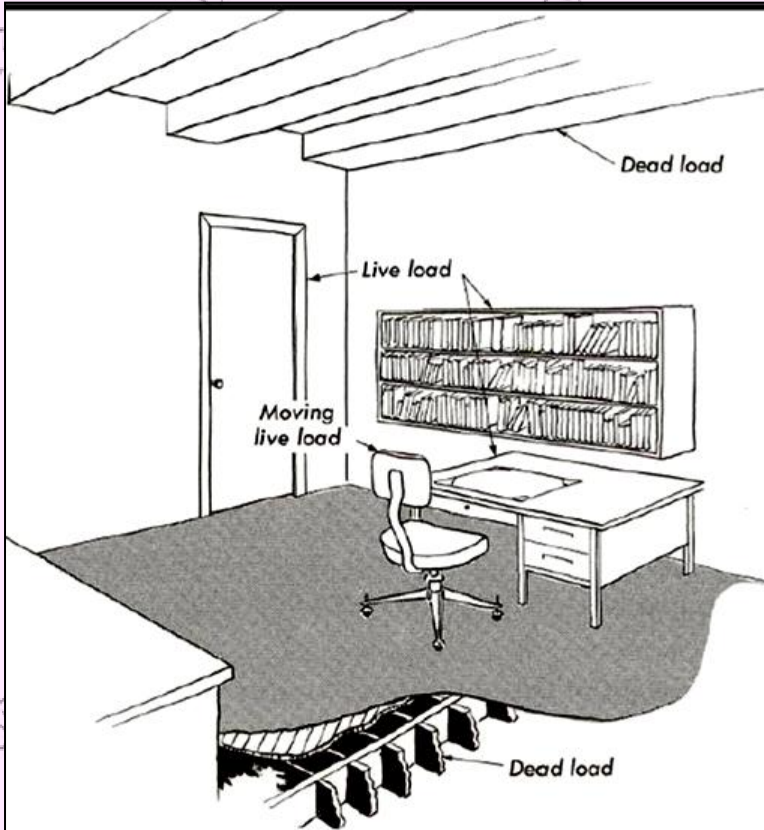
'Characteristic' implies a defined fractile of an assumed statistical distribution of the action, modelled as a random variable. For permanent loads, it is usually the mean value (50% fractile).

TYPES OF ACTIONS

✓- ***Variable actions (Q, q)*** 'actions for which the variation in magnitude with time is neither negligible nor monotonic'.

- Imposed floor & roof loads
- Snow loads
- Wind loads





TYPES OF ACTIONS

Variable actions are sub-divided into :

1-Leading variable actions

These are variable actions which when acting on a structure cause the most significant structural effects.

2- Accompanying variable actions (non-leading)

These are variable actions that act on a structure at the same time as the leading variable action.

Variable actions have four representative values:

- characteristic (Q_k), normally the upper 5% fractile
- combination ($\psi_0 Q_k$), for use where the action is assumed to accompany the design ultimate value of another variable action, which is the 'leading action';
- frequent ($\psi_1 Q_k$), for example, occurring at least once a week
- quasi-permanent ($\psi_2 Q_k$).

Imposed floor loads

BS EN 1991-1-1 identifies four categories of use:

A areas for domestic and residential activities

B office areas

C areas where people may congregate

D shopping areas.

All categories have additional sub-categories - the UK NA provides a large number of sub-categories with examples. For each category of loaded area, imposed loads are given both as a point load, Qk and a uniformly distributed load, q k . For most design purposes, the point load has little effect other than for local checking.

The uniformly distributed load will be used for general design.

TYPES OF ACTIONS

'On roofs (particularly for category H roofs), imposed loads, need not be applied in combination with either snow loads and/or wind actions.'

The intent is that:

(a) imposed roof loads and wind should not be combined
(b) imposed roof loads and snow should not be combined
(c) that snow loads and wind loads should be combined.

TYPES OF ACTIONS

Table NA.3 — Imposed loads on floors, balconies and stairs in buildings

Category of loaded area		q_k kN/m²	Q_k kN
Category A	A1	1,5	2,0
	A2	1,5	2,0
	A3	2,0	2,0
	A4	2,0	2,7
	A5	2,5	2,0
	A6	Same as the rooms to which they give access but with a minimum of 3,0	2,0 (concentrated at the outer edge)
	A7	Same as the rooms to which they give access but with a minimum of 4,0	2,0 (concentrated at the outer edge)
Category B	B1	2,5	2,7
	B2	3,0	2,7
Category C	C11	2,0	3,0
	C12	2,5	4,0
	C13	3,0	3,0
	C21	4,0	3,6
	C22	3,0	2,7

TYPES OF ACTIONS

Table NA.3 — Imposed loads on floors, balconies and stairs in buildings

Category of loaded area		q_k kN/m²	Q_k kN
	C31	3,0	4,5
	C32	3,0	4,0
	C33	4,0	4,5
	C34	5,0	4,5
	C35	4,0	4,0
	C36	3,0	2,0
	C37	5,0	3,6
	C38	7,5	4,5
	C39	4,0	4,5
	C41	5,0	3,6
	C42	5,0	7,0
	C51	5,0	3,6
	C52	7,5	4,5
Category D	D1/D2	4,0	3,6

TYPES OF ACTIONS

Table NA.5 — Imposed floor loads due to storage

Category of loaded area	q_k kN/m²	Q_k kN
E11	2,0	1,8
E12	4,0	4,5
E13	2,4 per metre of storage height	7,0
E14	5,0	4,5
E15	2,4 per metre of storage height but with a minimum of 6,5	7,0
E16	4,0 per metre of storage height	9,0
E17	4,8 per metre of storage height but with a minimum of 9,6	7,0
E18	4,8 per metre of storage height but with a minimum of 15,0	7,0
E19	5,0 per metre of storage height but with a minimum of 15,0	9,0

NOTE E13 is a general category, however, designers are encouraged to liaise with clients to determine more specific load values than the lower bound value given in this table.

TYPES OF ACTIONS

Table NA.6 — Imposed loads on garages and vehicle traffic areas

Categories of traffic areas	q_k kN/m²	Q_k kN
Category F (gross vehicle weight ≤ 30 kN)	2,5	10,0
Category G (30 kN < gross vehicle weight ≤ 160 kN)	5,0	To be determined for specific use
NOTE q_k and Q_k should not be applied simultaneously.		

Table NA.7 — Imposed loads on roofs not accessible except for normal maintenance and repair

Roof slope, α degrees	q_k kN/m²	Q_k kN
$\alpha < 30^o$	0,6	0,9
$30^o \leq \alpha < 60^o$	$0{,}6[(60 - \alpha)/30]$	
$\alpha \geq 60^o$	0	

NOTE 1 All roof slopes α are measured from the horizontal and all loads should be applied vertically.

NOTE 2 In evaluating Table NA.7 for curved roofs the roofs should be divided into not less than five equal segments and the mean slope of each segment considered to be equivalent to the roof slope, α.

NOTE 3 BS EN 1991-1-1:2002, Note 3 to Table 6.10 states that q_k may be assumed to act on an area A. It is recommended that the value of A should be the whole area of the roof.

TYPES OF ACTIONS

✓- ***Accidental actions*** **(A)** are caused by events that usually have a short duration but have a significant effect. It is considered that such events have a low probability of occurrence during the design working life of a structure. (fire, impact and explosion).

BASIS OF DESIGN

❑- ***'Effect of actions'***:

The effects of actions are the responses of the structure to the actions: stresses, strains, deformations, crack widths, etc., as well as bending moments, shear forces, etc.

$$E_d = E(F_d)$$

- function E represents the process of structural analysis. Where the effect is an internal force or moment.
- $F_d = \gamma_F F_k$ Design values of actions

  e.g. $G_d = \gamma_G G_k$

  $Q_d = \gamma_Q Q_k$ or $Q_d = \gamma_Q \psi_i Q_k$

Characteristic loads (G_k, Q_k, A_k) are those loads which have an acceptably small probability of not being exceeded during the lifetime of the structure.

BASIS OF DESIGN

The design (or factored) load (G_d, Q_d, A_d) is the characteristic (working) load multiplied by the relevant partial safety factor.

❑- Verification for an ***ultimate limit state*** consists of checking that

$$Ed \leq Rd$$

design *effect from structural analysis M, V, N (internal)* ≤ design resistance *from section Resistance*

e.g.

$$M_{Ed} \leq M_{Rd}$$

applied ultimate bending moment (an 'action effect' or 'effect of action') ≤ bending resistanc

BASIS OF DESIGN

$E_d \leq R_d$

The design effect = a load or characteristic action × various partial factors (usually to increase it for the design situation)

$$E_d = \gamma_f \psi F_k$$

E_d is the design value of the load

F_k is the characteristic value of the action

ψ factor that converts the characteristic value to a representative value

γ_f Partial load factor

≤

The design resistance = the characteristic strength of the material(s) being designed ÷ some partial factor (usually to reduce it for the design situation)

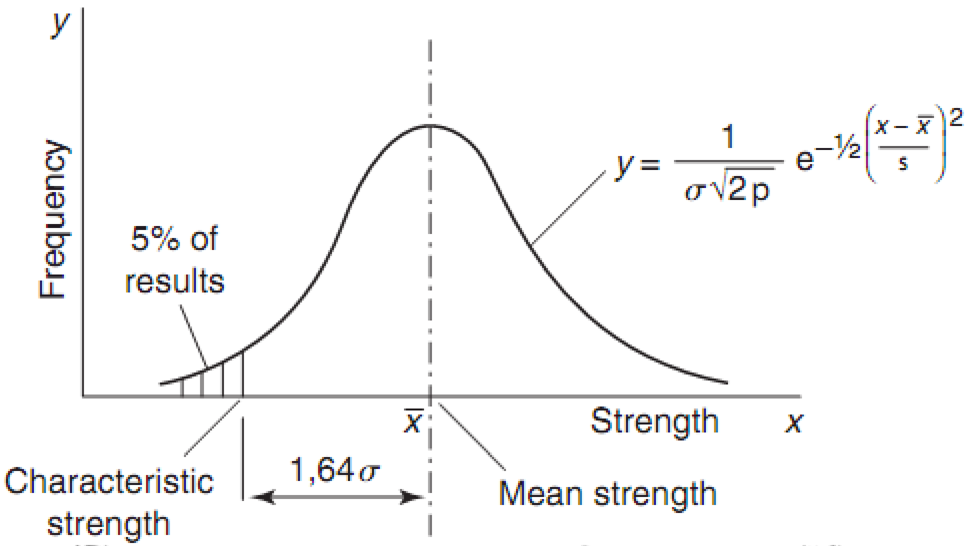
$$R_d = R_k / \gamma_m$$

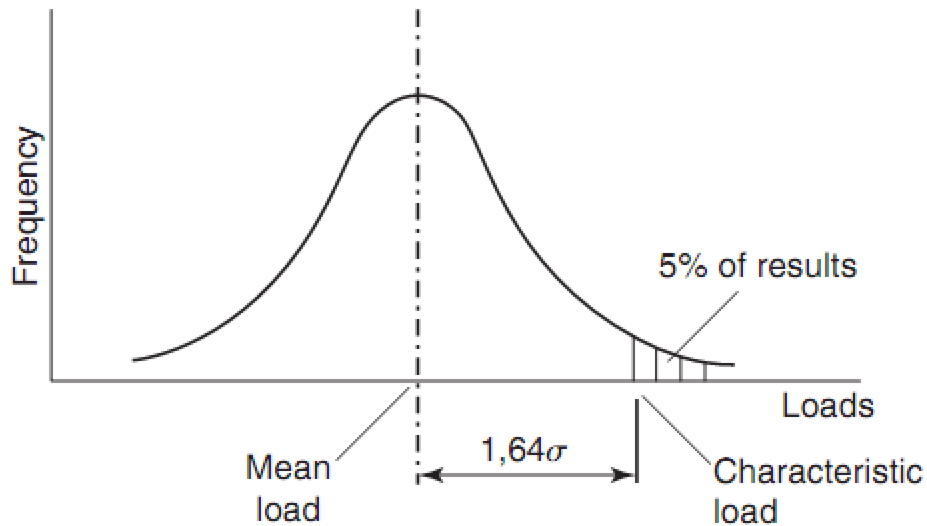
R_d is the design value of the material's resistance or strength

R_k is the characteristic value used in design

γ_m A partial material factor is applied to the material strength

Basis of design





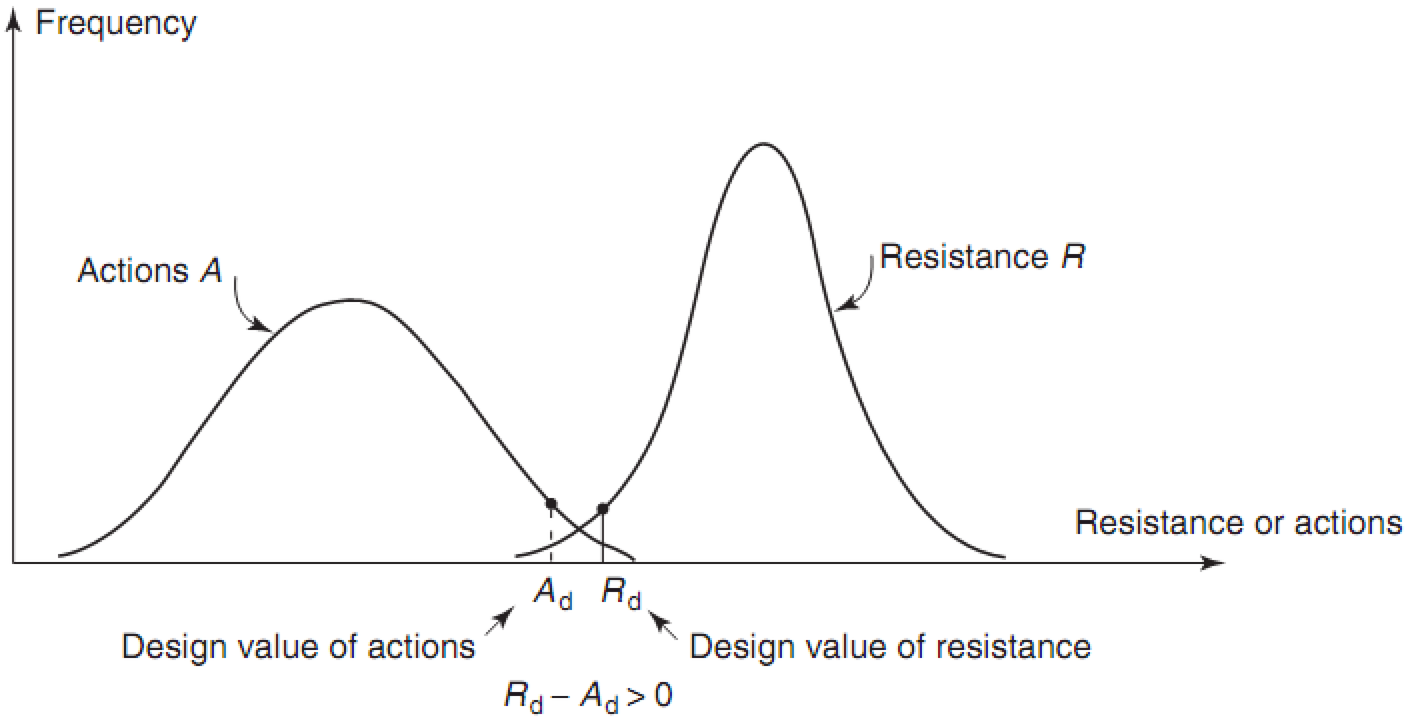
Variation in material properties

$$f_k = f_m - 1.64\sigma$$

Variation in loads (ACTIONS)

$$W_k = W_m + 1.64\sigma$$

Basis of design



Statistical relationship between actions and resistance

It is therefore accepted that 5% of the material in a structure is below the design strength, and that 5% of the applied loads are greater than the design loads.

Combination of actions and design resistance

Four ultimate limit states are identified in BS EN 1990:

EQU, which should be verified when considering overturning or sliding

STR, which concerns strength of the structure

GEO, covering strength of the ground and is used in foundation design

FAT, covering fatigue failure.

For ultimate limit states, the principles of combination are:

- - permanent actions are present in all combinations;
- - each variable action is chosen in turn to be the 'leading' action (i.e., to have its full design value) and is combined with lower 'combination' values of other variable actions that may co-exist with it;
- the design action effect is the most unfavourable of those found by this process.

Combination of actions and design resistance

Fundamental combinations of actions may be determined from EN 1990 using either of:

- ❑- Equation 6.10
- ❑- Less favourable of Equation 6.10a and 6.10b

Equation 6.10:

'to be combined with'

Actions due to prestressing

1.5 x combination factor x Other variable actions

$$\sum_{j\geq1}\gamma_{G,j}G_{k,j}\ \text{"+"}\ \gamma_P P\ \text{"+"}\ \gamma_{Q,1}Q_{k,1}\ \text{"+"}\ \sum_{i>1}\gamma_{Q,i}\psi_{0,i}Q_{k,i}$$

1.35 x Permanent actions

1.5 x Leading variable action

The combination factor ψ_0 is intended specifically to take account of the reduced probability of the simultaneous occurrence of two or more variable actions.

partial factors for actions for ultimate Limit states $\gamma_{Q,G,W}$

action	unfavourable effect	favourable effect
permanent actions γ_G (EQU)	1,10	0,9
permanent actions γ_G (STR)	1,35	1,0
variable action γ_Q (imposed loads on buildings acc. to EN 1991-1)	1,5	0
wind loads (EN 1991-4)	1,5	0
snow loads (EN 1991-3)	1,5	0
climatic temperature effects (EN 1991-5)	1,5	0
Shrinkage	1,0	1,0
prestressing by controlled imposed deformations (EN 1994-1-1)	1,0	1,0

Combination factor values for actions acc to EN 1990

action		ψ_0	ψ_1	ψ_2
category	**imposed loads** on buildings acc. to EN 1991-1			
A	domestic, residential areas	0,7	0,5	0,3
B	office areas	0,7	0,5	0,3
C	congregation areas	0,7	0,7	0,6
D	shopping areas	0,7	0,7	0,6
E	storage areas	1,0	0,9	0,8
F	traffic area (vehicle weight ≤ 30 kN)	0,7	0,7	0,6
G	traffic area (vehicle weight 30kN<Q ≤160kN	0,7	0,5	0,3
H	roofs	0	0	0
snow loads for sites located at altidude H ≤ 1000m (EN 1991-3)		0,5	0,2	0
wind loads on buildings (EN 1991-4)		0,6*	0,2	0
climatic **temperature effects** in buildings (EN 1991-5)		0,6	0,5	0

*** 0.5 is UK NA value, 0.6 is the unmodified EC value**

Combination of actions and design resistance

Equations 6.10a and 6.10b – use less favourable result:

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

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

Unfavourable dead load reduction factor (i.e. not applied when γ_G = 1), ξ = 0.925 in UK NA (0.85 is the unmodified EC value)

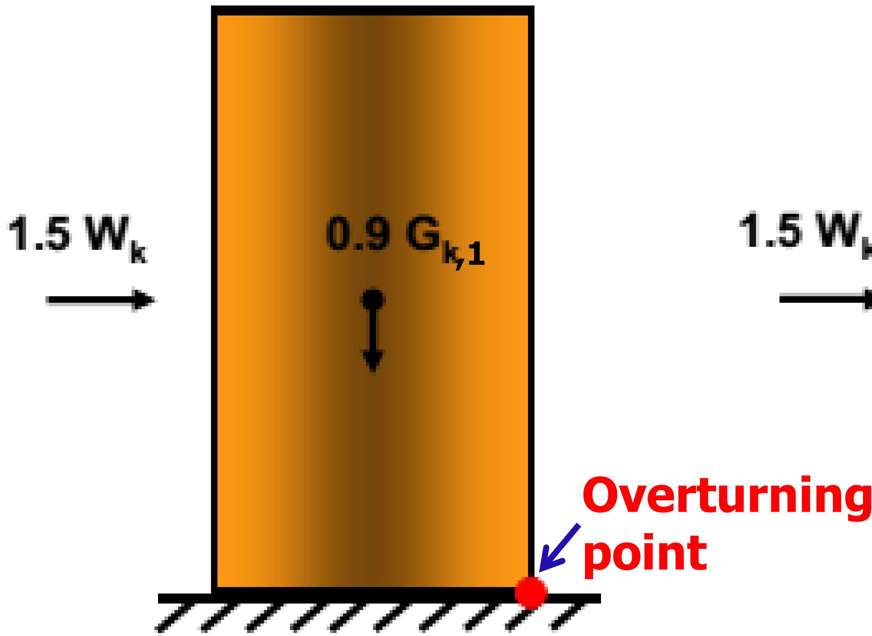
Equilibrium check (EQU):
For checking sliding or overturning of the structure as a rigid body, only Eq. 6.10 may be used.

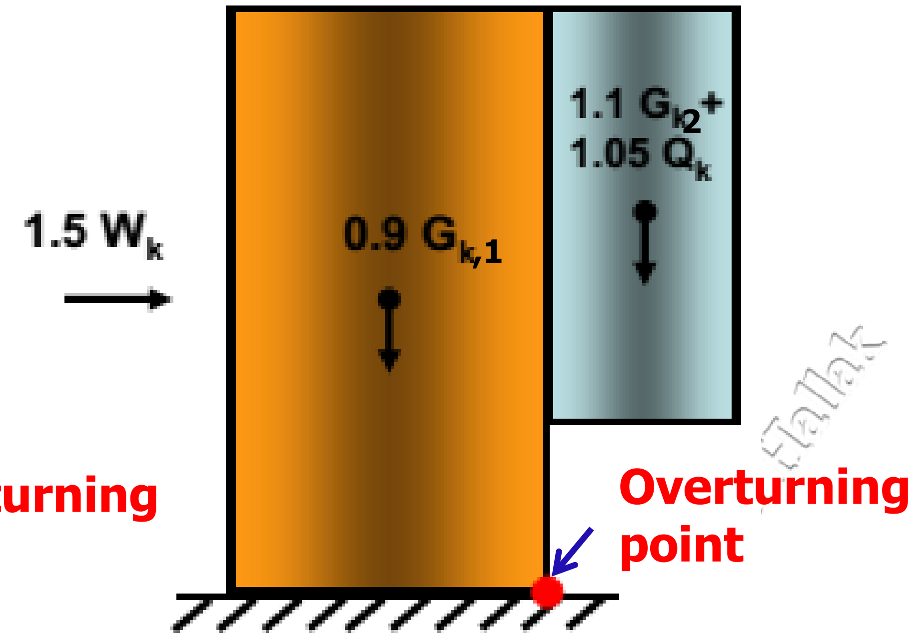
Combination of actions and design resistance

Equilibrium check (EQU): Favourable and unfavourable loading:

Wind load unfavourable, dead load favourable, imposed load favourable

Wind load unfavourable, part of dead load favourable, part unfavourable, part of imposed unfavourable





$\gamma_G G_k + \gamma_{Q1} Q_{k,1}$

$= 0.9 G_k + 1.5 W_k$

$\gamma_G G_k + \gamma_{Q1} Q_{k,1} + \gamma_{Q2} \psi_{0,2} Q_{k,2}$

$0.9 G_{k,1} + 1.1 G_{k,2} + 1.5 W_k + (1.5)(0.7) Q_k$

Combination of actions and design resistance

Table 14.4. Typical STR combinations of actions arising from equations (6.10a) and (6.10b) of EN 1990

Combination	Load factor γ		
	Dead γ_G	Imposed γ_Q	Wind γ_Q
Permanent + imposed: equation (6.10a)	1.35	1.05	–
Permanent + imposed + wind: equation (6.10a)	1.35	1.05	0.75
Permanent + imposed: equation (6.10b)	1.25	1.5	–
Permanent + wind (uplift): equation (6.10b)	1.0	–	1.5
Permanent + imposed + wind (imposed leading): equation (6.10b)	1.25	1.5	0.75
Permanent + imposed + wind (wind leading): equation (6.10b)	1.25	0.75	1.5

$\gamma_G = 1.35$

$\xi\,\gamma_G = 0.925 \times 1.35 = 1.25$

$\gamma_{Q1} = 1.5$ Leading (imposed or wind)

$\gamma_{Q2}\psi_{0,2} = 1.5 \times 0.7 = 1.05$ non-leading (imposed)

$\gamma_{Q2}\psi_{0,2} = 1.5 \times 0.5 = 0.75$ non-leading (Wind)

Combination of actions and design resistance

The use of the expression 6.10 and the pair of expressions 6.10a and 6.10b

The table assumes the permanent action is 3.5 kN/m²; the imposed floor load is 5 kN/m² and the snow load is 0.8 kN/m².

Expression	Leading variable action	Permanent action	Leading variable action	Other variable action	Total
		Factored loads (kN/m²)			
6.10	imposed floor load	4.73	7.50	0.60	12.83
6.10	snow load	4.73	1.20	5.25	11.18
6.10a	imposed floor load	4.73	5.25	0.60	10.58
6.10a	snow load	4.73	0.60	5.25	10.58
6.10b	imposed floor load	4.37	7.50	0.60	12.47
6.10b	snow load	4.37	1.20	5.25	10.92

6.10

$$1.35 \times G \text{"+"} 1.5 \times Q_f \text{"+"} 1.5 \times 0.5 \times Q_s$$

$$1.35 \times G \text{"+"} 1.5 \times Q_s \text{"+"} 1.5 \times 0.7 \times Q_f$$

6.10.a

$$1.35 \times G \text{"+"} 1.5 \times 0.7 \times Q_f \text{"+"} 1.5 \times 0.5 \times Q_s$$

$$1.35 \times G \text{"+"} 1.5 \times 0.5 \times Q_s \text{"+"} 1.5 \times 0.7 \times Q_f$$

6.10.b

$$0.925 \times 1.35 \times G \text{"+"} 1.5 \times Q_f \text{"+"} 1.5 \times 0.5 \times Q_s$$

$$0.925 \times 1.35 \times G \text{"+"} 1.5 \times Q_s \text{"+"} 1.5 \times 0.7 \times Q_f$$

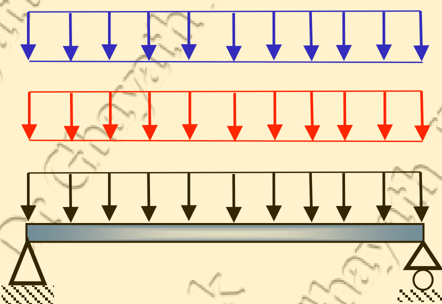
Combination of actions and design resistance

Example:

$\gamma_{Q2}\, Q_{k,2}$ = wind= 1.5 $Q_{k,2}$

$\gamma_{Q1}\, Q_{k,1}$ = imposed= 1.5 $Q_{k,1}$

$\gamma_G\, G_k$ =self weight & finishing = 1.35 G_k



The fundamental combinations for verification for persistent design situations are:

$$\gamma_G G_k + \gamma_{Q1} Q_{k,1} + \gamma_{Q2} \psi_{0,2} Q_{k,2}$$

$$1.35 G_k + 1.5 Q_{k,1} + 1.5\,(0.6)\, Q_{k,2} = 1.35 G_k + 1.5 Q_{k,1} + 0.9 Q_{k,2}$$

And

$$\gamma_G G_k + \gamma_{Q1} \psi_{0,1} Q_{k,1} + \gamma_{Q2} Q_{k,2}$$

$$= 1.35 G_k + 1.5(0.7)\, Q_{k,1} + 1.5 Q_{k,2} = 1.35 G_k + 1.5(0.7)\, Q_{k,1} + 1.5 Q_{k,2}$$

$$= 1.35 G_k + 1.05 Q_{k,1} + 1.5 Q_{k,2}$$

Take the max between this two combinations

Partial safety factors for material (recommended values)

ultimate limit states (STR)

design situation	structural steel	reinforcement	concrete	shear connectors (headed studs)
persistent and transient	$\gamma_{a,m0} = 1,0$ $\gamma_{a,m1} = 1,0$	$\gamma_s = 1,15$	$\gamma_c = 1,50$	$\gamma_V = 1,25$
accidental	$\gamma_{a,} = 1,0$	$\gamma_s = 1,00$	$\gamma_c = 1,20$	$\gamma_V = 1,00$

fatigue (FAT)

	structural steel		reinforcement	concrete	shear connection
	low consequence of failure	high consequence of failure			
damage tolerant	$\gamma_{f,a} = 1,00$	$\gamma_{f,a} = 1,15$	$\gamma_{f,s} = 1,15$	$\gamma_{f,c} = 1,50$	$\gamma_{f,V} = 1,00$
safe life	$\gamma_{f,a} = 1,15$	$\gamma_{f,a} = 1,35$			

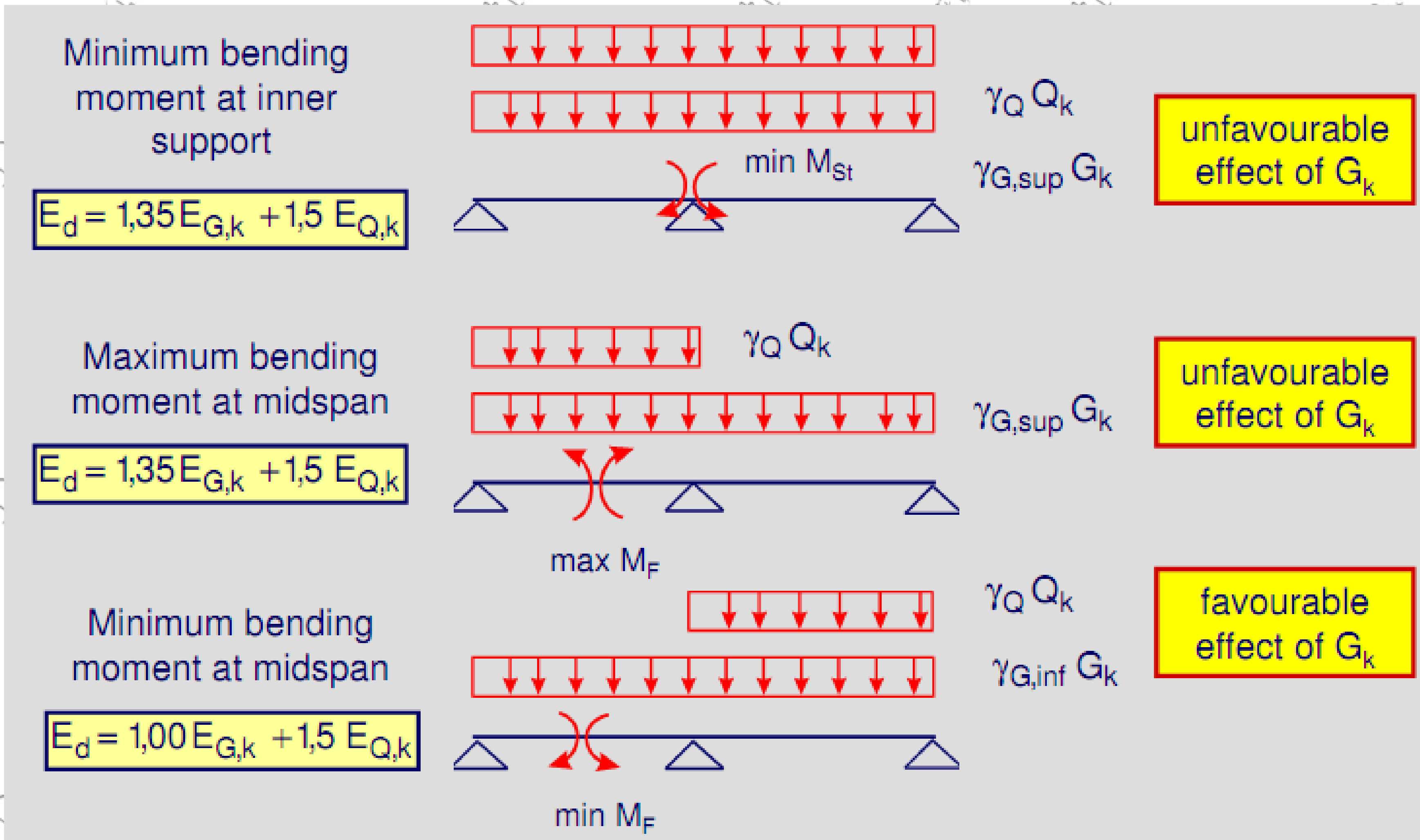
γ_a =1.25 for structural steel subjected to direct tension, bolts, plates and welds.

Partial safety factors for material

γ_M **account for material and modelling uncertainties:**

Partial factor γ_M	EC 3 value (UK NA value)	Application
γ_{M0}	1.00 (1.00)	Cross-sections
γ_{M1}	1.00 (1.00)	Member buckling
γ_{M2}	1.25 (1.10)	Fracture

Design values for favorable and unfavorable effects of permanent actions



Serviceability limit state

The UK NA states that the **characteristic combination** of actions should be used at SLS. The characteristic combination of actions is given as expression 6.14b in BS EN 1990:

$$\sum_{j\geq 1} G_{k,j} \text{"+"} Q_{k,1} \text{"+"} \sum_{i>1} \psi_{0,i} Q_{k,i} \qquad (6.14b)$$

The UK National Annex states that serviceability deflections should be **based on unfactored variable actions**, and that **permanent actions need not be included**. In the UK therefore, expression 6.14b reduces to:

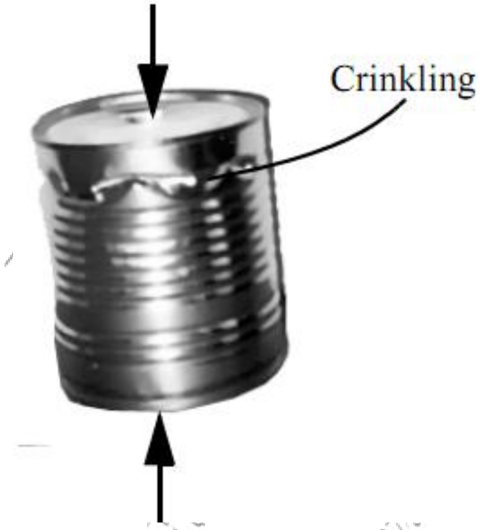
$$Q_{k,1} \text{"+"} \sum_{i>1} \psi_{0,i} Q_{k,i}$$

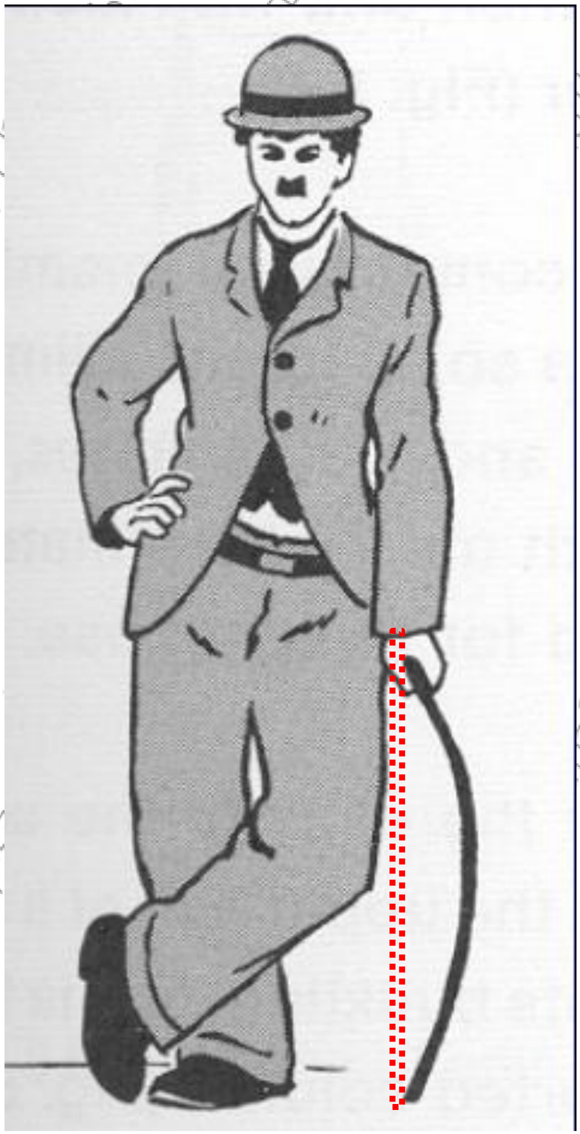
The calculated deflections should compared with certain deflection limits for members provides by the UK NA. Vertical deflection limits are given in the previous lecture.

STRUCTURAL INSTABILITY

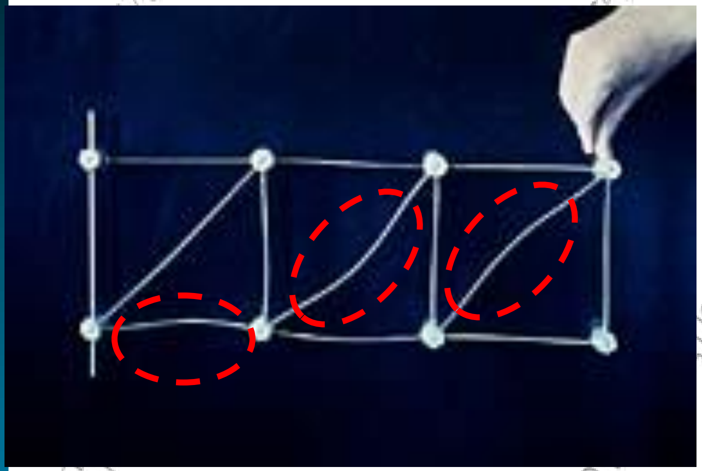
- When structural or mechanical systems are designed, the three factors that must always be considered are:
  - **Stiffness**: If a structural or mechanical system deflects or deforms too much under expected design loads, then it is not acceptable. In this case the system does not have sufficient stiffness.
  - **Strength**: if the yield or failure stress in any member in the structure is exceeded, the structure does not have sufficient strength.
  - **Stability**: Compression loads in long slender structural members can cause buckling behavior which is unstable.

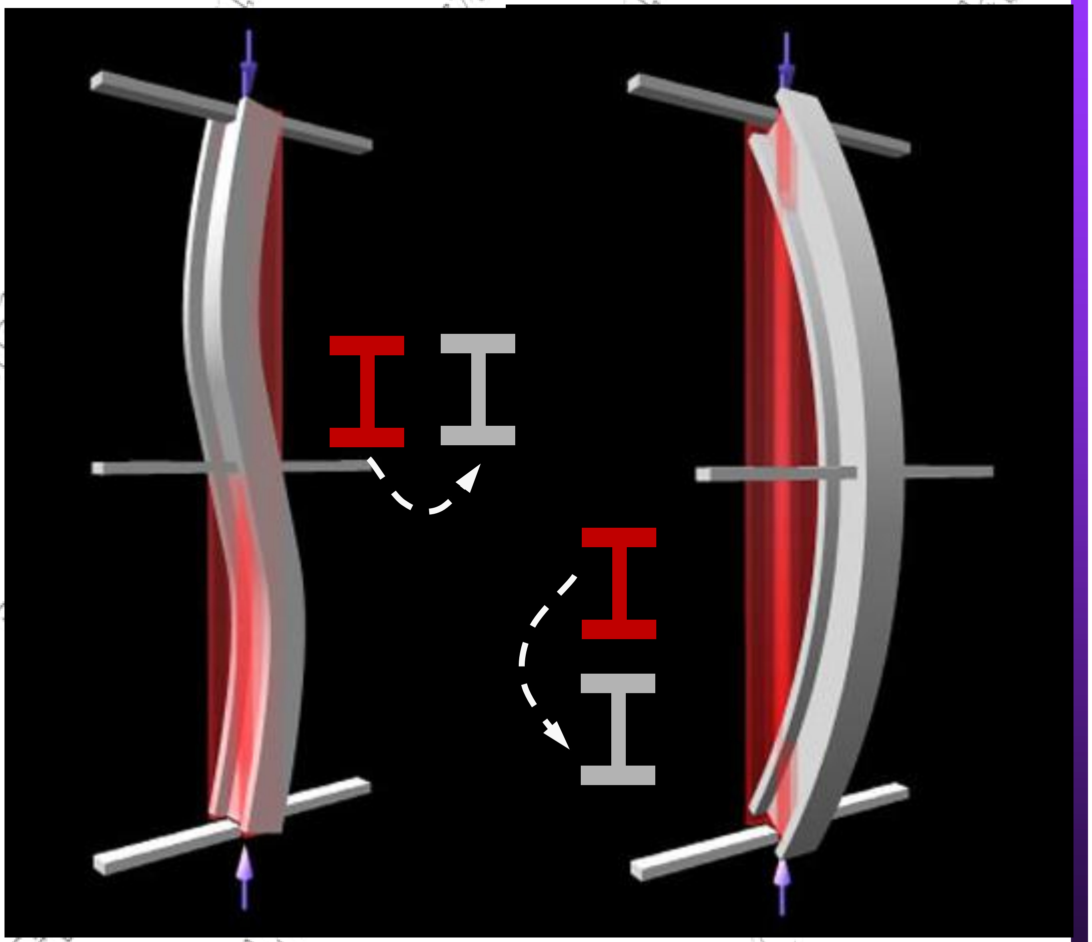
TYPES OF INSTABILITY:





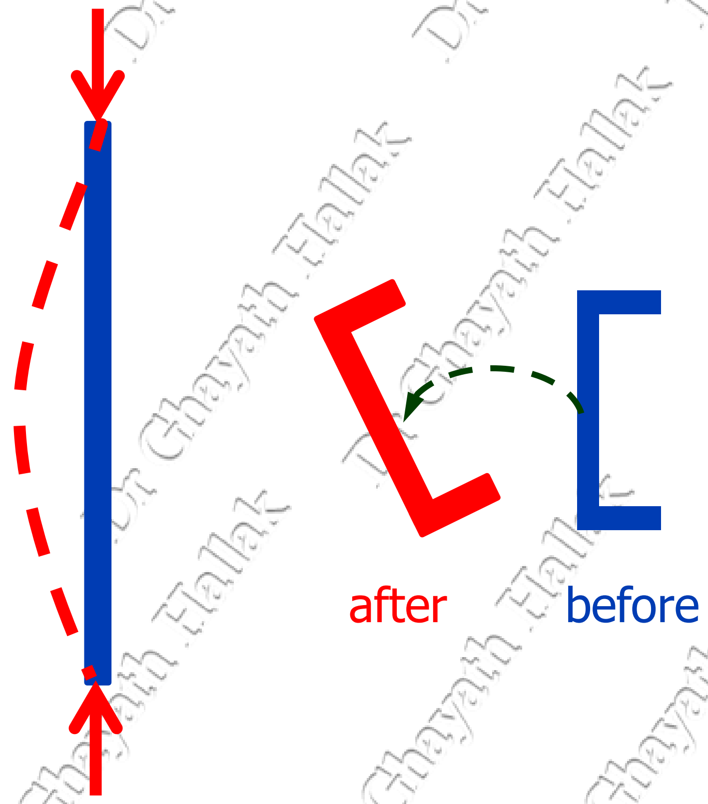
1-Global buckling (fluxeral Buckling)



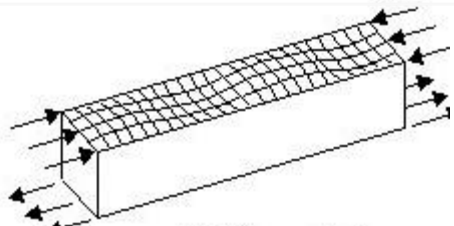


2- Torsional-fluxeral Buckling

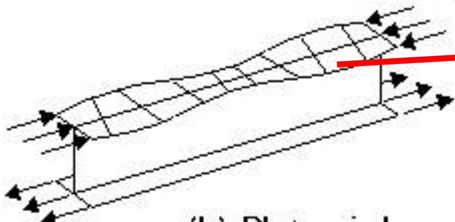
Combination of Flexural and Torsional Buckling
Only with unsymmetrical cross section (channels, structural Tee, double angles, equal and unequal single leg angles



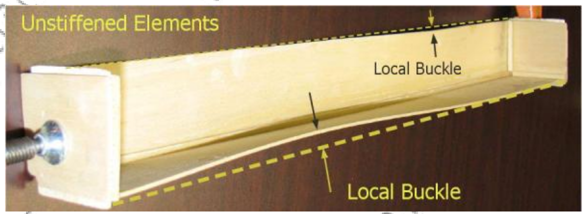
3 - Local buckling

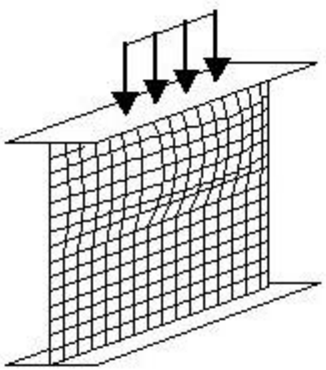


(a) Box girder

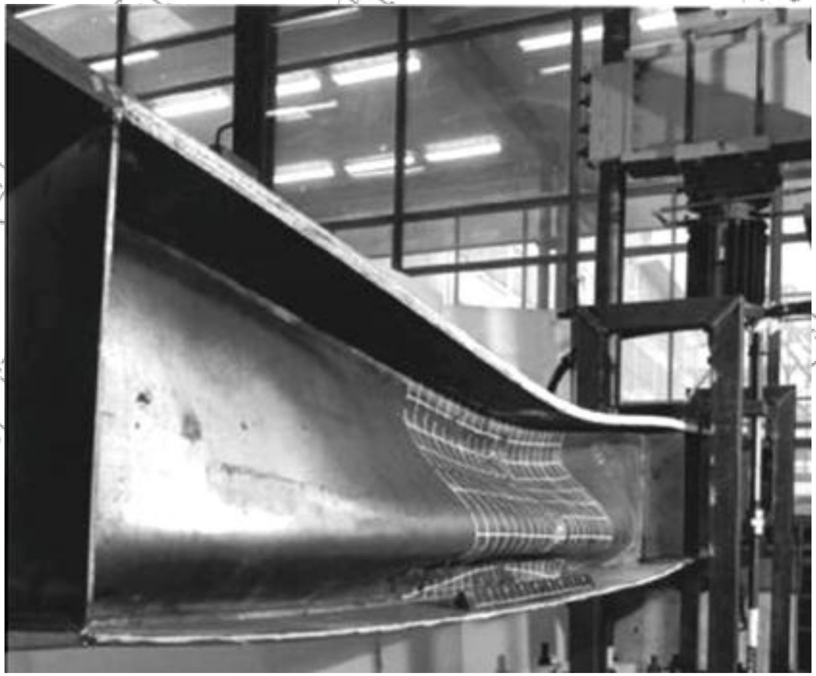


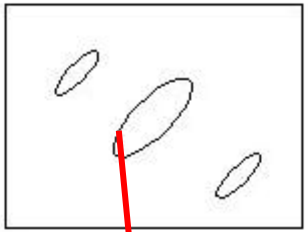
(b) Plate girder





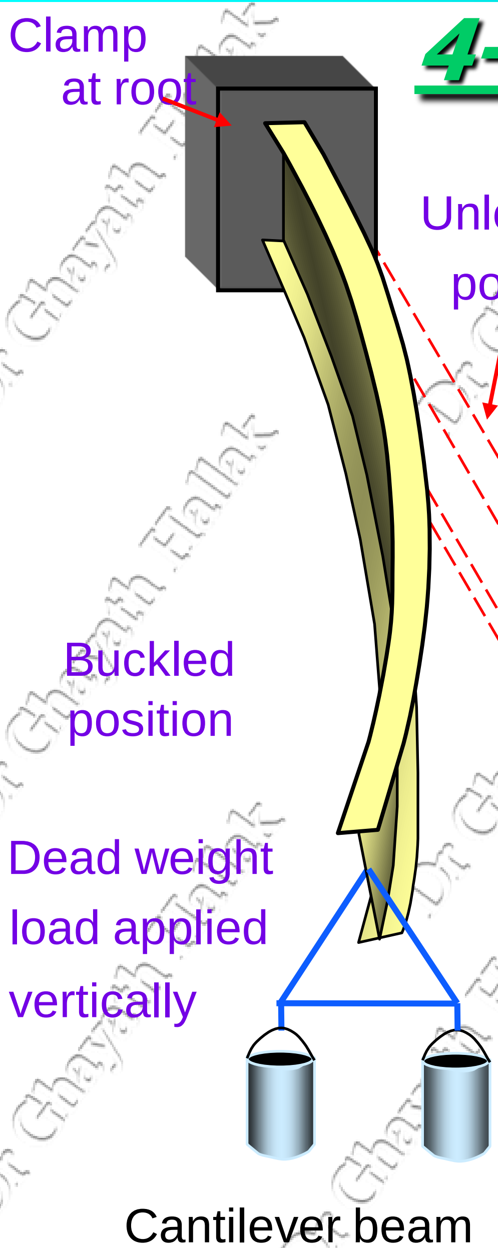
(c) Patch loaded web

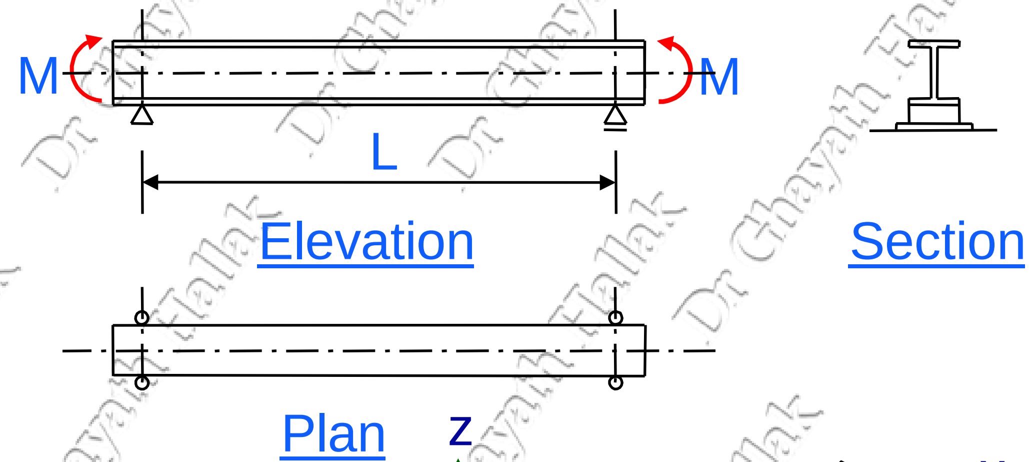


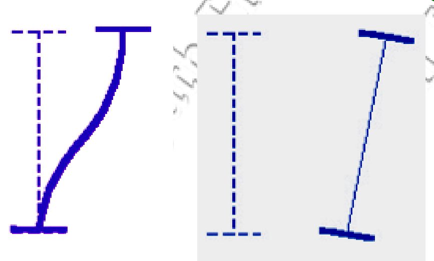


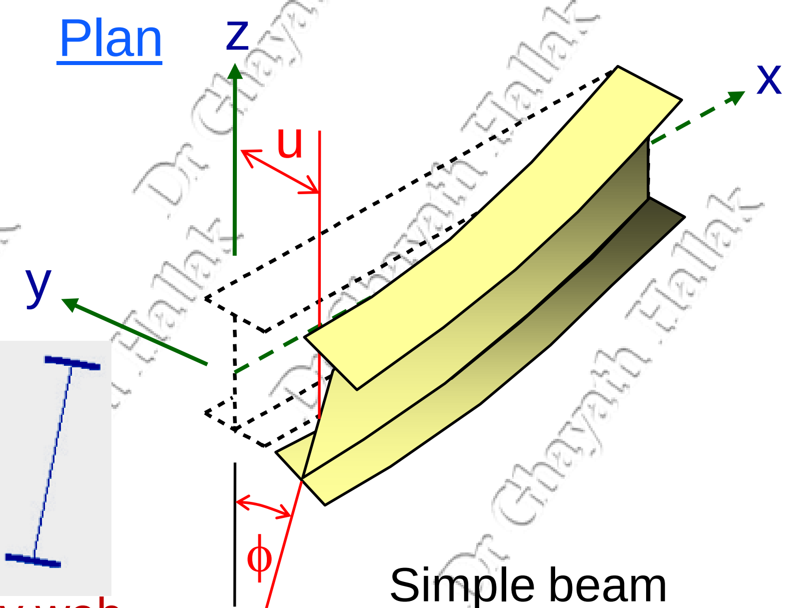
(d) Web subject to shear

4-Lateral-torsional buckling

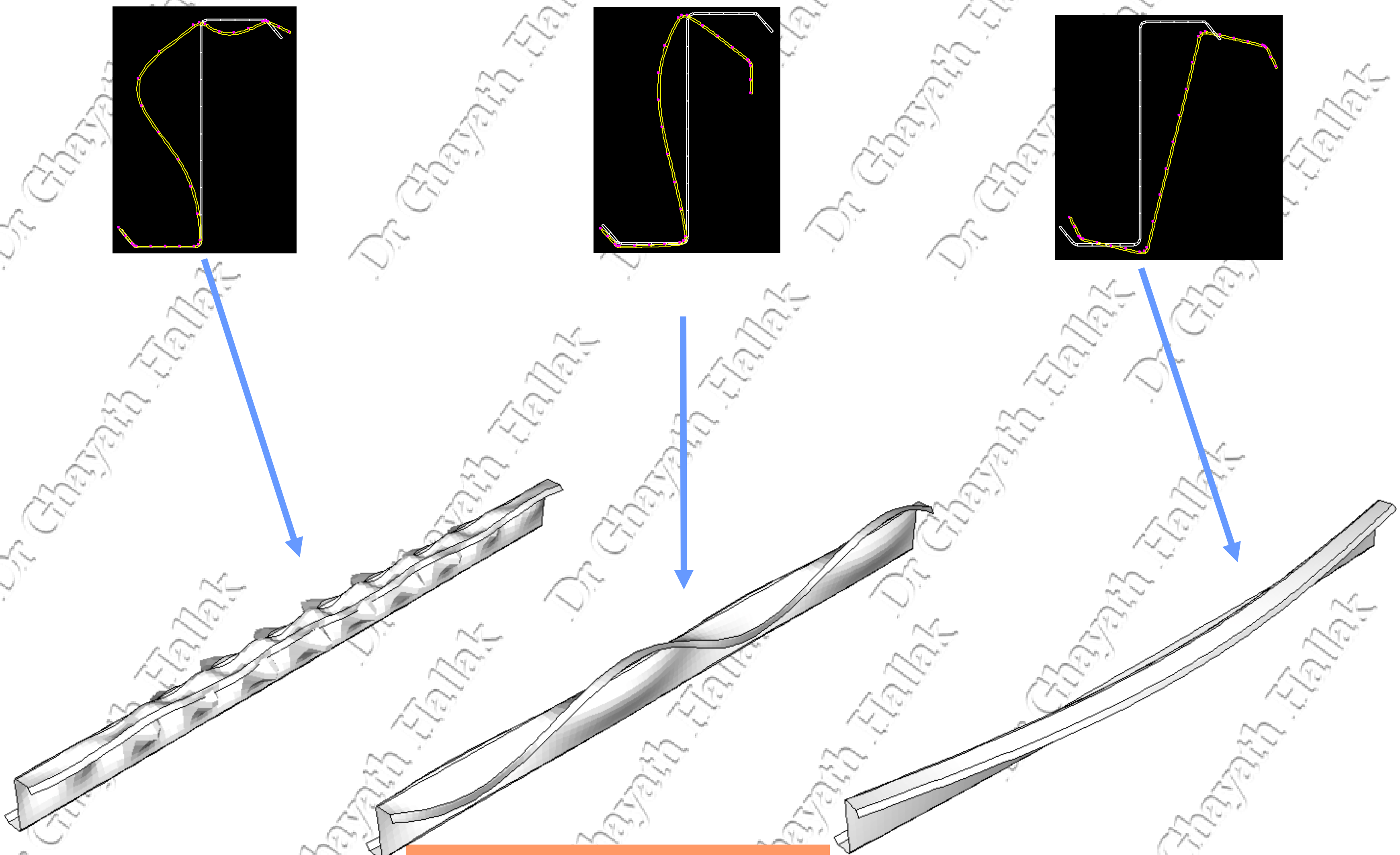








Thin-Walled Sections



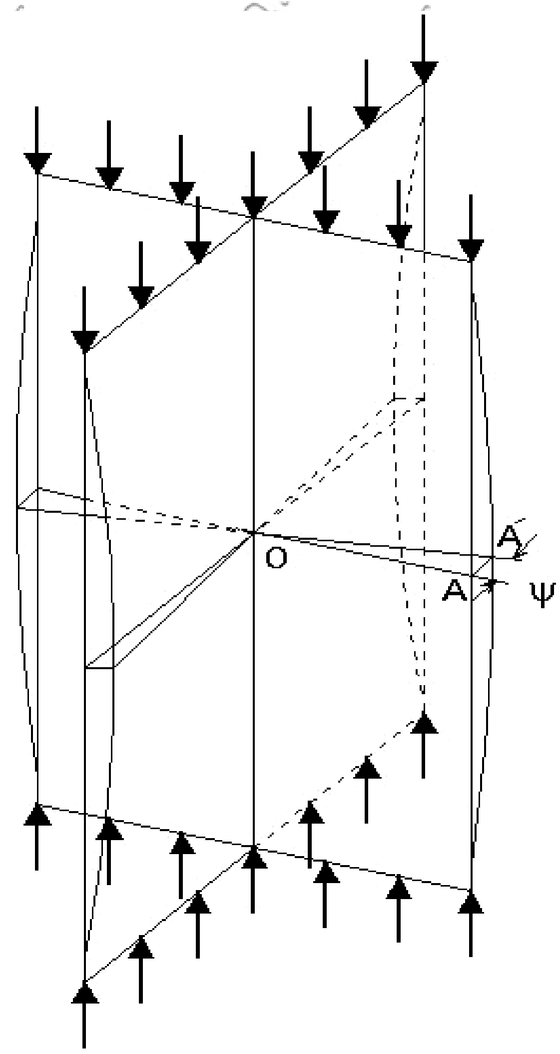
local buckling

distortional buckling

lateral-torsional buckling

5- Torsional buckling

Twisting about longitudinal axis of member.
Only with doubly symmetrical cross section with slender cross-sectional elements.
Standard Hot-Rolled shape are Not susceptible.



Torsional buckling of cruciform section