

Mohamed Kheider University - Biskra
Faculty of Science and Technology
Department of Architecture



COURSE HANDOUT

2nd YEAR BACHELOR'S DEGREE

Sector: Construction project management

Specialty: Operational project management

Dr. Sara Khelil

2024- 2025

Collection of theoretical courses and practical exercises

Lecturer

Dr. Sara Khelil

sara.khelil@univ-biskra.dz

Associate Professor “A”

Mohamed Kheider University - Biskra

Faculty of Science and Technology

Department of Architecture

Target Audience

This educational document is a collection of theoretical courses and practical learning exercises intended primarily for learners of 2nd YEAR BACHELOR'S DEGREE Specialty: Operational project management.

Identification of the course

- Subject identification: Construction 1
 - Course schedule: 1h30 per week
 - Teaching unit: UEF3
 - Coefficient: 3
 - Credit: 5

Course Overview

Foundations form the backbone of any structure, and understanding their types and design principles is essential for engineers and architects alike. This course introduces the **Common Types of Foundations**, covering shallow and deep foundations, their applications, and selection criteria based on soil and load conditions. It also delves into the **Bearing Capacity of Foundations**, exploring methods for calculating ultimate and allowable loads, ensuring structural safety. Lastly, the course examines **Types of Reinforced Concrete Construction**, focusing on various concrete systems like beam-slab and shear walls, reinforcing concepts, and modern innovations in construction.

By mastering these topics, students will gain a comprehensive understanding of foundation systems and reinforced concrete's role in structural integrity.

1. Common Types of Foundations

This section explores the various foundation systems used in building construction, including:

- **Shallow Foundations** (e.g., strip, isolated, and raft footings) used for lightweight structures.
- **Deep Foundations** (e.g., piles, caissons) for transferring heavy loads to deeper soil layers. The focus is on the suitability of each type based on soil conditions and load requirements.

2. Bearing Capacity of Foundations

The bearing capacity of soils is a critical factor in foundation design. This segment covers:

- The **theories and formulas** (like Terzaghi's) to calculate ultimate and allowable bearing capacities.
- **Factors affecting bearing capacity**, such as soil type, depth of foundation, and applied loads.
- Solutions for increasing the bearing capacity when soil is inadequate.

3. Types of Reinforced Concrete Construction

This section focuses on reinforced concrete, its applications, and structural performance. Topics include:

- **Basic Types** of reinforced concrete construction, such as beam-slab, frame, and shear wall systems.
- The **importance of reinforcement** (steel bars, fibers) in increasing tensile strength.

Table of Contents

CHAPTER 1: COMMON TYPES OF FOUNDATIONS	1
Introduction.....	2
1- Definition of foundations	2
2- Types of foundations	2
3- The role of foundations	2
4- Constitution of a foundation	2
5- Shallow Foundations	2
5.1- Design of Shallow Foundations	3
5.2 - Isolated Footings (Point Foundations)	3
5.3- Strip Footings (Linear Foundations)	3
5.4- Raft Foundation (Surface Foundations)	3
5.5- Ribbed Raft Foundations	3
5.6- Mushroom Raft Foundation	3
5.7- Vaulted Raft Foundation	3
6- DEEP FOUNDATIONS, RETAINING WALLS.....	2
7- SETTLEMENT OF FOUNDATIONS	2
7.1- Types of Settlements.....	3
CHAPTER 2: BEARING CAPACITY OF FOUNDATIONS	4
Introduction.....	2
1- Behavior of a Shallow Foundation	2
2- Foundation Design Philosophies	2
3- The bearing capacity of a shallow foundation	2
3.1- Types of Shear Failure	3
4- Bearing-capacity equations	3
4.1- Terzaghi Formula	3

4.2- Meyerhof Formula.....	3
5- Sliding considerations.....	5
6- Bearing capacity for foundations on rock	5
7- Exercices	5
CHAPTER 3: TYPES OF REINFORCED CONCRETE CONSTRUCTION	1
Introduction.....	2
1- Material characteristics	2
1.1- Concrete	3
1.2- Steel.....	3
2- Reinforced Concrete Frames	2
2.1- General definitions	3
2.2- Reinforced concrete frames	3
3. The elements of the frame	5
3.1- The poles	3
3.2- The beams	3
3.3- sails	3
4. The bracing	5
5. Carrier systems (RPA 99 Version 2003)	2
6. Concrete structural elements	2
6.1- Predimensioning and lowering of load.....	3

Table of figures

Figure 1: Components of a Building Front view

Figure 2: Important Building Components

Figure 3: Description of a foundation

Figure 4: Loads supported by a foundation

Figure 5: Plan view of footings

Figure 6: Loads supported by a building

Figure 7: Diagramm of foundation system classification

Figure 8: Classification of fondations

Figure 9: Application of various foundation types

Figure 10: Different types of shallow fondation

Figure 11: Isolated Footings (Point Foundations)

Figure 12: Strip Footings (Linear Foundations)

Figure 13: Strip Footings in Trenches

Figure 14: The minimum width of the Strip Footings

Figure 15: Reinforced Concrete Strip Footings

Figure 16: Raft Foundation (Surface Foundations)

Figure 17: Ribbed Raft Foundations

Figure 18: Mushroom Raft Foundation

Figure 19: Vaulted Raft Foundation

Figure 20: the launching of deep foundations

CHAPTER 1 : COMMON TYPES OF FOUNDATIONS

.

Introduction

An edifice, regardless of its shape and purpose, relies on a foundation on which it transfers a set of loads. The elements that act as an interface between the supporting structure and the ground are called foundations. Tailored to both the structure and the soil's characteristics, they come in various forms to ensure a proper distribution of stresses.

Foundations are an essential component of any building or structure, serving as the base upon which the entire edifice rests. They are designed to safely distribute the load of the structure to the underlying soil or rock, ensuring stability and preventing settlement or structural failure. A well-designed foundation is crucial for the longevity and safety of any construction project.

The Common Types of Foundations course is designed to provide a comprehensive understanding of various foundation systems used in construction. Foundations play a crucial role in supporting the weight of a building and transferring it to the ground. Participants will explore different foundation types, their design principles, and their suitability for various construction projects. By the end of this course, attendees will be equipped with the knowledge to make informed decisions about selecting the most appropriate foundation type for different building structures.

1- Definition of foundations

Foundations, in the context of construction and engineering, refer to the structural elements that support and distribute the loads of a building or any other type of structure to the underlying ground. They serve as the crucial link between the superstructure (the part of the building above ground) and the substructure (the ground or soil beneath). The primary function of foundations is to ensure stability, prevent settlement, and safeguard the overall integrity of the structure.

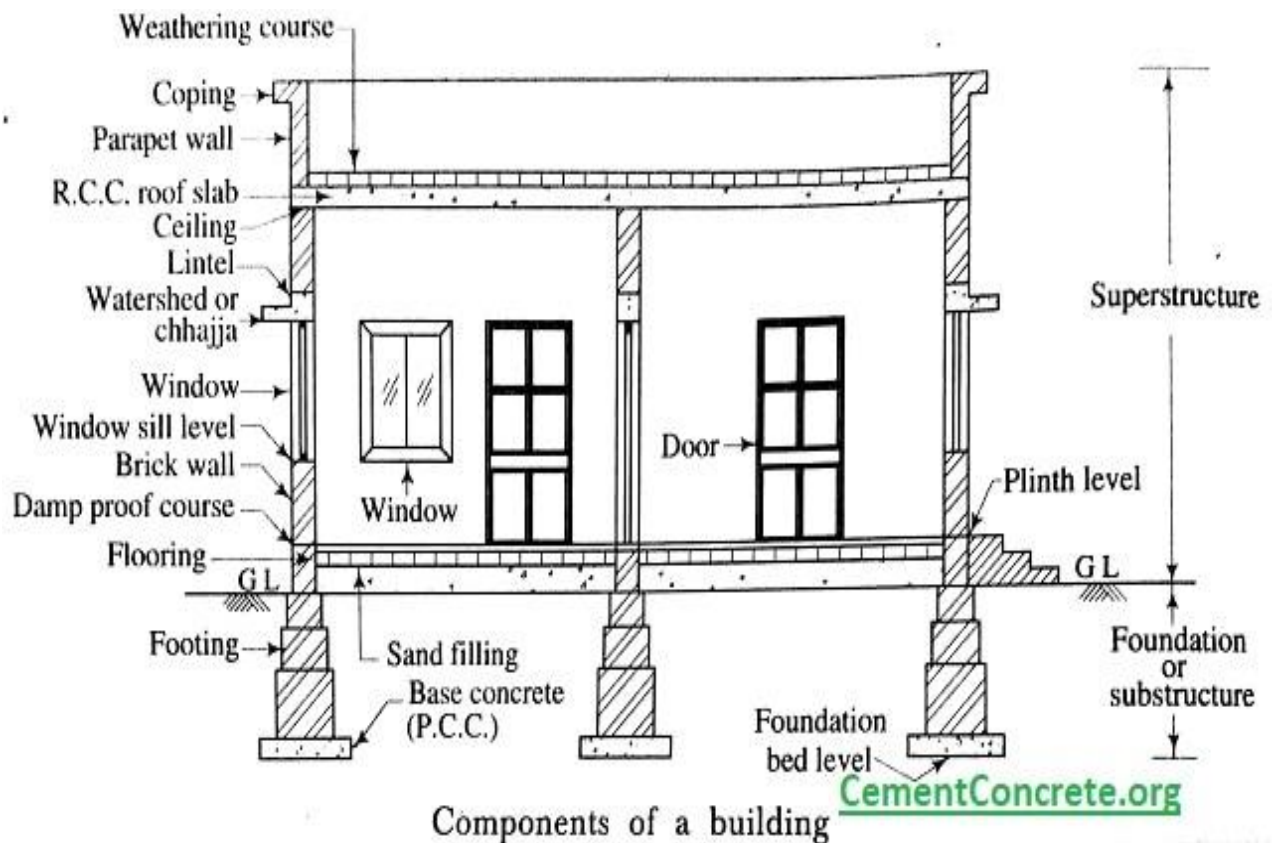
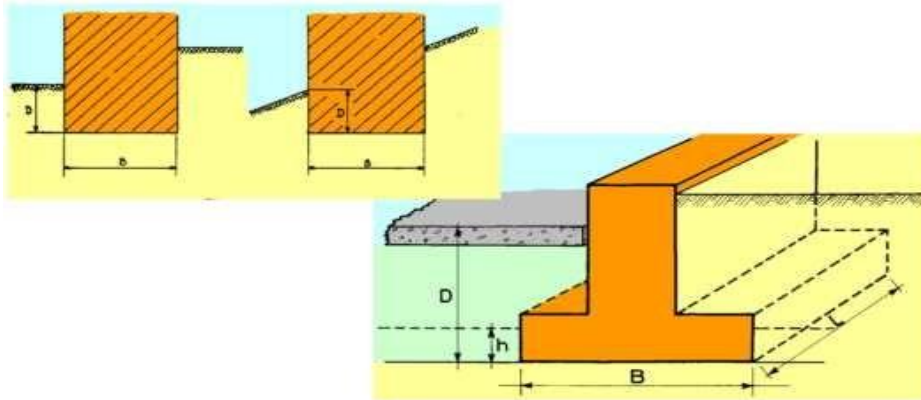


Figure 1: Components of a Building Front view

(Source: <https://i0.wp.com/btp-cours.com/wp>)

In essence, foundations are responsible for transmitting the dead loads (the weight of the structure itself) and live loads (loads from occupants, furniture, and other movable objects) to the ground in a manner that prevents excessive settlement, differential settlement, and structural failure.

Different types of foundations, such as shallow foundations (e.g., spread footings, strip footings) and deep foundations (e.g., piles, caissons), are employed based on the specific needs and site conditions of the construction project.



- Width of a footing : B
- Length of a footing : L
- Embedment height : D *minimum thickness of soil above the level of the foundation*
- Footing anchorage : h *depth of penetration into the bearing layer*

Figure 3: Description of a fondation

Foundations are designed to achieve various equilibriums for the structure:

1. **Transmitting Loads to the Ground:** Foundations serve as the interface between the superstructure and the ground, efficiently transferring the vertical and horizontal loads from the building to the underlying soil or rock.
2. **Deformation Management:** When loads are applied to the structure, the soil beneath may deform. Foundations are engineered to accommodate these deformations and prevent excessive settlement or differential movement, ensuring the stability and safety of the building.
3. **Overall Structural Stability:** Foundations play a critical role in maintaining the overall equilibrium and stability of the entire structure, preventing tilting, sliding, or collapse under the influence of applied loads and external forces. By distributing the loads evenly, foundations ensure that the structure remains steady and structurally sound throughout its lifespan.

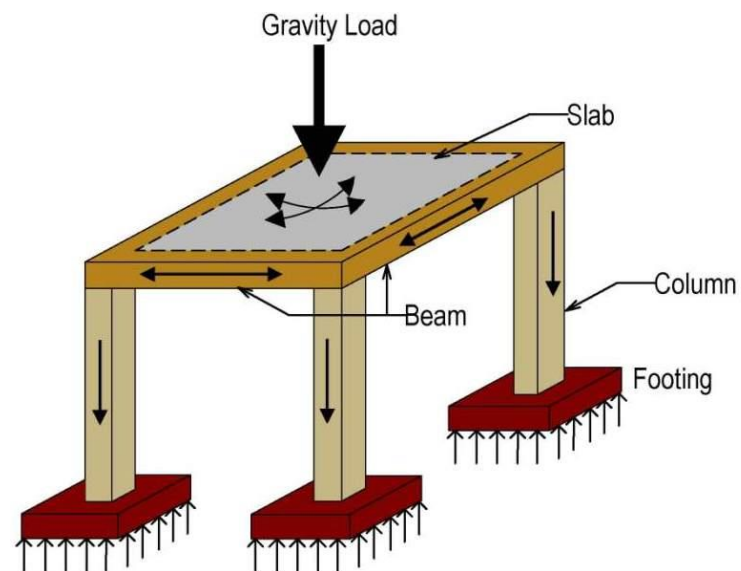
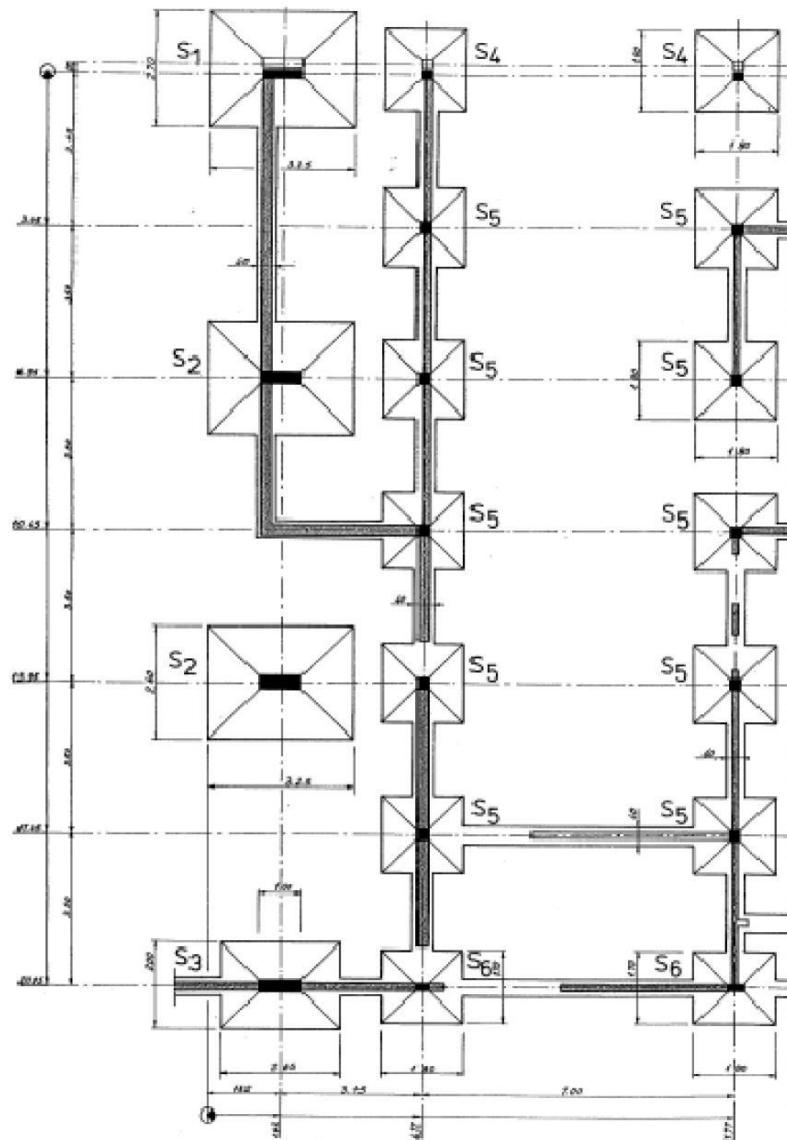


Figure 4: Loads supported by a foundation



The supporting structure of a construction bears various loads, such as:

1. Vertical Loads:

- Permanent loads, like the weight of load-bearing elements and non-load-bearing elements.
- Variable loads, including the weight of furniture, occupants, snow, etc.

2. Horizontal (or Oblique) Loads:

- Permanent loads, such as earth pressure.
- Variable loads, like water pressure or wind pressure.

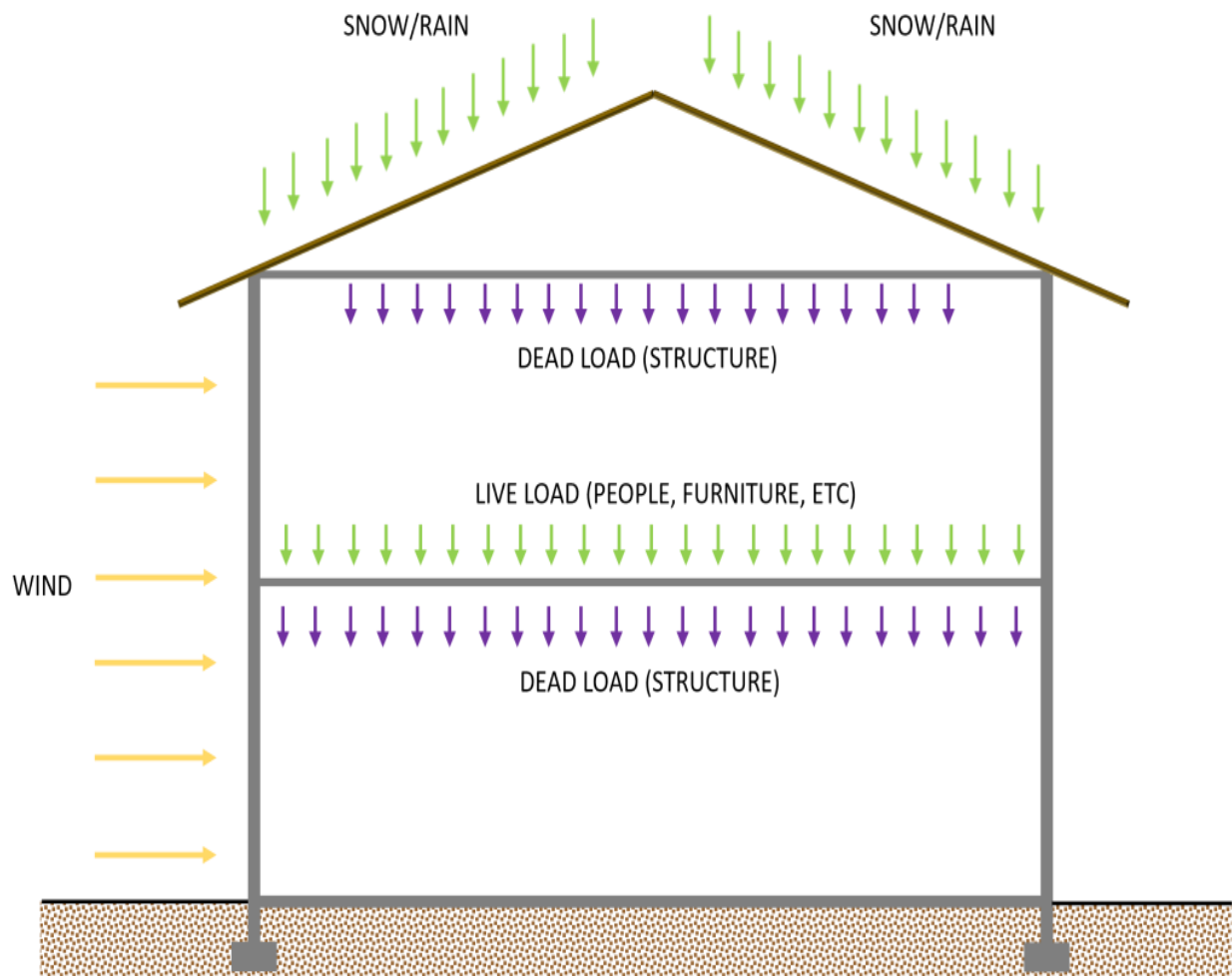


Figure 6: Loads supported by a building . (Source :

<https://www.engineer4free.com/blog/selecting-the-most-favourable-foundation>)

2- Types of foundations

There are several types of foundations used in construction, each designed to suit specific soil conditions, building requirements, and loads. If the forces are distributed to the surface of the soil, the foundations are referred to as shallow foundations; if the forces are distributed deeper into the ground, they are known as deep foundations. Due to cost considerations, shallow foundations are often preferred when possible.

However, if this option is not technically feasible (e.g., when the soil cannot support the applied load or settlements are too significant) or economical, a deep foundation solution is considered.

Considering the depth of embedment (D) of the foundation into the soil, its width (B), and its length (L), three types of foundations can be distinguished:

1. Shallow Foundations: $D/B \leq 4$ to 5
2. Deep Foundations: $D/B \geq 10$
3. Semi-Deep Foundations: $4 \leq D/B \leq 10$

These distinctions help in selecting the appropriate foundation type based on the specific site conditions and load requirements of the construction project.

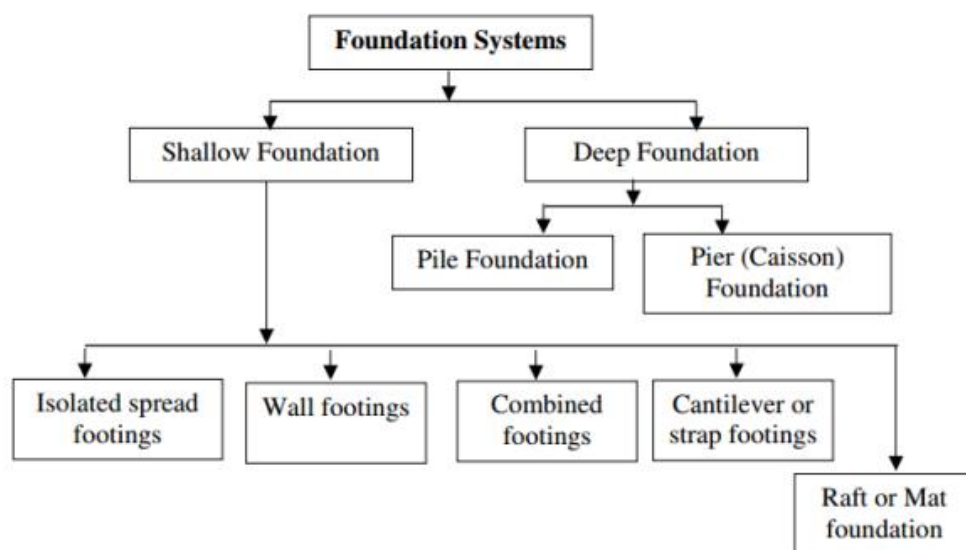


Figure 7: Diagramm of foundation system classification

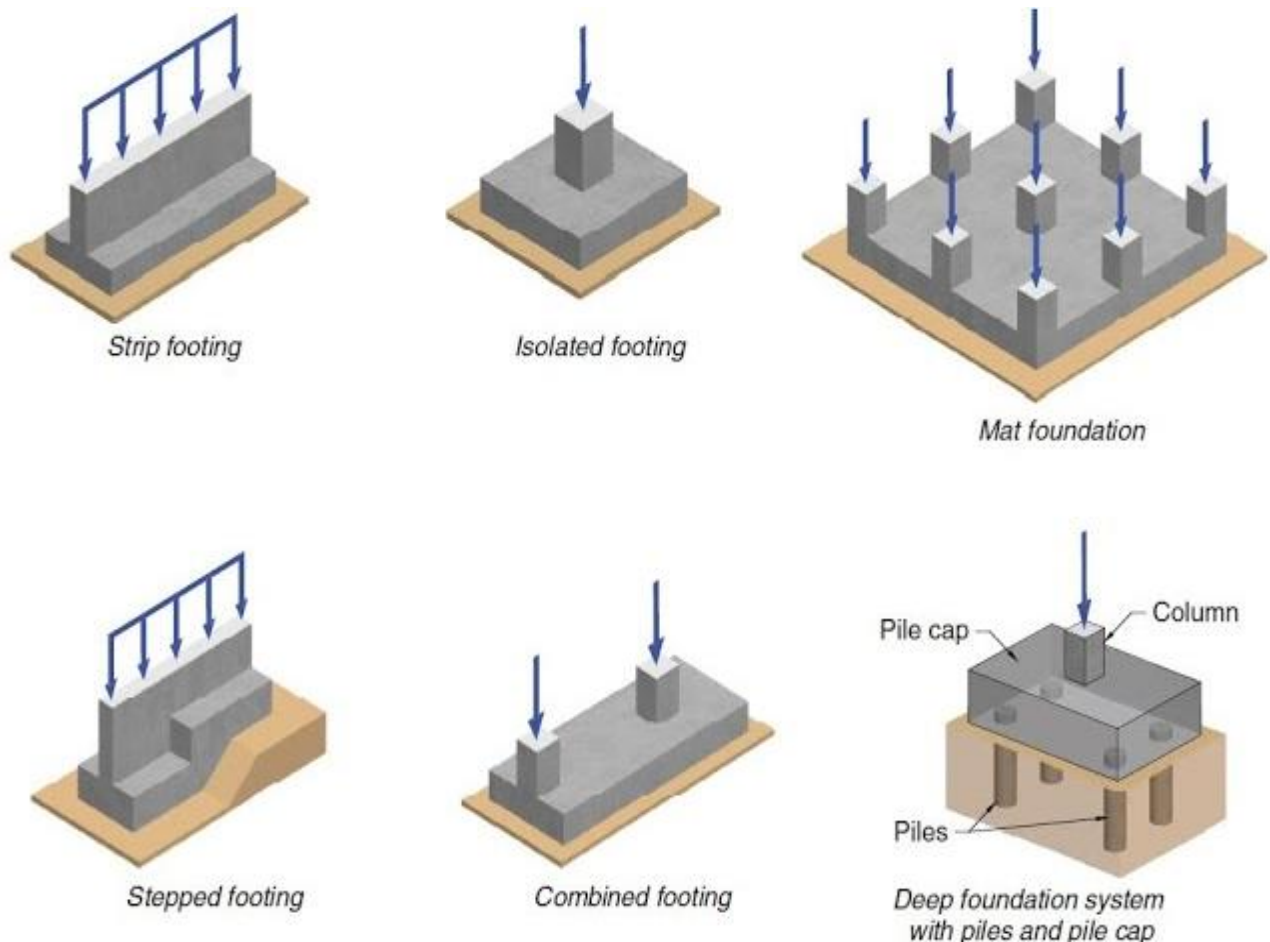


Figure 8: Classification of foundations.

The choice of a foundation is closely related to several important factors, including:

1. **Soil Quality:** The nature and characteristics of the soil beneath the construction site play a crucial role in the selection of the foundation. The soil's bearing capacity, stability, behavior under loads, and geotechnical properties influence the most suitable type of foundation.
2. **Loads Imposed by the Construction:** Vertical and horizontal loads induced by the construction, including the weight of the structure itself, permanent loads (furniture, equipment, etc.), temporary loads (such as people, snow, wind), and seismic or environmental loads, must be considered to design an adequate foundation.
3. **Cost of Execution:** The cost of implementing the foundation is an essential factor in the final decision. Different types of foundations have varying economic implications in terms of materials, labor, equipment, and construction timelines. Striking a balance between technical performance and cost is crucial to ensure an economically viable construction.

By considering these factors and other project-specific considerations, engineers and designers can choose the most suitable foundation to ensure the stability, durability, and long-term safety of the structure.

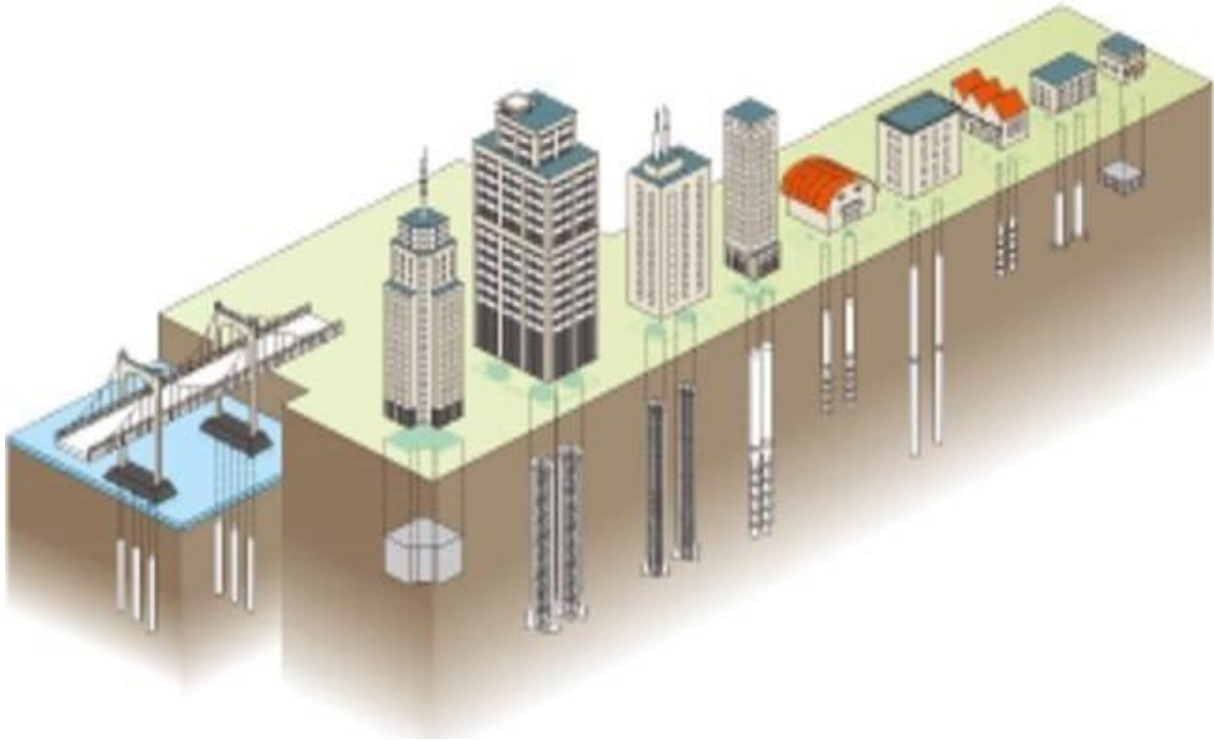


Figure 9: Application of various foundation types
(Source: philosophyofcivilengineering.wordpress.com)

The choice of the most appropriate foundation type is governed by certain important factors, such as:

- The nature of the structure
- The loads applied by the structure
- The characteristics of the soil beneath the foundation
- The costs of foundations

However, to decide on the type of foundation to use, one must first investigate the relevant soil layers, thoroughly assess the soil characteristics beneath the construction, and subsequently evaluate the allowable load that the ground can support. It is at this point that one can determine whether to use a shallow or deep foundation.

3- The role of foundations

1. Ensuring the stability of the structure and the foundations

This can be achieved through two types of tests:

- Limiting settlements (order of magnitude: a few millimeters to 5-25 mm) and differential settlements.
- Verifying that Archimedes' forces (water in the soil) are less than the weight of the structure.
- Preventing the structure from moving under the action of horizontal or oblique forces applied to the structure (wind, earth pressures, hydrostatic pressures) (use of anchors, sufficient soil/concrete friction, tie rods, etc.).
- Avoiding sliding for structures built on sloping terrain ($\text{slope} < 2/3$).
- Providing a peripheral drainage system.

2. Ensuring the resistance of the foundation masses The loads imposed on the foundations must not lead to their failure (complying with regulations, correct sizing of foundations based on the type of structure, loads and surcharges supported by the structure, nature of the soil, type of foundations, and materials used).

3. Verifying the strength of the foundation soil: The actions exerted on the soil must not cause punching or deformations incompatible with the use of the structure.

4. Ensuring the durability of the foundations: The foundation masses must be protected from oxidation, erosion, chemical decomposition, and the effects of freezing. The soil must be stable against erosion, landslides, and the dissolution of certain particles in water (e.g., gypsum, freezing, etc.).

5. Finding the most economical solution: Seeking economical solutions based on the type of structure, soil study recommendations, and accessibility to the site (earthmoving equipment, drilling equipment, etc.).

4- Constitution of a foundation

The constitution of a foundation depends on the type of foundation chosen for a specific construction project. However, generally, a foundation consists of the following elements:

1. **Slab or Raft:** In the case of shallow foundations such as spread footings or strip footings, a reinforced concrete slab or raft (a large concrete slab) is poured directly onto the ground to distribute the loads of the structure over a large area.
2. **Blocks or Piers:** In some shallow foundations, blocks or reinforced concrete piers are constructed to directly support the columns or beams of the building.
3. **Piles or Drilled Piers:** For deep foundations like piles, long cylindrical elements made of concrete, steel, or wood are driven or drilled deep into the ground to reach stronger soil layers capable of supporting the building loads.
4. **Blinding Concrete:** It is a thin layer of concrete poured on the ground before constructing the foundations to provide a smooth and stable surface.
5. **Reinforcement Steel:** Steel reinforcement bars are incorporated into the concrete to enhance the strength of the foundation.
6. **Backfill and Leveling Materials:** Certain types of foundations, like pile foundations, may require the addition of backfill or leveling materials to adjust the height or stability of the foundation.

The constitution of a foundation must be carried out in accordance with the applicable construction standards and based on the project specifications and the type of soil encountered at the construction site. Proper design and construction of foundations are essential to ensure the stability, durability, and long-term safety of the structure.

5- Shallow Foundations

Shallow foundations are a type of foundation used in construction when the soil at a relatively shallow depth beneath the surface is capable of supporting the load of the building or structure without requiring significant depth excavation. These types of foundations are commonly used when solid and load-bearing soil layers are relatively close to the surface.

Shallow foundations include different types, namely:

1. **Spread Footings:** Rectangular or square concrete footings, also known as "footings," are built under each column or load-bearing wall to distribute the load over a larger area of the soil. Spread footings are used for light to medium structures.

2. **Strip Footings:** These are elongated rectangular foundations, sometimes continuous, used to support aligned load-bearing walls. Strip footings are suitable for structures with closely spaced load-bearing walls.

3. **Raft Foundations:** Raft foundations are thick and continuous concrete slabs that cover the entire building footprint. They are particularly suitable for buildings with a large footprint or subjected to high uniform loads.

4. **Mat Foundations:** Similar to raft foundations, but incorporating integrated retaining walls within the slab, mat foundations are used for massive buildings requiring additional support.

Shallow foundations are generally less expensive and easier to construct than deep foundations. However, their selection depends on soil characteristics, structural loads, and specific requirements of the construction project. Thorough geotechnical evaluation is essential to determine the most suitable type of foundation for a given project.

Shallow foundations are implemented when the construction can be supported by a layer of acceptable strength at a shallow depth relative to the lowest level of the construction and not the natural ground level.

Three types of shallow foundations are distinguished:

1. Strip footings, usually with a modest width B and a long length L ($L/B > 10$ for illustration purposes); also includes foundations for retaining walls.

2. Isolated footings, with both plan dimensions B and L being a few meters at most; this category includes square footings ($B/L = 1$) and circular footings (with a diameter B).

3. Rafts or slabs with significant dimensions in plan B and L ; this category includes mat foundations.

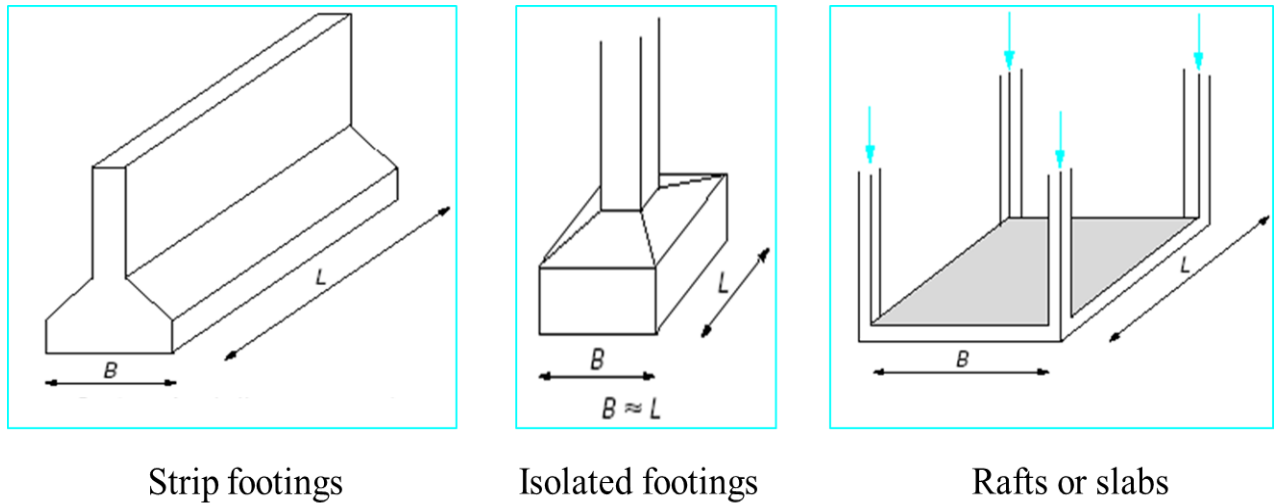


Figure 10: Different types of shallow fondation

5.1- Design of Shallow Foundations

The design of shallow foundations involves the process of determining the appropriate dimensions and specifications for the foundation elements that support the structure. This design process aims to ensure that the foundation can safely distribute the loads from the building or structure to the underlying soil without causing excessive settlement or structural failure.

The key steps in the design of shallow foundations include:

1. **Geotechnical Investigation:** Conducting a thorough geotechnical investigation of the site to assess the properties and bearing capacity of the soil. This information helps in selecting the suitable type of shallow foundation and determining the allowable bearing capacity.
2. **Load Analysis:** Calculating and analyzing the vertical and horizontal loads imposed on the foundation by the structure, including dead loads, live loads, and environmental loads such as wind and seismic forces.
3. **Foundation Type Selection:** Choosing the appropriate type of shallow foundation based on the soil conditions, structural requirements, and local building codes. Common types include spread footings, strip footings, raft foundations, and mat foundations.

4. **Sizing the Footings:** Determining the dimensions (width and length) of the footings to ensure that the bearing pressure on the soil is within the allowable limits and that settlements remain within acceptable limits.

5. **Reinforcement Design:** If needed, designing the reinforcement for the footings to enhance their load-carrying capacity and prevent cracking or failure.

6. **Soil Improvement Techniques:** Implementing soil improvement techniques if necessary to enhance the bearing capacity of the soil or mitigate potential settlement issues.

7. **Construction Considerations:** Taking into account construction aspects such as the sequence of construction, soil preparation, and ensuring proper compaction during the construction of the foundation.

The design of shallow foundations must adhere to local building codes, regulations, and safety standards to ensure the stability, durability, and safety of the entire structure. Professional expertise and geotechnical engineering knowledge play a crucial role in the successful design and implementation of shallow foundations.

The surface of the footing must be sufficient to distribute the vertical loads imposed by the structural elements onto the soil. Distributing a force over an area is to exert pressure:

$$\text{pressure [Pa]} = \frac{\text{Force [N]}}{\text{Surface [m}^2\text{]}}$$

The cross-sectional area is determined using the following formula:

$$S \text{ [mm}^2\text{]} \geq \frac{N_{\text{ult}} \text{ [N]}}{q \text{ [MPa]}}$$

With:

S: Surface area of the foundation footing

Nu: Represents the ultimate load applied by the structure

q: Represents the soil bearing capacity (stress)

5.2 - Isolated Footings (Point Foundations)

Isolated footings are structural elements used to support individual columns or piers. They are typically placed under each column, and their purpose is to distribute the load of the structure's vertical forces to the soil in a way that prevents excessive settlement and ensures the stability of the building. These footings are designed to carry the specific loads from the column and transmit them safely to the ground. The effective height of the footing will be equal to the greater value found by either of the relations (in the case of rectangular footings):

$$h_{u1} \geq \frac{A-a}{4} \quad , \quad h_{u2} \geq \frac{B-b}{4}$$

"hu" stands for "useful height of the footing"

A and B refer to the dimensions of the footing

a and b refer to the dimensions of the column

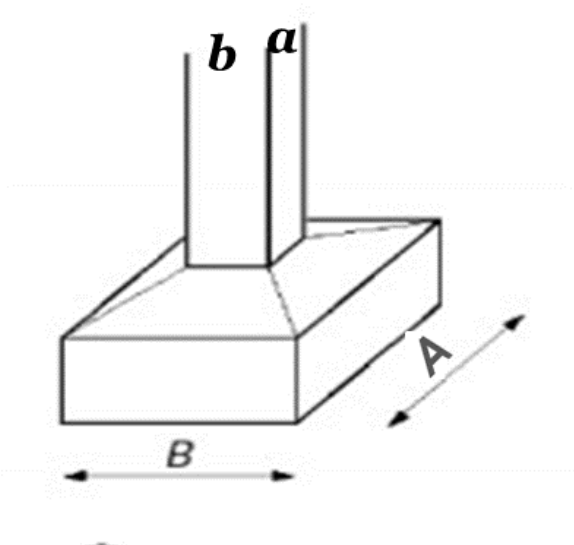


Figure 11: Isolated Footings (Point Foundations)

5.3- Strip Footings (Linear Foundations)

Strip footings, also known as continuous footings or linear foundations, are long and narrow concrete pads that support a load-bearing wall or a row of closely spaced columns. They are designed to distribute the load over a larger area of the soil and prevent excessive settlement. Strip footings are commonly used in building construction, especially for structures with load-bearing walls or columns arranged in a straight line.

Strip footings (continuous footings) are used when the design of isolated footings is no longer possible. Strip footings receive the loads from the superstructure through point supports (columns) and linear supports (shear walls, walls), or both at the same time.

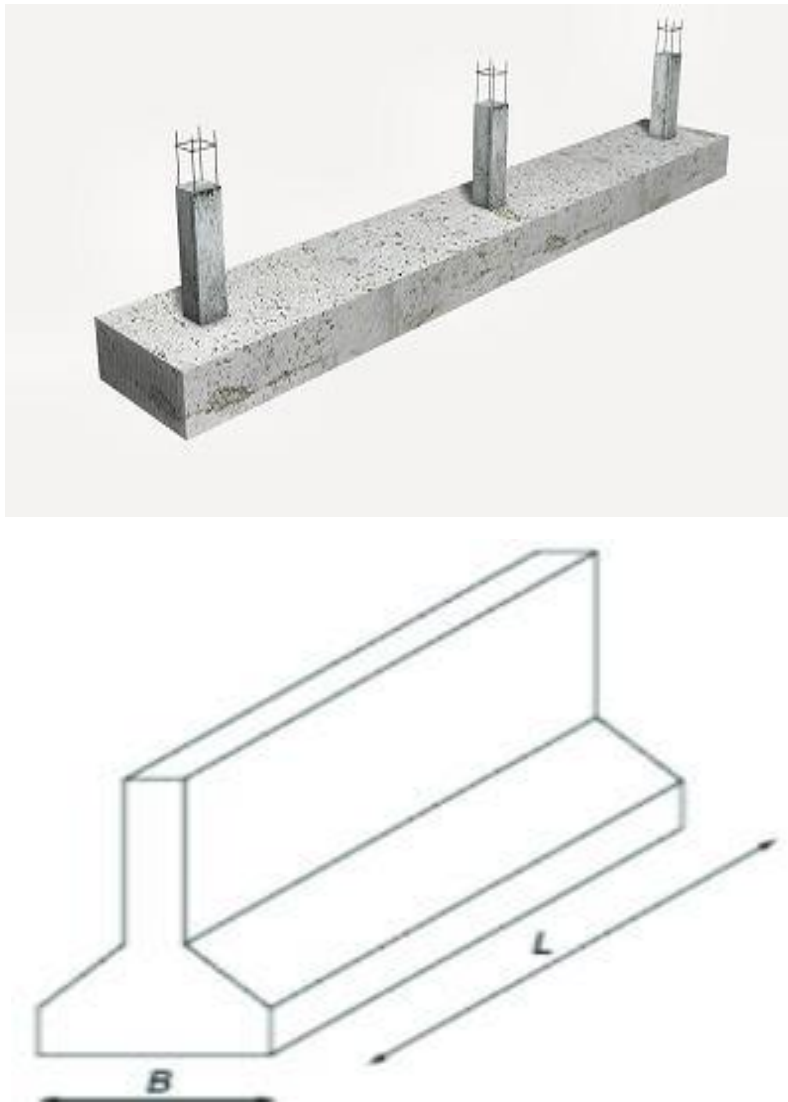


Figure 12: *Strip Footings (Linear Foundations)*

Strip Footings in Trenches

- These are concrete footings under masonry walls and serve as shallow surface foundations.
- They are usually placed at a depth of 60cm to 1m to avoid being affected by frost.
- The loads supported by these footings are relatively low (from 5 t/m to 40 t/m).



Figure 13: Strip Footings in Trenches

The width (A) of the footing is determined as follows:

$$A \text{ (cm)} \geq \frac{Q \text{ (charge totale /m de mur, en kg)}}{100 \sigma_a \text{ (containte admissible du sol, en kg/cm}^2\text{)}}$$

"A" is the minimum width to be given to the footing, whether it is reinforced or not. However, the accepted minimum dimensions are:

- $A = 40 \text{ cm}$;
- The depth $H = 30 \text{ to } 40 \text{ cm}$, provided there is sufficient anchorage and it is below the frost line;
- The height of the footing is generally at least equal to half of its width.

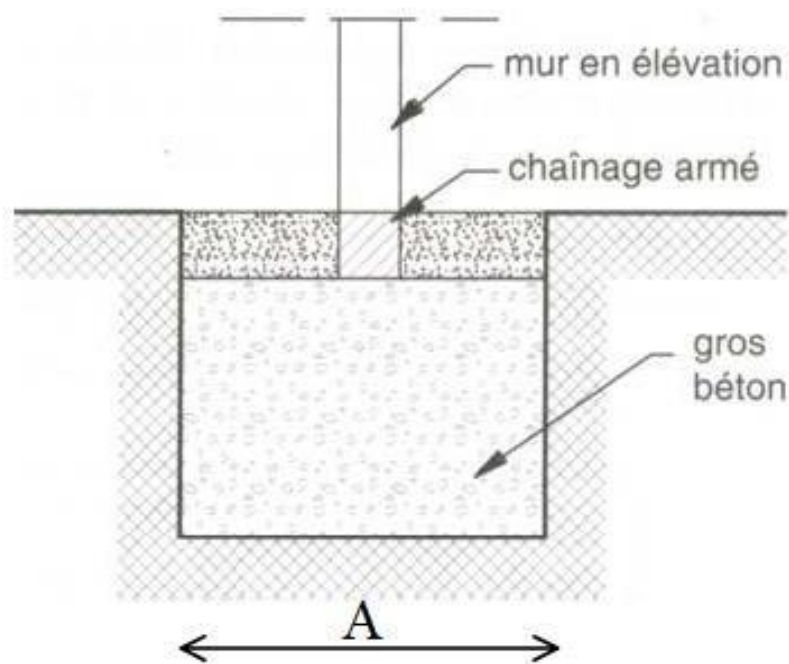


Figure 14: The minimum width of the Strip Footings

Reinforced Concrete Strip Footings

When the allowable stress of the soil is low compared to the loads to be transmitted, or when the calculated width of the footing requires significant overhang, a reinforced concrete strip footing is chosen.

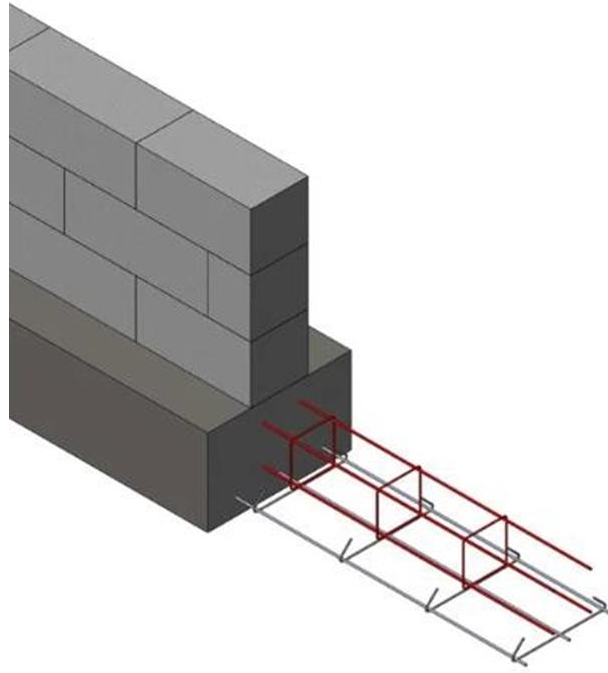
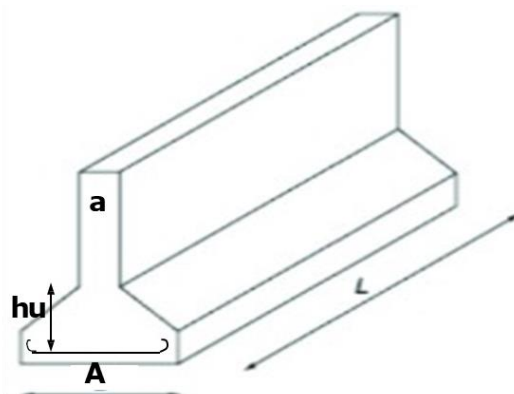


Figure 15: Reinforced Concrete Strip Footings

The width of the footing (A) is calculated in the same way as for the plain concrete footing, but the height can be reduced with the help of reinforcements that compensate for the low tensile strength of concrete.

$$A \text{ (cm)} \geq \frac{Q \text{ (charge totale /m de mur, en kg)}}{100 \sigma_a \text{ (containte admissible du sol, en kg/cm}^2\text{)}}$$

$$h_u \geq \frac{A - a}{4}$$



When the footings in a given direction are close to each other, a continuous footing is constructed under the row of columns they support. The width is determined in the same way as that of a reinforced strip footing under a wall.

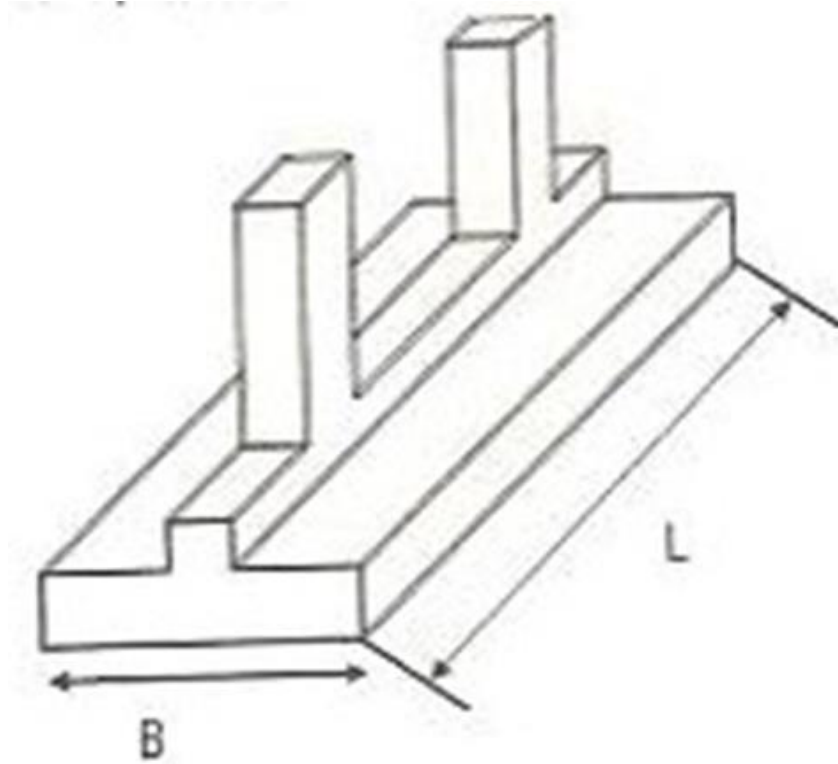


Figure 15: continuous footing under the row of columns

5-4. Raft Foundation (Surface Foundations):

- The raft foundation is in the form of a foundation plate that transmits the loads of the construction to the soil over an area equal to or larger than that of the structure.
- It can be constructed in two ways:
 - Either as a simple thick slab.
 - Or by using longitudinal and transverse beams connecting the load-bearing pillars and supporting a thinner slab (ribbed raft foundation).



Figure 16: Raft Foundation (Surface Foundations)

5.5- Ribbed Raft Foundations

- When the loads are significant, to avoid excessive thickness of the raft foundation, beams (ribs) are used to stiffen the slab.
- These ribs can be arranged in a single direction or in two directions, depending on the span and the layout of walls or columns.
- The average spacing of the beams is 2.5m.
- Ribbed raft foundations are preferred when the span between the support points is greater than 4m.

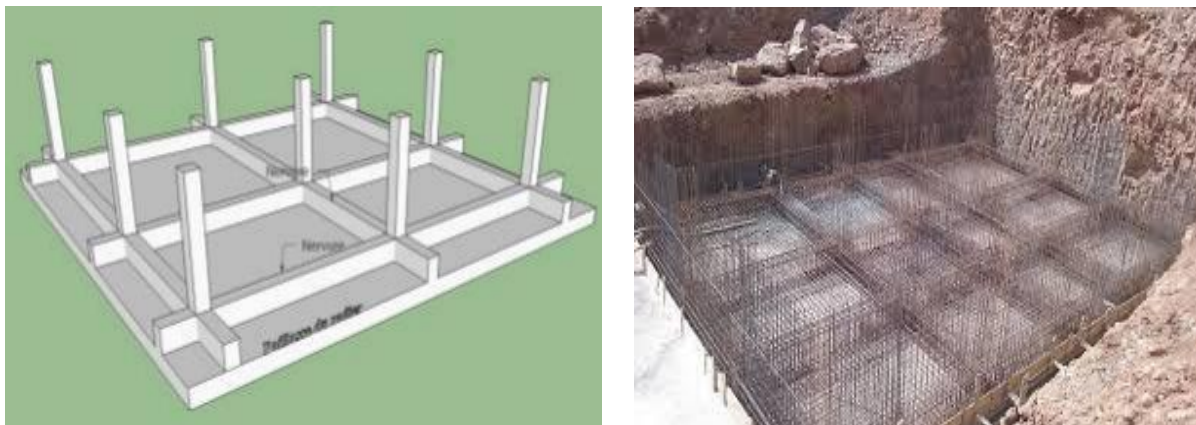


Figure 17: Ribbed Raft Foundations

5.6- Mushroom Raft Foundation

- This type of raft foundation does not have ribs, allowing for a flat and unobstructed surface for larger spans.
- The loads from the columns are transmitted to the thick slab (50 cm) through capitals, which enables a gradual distribution of the load.
- It is necessary to evenly distribute the columns (the span in one direction cannot exceed twice the span in the other direction).
- The capital can be incorporated into the slab (strongly reinforced concrete for the capital), resulting in a completely flat surface.

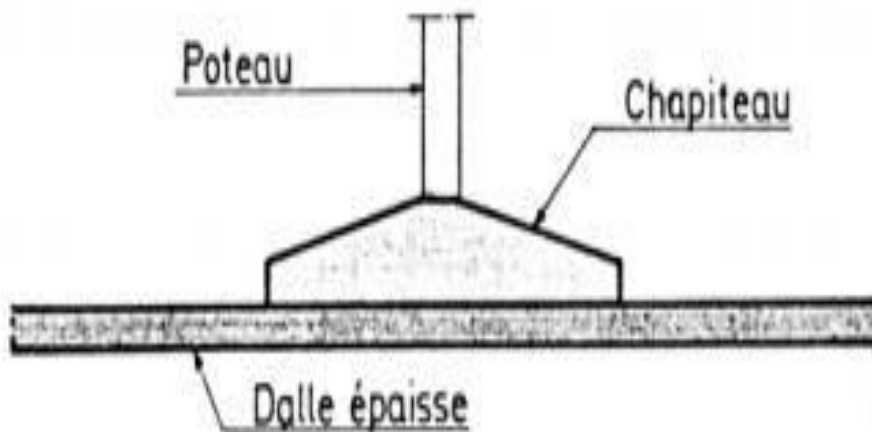


Figure 18: Mushroom Raft Foundation

5.7- Vaulted Raft Foundation

- Vaults allow for increasing spans (distance between load-bearing elements) without significantly increasing the thickness of the raft foundation.
- The implementation is quite complex, but vaulted rafts are thin (12 to 20 cm), making them economical in terms of concrete and steel. The reinforcement can be composed of steel bars or reinforced concrete beams (RC beams).

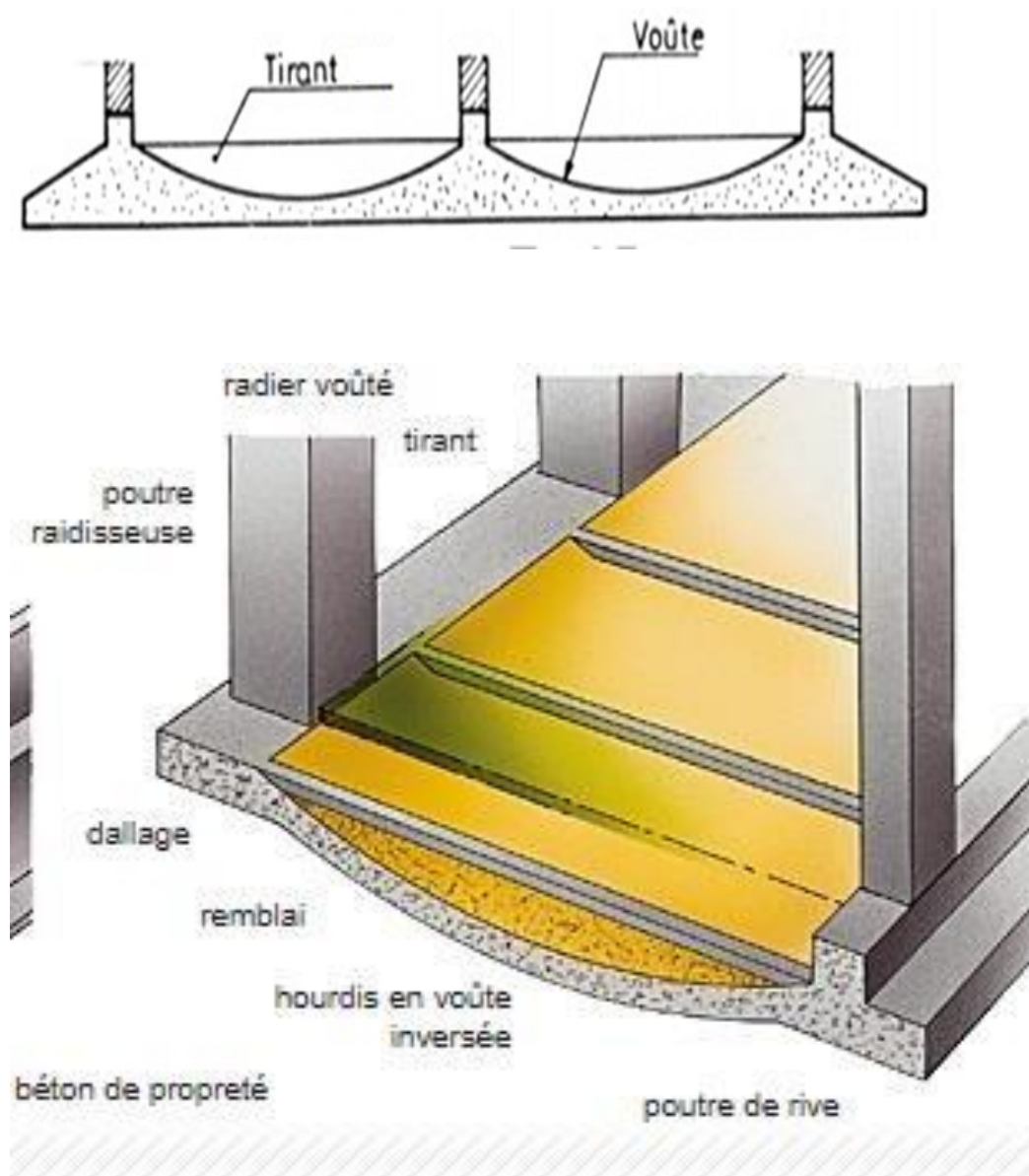


Figure 19: Vaulted Raft Foundation

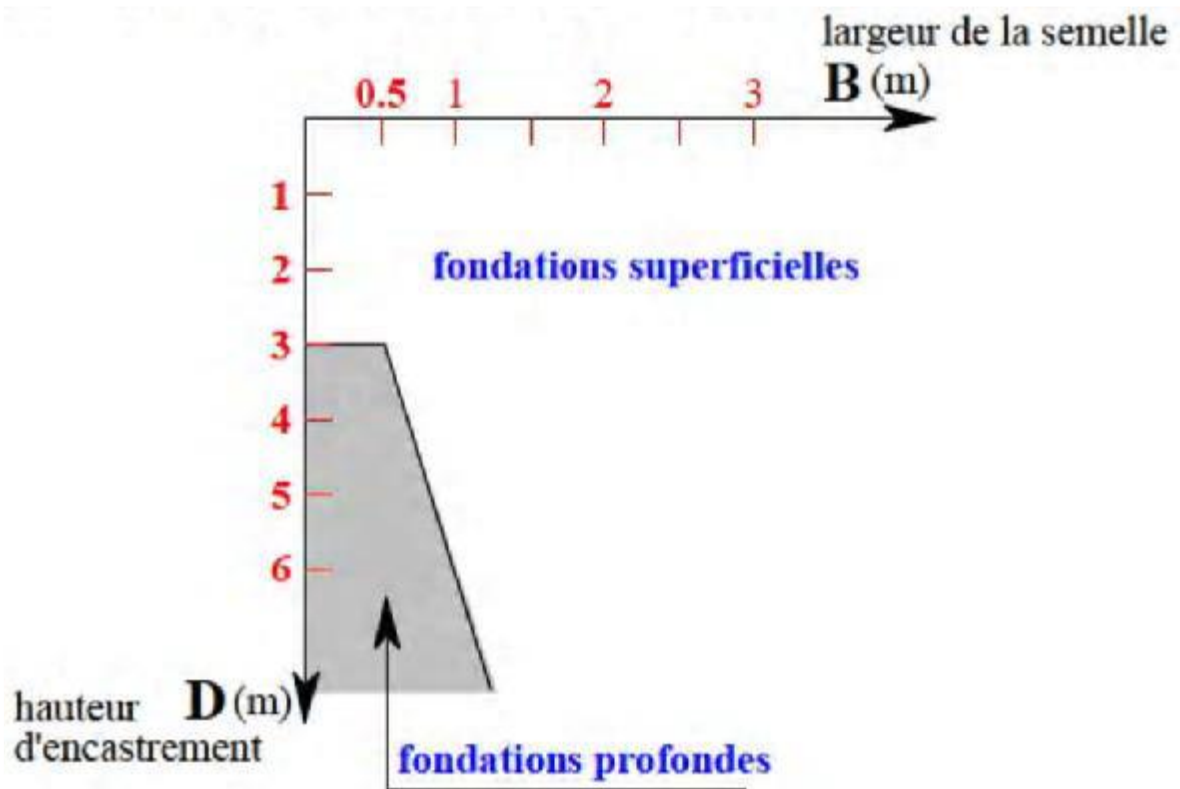
6- DEEP FOUNDATIONS, RETAINING WALLS

DEFINITION - TERMINOLOGY A deep foundation is characterized by the way the soil is stressed to resist the applied loads.

- Point resistance
- Lateral friction
- Combination of point resistance and lateral friction (common case) Its dimensions are defined by:

- D: Length of the foundation buried in the soil
- B: Width of the foundation or diameter Beyond $D/B > 6$, and $D > 3$, we enter the realm of deep foundations.

In general, deep foundations are often referred to as "piles."



A foundation is considered deep when the slenderness ratio is significant:

- $D/B < 4$ ☞ Shallow Foundations
- $D/B \geq 10$ ☞ Deep Foundations
- $4 \leq D/B < 10$ ☞ Semi-Deep Foundations

$D/B \nearrow$ Cost of Construction $\nearrow$

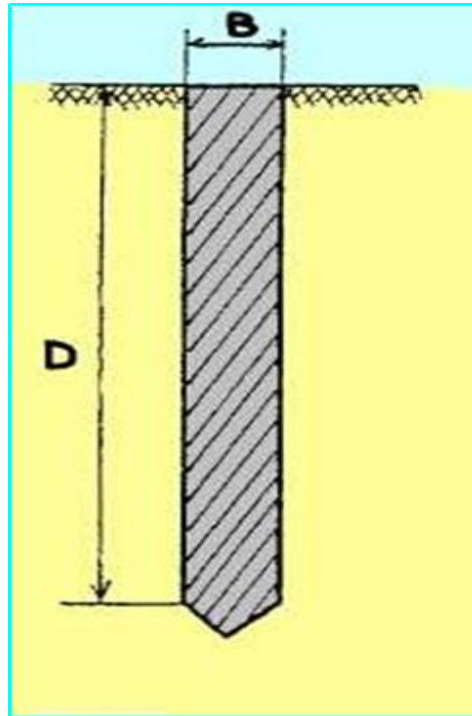


Figure 20: the launching of deep foundations

Anchoring Layer

An anchoring layer refers to a layer with favorable mechanical characteristics where the base of the foundation is anchored. Anchoring Depth (h) is the depth to which the pile penetrates into the bearing layer.

Foundation Types:

- **Monolayer:** When the pile is driven into a homogeneous layer.
- **Multilayer:** When the pile penetrates at least two layers with different characteristics.

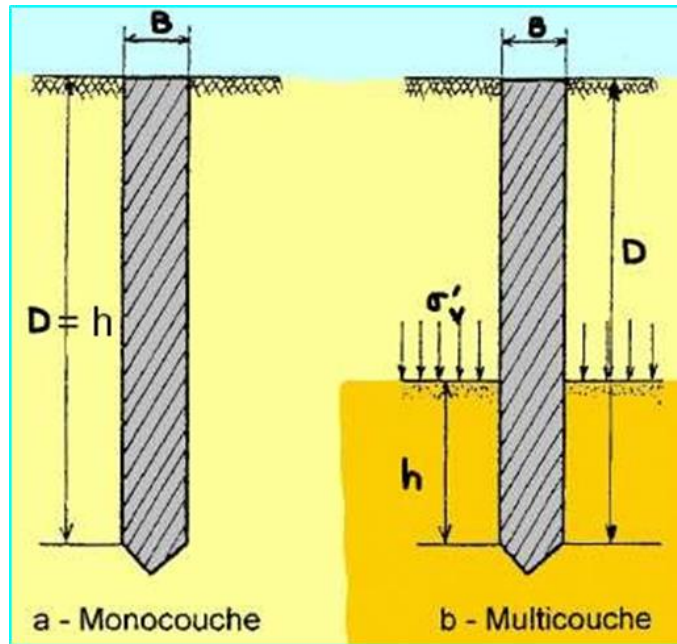


Figure 21: different types of Anchoring Layer

7- SETTLEMENT OF FOUNDATIONS

Definition: Undoubtedly, soils deform under the load of foundations. The total vertical displacement that occurs at the foundation level is called settlement. Settlement refers to the vertical settlement or subsidence of a construction under the effect of compression and deformation of the supporting soils. Most often, the load transmitted to the soil is directed vertically, and the resulting deformations are predominantly in this direction.

The cause of foundation settlement is the reduction of the void ratio in the soil. Settlements in unsaturated soils are almost instantaneous. However, in saturated soils, they can extend over a few seconds in sandy-gravelly soils or up to several decades in less permeable clays. Furthermore, the magnitude of foundation settlement is controlled by various factors, including the type of soil, the structure, and the type of foundations used.

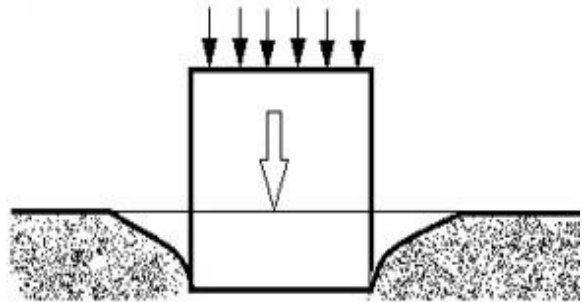


Figure 22: Tassement of Foundations

7.1- Types of Settlements

Settlements can be either uniform or varying from one point to another, depending on the nature of the soil in place. Hence, we distinguish:

1. Tassement uniforme (Uniform Settlement): Uniform settlement occurs when all points of the foundation settle at the same rate. This type of settlement typically happens in soils with relatively consistent properties and thickness.
2. Tassement différentiel (Differential Settlement): Differential settlement occurs when different points of the foundation settle at varying rates. This type of settlement is commonly observed in soils with variations in their properties or thickness across the foundation area. It can lead to uneven settlements and potential structural issues, such as tilting or cracking in the building. Engineers must consider and address potential differential settlements during foundation design to ensure the stability and integrity of the structure.



Figure 23: Types of foundation settlements

Uniform Settlements

If all parts of a building rest on the same type of soil, uniform settlement is the most likely type. Similarly, when the loads on the building and the design of its structural system are consistent throughout, the anticipated settlement would be of a uniform nature.

Uniform settlements have a relatively low impact on the structure itself, but the resulting movements can still damage utilities and accessories such as water pipes, underground passages, doors, windows, etc. Engineers must consider the potential for uniform settlements and design the building and its foundations accordingly to minimize any adverse effects.

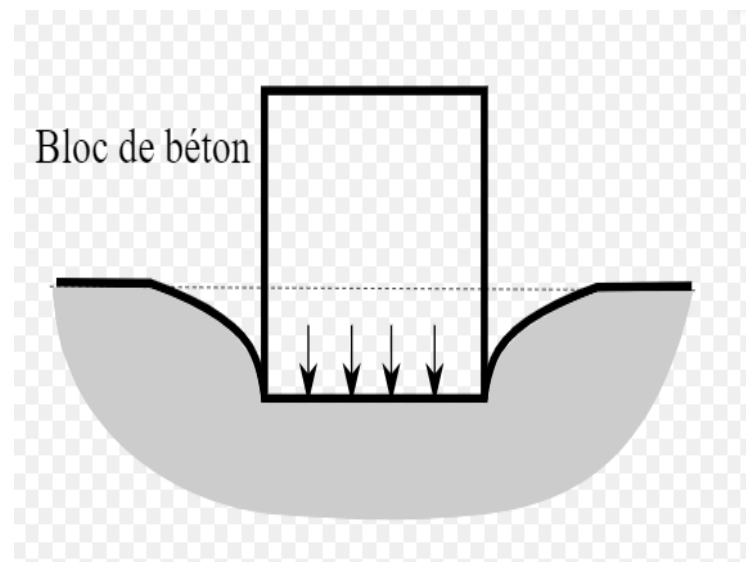


Figure 24: Uniform Settlements

Differential settlement

Differential settlement occurs when there is an uneven or non-uniform movement of the soil under different parts of a building. This non-uniform settlement happens due to variations in

soil conditions, loading, or structural systems across the building's foundation. It can lead to differential vertical displacements of different parts of the structure.

As a result, buildings may experience various deformations, such as tilting, leaning, or twisting. Differential settlement can cause cracks in walls and glass, making doors and windows difficult to operate. This type of settlement is a concern for engineers and architects as it can potentially lead to structural instability and affect the overall integrity and functionality of the building. Special design considerations, such as proper foundation design and soil investigation, are crucial to minimize the impact of differential settlement on the building.

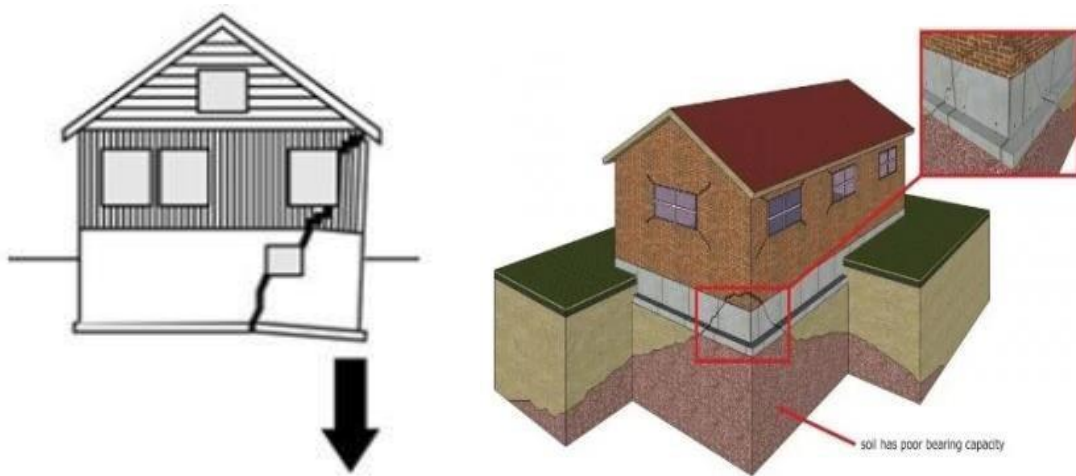


Figure 25:

Differential settlement of foundations can cause buildings to move out of their original plane or level. This non-uniform movement can lead to the appearance of cracks in the foundations, the structural elements, and even the finishes of the building. These cracks may not only be unsightly but also pose potential risks to the structural integrity and stability of the building.

Differential settlement can result from variations in soil properties, loading conditions, or foundation design. It is a critical consideration during the design and construction phase of any building to ensure that appropriate measures are taken to minimize the risk of significant differential settlement. Proper soil investigation, foundation design, and construction techniques are essential to mitigate the potential impact of differential settlement on the building's performance and longevity. Regular inspections and maintenance can also help identify and address any settlement-related issues before they escalate into more significant problems.



Figure :

The scenarios in which differential settlements can occur:

1. When foundations are of different types under the same structure.
2. When foundations are supported on different soil layers with varying properties.
3. When the structure is asymmetrically loaded, either by its superstructure or external loads.
4. When two adjacent buildings are constructed at different times.

Note:

- The design of such constructions is often based on the assumption of a rigid and non-deformable base. However, due to the weight of the building, settlement of the supporting soil is inevitable.
- If this settlement remains uniform, meaning the base stays flat, there is no immediate danger to the structure. However, any non-uniform (differential) settlement tends to modify the stress state within the structure.
- These additional stresses can jeopardize the structural integrity and cause irreversible damage.

Addressing and managing the potential risks associated with differential settlement is crucial during the design, construction, and maintenance of buildings to ensure their long-term stability and safety. Proper foundation design, soil investigation, and monitoring can help mitigate the effects of differential settlement and ensure the structural integrity of the building.

CHAPTER 2: BEARING CAPACITY OF FOUNDATIONS

Introduction

Any foundation project must include a thorough investigation of the supporting soil. Settlements must be less than the permissible settlements defined for the structure, and the stresses must be compatible with the soil's bearing capacity. From a mechanical behavior perspective, when a foundation is subjected to increasing load, the soil initially remains in elastic equilibrium as the load is applied. As the load becomes significant, the soil gradually transitions to plastic equilibrium and eventually reaches failure.

Significant research has been dedicated to this topic for nearly a century to establish, validate, and improve calculation methods, as the parameters to consider are varied, and these calculations involve numerous aspects of the mechanical behavior of soils and rocks.

One element that continues to capture the geotechnician's interest is determining the bearing capacity of a foundation. The corresponding calculation methods have been gradually developed since the twentieth century, thanks in large part to a few pioneers (Terzaghi, Meyerhof, Brinch Hansen, Caquot, de Beer...) who established a set of rules validated by experience and covering most common situations.

Since the 1950s, the evolution of plasticity theory has provided analytical tools offering a new perspective on traditional calculation methods (Salençon, 1974; Chen, 1975), although their use has not significantly altered the practice of foundation studies. Limit analysis and its generalization, failure analysis, define the rules for bounding ultimate loads through a so-called static approach or from the inside and a so-called kinematic approach or from the outside. Under certain conditions, these two approaches converge to a unique solution that is both statically and kinematically admissible, meaning it satisfies all imposed boundary conditions and respects the stability criteria of the materials.

The soil must be capable of carrying the loads from any engineered structure placed upon it without a *shear failure* and with the *resulting settlements* being acceptable for that structure.

A soil shear failure can result in excessive building distortion and even collapse

whereas excessive settlements can result in structural damage to a building frame. It is necessary to investigate both base *shear resistance* and *settlements* for any structure.

The recommendation for the allowable bearing capacity q_a to be used for design is based on the *minimum* of either

1. Limiting the settlement to acceptable amount.
2. The ultimate bearing capacity, which considers soil strength, as computed in the following sections.

The allowable bearing capacity based on shear control q_a is obtained by reducing (or dividing) the ultimate bearing capacity q_{ult} (based on soil strength) by a safety factor **SF** that is deemed adequate to avoid a base shear failure to obtain

$$q_a = \frac{q_{ult}}{\text{SF}}$$

1- Behavior of a Shallow Foundation

Consider a shallow foundation with a width B and a base located at a certain depth below the ground surface. If a load $q=Q/A$, with A being the area of the footing, is progressively applied to this footing, settlement increases with the load intensity. At the beginning of loading, the deformation of the soil beneath the footing increases approximately in proportion to the load, indicating a pseudo-elastic equilibrium. Then, the deformation becomes significantly larger. If the soil beneath the foundation base consists of firm material, such as dense sand or stiff clay, the application of the load leads to the formation of a wedge under the foundation base, which displaces the soil laterally along slip surfaces that reach the ground surface. The penetration of the foundation generally causes an uplift of the soil, which is more pronounced when the structure is less deformable.

Figure 1 shows the typical $Q-s$ curve obtained during the loading of a shallow foundation (where Q represents the load applied to the foundation and s its vertical displacement):

- At the beginning of loading, the behavior is roughly linear and elastic.
- For sufficiently high values of Q , zones of plasticized soil form and propagate beneath the foundation; the vertical displacement s accelerates.

- Beyond a certain load, the soil undergoes punching shear (the displacement s becomes very significant), and the soil can no longer support a higher load, reaching failure. The force causing the soil failure is called the ultimate force Q_u .

The figure simplistically shows the failure mode of the soil beneath a shallow foundation when the ultimate load Q_u is reached. Three zones can be distinguished:

- **Zone I:** A punch of soil forms beneath the base of the footing, displacing the soil laterally on either side up to the surface.
- **Zone II:** The soil in this zone is displaced toward the surface, is fully plasticized (failure by shear along complexly oriented surfaces), and undergoes significant displacements.
- **Zone III:** The external zones are subjected to much lower stresses, which do not lead to soil failure.

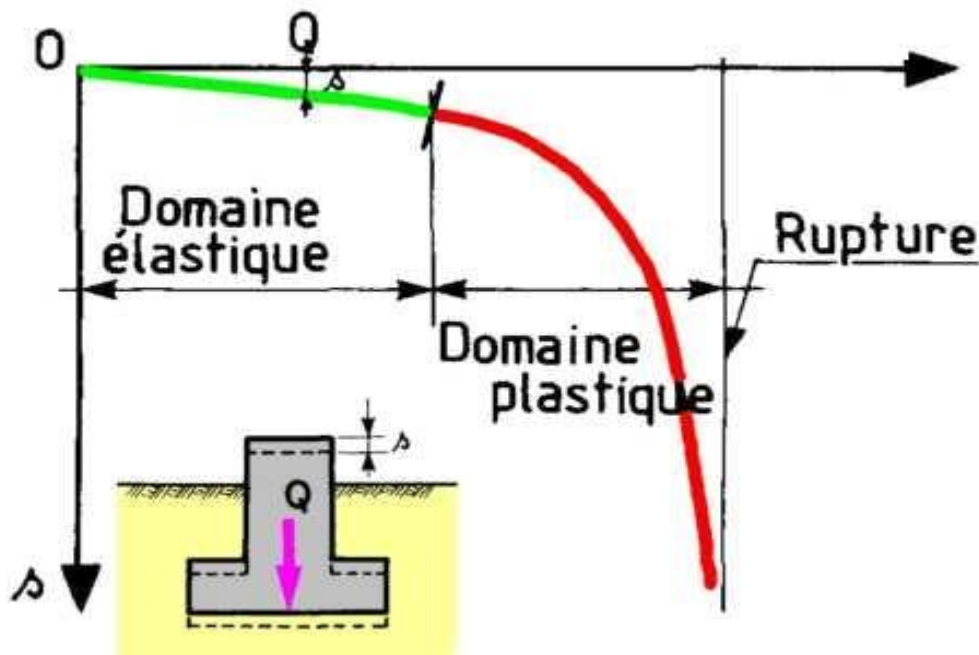


Figure: Typical curve obtained during the loading of a shallow foundation

2- Foundation Design Philosophies

- **Allowable Stress Method (Use of Safety Factor)** The safety factor, typically ranging from 2 to 3 or more, is employed to ensure that foundation loads are significantly less than the shear

strength of the supporting soil and that settlements are not excessive. The relatively high value of the safety factor accounts for:

- Uncertainties regarding loading conditions and unfavorable variations in loads,
- Uncertainties regarding soil conditions and its parameters,
- Consequences of failure, uncertainties in analysis methods (failure mode, etc.).

- **Limit State Method (Use of Partial Safety Factor)** The limit state method aims to ensure that all appropriate performance conditions are met under all conceivable circumstances:

- **Ultimate Limit State:** Concerned with collapse and major damage.
- **Serviceability Limit State:** Concerned with usability and minor damage.

Examples of limit states include:

- Shear failure
- Sliding failure
- Overturning failure
- Excessive settlement or heave
- Failure of the foundation element's structure

It should be noted that the allowable bearing capacity of shallow foundations is almost always governed by settlement criteria and very rarely by shear failure criteria. However, regarding safety against shear failure, the permissible structural load on a foundation is calculated using the allowable stress method.

During a preliminary study or when checking a calculation, it is useful to know the general range of allowable bearing capacities for typical rocks or soils. There is a range of empirical methods based on in situ test results.

3- The bearing capacity of a shallow foundation

The bearing capacity of a shallow foundation can be defined as the maximum value of the load applied, for which no point of the subsoil reaches failure point (*Frolich method*) or else for which failure extends to a considerable volume of soil (*Prandtl method and successive*).

3-1 Types of Shear Failure

Shear Failure: Also called “Bearing capacity failure” and it’s occur when the shear stresses in the soil exceed the shear strength of the soil.

There are three types of shear failure in the soil:

a)General Shear Failure

b)Local Shear Failure

c)Punching Shear Failure

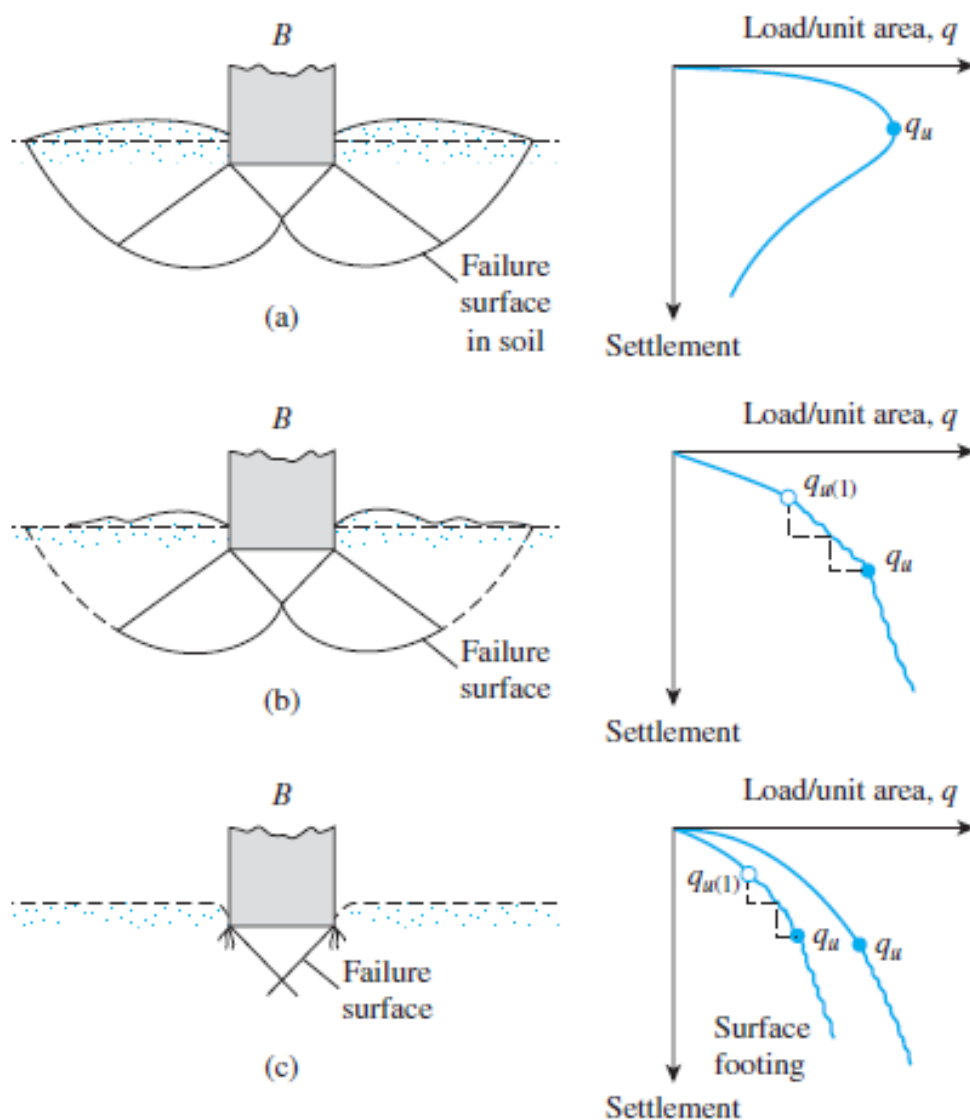


Figure: Types of Shear Failure

The following are some characteristics of general shear failure:

- Occurs over dense sand or stiff cohesive soil.
- Involves total rupture of the underlying soil.
- There is a continuous shear failure of the soil from below the footing to the ground surface (solid lines in the figure).
- When the (load / unit area) plotted versus settlement of the footing, there is a distinct load at which the foundation fails (Q_u)
- The value of (Q_u) divided by the area of the footing is considered to be the ultimate bearing capacity of the footing (q_u).
- For general shear failure, the ultimate bearing capacity has been defined as the bearing stress that causes a sudden catastrophic failure of the foundation.
- As shown in the figure, a general shear failure ruptures occur and pushed up the soil on both sides of the footing (In laboratory).

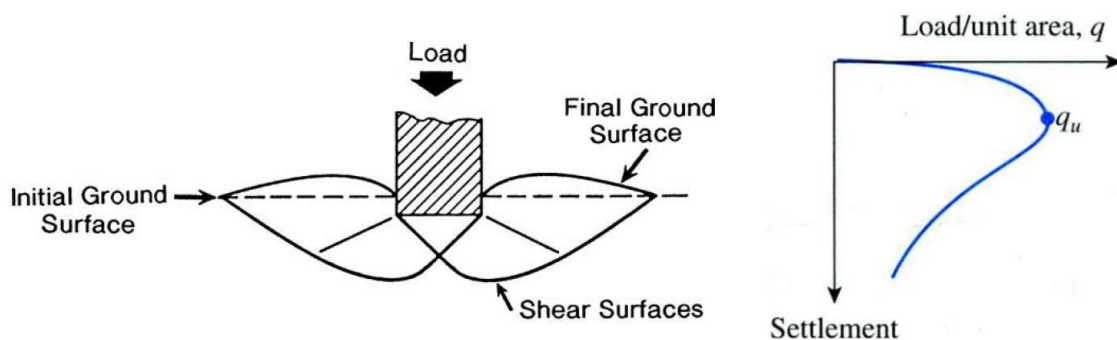


Figure:

For actual failures on the field, the soil is often pushed up on only one side of the footing with subsequent tilting of the structure as shown in figure below:

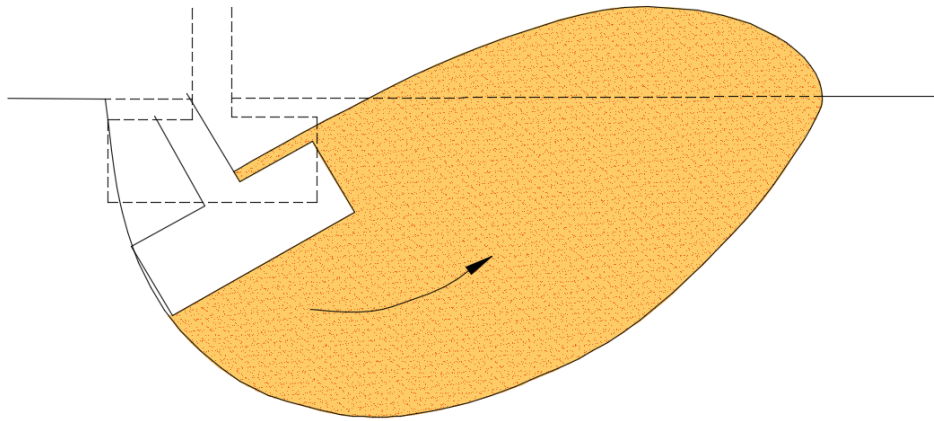


Figure:

The following are some characteristics of local shear failure:

- ☐ Occurs over sand or clayey soil of medium compaction.
- ☐ Involves rupture of the soil only immediately below the footing.
- ☐ There is soil bulging on both sides of the footing, but the bulging is not as significant as in general shear. That is because the underlying soil compacted less than the soil in general shear.
- ☐ The failure surface of the soil will gradually (not sudden) extend outward from the foundation (not the ground surface) as shown by solid lines in the figure.
- ☐ So, local shear failure can be considered as a transitional phase between general shear and punching shear.

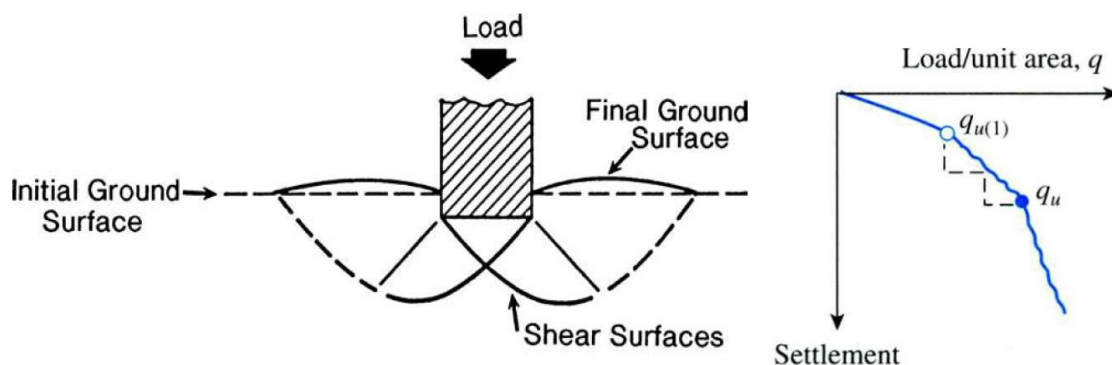


Figure:

□ Because of the transitional nature of local shear failure, the ultimate bearing capacity could be defined as the first failure load ($q_{u,1}$) which occurs at the point which has the first measure of nonlinearity in the load/unit area-settlement curve (open circle), or at the point where the settlement starts to rapidly increase (q_u) (closed circle).

□ This value of (q_u) is the required (load/unit area) to extend the failure surface to the ground surface (dashed lines in the figure).

□ In this type of failure, the value of (q_u) is not the peak value so, this failure is called (Local Shear Failure).

□ The actual local shear failure in the field is proceeded as shown in the figure below:

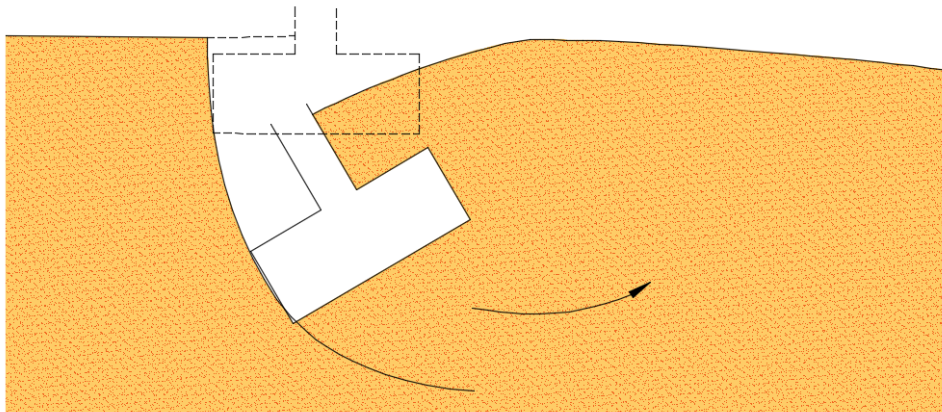


Figure:

The following are some characteristics of punching shear failure:

□ Occurs over fairly loose soil.

□ Punching shear failure does not develop the distinct shear surfaces associated with a general shear failure.

□ The soil outside the loaded area remains relatively uninvolved and there is a minimal movement of soil on both sides of the footing.

□ The process of deformation of the footing involves compression of the soil directly below the footing as well as the vertical shearing of soil around the footing perimeter.

□ As shown in figure, the (q)-settlement curve does not have a dramatic break and the bearing capacity is often defined as the first measure nonlinearity in the (q)-settlement curve ($q_{u(1)}$).

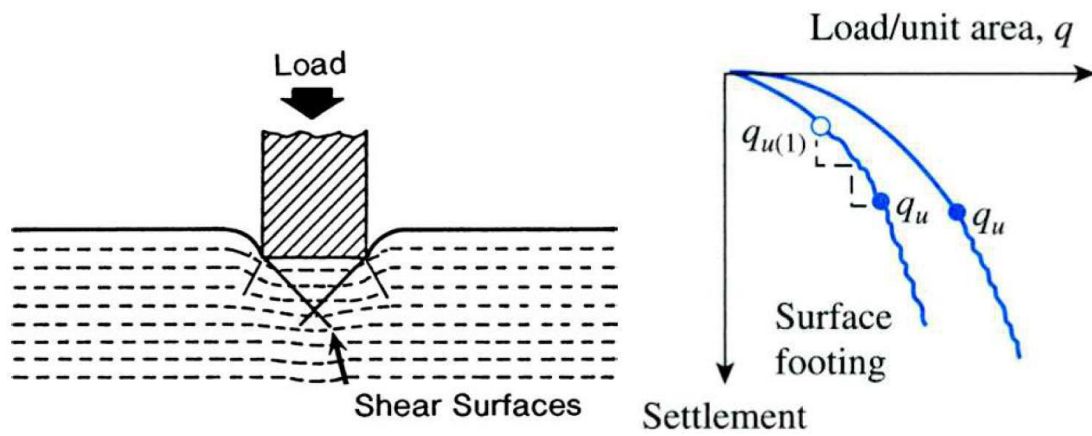
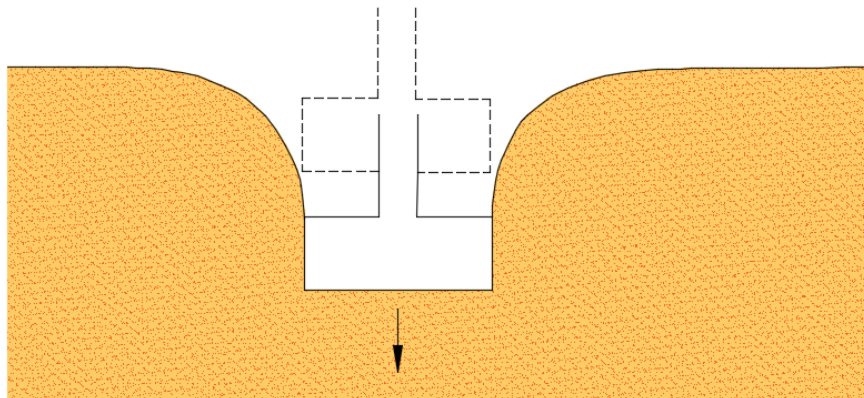


Figure:

□ Beyond the ultimate failure (load/unit area) (q_u), the (load/unit area)-settlement curve will be steep and practically linear.

□ The actual punching shear failure in field is proceed as shown in the figure below:



4- Bearing-capacity equations

Prandtl, has studied the problem of failure of an elastic half-space due to a load applied on its surface with reference to steel, characterizing the resistance to failure with a law of the type:

$$\tau = c + \sigma \cdot \tan \phi \text{ valid for soils as well}$$

Prandtl assumes:

- Weightless material, therefore $\gamma=0$;
- rigid – plastic behaviour;
- resistance to failure stated as: $\tau = c + \sigma \cdot \tan \phi$;
- uniform vertical load applied to an infinitely long strip of width $2b$ (Plane strain case);
- no tangential stresses on interface between load strip and bearing surface;
- no overload the edges of the foundation ($q'=0$).

Upon failure the yield of the material within the space $GFBCD$ is verified. Within the triangle AEB failure occurs according to two families of straight segments inclined by $45^\circ + \phi/2$ to the horizontal.

Within the triangle AEB failure occurs according to two families of straight segments inclined

by $45^\circ + \phi/2$ to the horizontal.

Within zones ABF and EBC failure occurs along two families of lines, the ones made up of straight lines passing through points A and E, and the other consisting of arcs of families of logarithmic spirals. The poles of these are points A and E. In the triangles AFG and ECD failure occurs along segments inclined at $\pm (45^\circ + \phi/2)$ to the vertical.

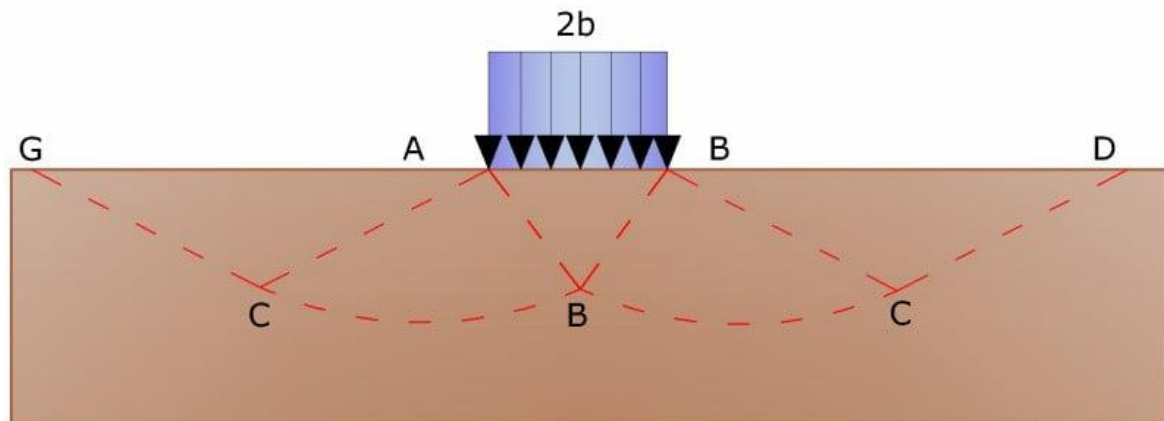


Figure: Solution of Prandtl

Having thus identified the soil tending to failure by application of the ultimate load, this can be calculated expressing the equilibrium between the forces acting in any volume of soil whose base is delimited by whichever slip surface.

Thus one reaches the equation $q = b \cdot c$, where the coefficient B depends only upon the soil's angle of friction ϕ .

$$b = \cot \phi \cdot [e^{(\pi \cdot \tan \phi)} \cdot \tan^2(45^\circ + \phi/2) - 1]$$

For $\phi = 0$ coefficient b is 5.14, and therefore $q = 5.14 \cdot c$.

In the alternate case, namely that where the soil is cohesionless ($c=0$, $\phi \neq 0$) $q=0$, so that according to Prandtl it would not be possible to apply any load to cohesionless soils.

Based on this theory, admittedly of little practical value, all the various investigations and developments have proceeded.

Caquot proceeds from the same premises as Prandtl excepting that the load strip is no longer placed on the surface but at a depth of $h \leq 2b$; the soil between surface and depth h has the following characteristics: $\gamma \neq 0$, $\phi = 0$, $c = 0$ i.e. that it is material with weight attribute but no resistance.

The equilibrium equations thus resolve to:

$$q=A\cdot\gamma_1+b\cdot c$$

which is certainly a step forward but hardly reflects reality.

4.1- Terzaghi Formula

Terzaghi (1955), continues on the same lines as Caquot but adds modifications to take into account of the real characteristics of the foundation-soil system. Under the action of the load transmitted by the foundation, the soil at the contact with the foundation tends to move laterally, but is restrained in this by the tangential resistances that develop between the soil and the foundation. This results in a change of the stress state in the ground placed directly below the foundation. Terzaghi assigns to the sides AB and EB of **Prandtl's** wedge, an inclination ψ to the horizontal, assigning to this a value as a function of the mechanical characteristics of the soil at the contact soil-foundation.

Thus $\gamma_2 = 0$ for soil below the foundation is reviewed assuming that the failure surfaces remain unaltered, the expression for ultimate load becomes:

$$q=A\cdot\gamma\cdot h+b\cdot c+C\cdot\gamma\cdot b$$

in which, is a coefficient that is a function of the angle of friction ϕ of the soil below the footing and of the angle ϕ defined above; and b is the half width of the strip..

Further on the basis of experimental data, **Terzaghi** introduces factors due to the shape of the foundation. Again **Terzaghi** refines the original hypothesis of **Prandtl** who considered the behaviour of soil as rigid-plastic. **Terzaghi** instead assigns such behaviour only to very compact soils.

In these soils the curve loads/settlements is at first linear, followed by a short curved segment (elastic-plastic behavior). Failure is instantaneous and the value of the ultimate load is easily identifiable (general failure). In a very loose soil however the relation loads/settlements has an accentuated curved line even at low levels of load due to a progressive failure of the soil (local failure) and thus the identification of ultimate load is not so clear like for compact soils.. For

very loose soils therefore Terzaghi introduces in the previous formula the reduced values for the mechanical properties of the soil:

$$\tan\phi_{rid}=(2/3)\cdot\tan\phi \text{ e } c_{rid}=(2/3)\cdot c$$

Thus **Terzaghi's** formula becomes:

Terzaghi (1943)

$$q_{ult} = c \cdot N_c \cdot s_c + \gamma \cdot D \cdot N_q + 0.5 \cdot \gamma \cdot B \cdot N_\gamma \cdot s_\gamma$$

$$N_q = \frac{a^2}{2 \cdot \cos^2(45 + \varphi/2)}$$

$$a = e^{(0.75\pi - \varphi/2) \cdot \tan \varphi}$$

$$N_c = (N_q - 1) \cdot \cot \varphi$$

$$N_\gamma = \frac{\tan \varphi}{2} \cdot \left(\frac{N_{py}}{\cos^2 \varphi} - 1 \right)$$

For:

strip

round

square

$S_c =$
1.0
1.3
1.3

$S_\gamma =$
1.0
0.6
0.8

Meyerhof (1963)

Vertical load:

$$q_{ult} = c \cdot N_c \cdot s_c \cdot d_c + \gamma \cdot D \cdot N_q \cdot d_q + 0.5 \cdot \gamma \cdot B' \cdot N_\gamma \cdot s_\gamma \cdot d_\gamma$$

$$N_q = e^{\pi \cdot \tan \varphi} \cdot \tan^2 \left(45 + \frac{\varphi}{2} \right)$$

Inclined load:

$$q_{ult} = c \cdot N_c \cdot d_c \cdot i_c + \gamma \cdot D \cdot N_q \cdot d_q \cdot i_q + 0.5 \cdot \gamma \cdot B' \cdot N_\gamma \cdot d_\gamma \cdot i_\gamma$$

$$N_c = (N_q - 1) \cdot \cot \varphi$$

$$N_\gamma = (N_q - 1) \cdot \tan(1.4 \cdot \varphi)$$

Hansen (1970)

$$q_{ult} = c \cdot N_c \cdot s_c \cdot d_c \cdot i_c \cdot g_c \cdot b_c + \gamma \cdot D \cdot N_q \cdot d_q \cdot i_q \cdot g_q \cdot b_q + 0.5 \cdot \gamma \cdot B' \cdot N_\gamma \cdot s_\gamma \cdot d_\gamma \cdot i_\gamma \cdot g_\gamma \cdot b_\gamma$$

$$\varphi = 0$$

$$q_{ult} = 5.14 \cdot c_u \cdot (1 + s'_c + d'_c - i'_c - g'_c - b'_c) + \gamma \cdot D$$

$$N_q = \text{same as Meyerhof above}$$

$$N_c = \text{same as Meyerhof above}$$

$$N_\gamma = 1.5 \cdot (N_q - 1) \cdot \tan \varphi$$

Vesic (1975)

Use Hansen equation above

$$\varphi = 0$$

$$q_{ult} = 5.14 \cdot c_u \cdot (1 + s'_c + d'_c - i'_c - g'_c - b'_c) + \gamma \cdot D$$

$$N_q = \text{same as Meyerhof above}$$

$$N_c = \text{same as Meyerhof above}$$

$$N_\gamma = 2 \cdot (N_q + 1) \cdot \tan \varphi$$

Table: *Bearing-capacity equations by the several authors indicated*

Table 4-2 Terzaghi Bearing capacity factors —Eqs. (4.15), (4.13), and (4.11).^a

ϕ'	N_c	N_q	N_γ^a	ϕ'	N_c	N_q	N_γ^a
0	5.70	1.00	0.00	26	27.09	14.21	9.84
1	6.00	1.10	0.01	27	29.24	15.90	11.60
2	6.30	1.22	0.04	28	31.61	17.81	13.70
3	6.62	1.35	0.06	29	34.24	19.98	16.18
4	6.97	1.49	0.10	30	37.16	22.46	19.13
5	7.34	1.64	0.14	31	40.41	25.28	22.65
6	7.73	1.81	0.20	32	44.04	28.52	26.87
7	8.15	2.00	0.27	33	48.09	32.23	31.94
8	8.60	2.21	0.35	34	52.64	36.50	38.04
9	9.09	2.44	0.44	35	57.75	41.44	45.41
10	9.61	2.69	0.56	36	63.53	47.16	54.36
11	10.16	2.98	0.69	37	70.01	53.80	65.27
12	10.76	3.29	0.85	38	77.50	61.55	78.61
13	11.41	3.63	1.04	39	85.97	70.61	95.03
14	12.11	4.02	1.26	40	95.66	81.27	115.31
15	12.86	4.45	1.52	41	106.81	93.85	140.51
16	13.68	4.92	1.82	42	119.67	108.75	171.99
17	14.60	5.45	2.18	43	134.58	126.50	211.56
18	15.12	6.04	2.59	44	151.95	147.74	261.60
19	16.56	6.70	3.07	45	172.28	173.28	325.34
20	17.69	7.44	3.64	46	196.22	204.19	407.11
21	18.92	8.26	4.31	47	224.55	241.80	512.84
22	20.27	9.19	5.09	48	258.28	287.85	650.67
23	21.75	10.23	6.00	49	298.71	344.63	831.99
24	23.36	11.40	7.08	50	347.50	415.14	1072.80
25	25.13	12.72	8.34				

^aFrom Kumbhojkar (1993)

The bearing capacity factors N_c , N_q , and N_γ are, respectively, the contributions of cohesion, surcharge, and unit weight of soil to the ultimate load-bearing capacity.

4.2- Meyerhof Formula

Meyerhof (1963) proposed a formula for calculation of bearing capacity similar to the one proposed by Terzaghi but introducing further foundation shape coefficients. He introduced a coefficient s_q that multiplies the N_q factor, depth factors d_i and inclination factors i_i depth factors d_i and inclination factors i_i for the cases where the load line is inclined to the vertical. Meyerhof obtained the N factors by making trials on a number of BF arcs (see *Prandtl mechanism*) whilst shear along AF was given approximate values.

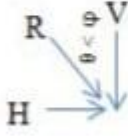
Factors	Value	For
Shape:		
	$s_c = 1 + 0.2 \cdot K_p \cdot \frac{B}{L}$	Any φ
	$s_q = s_\gamma = 1 + 0.1 \cdot K_p \cdot \frac{B}{L}$	$\varphi > 0$
	$s_q = s_\gamma = 1$	$\varphi = 0$
Depth:		
	$d_c = 1 + 0.2 \cdot \sqrt{K_p} \cdot \frac{D}{B}$	Any φ
	$d_q = d_\gamma = 1 + 0.1 \cdot \sqrt{K_p} \cdot \frac{D}{B}$	$\varphi > 0$
	$d_q = d_\gamma = 1$	$\varphi = 0$
Inclination:		
	$i_c = i_q = \left(1 - \frac{\theta^\circ}{90^\circ}\right)^2$	Any φ
	$i_\gamma = \left(1 - \frac{\theta^\circ}{\varphi^\circ}\right)^2$	$\varphi > 0$
	$i_\gamma = 0 \text{ for } \theta > 0$	$\varphi = 0$

Table: Shape, depth, and inclination factors for the Meyerhof bearing-capacity

Vesic (1975) proposes a formula that is analogous to **Hansen's** with N_q ed N_c as per Meyerhof and N_γ as below:

$$N_\gamma = 2 \cdot (N_q + 1) \cdot \tan \varphi$$

Shape and depth factors are the same as Hansen's but there are differences in load inclination, ground inclination and footing inclination factors.

Shape factors	Depth factors
$s'_{c(H)} = 0.2 \cdot \frac{B'}{L'} \quad (\varphi = 0)$	$d'_c = 0.4 \cdot k \quad (\varphi = 0^\circ)$
$s_{c(H)} = 1 + \frac{N_q}{N_c} \cdot \frac{B'}{L'}$	$d_c = 1 + 0.4 \cdot k$
$s_{c(V)} = 1 + \frac{N_q}{N_c} \cdot \frac{B}{L}$	$k = D/B \text{ for } D/B \leq 1$ $k = \tan^{-1}(D/B) \text{ for } D/B > 1$
$s_c = 1 \text{ for strip}$	$k \text{ in radians}$
$s_{q(H)} = 1 + \frac{B'}{L'} \cdot \sin \varphi$	$d_q = 1 + 2 \cdot \tan \varphi \cdot (1 - \sin \varphi)^2 \cdot k$
$s_{q(V)} = 1 + \frac{B}{L} \cdot \tan \varphi$	$k \text{ defined above}$
for all φ	
$s_{\gamma(H)} = 1 - 0.4 \cdot \frac{B'}{L'} \geq 0.6$	$d_\gamma = 1 \text{ for all } \varphi$
$s_{\gamma(V)} = 1 - 0.4 \cdot \frac{B}{L} \geq 0.6$	

*Shape and depth factors for use in either the Hansen (1970)
or Vesic (1975) bearing-capacity equations.*

Inclination factors	Ground factors (base on slope)
$i'_c = 0.5 - \sqrt{1 - \frac{H_i}{A_f \cdot C_a}}$	$g'_c = \beta^\circ / 147^\circ$ $g_c = 1 - \beta^\circ / 147^\circ$
$i_c = i_q - \frac{1 - i_q}{N_q - 1}$	$g_q = g_\gamma = (1 - 0.5 \cdot \tan \beta)^5$
$i_q = \left[1 - \frac{0.5 \cdot H_i}{V + A_f \cdot c_a \cdot \cot \varphi} \right]^{\alpha_1}$ $2 \leq \alpha_1 \leq 5$	Base factors (tilted base)
$i_\gamma = \left[1 - \frac{0.7 \cdot H_i}{V + A_f \cdot c_a \cdot \cot \varphi} \right]^{\alpha_2}$	$b'_c = \beta^\circ / 147^\circ \quad (\varphi = 0)$ $b_c = 1 - \beta^\circ / 147^\circ \quad (\varphi > 0)$
$i_\gamma = \left[1 - \frac{(0.7 - \eta^\circ / 450^\circ) \cdot H_i}{V + A_f \cdot c_a \cdot \cot \varphi} \right]^{\alpha_2}$ $2 \leq \alpha_2 \leq 5$	$b_q = \exp(-2\eta \tan \varphi)$ $b_\gamma = \exp(-2.7\eta \tan \varphi)$ $\eta \text{ in radians}$

Table of inclination, ground, and base factors for the Hansen (1970) equations

Inclination factors	Ground factors (base on slope)
$i'_c = 1 - \frac{m \cdot H_i}{A_f \cdot c_a \cdot N_c} \quad (\varphi = 0)$	$g'_c = \beta / 5.14 \quad \beta \text{ in radians}$ $g_c = 1 - \frac{1 - i_q}{5.14 \cdot \tan \varphi} \quad \varphi > 0$ i_q defined with i_c
$i_c = i_q - \frac{1 - i_q}{N_q - 1} \quad (\varphi > 0)$ i_q , and m defined below	$g_q = g_\gamma = (1 - 0.5 \cdot \tan \beta)^2$
$i_q = \left[1 - \frac{H_i}{V + A_f \cdot c_a \cdot \cot \varphi} \right]^m$	Base factors (tilted base)
$i_\gamma = \left[1 - \frac{H_i}{V + A_f \cdot c_a \cdot \cot \varphi} \right]^{m+1}$	$b'_c = g'_c \quad (\varphi = 0)$ $b_c = 1 - 2 \cdot \beta / (5.14 \cdot \tan \varphi)$ $b_q = b_\gamma = (1 - \eta \tan \varphi)^2$
$m = m_B = \frac{2 + B/L}{1 + B/L}$ $m = m_L = \frac{2 + L/B}{1 + L/B}$	

Table of inclination, ground, and base factors for the Vesic (1975) equations

Brich-Hansen (EC7-EC8) “In order that a foundation may safely sustain the projected load in regard to general failure for all combinations of load relative to the ultimate limit state, the following must be satisfied:

$$V_d \leq R_d$$

Where V_d the design load at ultimate limit state normal to the footing, including the weight of the foundation it self and R_d is the foundation design bearing capacity for normal loads, also taking into account eccentric and inclined loads. When estimating R_d for fine grained soils short

and long term situations should be considered.”

Bearing capacity **in drained conditions** is calculated by:

$$R/A' = (2 + \pi) \cdot c_u \cdot s_c \cdot i_c + q$$

Where:

$A' = B' \cdot L'$ design effective foundation area. Where eccentric loads are involved, use the reduced area at whose center the load is applied.

c_u undrained cohesion

q total lithostatic pressure on bearing surface

s_c foundation shape factor

$s_c = 1 + 0,2 (B'/L')$ rectangular shapes

$s_c = 1,2$ square or circular shapes

i_c correction factor for inclination due to a load H

$$i_c = 0,5 \cdot [1 + (1 - H/(A' \cdot c_u))^{0,5}]$$

Design bearing capacity in **drained conditions** is calculated as follows:

$$R/A' = c' \cdot N_c \cdot s_c \cdot i_c + q' \cdot N_q \cdot s_q \cdot i_q + 0,5 \cdot g' \cdot B' \cdot N_g \cdot s_g \cdot i_g$$

Where:

N_c = same as Meyerhof (1963) above

N_q = same as Meyerhof (1963) above

$N_\gamma = 2 \cdot (N_q - 1) \cdot \tan \phi$

Shape factors

$s_q = 1 + (B'/L') \cdot \sin \phi'$ rectangular shape

$s_q = 1 + \sin \phi'$ square or circular shape

$s_\gamma = 1 - 0,3 \cdot (B'/L')$ rectangular shape

$s_\gamma = 0,7$ square or circular shape

$s_c = (s_q \cdot N_q - 1) / (N_q - 1)$ rectangular, square, or circular shape.

In addition to the correction factors reported in the table above will also be considered the ones complementary to the depth of the bearing surface and to the inclination of the bearing surface and ground surface (Hansen).

5- Sliding considerations

The stability of a foundation should be verified with reference to collapse due to sliding as well as to general failure. For collapse due to sliding, the resistance is calculated as the sum of the adhesion component and the soil-foundation friction component. Lateral resistance arising from passive thrust of the soil can be taken into account using a percentage supplied by the user. Resistance due to friction and adhesion is calculated with the expression:

$$F_{Rd} = N_{sd} \cdot \tan \delta + c_a \cdot A'$$

In which N_{sd} is the value of the vertical force, δ is the angle of shearing resistance at the base of the foundation, c_a is the foundation-soil adhesion, and A' is the effective foundation area. There where eccentric loads are involved, use the reduced area at whose centre the load is applied.

6- Bearing capacity for foundations on rock

Where foundations rest on rock, it is appropriate to take into consideration certain other significant parameters such as the geologic characteristics, type of rock and its quality measured as **RQD**. It is the practice to use very high values of safety factor for bearing capacity of rock and correlated in some way with the value of **RQD** (*Rock quality designator*). For example for a rock whose **RQD** is up to a maximum of 0.75 the safety factor oscillates between 6 and 10. Terzaghi's formula can be used in calculation of rock bearing capacity using friction angle and cohesion of the rock or those proposed by Stagg and **Zienkiewicz (1968)** according to which the coefficients of the bearing capacity are:

$$N_q = \tan^6(45 + \phi/2)$$

$$N_c = 5 \cdot \tan^4(45 + \phi/2)$$

$$N_\gamma = N_q + 1$$

These coefficients should be used with form factors from the formula of Terzaghi. Ultimate bearing capacity is a function of RQD as follows:

$$q' = q_{ult}(RQD)^2$$

If rock coring does not render whole pieces (RQD tends to 0) the rock is treated as a soil estimating as best the factors: c and ϕ .

7- Exercices

Exercise 1: Shallow Foundation on Clayey Soil

Problem: A rectangular footing $2 \text{ m} \times 3 \text{ m}$ is placed at a depth of 1.5 m on a clayey soil with $\gamma = 18 \text{ kN/m}^3$, $c = 40 \text{ kPa}$, and $\phi = 0^\circ$. Determine the ultimate bearing capacity and allowable bearing capacity if the factor of safety is 3.

Solution

Given:

- $B = 2 \text{ m}, L = 3 \text{ m}, D_f = 1.5 \text{ m}$
- $\gamma = 18 \text{ kN/m}^3, c = 40 \text{ kPa}, \phi = 0^\circ$
- $N_c = 5.7, N_q = 1, N_\gamma = 0$

Using Terzaghi's formula for ultimate bearing capacity:

$$q_{ult} = cN_c + \gamma D_f N_q$$

$$q_{ult} = 40 \times 5.7 + 18 \times 1.5 \times 1 = 228 + 27 = 255 \text{ kPa}$$

Allowable bearing capacity:

$$q_{allow} = \frac{q_{ult}}{FS} = \frac{255}{3} = 85 \text{ kPa}$$

Exercise 2: Strip Foundation on Sand

Problem: A strip foundation 1.5 m wide is placed at 1.2 m depth in dry sand with $\gamma = 19 \text{ kN/m}^3$, $\phi = 30^\circ$, and $c = 0$. Calculate the ultimate bearing capacity using the following bearing capacity factors: $N_c = 30.14$, $N_q = 18.40$, and $N_\gamma = 15.70$.

Solution

Given:

- $B = 1.5 \text{ m}$, $D_f = 1.2 \text{ m}$
- $\gamma = 19 \text{ kN/m}^3$, $\phi = 30^\circ$, $c = 0$
- $N_c = 30.14$, $N_q = 18.40$, $N_\gamma = 15.70$

Using Terzaghi's formula:

$$q_{ult} = \gamma D_f N_q + \frac{1}{2} \gamma B N_\gamma$$
$$q_{ult} = 19 \times 1.2 \times 18.40 + \frac{1}{2} \times 19 \times 1.5 \times 15.7$$
$$q_{ult} = 419.04 + 224.18 = 643.22 \text{ kPa}$$

Allowable bearing capacity:

$$q_{allow} = \frac{q_{ult}}{FS} = \frac{643.22}{3} = 214.41 \text{ kPa}$$

Exercise 3: Strip Foundation on Cohesive Soil

Problem: A strip footing 2 m wide is placed at a depth of 1.5 m in saturated cohesive soil. The soil has the following properties: $\gamma = 18 \text{ kN/m}^3$, $c = 50 \text{ kPa}$, and $\phi = 15^\circ$. Calculate the ultimate and allowable bearing capacities assuming a factor of safety of 3. Use $N_c = 12.86$, $N_q = 4.40$, and $N_\gamma = 2.47$.

Solution

Using Terzaghi's formula for ultimate bearing capacity:

$$q_{ult} = cN_c + \gamma D_f N_q + \frac{1}{2} \gamma B N_\gamma$$

Substitute the given values:

$$q_{ult} = 50 \times 12.86 + 18 \times 1.5 \times 4.40 + \frac{1}{2} \times 18 \times 2 \times 2.47$$

$$q_{ult} = 643 + 118.8 + 44.46 = 806.26 \text{ kPa}$$

Allowable bearing capacity:

$$q_{allow} = \frac{q_{ult}}{3} = \frac{806.26}{3} = 268.75 \text{ kPa}$$

Exercise 4: Circular Foundation on Sandy Soil

Problem: A circular footing of diameter 1.5 m is placed at a depth of 1 m in dry sandy soil with the following properties: $\gamma = 19 \text{ kN/m}^3$, $\phi = 35^\circ$, and $c = 0$. Bearing capacity factors: $N_c = 57.8$, $N_q = 41.4$, and $N_\gamma = 42.4$. Determine the ultimate bearing capacity.

Solution

For a circular footing, Terzaghi's formula for ultimate bearing capacity is:

$$q_{ult} = \gamma D_f N_q + 0.3 \gamma B N_\gamma$$

Substitute the values:

$$\begin{aligned} q_{ult} &= 19 \times 1 \times 41.4 + 0.3 \times 19 \times 1.5 \times 42.4 \\ q_{ult} &= 786.6 + 361.26 = 1147.86 \text{ kPa} \end{aligned}$$

If a factor of safety of 3 is used, the allowable bearing capacity is:

$$q_{allow} = \frac{q_{ult}}{3} = \frac{1147.86}{3} = 382.62 \text{ kPa}$$

Exercise 5: Rectangular Foundation on Cohesive Soil

Problem: A rectangular footing $2 \text{ m} \times 4 \text{ m}$ is placed at a depth of 1.2 m in cohesive soil. The soil has $\gamma = 17 \text{ kN/m}^3$, $c = 30 \text{ kPa}$, and $\phi = 10^\circ$. Calculate the ultimate bearing capacity and allowable bearing capacity with a factor of safety of 3. Use $N_c = 12.1$, $N_q = 3.29$, and $N_\gamma = 1.32$

Solution

Use Terzaghi's formula for ultimate bearing capacity:

$$q_{ult} = cN_c + \gamma D_f N_q + \frac{1}{2} \gamma B N_\gamma$$

Substitute the given values:

$$\begin{aligned} q_{ult} &= 30 \times 12.1 + 17 \times 1.2 \times 3.29 + \frac{1}{2} \times 17 \times 2 \times 1.32 \\ q_{ult} &= 363 + 67.15 + 22.44 = 452.59 \text{ kPa} \end{aligned}$$

Allowable bearing capacity:

$$q_{allow} = \frac{q_{ult}}{3} = \frac{452.59}{3} = 150.86 \text{ kPa}$$

Exercise 6: Square Footing on Sand

Problem: A square footing with dimensions $1.8 \text{ m} \times 1.8 \text{ m}$ is placed at a depth of 1 m in dry sand. The properties of the soil are: $\gamma = 19.5 \text{ kN/m}^3$, $c = 0$, and $\phi = 35^\circ$. Bearing capacity factors are $N_c = 57.8$, $N_q = 41.4$, and $N_\gamma = 42.4$. Find the ultimate bearing capacity.

Solution

For a square footing, use Terzaghi's formula for ultimate bearing capacity:

$$q_{ult} = \gamma D_f N_q + 0.4 \gamma B N_\gamma$$

Substitute the values:

$$q_{ult} = 19.5 \times 1 \times 41.4 + 0.4 \times 19.5 \times 1.8 \times 42.4$$

$$q_{ult} = 807.3 + 595.9 = 1403.2 \text{ kPa}$$

If a factor of safety of 3 is used:

$$q_{allow} = \frac{1403.2}{3} = 467.7 \text{ kPa}$$

Exercise 7: Rectangular Footing on Saturated Soil

Problem: A rectangular footing $1.5 \text{ m} \times 3 \text{ m}$ is placed at a depth of 1 m in saturated sandy soil with the following properties: $\gamma = 19 \text{ kN/m}^3$, $\phi = 20^\circ$, and $c = 10 \text{ kPa}$. Use $N_c = 17.7$, $N_q = 7.4$, and $N_\gamma = 3.9$. Determine the ultimate bearing capacity.

Solution

Use Terzaghi's formula:

$$q_{ult} = cN_c + \gamma D_f N_q + \frac{1}{2} \gamma B N_\gamma$$

Substitute the values:

$$q_{ult} = 10 \times 17.7 + 19 \times 1 \times 7.4 + \frac{1}{2} \times 19 \times 1.5 \times 3.9$$

$$q_{ult} = 177 + 140.6 + 55.575 = 373.175 \text{ kPa}$$

Allowable bearing capacity:

$$q_{allow} = \frac{q_{ult}}{3} = 124.39 \text{ kPa}$$

Exercise 8: The load-bearing capacity of foundations

We consider a 3m wide continuous foundation, embedded 1m into a ground with the following characteristics:

$$Y = 19 \text{ kN/m}^3; c_u = 40 \text{ kPa}; c' = 20 \text{ kPa}; \theta = 30^\circ$$

Calculate the limit bearing capacity q_l and the permissible bearing capacity q_{adm} of the strip footing in the following cases:

- Fast Charging (Drained Conditions)
- Slow loading (Undrained conditions)

NB: Take the safety coefficient $F_s = 3$

ϕ°	0	5	10	15	20	25	30	35	40	45	50
N_c	5,14	6,49	8,34	10,98	14,83	20,72	30,14	46,02	75,31	133,87	266,88
N_γ	0	0,09	0,47	1,42	3,54	8,11	18,10	41,10	100,00	254,00	758,09
N_q	1,00	1,57	2,47	3,94	6,40	10,66	18,40	33,30	64,20	134,87	319,06

CHAPTER 3: TYPES OF REINFORCED CONCRETE CONSTRUCTION

Introduction

In a reinforced concrete structure, the main steels are positioned in the tensioned parts of the concrete to compensate for the poor tensile strength of the concrete. For a reinforced concrete slab, for example, the main reinforcements are placed in the lower part of the spans and in the upper part at the supports.

1- Material characteristics

The objective of this part is to present the main characteristics of the materials used in Reinforced Concrete. Reinforced Concrete is an element mixed by several materials. It is constituted by the meeting of two materials that we suppose simple; it is concrete and steel, arranged in a way to use economically the resistance of each of them.

1.1- Concrete

- Definition and composition of concrete

Reinforced concrete is a judicious marriage of materials with complementary characteristics (see Figure....). Concrete does not resist traction well, on the other hand steel resists both traction and compression, the principle of reinforced concrete is to insert steel sections in the tense areas of the concrete. This association is effective because:

- The coefficient of thermal expansion of the two materials is of the same order of magnitude ($\alpha_{\text{concrete}} = 10.10^{-6}$ and $\alpha_{\text{steel}} = 11.10^{-6}$).
- Steel adheres well to concrete, which allows forces to be transmitted from one material to the other.

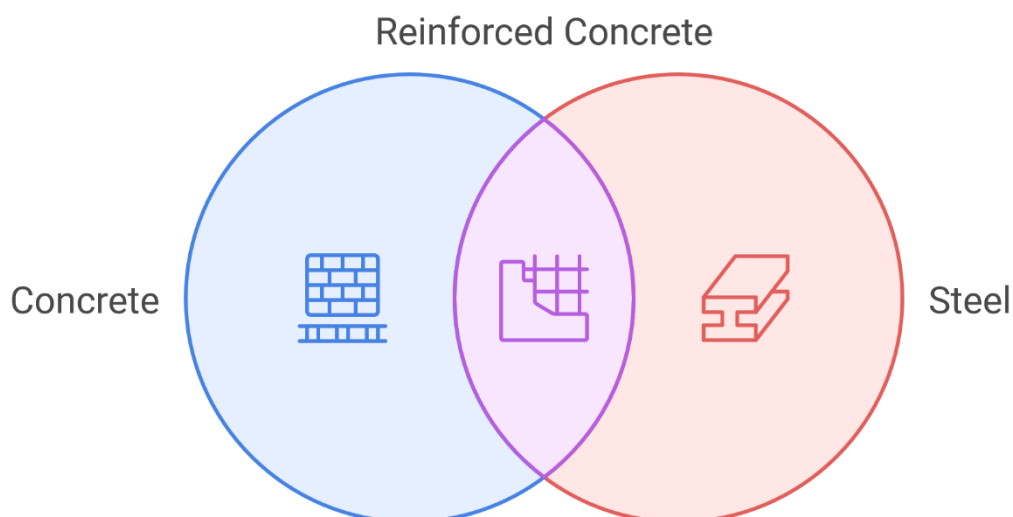


Figure: The Synergy of Reinforced Concrete

Qualities sought for good concrete

- High mechanical resistance (25-40 MPa).
- Waterproof and no chemical reaction with steel.
- Good implementation (easy to pour).
- Good resistance over time

These results will be obtained by playing on the following parameters:

- Cement and aggregate quality.
- The dosage (quantity).
- A good mix (homogeneity).

- **Physical and mechanical characteristics of concrete**

A- Density

- The density of concrete with common aggregates (normal) == 2200 , 2400 kg/m³
- The density of lightweight aggregate concrete == 700 , 1500 kg/m³
- The density of heavy aggregate concrete == 3500 , 4000 kg/m³
- The density of reinforced concrete == 2500 kg/m³

B- Concrete deformations independent of applied loads

1. Thermal deformation: The coefficient of expansion of concrete varies from 7.10^{-6} to 12.10^{-6}

and the coefficient of expansion of steel is 11.10^{-6} , hence reinforced concrete 10.10^{-6} .

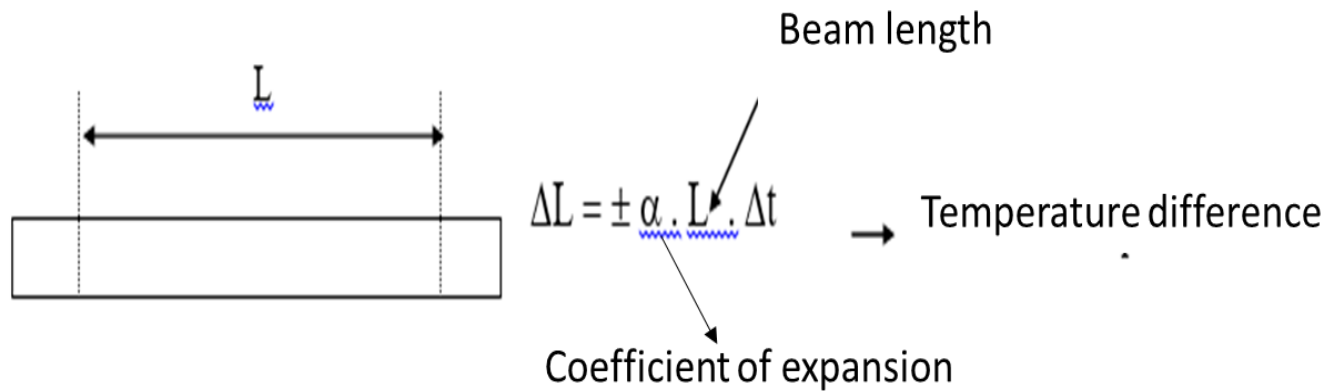


Figure: Beam thermal deformation

- Hygrometric withdrawal: concrete after its preparation (manufacturing) contains an excess of water, if the hardening is done in the open air the water will evaporate. This evaporation is automatically accompanied by a decrease in volume. This decrease is called: shrinkage.
- Factor and influence of withdrawal: the withdrawal increases with:
 - The proportion of thin elements: the shrinkage increases if the element is thin.
 - The amount of cement: the shrinkage increases if the amount of cement increases.
 - Addition of adjuvants: more water to react.
 - Dryness of the air: the drier the climate, the more shrinkage there is.

For standard constructions, the effects of temperature variation and shrinkage will be neglected if expansion joints are provided every 20 to 30 meters.

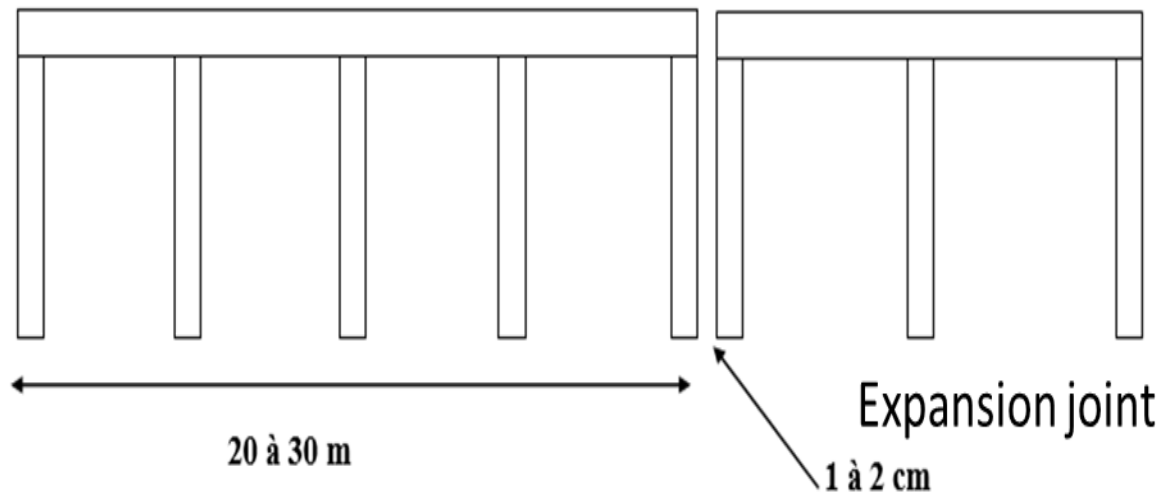


Figure: Hygrometric withdrawal

- Concrete as a structural material

This table below – “Concrete as a Structural Material” – provides general information on concrete, valid for the material in all its forms in structural application.

Description	• Concrete is a composite building material made from natural aggregates (sand, gravel) or artificial aggregates (lightweight aggregates) agglomerated by a binder, most often cement. When it is combined with metal reinforcements, it is called reinforced concrete. It can also be prestressed. • It can also be treated with adjuvants to make it water-repellent (it then becomes	• The addition of different materials (textile fibers, wood chips, plastics, etc.) makes it possible to modify its physical properties. • Cast or “formed” (i.e. cast in formwork: a removable mold set up on site and dismantled after setting), concrete can take any shape.
--------------------	--	---

	waterproof, preventing rising damp).	
Prescription	• The prescription of concrete must follow the standards NBN EN 206-01:2001 and NBN B 15-001:2004. • It is necessary to determine its resistance class, the area of use, the environmental class, the consistency class and the maximum nominal dimension. • These parameters are the responsibility of the stability engineer.	
Use	• sails (walls) • beams • slabs • floors	• posts / columns • vaults • shells (shotcrete)
	A distinction should be made between cast-in-place concrete and prefabricated elements.	
Benefits	• Very wide range of shapes and products • High compressive strength • High tensile strength in case of reinforced concrete • Very good fire resistance • Very long life span • Recyclable (crushing) • Very good acoustic performance • High mass: significant contribution to the building's inertia • High dimensional accuracy • Waste control on construction sites • Large ranges possible • No impact on the health of building occupants (does not release VOCs) • For prefabricated elements: • Speed of implementation • Cost	

	• Waste control on construction sites	
Disadvantages	• Products with significant grey energy • Self-build implementation severely limited • For cast-in-place concrete: • Implementation time (formwork, pouring, vibration, drying time) • Not dismountable: demolition required at end of life • For prefabricated elements: • Their implementation generally requires the use of lifting equipment • Disassembly dependent on a thorough study, from the design stage, of the assembly details and techniques and the choice of products	
Finishing	• Concrete can be mass-tinted by incorporating natural pigments or metallic oxides.	• Its facing can be smoothed or worked, cement concrete is sometimes left exposed (“rough”) for its minimalist, raw and modern appearance.
Theoretical lifespan	• 100 years	
End of life	• Preferred: Reuse of complete element (attention: precise study of details and assembly techniques required) • Second choice: recycling (crushing) • To avoid: Landfilling	

1.2- Steel

It is the alloy of iron and carbon. We distinguish between soft steels, medium-hard steels and hard steels.

- Mild steel == % carbon 0.15 - 0.25%
- Medium hard and hard steel == % carbon 0.25 - 0.45%

Reinforced concrete is the material obtained by adding steel bars to concrete. These steel bars are generally called reinforcements.

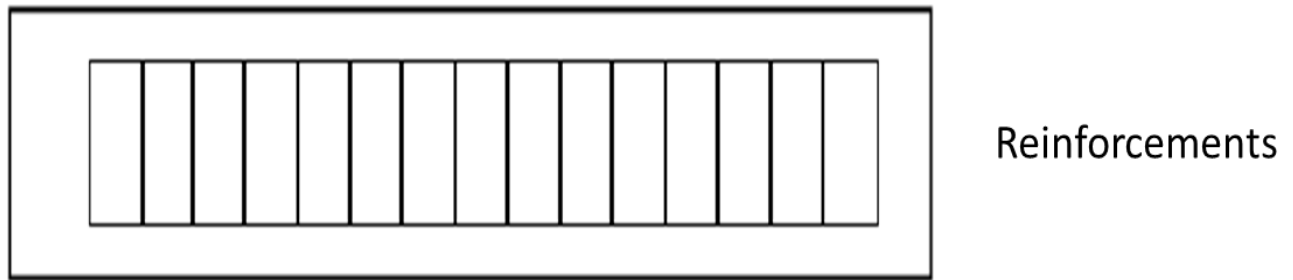


Figure : Reinforced concrete

In the concrete + steel combination, the concrete resists the compressive forces and the steel resists the tensile forces and possibly the compressive forces if the concrete is not sufficient to take all the compressive forces that exist.

- Concrete = Compression (Compressive strength = 20 MPa to 40MPa) (Tensile strength = 2 MPa to 4MPa)
- Steel = Tension or compression (200 MPa to 500 MPa)

A construction will be called reinforced concrete if the two materials contribute to the resistance of the whole.

- Advantages and disadvantages of reinforced concrete

A- Benefits

- **Economic interest:** Concrete is the least expensive material that resists compression and can be combined with other elements.
- It is said that steel is currently the only material used in the manufacture of reinforcement because its resistance is lower than that of materials that can be resisted to tension.
- **Flexibility of use:** the concrete being placed (in molds: formwork) in a pasty state; it is possible to make constructions with the most varied shapes and the

reinforcements can be easily linked. The assemblies between different concrete elements are made by simple contact.

- Reinforced concrete is easily processed during pre-fabrication in the factory.
- **Maintenance savings:** Reinforced concrete constructions require no maintenance while metal constructions need to be painted regularly.
- **Fire resistance:** Reinforced concrete constructions behave much better in case of fire than metal or wooden constructions. Concrete, thanks to its poor thermal conductivity, delays the effects of heat on the reinforcements, it is possible to put the construction back into service after superficial repairs, which is impossible for metal constructions. This property has made it possible to use reinforced concrete in some parts of the furnaces.
- **Resistance to accidental forces:** Reinforced concrete, due to its significant weight, is less sensitive to variations in overloads than other construction methods.
- **Sustainability :** Reinforced concrete resists the action of water and air well, the only condition to be observed is the protection of the reinforcements.

B- The disadvantages of reinforced concrete

- **Weight:** reinforced concrete structures are heavier than other construction methods.
- **Execution:** To carry out a reinforced concrete work, you must:
 - Formwork preparation that requires a lot of time and significant structural work. This formwork must remain in place until the concrete reaches sufficient strength.
 - placement of reinforcements
 - During and after concrete placement, precautions must be taken to protect it from freezing and water evaporation.
 - Quality control of the material improved during mixing.
- **Brutality of accidents:** Accidents that occur in reinforced concrete structures are generally sudden or brutal, and are generally due to calculation or construction errors.

- **Difficulty in modifying a work already completed:** It is difficult to modify an element already made.

- Principle of Reinforced Concrete

Concrete has very low tensile strength. On the other hand, steel has very good tensile strength. Also, the principle underlying reinforced concrete is to insert steel into the concrete matrix in the tense areas.

A- Case of the tie rod (N in tension): The entire concrete section is tensioned, the longitudinal steels alone take up the tensile force (the concrete only has a coating function).

B- Column case (N in compression) : the concrete section is generally compressed, the presence of longitudinal steel only reinforces the resistance of the post.

C- Case of the bending beam (M and V present): Longitudinal steels are inserted in the tensioned zone of the beam to take up the effect of M. Transverse steels take up the shear force V. They are also called seam steels.

D- Cauchy's reciprocity theorem: Consider a beam resting on two supports subjected to a vertical force P. Figure 2-1 shows the shape of the shear force and bending moment diagram.

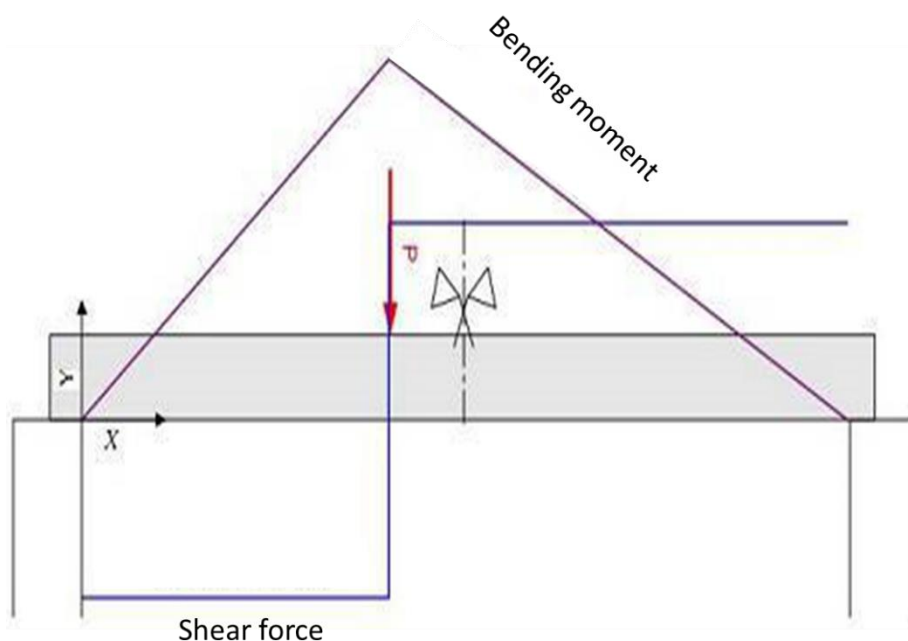


Figure : V and M stresses in a beam subjected to simple bending

Let us now look at a small beam cube (Figure) by isolating it and taking stock of the actions. This cube, like the beam in general, is in equilibrium. The sum of the forces and the sum of the moments must therefore be zero.

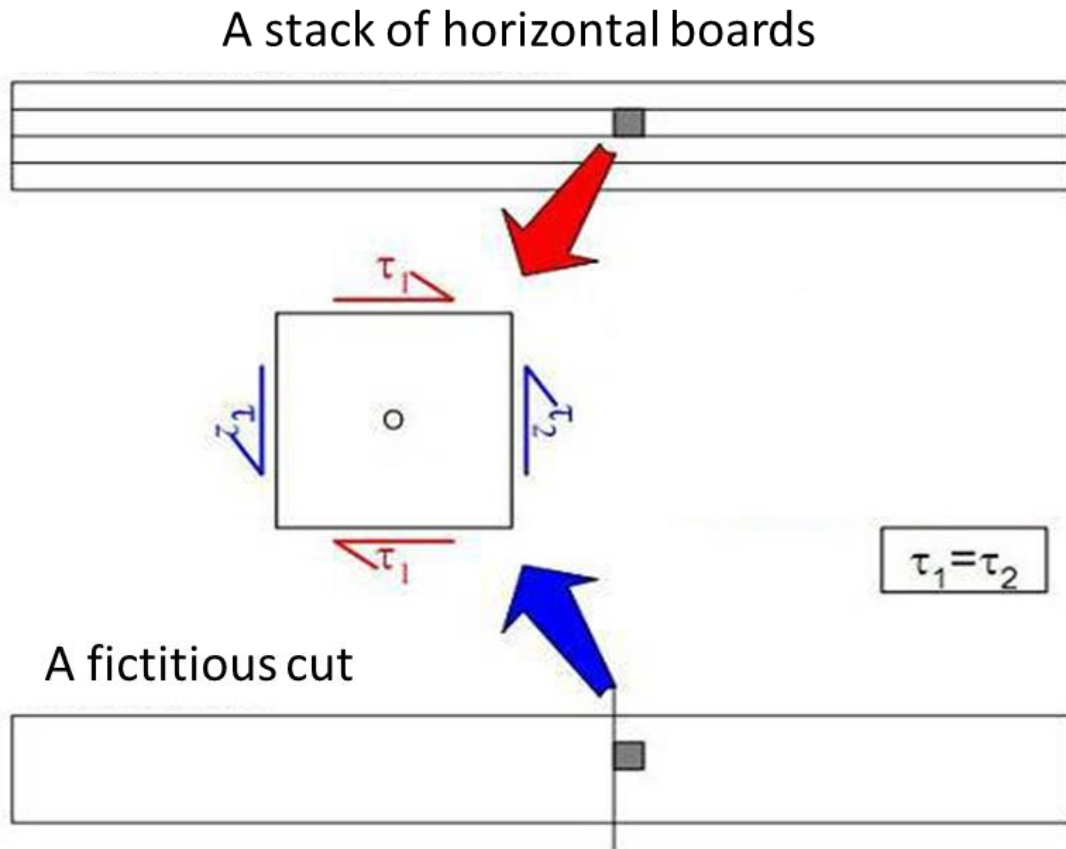


Figure : Cauchy's Theorem

Figure 2-2 highlights Cauchy's theorem: namely, there is equality of the tangential stresses on the 4 sides of the cube with the direction of these stresses specified in this same figure.

- **Highlighting the need for sewing steels**

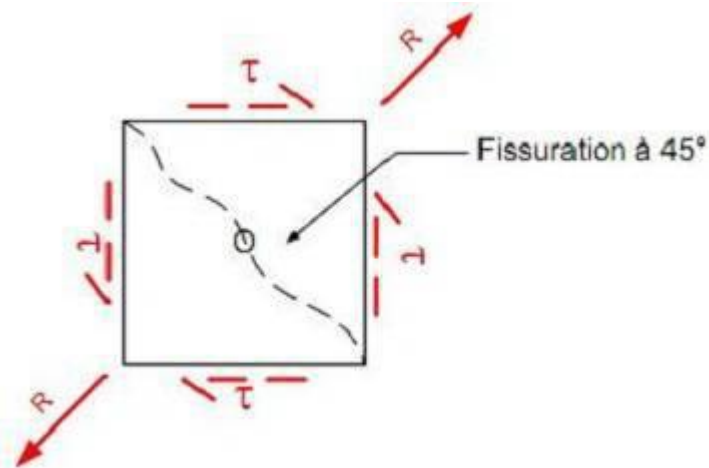


Figure 2-3 - Demonstration of the need for sewing steels

Taking into account Cauchy's theorem, the resultant of the tangential stresses shows that in the concrete a crack will appear at 45°.

This crack must be sewn with steels perpendicular to it. In reality, it is not very practical to arrange the steels at 45°. Also, in the majority of cases, the steels are positioned vertically.

2- Reinforced Concrete Frames

2.1- General definitions

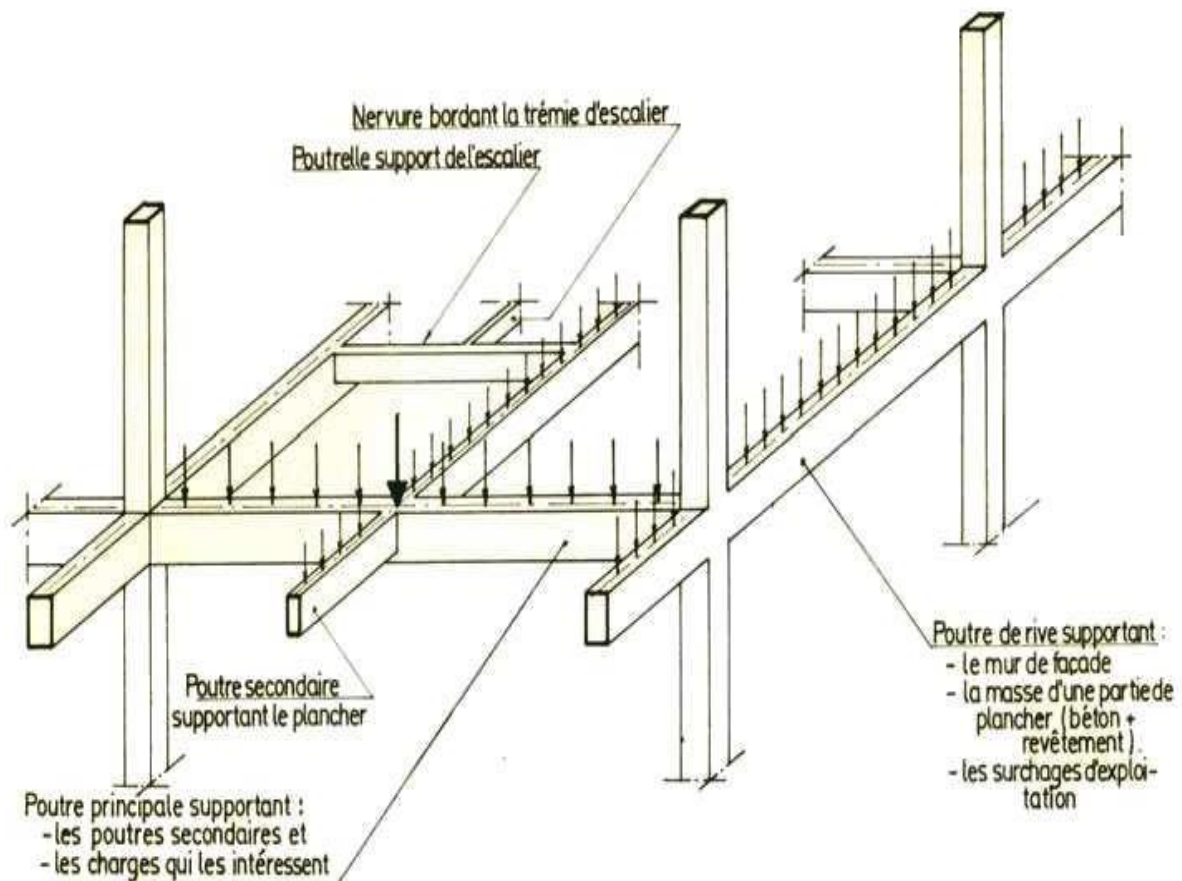
In some medium-sized constructions, a skeleton called a framework is made on which the floors will rest. This skeleton is made up of a series of beams and bracing posts. Between these resistant elements made up of the framework, a filling is made of bricks, stones, glass, steel (corrugated sheet metal) which only has an insulating function to ensure.

The load-bearing element is the element of a construction which serves to absorb the vertical forces due to the self-weight of the various constituent elements and to vertical overloads (mainly operational) and to transmit them to the ground via the foundations.

2.2- Reinforced concrete frames

The association of vertical and horizontal elements is called a frame. The frame

has the function of resisting vertical forces generated by permanent loads, operating overloads and horizontal forces due to winds and earthquakes.

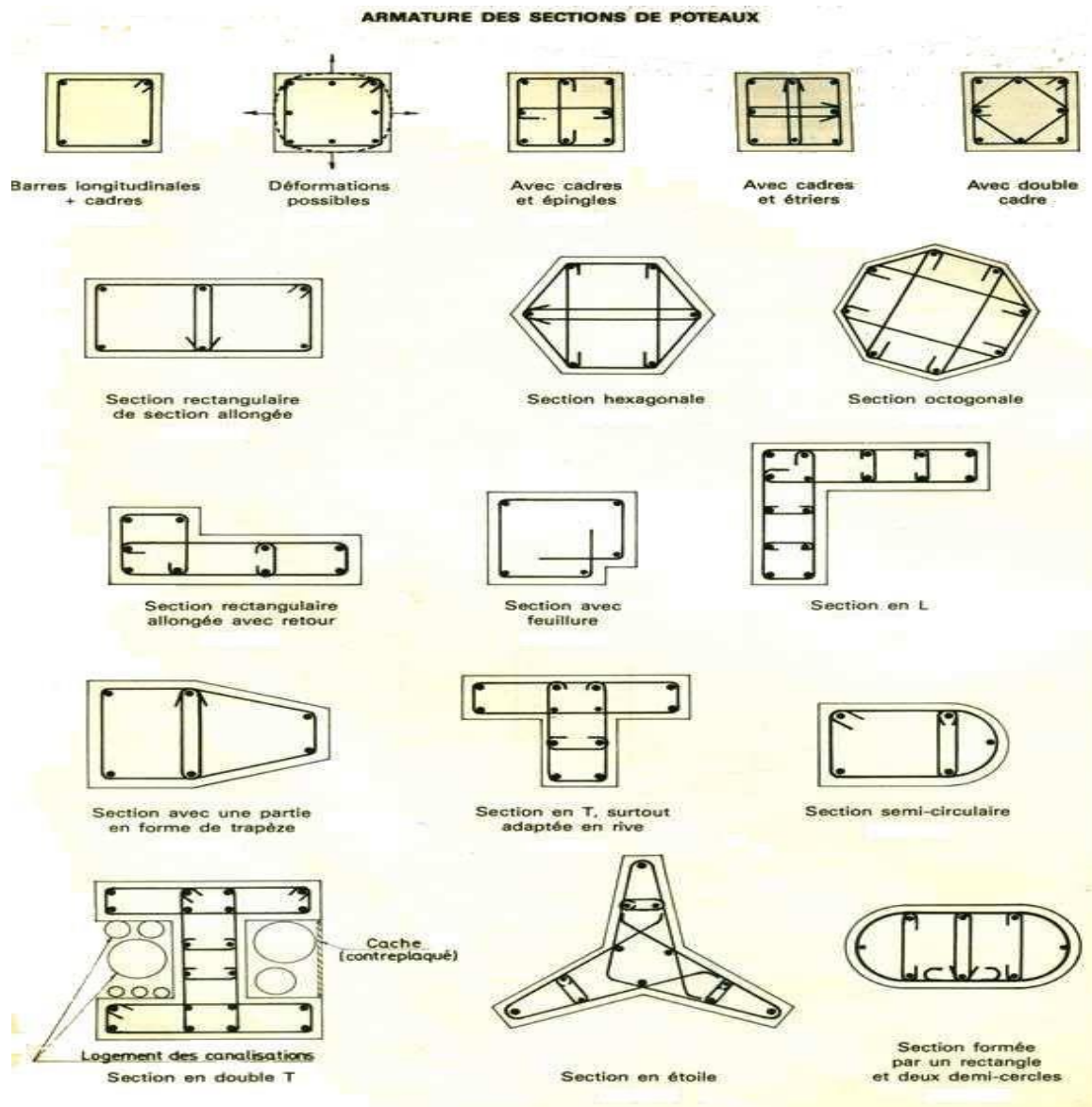


3. The elements of the frame

3.1- The poles

These are vertical load-bearing elements made of concrete with incorporated reinforcement. They are generally subjected to compression, sometimes accompanied by bending. The posts constitute support points for the horizontal elements, to transmit the loads to the foundations. Depending on their location in the construction, they are called: corner posts, edge or facade posts, interior or central posts.

Shape of the cross section: it is varied; it is sometimes a function of the available space. Square or rectangular posts are the most common because they are simple to make (easy formwork). The advantage of rectangular posts is the possibility of increasing inertia in the desired direction, especially if the lateral forces are very high in one direction compared to another.



Post dimensions: The height of the post depends on the comfort you want to obtain and the price you are willing to invest.

The transverse dimensions of the posts (cross-section) are a function of the loads to be taken up, hence the need to make a load descent for the characteristic posts. The characteristic posts are: the most loaded central post, the edge post and the most loaded corner post.

The minimum sections of the posts are given by the RPA (Algerian Paraseismic Regulations) (Figure):

For a rectangular or square post:

Min (b,h) ≥ 25 cm in zone I and IIa

Min (b,h) ≥ 30 cm in zone IIb and III

Min (b,h) ≥ H/20 (H : height of the post) $1/4 < b/h < 4$

For a circular post:

D ≥ 25 cm in zone I

D ≥ 30 cm in zone IIa

D ≥ 35 cm in zone IIb and III

D ≥ H/15 (H : height of the post)

The calculation of reinforcements is not part of this note, however it should be noted that:

- Vertical steels support the concrete in compression and oppose the bending moment in the tense zones;
- The transverse steels contribute to the resistance and prevent the concrete from splitting laterally.
- Arrangement of reinforcements for posts

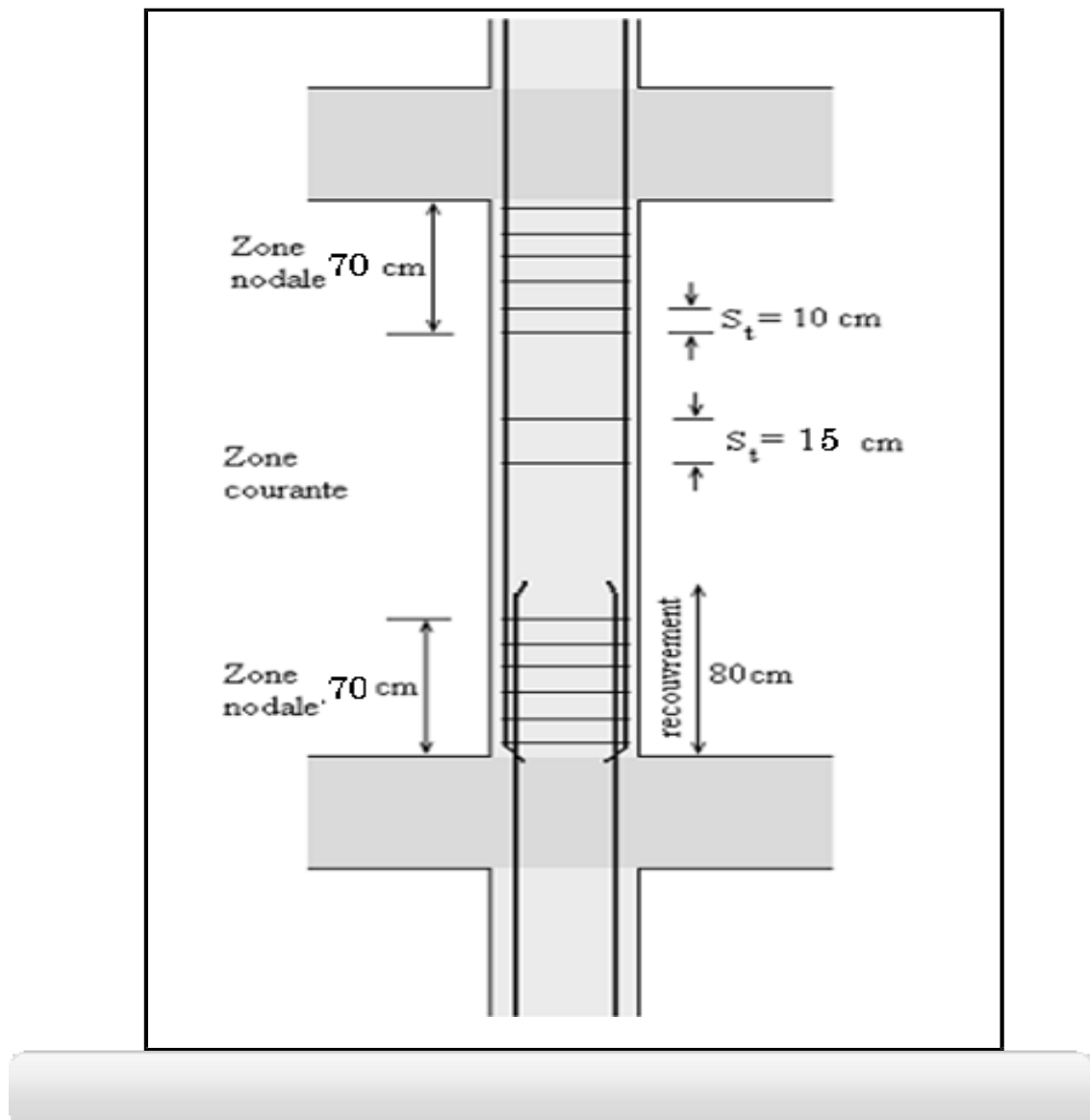


Figure: Minimum sections and reinforcements

3.2- The beams

These are horizontal load-bearing elements made of concrete with incorporated reinforcement. They transmit the loads to the columns and can have any shape, but in general, a rectangular or T-shaped cross-section is adopted. In fact, T-beams are rectangular beams but part of the floor on either side of the beam is used to absorb the forces.

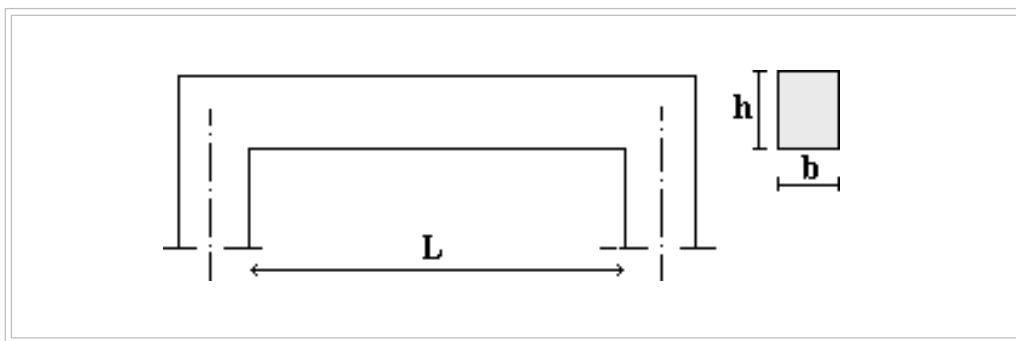
Architectural constraints sometimes require the choice of flat beams embedded in the floor and not projecting into the ceiling, or very narrow thin beams not projecting into the walls and partitions.

When you have a free choice of dimensions, it is better to choose a beam that is higher than it is wide (better resistance to bending and punching).

3.2-1. Pre-dimensioning of beams

Beams are linear elements with a rectangular or T-shaped section, their span is much greater than the dimensions of the section.

Beams are horizontal structural elements responsible for transmitting vertical and horizontal loads to the load-bearing elements (columns and walls). They are sized according to the resistance and deflection conditions imposed by the rules (CBA 93).



3.2-1.1. b: width of the base of the beam.

3.2-1.2. h: total height of the beam.

3.2-1.3. L: the largest span measured without supports.

The pre-dimensioning of the beams is given by the following empirical formulas:

➤ $L(\text{max range})/15 \leq h \leq L(\text{max range})/10$

➤ $0.3h \leq b \leq 0.7h$

The minimum beam dimensions required by Regulation RPA99 Version 2003 are:

➤ $h \geq 30 \text{ cm}$

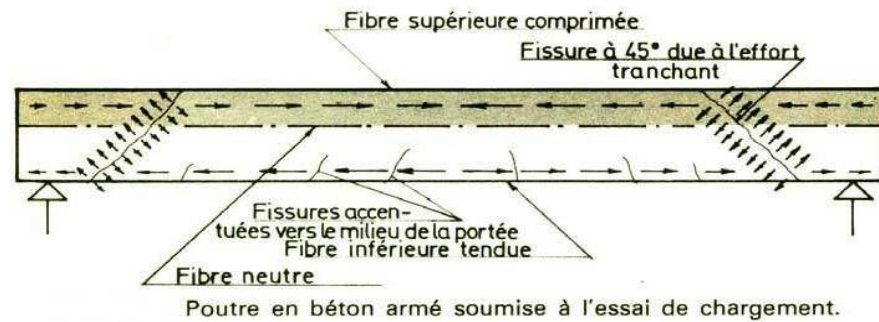
➤ $b \geq 20 \text{ cm}$

➤ $h/b \leq 4$

The calculation of reinforcements is not part of this note, however some constructive provisions are given:

Under the effect of the loads, the beam is subjected to:

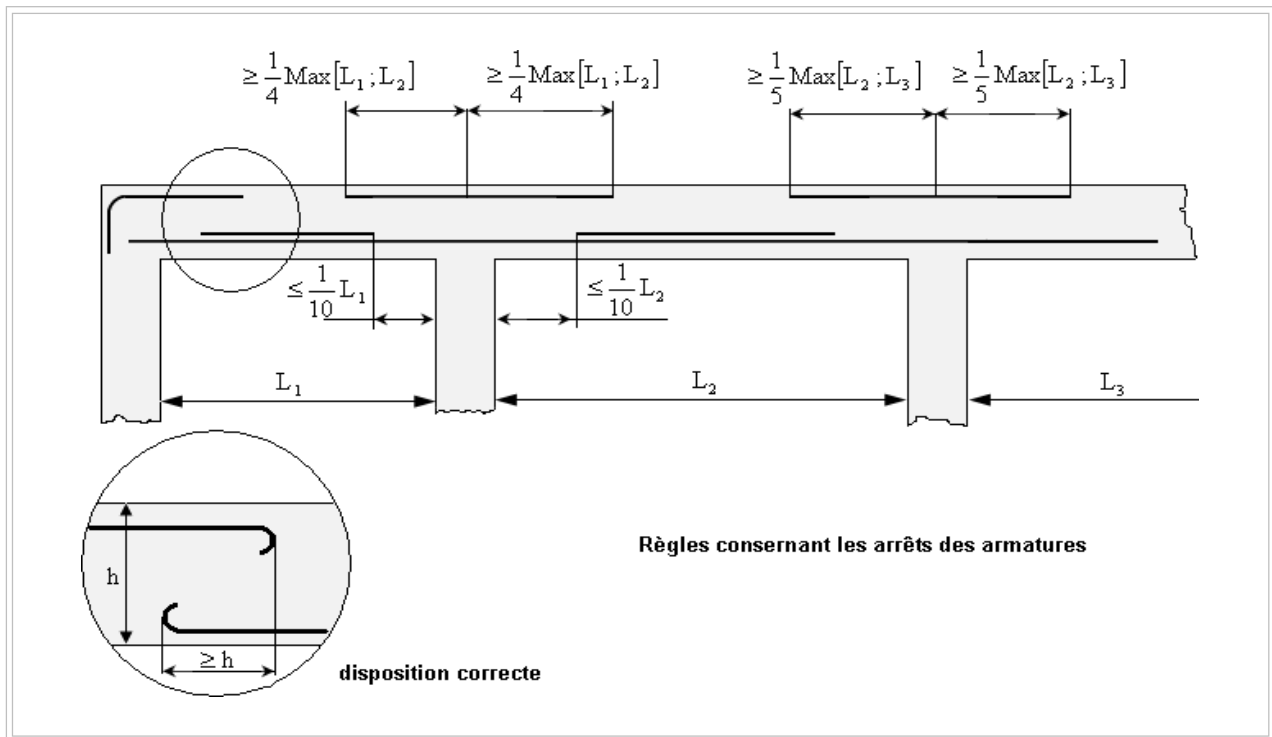
- a bending due to the bending moment which causes compression in the upper part of the beam section and tension in the lower part of this section;
- oblique shear due to shear force.



The reinforcements are placed in the beam according to these forces. Thus, the lower zone of the beam is tensioned, main steels are then placed in this zone to take up the tensile forces.

In the upper compressed zone, the concrete alone can take up the compressive forces; however, distribution (assembly) steels are placed.

The frames (cross-beam reinforcement) are placed transversely to prevent shear cracks.



Arrangement of reinforcements for beams

3.3- Sails

The sails are rigid elements made of reinforced concrete cast on site. They are intended for part to take up part of the vertical loads and on the other hand to ensure the stability of the work under the effect of horizontal loads.

Role of the sails:

- According to RPA99, the sails take up almost all of the horizontal loads (earthquake and/or wind effects) and 20% of vertical loads (dead loads and overloads).
- The sails providing the bracing are assumed to be full.
- Provide sound insulation between two rooms, particularly between dwellings.
- Also provide fire protection.

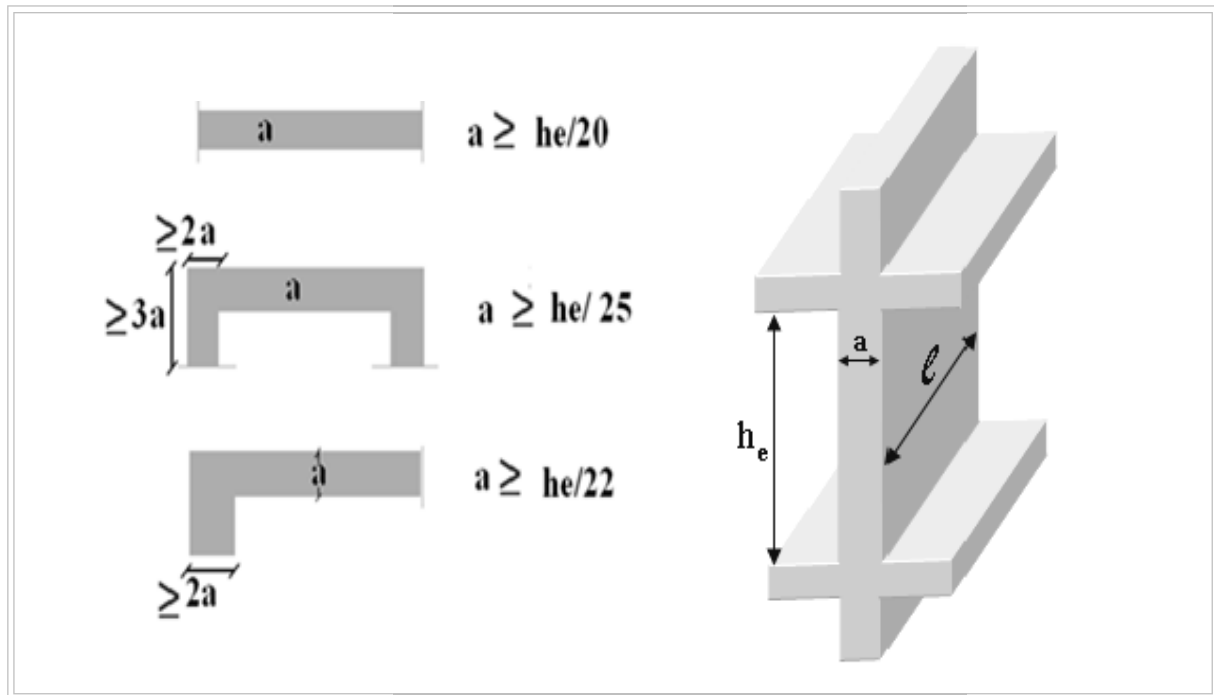
➤ Pre-sizing of sails

The sails are walls made of reinforced concrete, their role will be to brace the building and possibly support a fraction of the vertical loads.

We consider as sails the elements satisfying the condition $L \geq 4a$. In the case

Otherwise, these elements are considered linear elements.

The RPA99 version 2003 requires a minimum thickness of 15 cm, in addition, the thickness must be determined according to the free height of the floor h_e and the rigidity conditions at the ends.



➤ Reinforcing the sails

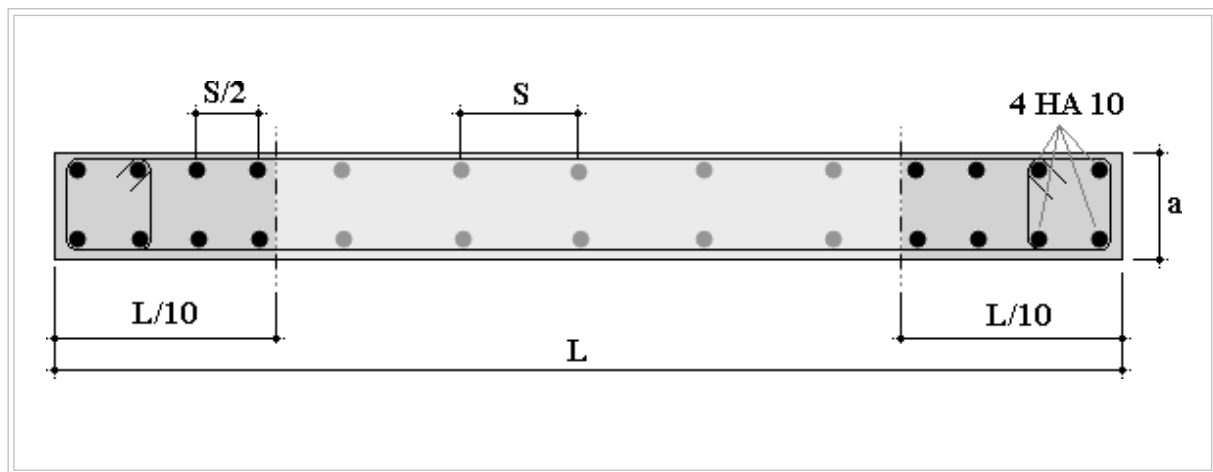
The reinforcement of the sails will be carried out according to the CBA93 regulation and the checks according to the Algerian parasismic regulation RPA99v2003 under the action of horizontal forces (earthquake) as well as the forces due to vertical loads.

The stresses generated in the veil are:

- Bending moment and shear force caused by the action of the earthquake.
- Normal force due to the combination of permanent loads, operating loads and seismic load.

The reinforcement of the walls will be calculated in composite bending with shear force, each wall must have three types of reinforcement:

- vertical frames.
- horizontal frames.
- transverse reinforcements.



Example of arrangement of vertical reinforcements in the sails

4. The bracing

A bracing system is a set of construction elements that provide stability against horizontal forces generated by wind or earthquake.

➤ The choice of bracing

Vertical bracing by piers must meet specific criteria such as:

Their number : at least three non-parallel and non-concurrent blades per floor.

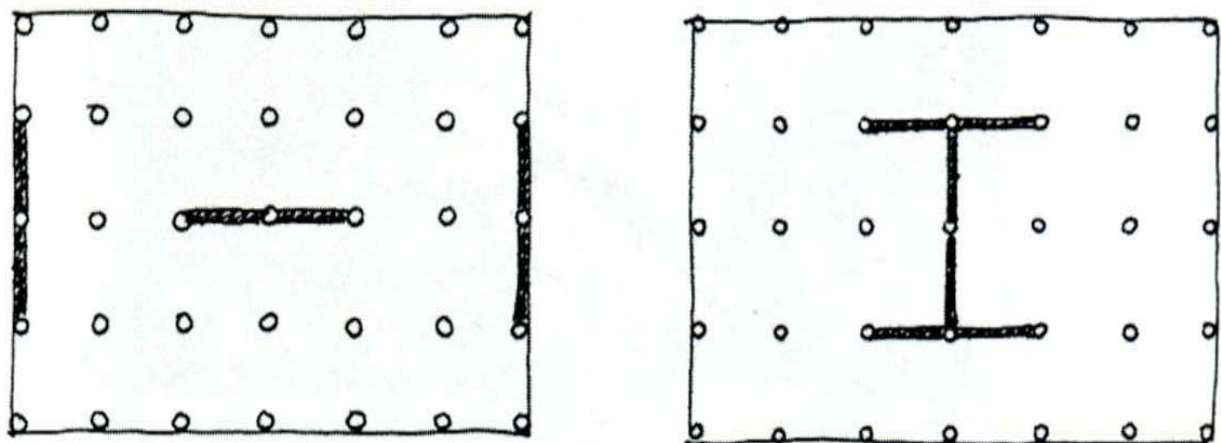
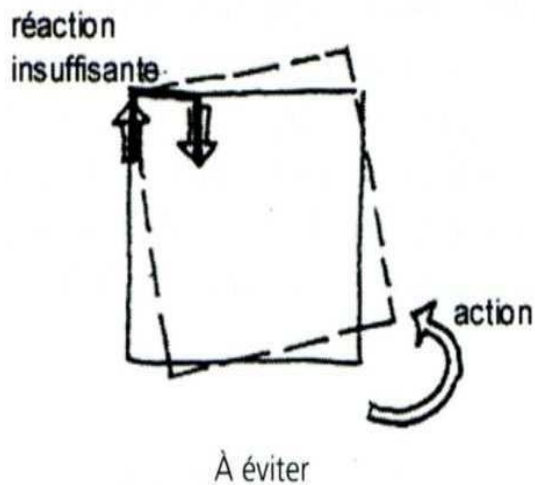


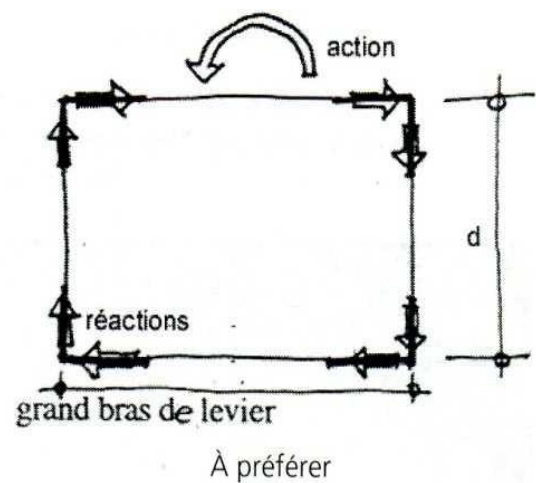
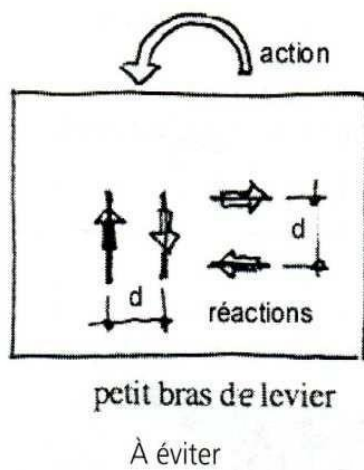
Figure:

Minimum number of vertical bracing elements: two to oppose the translations of the diaphragm respectively in the x, y directions, and a third producing with one of the other two, a couple resisting the torsion of the vertical axis.

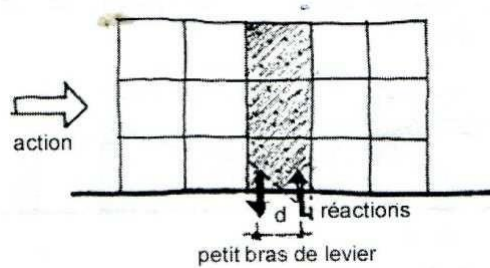
Their arrangement: they will be located as symmetrically as possible in relation to the centre of gravity of the floors and preferably at the corners (and/or on the periphery) with sufficient width.



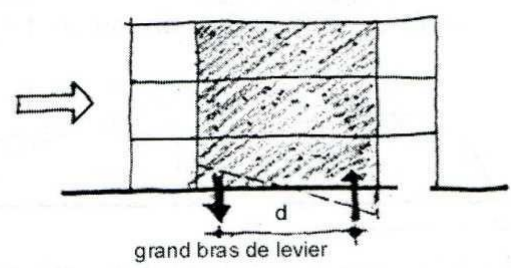
An off-center position of the bracing elements causes torsional stress on the building. In addition, the lever arm of the resisting moment produced by the bracing is very small..



A large distance between the bracing elements parallèles favorsthe resistance of the structure to torsion.



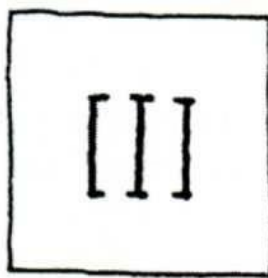
À éviter



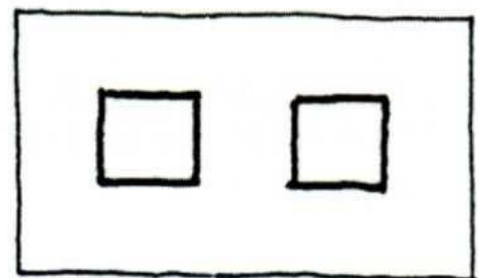
À préférer

Wide elements provide better resistance to horizontal forces due to the larger lever arm (in the vertical plane)

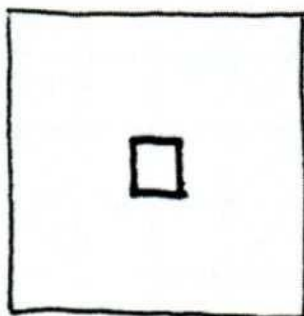
The bracing may optionally consist of a large closed central core (and not U-, X- or Z-shaped) in order to minimize the stresses due to torsion. Indeed, the resistance to vertical axis torsion of open cores is low.



noyau ouvert

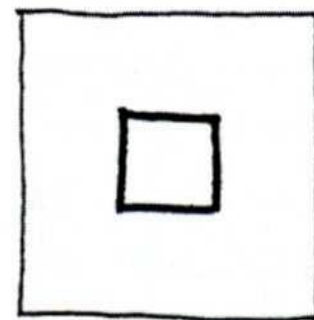


noyaux fermés



noyau de faibles dimensions

À éviter



noyau fermé de dimensions adéquates

À préférer

Figure : Bracing forming a central core

Their vertical distribution: be regular; the blades will preferably be superimposed in order to give the different levels comparable rigidity both in translation and in torsion.

Soft (flexible) levels such as a transparent ground floor of a building should be properly braced if possible with sails.

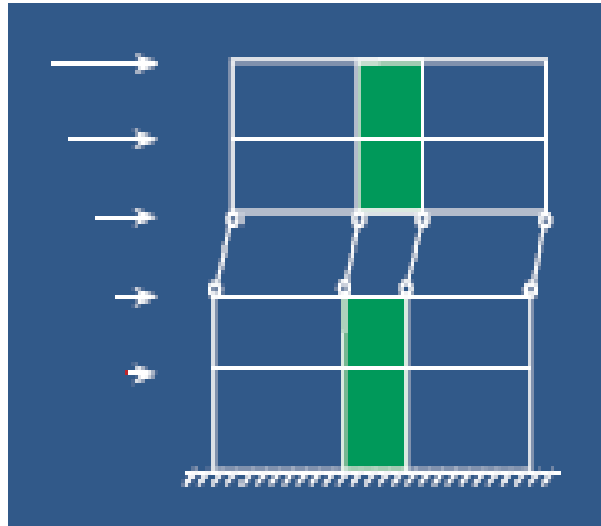


Figure: Avoid soft (flexible) floors

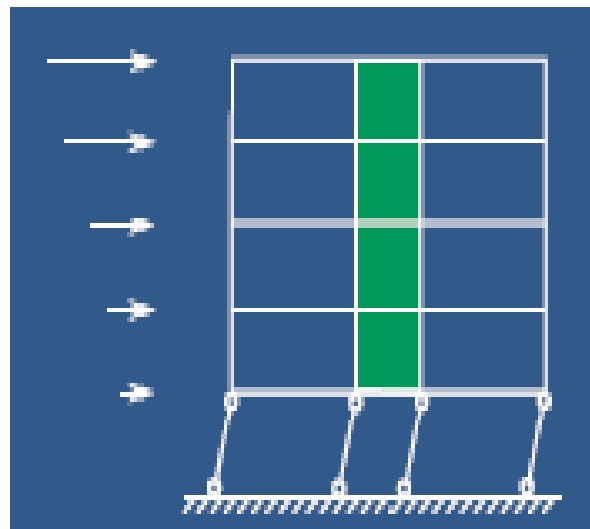
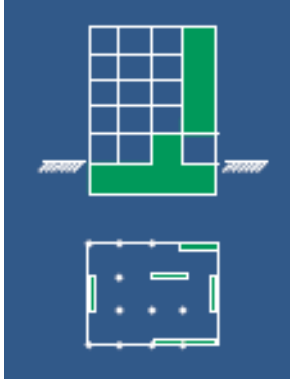
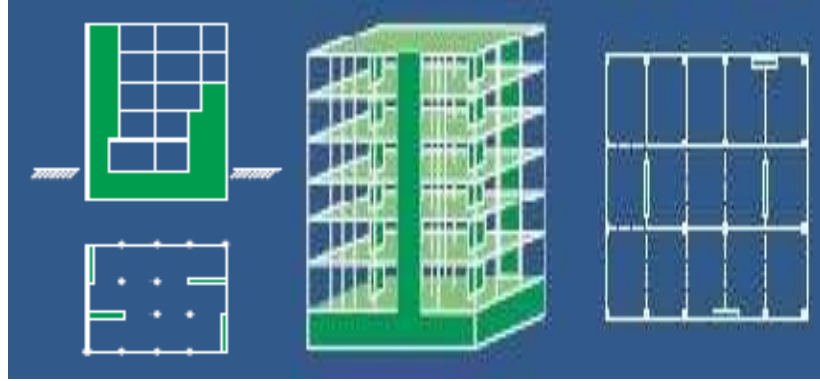


Figure: Avoid flexible DRCs

In all cases, the bracing should give the different levels comparable stiffness. Consequently, neither the number nor the nature of the bracing elements should vary significantly from one level to another (figure below). However, the stiffness may also increase towards the lower levels. In this case, the difference in stiffness between two successive levels should not exceed 25% (RPA 99 V2003).



Avoid offset bracing



Jumps in stiffness and strength cause problems *Two slender reinforced concrete walls per main direction*

Poor arrangement of the stability beams (bracing) could lead to collapses due to excessive deformation.

5. CARRIER SYSTEMS (RPA 99 Version 2003)

The load-bearing systems of reinforced concrete buildings included in RPA 99 Version 2003 are classified according to the following categories:

1/ Self-supporting gantries in CS with or without rigid masonry filling:

It is a framework made up solely of portal frames capable of absorbing all the stresses due to vertical and horizontal loads.

The buildings concerned must not exceed five levels or 17m in zone I, four levels or 14m in zone IIa and three levels or 11m in zone IIb and two levels or 8m in zone III.

2/ Bracing system consisting of reinforced concrete sails (load-bearing or not):

The system consists of sails only or sails and gantries. The sails can take part of the vertical loads but must take all the horizontal loads.

3/ Mixed bracing system provided by sails and gantries:

The sails and the gantries jointly take up the vertical loads and the horizontal loads.

4/ Reinforced concrete frame structures braced entirely by a core in ba:

The building is entirely braced by a rigid reinforced concrete core which takes all the horizontal loads.

6. Concrete structural elements

Concrete structural elements come in various forms, from columns to beams to walls or slabs cast on site, including prefabricated slabs. The advantages of these elements are numerous: long service life, recycling potential, acoustic performance, large possible span, cost, etc. However, their grey energy is significant and the possibility of dismantling is almost zero.

6.1- Predimensioning and lowering of load

The presizing of elements of a structure (beams, posts and walls) is an essential step in a construction project. It is based on the principle of load descent, for defining the load and overload. The purpose of pre-sizing is to “pre-calculate” the sections of the various resistant elements. It will be done according to the rules of RPA 99 Version 2003, to arrive at determining an economical thickness.

Pre-dimensioning of beams

Beams are horizontal elements, the section of which can have different shapes (rectangular, I-shaped or T-shaped), their role is to transmit the loads to the posts. The beams are sized in relation to the conditions of the admissible deflection and are checked in relation to the requirements of RPA 99 Version 2003

Determination of h and b

The purpose of pre-sizing the beams is to select and verify the dimensions (heights and widths) of the latter in the plan. For this, our calculations will be based on the RPA99 V2003 rules.

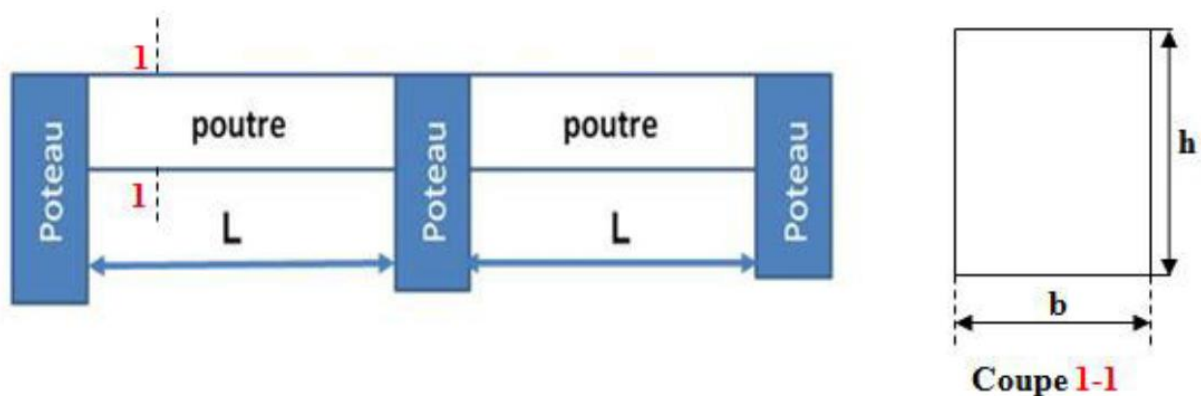


Figure 2.1: Section of a concrete beam.

The height of the beam is determined by the following expression:

$$\frac{L_{max}}{15} \leq h \leq \frac{L_{max}}{10}$$

Or,

Lmax: Length of the maximum span of the beam between bare'supports;

h: Height of the beam.

oThe width of the beam, depending on its height, is given as follows:

$$0.3h \leq b \leq 0.7h$$

Verification according to RPA99/V2003

The beams must respect the following dimensions:

$$b \geq 20 \text{ cm}$$

$$h \geq 30 \text{ cm}$$

$$h/b \leq 4$$

$$b_{max} \leq 1.5h + b_1 \text{ (} b_1 \text{ is the smallest dimension of the column section)}$$

Pre-sizing of posts

The pre-dimensioning of the posts is done by checking the load-bearing capacity of a chosen section, based on the simple compression calculation stresses. $\sigma_{ELU} = (1.35G + 1.5Q)$.

These dimensions are determined by the descent of the loads of the most stressed post. 'ultimate normal effort N_u acting on a pole must be equal to the following value:

$$N_u \leq \alpha \left(B_r \frac{f_{c28}}{0.9 \cdot \theta \cdot \gamma_b} + A \frac{f_e}{\gamma_s} \right)$$

With ;

B_r : Reduced section of the post (in cm^2);

$B_r = (b - 2\text{cm}) \times (a - 2\text{cm})$ for a rectangular section.

$B_r = (a - 2\text{cm})^2$for a square section

A : Section d'compressed steels taken into account in the calculation;

- □ f_{c28} : Compressive strength of concrete;
- □ f_e : Limit of elasticity of the steel used;
- □ $\gamma_b = 1.5$: Safety coefficient of concrete (durable case);
- □ $\gamma_s = 1.15$: Steel safety coefficient;
- □ α : Reduction coefficient, function of the slenderness mechanic (λ) which takes the value:

$$\begin{aligned} \text{Pour } \lambda \leq 50 & \quad \left\{ \begin{aligned} \alpha &= \frac{0.85}{\left[1 + 0.2 \left(\frac{\lambda}{35} \right)^2 \right]} = \frac{0.85}{\beta} \\ \beta &= 1 + 0.2 \left(\frac{\lambda}{35} \right)^2 \end{aligned} \right. \\ \text{Pour } 50 < \lambda \leq 70 & \quad \left\{ \begin{aligned} \alpha &= 0.6 \left(\frac{50}{\lambda} \right)^2 = \frac{0.85}{\beta} \\ \beta &= \frac{0.85 \lambda^2}{1500} \end{aligned} \right. \end{aligned}$$

-The values of α are to be divided by 1.10 if more than half of the loads are applied before 90 days.

-An additional reduction should be applied when the majority of the loads are applied before 28 days (the constraint f_{cj} is taken instead of f_{c28} and the reduction coefficient is 1.20 instead of 1.10).

Such as : □ □ □ □ L_f / i

□ □ L_f : Buckling length;

For multi-storey buildings which are braced by reinforced concrete walls, the length $L_f \leq 0.7 L_o$

□ □ L_o : Free height of the post.

Free length L_o of a post belonging to a multi-storey building is counted between the upper faces of two consecutive floors or from its junction with the foundation to the upper face of the first floor.

ANNEXES

ANNEX 1: INTRODUCTION TO CONSTRUCTION

Construction is the set of activities leading to the realization of any work linked to human activity (social, economic, environmental). The land use plans drawn up by urban planners necessarily involve consultations, studies and project assessments.

Role of the Building

The role of a building is to shelter individuals for a specific use. This may be for a use:

- residential (villas, buildings, skyscrapers, etc.).
- industrial (factories, warehouses, etc.).
- commercial (stores, etc.).
- Public (hospitals, administration, educational establishments).
- Leisure activities (cinema, theater, gym, etc.).

From a construction point of view, the building comprises two parts:

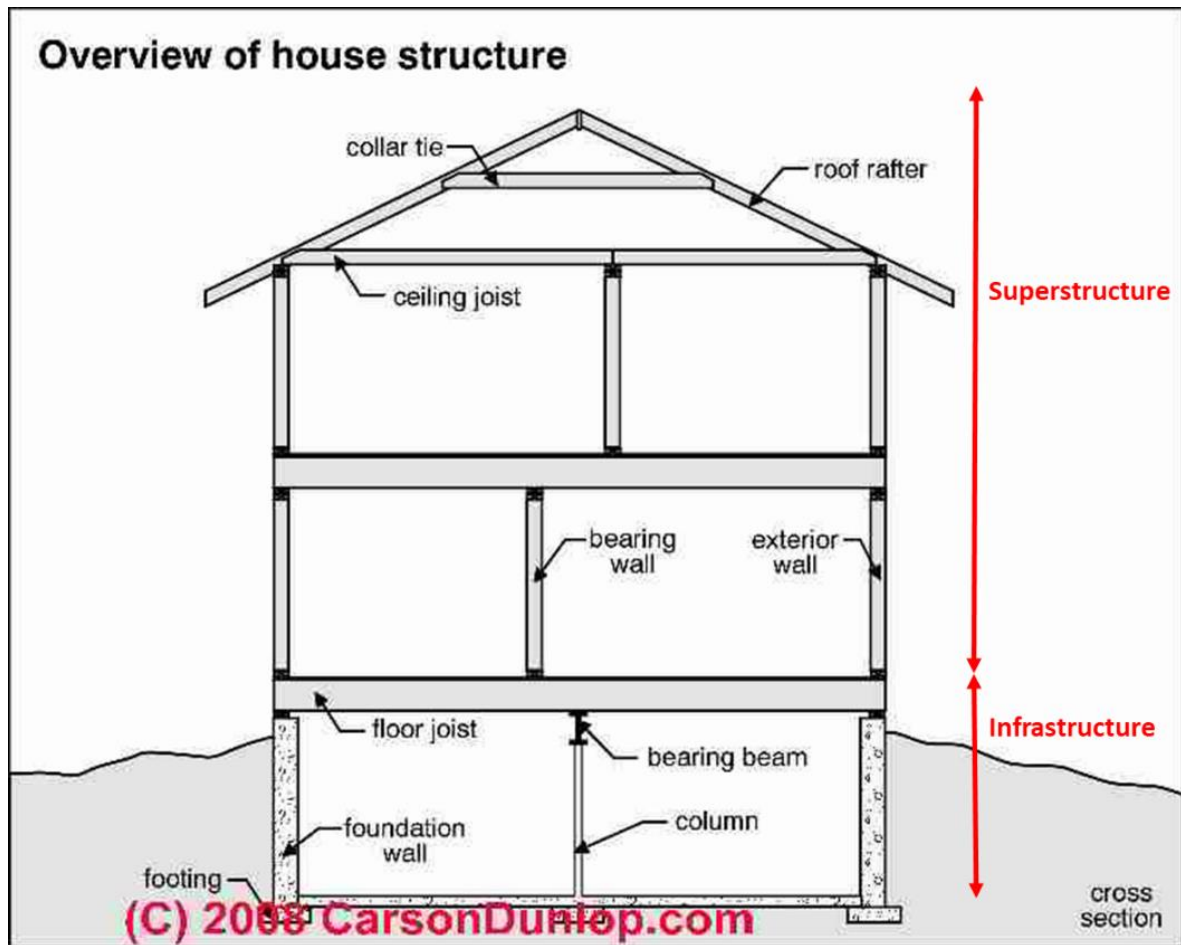


Figure 1: Functional breakdown of a structure

The structural work

Structural work refers to all the work that contributes to the solidity and stability of a building. Structural work must therefore enable the building to withstand the forces it is subjected to permanently (loads related to the building itself) and those it is subjected to temporarily (bad weather, earthquakes, etc.). Structural work includes:

- Earthworks.
- Infrastructure.
- Superstructure.

In a supporting structure, which ensures the stability of the building, we find: Foundations, solid slabs, floors, shear or load-bearing and partition walls, posts and beams in general for reinforced concrete constructions.

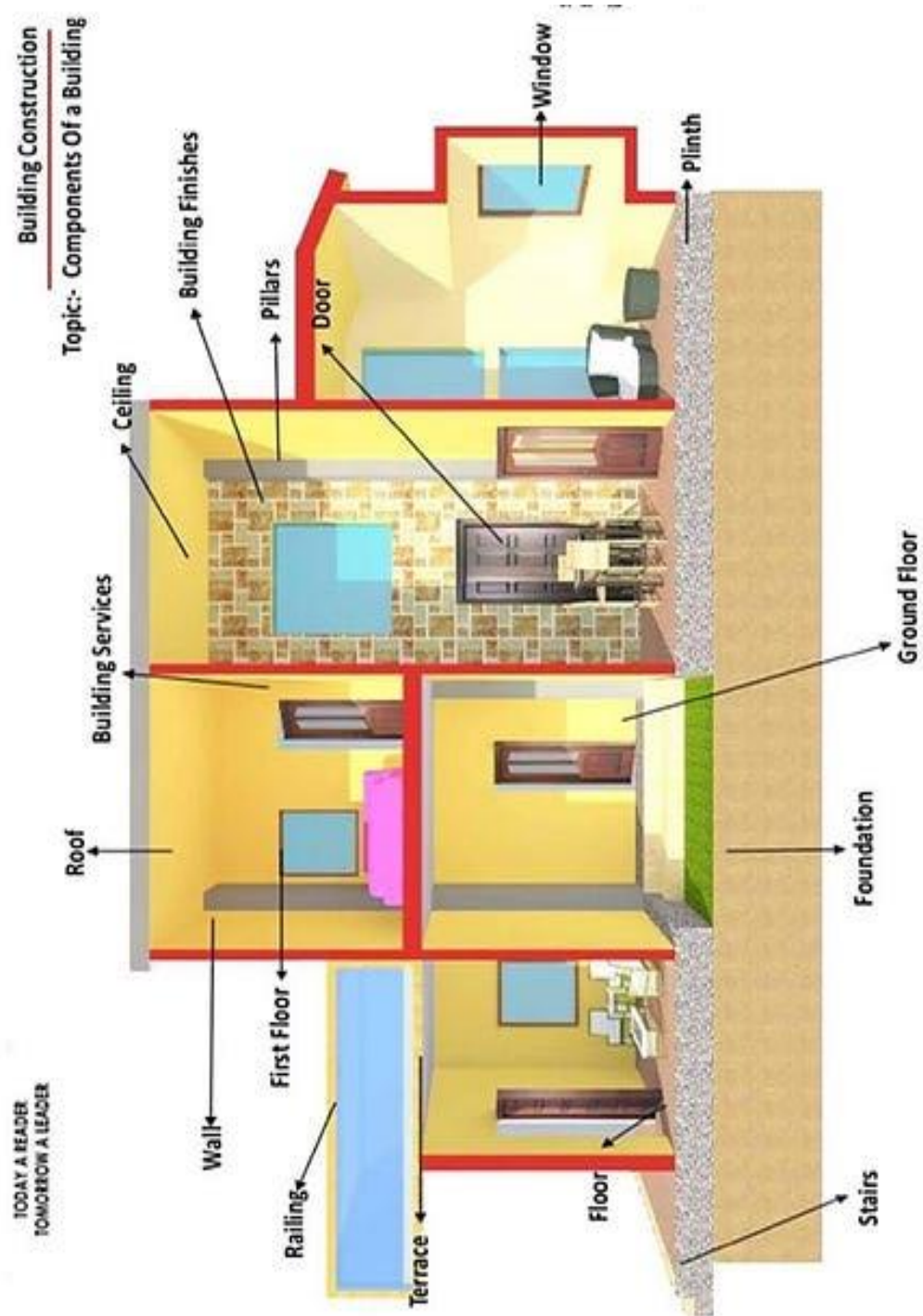


Figure :

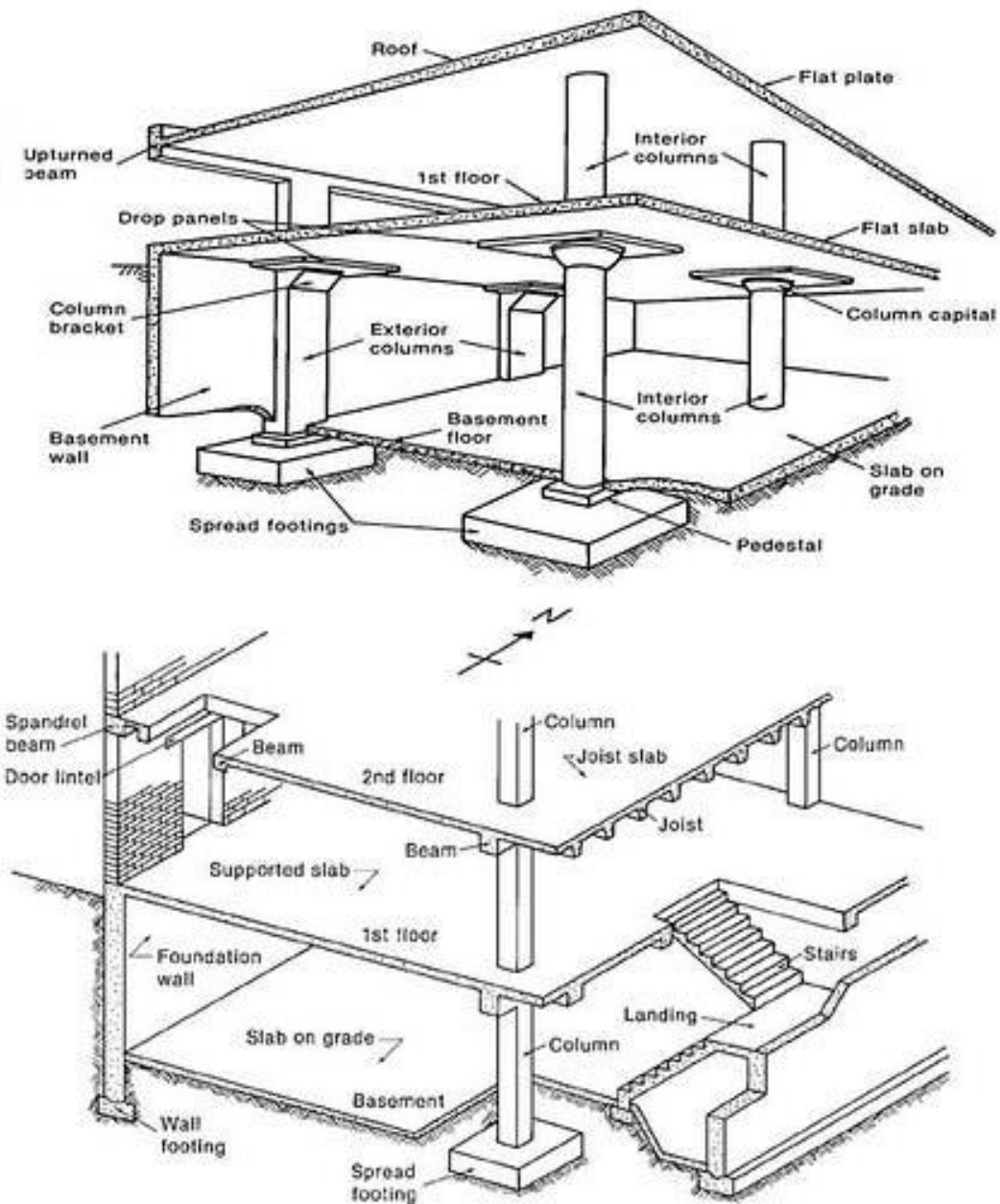


Figure: Frame of a building

The second work

The second work contributes to dressing and making the building functional. It is divided into several lots, we will mention:

- Carpentry.
- Electricity.
- Sanitary installation.
- heating

- The partitions.
- Painting
- Public works

Public works

Public works are works that meet the needs of the public. The sustainability of the work is an essential factor in this case. They can be separated into three categories

- Roads (earthworks, construction of roads, pipelines, markings).
- VRD (pipework, construction of sidewalks, public lighting, construction of platforms).
- Civil engineering structures (bridges, tunnels, dams)

The different actors involved in the construction process

The construction of a building is a complex operation which requires the collaboration of many stakeholders (project owner, project manager, companies), and which is based on a set of files including written documents and drawn documents.

- Project owner (the client)

This is the one who finances the project, it can be:

- An individual: general case for an individual construction.
- A company, a public institution or a private company: in the case of the construction of buildings
- An administration or a local authority; in the case of construction of municipal premises, town halls, ministries, etc.

- The project manager

This is the one who establishes the call for tender file containing the construction project file of the companies with the specifications, the plans, and the descriptive estimate. His role can range from simple design to monitoring of the implementation operation.

- **The production company**

This is the company that was chosen by the project manager and the contracting authority to carry out the work in accordance with the call for tender.

Types of constructions

We can distinguish five types of construction: residential, commercial, industrial, public works (TP) and institutional.

ANNEX 2: STAGES OF CONSTRUCTION OF A BUILDING

1. Designing a real estate project

Before building a building, it must be designed, according to the needs of the project owner and the users. Here are the different stages of design.

2. Programming and Preliminary Studies

While the Project Owner establishes the needs, constraints, budget and schedule of the project, other stakeholders such as the programmer, the urban planner and other specialists depending on the specificities of the project will then intervene during this phase. Similarly, surveyors and engineers participate in the production of the Diagnosis, which will be submitted for validation to the MOA as well as to the Institutions and Administrations for obtaining the building permit. Users can also transmit their needs during this stage.

3. Competition or Sketch

This is the tender phase. This is the moment when the Project Owner will organize a competition of architects, landscapers, urban planners and all trades and other specialists according to the specificities of the project.

This allows, on the one hand, the MOA to choose the best Project Manager (or MOE) who will be in charge of carrying out the project and, on the other hand, to carry out a feasibility study of the operation.

To be selected, the various Project Management teams will have to produce several graphic documents (site plan, level plan, section, facade, perspective, etc.) and other written documents, detailing the project to be carried out.

4. Summary Preliminary Draft (APS)

Once the MOE has been selected, we move on to the project adjustment phase. We adapt the project and the budget, we readjust elements of the program to meet certain regulations or sometimes contradictory objectives. This is also the time when we can organize a user consultation if this has not yet been done.

5. Detailed Preliminary Project (APD)

Then, we move on to the APD phase, where we determine and finalize the dimensions of the building, the construction and technical choices and the financial estimate. The APD makes it possible to put together the file for requesting a building permit from the municipality. It must present the exterior appearance of the building (volumes, facades, exterior spaces) and the relationship of the building to its context.

The documents already drawn up must be detailed by the MOE and validated by the MOA.

6. Obtaining the Building Permit

As you will have understood, this is a decisive phase in the realization of a construction project. The concept detailed through the various documents must be imperatively validated by the administrations concerned. For this, the projected building must respect the town planning rules concerning in particular: the location of the constructions, their destination, their nature, their external appearance and the development of their surroundings.

7. Business Consultation Project and File

The Project phase is the phase of definition and technical description of the building. It allows the establishment of the DCE (Business Consultation File) and the various quotes which will facilitate the MOA and MOE in the selection of the companies which will intervene on the construction site.

8. Preparation and Roads Various Networks (VRD)

The first step is to set up the construction site. This includes workers' premises, protecting the surroundings and neighbourhood, creating access for construction vehicles, etc.

It is also necessary to carry out VRD (Roads and Miscellaneous Network) works, i.e. digging trenches for the passage of networks for electrical connections, water supply and waste water evacuation.

9. Foundation and Structural Work

Once the construction site is well established and open, the construction of the foundations begins, which is supposed to guarantee the stability of the building and support the entire building.

Then comes the structural work: the main walls (load-bearing), the posts, the floors and all other parts making up the primary structure of the building.

When building the frame, it is important to leave gaps to accommodate stairs and elevators, as well as ducts, pipes and various electrical cables that will prove essential later in the life of the building.

10. The enclosure and the cover

This step corresponds to the creation of the exterior envelope. That is to say the facades and the roof, which must be well insulated from temperature variations but also well sealed.

11. The technique

Then comes the time for all the technical installations, i.e. electricity, heating, water supplies, etc.:

- plumber ;
- electrician ;
- locksmith ;
- carpenter...

12. Second Work and Finishing

The Second Work consists of all the finishing work necessary to make the building habitable:

- interior design, partitioning of apartments;
- installation of coverings (tiles, parquet floors, painting of walls and ceilings);

- installation of all electronic devices;
- cleaning the site.

13. Delivery of works

- The final act of the construction project in which the project owner receives the property and acknowledges that it has been completed in accordance with the requirements and contracts previously certified.

Annex 3: The most common problems in a base floor and proposal of suitable solutions

The perfect structure is based on:

- a seismic design
- choosing the right type of foundation
- the right calculations
- The right building materials
- the right follow-up

Ground movements:

They bring together a set of ground movements, of origin:

- natural (rain, earthquake, etc.)
- anthropogenic (earthworks, vibrations, exploitation of materials, etc.)

We distinguish:

Slow / continuous

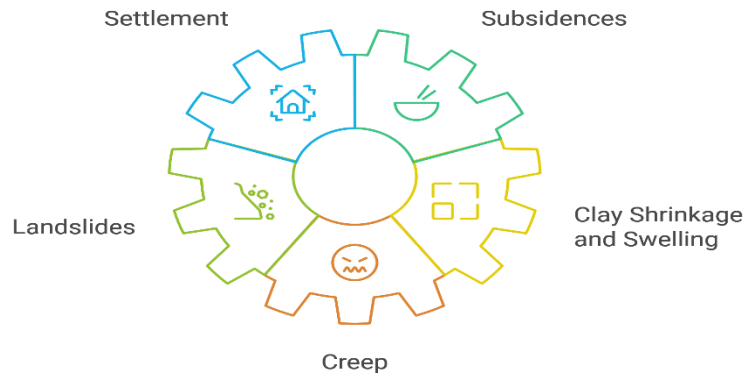


Figure : Understanding Ground Movements

- Settlement refers to the vertical sinking of a construction under the effect of compression and deformation of the soils which support it.
- Subsidence are topographic depressions in the shape of a more or less deep bowl, and most often caused by earthquakes, extraction of water, oil, gas or mineral resources from the ground by pumping, fracturing or mining operations.
- A landslide is a geological phenomenon designating the displacement, downwards and outwards, of a mass of soil.
- Clay shrinkage and swelling: characterized by small-amplitude differential ground movements, caused by variations in the volume of certain clayey soils when their water content changes.
- Creep: Complex to predict, this type of movement appears when a malleable soil is subjected to a significant load upstream.

Fast / discontinuous

- Collapses occur suddenly. They result from the rupture of the supports or roof of an underground cavity rupture which propagates to the surface
- rock collapses : One or more stones or blocks may break off and spread, partly falling, then bouncing and rolling.
- Mud flows: consist of the propagation of materials without cohesion or having lost their cohesion upon starting to move.

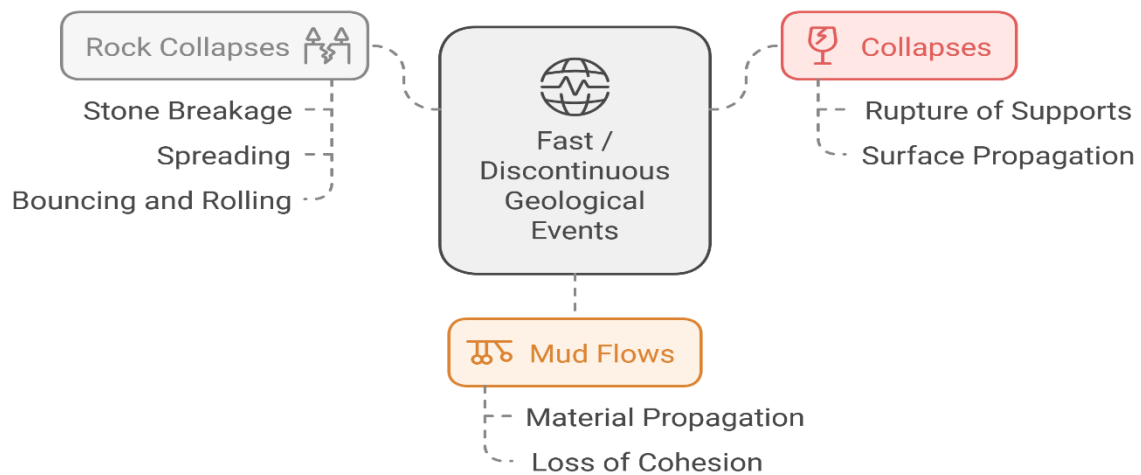


Figure: Fast Geological events

The solutions

Soil improvement:

- Can be understood as the increase of certain mechanical characteristics with or without addition of materials by acting on the reduction of the void index, rearrangement of grains by mechanical action, consolidation or by vibration.
- a- Mechanical methods
 - Surface compaction: Compaction is a process of densifying soils in place. This process leads to: reduction of soil voids by mechanical means, increase in density and strength, reduction in compressibility. Surface compaction can be used to a maximum depth of 3m
 - Dynamic compaction: This is a process that allows soils to be densified at great depth by creating very high energy shock waves.
 - Vibrocompaction: Vibrocompaction is a technique for improving coarse, cohesionless soils.
- b- Hydromechanical methods
 - Pre-compression (consolidation): The pre-compression technique is simply to place an additional surcharge above the ground before construction work.
- c- Chemical methods

- Use of lime: A lime-stabilized soil provides structural performance equivalent to that of a natural gravel or crushed stone soil.
- Use of cement: Cement soil treatment is used for soils that have a low percentage of clay. It is mainly used for the purpose of obtaining a rapid and lasting development of mechanical resistances. It allows a reduction in water content just like lime

Soil reinforcement:

more specifically includes all the techniques leading to the inclusion of vertical elements in the ground (inclusions) in order to improve their resistance under the effect of a static or dynamic load provided by a structure (surface foundations or backfill) or under the action of earth pressure in the case of retaining structures or stabilization of natural slopes.

a- By soft injections:

The aim: to modify the intrinsic characteristics of the soil to make it more resistant from the inside (more load-bearing, less compressibility, less risk of liquefaction, etc.).

Flexible injections are often made using cement mortar, in order to fill the voids.

b- By rigid inclusions:

The aim: rigid inclusions make it possible to improve the mechanical characteristics of existing soils by incorporating a mesh of cylindrical vertical elements, made of a material based on hydraulic binder (concrete).

Bibliography

Books and Manuals

- Bowles, J. E. (1996). Foundation analysis and design (5th ed.). McGraw-Hill.
- Das, B. M. (2017). Principles of foundation engineering (8th ed.). Cengage Learning.
- Terzaghi, K., Peck, R. B., & Mesri, G. (1996). Soil mechanics in engineering practice (3rd ed.). Wiley.
- Das, B. M. (2009). Advanced soil mechanics (4th ed.). Taylor & Francis.
- Wang, C. K., Salmon, C. G., & Pincheira, J. A. (2007). Reinforced concrete design (7th ed.). Wiley.
- Park, R., & Paulay, T. (1975). Reinforced concrete structures. Wiley.
- Coduto, D. P. (2001). Foundation design: Principles and practices. Pearson.
- Jumikis, A. R. (1984). Soil mechanics. Krieger Publishing.

Research Papers

- Vesic, A. S. (1975). Bearing capacity of shallow foundations. Journal of the Soil Mechanics and Foundations Division, 101(SM3), 111–147.
- ACI Committee 318. (2014). Building code requirements for structural concrete (ACI 318-14) and commentary. American Concrete Institute.

Online Resources

- The Construction Civil. (n.d.). Types of foundations. Retrieved December 11, 2024, from <https://www.theconstructioncivil.com>
- Geotechdata.info. (n.d.). Bearing capacity of soils. Retrieved December 11, 2024, from <https://www.geotechdata.info>

- The Constructor. (n.d.). Reinforced concrete basics. Retrieved December 11, 2024, from <https://theconstructor.org>
- NPTEL. (n.d.). Foundation engineering lectures. Retrieved December 11, 2024, from <https://nptel.ac.in>

Industry Standards

- American Society of Civil Engineers. (2010). Minimum design loads for buildings and other structures (ASCE 7-10). ASCE.
- European Committee for Standardization. (2004). Eurocode 7: Geotechnical design – Part 1: General rules. European Committee for Standardization.
- Bureau of Indian Standards. (2000). IS 456: Code of practice for plain and reinforced concrete. BIS.
- Bureau of Indian Standards. (1981). IS 6403: Code of practice for determination of bearing capacity of shallow foundations. BIS.