Technical assessment

In the technical assessment of a structure, one identifies all possible ways that its performance might be unsatisfactory and seeks to ensure that such situations are avoided. The use of codes of practice is the standard approach for this but there may be situations that are beyond the scope of the codes (see Millennium Bridge). A set of structural *Eurocodes* are used in the UK and throughout Europe.

The codes of practice give rules for a range of technical criteria. Checking against the rules is traditionally called 'structural design' but 'technical assessment' is used here as a more precise term.

The Eurocodes are based on a 'limit state' approach. A limit state is a condition of a structure beyond which it no longer fulfils the relevant design criterion. Main limit states are for *strength*, i.e. prevention of collapse, and for *serviceability*, i.e. that the structure will perform satisfactorily in normal use.

Strength criteria

A very important issue is strength – the ability of a structure to support loads. The basic approach to strength is to ensure that the strength criterion will be satisfied:

$$F \leq R$$

That is, the load - F - on the structure, must be less than or equal to the resistance - R - of the part.

Allowable stress method

This method was used prior to the adoption of the partial factor method in the 1970s. It is still used by some engineers when doing check calculations because it is easier to use.

$\sigma_{allowable}$ is the maximum permitted stress in the material. This is normally the yield stress divided by a factor of safety, FoS, i.e.

$$\sigma_{allowable} = f_y/FoS$$

The working stress - $\sigma_{working}$ - is the maximum stress in the material of the structure under an applied load that is the maximum likely to be encountered in normal use.

The value of the factor of safety depends on the level of risk. It is not normally less than 2.0

The *strength criterion* is:

$$\sigma_{working} \leq \sigma_{allowable} \text{ i.e. } \sigma_{working}/\sigma_{allowable} \leq 1.0$$

Example:

The safe working load (SWL) for a crane is 50 kN. This means that a lift greater than 50kN is not allowed. If the area of the lifting cable is 800mm^2, the axial stress in the cable is:

$$\sigma_{working} = F/A = 50000/800 = 62.5 \text{ N/mm}^2$$

If the yield stress in the cable is: f_y = 345 N/mm^2, and the factor of safety is 2.0, the allowable stress is:

$$\sigma_{allowable} = f_y = 345/2.0 = 172 \text{ N/mm}^2$$

The strength criterion is:

$$\sigma_{working}/\sigma_{allowable} \leq 1.0 \quad \text{i.e. } 62.5/172 = 0.35 \leq 1.0$$

Therefore the criterion is satisfied.

Partial factor method

This method is adopted in the structural Eurocodes that are used across Europe. Instead of working with stress, the force that a member is required to resist is compared to its resistance i.e. to the force that it can resist. (Note that the Eurocode for design in timber uses stress in the strength criteria).

Basic principles

The explanation that follows refers to is a simplified version of the Eurocodes approach. Only some of the Eurocode notation is used.

Design force

The maximum load that the structure is likely to be required to resist in normal circumstances is defined as the *working load* - F_k (Note that in the Eurocodes this is known as the 'characteristic value of an action'.)

The working load is multiplied by *partial safety factors* to convert it to the *design load* - F_d - i.e. to the maximum load that the structure might need to resist in exceptional circumstances i.e.

$F_d = F_k \gamma_f$ where γ_f is the partial safety factor for load.

F_d is applied to the structure and the corresponding internal force actions in the members are calculated. These are the design forces that are used in the strength criteria. The internal force actions can be axial forces - N_{Ed}, bending moments - M_{Ed}, or shear forces - V_{Ed}. The E subscript is for 'effect' i.e. load/force.

In the Eurocodes, the dead load (i.e. permanent load) and the live load (i.e. non-permanent load) are given different partial safety factors due to the fact that there is more uncertainty about the value of the live load than that of the dead load. As a simplification here a total working load and a single partial safety factor for load = 1.5 is used.

Design resistance

The characteristic value of the resistance of a member - R_k - i.e. the load that may cause it to fail in normal circumstances is estimated. For example, for axial force in a member, the characteristic value of the axial resistance might be:

$N_{Rk} = A f_y$ where A is the cross-sectional area of the member and f_y is the yield stress.

The characteristic value of the resistance is divided by a partial safety factor γ_M to define the minimum likely strength in exceptional circumstances - i.e. the design axial resistance is:

$N_{Rd} = N_{Rk}/\gamma_M$

Strength criteria

The strength criterion for axial force in a member is: $N_{Ed} \leq N_{Rd}$ i.e. $N_{Ed} / N_{Rd} \leq 1.0$

For bending moment: $M_{Ed} / M_{Rd} \leq 1.0$

For shear force: $V_{Ed} / V_{Rd} \leq 1.0$

A very important principle in using a strength criterion is that, to be on the safe side, the load should be overestimated and the strength underestimated. Since partial factors are quoted as numbers greater than or equal to 1.0 (except in the special case of wind uplift where the factor for dead load is less than 1.0), *multiplying* the working load by the partial factor for load and *dividing* the characteristic strength by the partial factor for resistance implements this principle.

Process for partial factor strength criteria

1. Identify the characteristic load F_k - from code of practice or data sheet.
2. Multiply F_k by the partial safety factor for load - γ_f. For check calculations uses γ_f = 1.5. For final design use full Eurocode process.
3. Calculate the internal force actions due to F_k - N_{Ed}, M_{Ed}, or V_{Ed}.
4. Calculate the characteristic value of the resistance - N_{Rk}, M_{Rk}, or V_{Rk}.
5. Calculate the design values of resistance by dividing by γ_M to get the design values of resistance - N_{Rd}, M_{Rd}, or V_{Rd}. Use the following values for γ_M Steel: 1.0, Concrete: 1.5, Timber 1.2.
6. Apply the strength criterion - as listed above

Example - steel column

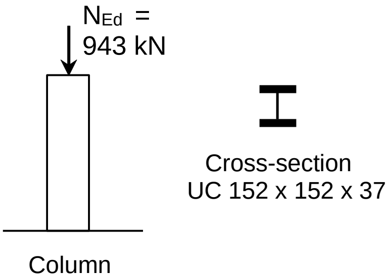


Figure 1 Stocky column

Figure 1 shows steel column with section UC 152 x 152 x 37. It is required to take an axial design force of 943kN. This force is from the results of a structural analysis where the applied load is a working load multiplied by a partial safety factor. For a ‘stocky’ column no allowance for buckling is required.

N_{Ed} = 943 kN

f_y = 235 N/mm^2 (Grade S235 steel)

A = 4740 mm^2 (from steel sections table)

γ_M = 1.0

$N_{Rd} = (A f_y)/\gamma_M$ = 4740*235/1.0 = 1114 kN

$N_{Ed} / N_{c,Rd}$ = 943/1114 = 0.85

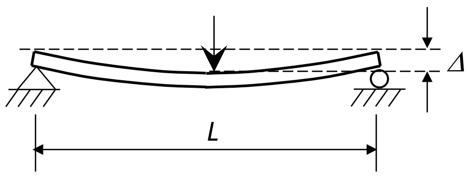
Since N_{Ed} / N_{Rd} is less than 1.0 the section satisfies the criterion for compressive load.

Serviceability

A main serviceability criterion is that the stiffness of a beam or a floor will be adequate. This is measured by the maximum deflection. A common criterion is:

$\Delta/L \leq 1/300$

where Δ is the maximum deflection (normally at the centre of the span) due to the characteristic load and L is the span of the beam.



Metadata

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