STRUCTURAL SAFETY

Modern Approach to Structural Safety

In the light of the above discussion safety can be defined as:

$$\frac{R_k}{\gamma_m} \geq F_k \gamma_f$$

Modern Approach to Structural Safety

In working stress design, γ_m and γ_f are combined into one factor, called, "factor of safety". If the factor of safety is denoted as "FS", then the safety equation can be rewritten as shown below.

$$\frac{R_k}{\gamma_m \gamma_f} = \frac{R_k}{(FS)} \geq F_k$$

Modern Approach to Structural Safety

$$\cancel{\frac{R_k}{\gamma_m \gamma_f} = \frac{R_k}{(FS)} \geq F_k}$$

Unfortunately, for reinforced concrete structures R_k and F_k are not independent variables, hence the transformation given in above expression is not permissible.

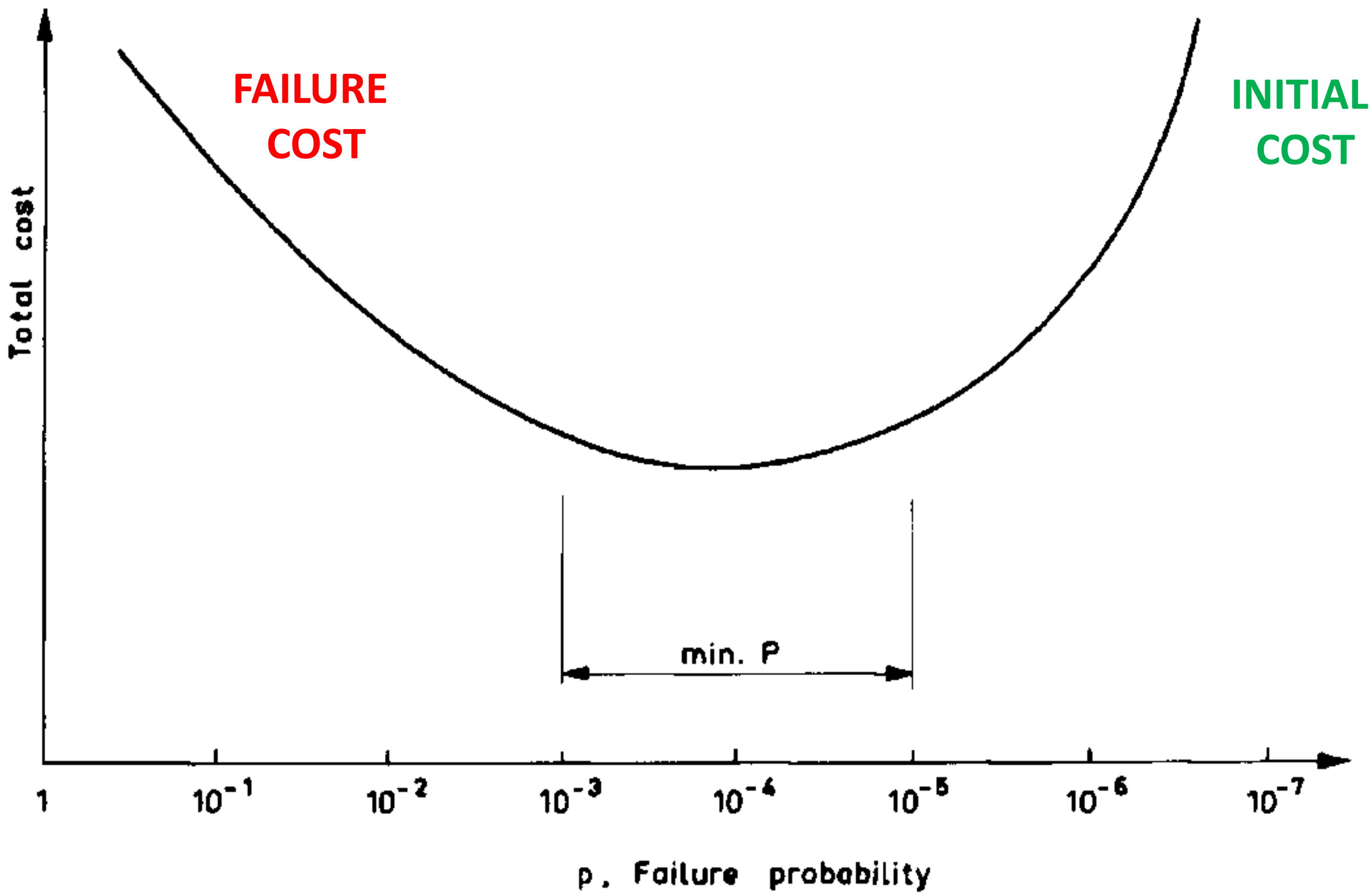
Modern Approach to Structural Safety

The magnitudes of γ_m and γ_f depend on many factors, among which perhaps the probability of failure assumed is the most important one. The main objective in applying γ_m and γ_f factors is to reduce the probability of failure to a certain level. Besides, γ_m and γ_f depend on the type and purpose of the structure, type of material, type of loading etc. These will be discussed later in this chapter.

Structural Safety and Cost

"*The strength of the structure must be weighed against the corresponding risk of failure or other damage so that <u>the total cost of the structure</u>, which is equal to the capital expenditure plus the probable cost of failure or other damage, shall be minimum.*"

STRUCTURAL SAFETY AND COST



Limit State Design

There are mainly two limit states. These are (a) the Ultimate Limit State and (b) Serviceability Limit State.

Ultimate Limit State (ULS) may be reached due to:

- Loss of equilibrium of a part or the whole of the structure,
- Rupture of critical sections,
- Loss of stability (formation a mechanism),
- Buckling due to instability,
- Fatigue.

Ultimate Limit State

In the ULS, loads considered should be the characteristic loads

$$F_k = F_m + u\,\overline{\sigma}$$

This requires the knowledge of F_m, u and σ. In the absence of this information the nominal load values given in the National Codes should be used as the characteristic values.

Ultimate Limit State

At the ULS, each type of loading should be multiplied by a different load factor depending on how accurately the load can be estimated. For example, the load factor applied to the dead load is smaller as compared to the factor applied to the live load, because the dead load can be calculated with fairly good degree of precision.

Ultimate Limit State

When several types of loads act at the same time, probability of each load reaching the characteristic value decreases. Therefore, for such combinations an additional factor, called, the "**Combination Factor**" (which is $\psi_0 \leq 1.0$) is introduced.

$$F_d = \gamma_g G + \gamma_q \left\{ Q_{lk} + \sum \psi_{oi} Q_{ik} \right\}$$

F_d = design load	**Q_{ik} = other live load**
G = dead load	**Q_{lk} = basic live load,**
γ_g = load factor for the dead load	**ψ_{oi} = combination factor which less than unity.**
γ_{qv} = load factor for the live load	

Ultimate Limit State

For the ULS, the material strengths to be used are called “the Design Strength". Design strengths are obtained by dividing the characteristic strength by the proper material factors.

$$f_d = \frac{f_k}{\gamma_m}$$

where; f_d = design strength, f_k = characteristic strength and γ_m = material factor which is equal to or greater than unity.

Ultimate Limit State

Design strengths are defined for concrete and steel using different material factors.

Steel: $f_{yd} = \frac{f_{yk}}{\gamma_{ms}}$; Concrete: $f_{cd} = \frac{f_{ck}}{\gamma_{mc}}$

Since variation in concrete strength is much greater than the variation in steel strength, γ_{mc} should be greater than γ_{ms}.

Ultimate Limit State

The greatest advantage of the limit state design is that, different load factors and different material factors can be applied to different types of loads and materials. Then the designer can adjust these factors depending on the degree of precision in determining the loads or the material strengths and their distributions. This of course cannot be done in working stress design method, where only a single factor of safety is used.

THIS MEANS ===> ECONOMY!

Serviceability Limit State (SLS)

A structure can be unserviceable if there is:

(a) excessive cracking,

(b) excessive deformations, or

(c) excessive vibration.

Then, for every structure and structural component, the serviceability limit state should be checked because the structure has to remain functional.

In SLS, loads are multiplied by load factors and material strengths are divided by material factors similar to ULS. However, for serviceability limit state, all load factors and material factors should be taken as 1.0.

Safety Provisions in TS-500

The Turkish Code released by the **Turkish Standards Organization** in 1984 takes **Limit State Design** as the basis for the safety provisions. The Turkish Code uses the same principles as **European Code**, i.e. load and combination factors are applied to the characteristic loads and characteristic material strengths are divided by the material factors to obtain what is called **"the design strength.“**

Although the procedure is same, factors used are somewhat different from the European Code.

Safety Provisions in TS-500

Load factors and possible combinations for the ultimate limit state are as follows:

GRAVITY + EARTHQUAKE	GRAVITY + WIND
1.4G + 1.6Q	1.4G + 1.6Q
1.0G + 1.0Q + 1.0E	1.0G + 1.3Q + 1.3W
1.0G + 1.2Q + 1.2T	1.0G + 1.2Q + 1.2T
0.9G + 1.0E	0.9G + 1.3W

SAFETY PROVISIONS IN TS-500

E is the earthquake load and **W** is the wind load. It is assumed that wind and earthquake loadings do not occur at the same time. **T** is the load effect created by deformations, like differential settlement, creep, shrinkage or temperature changes.

Since adequate statistical data is not yet available, it is recommended to assume that the loads given in the related standard (TS-498) are the characteristic loads.

Safety Provisions in TS-500

The material factors specified in TS-500 are similar to those given in the European Recommendations. However, in European Code (1-R) = 0.05 but in TS-500 (1-R) = 0.10, i.e. 10%.

In TS-500, it is stated that the **characteristic yield strength for steel can** be taken as the **minimum yield strength** specified in the related standard, (TS-708). The **design strength of steel** is defined as:

Safety Provisions in TS-500

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$$f_{yd} = \frac{f_{yk}}{\gamma_{ms}} \qquad \text{or} \qquad f_{ywd} = \frac{f_{ywk}}{\gamma_{ms}}$$

γ_{ms} = 1.15 (reinforcing steel)

f_{yk} and f_{ywk} are the characteristic strengths of longitudinal and transverse steels.

Safety Provisions in TS-500

For concrete, **the characteristic value is the strength** on which the design is based (strength marked on the design drawing). The **design strength for concrete** are defined as,

$$f_{cd} = \frac{f_{ck}}{\gamma_{mc}} \qquad \text{or} \qquad f_{ctd} = \frac{f_{ctk}}{\gamma_{mc}}$$

SAFETY PROVISIONS IN TS-500

$$f_{cd} = \frac{f_{ck}}{\gamma_{mc}} \qquad \text{or} \qquad f_{ctd} = \frac{f_{ctk}}{\gamma_{mc}}$$

where;

f_{ctk} = Characteristic tensile strength of concrete.

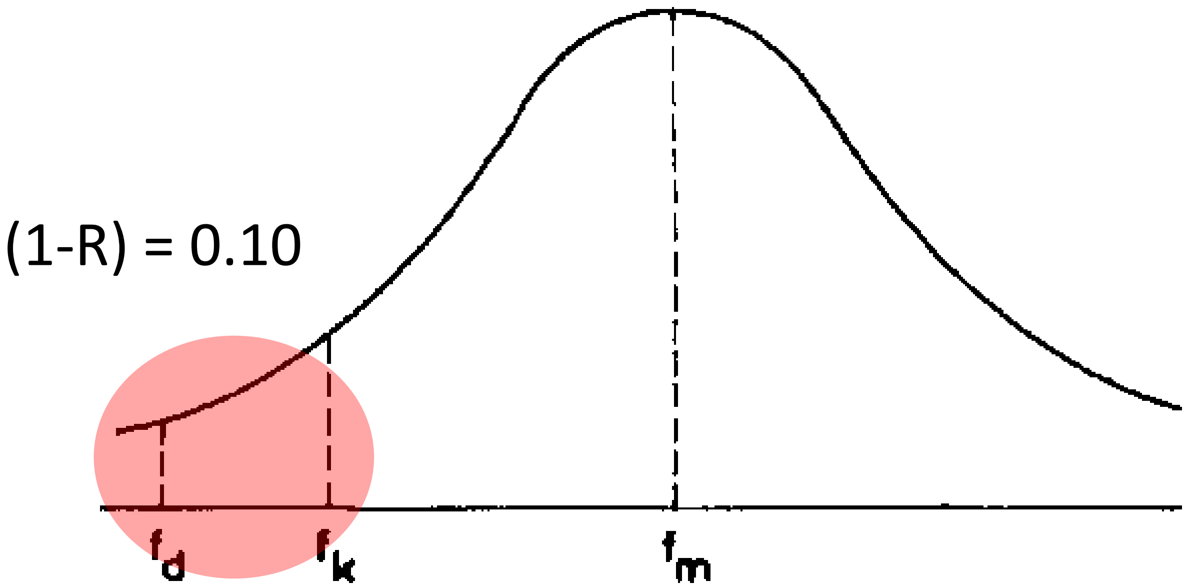
Values of material factors to be used in ultimate limit state are,

γ_{mc} = 1.5 (cast in place concrete)

γ_{mc} = 1.4 (precast concrete)

γ_{mc} = 1.6 or 1.7 (if standard control is not available)

SAFETY PROVISIONS IN TS-500

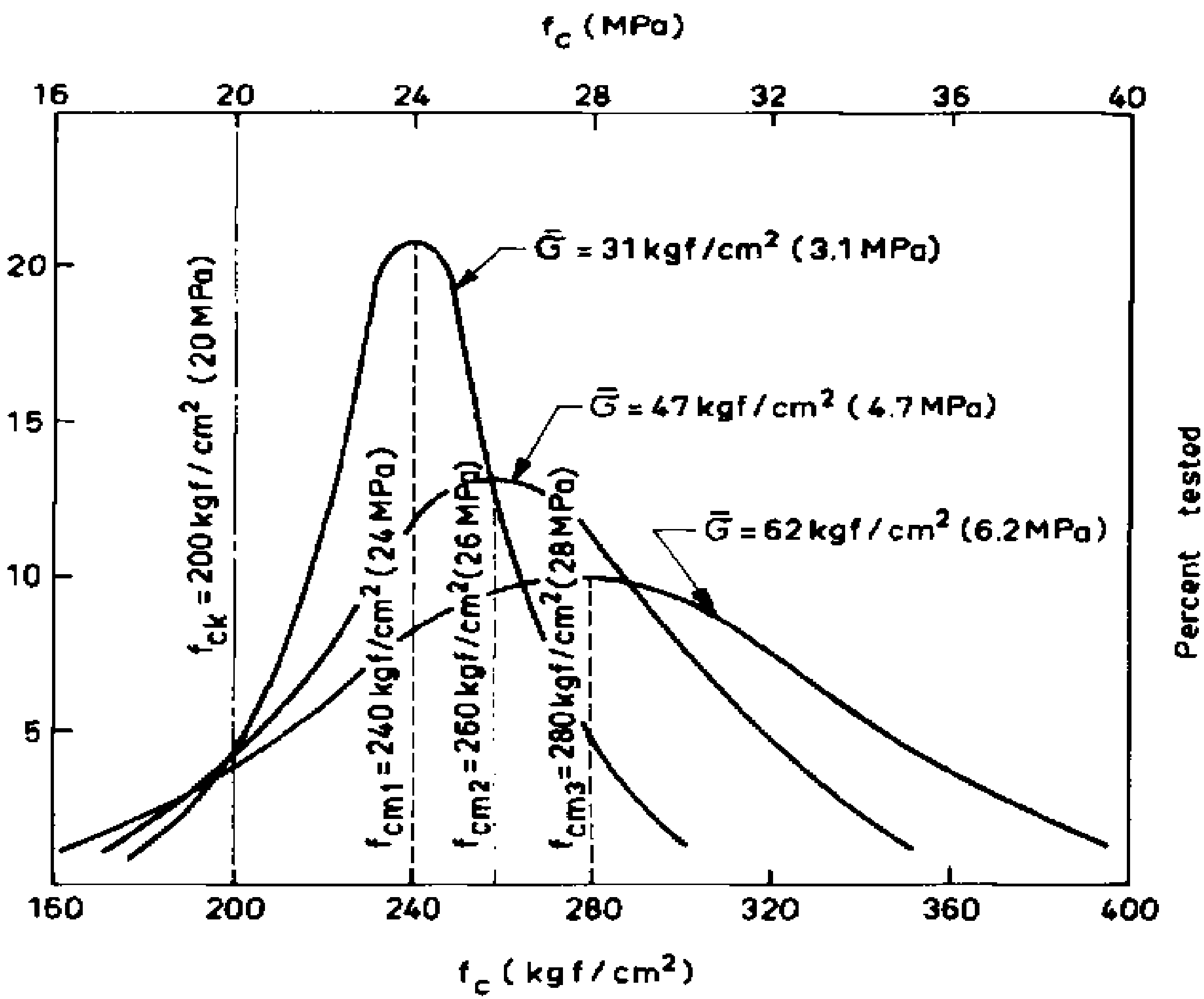


Mean, characteristic and design values for concrete strengths are marked on normal distribution curves shown in figure.

SAFETY PROVISIONS IN TS-500

Concrete characteristic strength f_{ck} (or f_{ctk} if tension) is the value on which the design is based. It refers to the grade of concrete given in Table 1.9 in Chapter-l. The design value, f_{cd} (or f_{ctd}) as defined by Eq. (3.21) is the strength to be used in all design computations. The mean strength, f_{cm} is the strength on which the mix design is based, or it is to strength to be specified to the contractor. In TS-500 the relationship between f_{cm} and f_{ck} is expressed as, $f_{cm} = f_{ck} + 1.28\overline{\sigma}$

SAFETY PROVISIONS IN TS-500



SAFETY PROVISIONS IN TS-500

When it is not possible to estimate the standard deviation , the code recommends the following equation to be used.

$$f_{cm} = f_{ck} + \Delta f$$

Δf should be taken as 4 MPa for concrete grades of C12 and C16, 6 MPa for C20, C25 and C30 and 8 MPa for higher strength concrete.

Live Load Arrangements

The dead load exists on all spans of the structure. However live load may or may not be present on a given span. Therefore TS500-2000 requires the live load to be arranged in such a way as to produce the maximum internal force at that point. The internal force can be moment, shear or axial load.

It is not difficult to find the necessary live load arrangements which will result in maximum internal forces. With the help of "***influence line***" knowledge it is very easy to decide on the most critical live load arrangements on structures.

What is an influence line?

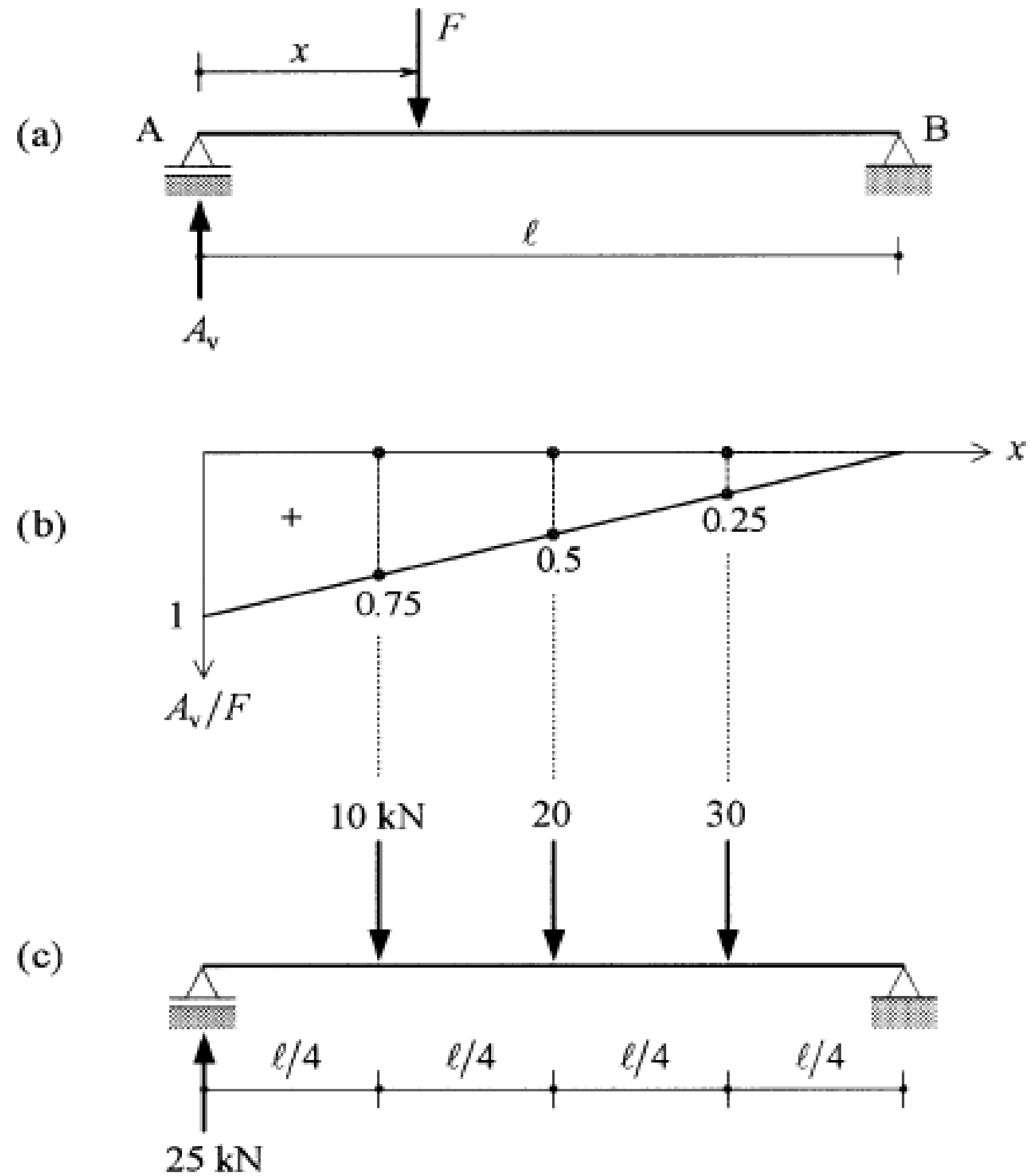
In many structures, the support reactions and section forces depend not only on the magnitudes of the loads, but also on their placement. This is particularly true for bridges, where an important part of the load consists of moving vehicles.

If we want to choose the dimensions of a structural element to check it for strength and rigidity, it is important to know the location at which the load or set of loads generate the most severe effects.

What is an influence line?

Important tools for finding the most unfavorable placement of loads are the so-called ***influence lines***. ***Influence lines*** are graphic representations of the magnitude of a support reaction or section force at a fixed location due to a single point load with variable position, i.e. moving load.

EXAMPLE: INFLUENCE LINE FOR A SUPPORT REACTION

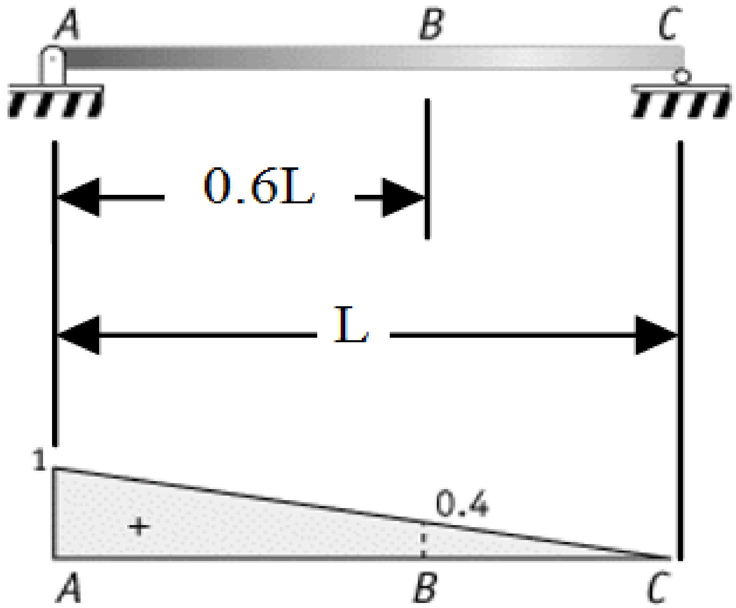


How to Draw Influence Lines

Müller-Breslau Principle: The Müller-Breslau Principle is a tool to draw the influence lines for statically determinate and indeterminate structures.

This principle simply states that the influence line for a support reaction or a section force is proportionally equivalent to the deflected shape of the structure when it undergoes a displacement as a result of the application of the corresponding support reaction or section force.

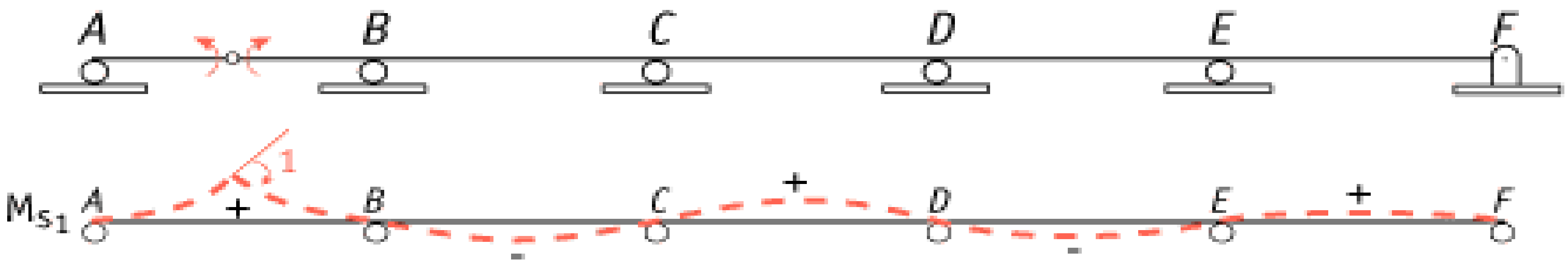
How to Draw Influence Lines



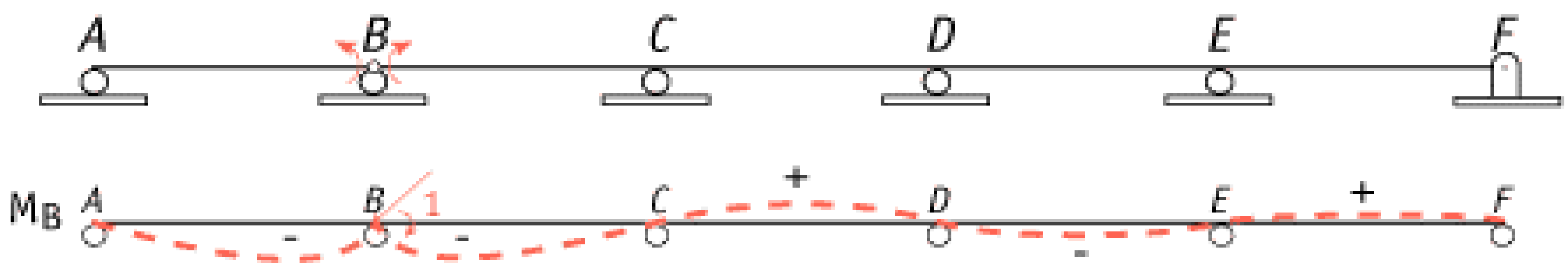
To determine the influence line for the support reaction at A, the "Müller-Breslau Principle" requires **the removal of the support restraint** and the **application of a positive unit deformation at this point** that corresponds to the direction of the force. In this case, apply a unit vertical displacement in the direction of A_v.

CONTINUOUS BEAMS: THE INFLUENCE LINE FOR SUPPORT REACTIONS

Span Moment @ “AB”

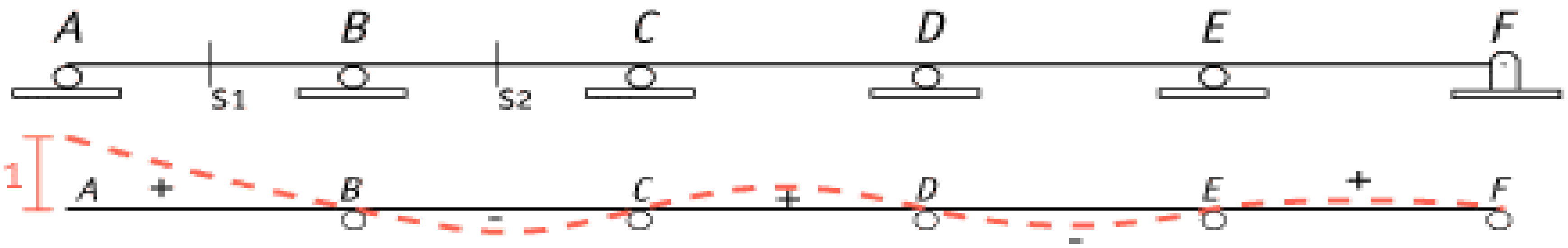


Support Moment @ “B”

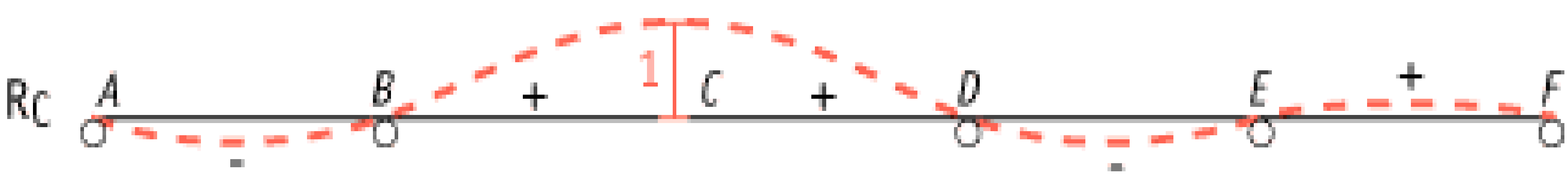


CONTINUOUS BEAMS: THE INFLUENCE LINES FOR MOMENTS

Support "A"



Support "C"

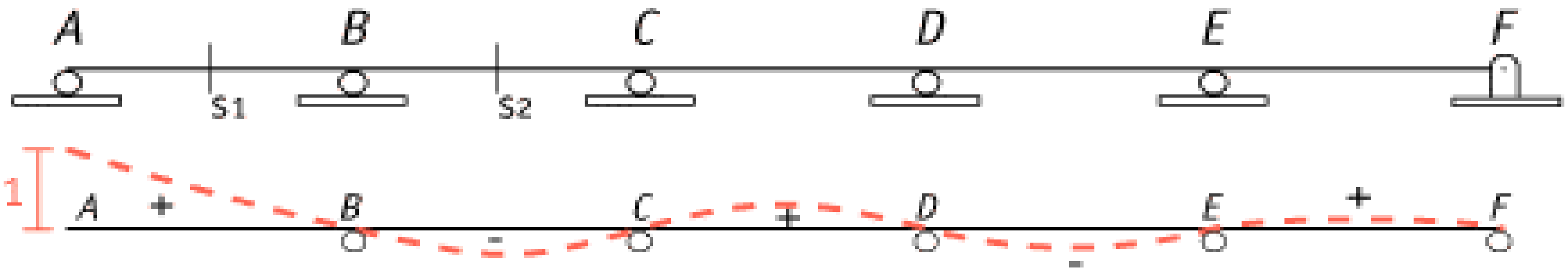


CONTINUOUS BEAMS: LOADING CASES FOR MOMENT AND SHEAR ENVELOPES

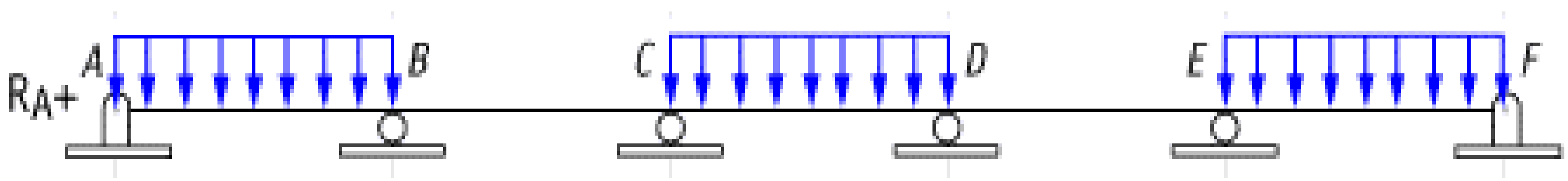
Using the influence lines found above, we are now going to illustrate the loading cases that are needed to calculate the maximum positive and negative A_v, M_B, V_{S1}, and M_{S1}.

The load cases are generated for the maximum positive and negative values by **placing a distributed load on the spans where the algebraic signs of the influence line are the same**, i.e., to get a maximum positive value for a function, place a distributed load where the influence line for the function is positive.

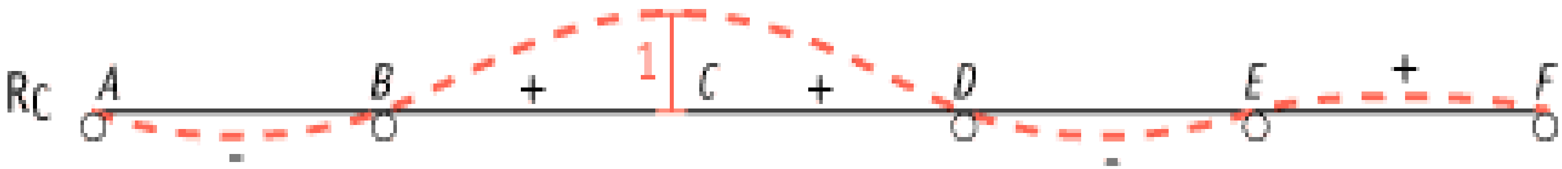
CONTINUOUS BEAMS: LOADING CASES FOR MOMENT AND SHEAR ENVELOPES



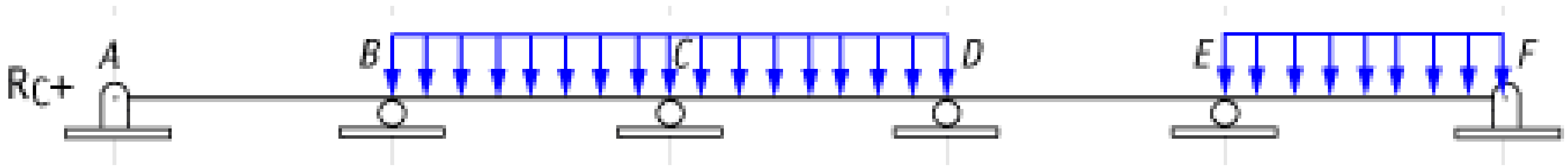
max (+)'ve reaction at support A



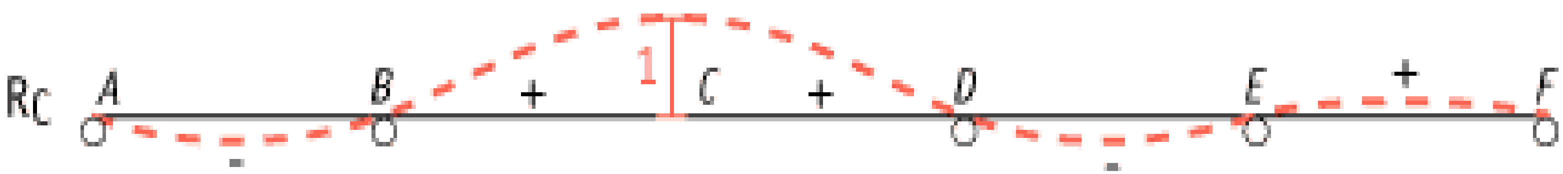
CONTINUOUS BEAMS: LOADING CASES FOR MOMENT AND SHEAR ENVELOPES



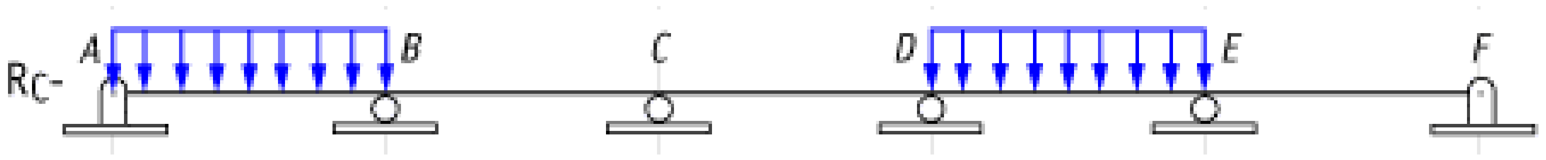
max (+)'ve reaction at support C



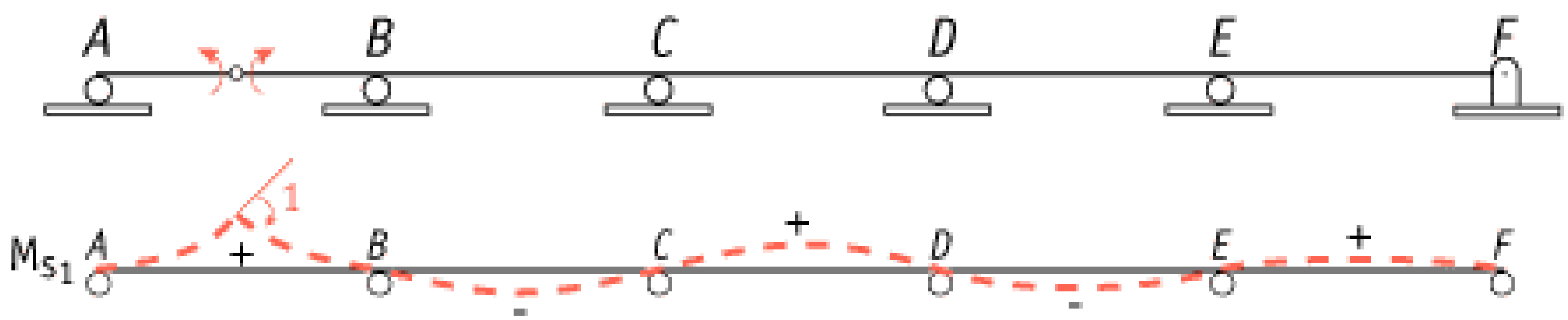
CONTINUOUS BEAMS: LOADING CASES FOR MOMENT AND SHEAR ENVELOPES



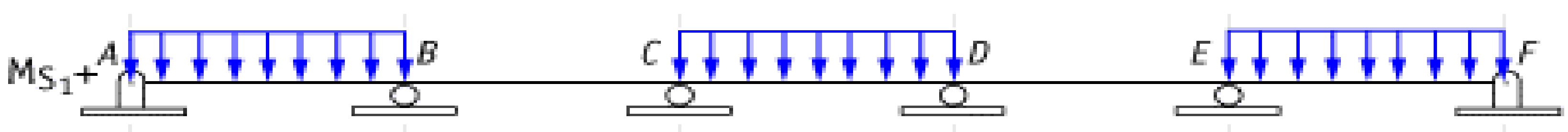
max (-)'ve reaction at support C



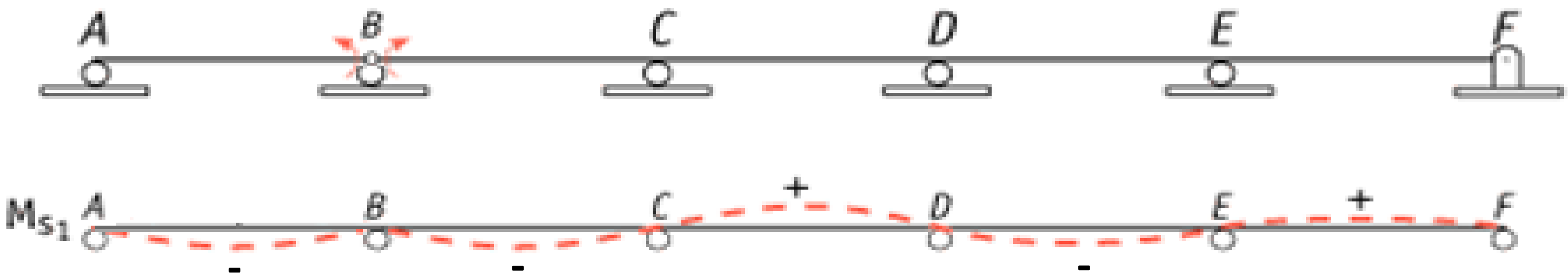
CONTINUOUS BEAMS: LOADING CASES FOR MOMENT AND SHEAR ENVELOPES



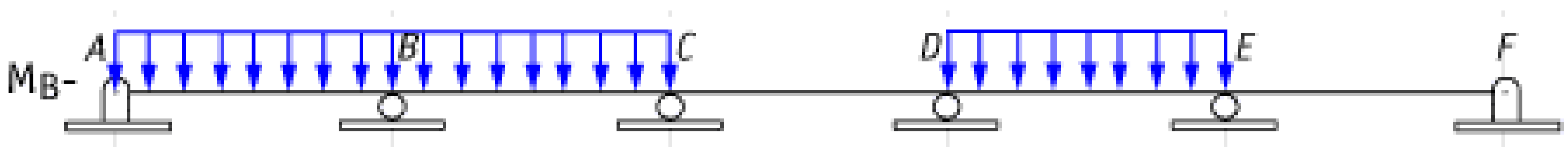
max (+)'ve bending moment, $M_{s1,}$ in Span AB



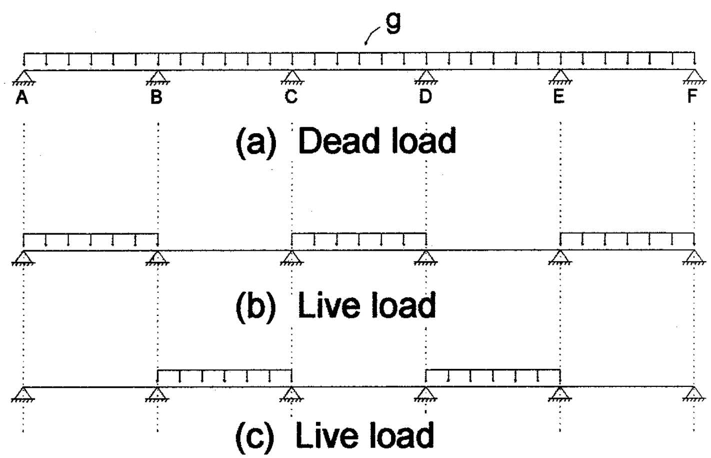
Continuous Beams: Loading cases for moment and shear envelopes

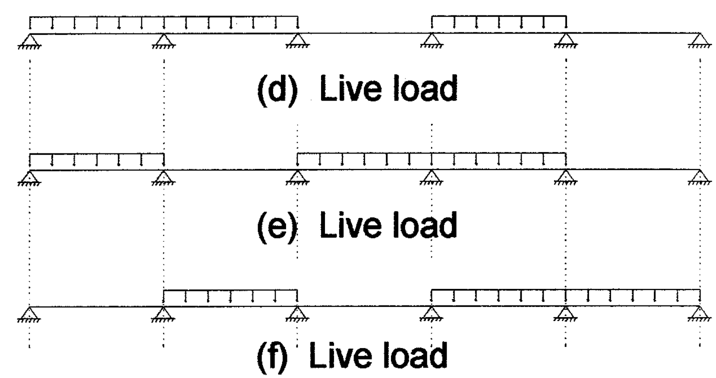


max (-)'ve bending moment, $M_{s1,}$ in Support B



In the light of this discussion, it can be concluded that with a few live load arrangements shown in figures above maximum positive moment at each span can be obtained. These load arrangements are called, “checker board loading.”





maximizes all span moments	**maximizes support moments at B, D and E & maximizes the shear forces in these spans**