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UNIVERSITÉ DE TLEMCEM  
Faculté de Technologie



## **A3 ARCHITECTURE**

**SUBJECT: STRUCTURE IN ARCHITECTURE 1**

# **CHAPTRE 2 : REINFORCED CONCRETE BEAMS**

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# INTRODUCTION

A beam is a structural element designed to transfer loads applied perpendicular to its longitudinal axis to the supports, which are the columns.



# REINFORCED CONCRETE

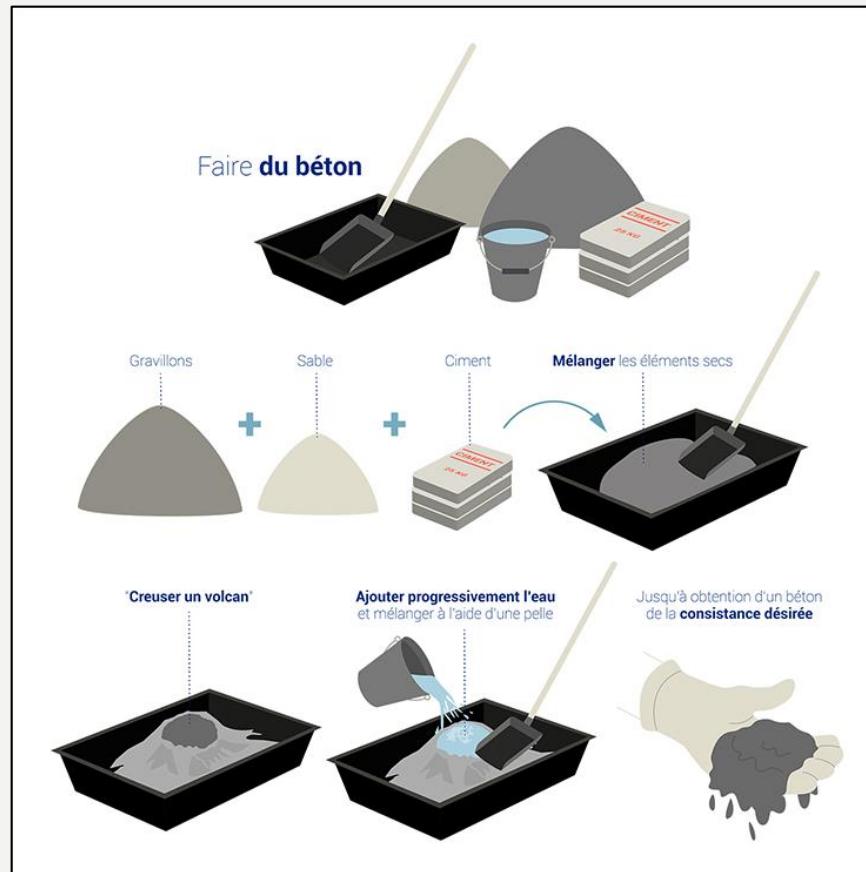
- Since its invention around 1850, concrete has become one of the most widely used construction materials.



- Architects consider it a symbol of modern architecture, enabling various technical solutions such as frameworks, cantilevers, shells, and thin walls.

# REINFORCED CONCRETE

Concrete is a composite construction material made from aggregates, sand, cement, and water, with optional additives used to modify its properties (plasticizers, retarders, accelerators, colorants, etc.).



# BEHAVIOR OF CONCRETE

The mechanical properties of concrete can be determined by performing standard tensile and compressive tests on cylindrical specimens (160×320), in accordance with the Eurocode 2 standard.



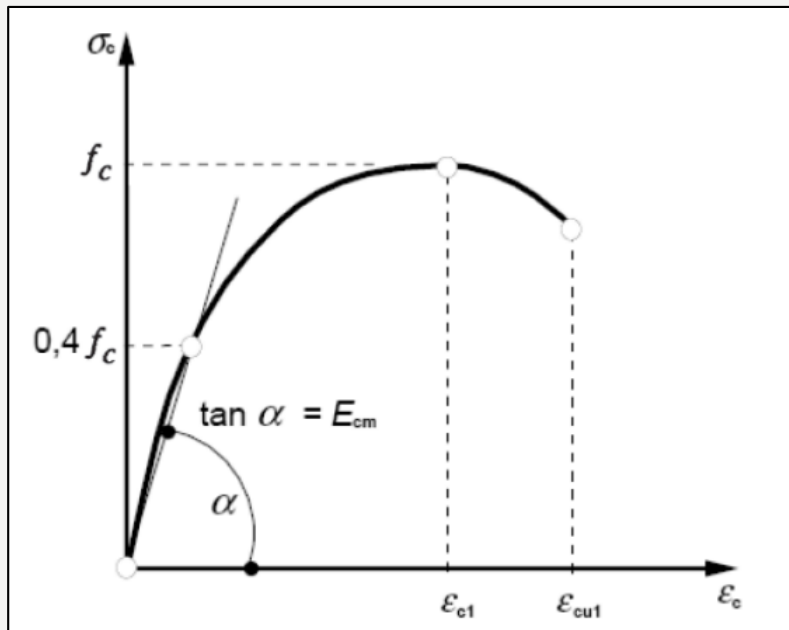
Compression Test



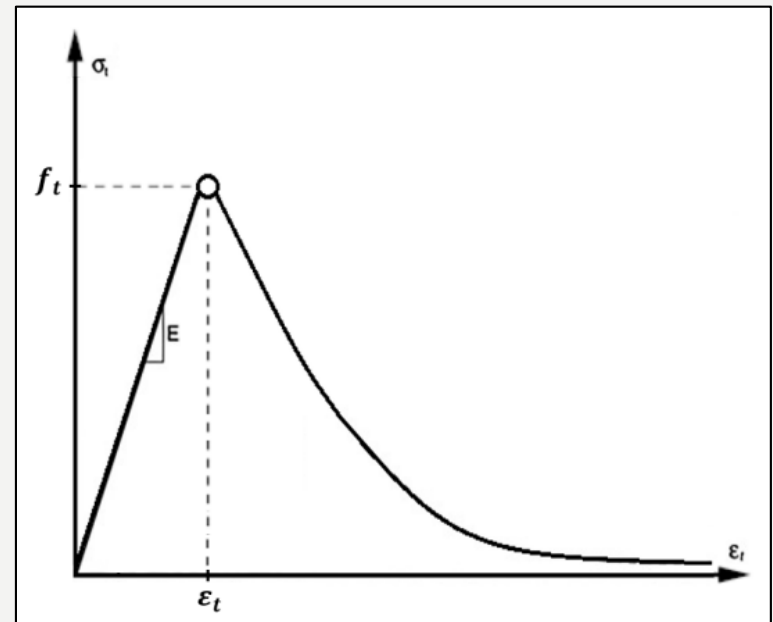
Tensile test

# BEHAVIOR OF CONCRETE

From these tests, the stress–strain curves, which represent the concrete's behavior law in compression and tension, are obtained as shown below.



Courbe de compression



Courbe de Traction

***fc: compressive strength; ft: tensile strength; E: modulus of elasticity***

# BEHAVIOR OF CONCRETE

Résistance moyenne à la traction du béton :

$$\text{si } f_{ck} \leq 50 \text{ MPa} \quad f_{ctm} = 0.3 \times (f_{ck})^{2/3} \text{ en MPa}$$

$$\text{si } f_{ck} > 50 \text{ MPa} \quad f_{ctm} = 2.12 \times \ln \left( 1 + \frac{f_{cm}}{10} \right) \text{ en MPa}$$

Module d'élasticité sécant du béton (déformation instantanée) :

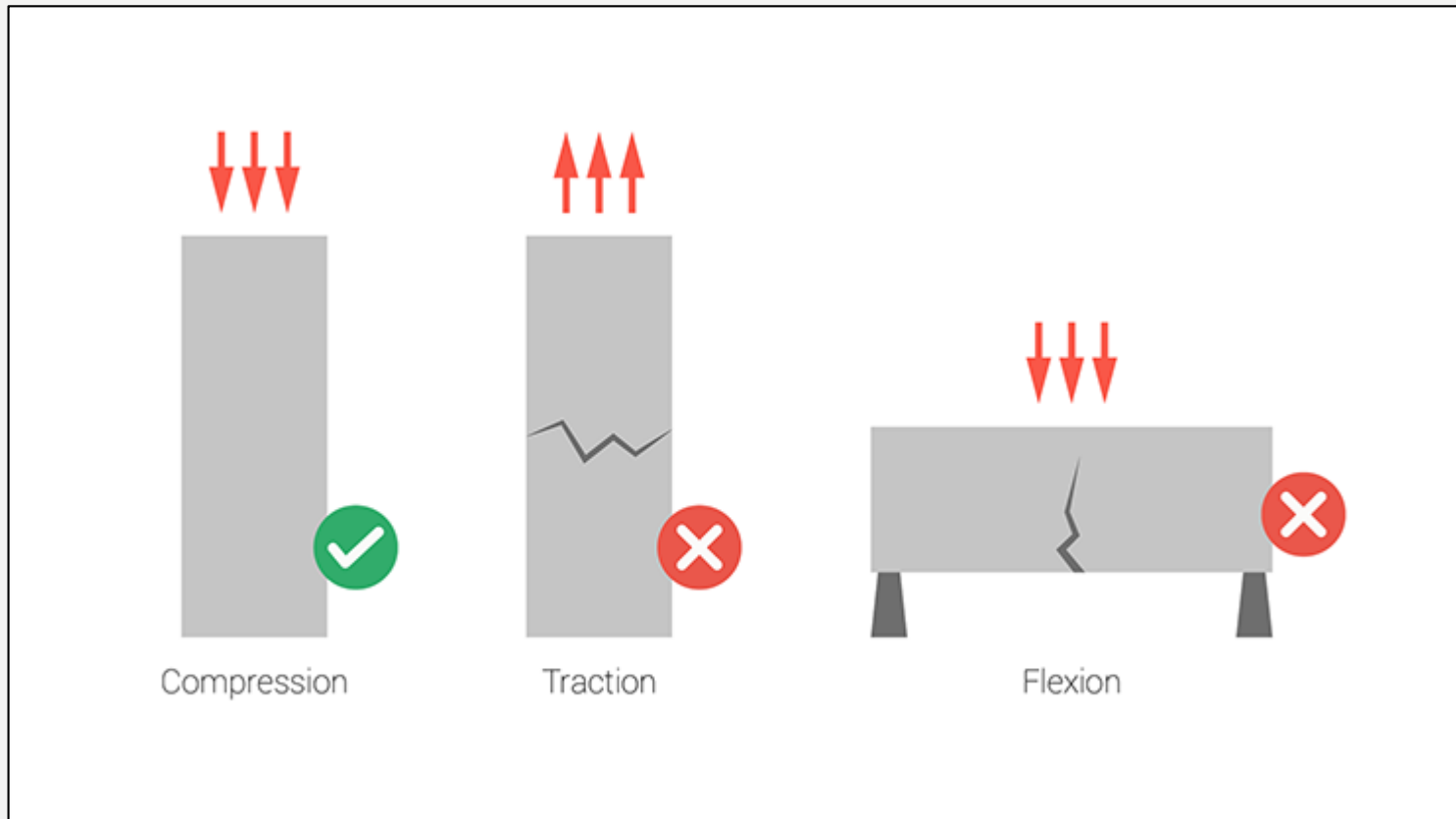
$$E_{cm} = 22000 \times \left( \frac{f_{cm}}{10} \right)^{0.3} \text{ en MPa}$$

Classes de résistance	C 12/15	C 16/20	C20/25	C 25/30	C30/37	C 35/45	C 40/50	C 45/55	C 50/60
$f_{ck}$ (N/mm <sup>2</sup> )	12	16	20	25	30	35	40	45	50
$f_{ctm}$ (N/mm <sup>2</sup> )	1.6	1.9	2.2	2.6	2.9	3.2	3.5	3.8	4.1
$E_{cm}$ (N/mm <sup>2</sup> )	27000	29000	30000	31000	33000	34000	35000	36000	37000

***fc: compressive strength; ft: tensile strength; E: modulus of elasticity***

# BEHAVIOR OF CONCRETE

Concrete has very low tensile strength and therefore cannot be used alone in a structure. Consequently, it is necessary to add steel reinforcement bars.



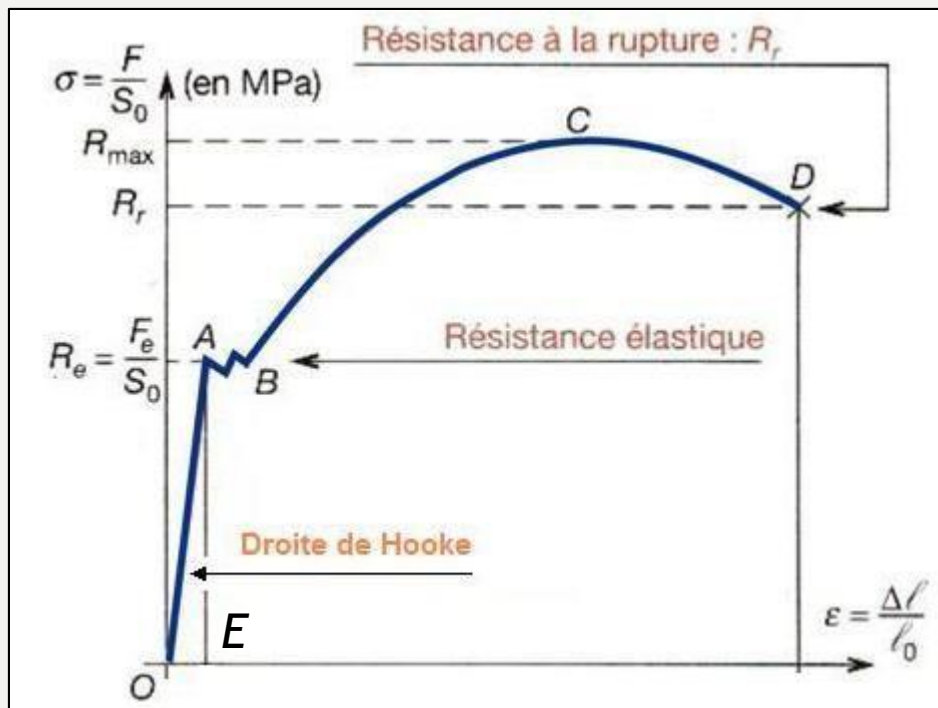
# STEEL REINFORCEMENT

Steel reinforcements are manufactured as high-bond bars. They are placed in tension zones, as these bars have excellent tensile strength.



# BEHAVIOR OF STEEL

Steel is a durable and strong material capable of withstanding heavy loads. It performs well under both tension and compression without undergoing permanent deformation. It is also ductile, which makes it valuable in construction for absorbing the energy from sudden loads such as earthquakes.



**$R_e$ : limite élastique;  $R_{max}$ : résistance max en traction;  $E$ : module d'élasticité**

# BEHAVIOR OF STEEL

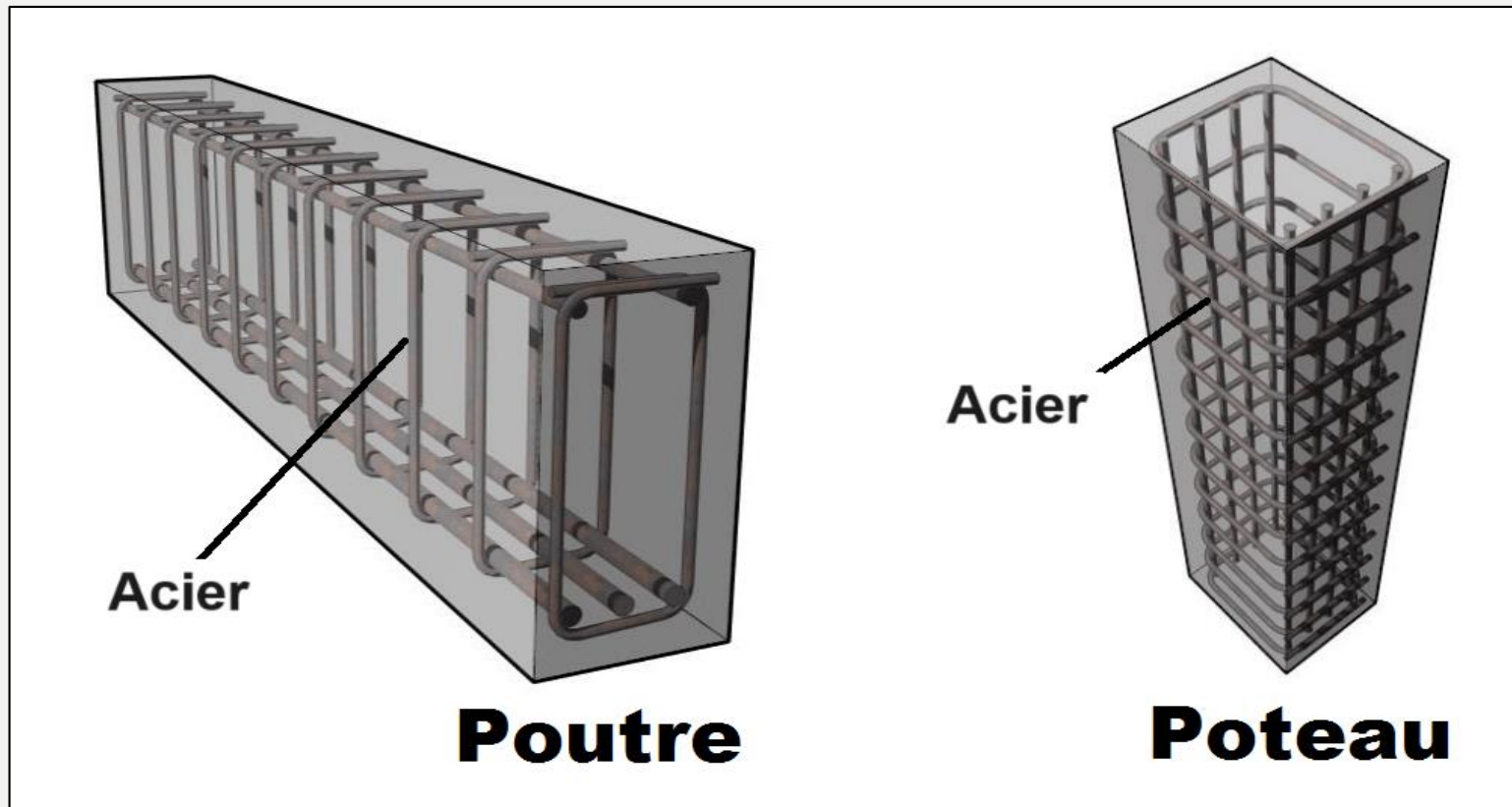
Les valeurs de calcul normalisées des principales caractéristiques des aciers de construction sont les suivants :

- Module d'élasticité :  $E = 210000N/mm^2 = 210KN/mm^2$
- Module de cisaillement :  $G = \frac{E}{2(1+\nu)} = 81KN/mm^2$
- Coefficient de Poisson :  $\nu = 0.3$
- Coefficient de dilatation thermique :  $\alpha_T = 1.2 \times 10^{-5} / ^\circ C$
- Charge volumique :  $\gamma = 78.5KN/m^3$

Caractéristiques	Types d'acier			
	Doux et lisses		A Haute Adhérence (symbole	
Dénomination	FeE215	Fe E 235	Fe E 400	Fe E 500
Limite élastique $f_e$ en MPa	<b>215</b>	<b>235</b>	<b>400</b>	<b>500</b>
Resistance a la rupture $\sigma_r$ en MPa	$\geq 330$	$\geq 410$	$\geq 480$	$\geq 550$
Allongement à la rupture	22%		14%	12%
Coefficient de scellement, symbole $\psi_s$	1		1,5	
Coefficient de fissuration, symbole $\eta$	1		1,6	
Diamètres courants en mm	6-8-10-12		6-8-10-12-14-16-20-25-32-40	

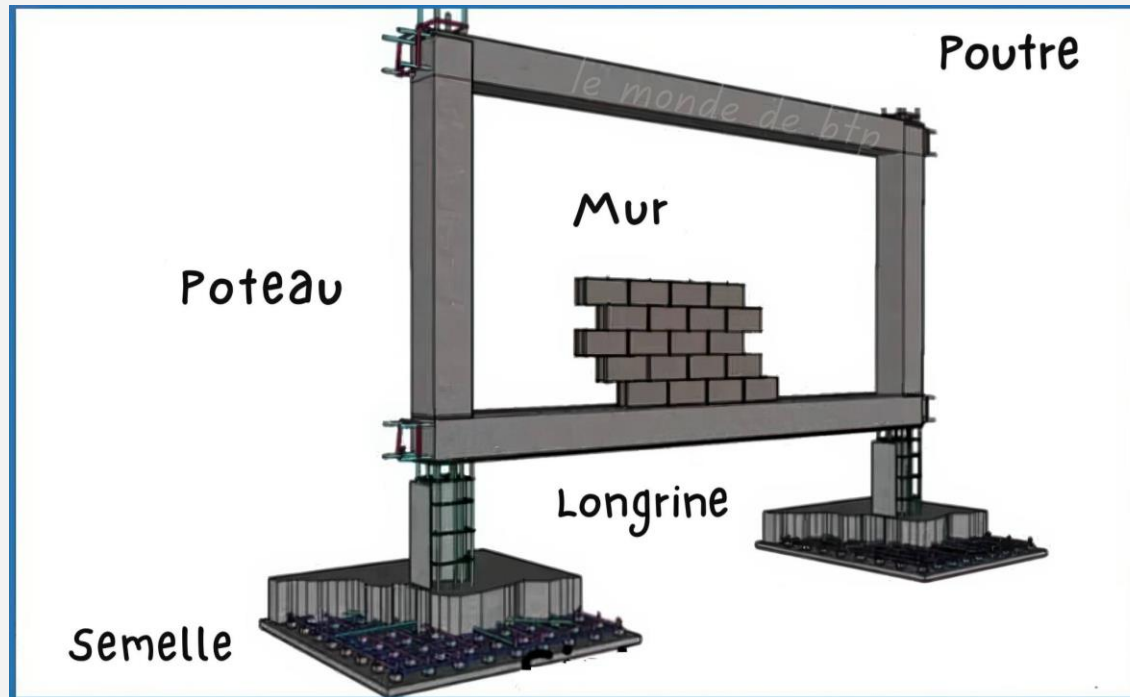
# REINFORCED CONCRETE

Concrete with steel reinforcement makes the whole structure resistant to all forces in any direction.



# REINFORCED CONCRETE FRAMES (COLUMN-BEAM PORTAL FRAME)

The column-beam system (or portal frame) is a framework consisting of vertical columns and horizontal beams, rigidly connected to each other to ensure the stability and strength of the structure.



# REINFORCED CONCRETE FRAMES (COLUMN-BEAM PORTAL FRAME)



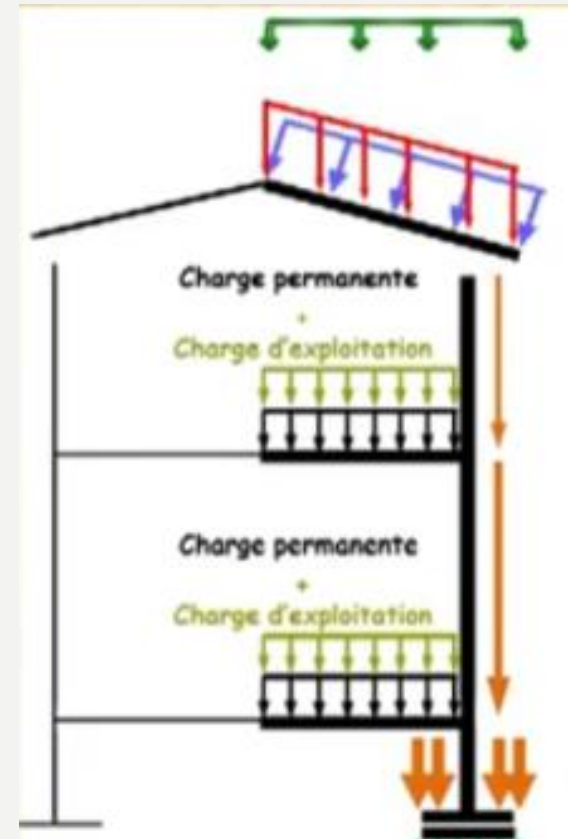
Column-beam system (portal frame)

# **FORCES ON THE STRUCTURE**

# FORCES ON THE STRUCTURE

Une action désigne aussi bien des charges appliquées à la structure que des déformations imposées par les effets thermiques ou des déplacements d'appui. Trois types d'action sont à considérer :

- **Les actions permanentes G**
- **Les actions d'exploitation Q**
- **Les actions accidentelles A**



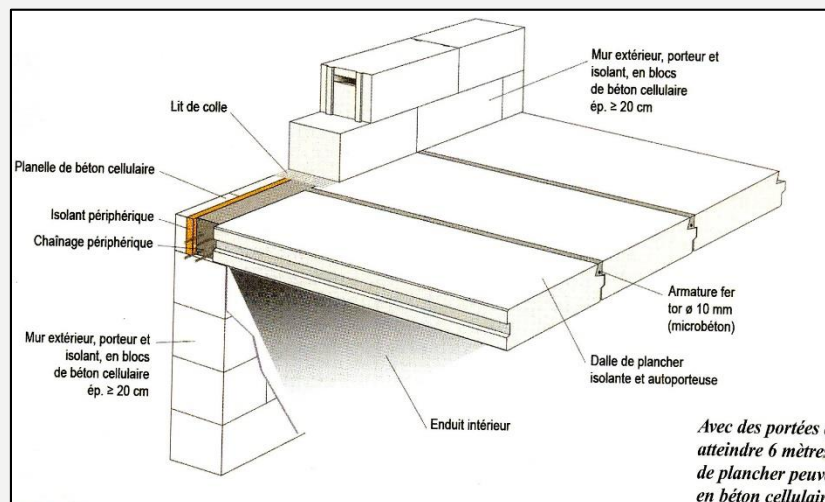
# FORCES ON THE STRUCTURE

## (PERMANENT LOADS G)

These are constant loads that act continuously on the structure. They do not vary over time.

### Examples:

- Self-weight of beams, columns, floors, slabs
- Weight of walls and fixed partitions
- Floor and ceiling finishes
- Weight of fixed equipment (ducts, stairs, etc.)



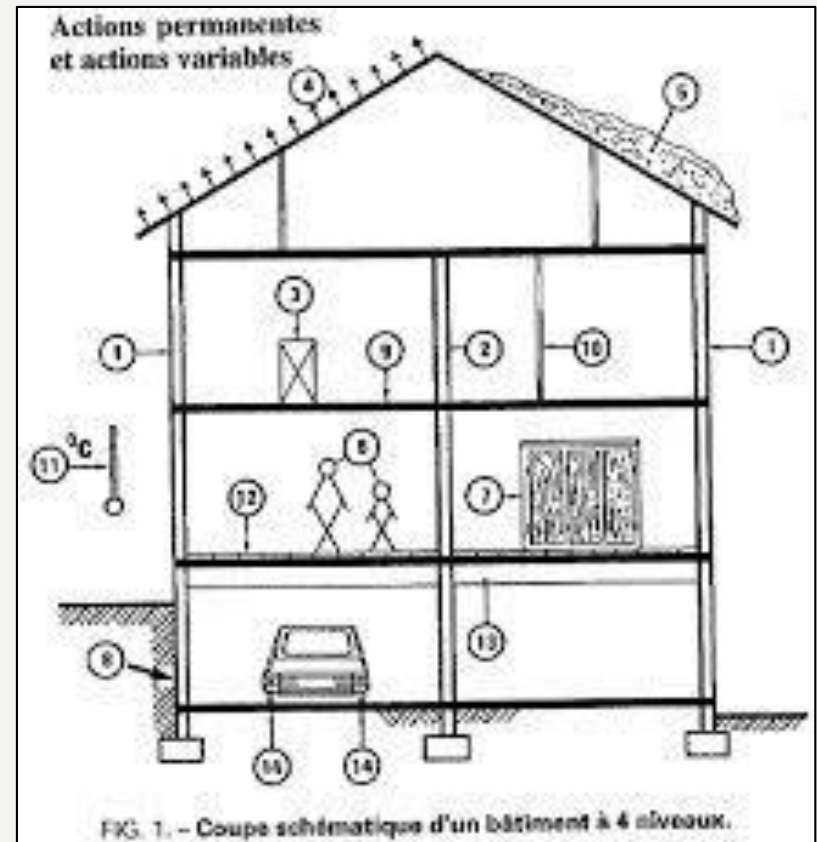
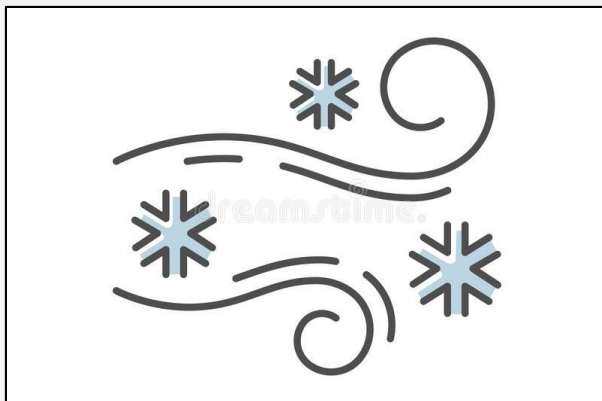
# FORCES ON THE STRUCTURE

## (LIVE LOADS Q)

These are loads that can vary over time (acting temporarily or intermittently) depending on the building's use.

### Examples:

- Human occupancy (people, furniture)
- Machines, vehicles, storage
- Wind, snow (environmental/climatic loads)

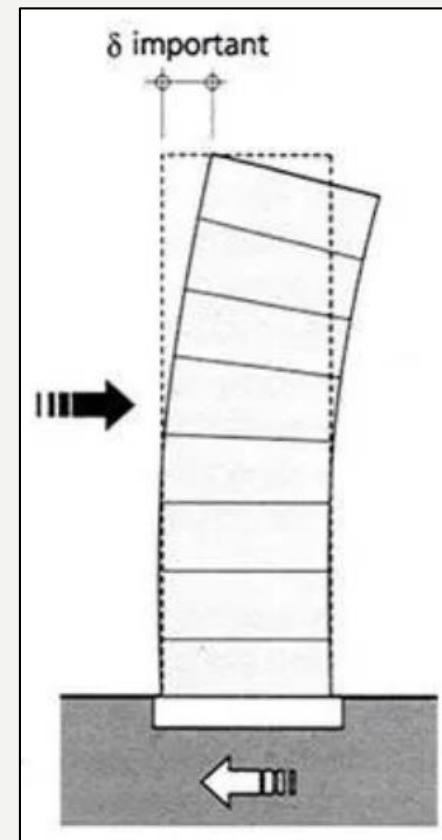
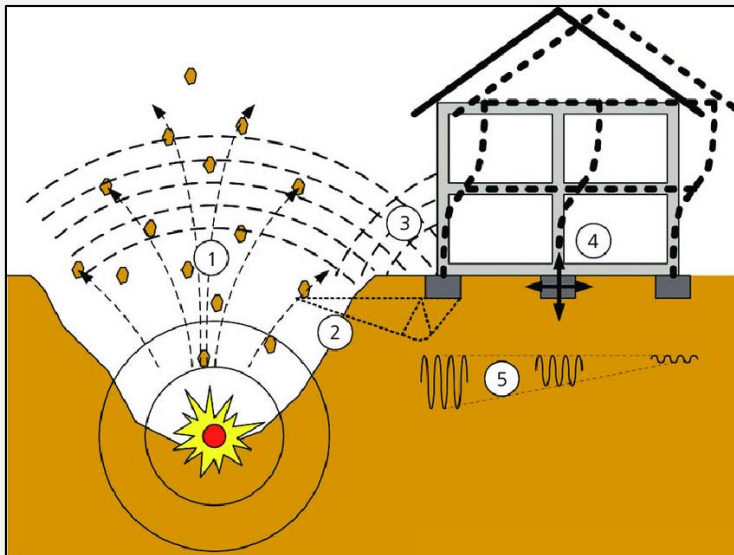


# FORCES ON THE STRUCTURE (ACCIDENTAL LOADS A)

These are loads that act for a short duration but can have very significant effects on the structure.

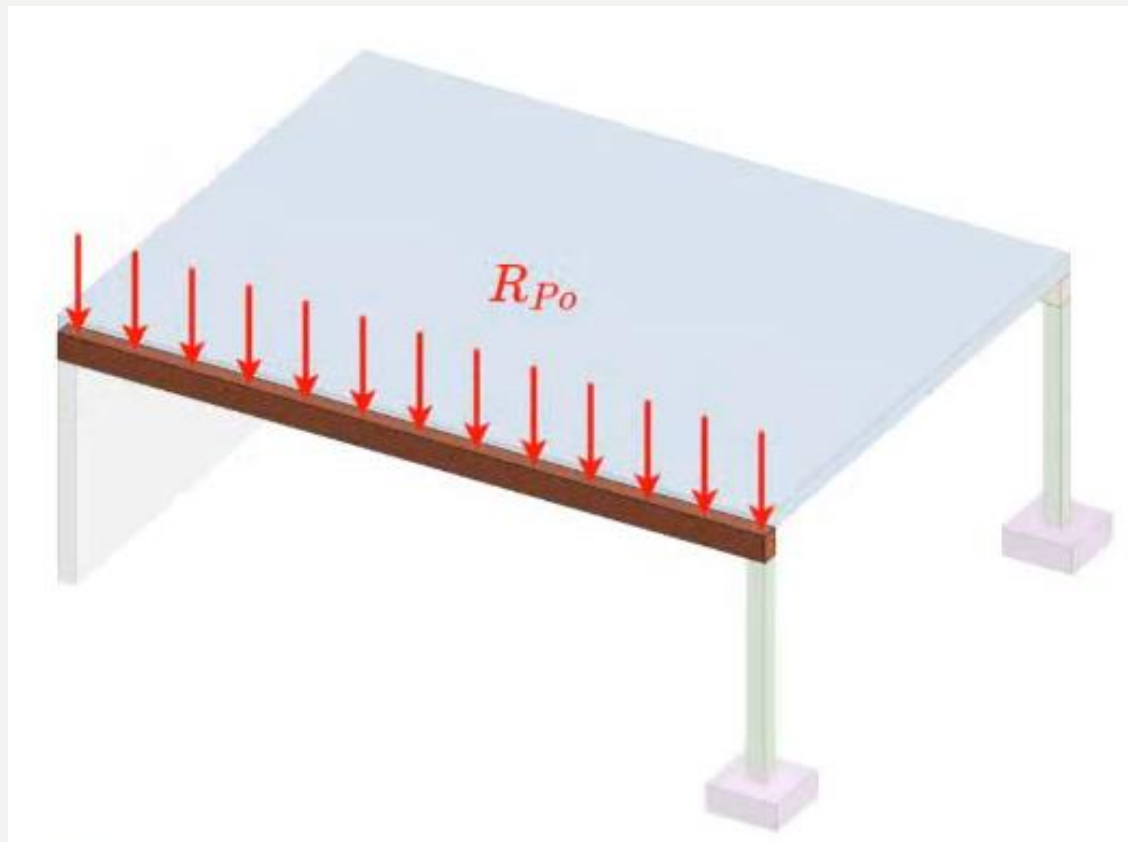
## Examples:

- Earthquake
- Vehicle collisions
- Explosion, fire
- Impact or failure of elements



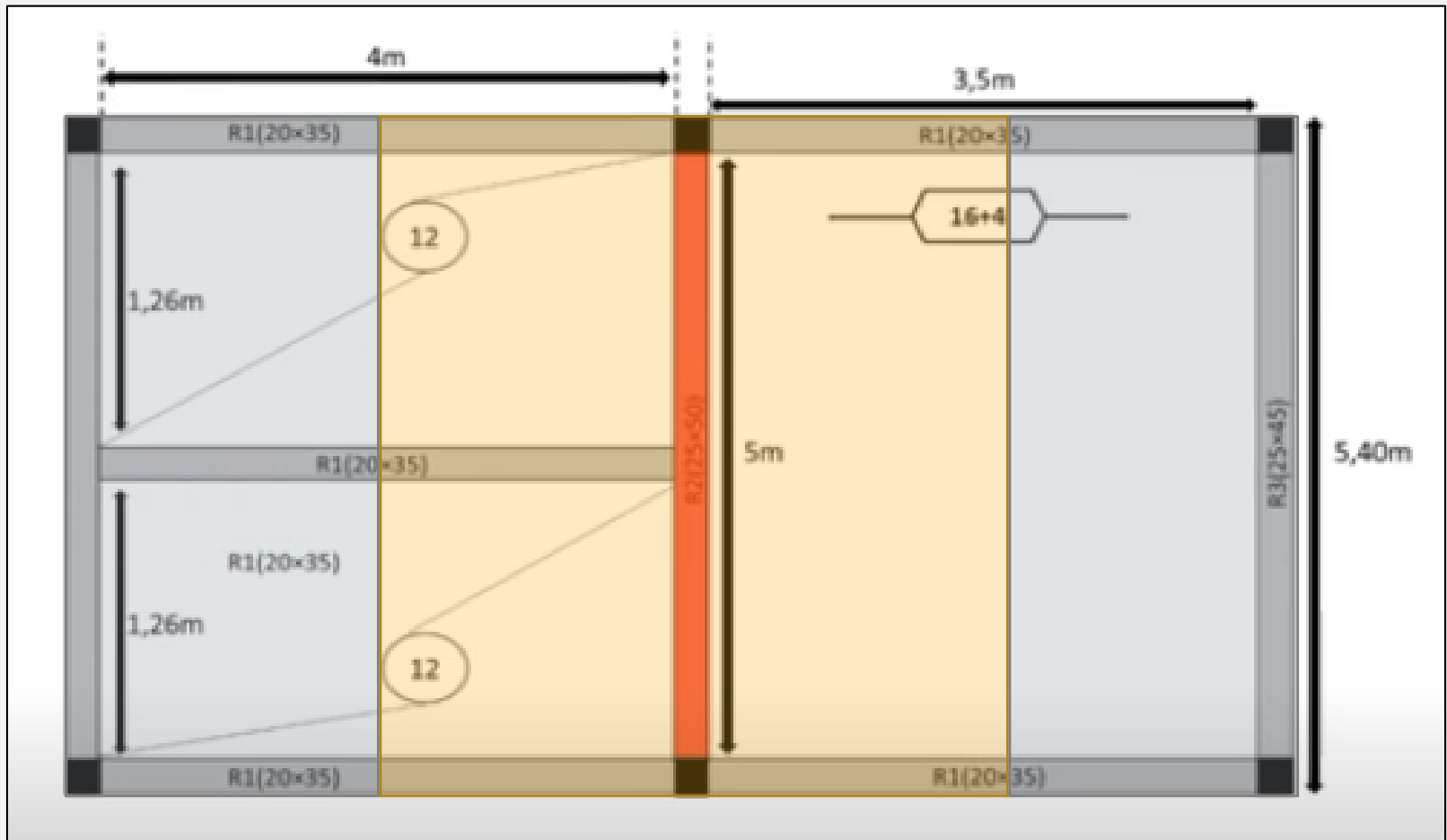
# FORCES ON BEAMS

A reinforced concrete beam is a horizontal element that supports loads and transfers them to its supports.



# FORCES ON BEAMS

The beam carries half of the area located on each side of its axis.



# FORCES ON BEAMS

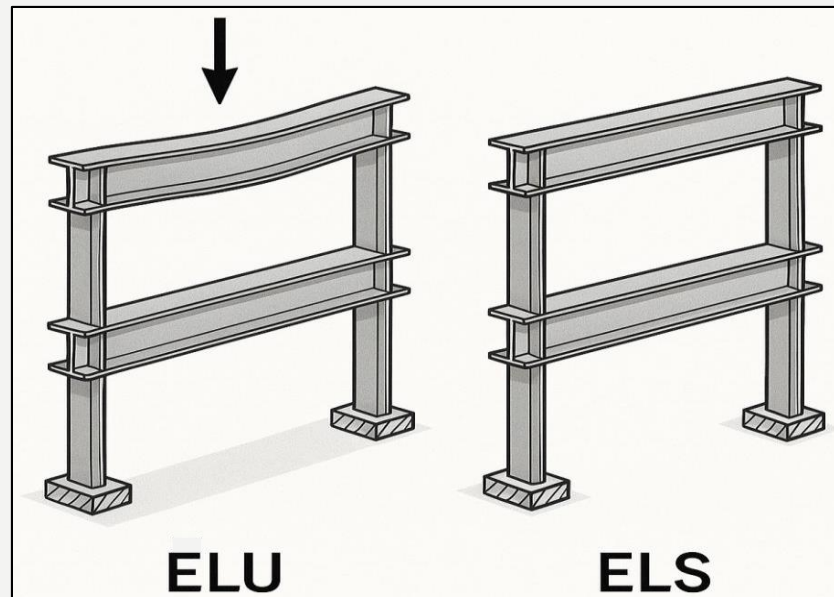
Type of Load	Symbole	Origin	Exemples	Remarks
<b>Permanent Loads</b>	G	Constant and always present	<ul style="list-style-type: none"> <li>•Self-weight of the beam</li> <li>•Weight of the floor</li> <li>•Fixed partitions</li> <li>•Finishes</li> </ul>	Always present; calculated based on the unit weight of the materials (concrete $\approx 25$ kN/m <sup>3</sup> ).
<b>Live Loads</b>	Q	Variable depending on the use of the space	<ul style="list-style-type: none"> <li>•People</li> <li>•Furniture</li> <li>•Equipment</li> <li>•Storage</li> </ul>	Depend on the type of building use (residential, office, hall, etc.).
<b>Accidental Loads</b>	A	Exceptional and rare (earthquake, impact, explosion)	<ul style="list-style-type: none"> <li>•Earthquake</li> <li>•Vehicle impact</li> <li>•Explosion</li> </ul>	These loads do not act directly on the beams but affect the structure as a whole, especially the columns and foundations.
<b>Environmental Loads</b>	—	Wind, snow, rain	—	They concern only the exposed roof elements (purlins, trusses, edge beams).

# FORCES ON BEAMS

## (LIMIT STATES)

Limit states are conditions beyond which the structure no longer meets the performance requirements for which it was designed.

- **Ultimate Limit States (ULS):** Ultimate limit states are associated with the collapse of the structure.
- **Serviceability Limit States (SLS):** Serviceability limit states are related to occupant comfort (excessive deformations and vibrations).



# FORCES ON BEAMS (LIMIT STATES)

Actions are combined with each other, and their values are multiplied by various factors. This includes permanent loads  $G$ , a primary variable load  $Q$  with its nominal value.

- **Ultimate Limit States (ULS):**

$$q_{ULS} = 1,35G + 1,5Q$$

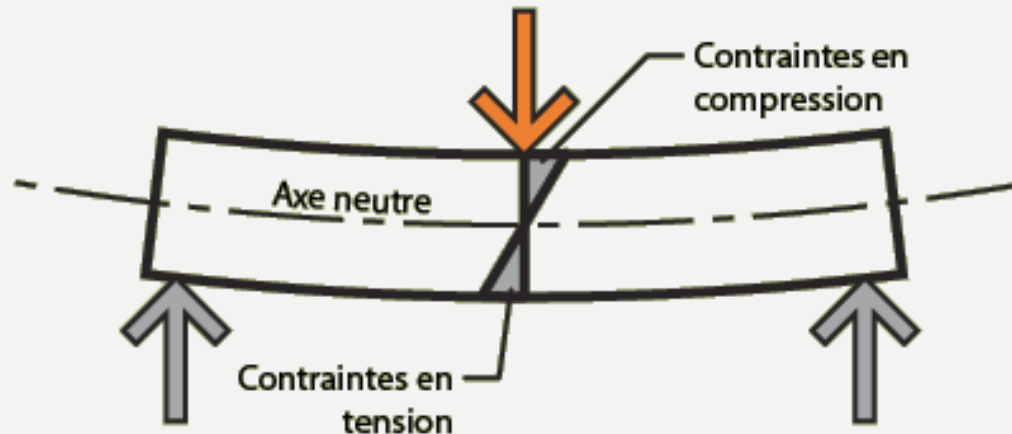
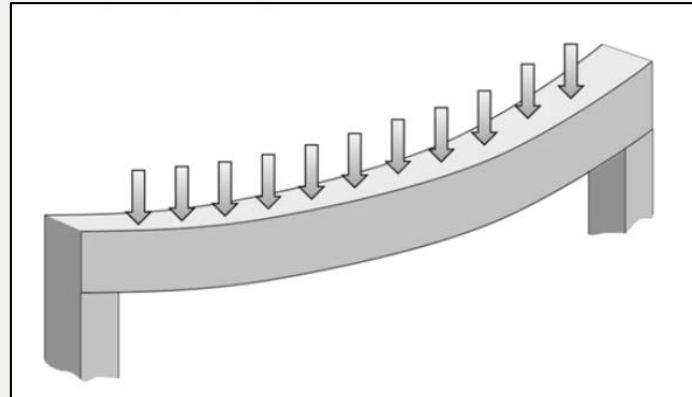
- **Serviceability Limit States (SLS):**

$$q_{SLS} = G + Q$$

# **BENDING OF REINFORCED CONCRETE BEAMS**

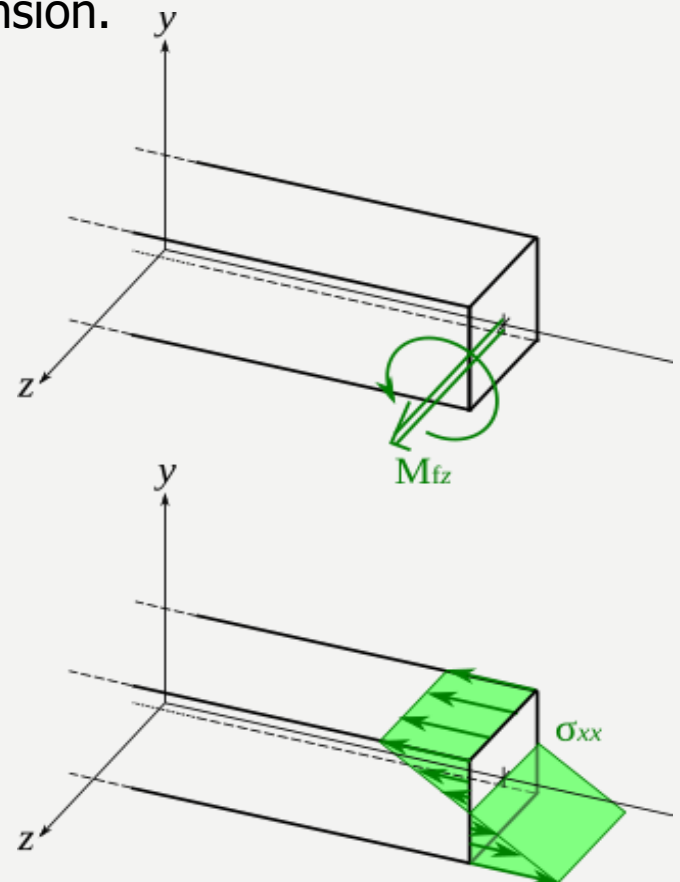
# BENDING OF REINFORCED CONCRETE BEAMS

A reinforced concrete beam mainly resists bending. It is primarily subjected to bending, causing compression at the top and tension at the bottom of the section.



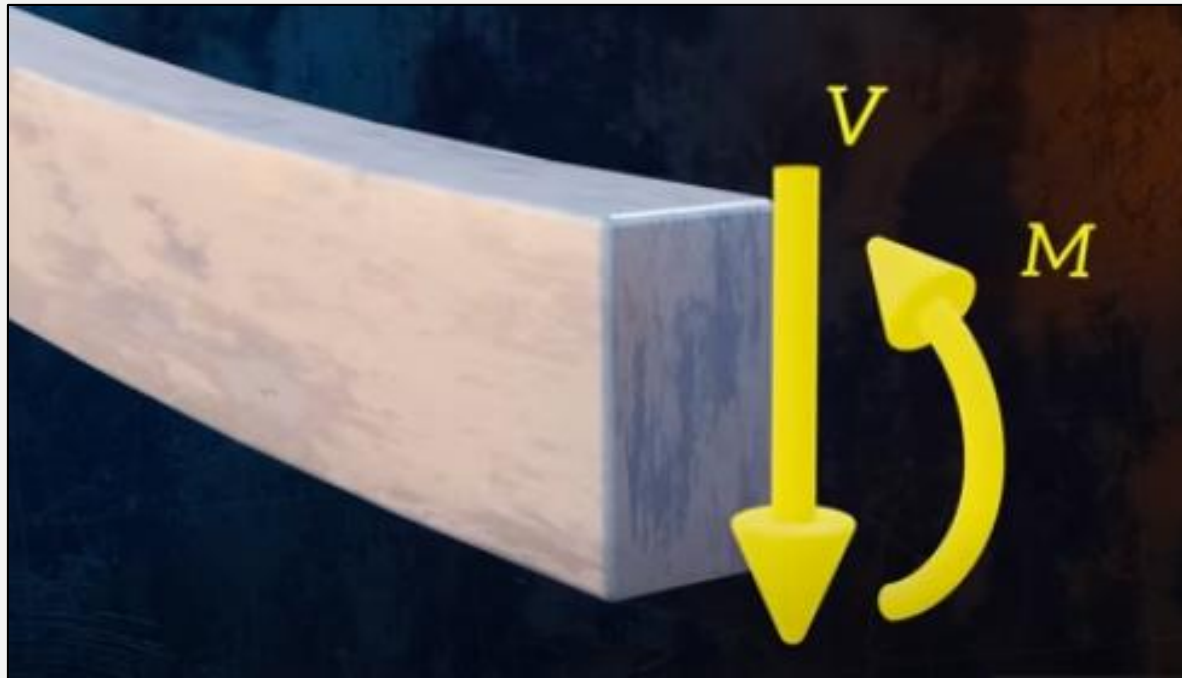
# BENDING OF REINFORCED CONCRETE BEAMS

A bending moment ( $M$ ) is a moment that causes the beam to bend, creating a curvature and dividing the cross-section into two parts: one in compression and the other in tension.



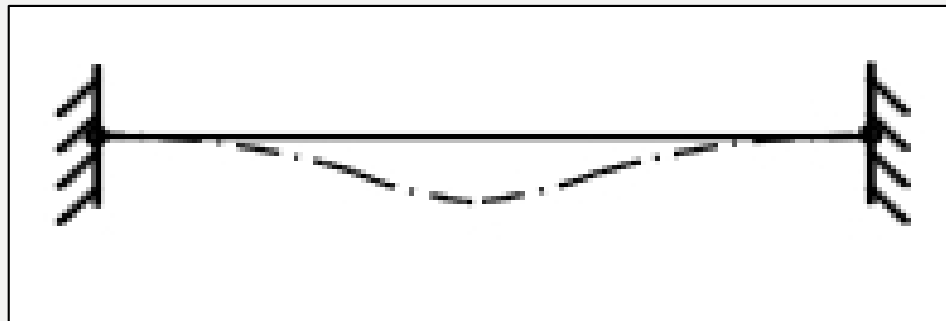
# BENDING OF REINFORCED CONCRETE BEAMS

Thus, when a beam is subjected to bending, two forces act on its cross-section: the bending moment  **$M$** , responsible for tensile and compressive stresses, and the shear force  **$V$** , which generates shear stresses.

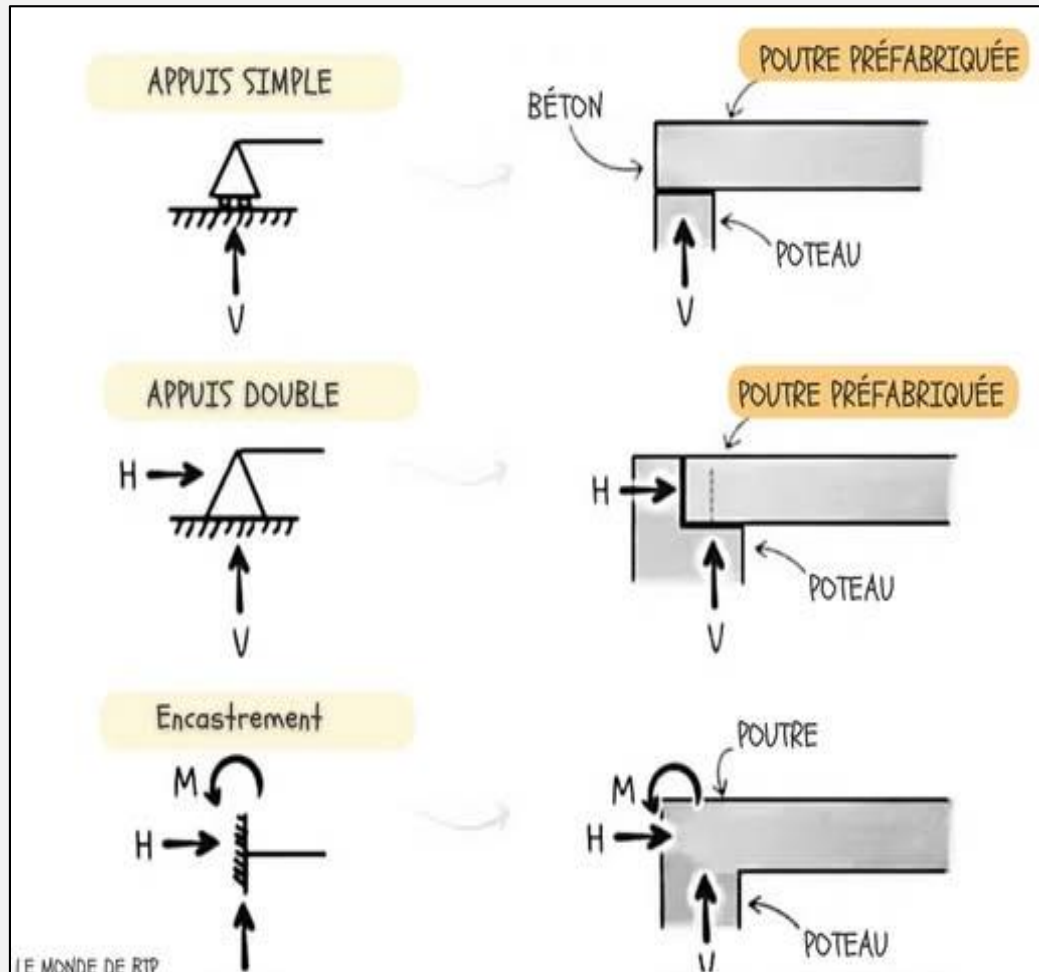


# BENDING OF REINFORCED CONCRETE BEAMS (SUPPORT CONDITIONS)

Supports are the connections between two elements, and depending on the type of support, the behavior of the element changes, particularly in reinforced concrete beams.



# BENDING OF REINFORCED CONCRETE BEAMS (SUPPORT CONDITIONS)



# **BENDING OF REINFORCED CONCRETE BEAMS (SUPPORT CONDITIONS)**

Reinforced Concrete Beam on Simple Supports



# **BENDING OF REINFORCED CONCRETE BEAMS (SUPPORT CONDITIONS)**

Reinforced Concrete Beam on Double Supports



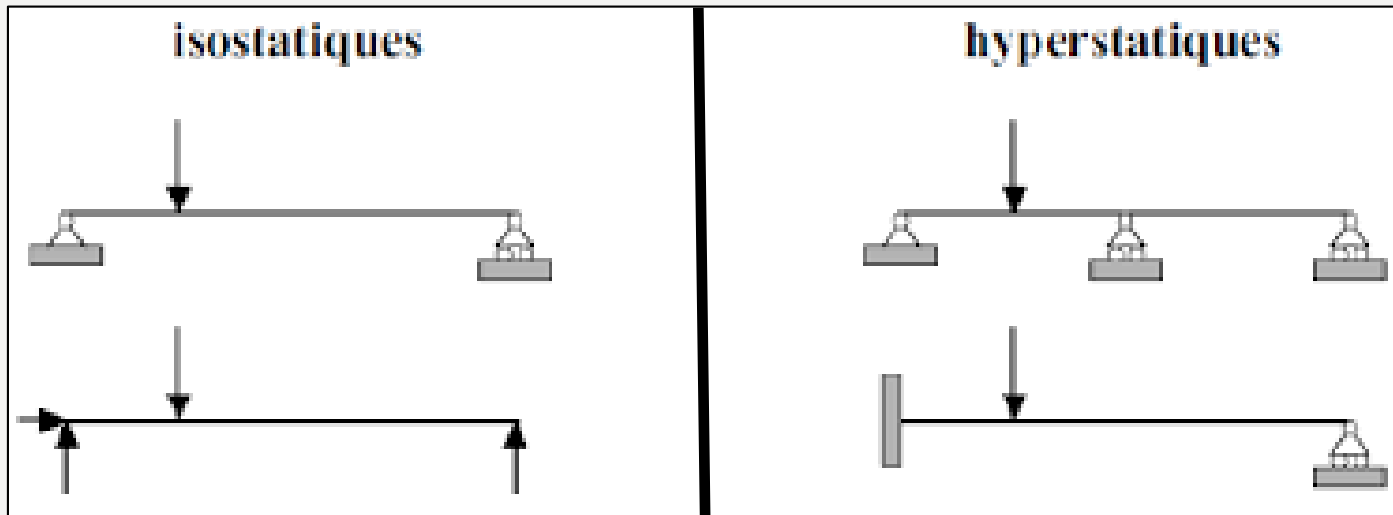
# **BENDING OF REINFORCED CONCRETE BEAMS (SUPPORT CONDITIONS)**

Reinforced Concrete Fixed Beam



# BENDING OF REINFORCED CONCRETE BEAMS (SUPPORT CONDITIONS)

For beams, if the number of reactions is equal to 3, the system is called "isostatic"; if it is greater than 3, it is "hyperstatic"; and if it is less than 3, it is "hypostatic" (unstable).



*Nombre de réactions = 3*

*Nombre de réactions > 3*

# IN PARENTHESES: (SUPPORT CONDITION)

For portal frames, we have the following formula:

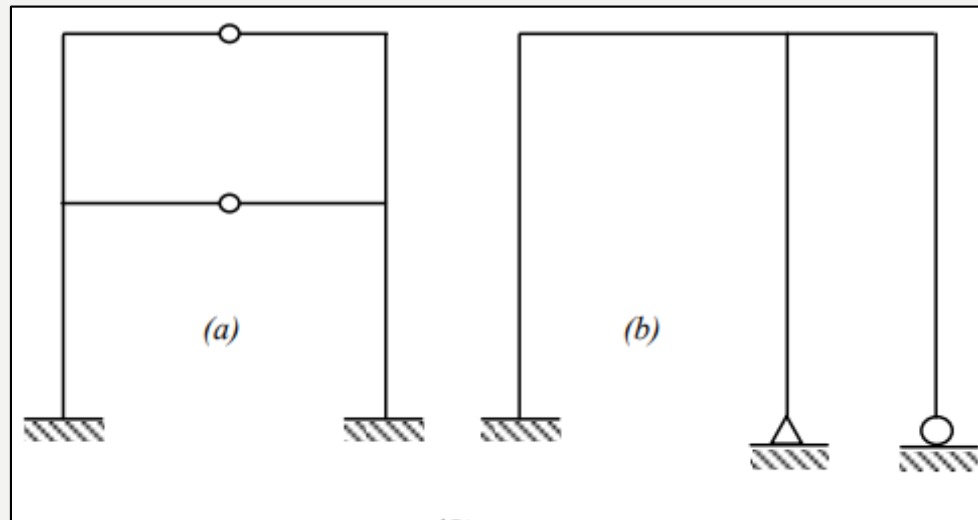
$$H = r + i - 3n$$

Where:

$r$  = number of support reactions

$i$  = number of internal connections (bars, internal hinges, etc.)

$n$  = number of rigid bodies (bars, elements)



# IN PARENTHESES: [SUPPORT CONDITION]

For trusses, we have the following formula:

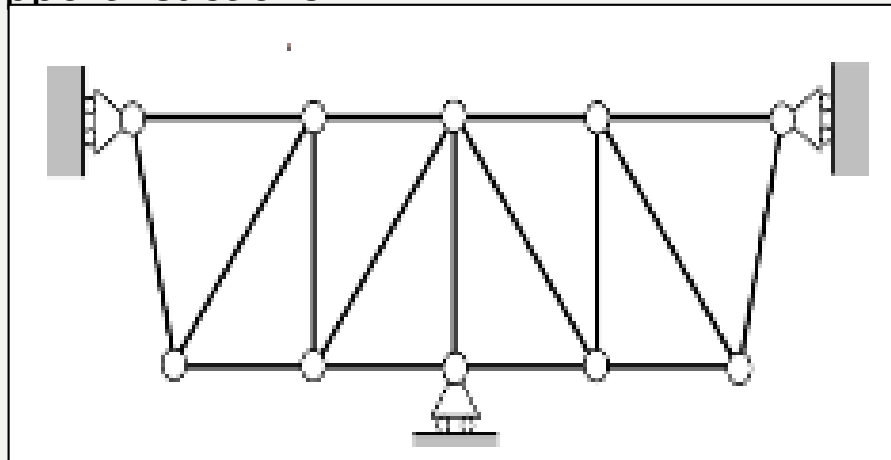
$$H = b + r - 2n$$

Where:

$b$  = number of bars

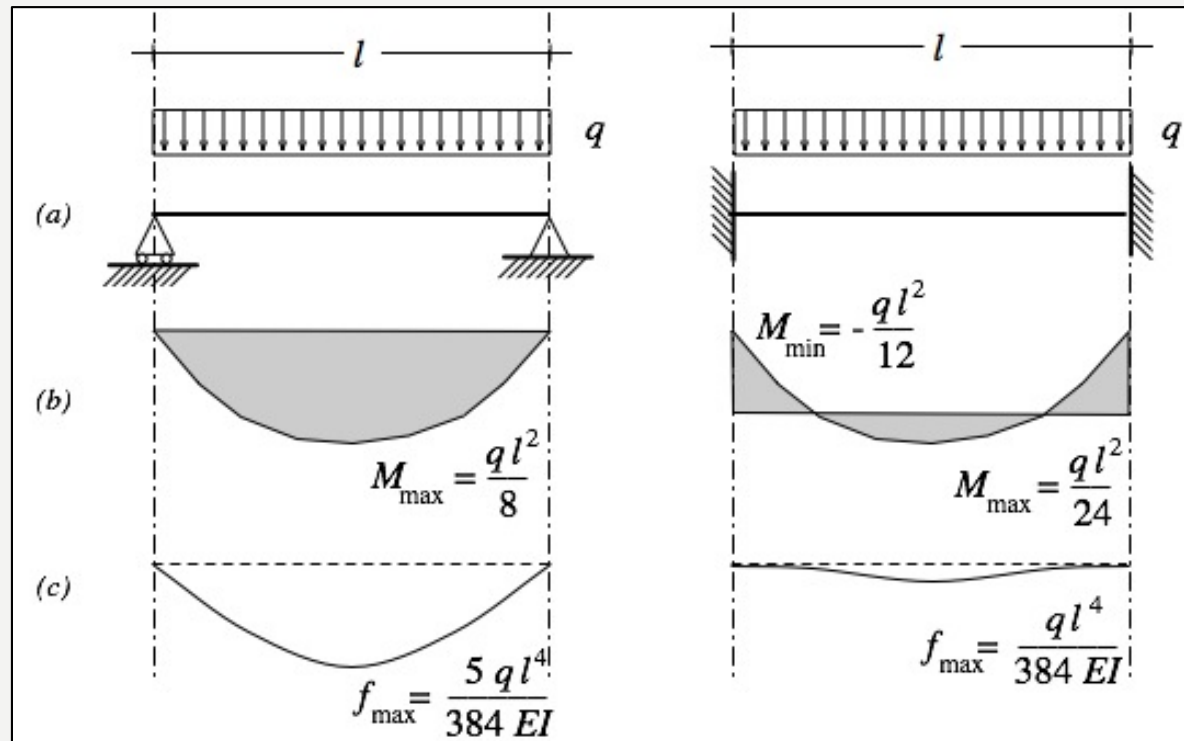
$n$  = number of nodes

$r$  = number of support reactions



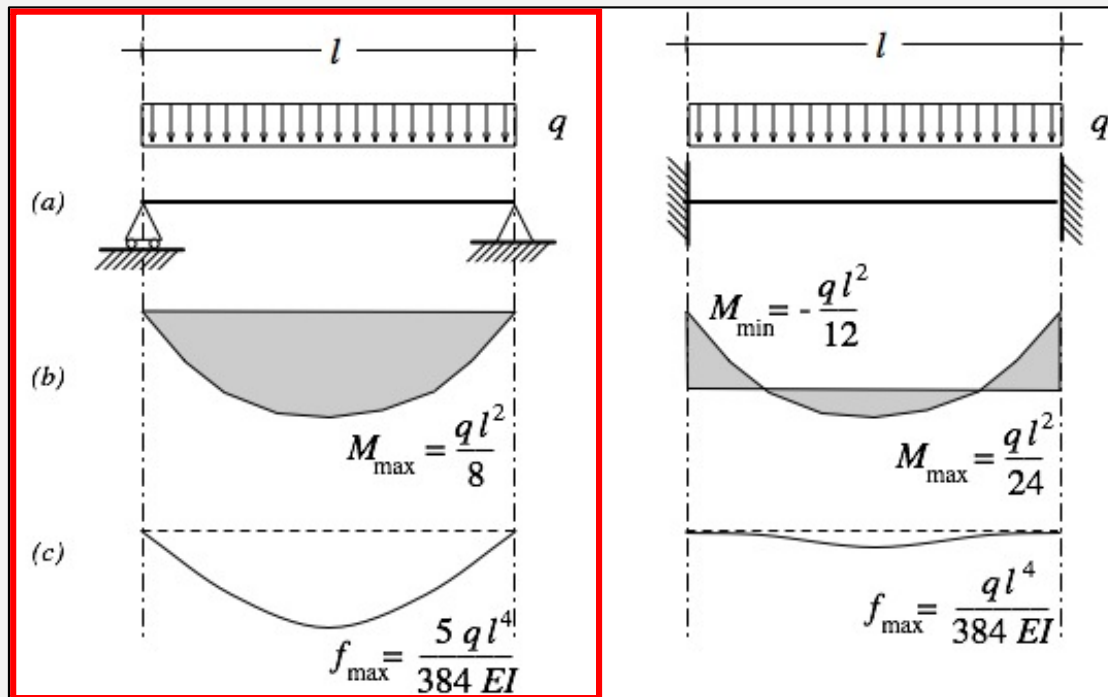
# BENDING OF REINFORCED CONCRETE BEAMS (SUPPORT CONDITIONS)

Supports are the connections between two elements, and depending on the type of support, the behavior of the element changes, particularly for reinforced concrete beams.



# BENDING OF REINFORCED CONCRETE BEAMS (SUPPORT CONDITIONS)

The column-beam joint, although cast monolithically, does not provide a perfect fixity due to possible deformations and rotations of the columns. Thus, the beam is generally considered simply supported to simplify calculations, but in more precise analyses or rigid frames, it can be modeled as fixed or semi-fixed.



# FORMWORK FOR RC BEAMS

Formwork is used to hold the concrete in place during its curing, before it takes its final shape. Reinforced concrete beams are generally cast together with the slab.



# FORMWORK FOR RC BEAMS

Formwork is used to support the concrete while it hardens, before it reaches its final shape. Reinforced concrete beams are generally cast together with the slab.



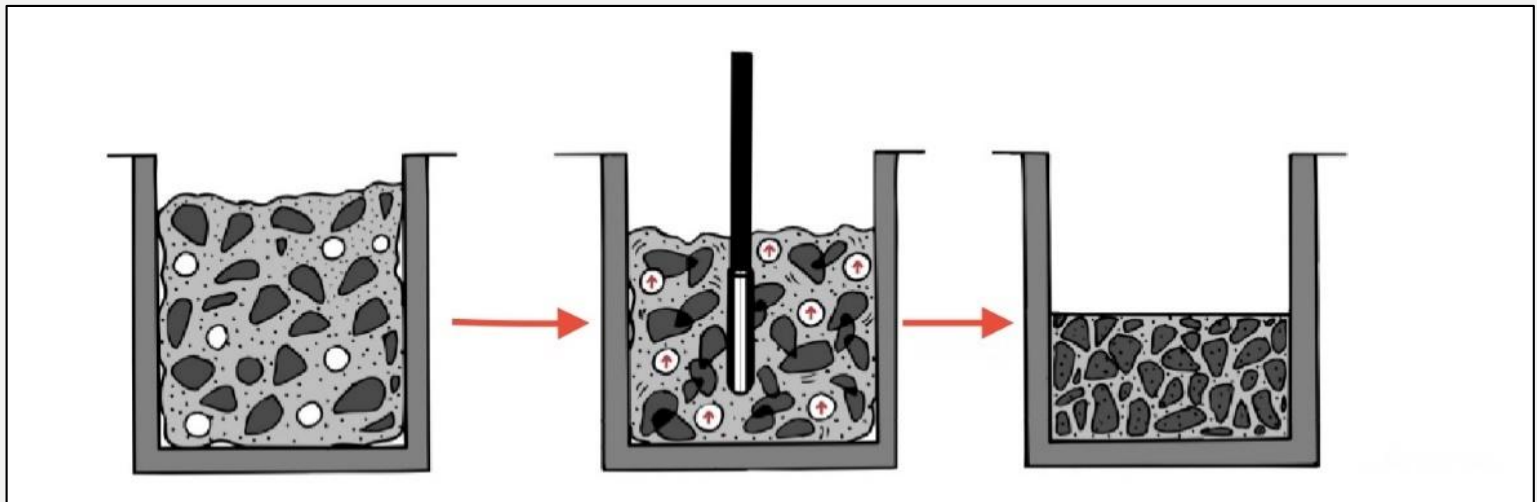
# FORMWORK FOR RC BEAMS

Formwork is used to keep the concrete in place during its hardening, before it attains its final shape. Reinforced concrete beams are generally cast together with the slab.



# CASTING OF RC BEAMS

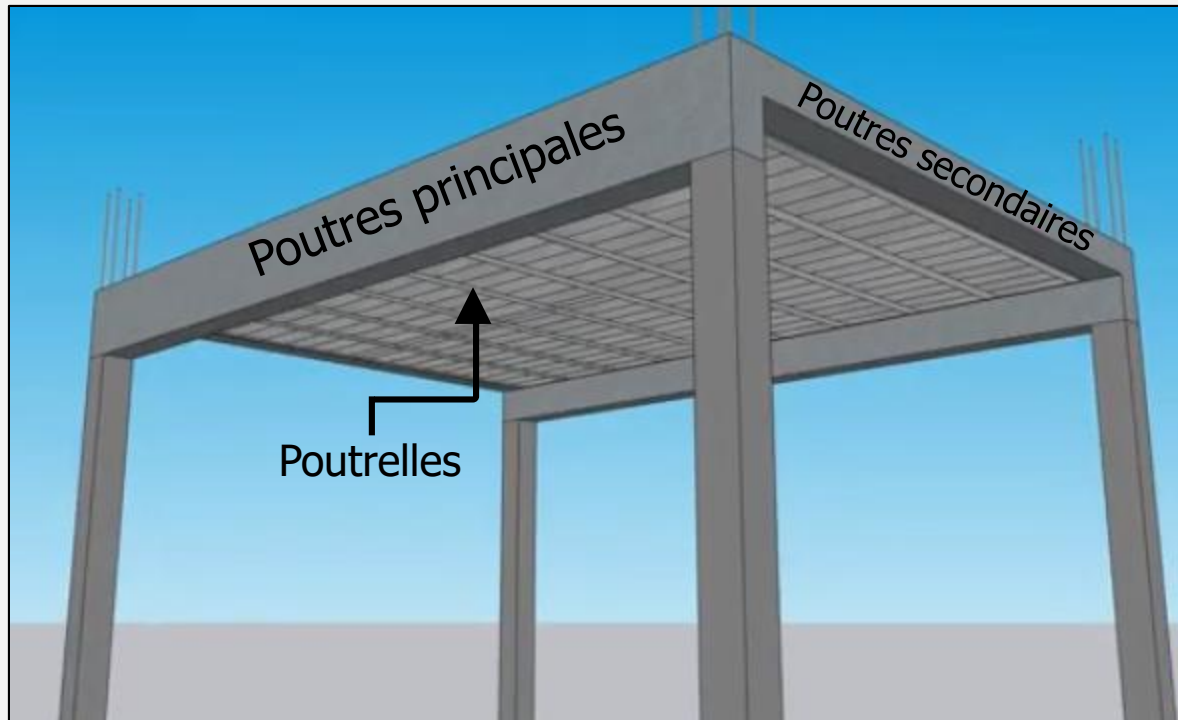
Concrete is generally cast in place or delivered by a concrete mixer truck. Vibrating the concrete is an important step in the casting process to ensure its strength, durability, and overall quality.



# TYPES OF RC BEAMS

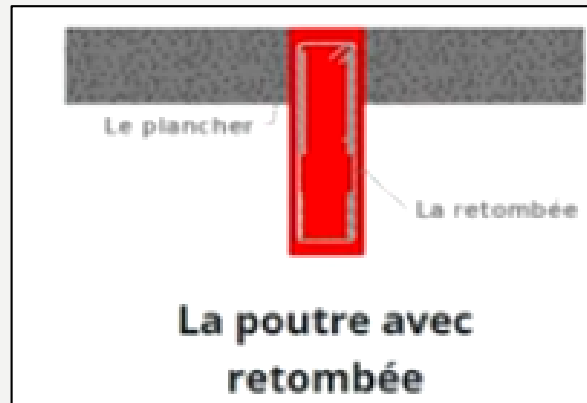
Il existe principalement trois type de poutres en béton armé :

- Poutres principales
- Poutres secondaires
- Poutrelles



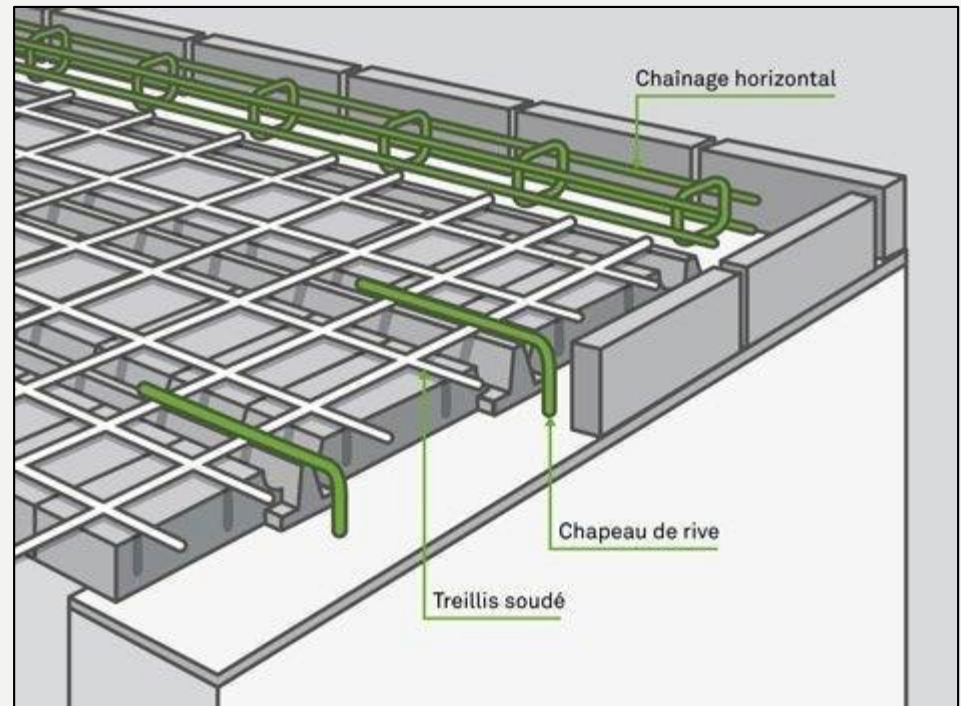
# TYPES OF RC BEAMS

- **Main Beams:** These are horizontal load-bearing elements of the reinforced concrete framework. Their role is to directly receive loads from the secondary beams or the slab and then transfer them to the columns or vertical supports.



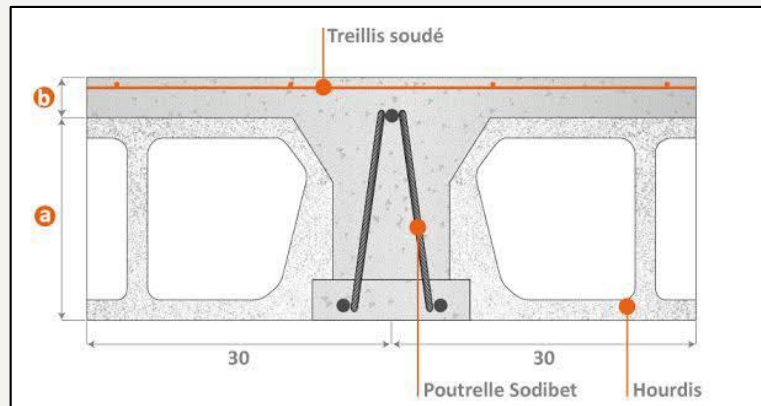
# TYPES OF RC BEAMS

- **Secondary Beams:** These are less significant than the main beams and are placed at the periphery. They serve as horizontal ties, ensuring the continuity and rigidity of the structure.



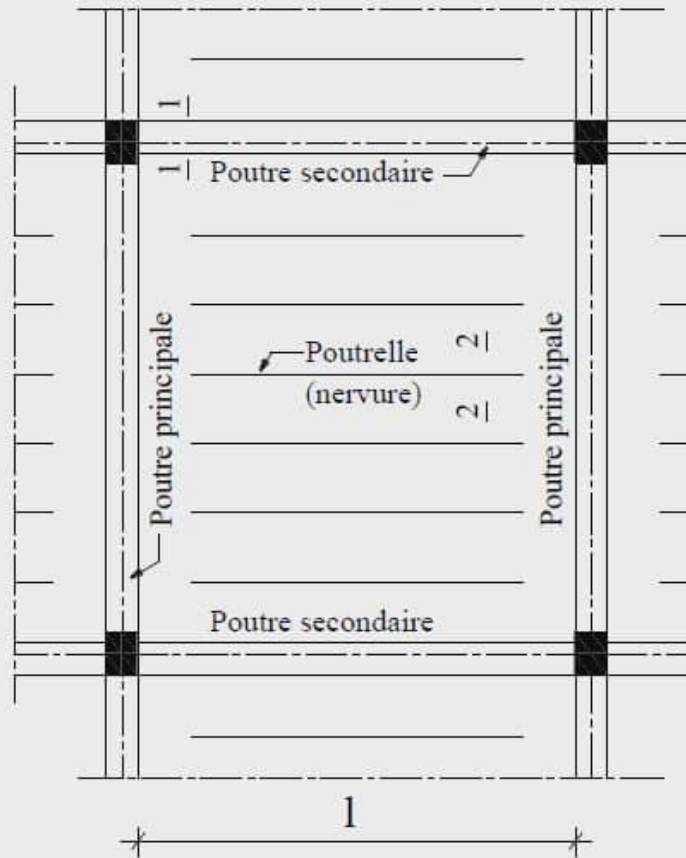
# TYPES OF RC BEAMS

- **Joists:** A joist is a narrow load-bearing element of the floor, placed between the hollow blocks. It carries the floor loads and transfers them to the main beams, working in bending together with the compression slab to form a lightweight and efficient monolithic system.



# TYPES OF RC BEAMS

On a slab plan, the direction of the joists is represented by lines to indicate the main beams and secondary beams.



# **PRELIMINARY DESIGN OF REINFORCED CONCRETE BEAMS**

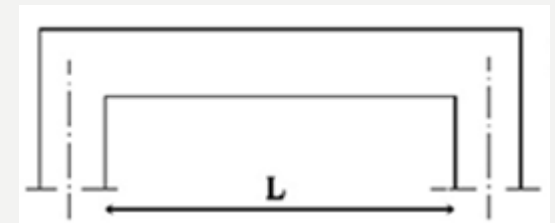
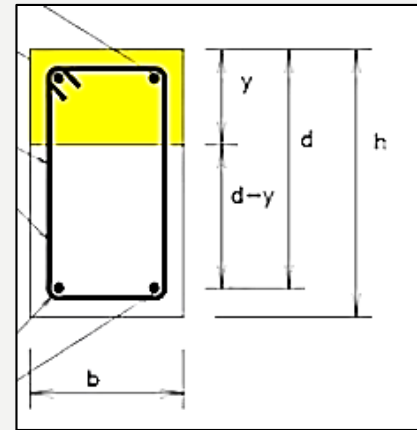
# PRELIMINARY DESIGN OF REINFORCED CONCRETE BEAMS

The height of the beam is given according to BAEL99 (France) and CBA93 (Algeria) as follows:

$$\frac{L}{15} \leq h \leq \frac{L}{10}$$

$$d = 0,9h$$

$$0,3d \leq b \leq 0,4d$$



L: the clear span of the beam between columns  
(the largest span for the main beam)

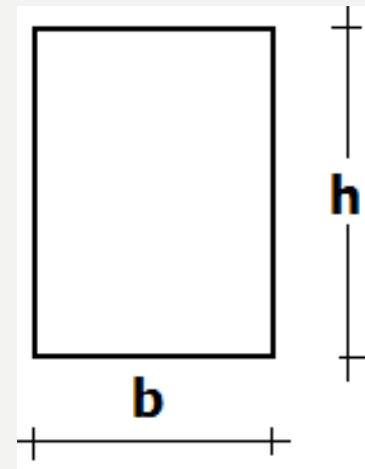
h: height of the beam

d: distance between the top fiber and the tensile reinforcement

# PRELIMINARY DESIGN OF REINFORCED CONCRETE BEAMS

Beams must comply with the following dimensions (Algerian Seismic Code: RPA 2024):

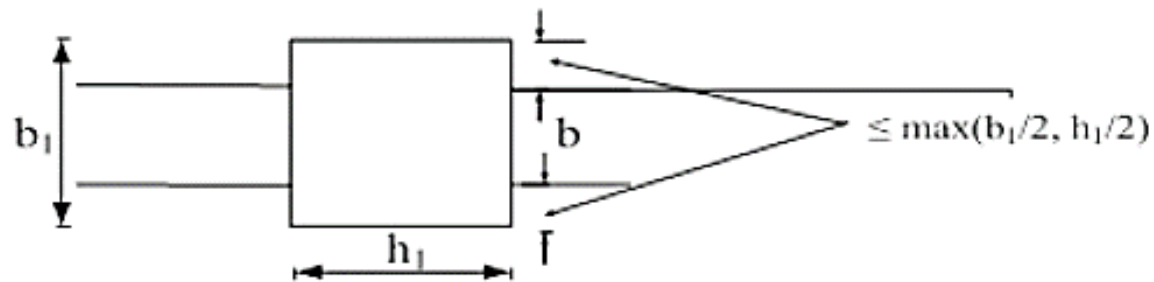
$$\left\{ \begin{array}{l} b \geq 20 \text{ cm} : \text{en zones I, II et III} \\ b \geq 25 \text{ cm} : \text{en zones IV, V et VI} \\ h \geq 30 \text{ cm} \\ \frac{h}{b} \leq 4.0 \\ b_{max} \leq (1.5h + b_1) \end{array} \right.$$



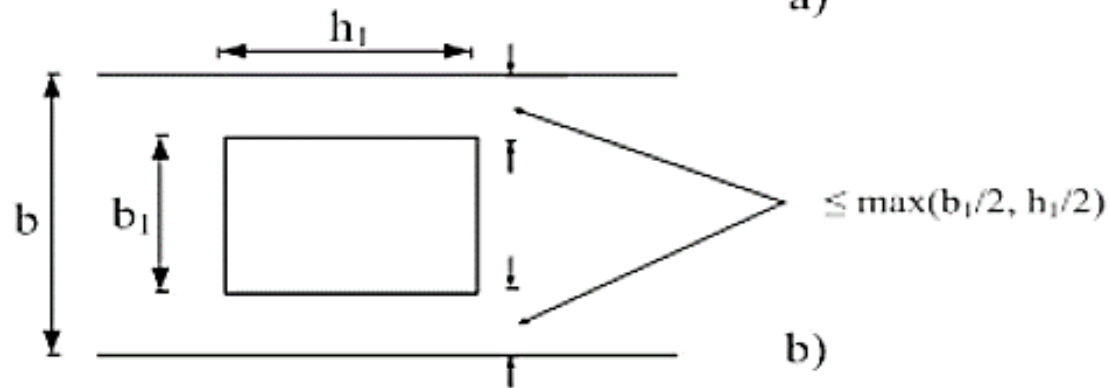
**b<sub>1</sub>** is the width of the column on which the beam rests.

# PRELIMINARY DESIGN OF REINFORCED CONCRETE BEAMS

The width spacing for placing beams on columns (Algerian Seismic Code: RPA 2024):



a)

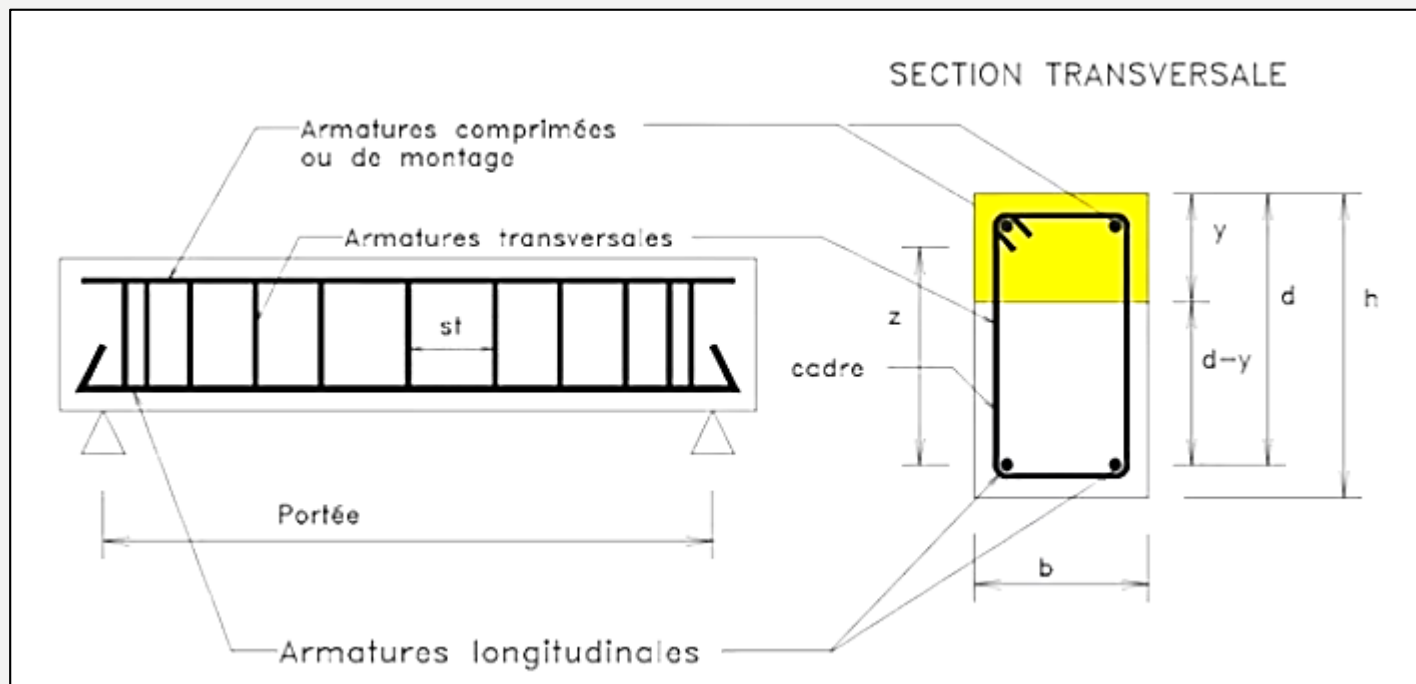


b)

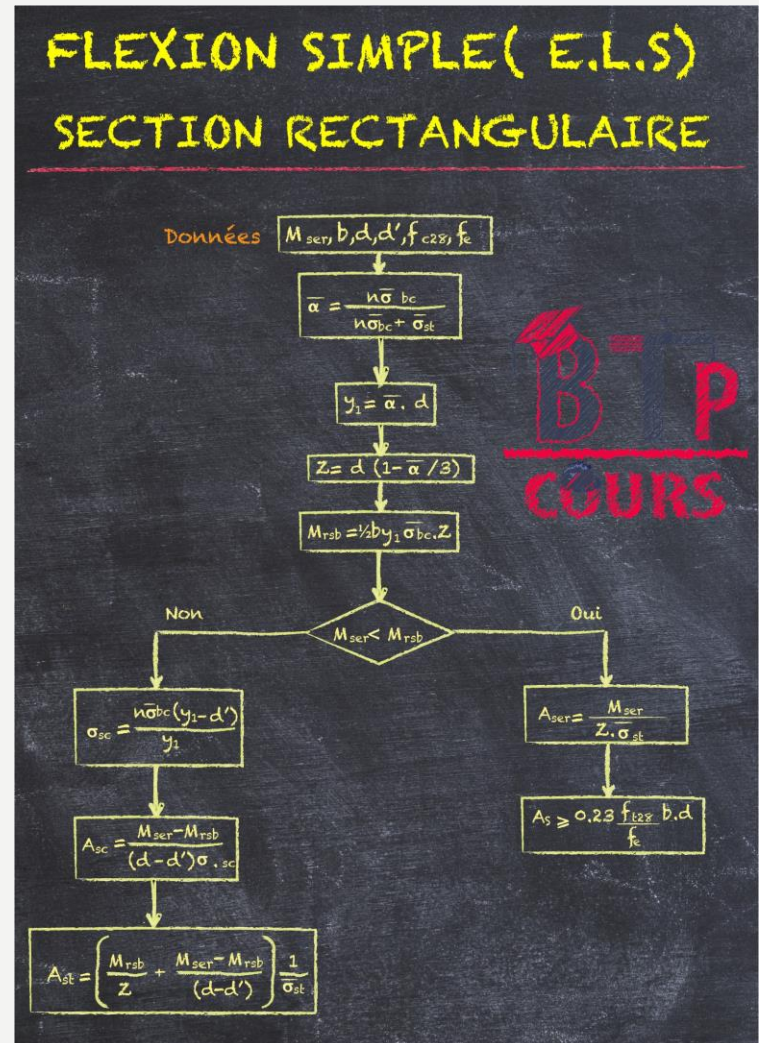
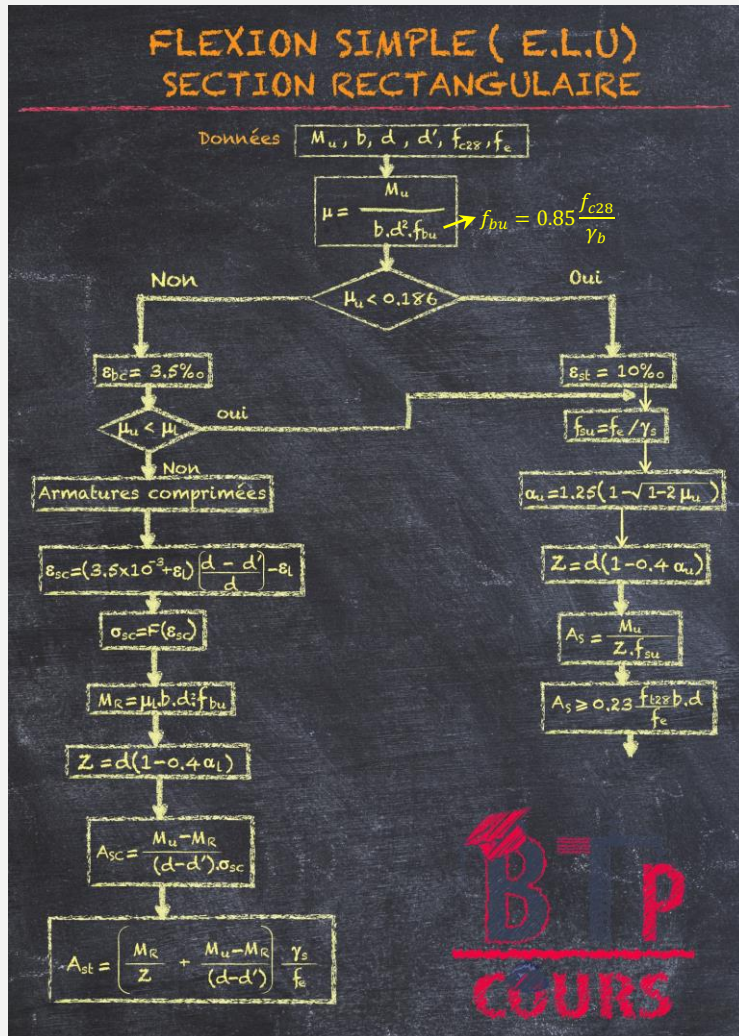
# **REINFORCEMENT OF REINFORCED CONCRETE BEAMS**

# REINFORCEMENT OF REINFORCED CONCRETE BEAMS

- Les aciers longitudinaux s'opposent au moment de flexion dans zones tendues.
- Les aciers transversaux résiste contre le cisaillement.



# REINFORCEMENT OF REINFORCED CONCRETE BEAMS



# REINFORCEMENT OF REINFORCED CONCRETE BEAMS

La contrainte de compression du béton  $\sigma_{bc}$  est limitée à :

$$\bar{\sigma}_{bc} = 0.6 f_{cj}$$

coefficient d'équivalence

$$n = \frac{E_s}{E_b} = 15$$

**Contraintes limites de traction des aciers**

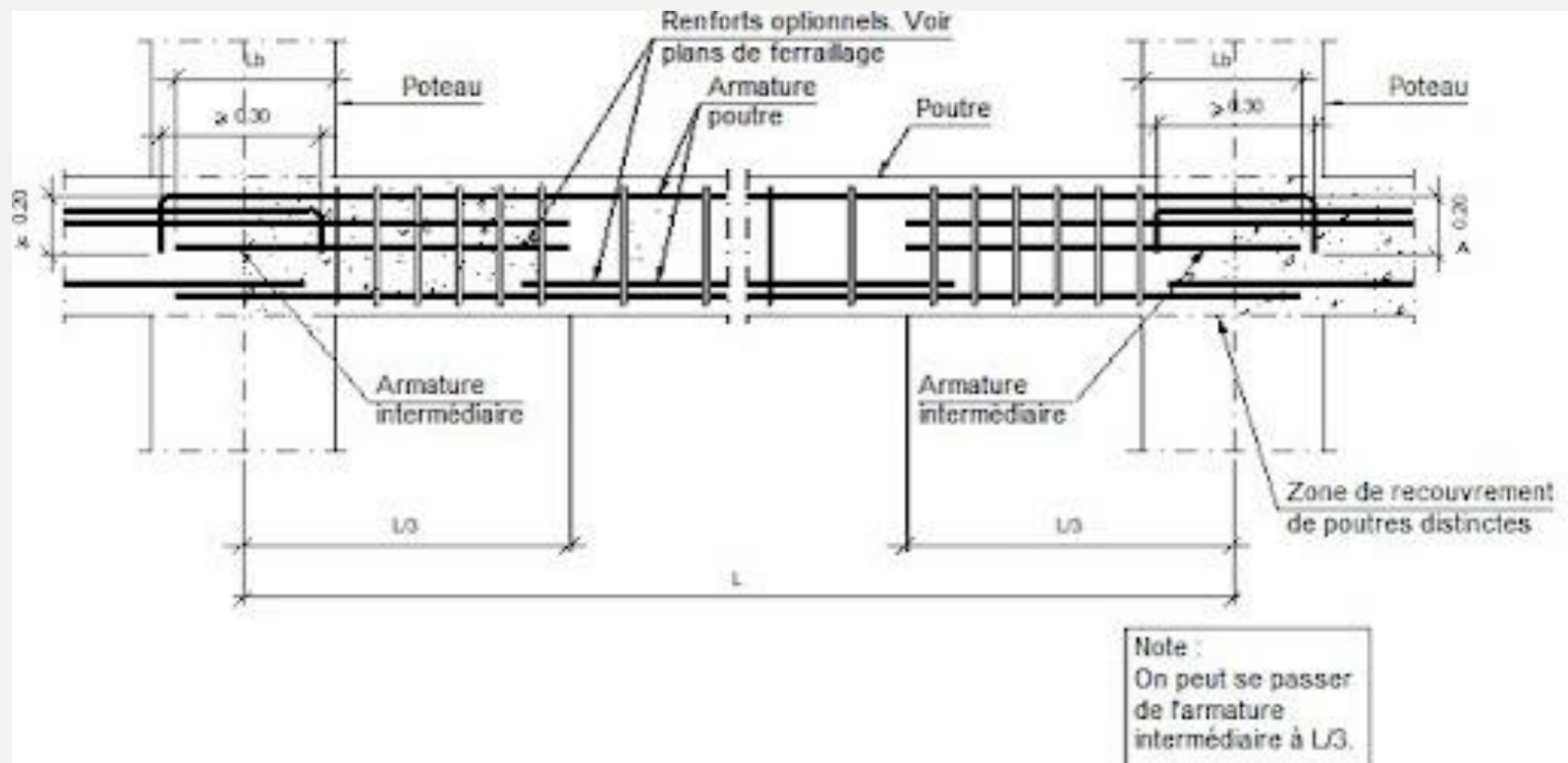
Cas	Conditions particulières	Contraintes limites de traction (en MPa)
Fissuration peu préjudiciable	Locaux couverts et clos non soumis à condensations	$\sigma_{st} \leq f_c$
Fissuration préjudiciable	Coefficient de fissuration (symbole) : $\eta$ $\eta = 1$ pour ronds lisses $\eta = 1,6$ pour aciers HA diamètre $\geq 6$ mm $\eta = 1,3$ pour aciers HA si diamètre $< 6$ mm (*)	$\bar{\sigma}_{st} = \inf \left( \frac{2}{3} f_c; 110 \sqrt{\eta f_{tj}} \right)$
Fissuration très préjudiciable	Diamètres des aciers $> 8$ mm (**)	$\bar{\sigma}_{st} = \inf \left( 0,5 f_c; 90 \sqrt{\eta f_{tj}} \right)$

*N.B. Aciers de peau à prévoir dans les poutres de grande hauteur (hauteur totale  $> 60$  cm).  
 (\*)  $3 \text{ cm}^2$  par mètre de longueur de parement dans le cas de fissuration préjudiciable.  
 (\*\*)  $5 \text{ cm}^2$  par mètre de longueur de parement dans le cas de fissuration très préjudiciable.*

$$f_{tj} = 0.6 + 0.06 f_{cj}$$

# REINFORCEMENT OF REINFORCED CONCRETE BEAMS

∅ Arrangement of Longitudinal and Transverse Reinforcement



# REINFORCEMENT OF REINFORCED CONCRETE BEAMS

∅ Minimum and Maximum Longitudinal Reinforcement According to  
BAEL99

$$A_{s,\min} \leq A_s \leq A_{s,\max}$$

$$0,0015 b d \leq A_s \leq 0,04 b d$$

∅ Minimum and Maximum Longitudinal Reinforcement According to  
RPA 2024

Regular Zone :

$$0,005 b h \leq A_s \leq 0,04 b h$$

Splicing Zone :

$$0,005 b h \leq A_s \leq 0,06 b h$$

# REINFORCEMENT OF REINFORCED CONCRETE BEAMS

∅ Armatures longitudinales minimale et maximale

◆ If:

$$A_{min} < A_s^{calculated} < A_{max}$$

→ Reinforce with the **calculated steel area**  $A_s^{calculated}$

◆ If:

$$A_s^{calculated} < A_{min}$$

→ Reinforce with the **minimum steel area**  $A_{min}$  ( $\varnothing_{min} = 12 \text{ mm}$ )

◆ If:

$$A_s^{calculated} > A_{max}$$

→ **Increase the concrete section (B)** and recalculate a new  $A_s$

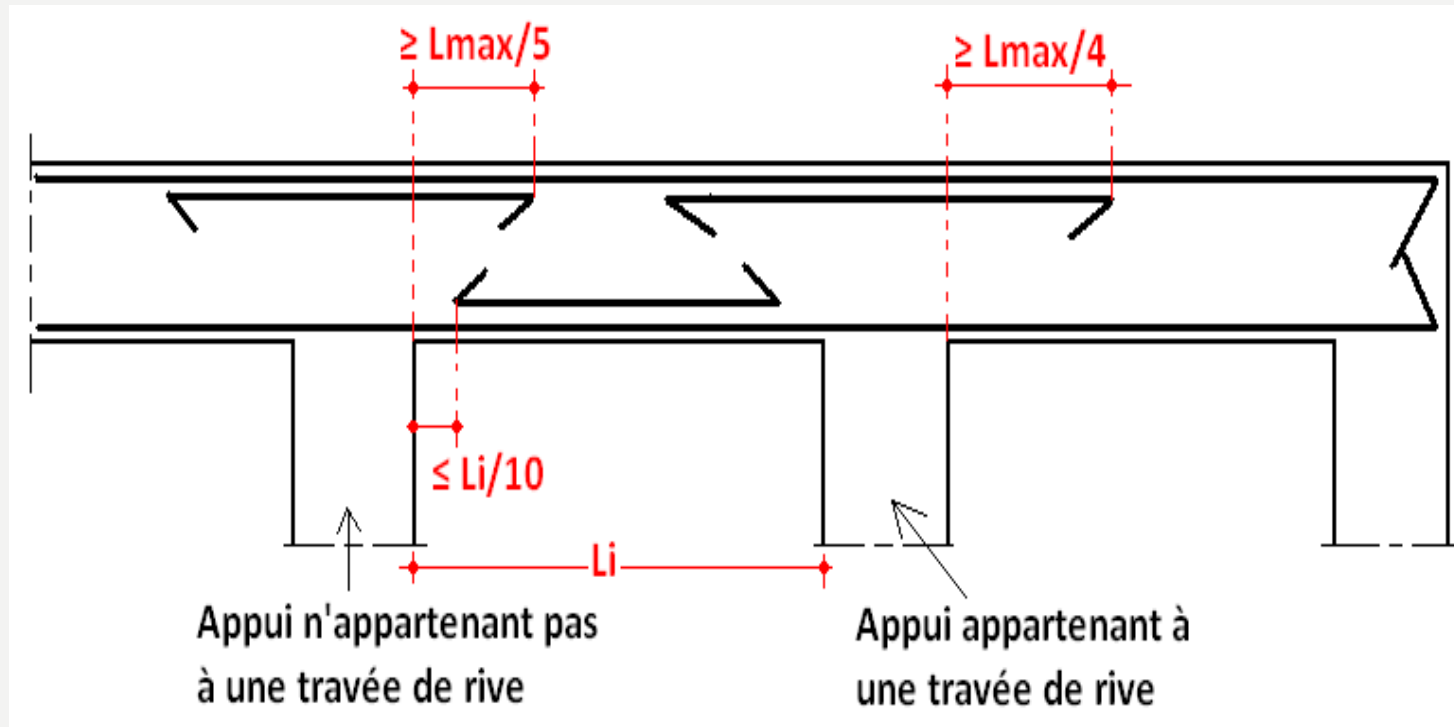
# REINFORCEMENT OF REINFORCED CONCRETE BEAMS

∅ Once the reinforcement area  $A_s$  is determined, the diameter  $\emptyset$  and the number  $n$  of bars required are obtained from the bar size table.

Diamètre	Section en cm <sup>2</sup> pour :									
en mm	1 barre	2 barres	3 barres	4 barres	5 barres	6 barres	7 barres	8 barres	9 barres	10 barres
4	0,126	0,252	0,378	0,504	0,630	0,756	0,882	1,008	1,134	1,260
5	0,196	0,392	0,588	0,784	0,980	1,176	1,372	1,568	1,764	1,960
6	0,283	0,566	0,849	1,132	1,415	1,698	1,981	2,264	2,547	2,830
7	0,385	0,770	1,155	1,540	1,925	2,310	2,695	3,080	3,465	3,850
8	0,503	1,006	1,509	2,012	2,515	3,018	3,521	4,024	4,527	5,030
10	0,785	1,570	2,355	3,140	3,925	4,710	5,495	6,280	7,065	7,850
12	1,131	2,262	3,393	4,524	5,655	6,786	7,917	9,048	10,179	11,310
14	1,539	3,078	4,617	6,156	7,695	9,234	10,773	12,312	13,851	15,390
16	2,011	4,022	6,033	8,044	10,055	12,066	14,077	16,088	18,099	20,110
20	3,142	6,284	9,426	12,568	15,710	18,852	21,994	25,136	28,278	31,420
25	4,909	9,818	14,727	19,636	24,545	29,454	34,363	39,272	44,181	49,090
32	8,042	16,084	24,126	32,168	40,210	48,252	56,294	64,336	72,378	80,420
40	12,566	25,132	37,698	50,264	62,830	75,396	87,962	100,528	113,094	125,660
50	19,64	39,280	58,920	78,560	98,200	117,840	137,480	157,120	176,760	196,400

# REINFORCEMENT OF REINFORCED CONCRETE BEAMS

It is necessary to add caps in the critical zones:

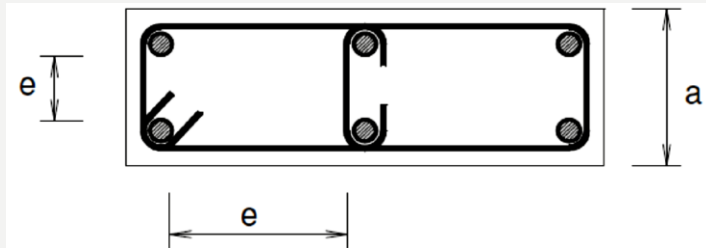


$L_{max}$  and  $L_i$  between support faces

$L_{max}$  = the largest span of the two spans adjacent to the considered support

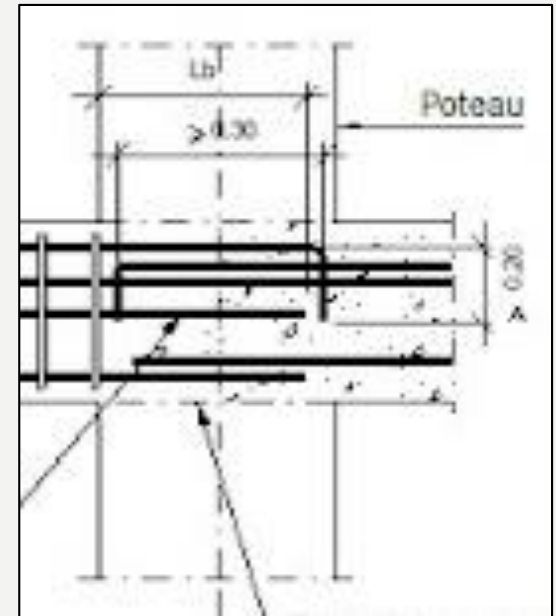
# REINFORCEMENT OF REINFORCED CONCRETE BEAMS

∅ Disposition constructive des armatures longitudinales



$$e \leq \min \left( \frac{b}{3}, 10 \text{ cm}, 6 \varphi_l \right)$$

- The **minimum lap length** is:
  - 50  $\phi$  in zones I, II, and III
  - 60  $\phi$  in zones IV, V, and VI



# REINFORCEMENT OF REINFORCED CONCRETE BEAMS

## ∅ Concrete Cover for Reinforcement Bars

**Concrete cover** is the distance between the concrete surface and the nearest reinforcement bar.

It is a fundamental parameter to ensure the durability of structures.

It is designed to guarantee:

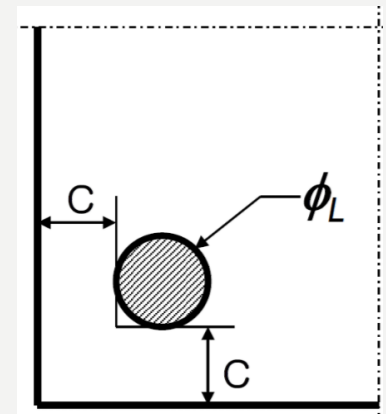
- ◆ Protection of the steel against corrosion;
- ◆ Proper transmission of forces (steel–concrete bond);
- ◆ Fire resistance.

The concrete cover ( $C$ ) of the reinforcement must be at least:

$$C \geq \begin{cases} 1 \text{ cm} & \rightarrow \text{slightly aggressive environment} \\ 3 \text{ cm} & \rightarrow \text{moderately aggressive environment} \\ 5 \text{ cm} & \rightarrow \text{highly aggressive environment} \end{cases}$$

The concrete cover ( $C$ ) must also satisfy the following condition:

$$C \geq \phi_L$$



# REINFORCEMENT OF REINFORCED CONCRETE BEAMS

## ∅ Transverse Reinforcement (Stirrups)

$$A_t = (0.003).s.b$$

Or 
$$\phi_t = \frac{\phi_{l\max}}{3} \geq 6 \text{ mm}$$

## ∅ Spacing between transverse reinforcements (stirrups)

### ∅ Nodal Zones

$$s = \min(h/4; 24\phi_t; 17.5 \text{ cm}; 6\phi_l) \text{ avec:}$$

- $h$  : hauteur de la poutre
- $\phi_t$  : diamètre des armatures de confinement
- $\phi_l$  : diamètre minimal des barres longitudinales

### ∅ Regular Zones

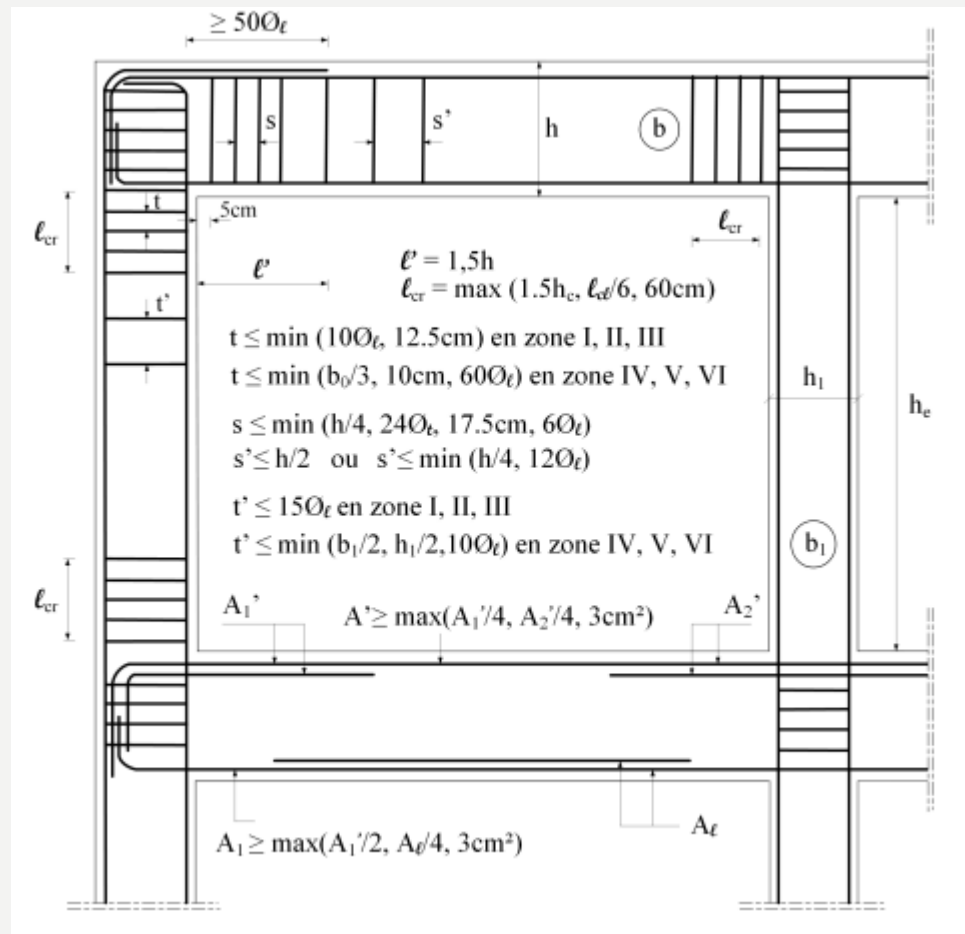
$$s' \leq h/2$$

avec :

$$s' = \min(h/4; 12\phi_l) \text{ si les armatures comprimées sont nécessaires}$$

# REINFORCEMENT OF REINFORCED CONCRETE BEAMS

## ∅ Transverse Reinforcement (Stirrups)



# REINFORCEMENT OF REINFORCED CONCRETE BEAMS

The deflection of a beam is the maximum vertical deformation it undergoes under the effect of loads. Measured at midspan, it constitutes a serviceability criterion (SLS) influencing the comfort, aesthetics, and durability of the structure.

Type of Beam	Maximum Allowable Deflection
Ordinary beam supporting a floor or partition	( L/500 )
Exposed or commonly used beam	( L/400 )
Beam supporting a rigid floor (concrete)	( L/250 )
Beam serving only decorative purposes or without fragile finishes	( L/200 )

# EXERCICE ON REINFORCED CONCRET BEAM

Consider a building with (G+2) floors for residential use. The floor has a load of  $3 \text{ kN/m}^2$ , and the live load from occupants is  $1.5 \text{ kN/m}^2$ . The column section is  $30 \times 30 \text{ cm}^2$ .

1. Perform a preliminary design of the main beam
2. Check the deflection at the SLS
3. Calculate the reinforcement at the ULS

## Data:

Oran, Algeria (Seismic Zone VI)

Unit weight of concrete:  $\gamma_{\text{béton}} = 25 \text{ kN/m}^3$

Concrete strength  $f_{c28} = 25 \text{ MPa}$

Young's modulus  $E_b = 30000 \text{ MPa}$

Steel strength  $f_e = 400 \text{ MPa}$

