الجـــمهورية الجـــزائرية الديمـــقراطية الشـــعبية
People's Democratic Republic of Algeria

Ministry of Higher Education and Scientific Research
University Mohamed Boudiaf of M'sila
Faculty of Technology
Civil Engineering Department

وزارة التعليم العالي والبحث العلمي
جـامـعة محمد بوضياف- المـسيلة
كلية التكنولـــوجيا
قسم الهندسـة المدنيـة

جامعة محمد بوضياف - المسيلة
Université Mohamed Boudiaf - M'sila

رقم : 98 /هـ م/2025 المسيلة في:2025/06/12

شهـــادة إدارية

بخصوص تقييم المطبوعة البيداغوجية المنجزة من طرف الأستاذ: بوقرة خير الدين

بعد الاطلاع على تقارير الخبراء المعينين من طرف أعضاء اللجنة العلمية لقسم الهندسة المدنية ضمن اجتماعها المنعقد يوم الثلاثاء عشرون من شهر ماي عام ألفين وخمسة وعشرون ميلادي، قصد إنجاز خبرة حول المطبوعة البيداغوجية المقدمة من طرف الاستاذ **بوقرة خير الدين،** أستاذ محاضر "أ" بقسم الهندسة المدنية بجامعة محمد بوضياف والمعنونة ب:

Steel Structures

(Support pédagogique destiné aux étudiants de 2ère année Ingénieur ainsi qu''aux 3ème année Licence en Génie Civil)

حيث أن كل تقارير الخبراء كانت إيجابية، تم المصادقة على المطبوعة واعتمادها لطلبة السنة الثانية للمهندسين والسنة الثالثة ليسانس هندسة مدنية.

تتكون لجنة الخبراء المعينة من طرف أعضاء اللجنة العلمية للقسم من السادة الآتية أسماءهم:

الأستاذ: تيطوم مسعودا أستاذ للتعليم العالي بجامعة محمد بوضياف بالمسيلة

الأستاذ: مناصري يوسف أستاذ محاضر "أ" بجامعة محمد بوضياف بالمسيلة

الأستاذ: مازوز عايدة أستاذة محاضرة "أ" بجامعة البشير الإبراهيمي ببرج بوعيريج.

تستعمـــل هاته الشهـــادة فيما يسمـــح به القانـــون

رئيسة اللجنة العلمية للقسم
د. بكيـــر نسيمـــة

رئيس القسم
مكي لخضر

جامعة محمد بوضياف المسيلة - رئيس اللجنة العلمية لقسم الهندسة المدنية - كلية التكنولوجيا

جامعة محمد بوضياف المسيلة - رئيس قسم الهندسة المدنية - كلية التكنولوجيا

REPUBLIQUE ALGERIENNE DEMOCRATIQUE ET POPULAIRE

MINISTERE DE L'ENSEIGNEMENT SUPERIEUR ET DE LA RECHERCHE SCIENTIFIQUE

MOHAMED BOUDIAF UNIVERCITY - M'SILA

FACULTY OF TECHNOLOGY **DEPARTEMENT OF CIVIL ENGINEERING**

LECTURE NOTES

STEEL STRUCTURES

Prepared by :

KHEIREDDINE BOUGUERRA, Ph.D.

2024/2025

Overview

These lecture notes on steel structures are intended for second-year civil engineering students in engineering programs, as well as third-year civil engineering students in the LMD (License-Master-Doctorate) system.

The lecture notes on steel structures provides an in-depth introduction to the fundamental principles of metallic framework construction according to Eurocode 3 and CCM97. It begins with essential safety concepts, emphasizing the importance of personal protective equipment, risk prevention, and site safety regulations. The course then explores the main types of structural connections, such as bolted and welded joints, highlighting their design, advantages, and applications. Students also learn to perform calculations for components under simple tension, using fundamental formulas to ensure structural integrity. Finally, the course covers the analysis and design of flexural members (bent elements), focusing on determining internal stresses and deflections according to recognized engineering standards. This comprehensive training equips students with the knowledge required to design safe and efficient steel structures.

TABLE OF CONTENTS

4- Design of elements under simple tensile loading

5- Design of Flexural Members

Chapter 1: Generalities

1.1. Introduction

Metal as a construction material was first used in England in 1779 when building a 30-meter span arch. Between 1780 and 1820, a large number of bridges were built using cast iron. The development of furnaces allowed for the evolution of metal. In 1890, steel replaced cast iron.

Steel structures are widely used in buildings and various constructions:

- Residential buildings
- Industrial buildings
- Road bridges
- High-rise buildings
- Parking garages

Steel structures are formed either:

- By a system of bars: Beams, columns, trusses
- By Shell systems

1.2. The advantages of steel construction

- A remarkable load-bearing capacity, due to the high resistance that steel provides under different loads.
- Short lead times (manufacturing of elements in the factory and their assembly on site).
- The perfect disassemblability and interchangeability of steel constructions, which facilitates the reinforcement or replacement of certain parts of the structure.
- Possibility of recovering the material from a collapsed construction (in the event of an earthquake).
- Aesthetics.

1.3. Disadvantages of steel construction

- Corrodibility, which makes protection by painting or another process necessary.
- Poor fire resistance
- The risks of instability
- Expensive construction (study / realization)

- Risk of fatigue due to dynamic stresses (cyclic loads)

1.4. Chemical composition of steel

Steel is a material primarily composed of iron (content > 95%) and carbon, which only makes up a small portion (≤ 1.7%). Steel may contain other elements in small quantities, which are either impurities or intentionally added.

1.4.1. Classification of steels based on carbon content

Grade of Steel	Carbon Content (%)	Use Cases
Mild Steel	0.05 < C < 0.3	Structural work, bolts
Medium-hard steel	0.3 < C < 0.6	Rails, forged parts
Hard steel	0.6 < C < 0.75	Tools
Extra hard steel	0.75 < C < 1.2	Tools, punches
Wild steel	1.2 < C < 1.7	Special parts

1.5. Steels used in metal construction

- General purpose steel
- Corrosion-resistant stainless steel
- Heat-treated steels for high strength

1.6. Mechanical properties of steels

The main mechanical properties of steel are:

- **Strength** is the ability of a material to resist deformation or failure under stress.
- **Ductility** is the ability of a material to deform plastically without breaking.
- **Hardness** is the ability of a material to resist indentation or scratching.
- **Resilience** is the ability of a material to absorb energy and return to its original shape after being deformed.

The mechanical properties of steel are important considerations in the design and selection of steel for various applications. For example, steel used in bridges and buildings must have high strength and ductility to withstand the weight of the structure and resist deformation from wind and other loads. Steel used in cutting tools must have high hardness to resist wear and tear.

1.6.1. Tensile testing

The tensile test is performed on a cylindrical specimen subjected to a progressively increasing tensile force from zero until rupture. The successive elongations of the specimen are measured, and a stress-strain diagram is obtained as shown in the curve below.

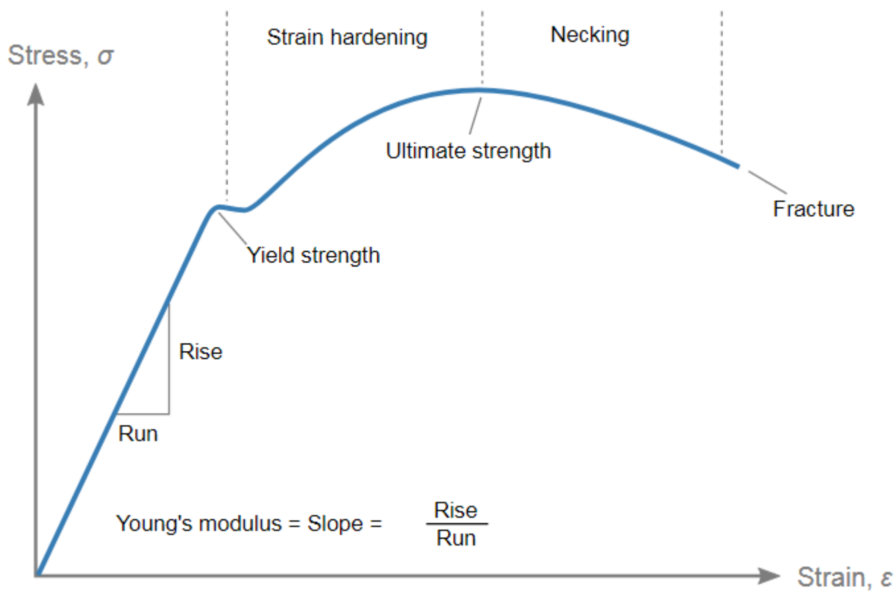


Figure 1.1 : Stress-strain curve of a steel specimen

- The tensile test is a fundamental materials science test that measures a material's resistance to a tensile force being applied to it.
- The results of the tensile test are used to determine a material's tensile strength, yield strength, and elongation.
- The stress-strain diagram is a graphical representation of the relationship between stress and strain in a material.
- The tensile test is typically performed on a universal testing machine.

1.6.2. Hardness Test

It allows to determine more quickly the grade of steel and it is established by the penetration of a point in the steel. The test can be carried out by one of the following three procedures:

- Brinell test

- Rockwell test
- Vickers test

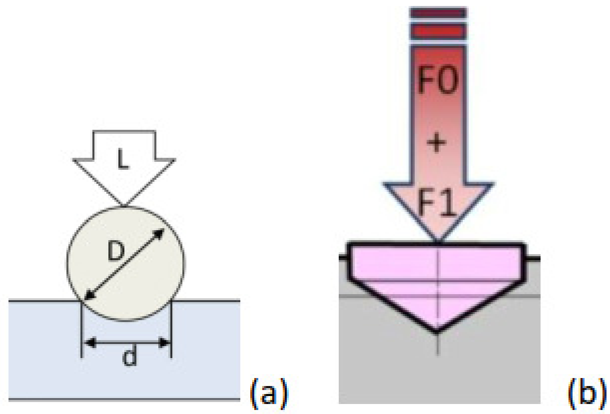
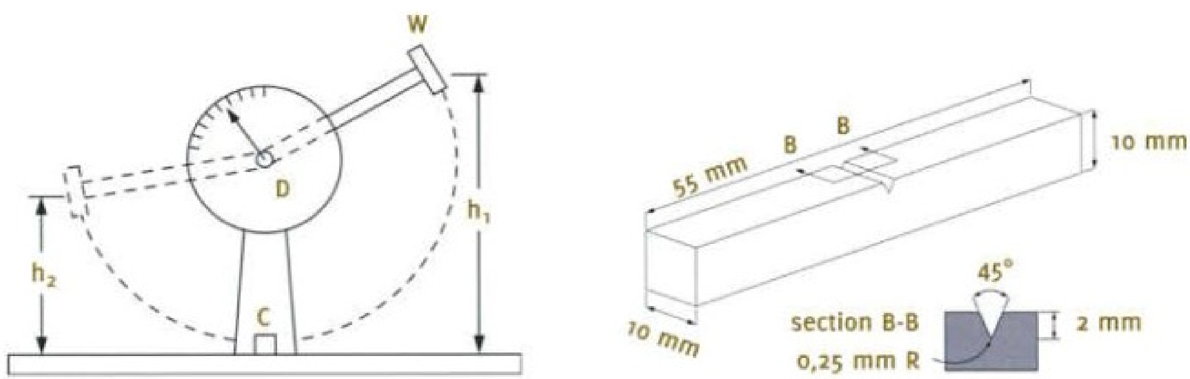


Figure 1.2 : (a) Brinell Test, (b) Rockwell Test

1.6.3. Impact Test

Impact strength is the ability of a material (steel) to resist impact at room temperature. [CHARPY Test]. (An Impact is an external action applied at high speed)."

The Charpy test is a common method for measuring the impact strength of materials. In this test, a pendulum-mounted hammer strikes a notched specimen, and the amount of energy absorbed by the specimen is measured. This energy is a measure of the material's impact



strength.

Figure 1.3 : Charpy Test

1.7. Performance of Steel for Metal Structures

Structural steels are primarily defined by their performance properties, which are subject to guarantees. These include:

- **Yield strength at 20°C:** $ReH = f_y$ expressed in N/mm²
- **Tensile strength at 20°C:** $Rm = f_u$ expressed in N/mm²
- **Elongation at rupture at 20°C:** A = ε_{rup} expressed in %
- **Impact strength in bending by Charpy test:** (KV) expressed in Joules (this is resilience)

1.8. Steel grades

Each country has its own standards. In this course, we will use European standards for steel products and, in most cases, French standards. The commonly used construction standards are:

- Steels after hot rolling and return to ambient temperature which have undergone a complete normalizing treatment and which are delivered in the normalized condition (designated by the letter N). The designation of steels is as follows:

S 235 JR N O

S: Structural steels

235: mechanical properties $ReH = fy$ "yield strength"

JR: symbols characterizing the breaking energy (Ductility also)

J				R				
Energy J	27	40	80	Test temperature	+20°C	0°C	-20°C	-30°C
Symbol	J	K	L	Symbol	R	0	2	3

N: 1st group of main additional symbols (related to manufacturing process) N, M and Q

N: delivered in the normal condition

M: delivered after a thermomechanical treatment (to obtain high-strength steels)

Q: delivered after undergoing a quenching and tempering treatment (to obtain high-strength steels).

Q: 2nd group of additional symbols

O: Offshore (marine oil structure)

S: Shipbuilding

D: Galvanization

The various construction steels and their grades are defined by standards. We limit ourselves to 3 main grades of steel:

- **S235** steel used in the majority of cases
- **S275** steel
- **S355** steel used in structural works

Standard and steel grade	Thickness t mm *			
	$t \leq 40$ mm		40 mm < $t \leq 80$ mm	
	f_y (N/mm^2)	f_u (N/mm^2)	f_y (N/mm^2)	f_u (N/mm^2)
S235	235	360	215	340
S275	375	430	255	410
S355	355	510	335	490

* t is the nominal thickness of the element

1.9. Calculation values of common steel coefficients

- Longitudinal modulus of elasticity: E = 210000 N/mm²
- Shear modulus:

$$G = \frac{E}{2\,(1 + \nu)} = 81000 \text{ N}/mm^2$$

ν: Poisson's ratio: $\nu = 0.3$

- Density: $\rho = 7850$ kg/m^3
- Coefficient of expansion: $\alpha = 12 \times 10^{-6}$ /°C (for T ≤ 100 °C)

1.10. Steelmaking products

Steel products used in metal construction are obtained through various processes. The most commonly used process is hot rolling.

The geometric characteristics of these products are provided in catalogs that are regularly updated.

The production of steel products involves the following stages:

* Liquid raw steel

* Semi-finished products (Billet, Slab, Bloom)

* Finished products (Flat products, Long products)

1.11. Flat Products

Steel sheets that are rolled and used for roofing or cladding. They are classified into three categories:

- Thin sheets, with a thickness of $t < 3$ mm
- Medium sheets, with a thickness of $3 \leq t \leq 4.76$ mm
- Thick sheets, with a thickness of $t \geq 4.76$ mm

These products are supplied in plates or coils.

Thin sheets with a thickness of $t \leq 1.5$ mm are intended for cold forming (cold bending) to create shapes such as:

- Ribbed (TN 40)
- Corrugated

(a) (b) (c) (d)

Figure 1.4. Sheets: a) thin, b) ribbed, c) corrugated, d) thick sheets.

1.12. Long Products

Long products are formed from blooms or billets using grooved cylinders.

Long products include :

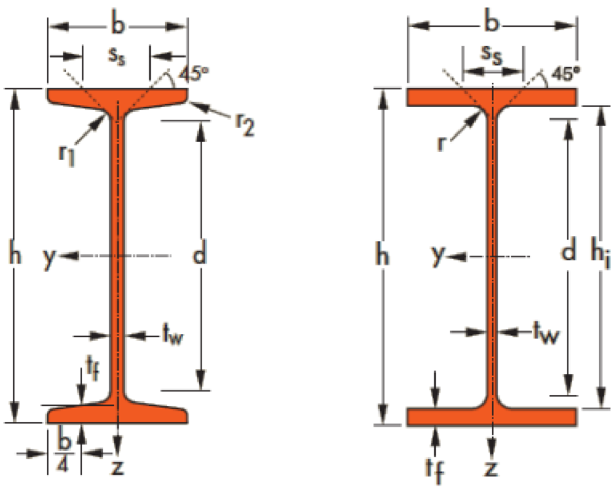
- Rolled profiles or beams (IPN, IPE, HE, UAP, UPN)
- Merchant bars (rounds, squares, flats, tees, and angles)
- Tubular profiles
- Reconstituted profiles by welding
- Cold-formed profiles

1.12.1. Rolled Profiles

a) I-Section Profiles:

In this type, four series are available:

- **IPN**: Normal I-shaped profile with inclined flanges (b = h/2, 80 ≤ h ≤ 600 mm)
- **IPE**: European I-shaped profile with parallel-faced flanges (b = h/2, 80 ≤ h ≤ 600 mm)
- **IPEA**: European I-shaped profile with reduced weight
- **IPER**: European I-shaped profile with increased strength



a) **IPN h (mm)** b) **IPE h (mm)**

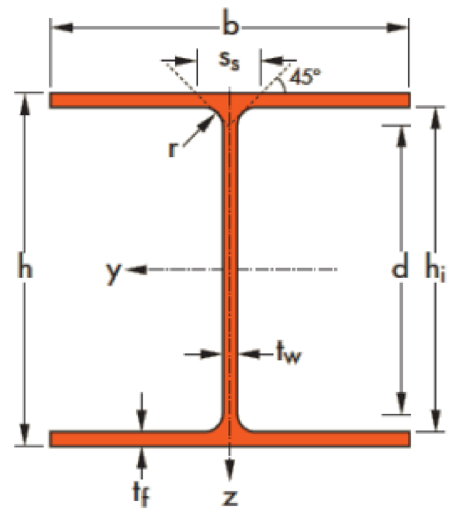
Figure 1.5. I- Shaped Profiles: a) IPN, b) IPE.

These profiles are generally used for flexed elements because of their high inertias around the y-axis.

b) <u>H-Section Profiles:</u>

H-Section Profiles (double T and wide flange) are generally used for elements subjected to composite bending (normal stress) such as columns. They include three series in order of increasing weight:

- **HEA**: H-Section Profile type A
- **HEB**: H-Section Profile type B
- **HEM**: H-Section Profile type M.



HEA h (mm)
Figure 1.6. H-Section Profiles

c) <u>U-profiles:</u>

This type of section is generally used as purlins or girders, lattice trusses, or for diagonals of bracing panels. There are two types marketed :

- **UPN:** European Standard U-profile
- **UAP** (UPE): U-profile with parallel flanges

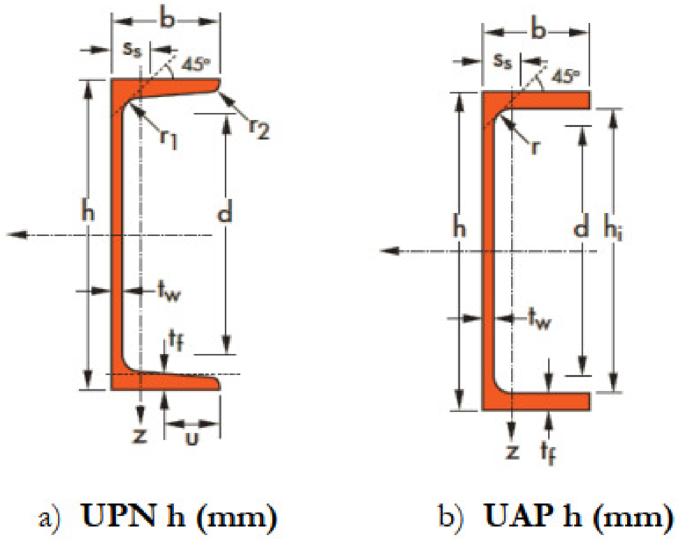


Figure 1.7. U-Shaped Profiles : a) UPN, b) UAP

1.12.2. Merchant Rolled Sections

a) <u>Angles:</u>

They are generally used for constructing truss frames or for diagonal bracing bays. They are available in two types:

- Equal-leg angles
- Unequal-leg angles

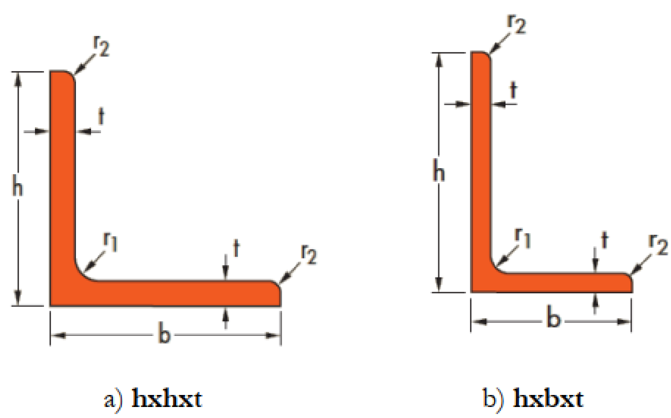
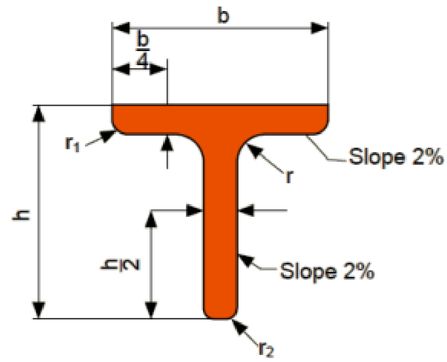


Figure 1.8. U-Shaped Profiles : a) Equal-leg angles, b) Unequal-leg angles

b) <u>T-section Steel Profiles:</u>

T-section steels can in many cases replace equal or unequal angles steels.

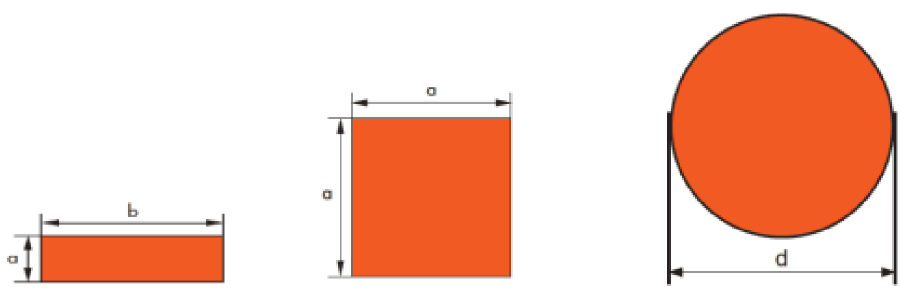


Té h (mm)

Figure. 1.9. T-Section Profiles

c) <u>Flat/Round/Square Bars:</u>

- Square bar (8 < a < 90 mm)
- Round bar (12 < d < 250 mm)
- Flat bar (t > 5mm)



a) b) c)

Figure 1.10. Bars: a) Flat, b) Square, c) Round

1.12.3. Tubular Profiles

They are also called "hollow sections." There are:

- Square hollow section ("Square tube")
- Rectangular hollow section ("Rectangular tube")
- Circular hollow section ("Circular tube")

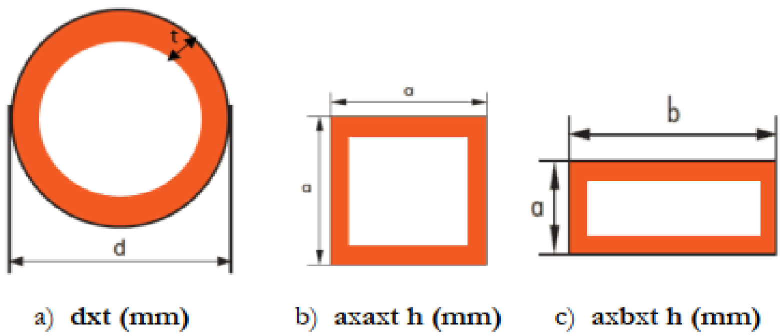


Figure 1.11. Hollow Section: a) Circular, b) Square, c) Rectangular

1.12.4. Welded built-up sections "W.B.S."

W.B.S. are elements (medium or heavy plates) reconstructed by welding. They offer a greater economic advantage than rolled sections.

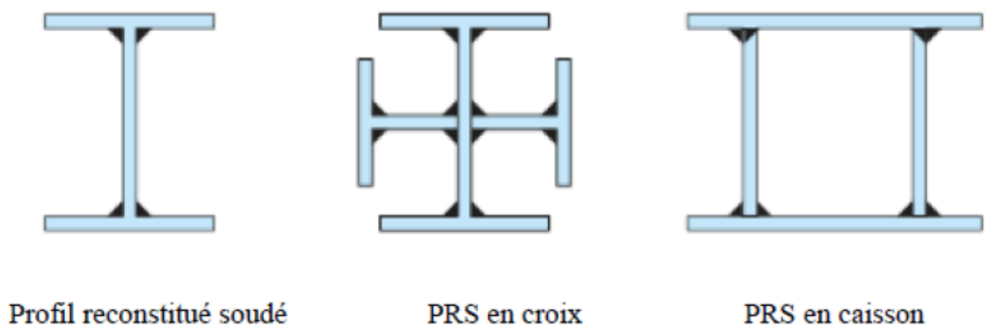


Figure 1.12. Different types of WBS Sections in manufacturing

1.12.5. Cold-Formed Profiles

These are profiles obtained by cutting and cold-bending thin sheet metal.

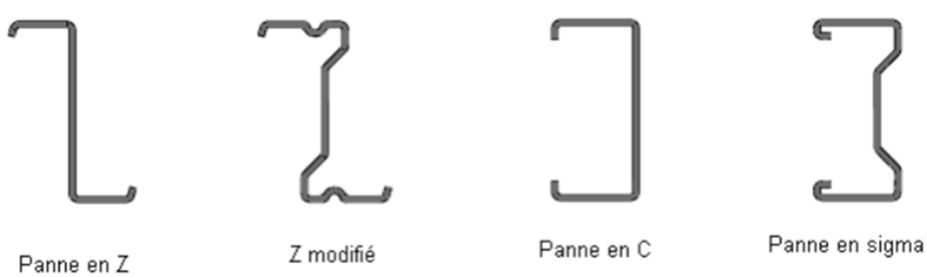


Figure 1.13. Different types of cold-formed profiles.

Chapter 2: Basic concepts and safety

2.1. Introduction

Construction safety is defined as:

- Structural strength and stability
- Fitness for use (operation)
- Durability

It is impossible to design buildings with absolute safety. Humans must accept a non-negligible probability of accidents.

2.2. Regulations

The dimensioning of structures and the verification of safety cannot be done empirically. They are based on calculation rules that use calculation methods.

The calculation rules for steel constructions applicable in Algeria are:

- CCM 97 (EC03)
- CCM 66

2.3. Calculation Basis

The global analysis of a structure subjected to a combination of actions results in an effect Ed (weighted).

- **E_d (S_d):** Design solicitation (normal force, bending moment, shear force, etc.).

The performance or failure prevention requirement is met when:

$$E_d \leq R_d \qquad (2.1)$$

Where: R_d is the design resistance for the considered failure mode (minimized).

Partial safety factors are introduced to account for uncertainties affecting solicitations (**E = S**) through amplification and resistances (**R**) through reduction. This concept is known as the **Limit States** approach.

2.4. Notion of Limit States

Limit states are classified into:

2.4.1. Ultimate Limit State (ULS)

It considers:

- Static equilibrium
- The resistance of cross-sections
- The resistance of elements
- The resistance of the assembly

2.4.2. Serviceability Limit State "SLS"

It considers:

- The deformation limit
- The vibration of structures.

2.5. Actions/Loads and Combinations of Actions

2.5.1. Actions

In the calculations and verifications of structures, the following loads must be taken into account:

- **Permanent Loads (G)**
- **Variable Loads (Q)**: These include both operational (or imposed) loads and climatic loads (such as wind or snow)
- **Accidental Loads (A)**: These are loads that are infrequent, such as those caused by earthquakes.
- **Effects Due to Temperature Variation or Support Displacement:** This refers to forces and stresses induced by changes in temperature or movement in the structure's supports.

a) Permanent Loads (G):

These are actions that exhibit very little variation over time:

- Self-weight
- Fixed equipment
- Support displacement
- Imposed deformation of the structure
- Pre-stressing

b) Variable Loads (Q):

The intensity of this type of action varies frequently and significantly over time. They include:

- Live loads: (People, furniture, etc.)
- Wind actions : (see RNVA99)
- Snow actions : (see RNVA99)
- Thermal gradient actions.

c) Accidental Actions (A):

This type of action originates from phenomena that occur rarely with a short duration of application: explosions, earthquakes (see RPA99 V2003).

2.5.2. Solicitations (S or E):

These are stresses due to normal forces, shear forces, bending moments, and torsion. They are calculated based on external actions, the geometric data of the element, and support conditions, using the methods of strength of materials calculations.

2.5.3. Combinations of Actions:

For each load case, the design values Ed of the effects of actions can be determined by applying the combination rules below.

a) Ultimate Limit State: "ULS"

<u>a.1. Fundamental Combinations:</u>

During persistent and transient design situations:

$$\sum_{j} \gamma_{GJ} G_{kj} + \gamma_{Q1} Q_{k1} + \sum_{i>1}^{n} \gamma_{Qi} \Psi_{0i} Q_{ki} \qquad (2.2)$$

Basic variable actions

Accompanying variable actions

γ_G and γ_Q are partial safety coefficients affecting actions and taking the values given in the table.

	Permanent Actions (γ_G)	Variable Actions (γ_Q)	
		Basic variable actions	Accompanying variable actions
Favorable Effect $\gamma_{G,\min}$	1.0	0	0
Unfavorable Effect $\gamma_{G,\max}$	1.35	1.5	1.5

a.2. Accidental combinations:

When accidental actions are introduced, it is written as:

$$\sum_j \gamma_{GJ} G_{kj} + \gamma_{Q1} Q_{k1} + \sum_{i>1}^{n} \gamma_{Qi} \Psi_{0i} Q_{ki} + \gamma_d A_d \qquad (2.3)$$

The partial safety coefficients in this case are given in the following table

Accidental	γ_{Gj}	γ_{Qi}	γ_d	Combination
1st Situation	1.0	1.0	1.0	$G_{kj} + Q_{k1} + A_d$
2nd Situation	1.0	1.0	1.2	$G_{kj} + Q_{k1} + 1.2A_d$
3rd Situation	0.8	0	1.0	$0.8\ G_{kj} + A_d$

b) Serviceability Limit State: "SLS"

The serviceability limit state combination is:

b.1. Rare combinations:

$$\sum_j G_{kj} + Q_{k1} + \sum_{i>1}^{n} \Psi_{0i} Q_{ki} \qquad (2.4)$$

b.2. Frequent combinations

$$\sum_j \gamma_{GJ} G_{kj} + \Psi_{11} Q_{k1} + \sum_{i>1}^{n} \Psi_{2i} Q_{ki} \qquad (2.5)$$

b.3. Quasi-permanent combination :

$$\sum_{j} G_{kj} + \sum_{i>1}^{n} \Psi_{2i} Q_{ki} \qquad (2.6)$$

Usually the combination is written : $G_{kj} + Q_{k1}$

Action	Ψ_0	Ψ_1	Ψ_2
building operating loads	0.87	1.0	1.0
Snow load	0.87	1.0	1.0
Wind Load (RNVA 99)	0.67	0.2	0
Temperature load excluding fire	0.53	0.5	0

2.6. Verification Principles

2.6.1. Ultimate Limit State (ULS) Verification:

At the Ultimate Limit State, the load effects are calculated under weighted load combinations. In this state, it must be verified that:

$$S_d \leq R_d = \frac{R_r}{\gamma_{Mi}} \qquad (2.7)$$

γ_{Mi} (γ_{M0}, γ_{M1}, γ_{M2}) is a partial safety coefficient used (≥ 1.0) to reduce the resistance R_r.

2.6.2. Serviceability Limit State (ULS) Verification (SLS):

In general, without load factoring at the ultimate serviceability limit state, it must be verified that:

$$E_d \leq C_d \qquad (2.8)$$

E_d: Design value of the effect of the action at the SLS (displacement, vibration, stress, ...)

C_d: Limit value of the material design property considered by this effect.

Chapter 3: Assemblies

3.1. Introduction

Steel structures are composed of a set of bar elements (columns and beams) that are assembled together to form a framework. As such, connections play a very important role in the strength and stability of these structures.

A connection is a joining device that allows multiple steel elements to be joined and secured together, ensuring the transmission and distribution of the various internal forces (N_{sd}, M_{sd}, V_{sd}) between the connected elements.

Figure 3.1. Assembly in steel structures

3.2. Various Types of Assembly

In most metal constructions, the different types of assembly that are commonly encountered are shown in the figure 6.2.

In this figure we find the following types of connections:

A: Beam-to-edge column

B: Beam-to-intermediate column

C: Beam continuity

D: Column continuity

E: Column base

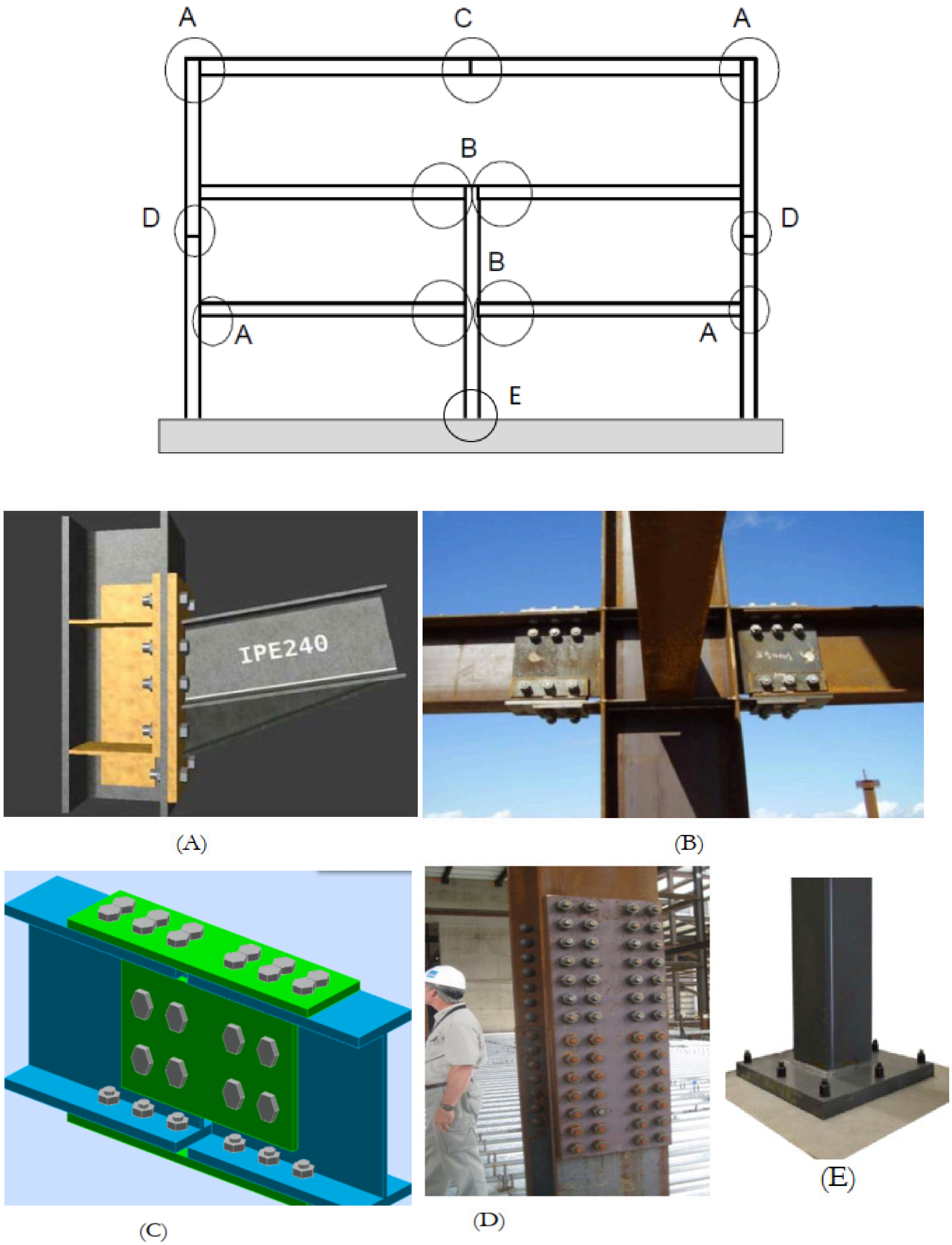


Figure 3.2. Types of Assemblies in Steel Structures

3.3. Main Assembly Methods

3.3.1. Riveting

Riveting is the oldest assembly method used. This technique, which is being used less and less, involves inserting a heated rivet through a hole and forging the protruding part of the shank by pressure or hammering (using a rivet set) to form a second head on the opposite side of the joint.

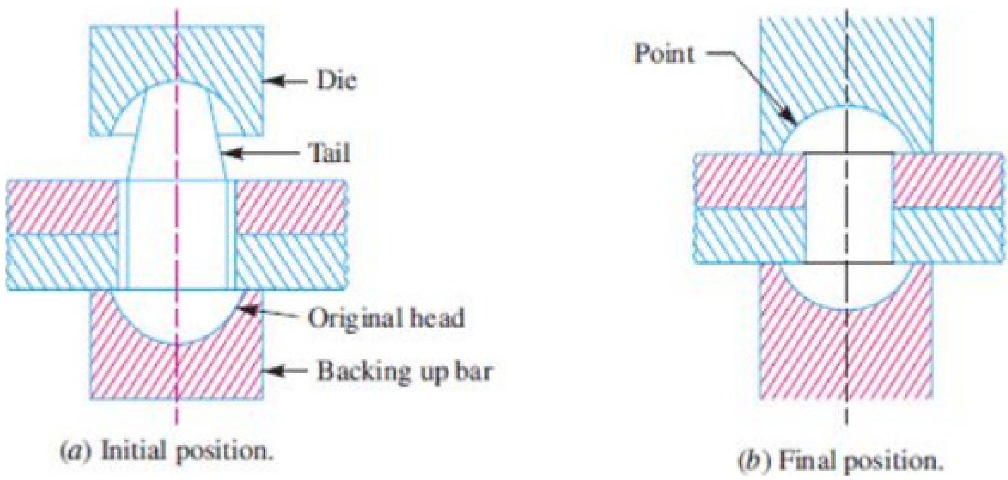


Figure 3.3. Methods of riveting

3.3.2. Bolting

Bolting is an assembly method used in steel structures. It involves joining elements using bolts inserted into pre-drilled holes in the components. These fasteners function through their shanks to resist the applied loads.

In this case, either of the following is used:

- Ordinary bolts
- High-strength bolts (H.S.)

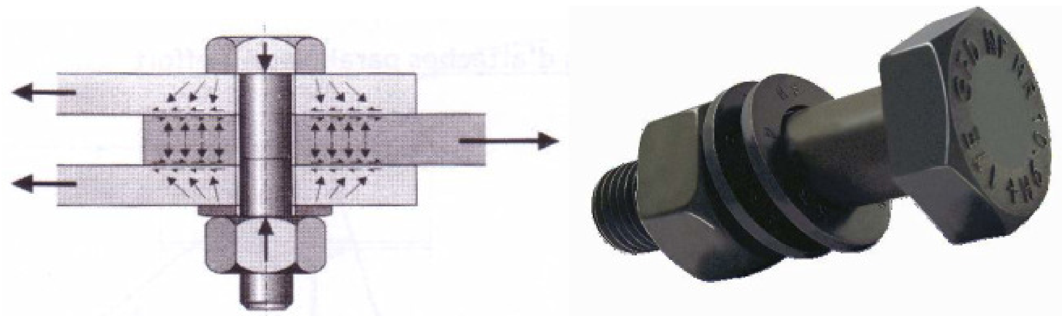


Figure 3.4. Bolting

3.3.3. Welding

The assembly is achieved through the application of weld beads

Figure 3.5. Welded assembly

The choice of assembly type is dictated by technical considerations (manufacturing, installation, transportation, etc.).

Note:

Assemblies are also classified as:

- Rigid assembly;
- Semi-rigid assembly;
- Articulated (or hinged) assembly.

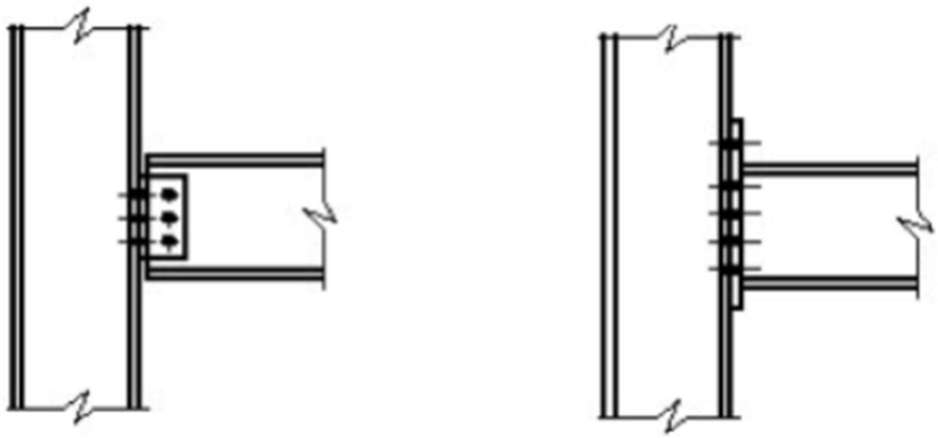


Figure 3.6. Creation of a joint/fixed connection by assembly

3.4. Ordinary Bolting "OB"

Ordinary bolts, also referred to as non-preloaded bolts, are intended to be installed with simple tightening, without controlled preload. Such bolted connections are designed to resist forces through bearing and/or friction depending on the type of joint. These connections can transmit forces in any direction with respect to the bolt axis.

It is standard practice to consider separately the forces **parallel** (shear) and **perpendicular** (tension) to the bolt axis, as they represent different load transfer mechanisms and require independent verification in accordance with the relevant design checks specified in the CCM97/Eurocode.

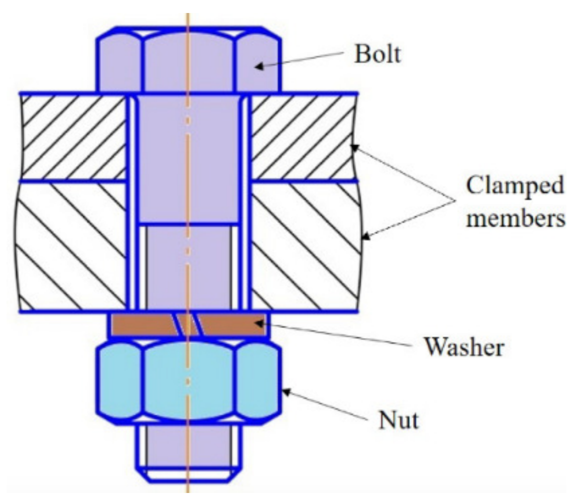
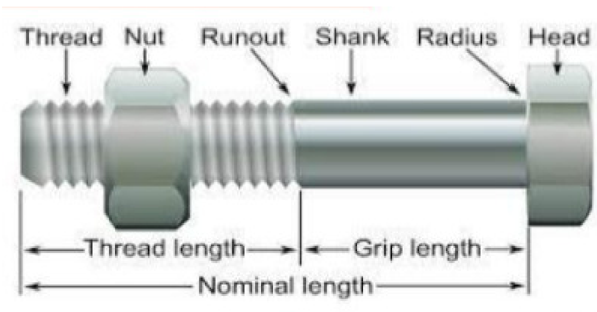


Figure 3.7. A typical nut–bolt assembly

3.4.1. Geometric Characteristics of Bolts:

A standard bolt is a set consisting of a round threaded rod designed to secure a hexagonal-shaped nut, which, along with the bolt head, ensures the clamping of the assembled parts. A round washer can be placed under the nut.



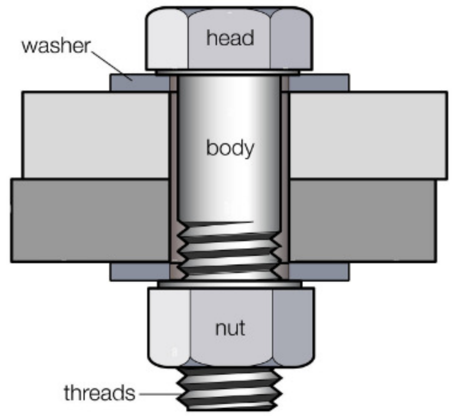


Figure 3.8. Composition of a Standard Bolt.

The geometric characteristics of bolts are summarized in Table 6.1.

The designation of a bolt is determined by the diameter (d in mm) of the unthreaded part of the bolt body, preceded by the uppercase letter (M). For example, if d = 18 mm, the designation is: M18.

Table 6.1. Geometric Characteristics of Bolts

Designation	M10	M12	M14	M16	M18	M20	M22	M24	M27	M30
d (mm)	10	12	14	16	18	20	22	24	27	30
d_0 (mm)	11	13	15	18	20	22	24	26	30	33
A (mm^2)	78.5	113	154	201	254	314	380	452	573	707
A_s (mm^2)	58	84.3	115	157	192	245	303	353	459	561
d_m (mm)	18.3	20.5	23.7	24.6	29.1	32.4	34.5	38.8	44.2	49.6

d : the nominal bolt diameter (Unthreaded part)

d_0 : the hole diameter for a bolt

A : the gross cross-section area of bolt (Unthreaded part)

A_s : the tensile stress area of the bolt (Threaded part)

d_m : the mean of the across points and across flats dimensions of the bolt head or the nut, whichever is smaller

3.4.2. Mechanical Characteristics of Bolts

Bolts are manufactured in seven grades of steel, known as **bolt classes**. Each class has a yield strength limit (f_{yb}) and an ultimate tensile strength (f_{ub}). A class is defined by two numbers (a.b), with the following considerations:

$$\begin{cases} f_{yb} = 10.\,a.\,b \\ f_{ub} = 100.\,a \end{cases} \qquad (N/mm^2) \qquad (3.1)$$

Table 3.2. Nominal values of the yield strength f_{yb} and the ultimate tensile strength f_{ub} for bolts

Bolt class	4.6	4.8	5.6	5.8	6.8	8.8	10.9
f_{yb} (N/mm^2)	240	320	300	400	480	640	900
f_{ub} (N/mm^2)	400	400	500	500	600	800	1000

Class 8.8 and 10.9 bolts are called "high-strength bolts."

3.4.3. Design of Ordinary Bolts

Bolts resist with their bodies to transmit the overall forces from one part to another. The types of loading can be summarized in three cases:

A. Shear

B. Tension

C. Combined shear and tension

A. Bolts subjected to shear force:

In this case, the following verifications should be carried out in accordance with CCM97/Eurocode 3:

- Shear resistance of the bolts
- Bearing resistance of the connected plates

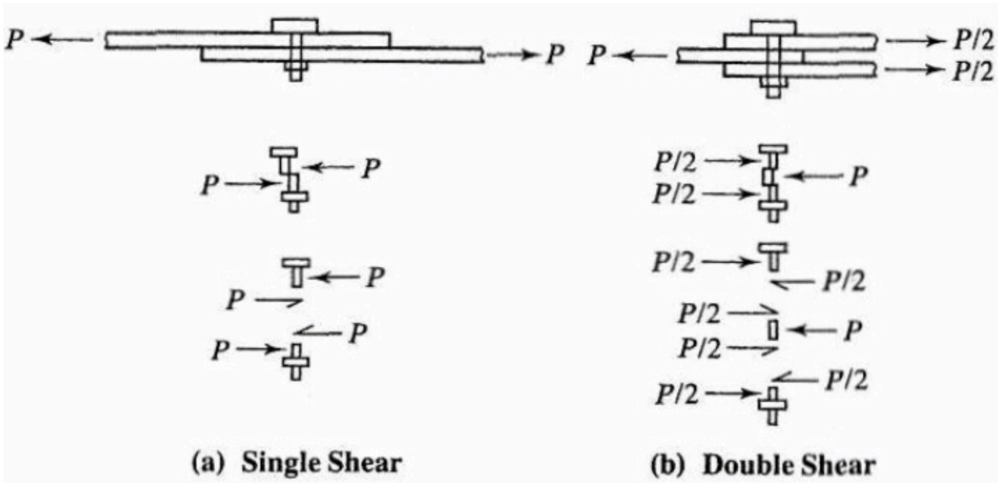


Figure 3.9. Bolts subjected to shear force (single shear / double shear)

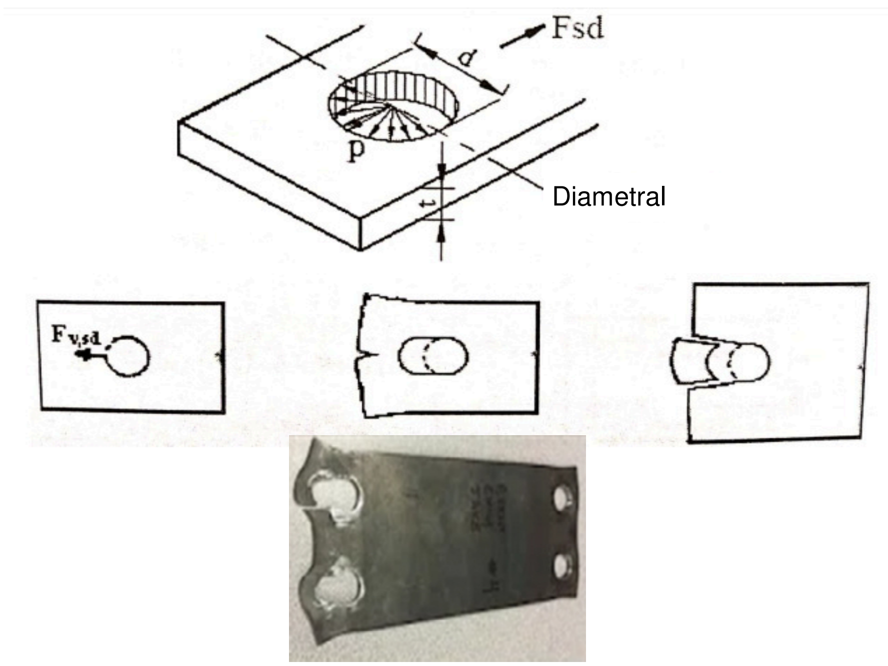


Figure 3.10. Diametral pressure on an assembled part

<u>A.1. Shear Resistance of Bolts:</u>

The design shear force acting on each bolt, $F_{v,,\mathrm{sd}}$ must be less than or equal to the design shear resistance, $F_{v,Rd}$.

$$F_{v,\mathrm{sd}} \leq F_{v,d} \qquad (3.2)$$

- For bolts of grades 4.6, 5.6, and 8.8:

$$F_{v,Rd} = \frac{0.6\, f_{ub}\, A_s}{\gamma_{Mb}} \tag{3.3}$$

- For bolts of grade 4.8, 5.8, 6.8, and 10.9:

$$F_{v,Rd} = \frac{0.5\, f_{ub}\, A_s}{\gamma_{Mb}} \tag{3.4}$$

- If the shear plane passes through the unthreaded portion of the bolt:

$$F_{v,Rd} = \frac{0.6\, f_{ub}\, A}{\gamma_{Mb}} \tag{3.5}$$

With:

A_s: cross-sectional area of the threaded portion of the bolt

A: nominal cross-sectional area of the unthreaded portion of the bolt

f_{ub}: ultimate tensile strength of the bolt steel

γ_{Mb}: partial safety factor, γ_{Mb} = 1.25

Note:

In the case of an assembly involving multiple components (>2), the resistance of a bolt must be multiplied by the number of shear planes.

A.2. Resistance of Assembled Parts to Diametral Bearing Pressure:

This check accounts for the geometric dimensions of the assembled parts near the bolts:

$$F_{v,Sd} \leq F_{b,Rd} \tag{3.6}$$

$$F_{b,Rd} = \frac{2.5\, \alpha\, f_u\, d\, t}{\gamma_{Mb}} \tag{3.7}$$

$$\alpha = \min(\frac{e_1}{3\, d_0};\ \frac{p_1}{3d_0} - \frac{1}{4};\ \frac{f_{ub}}{f_u}; 1) \tag{3.8}$$

F_b,: the resistance of the member to bearing pressure at the edge of a standard hole.

d: diameter of the unthreaded portion of the bolt shank.

d_0: nominal diameter of the hole.

t: Thickness of the assembled part.

f_u: Ultimate tensile strength of the steel in the assembled part.

e_1, p_1: For constructional details (Figure 6.11).

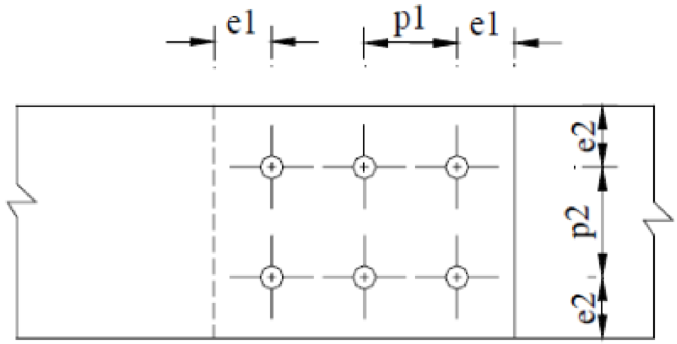


Figure 3.11. Distances $e1$ and $p1$

Note:

If oversized holes are used, the value of F_b, should be multiplied by 0.8. If the holes are slotted and the force is perpendicular to the slot, 0.6 × , is used.

A.3. Assembly Category:

An assembly using standard bolts, designed based on ultimate shear force and bearing pressure, is classified as ***Category A*** according to CCM 97 (EC3).

Assemblies in this category are referred to as bearing-type connections.

B. Bolts Subjected to Tensile Force:

Bolts are under tensile stress when the load is parallel to the axis of the shank. In this case, the following must be verified:

- The tensile strength of the bolts
- Punching shear resistance

B.1. Tensile Resistance of Bolts:

For a bolt under tension, the following condition must be met:

$$F_{t,Sd} \leq F_{t,Rd} \qquad (3.9)$$

$$F_{t,Rd} = \frac{0.9\, f_{ub}\, A_s}{\gamma_{Mb}} \qquad (3.10)$$

γ_{Mb} = 1.5 (In the case where the bolts are subjected to tension);

A_s: the tensile stress area of the threaded part of the bolt;

f_{ub}: the ultimate tensile strength of the bolt steel.

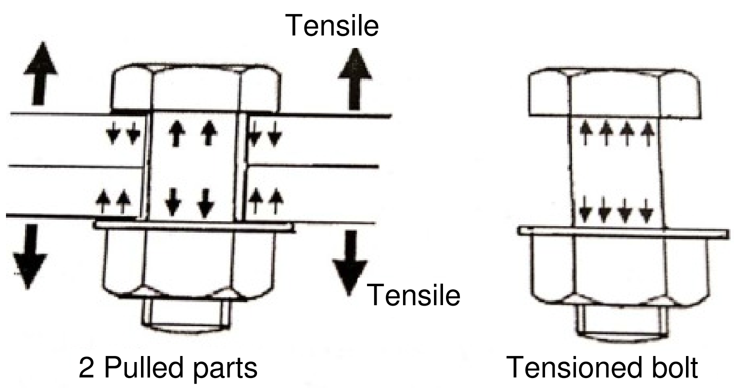


Figure 3.12. Bolt subjected to a tensile force

B.2. Punching Shear Check:

The punching shear check evaluates the resistance of the component under the concentrated load applied by the bolt head or nut. It is expressed as:

$$F_{t,Sd} \leq B_{p,Rd} \qquad (3.11)$$

$$B_{p,Rd} = 0.6\, \pi\, d_m\, t_p\, \frac{f_u}{\gamma_{Mb}} \qquad (3.12)$$

$B_{p,Rd}$: the punching shear resistance of the part.

γ_{Mb} **=** 1.25 : partial safety factor for the material.

d_m : average diameter between the circumscribed and inscribed circle of the bolt head.

t_p : thickness of the assembled part.

f_u : ultimate tensile strength of the steel of the assembled part.

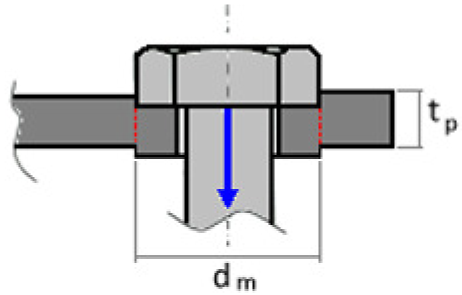


Figure 3.13. Punching shear resistance

B.3. Assembly Category:

Bolted assemblies subjected to tensile force and verified for punching shear are classified by C.C.M. 97 (EC3) as **Category D**. This category refers to non-preloaded tensioned bolt assemblies.

C. Combined effort of tension and shear:

An inclined load on the assembled parts results in an interaction between shear and tension (see following figure).

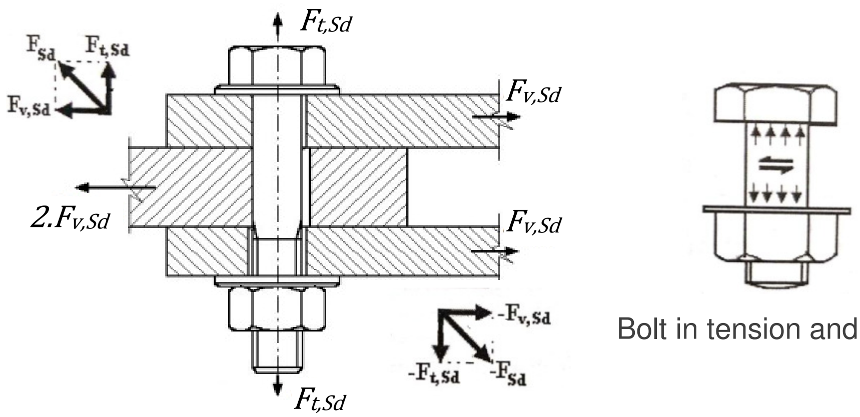


Figure 3.14. Combined effort of tension and shear

C.1. Verification of a bolt subjected to combined effects:

In this case, the CCM97 (EC3) recommends satisfying the following conditions:

- The bolt under combined effects :

$$\frac{F_{t,Sd}}{1.4\,F_{t,Rd}} + \frac{F_{v,Sd}}{F_{v,Rd}} \leq 1 \qquad (3.13)$$

➢ Tensioned bolt :

$$F_{t,Sd} \leq F_{t,Rd} \quad (3.14)$$

➢ Diametral pressure (Bearing)

$$F_{v,Sd} \leq F_{b,Rd} \quad (3.15)$$

➢ Punching for the bolts only

$$F_{t,Sd} \leq B_{p,Rd} \quad (3.16)$$

3.4.4. Nominal Hole Dimensions

The proposed play standards by CCM97 (EC3) are for the following holes:

- Standard holes: for assemblies of all categories.
- Oversized holes: for assemblies in categories A, B, and C (assemblies working under shear).
- Short Slot: for assemblies in categories A, B, and C.
- Long Slot: for assemblies in categories A, B, and C.

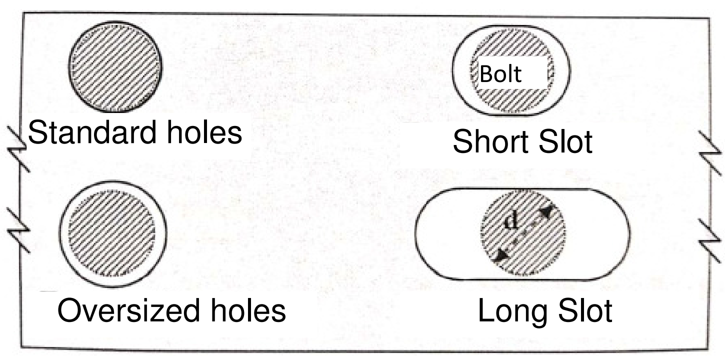


Figure 3.15. Types of bolt holes

Table 3.3. Standard dimensions of bolt holes (mm)

<table>
<tr><th>Hole \ Bolt</th><th>To/From M12</th><th>To/From M14</th><th>To/From M16</th><th>To/From M22</th><th>To/From M24</th><th>Over M27</th></tr>
<tr><td>Standard "d_0"</td><td colspan="2">d + 1</td><td colspan="2">d + 2</td><td colspan="2">d + 3</td></tr>
<tr><td>Oversized "d_0"</td><td>d + 3</td><td colspan="3">d + 4</td><td>d + 6</td><td>d + 8</td></tr>
<tr><td>Short Slot</td><td colspan="2">(d + 1) x (d + 4)</td><td colspan="2">(d + 2) x (d + 6)</td><td>(d + 2) x (d + 8)</td><td>(d + 3) x (d + 10)</td></tr>
<tr><td>Long Slot</td><td colspan="2">(d + 1) x 2.5d</td><td colspan="3">(d + 2) x 2.5d</td><td>(d + 13) x 2.5d</td></tr>
<tr><td colspan="7">d: nominal diameter of the bolt in mm</td></tr>
</table>

Note:

For long assemblies of category A, if the distance between the centers of the two rows of end bolts is large ($Lj > 15\ d$), the following condition must be met:

$$F_{v,Sd} \leq \beta_{Lf}\, F_{b,Rd} \qquad (3.17)$$

With:

$$\beta_{Lf} = 1 - \frac{L_j - 15d}{200\ d} \quad \left(0.75 \leq \beta_{Lf} \leq 1.0\right) \qquad (3.18)$$

β_{Lf}**:** a reduction factor.

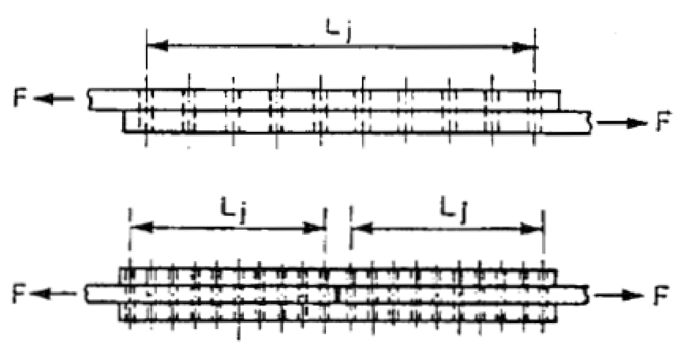


Figure 3.16. Long joints

3.5. High-Strength Bolting "HS"

An H.S. or high-strength bolt looks the same as an ordinary bolt but is made from high-yield-strength steel. It also includes an additional washer that must be placed under the bolt head to prevent punching of the assembled parts (see figure below).

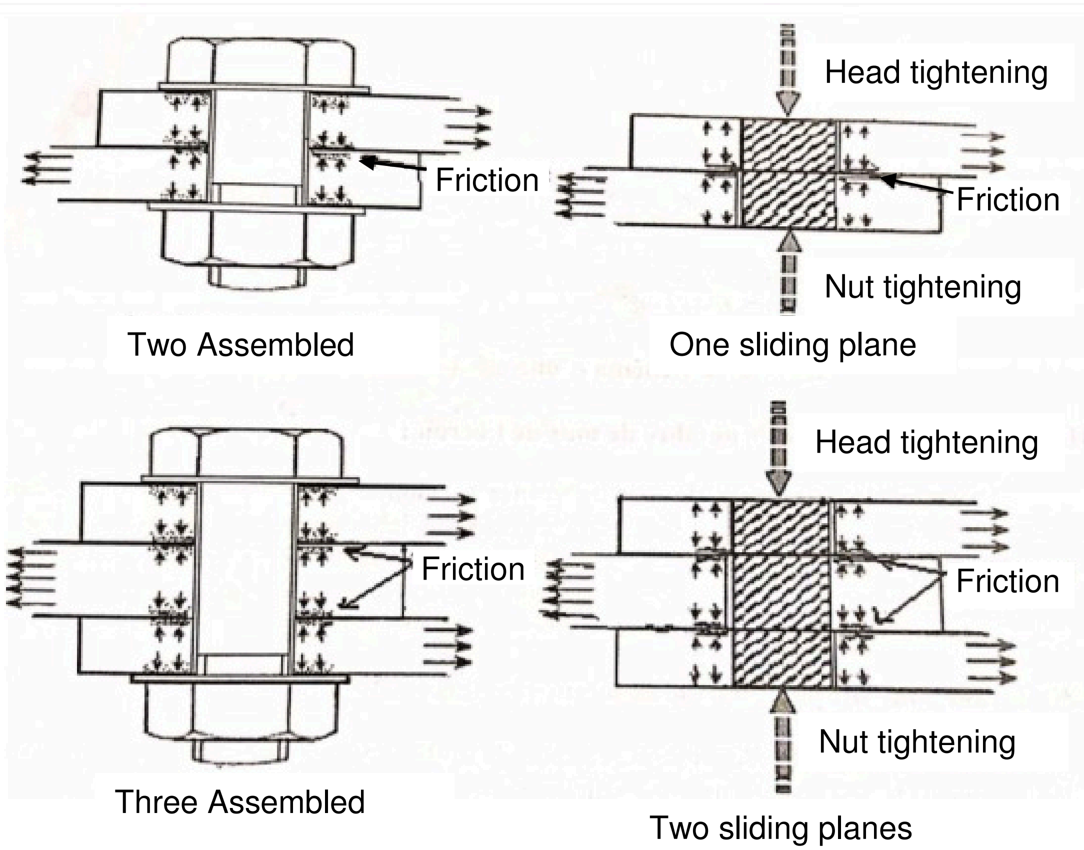


Figure 3.17. Assemblies with H.R. bolt

3.5.1. Operating Principle of a High-Strength (HS) Bolted Joint

During tightening, the bolt is subjected to high torque, which induces a **preload force** that tensions the bolt shank. This preload acts perpendicular to the contact surface of the assembled parts, creating strong **friction resistance** between them and preventing relative slip.

Unlike standard bolts, **high-strength (HS) bolts** do not rely on shear resistance but instead transfer loads through **friction** (or adhesion). They are also referred to as preloaded bolts or controlled-tightening bolts.

The load capacity depends on:

- The preload force
- The surface condition

Only two strength grades are defined for HS bolts: **8.8** and **10.9**.

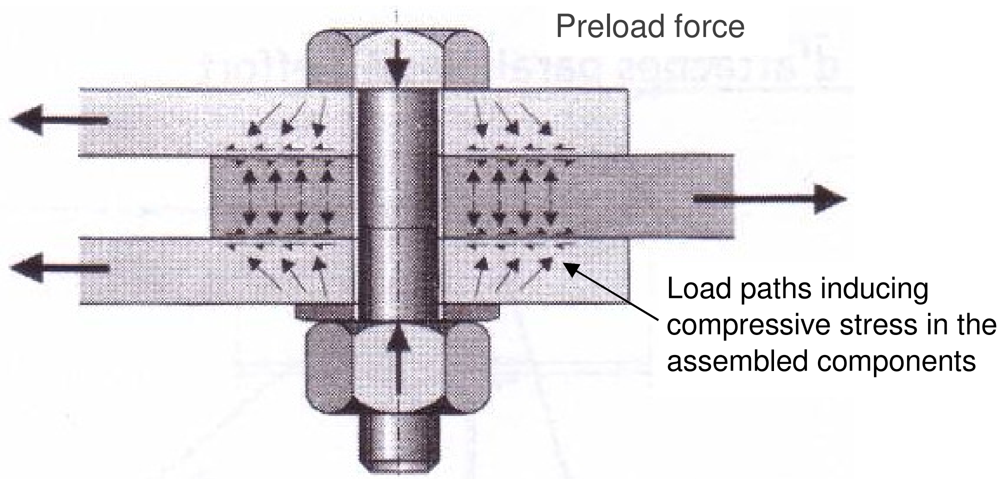


Figure 3.18. Operating principle of a high-strength bolt

3.5.2. Installation of High-Strength (HS) Bolting

The implementation of controlled tightening on construction sites can be achieved through several methods, including:

➢ Torque wrench tightening:

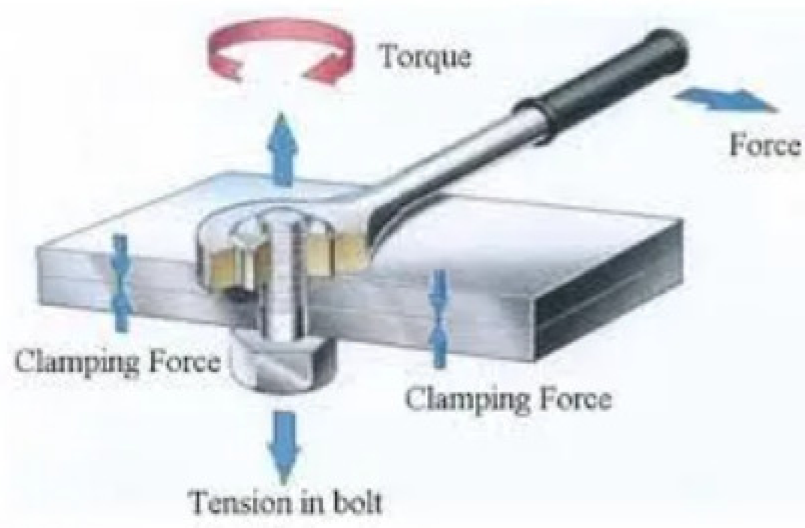


Figure 3.19. Torque wrench

- Tightening controlled by the number of nut turns
- Tightening controlled by a load indicating washer

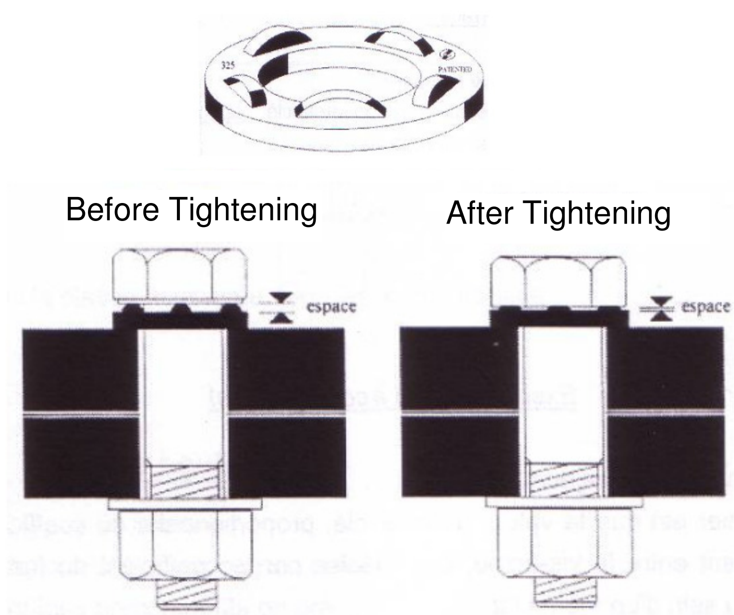


Figure 3.20. Tightening controlled by a load indicating washer

➢ Torque-controlled fastening with a shear groove

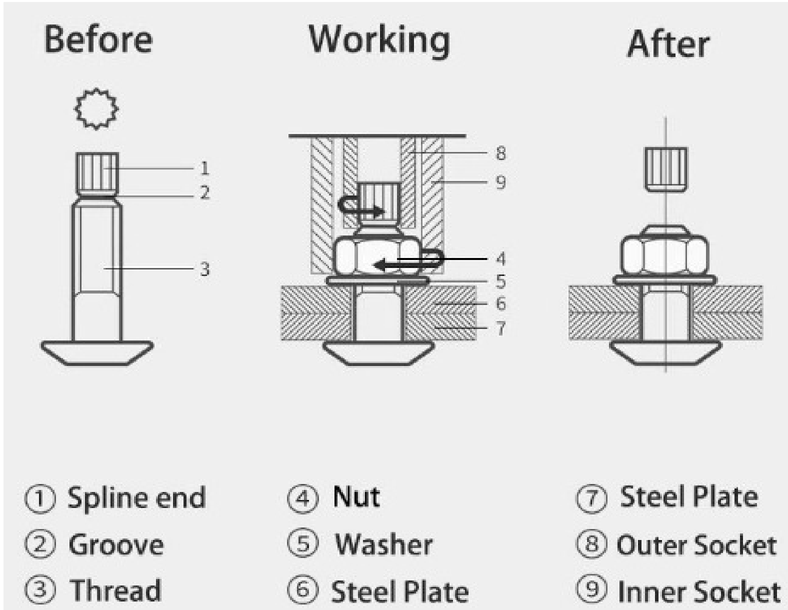


Figure 3.21. Torque-controlled fastening with a shear groove

3.5.3. Resistance of High-Strength (H-S) Bolted Assemblies

High-Strength bolts resist:

A – Slip

B – Tension

C – Both slip and tension

A. Design of H.S bolts in slip-resistant assemblies:

The CCM 97 (EC 3) classifies slip-resistant assemblies into two categories:

A.1. Category B Assembly:

It must be verified that: (at SLS and ULS)

$$F_{v,Sd}^{ser} \leq F_{s,Rd}^{ser} \quad (3.19)$$

$$F_{v,Sd} \leq F_{v,Rd} \quad (3.20)$$

$$F_{v,Sd} \leq F_{b,Rd} \quad (3.21)$$

A.2. Category C Assembly:

The following checks shall be performed at the Ultimate Limit State (ULS):

$$F_{v,Sd} \leq F_{s.Rd} \quad (3.22)$$

$$F_{v,Sd} \leq F_{b,Rd} \quad (3.23)$$

For both categories B and C, $F_{s.Rd}$ is the slip resistance of a preloaded bolt given by the following formula:

$$F_{s.Rd} = \frac{k_s \, n \, \mu \, F_{p.Cd}}{\gamma_{Ms}} \quad (3.24)$$

$F_{p.Cd}$: The preload force

$$F_{p.Cd} = 0.7 \, f_{ub} \, A_s \quad (3.25)$$

A_s: the effective cross-sectional area of the threaded part of the bolt

f_{ub}: the ultimate tensile strength of the high-strength bolt steel

n: the number of friction surfaces (slip planes)

k_s: coefficient depending on the size of the drilled holes (Table 3.4)

μ: coefficient of friction depending on the surface treatment quality of the contact surfaces between assembled parts (Table 3.5)

γ_{Ms}: partial safety factor (Table 3.6)

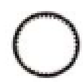
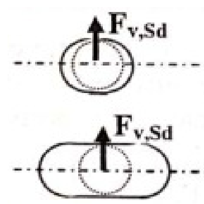
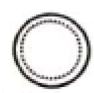
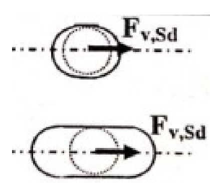
Table 3.4. Values of k_s

Description	k_s
Bolts in normal holes.	1,0
Bolts in either oversized holes or short slotted holes with the axis of the slot perpendicular to the direction of load transfer.	0,85
Bolts in long slotted holes with the axis of the slot perpendicular to the direction of load transfer.	0,7
Bolts in short slotted holes with the axis of the slot parallel to the direction of load transfer.	0,76
Bolts in long slotted holes with the axis of the slot parallel to the direction of load transfer.	0,63

Table 3.5. Slip factor, *μ*, for preloaded bolts

<table>
<tr><th>Surface treatment</th><th>Class</th><th>Slip factor (μ)</th></tr>
<tr><td>Surfaces blasted with shot or grit with loose rust removed, not pitted</td><td>A</td><td>0.50</td></tr>
<tr><td>Surfaces hot-dip galvanized and flash (sweep) blasted and with alkali-zinc silicate paint with a nominal thickness of 60 μm</td><td rowspan="2">B</td><td rowspan="2">0.4</td></tr>
<tr><td>Surfaces blasted with shot or grit;
a) coated with alkali-zinc silicate paint with a nominal thickness of 60 μm⁺
b) thermally sprayed with aluminium or zinc or a combination of both to a nominal thickness not exceeding 80 μm</td></tr>
<tr><td>Surfaces cleaned by wire brush or flame cleaning, with loose rust removed</td><td>C</td><td>0.30</td></tr>
<tr><td>Surfaces as rolled</td><td>D</td><td>0.20</td></tr>
</table>

Table 3.6. Partial safety coefficient, γ_{Ms}

Partial Safety Factor		γ_{Ms}	
Assembly Category		C	B
Design Limit State		Ultimate	Service
Type of Holes and Force Direction	Diagram	γ_{Ms}, ult	γ_{Ms}, ser
Standard Holes		1.25	1.1
Short or long slotted holes with force ⊥ (perpendicular) to the slot direction			
Oversized Holes		1.4	-
Short or long slotted holes with force // (parallel) to the slot direction			

B. Design of High-Strength Bolts (H.S) in Tension-Resistant Connections:

The verification becomes:

$$F_{t,Sd} \leq F_{t,Rd} \quad (3.26)$$

and

$$F_{t,Sd} \leq B_{p,Rd} \quad (3.27)$$

Note:

High-strength bolted connections subjected to tension are classified as Category E by CCM 97 (EC 3).

C. Combined Tension and Slip Resistance:

When a tensile force is applied to the bolts in a slip-resistant connection, it reduces the clamping force. Approximately 80% of the tensile force is deducted from the preload. This tensile force decreases the slip resistance at the contact interface.

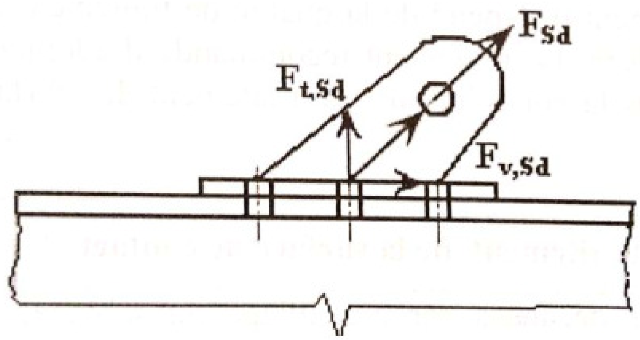


Figure 3.22. Combined loading on a bolting system.

The following table summarizes the necessary verifications for both categories of connections B and C.

Table 3.7. Verification of a high-strength bolted connection under slip resistance and tensile forces

	Catégorie B	Catégorie C
$F_{s,Rd}$	$F_{s,Rd.ser} = \frac{k_s \cdot n \cdot \mu \cdot (F_{p.Cd} - 0{,}8.F_{t.sd.ser})}{\gamma_{Ms.ser}}$	$F_{s,Rd} = \frac{k_s \cdot n \cdot \mu \cdot (F_{p.Cd} - 0{,}8.F_{t.sd})}{\gamma_{Ms.ult}}$
Vérifications	$F_{v,Sd.ser} \leq F_{s,Rd.ser}$ $F_{v,Sd} \leq F_{v,Rd}$ $F_{v,Sd} \leq F_{b,Rd}$ $F_{t,Sd} \leq B_{p,Rd}$	$F_{v,Sd} \leq F_{s,Rd}$ $F_{v,Sd} \leq F_{b,Rd}$ $F_{t,Sd} \leq B_{p,Rd}$

3.6. Assembly by Welding

Welding is a process of joining metal parts by bonding their material in a plastic or molten state. This bond, called a weld bead, is achieved by heating the joint areas of the parts to the point of fusion, along with the filler metal used for welding. The filler metal is supplied in the form of rods or coiled wire for use with electrodes or torches.

Figure 3.23. Assembly by Welding

3.6.1 Types of Welding position and Design Arrangements

Depending on their types, welds are classified as follows:

***A**. <u>Fillet Welds</u>*

Generally used to join parts forming an angle between 60° and 120°, fillet welds made at angles greater than 120° should not be considered suitable for transmitting loads. The following types are distinguished:

- T-joint assembly
- Lap joint assembly

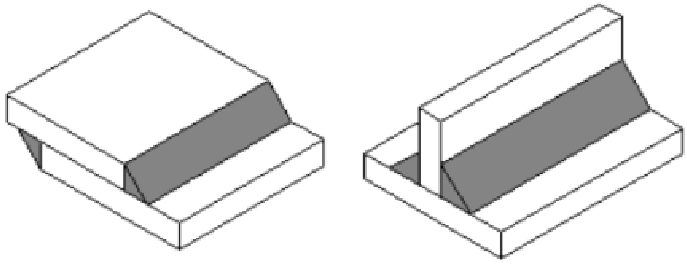


Figure 3.24. Fillet Welds

B*. *Butt Welds

These are welds made on parts joined end-to-end or in T-joints, where the weld bead penetrates into a beveled or non-beveled portion of the thickness at the end of the transverse piece.

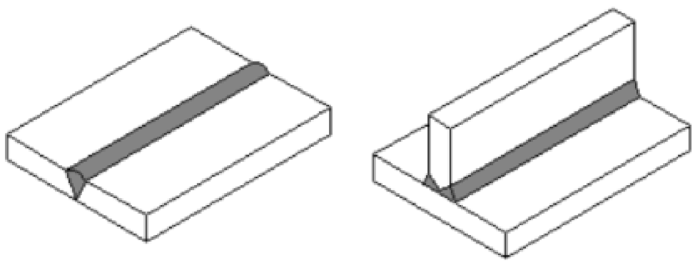


Figure 3.25. Butt Welds

C. Groove Welds

These are fillet welds made in circular or elongated holes. They are used solely to transmit shear forces and serve to prevent warping or separation at the interfaces of overlapping parts. The diameter of a circular hole or the length of an elongated hole must not be less than one-quarter of the thickness of the perforated piece.

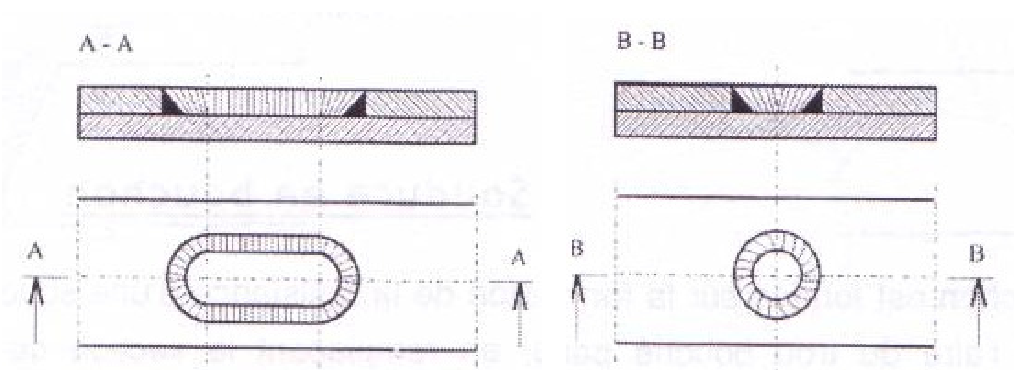


Figure 3.26. Groove Welds

D. ***<u>Plug Welds</u>***

These weld beads fill circular or elongated holes. The diameter of a circular hole or the width of an elongated hole intended for a plug weld must meet the following conditions:

$$tp \leq 16\,mm \implies t\ soudure = tp \qquad (3.28)$$

$$tp > 16\,mm \implies t\ soudure \geq \max\left(\frac{tp}{2}; 16\,mm\right) \qquad (3.29)$$

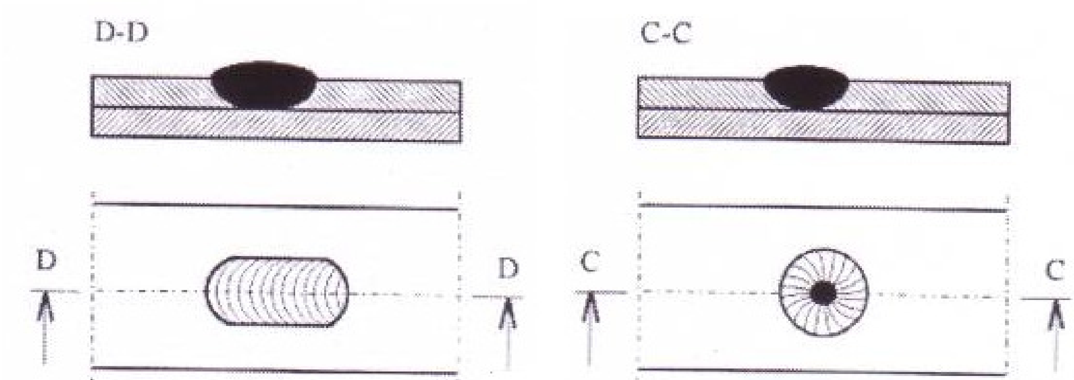


Figure 3.27. Plug Welds

E. ***<u>Welds on Rolled Edges</u>***

The four corners of the cross-section of a rectangular or square hollow section are rolled (rounded) edges. In assemblies made using the rolled edges of such profiles, the thickness of the weld beads is determined through preliminary welding tests for each type of configuration.

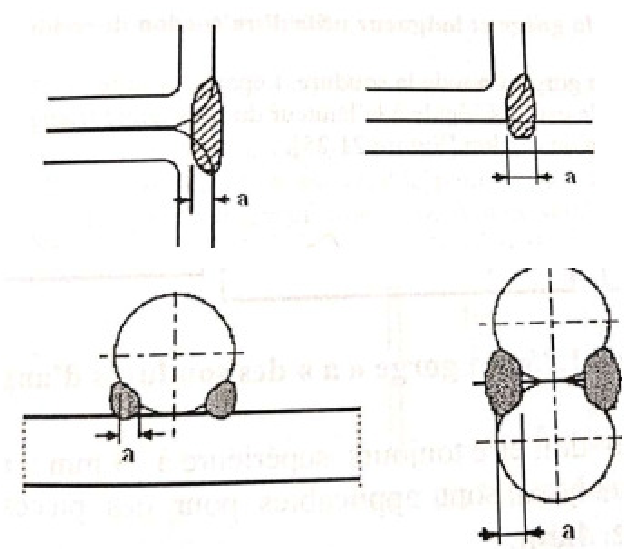


Figure 3.28. Welds on Rolled Edges

3.6.2. Design Strength of Fillet Welds

The stresses induced by forces applied to a weld bead are concentrated in an internal plane with the minimum cross-sectional area of the weld, known as the weld throat.

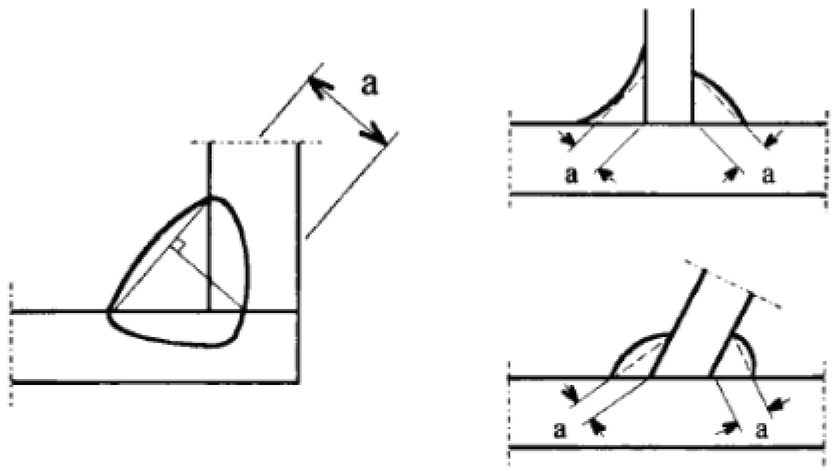


Figure 6.29 Weld Throat

In the minimum cross-sectional plane of a loaded weld bead, the following stress components can be distinguished:

$\sigma_\perp$: The normal stress perpendicular to the weld throat.

$\sigma_\parallel$: The normal stress parallel to the weld axis.

$\tau_\perp$: The shear stress in the throat plane, perpendicular to the weld axis.

$\tau_\parallel$: The shear stress in the throat plane, parallel to the weld axis.

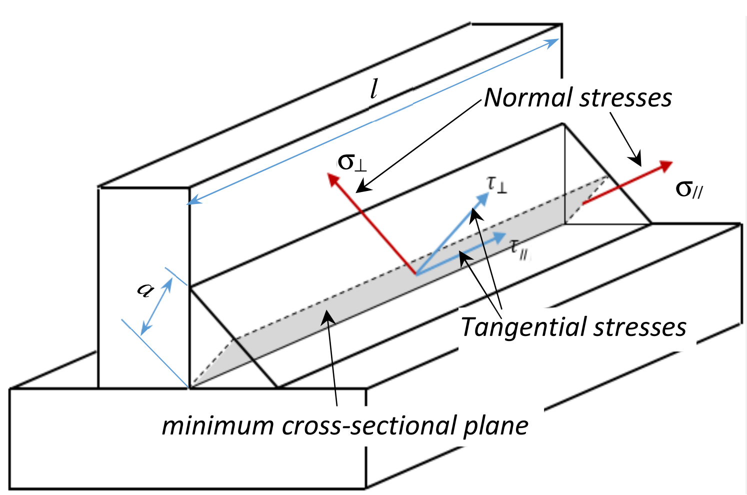


Figure 3.29: Stresses on the Throat Section of a Fillet Weld

According to the main directions of the weld bead, the forces acting on it are decomposed by projecting them onto the throat plane to obtain:

$$\sigma_{\perp} = \frac{F_{\sigma_{\perp}}}{a.L} \tag{3.30}$$

$$\sigma_{\parallel} = 0 \tag{3.31}$$

$$\tau_{\perp} = \frac{F_{\tau_{\perp}}}{a.L} \tag{3.32}$$

$$\tau_{\parallel} = \frac{F_{\tau_{\parallel}}}{a.L} \tag{3.33}$$

The strength of the fillet weld is sufficient if the following two conditions are met:

$$\begin{cases} \sqrt{(\sigma_{\perp})^2 + 3(\tau_{\perp}{}^2 + \tau_{\parallel}{}^2)} \leq \dfrac{f_u}{\beta_w \cdot \gamma_{Mw}} \\ et \quad \sigma_{\perp} \leq \dfrac{f_u}{\gamma_{Mw}} \end{cases} \tag{3.34}$$

Where f_u is the ultimate tensile strength of the weakest material in the assembled parts (between the parts and the filler metal).

a: the weld throat.

β_w: the appropriate correlation factor, which takes the following values:

Table 3.8. Values of the correlation factor β_w.

Steel Grade	Fe360(S235)	Fe430(S275)	Fe510(S355)
β_w	0.8	0.85	0.9

γ_{Mw}: partial safety coefficient, it is equal to:

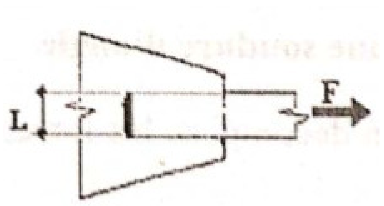
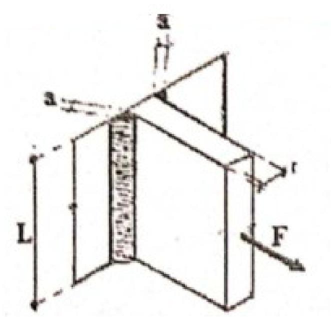
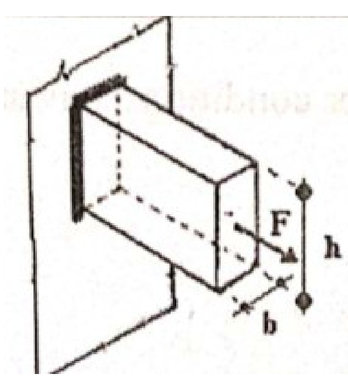
Table 3.9. Values of the partial safety coefficient γ_{Mw}.

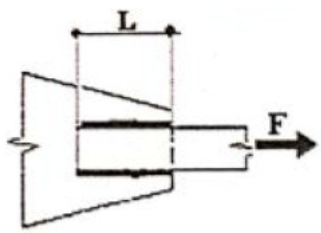
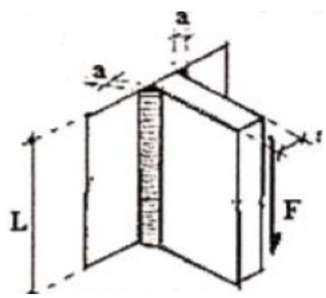
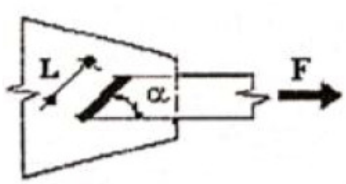
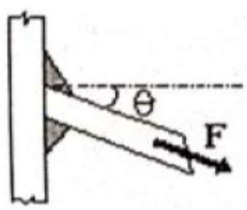
Steel Grade	Fe360(S235)	Fe430(S275)	Fe510(S355)
γ_{Mw}	1.25	1.3	1.35

To better illustrate the concept of force projection onto the weld throat, we will provide some simple examples in the following.

Notes:

- The throat "a" must always be greater than 3 mm: a ≥ 3 mm
- The assembled parts must have a thickness greater than 4 mm: $tp \geq 3$ mm
- If the weld bead length $L \leq (6.a; 40 \text{ mm})$, it is not considered for transmitting forces.
- Sometimes, mixed loading conditions occur.

Description	Perpendicular (⊥) Stresses	Parallel (‖) Stress
	$\sigma_{\perp} = \frac{F}{\sqrt{2}\ .a.L}$ $\tau_{\perp} = \frac{F}{\sqrt{2}\ .a.L}$	$\tau_{//} = 0$
	$\sigma_{\perp} = \frac{F}{2.\sqrt{2}\ .a.L}$ $\tau_{\perp} = \frac{F}{2.\sqrt{2}\ .a.L}$	$\tau_{//} = 0$
	$\sigma_{\perp} = \frac{F}{\sqrt{2}\ .a.2.(h+b)}$ $\tau_{\perp} = \frac{F}{\sqrt{2}\ .a.2.(h+b)}$	$\tau_{//} = 0$

Description	Perpendicular (⊥) Stresses	Parallel (∥) Stress
	$\sigma_{\perp} = 0$ and $\tau_{\perp} = 0$	$\tau_{//} = \frac{F}{a\,.\,2L}$
	$\sigma_{\perp} = 0$ and $\tau_{\perp} = 0$	$\tau_{//} = \frac{F}{a\,.\,2L}$
	$\sigma_{\perp} = \frac{F\ .\sin\alpha}{\sqrt{2}\ .a\,.\,L}$ $\tau_{\perp} = \frac{F\ .\sin\alpha}{\sqrt{2}\ .a\,.\,L}$	$\tau_{//} = \frac{F\ .\cos\alpha}{a\,.\,L}$
	$\sigma_{\perp} = \frac{F\ .}{a\,.\sum L}.\cos\left(\frac{\pi}{4} - \frac{\theta}{2}\right)$ $\tau_{\perp} = \frac{F\ .}{a\,.\sum L}.\sin\left(\frac{\pi}{4} - \frac{\theta}{2}\right)$	$\tau_{//} = 0$

Chapter 4: Design of elements under simple tensile loading

4.1. Introduction

Steel construction is composed of a set of structural elements subject to:

- Tension ;
- Compression ;
- Bending ;
- Torsion ;
- Shear ;
- Or: to combined stresses.

The elements subjected to pure tension are commonly called tensioned elements. A component is said to be in tension if the resultant of the forces acting on a section reduces to a normal force applied at the center of gravity (G) of the section and directed outward.

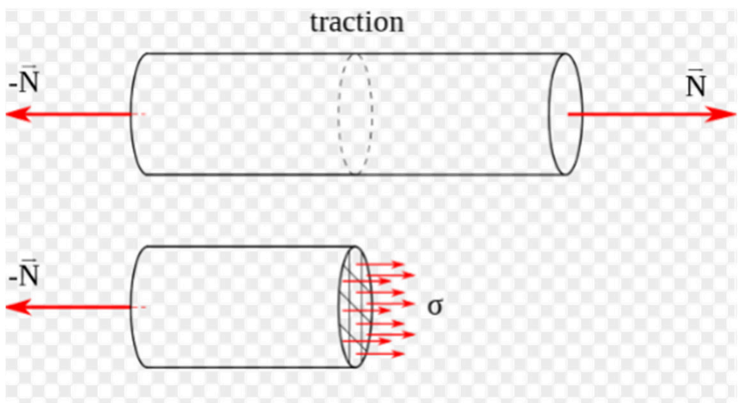


Figure 4.1. Simple tension

The stress σ, at any point of the cross-section is given by the relation:

$$\boldsymbol{\sigma = \frac{N}{A}} \qquad \textbf{(4.1)}$$

With:

$\boldsymbol{N}$: Normal tensile force

$\boldsymbol{A}$: Cross-sectional area

In general, common cross-sections of tension members are rolled profiles in the form of:

- Flat bars, round bars, square bars
- Angle sections
- Channel sections
- I-sections
- H-sections

4.2. Areas of application of tension elements

Tension elements are found in almost all metallic structures. In truss beams, some diagonals of bracing systems, tie rods, hangers, tie beams, and cables.

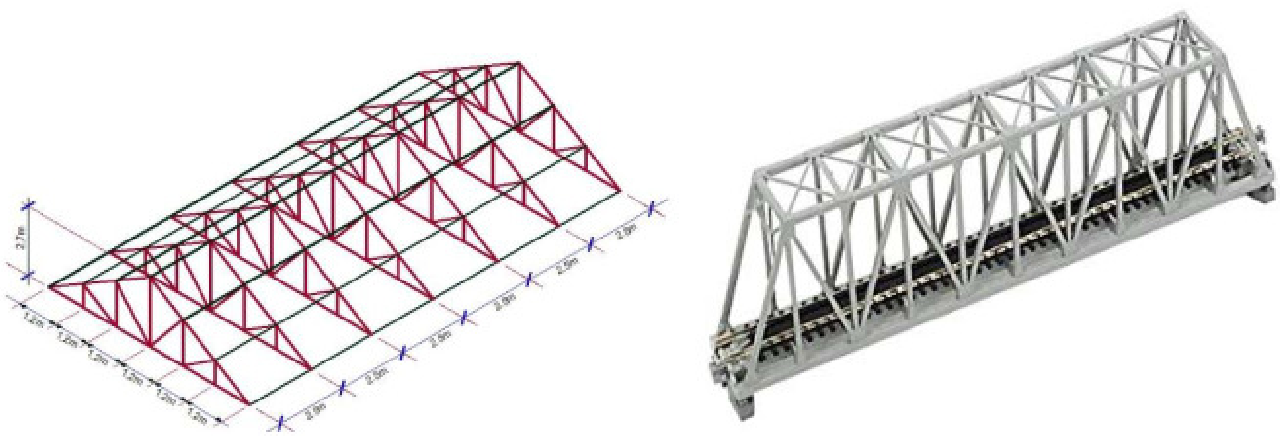


Figure 4.2. Truss Systems

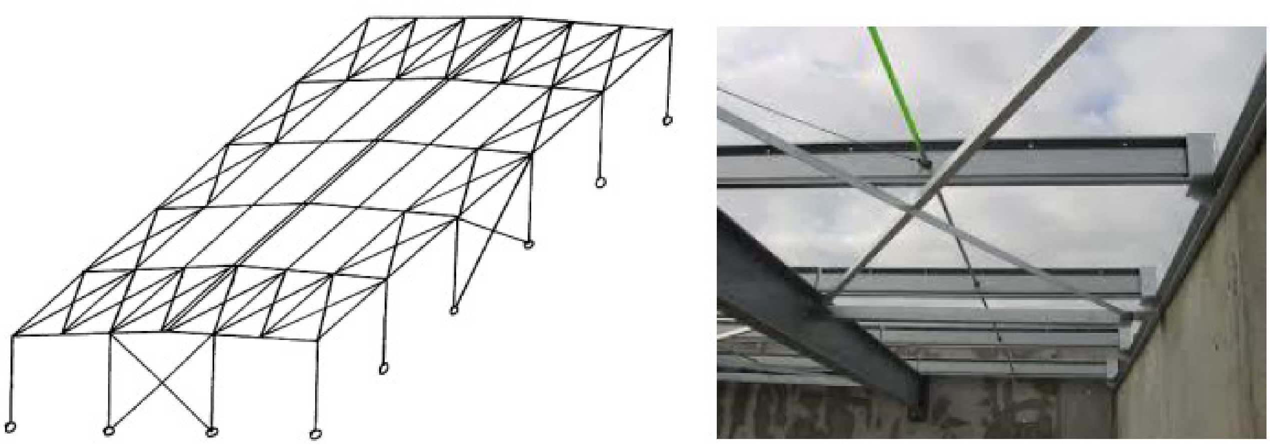


Figure 4.3. Stability bracing, wind beam, and Purlins

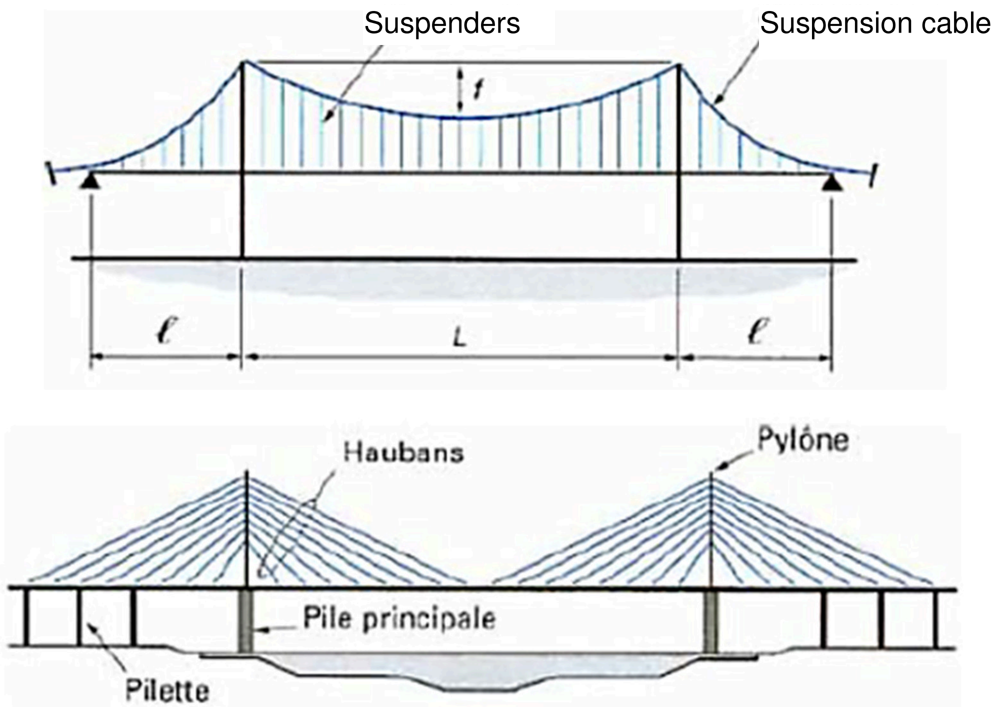


Figure 4.4. Suspension bridge and cable-stayed bridge

4.3. Behavior and Design

4.3.1. Behavior and Failure Mode

The failure or breakdown of a tensioned element can occur in the main area or the connection area.

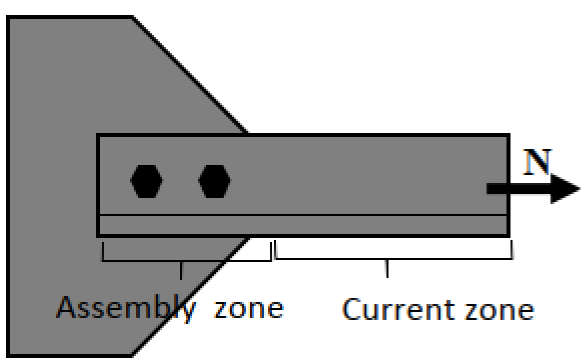


Figure 4.5. Tensioned element attached to a connection

a- Current Zone

In the current zone, the failure is due to excessive elongations resulting from the plasticization of the sections

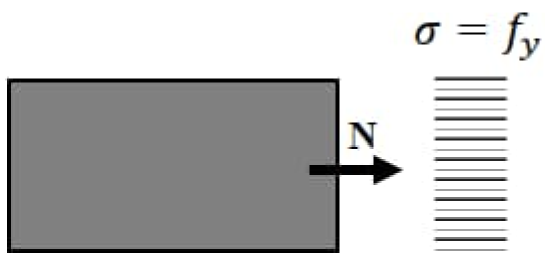


Figure 5.6. Plasticization of the section of the tensioned element

$$N_{pl,Rd} = \frac{A\, f_y}{\gamma_{M0}} \qquad (4.2)$$

- $N_{pl,Rd}$: The design resistance of the gross section
- f_y: Yield strength of the material
- A: Area of the gross section
- γ_{M0}: Partial safety factor for steel (γ_{M0} = 1.0)

b- Assembly zone:

In the assembly zone, failure is due to the rupture of sections with holes, which are weakened. This is a brittle failure mode, as opposed to the first one, which is a ductile phenomenon.

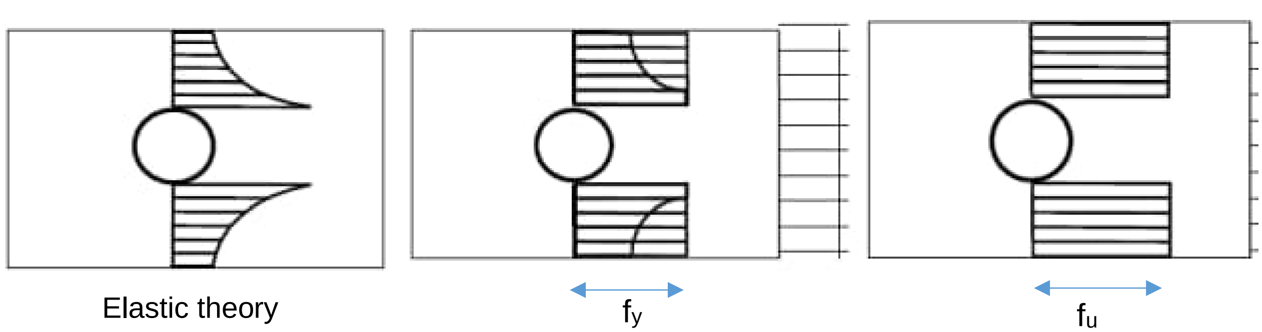


Figure 4.7. Failure mode of the tensioned element at the assembly zone

$$N_{u,Rd} = \frac{A_{net}\, f_u}{\gamma_{M2}} \quad (4.3)$$

- $N_{u,Rd}$: The ultimate design resistance of the net section at the location of the fastening holes.
- A_{net}: Area of the net section at the location of the fastening holes.
- f_u: The ultimate tensile strength of the steel.
- γ_{M2}: Partial safety factor to be applied to the net section, γ_{M2} = 1.25.

4.3.2. Design Criteria

The design value of the tensile force N_{sd} in the element must satisfy :

$$N_{sd} \leq N_{Rd} = Min\left[N_{pl,Rd}, N_{u,Rd}\right] \quad (4.4)$$

With

$$N_{pl,Rd} = \frac{A\, f_y}{\gamma_{M0}} \quad (4.5)$$

and

$$N_{u,Rd} = 0.9\,\frac{A_{net}\, f_u}{\gamma_{M2}} \quad (4.6)$$

The 0.9 factor is a reduction coefficient that accounts for the inevitable eccentricities that may exist between the center of gravity of the cross-section and the centroid of the fixing holes

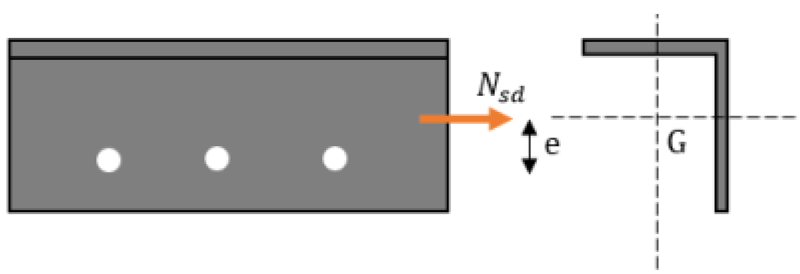


Figure 4.8. Eccentricity in the transmission of forces *M= N_{sd} x* e

Note: If a ductile behavior is required (in order to avoid stress concentration near the holes), it must be verified that :

$$N_{pl,Rd} \leq N_{u,Rd} \quad (4.7)$$

$$\Leftrightarrow \frac{A\,f_y}{\gamma_{M0}} \leq 0.9\,\frac{A_{net}\,f_u}{\gamma_{M2}} \quad (4.8)$$

$$\Leftrightarrow 0.9\,\frac{A_{net}}{A} \geq \frac{\gamma_{M2}}{\gamma_{M0}}\,\frac{f_y}{f_u} \quad (4.9)$$

4.3.3. Case of Angles

For tensioned metal elements with a U-section or angle (L) sections assembled by a single flange, it is necessary to consider the effects of shear lag and eccentricity.

The design force for angle sections remains the tensile force N_{sd}, without considering the secondary moment that may be induced by eccentricities. However, the resistance $N_{u,Rd}$ is modified based on the number of fastening holes.

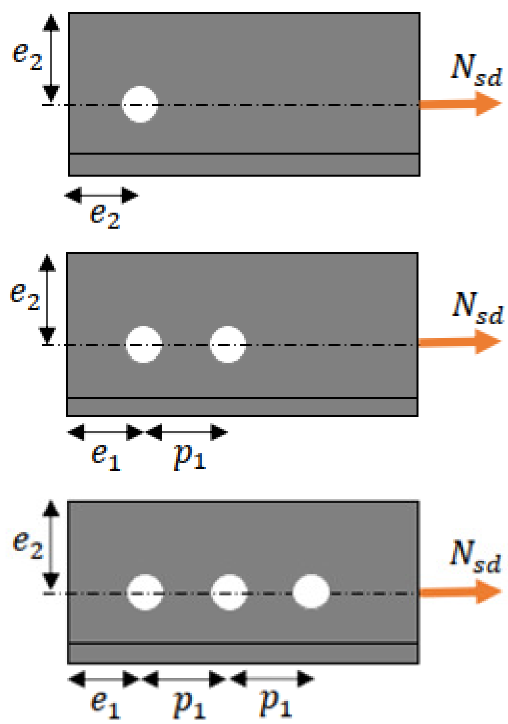


Figure 4.9. Angle attachment

a- Single-bolt attachment (connection) :

$$N_{u,Rd} = \frac{2\,[e_2 - 0.5d_0]\,t\,f_u}{\gamma_{M2}} \quad (4.10)$$

With :

d₀: diameter of the fixing hole

t: thickness of the section flange

b) 2-bolt attachment:

$$N_{u,Rd} = \beta_2 \frac{A_{net}\, f_u}{\gamma_{M2}} \qquad (4.11)$$

c) 3-bolt attachment:

$$N_{u,Rd} = \beta_3 \frac{A_{net}\, f_u}{\gamma_{M2}} \qquad (4.12)$$

β_2 et β_3 are reducing coefficients given by the table below as a function of the center-to-center distance p_1.

	Coefficients β_2 et β_3	
p_1	$\leq 2.5d_0$	$\geq 5d_0$
β_2	0.4	0.7
β_3	0.5	0.7

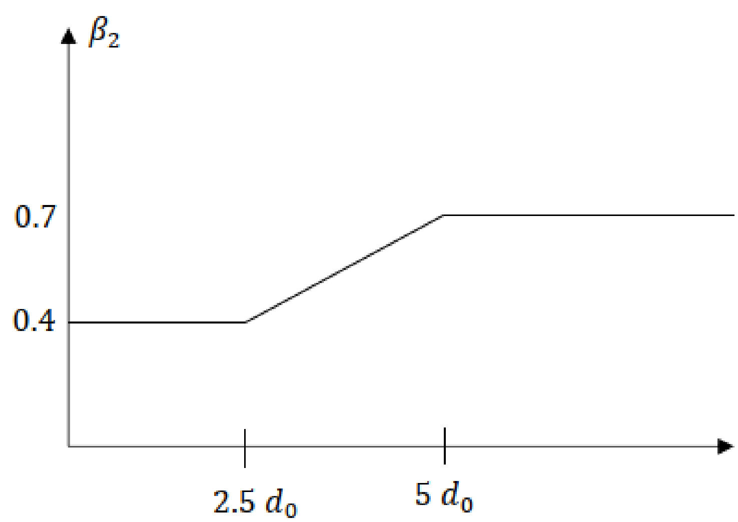


Figure 4.10. Values of β_2

4.3.4. Calculation of Net Section

a- Case of Aligned Holes:

$$A_{net} = A - n * d_0 * t \tag{4.13}$$

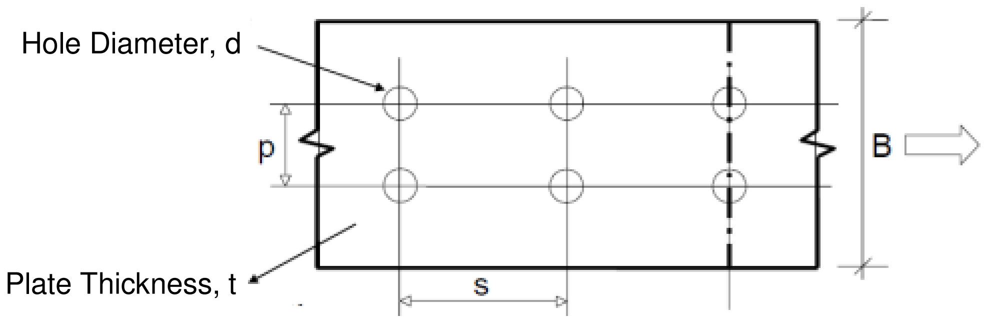


Figure 4.10. Case of aligned holes

b- Case of Staggered Holes

$$A_{net} = A - n * d_0 * t + \left(\sum \frac{s_i^2}{4\,p_i} * t\right) \tag{4.14}$$

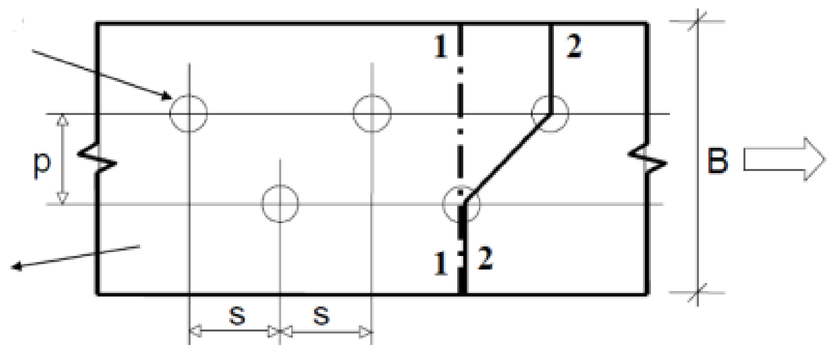


Figure 4.11. Case of staggered holes

Chapter 5: Design of Flexural Members

5.1. Introduction

In each cross-section and under the applied loading, internal forces appear, called: the bending moment M, the shear forces V that balance this loading, and the support reactions.

Bending members in a steel structure, depending on their role, can be rolled sections (IPN, IPE, H, etc.), trusses, etc.

Generally, IPE sections are used as main floor beams in buildings. IPN sections are used as secondary beams and joists. H-sections can be used to support significant and substantial loads (large-span beams, crane runways, columns, etc.).

Bending members are subjected to transverse loads applied along their largest dimension. These loads can be distributed or concentrated (Q, P, M, etc.).

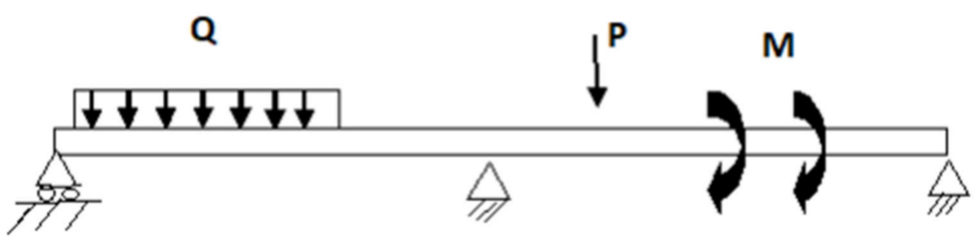


Figure 5.1. Beam under different loads

<u>Types of Flexural Members:</u>

In a structure, various types of elements may be subjected to bending, such as:

- Main beams and secondary beams
- Purlins (used to support the roof)
- Girts (used to support wall cladding)
- Runway beams (e.g., for crane systems)

5.2. Classification of Cross-Sections

Cross-sections are categorized into four classes by EC3. This classification is carried out according to various criteria, such as:

- Slenderness of the plate elements

- Design resistance
- Plastic rotation capacity
- Risk of local buckling, etc.

Determining the class of a section provides insight into its behavior and strength, and thus allows the selection of the most appropriate calculation method.

Eurocode 3 classifies cross‑sections into four classes based on their susceptibility to local buckling and their rotation capacity under bending:

Class 1 sections can form a plastic hinge and develop full plastic moment resistance with sufficient rotation capacity before local buckling occurs

Class 2 sections can still develop their plastic moment resistance but have limited rotation capacity due to local buckling

Class 3 sections can reach yield stress in the extreme compression fibre assuming elastic stress distribution, but local buckling prevents attaining plastic moment resistance

Class 4 sections experience local buckling before yield stress is reached in one or more parts; their resistance must therefore be calculated using effective (reduced) cross‑section properties

Table 5.1: Method of Calculation by Section Class

Class	Calculation Method
1	Plastic analysis allowing formation of a plastic hinge
2	Plastic analysis without full hinge rotation
3	Elastic calculation on the gross (full) cross-section
4	Elastic calculation on the effective (reduced) cross-section

5.3. Design of the Cross-Section under Pure Bending

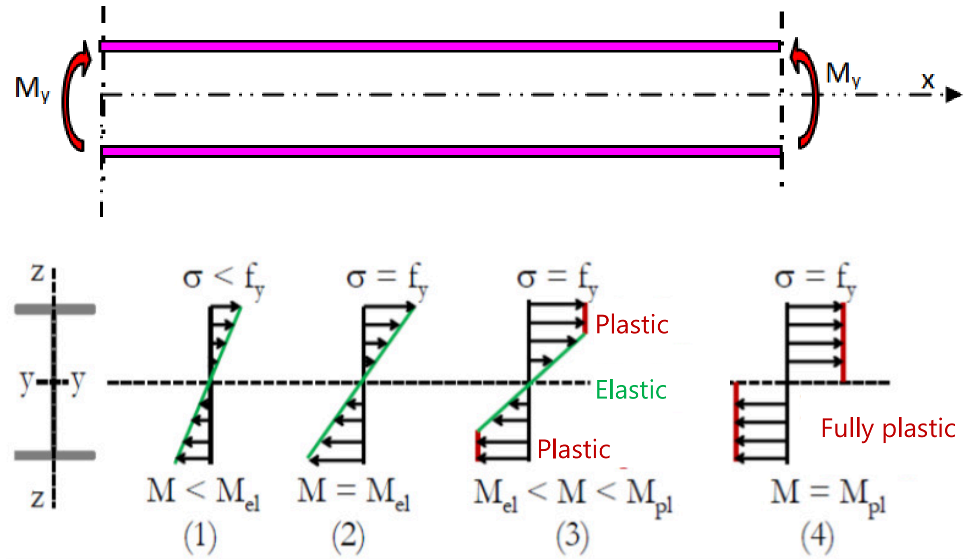


Figure 5.2. Cross-Section under Pure Bending

In the absence of shear force, the bending moment *M* in each cross-section must satisfy the following condition:

$$M_{sd} \leq M_{c,Rd} \qquad (5.1)$$

The applied bending moment M_{sd} must remain less than the design bending resistance $M_{c,Rd}$, which depends on the section class.

- For **Class 1 and Class 2 sections** (plastic behavior of the cross-section):

$$M_{sd} \leq M_{c,Rd} = M_{pl,Rd} = \frac{W_{pl}*f_y}{\gamma_{Mo}} \qquad (5.2)$$

Where $W_{pl,}$ is the Plastic section modulus of the gross cross-section

- For **Class 3 sections** (elastic behavior of the cross-section):

$$M_{sd} \leq M_{c,Rd} = M_{el,Rd} = \frac{W_{el}*f_y}{\gamma_{Mo}} \qquad (5.3)$$

Where W_{el} is the Elastic section modulus of the gross cross-section

➢ For **Class 4 sections** (elastic behavior of the *effective* cross-section):

$$M_{sd} \leq M_{c,Rd} = M_{eff,Rd} = \frac{W_{eff} * f_y}{\gamma_{M1}} \quad (5.4)$$

$\gamma_{M1} = 1.1$

Where W_{eff} is the Elastic section modulus of the effective cross-section for a Class 4 section

<u>Case of a Section with Fixing Holes:</u>

For sections with fixing holes on the tension flange, the previous expressions remain valid if the following condition is satisfied:

$$0.9 \frac{A_{f\ net}}{A_f} \geq \frac{f_y}{f_u} * \frac{\gamma_{M2}}{\gamma_{M0}} \quad (5.5)$$

If this condition is not satisfied, a reduced area is adopted for the calculation of the section modulus W:

$$A_{f,réduite} = 0.9 * A_{f\ net} * \frac{f_u}{f_y} * \frac{\gamma_{M0}}{\gamma_{M2}} \quad (5.6)$$

- A_f is the gross area of the tension flange
- $A_{f,net}$ is the net area of the tension flange (after accounting for the holes)
- f_y is the yield strength of the material
- f_u is the ultimate strength of the material
- γ_{M0} is the partial safety factor for resistance (typically 1.1)
- γ_{M2} is the partial safety factor for local buckling (typically 1.25)

Bibliography

1. J. MOREL, "Calcul des Structures Métalliques selon l'EUROCODE 3".

2. "Règles de conception des structures en acier CCM97", édition CGS,Alger 1999

3. "Eurocode 3 version", 2008

4. J. BROZZETTI, M.A. HIRT, R. BEZ, "Construction Métallique, Exemples Numériques adaptés aux Eurocodes", Presses Polytechniques et Universitaires Romandes.

5. S.P. TIMOSHENKO, "Théorie de la Stabilité Élastique", DUNOD.

6. BARAKA Abdelhak, "Cours en Charpente métallique I, Selon le règlement Algérien C.C.M 97 et l'Eurocode 3", Office des publications universitaires

Overview

These lecture notes on steel structures are intended for second-year civil engineering students in engineering programs, as well as third-year civil engineering students in the LMD (License-Master-Doctorate) system.

The lecture notes on steel structures provides an in-depth introduction to the fundamental principles of metallic framework construction according to Eurocode 3 and CCM97. It begins with essential safety concepts, emphasizing the importance of personal protective equipment, risk prevention, and site safety regulations. The course then explores the main types of structural connections, such as bolted and welded joints, highlighting their design, advantages, and applications. Students also learn to perform calculations for components under simple tension, using fundamental formulas to ensure structural integrity. Finally, the course covers the analysis and design of flexural members (bent elements), focusing on determining internal stresses and deflections according to recognized engineering standards. This comprehensive training equips students with the knowledge required to design safe and efficient steel structures.

Keywords :

Steel Structures, metallic framework construction, CCM 97, Eurocode 3, bolted and welded joints, tensile force, resistance of bolts, punching shear, bearing, high-strength bolting, Ordinary Bolting.