TeamAware

TEAM AWARENESS ENHANCED WITH ARTIFICIAL INTELLIGENCE AND AUGMENTED REALITY

Deliverable D4.4

Non-technical Pilot Support Manual v1

Editor(s):	EUCENTRE: Chiara Casarotti, Ilaria E. Senaldi, Martina Mandirola, Pasquale Pipino, Alessio Cantoni
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v0.4	27/10/2022	Revised document	EUCENTRE
v1.0	03/01/2023	Final version to be released to the EC	SIMAVI

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Terms and Abbreviations

AI	Artificial Intelligence
AOD	Area Of Damage
API	Application Programming Interface
CG	Capability Gap
CNN	Convolutional Neural Network
DCNN	Deep Convolutional Neural Network
EC	European Commission
FHD	Full High Definition
FR	First responder
GNSS	Global Navigation Satellite System
GSD	Ground Sampling Distance
GUI	Graphical User Interface
IFAFRI	International Forum to Advance First Responder Innovation
IMS	Infrastructure Monitoring System
LEA	Law Enforcement Agency
LOS	Line of Sight
UAS	Unmanned Aircraft System
UAV	Unmanned Aircraft Vehicle
RC	Reinforced Concrete
RGB	Red Green Blue
SfM	Structure from Motion
VLOS	Visual Line of Sight
VSAS	Visual Scene Analysis System
WP	Work package

Executive Summary

The present deliverable proposes the first version of a manual with basic glossary to identify the most common structural elements and components of typical structural typologies.

The glossary has been collected within the context of Task 4.2 “Structural damage inspection”, with the aim to provide technical vocabulary in conjunction with methodologies for surveys in order to correctly acquired visual data to feed the Infrastructure Monitoring System (IMS) for the assessment of the structural safety.

The following sections were included in the document:

- Chapter 1: introduction to the deliverable contents, identification of structural typologies considered in this first version of the procedures;
- Chapter 2: basic glossary on construction materials;
- Chapter 3: basic glossary on damage to structures;
- Appendix 1: Non-technical Pilot support Manual for bridges inspections;
- Appendix 2: Non-technical Pilot support Manual for long-span structures (industrial and commercial buildings).

The deliverable is conceived to provide support for a clear communication between non-technical drone pilot and structural experts, during the inspection of buildings and infrastructures for damage detection. The document is meant to be employed in parallel with deliverable D4.3 “Structural Inspection Procedures”, which provided procedures for UAS-based (Unmanned Aircraft Systems) inspections of buildings and infrastructures for damage detection.

The next version of the document will include the integrations of the glossary with elements of further structural typologies, collected during the remaining timespan of the TeamAware project (D4.8 due in M30).

1 Introduction

1.1 About this deliverable

This manual includes the basic glossary for non-technical drone pilots and payload operators who have the task of supporting the structural experts in charge of the structural damage assessment in the area of first-responders' operations. The purpose of this glossary, according to the objectives of Task 4.2 "Structural damage inspection", is to establish a common language between pilot and structural engineers, in order to simplify the inspection operations and correctly acquire the visual data that will feed the Infrastructure Monitoring System.

1.2 Document structure

The glossary aims to provide an overview of the structural parts that could be inspected and provide information to any non-technical pilot involved to the flight operations performed during surveys and inspections in order to correctly identify them. The terms constituting the glossary are in bold character and underlined in the text for better readability.

Two introductory chapters are devoted respectively to the glossary of selected construction technologies (such as reinforced concrete, unreinforced masonry and steel structural components) and of the damage typologies detected by IMS, with relevant photographic examples. The latter aims to support correctly the identification of damages in relation to the functionalities of the Infrastructure Monitoring System (IMS).

The following annexes are each devoted to specific typologies of structure, in particular the following will be considered in the present version of the manual:

- Bridges, viaducts;
- Industrial/commercial long-span buildings.

In the final version of the glossary, additional typologies of structures will be included.

For each structural typology identified, the following sub-chapters will report:

- Schemes for structural element identification
- Glossary with description of structural an elements and related photographic collection.

1.3 Relation with other tasks and deliverables

The deliverable D4.4 is issued to be used in conjunction with deliverable D4.3 ("Structural Inspection Procedures) in order to provide guidance and correct means of communications to non-technical drone pilots and structural experts, during the acquisition of visual data that will feed TeamAware's IMS.

1.4 Next version

The next version of the document (D4.8 due in M30) will include the glossary for additional structural typologies.

2 Construction materials

2.1 Selection of construction materials

The current manual aims to provide a comprehensive glossary focused on structural engineering to identify materials, components and structural elements depending on the construction technology and structural typology. A selection of terms relative to the most common construction materials is provided, in particular for:

- Reinforced concrete;
- Unreinforced masonry;
- Steel.

2.2 Reinforced concrete components

Concrete is a material of high compression strength, but very low tensile strength unless reinforced. The combination of concrete and embedded steel reinforcement, i.e. **reinforced concrete** (RC), allows creating structural elements suitable to resist a variety of applied forces. In particular, longitudinal **rebars** in beams and piers undertake the tensile stresses due to axial or flexural loads, while **stirrups**, arranged in the transverse direction resist shear forces and provide confinement to the concrete section. The least distance between the surface of embedded reinforcement and the outer surface of the section is called **concrete cover**. It is essential for ensuring the bond strength between concrete and steel. In addition, a proper cover thickness can protect from environmental effects, and prevent reinforcement corrosion.

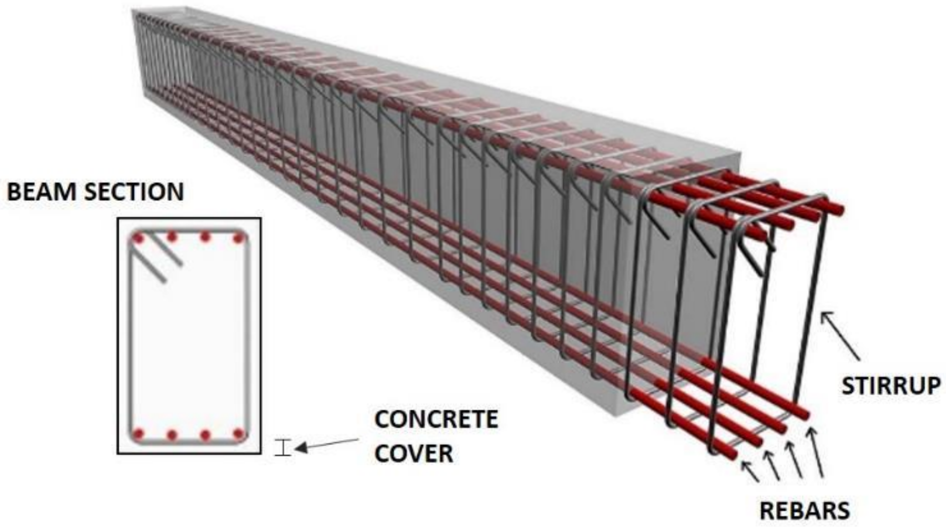

Figure 1: Schematic representation of stirrups and rebars in a reinforced concrete beam – Source: [1]

2.3 Unreinforced masonry components

Unreinforced masonry is a material composed of **brick/block** units hold together by **mortar joints**, without steel reinforcing bars embedded in it (Figure 2).

The method by which individual masonry units are interlocked or hold together is defined **bond**. There are several possible patterns, as showed for example in Figure 3 and Figure 4.

In masonry walls with openings, usually two main structural components may be identified: **piers** and **spandrels**. Piers are the main vertical resisting elements carrying both vertical and lateral loads, while spandrel elements, which are intended to be those parts of walls between two vertically aligned openings, are secondary horizontal elements (for what concerns vertical loads), which couple the response of adjacent piers in the case of lateral loads.

Figure 2. Example of masonry typologies - Source: [2]

Figure 3. Examples of stone bond - Source: [3]

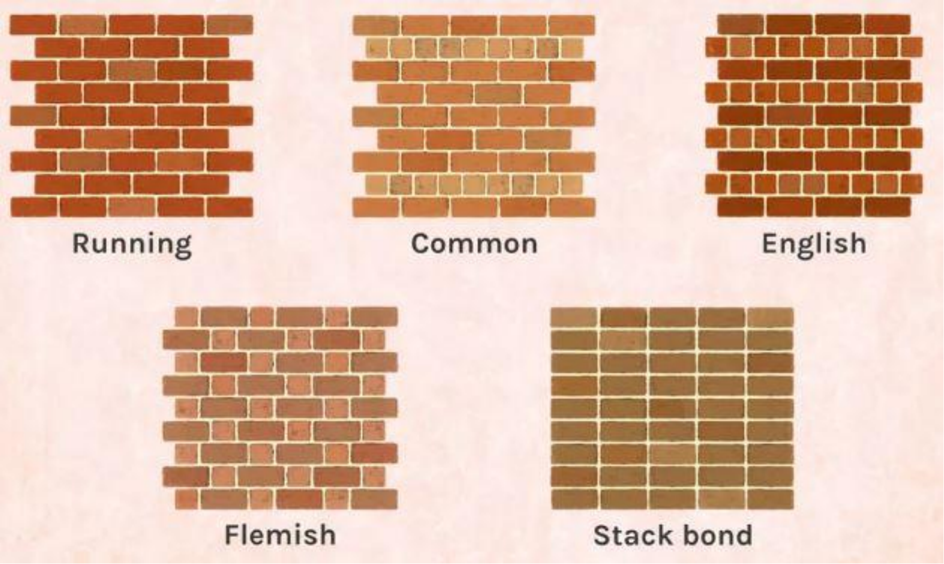

Figure 4. Examples of brick bond – Source: [4]

2.4 Steel structural components

In steel structural members as I-section beam or H-section column, the parallel elements are defined **flanges**, while the transverse element is called **web** (Figure 5). **Connections** or **joints** between two or more members can be **welded** or **bolted**, as showed in Figure 6.

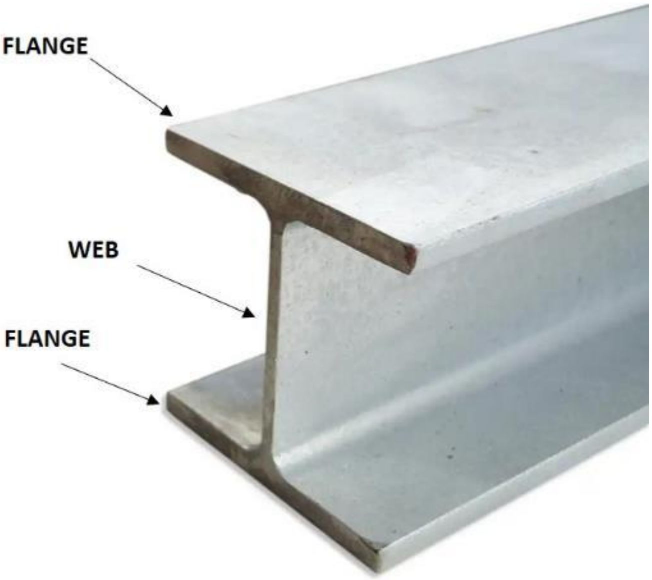

Figure 5. Identification of flanges and web in a H-section steel member – Source: [5]

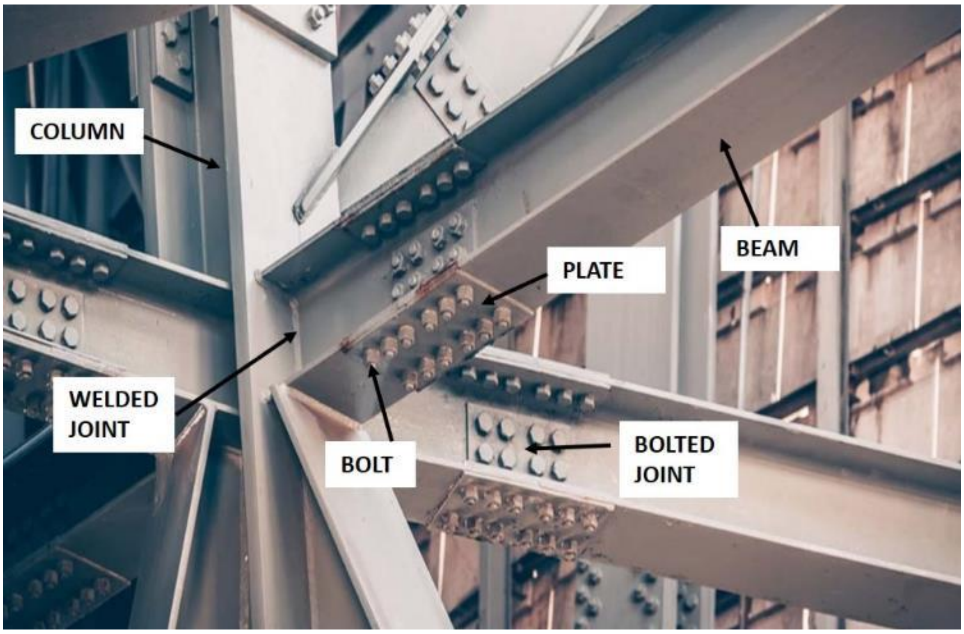

Figure 6. Example of welded and bolted connections of steel structural members – Source: [6]

3 Damage to structural elements

3.1 Typologies of structural damages detected by IMS

This paragraph briefly describes the main types of damage detected by the Infrastructure Monitoring System:

- Cracking;
- Spalling;
- Corrosion;
- Exposed/deformed rebars.

3.2 Glossary

Cracking is a partial or complete separation of concrete or masonry into two or more parts produced by breaking or fracturing. Cracking can occur due to several factors like drying shrinkage, thermal stresses, chemical reactions, corrosion of the steel reinforcement, settlements and externally applied loads. Cracks can have different pattern and dimensions (width and length) based on their cause and on the severity and extent of damage.

Spalling consists in flaking and detachment of concrete or masonry from structure surface. Typical causes are freeze-thaw cycles and expansion of corroded steel reinforcement, as well as extreme load conditions, like earthquake or impact.

Corrosion is a deterioration process that can affect either steel structural members or rebars in reinforced concrete. The exposure to aggressive environment and the absence of proper concrete cover can accelerate this process, and lead to cracking and spalling phenomena. Furthermore, corrosion in advanced state results in a loss of cross-sectional area of reinforcing bar, hence reducing its strength and capacity.

The spalling of concrete cover leaves the reinforcing bars directly exposed to environment and thus to corrosion process. Another damage that can be observed in reinforced concrete structures is **rebar deformation**, due to excessive load conditions, especially if stirrups have inadequate spacing or they are broken.

Figure 7. Shear cracks and masonry spalling on the façade of a residential unreinforced masonry building – Source: [37]

Figure 8. Cracks and masonry spalling on unreinforced masonry building - Source: [37]

Figure 9. Crack on masonry arch bridge, with leaching and spalling - Source: [37]

Figure 10. Masonry spalling on arch bridge - Source: [37]

Figure 11. Pier cap with vertical flexural cracks over the column region and shear crack propagating from the girder – Source: [37]

Figure 12. Spalling of RC beam and slab with leaching and corrosion of reinforcement, severe in the Gerber saddle - Source: [37]

Figure 13. Severe spalling of bridge pier with reinforcement corrosion – Source: [45]

Figure 14. On the left, damage to the arch of Saby's Road Bridge – Source:[46]. On the right, pier cap damaged – Source: [47]

Figure 15. On the left, flexural break of the pier in the overlapping bar zone – Source: [48]. On the right, shear break and consequent overturning of a pier of Wushi Bridge, after Taiwan earthquake in 1999 – Source: [49].

Figure 16. On the left, spalling and reinforcement corrosion in RC column. On the right, spalling in RC column, with corrosion and deformation of steel reinforcement - Source: [37]

Figure 17. On the left, shear crack on RC column, with spalling, corrosion of reinforcement and debris from the collapsed infill and cladding. On the right, flexural crack on RC column, with spalling and reinforcement corrosion - Source: [37]

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APPENDIX 1: Non-technical Pilot support Manual for bridges inspections

A. Schemes for structural element identification

A **bridge/viaduct** is a structure built to span a physical obstacle (such as a body of water, valley, road, or rail) without blocking the way underneath. Bridges may be distinguished by the type of design, depending on their function, the terrain where it is built, and the construction material or type of structural elements used. From Figure 18 to Figure 22 some examples of bridge typologies are shown, with the identification of the main structural parts.

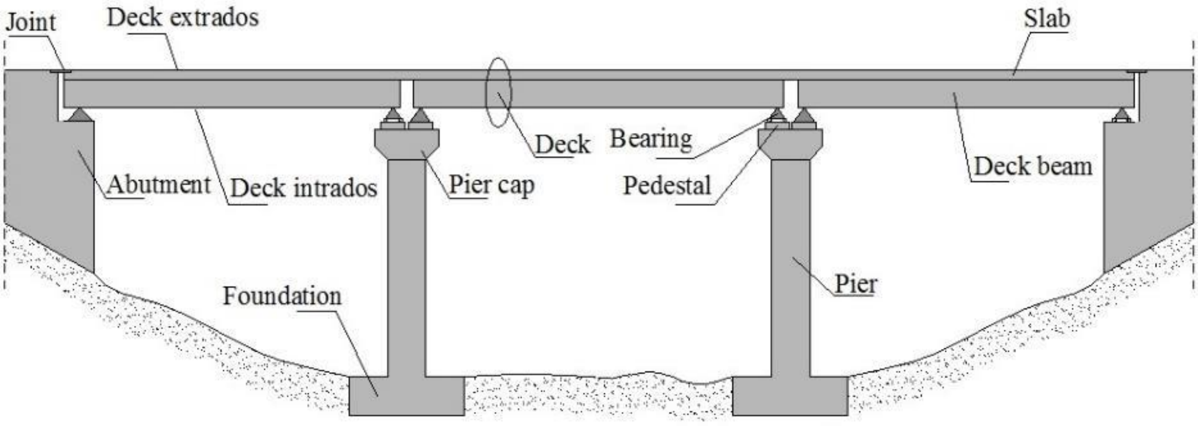


Figure 18. Example of girder bridge, with the identification of the main elements

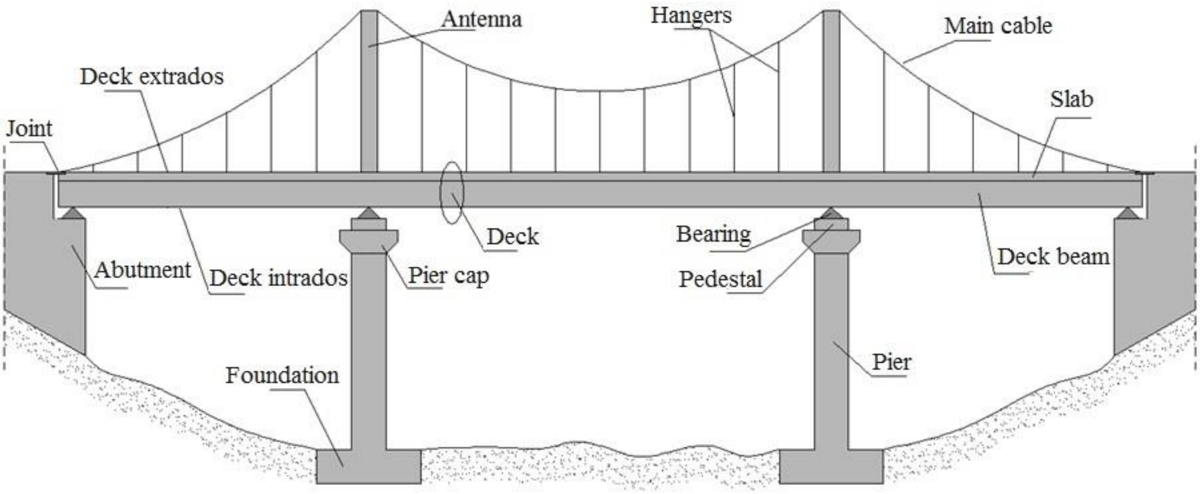


Figure 19. Example of suspension bridge, with the identification of the main elements

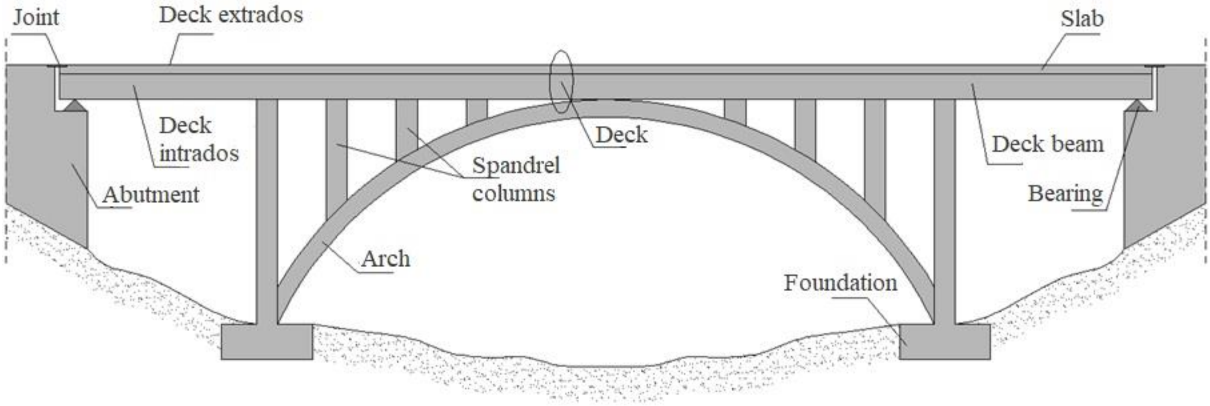


Figure 20. Example of deck arch bridge

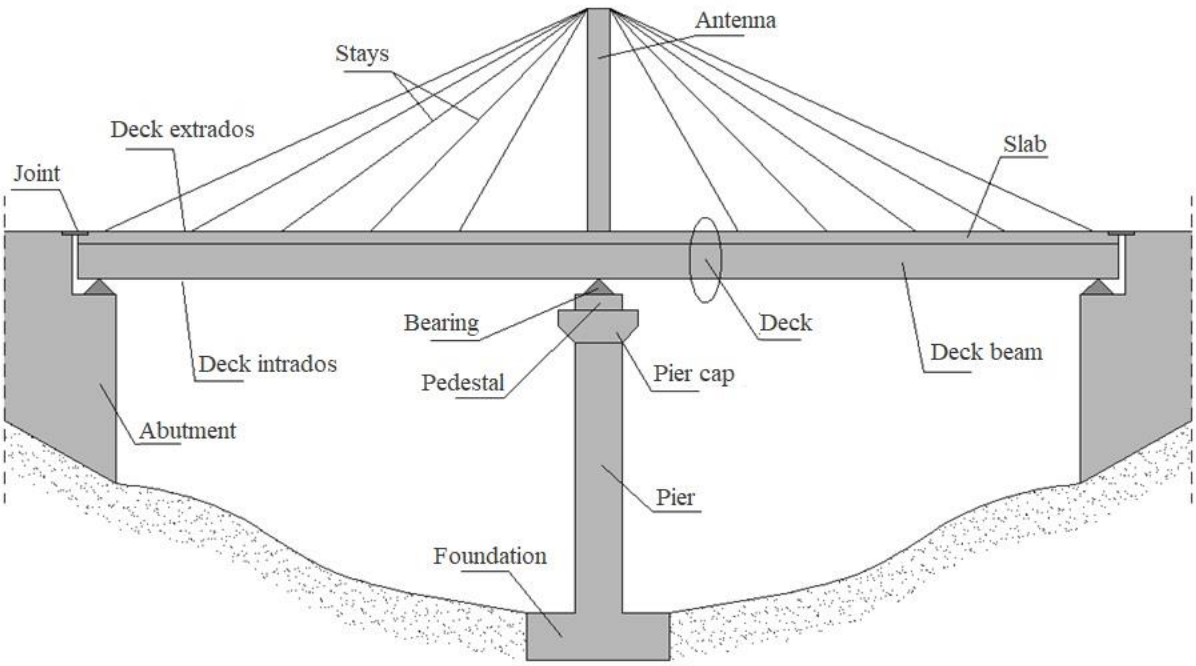


Figure 21. Example of cable-stayed bridge

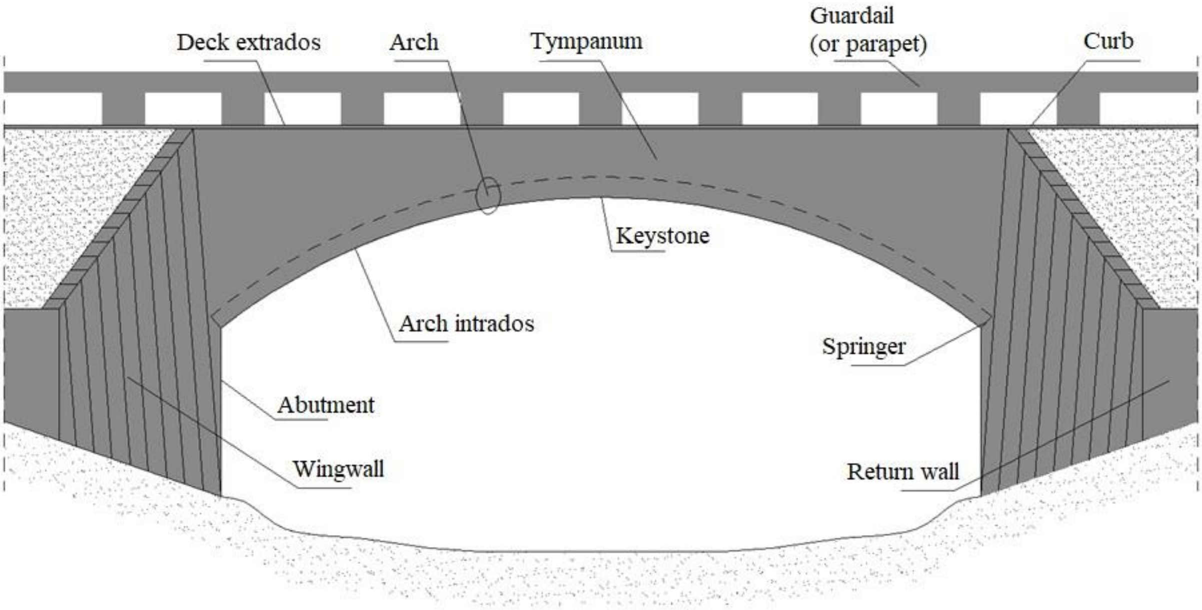


Figure 22. Example of masonry closed-spandrel arch bridge

B. Glossary

The elements of the bridge are listed below in alphabetical order, with a brief description and the relative picture, which indicates the element under examination together with some of the most visible elements.

Abutments: they are the transition element between the bridge and the road embankment. Abutments are massive and large elements, usually in masonry or reinforced concrete, rarely in prestressed concrete, that separate the earth embankment from the bridge span (Figure 23).

Antennas and stays: in cable-stayed bridges, *antennas* (also called *towers*) are vertical elements made of steel or prestressed concrete to which steel cables, called *stays,* are connected. The latter may belong to a single vertical plane or can be arranged in two separate planes (Figure 24).

Arch and tympanum: the *arch* is the curved structural element that transfers the load to the piers or to the abutments. It can be located below the deck (Figure 25: deck arch bridge), at the same height (Figure 25: half-through arch bridge), or over the deck (Figure 26: through arch bridge). Masonry arch bridges are very common (like that shown in Figure 26), where the part at the top of the arch is called *keystone*, while the extreme parts, where the arch is supported, are named *springers*. The walls at the extrados of the arch are called *tympanum* or *spandrel*.

Bearings: they are restraint devices whose task is to transfer loads from the deck to the substructure, preventing some movements and allowing others (translations and/or rotations). They can be *fixed* or *movable* and can be made of different materials: rubber or reinforced rubber, steel and Teflon. Figure 27 shows the position of the supports, while in Figure 28 presents a typical example of rubber and steel bearings.

Curb, guardrail and parapet: the *curb* is the element along the edges of the deck where *parapets* or *guardrails* are installed. Parapets are non-structural elements that limit the roadway, whereas guardrails are metal sheet protections installed along the lane in order to prevent vehicles from leaving the carriageway (Figure 29).

Deck, beam and slab: the *deck* is the set of structural elements that support the road or the railway, in case of railway bridges (Figure 30). It consists of beams (in steel or reinforced concrete) parallel to the road axis connected by secondary beams. On the top, a slab in reinforced concrete or corrugated sheet contains the road surface. Otherwise, the deck can be formed by a single box girder (in steel or reinforced concrete) (Figure 31).

Foundation: it is at the base of piers and abutments (Figure 32). Usually, foundations are not visible because they are located below the ground level or the water level (in case of piers in the riverbed); however, they are included in this glossary, because they may need to be inspected due to events of sliding, erosion or scouring.

Gerber saddles: they are particular types of joint that are often found in reinforced concrete bridges. They are used in order to connect a beam to another with a simple support (Figure 33).

Hangers and main cables: *hangers* are used in suspension bridges (Figure 34). They can be vertical or inclined and have the task of connecting the deck to the *main cables* (cables with the shape similar to a parabola that are connected to the top of the antennas).

Intrados and extrados: in this context, they refer to either the deck or the arch of a bridge. The *intrados* indicates the lower side, while the *extrado*s refers to the upper side of the element (Figure 35).

Joint: it allows sliding and rotation between decks, still ensuring the continuity of road surface and waterproofing (Figure 36).

Pedestals: they are the structural elements on which bearings are placed and allow setting the desired slope of the deck (Figure 37).

Pier: it is the vertical element that has the function to transfer the load from the deck to the foundations. It can have several shapes: polygonal, wall-type, or circular/elliptical. Piers may have different configurations: single or multiple column and frame type (Figure 38).

Pier cap: it is a beam placed between the top of the piers and the intrados of the deck. In case of single columns, the pier cap supports the deck and remains cantilevered on both sides of the column, while it connects the head of the piers in case of multiple columns (Figure 39).

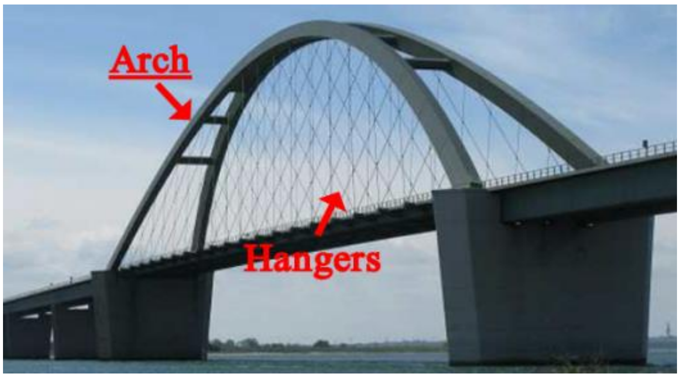
Spandrel columns: elements in steel or prestressed concrete that connect the arch to the deck. They can be vertical or inclined (Figure 40).

Wingwall and return wall: in masonry bridges, *wingwalls* are those built in extension to the abutments and have the function of connecting abutments with the embankment scarps (Figure 41). Vertically, they always have an inclination and often end with *return walls* parallel to deck direction.

Figure 23. Bridge abutment – Source (left): [8]. Source (right): [9]

Figure 24. On the left, cable-stayed bridge Emanuela Loi, Monserrato, Sardegna – Source: [10]. On the right, Viadotto Favazzina, Bagnara Calabra-Scilla, Calabria – Source: [11]

Figure 25. On the left, a deck arch bridge: Ponte Arrabida, Porto - Source: [12]. On the right, a half-trough arch bridge: Lupu Bridge, China. Source: [13]



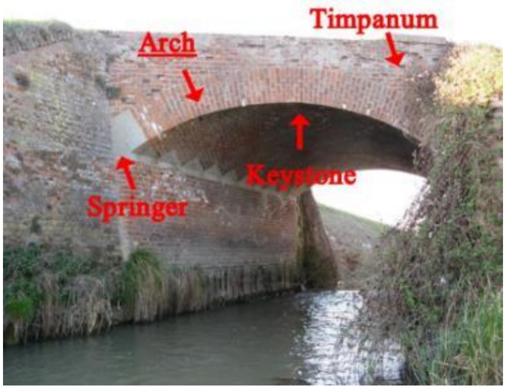


Figure 26. On the left, a through arch bridge: Fehmarnsund Bridge in Germany - Source: [12] On the right, a masonry bridge: Ponte di Aselogna – Source: [14]

Figure 27. On the left, Viadotto Castagne – Source: [15]. On the right, identification of bridge bearings – Source: [16]

Figure 28. Close view of a rubber bearing with anchor plate (left) and a steel bearing (right) – Source: [17]

Figure 29. On the left, an example of bridge with curb and guardrail – Source: [18]. On the right, an example of bridge with parapet - Source: [19]

Figure 30. On the left, Viadotto Caballa Nord-Sud, Morano Calabro – Source: [20]. On the right, Ponte sul Torrente Chisone, Macello (TO) – Source: [21]

Figure 31. On the left, Ponte di Baceno (VB), with steel girders and reinforced concrete slab – Source: [22]. On the right, Autostrada SA – RC, viaduct with box deck – Source: [23]

Figure 32. On the left, scouring of foundations - Source: [24]. On the right, scouring of foundation plinths: Ponte della Pedemontana – Source: [25]

Figure 33. Gerber saddles – Source (left): [26]. Source (right): [27]

Figure 34. On the left, Akashi Kaikyo suspension bridge – Source: [28]. On the right, San Francisco Golden Gate – Source: [29]

Figure 35. On the left, Cavalcavia s.s. Aurelia – Source: [30]. On the right, Ponte Sant'Angelo, Roma – Source: [31]

Figure 36. Expansion joint – Source: [32]

Figure 37. On the left, bridge pedestals of Pian del Bruscolo cycle path - Source: (Rossi, 2014). On the right, identification of bridge pedestals – Source: [16]

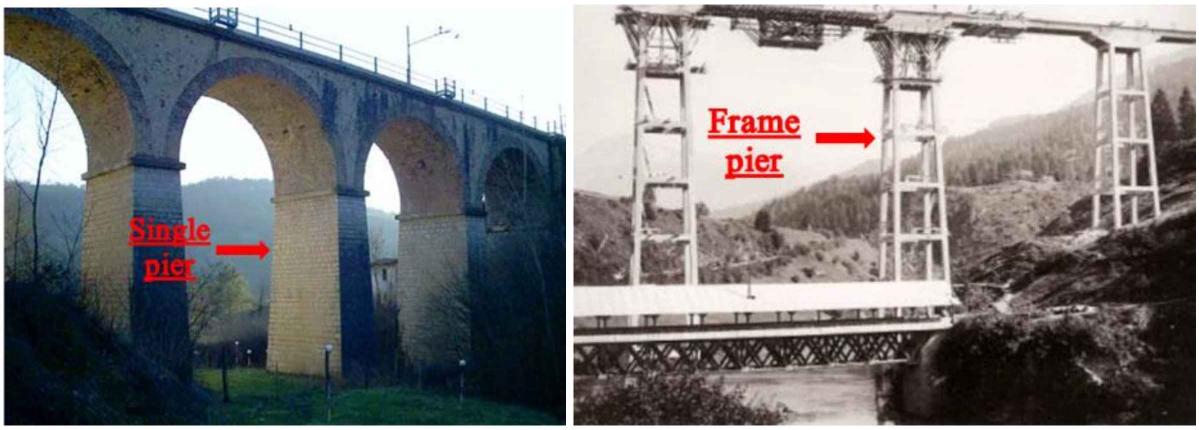


Figure 38. On the right, single piers – Source: [33]. On the right, frame piers of Ponte Vallesella, Belluno – Source: [34]

Figure 39. On the left, pier cap on single column – Source: [35]. On the right, multiple columns and pier cap. – Source: [8]

Figure 40. On the left, Los Tilos bridge, La Palma, isole Canarie – Source: [13]. On the right, Viadotto Sfalassà, Bagnara Calabra, Calabria – Source: [11]

Figure 41. On the left, Sottopasso Manlio Cavalli – Source: [36]. On the right, Sottovia di Loreggia – Source: [14]

APPENDIX 2: Non-technical Pilot support Manual for long-span structures

A. Schemes for structural element identification

Long-span structures, in particular industrial buildings, warehouses, plants, factories etc., are usually characterised by a frame-type structural configuration. From Figure 42 to Figure 47 some examples of long-span buildings and roof typologies are shown, with the identification of the main structural elements.

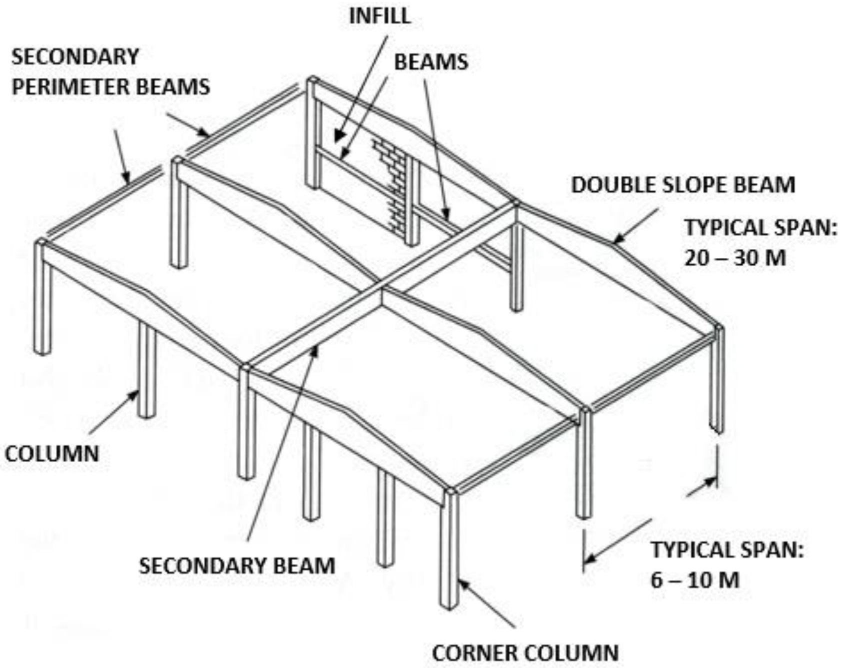


Figure 42. Example of long-span structure

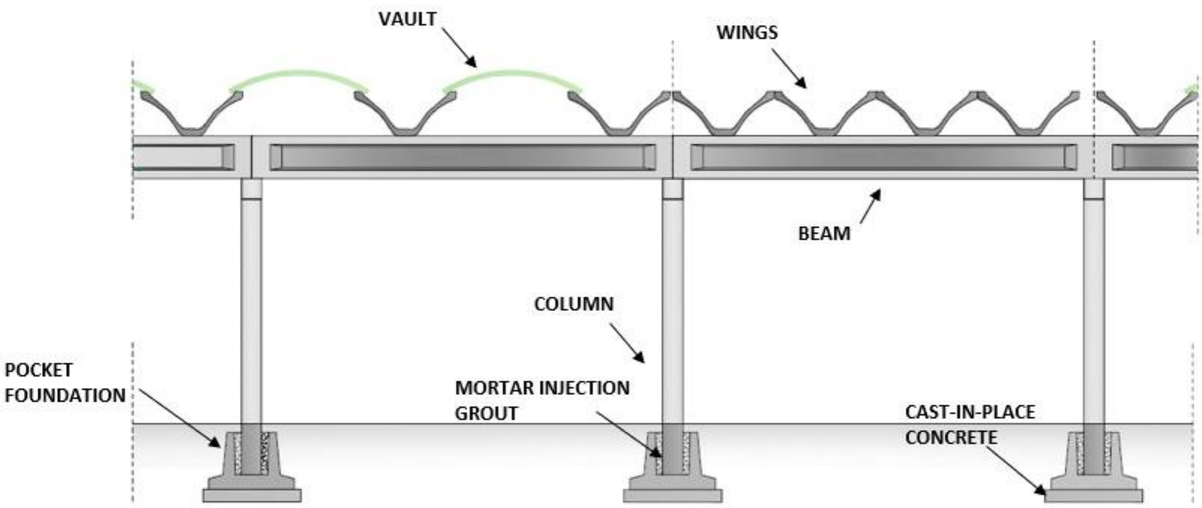


Figure 43. Example of roof with wings and vaults

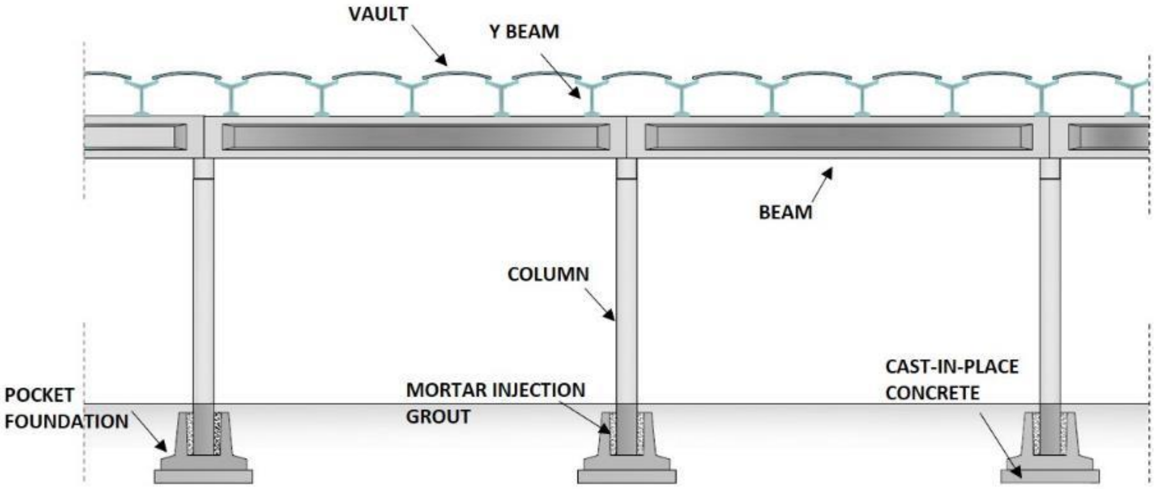


Figure 44. Example of roof with Y beams and vaults

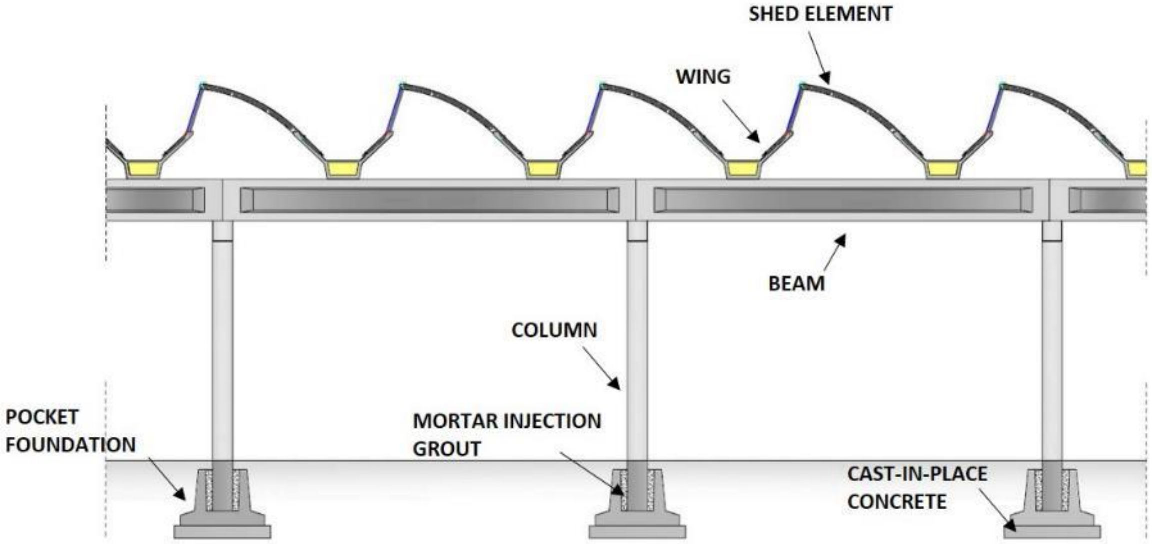


Figure 45. Example of roof with wings and shed elements

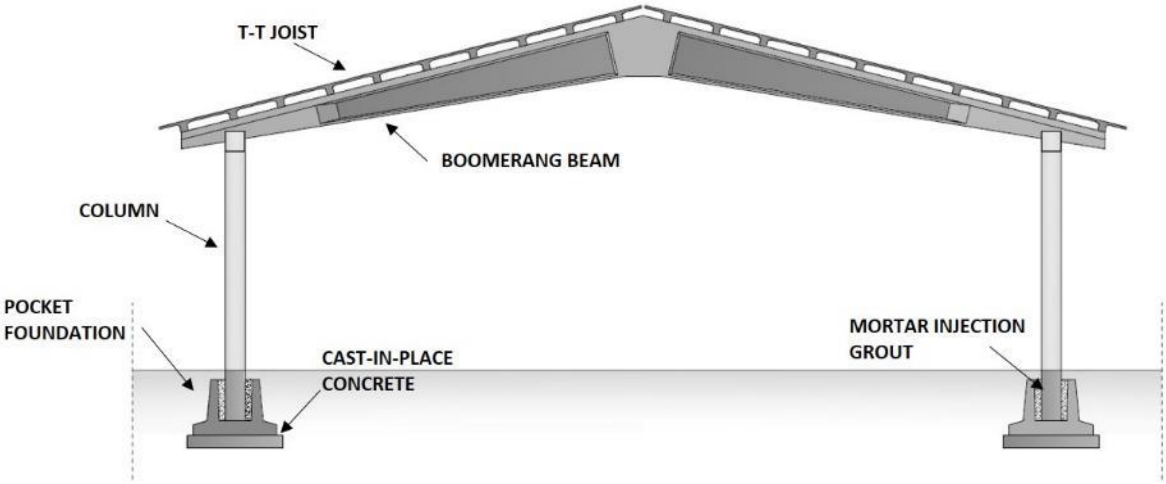


Figure 46. Example of roof with boomerang beam and T-T joists

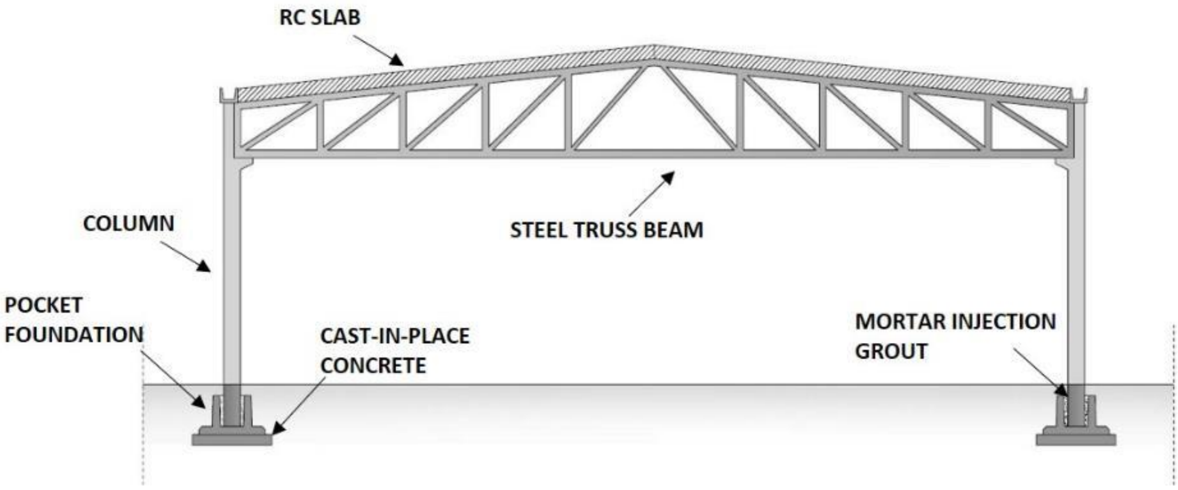


Figure 47. Example of roof with steel truss beam and RC slab

B. Glossary

The elements of long-span buildings are listed below in alphabetical order, with some pictures showing these elements.

Boomerang beam: precast elements with great slope, up to 30%, typically used for factories and agricultural buildings (stables, arcades, warehouses, etc.) (Figure 48, on the left).

Double slope beam: they are the traditional precast elements used for industrial and agricultural buildings, or other long-span structures as gymnasiums, with double pitched roof (Figure 48, on the right).

Glulam beam: it is a structural engineered wood beam composed by layers of wood laminations bonded together with industrial adhesives (Figure 49, on the left). The acronym Glulam stands for "Glued laminated timber".

Steel truss beam: it is a triangulated system of straight interconnected structural elements joined at the nodes by welded or bolted connections (Figure 49, on the right). External loads and reactions are considered to act only at the nodes and the members are subjected only to tensile or compressive forces.

Brace: steel structural element employed to support horizontal forces. Braces can be arranged both in vertical and horizontal plan and are typically assembled with circular, L or C cross-section profiles (Figure 50, on the left). A *braced frame* is a structural system designed to resist wind and earthquake forces, constituted by the assembly of beams, columns and braces.

Column: vertical element that has the function to transfer the load from the beams to the foundations (Figure 50, on the right). Columns in long-span buildings are usually precast in reinforced concrete, otherwise steel members with different possible cross-sections can be employed.

Hollow-core slab: prestressed concrete slab generally used for commercial long-span buildings with the advantage of flexibility in design and fast construction (Figure 51, on the left). Longitudinal voids throughout the slabs make them lighter than massive concrete floor slabs.

Horizontal and vertical panel: wall panels arranged in horizontal or vertical direction typically used for the façade of long-span buildings (Figure 52).

Infill: it is the wall delimited by the perimeter of a frame structure (i.e. by RC beams and columns), separating inner and outer space (Figure 53, on the left).

Slab: structural element used to realize flat surfaces in buildings as floors and roofs (Figure 51, on the right). It can be in reinforced concrete, either precast or cast-in-place, or in steel.

Shed: precast elements often used to realize roof in long-span buildings. They guarantee natural lights thanks to vertical or sloped windows (Figure 53, on the right)).

T-T joist: double tees are precast elements used for roof construction in buildings requiring long spans, as swimming pools, gymnasiums, commercial and industrial buildings (Figure 54, on the left).

Vault: precast curve element used in combination with Y-beams or wings to realize flat roofs in long-span buildings (Figure 54, on the right).

Wing: precast wing-shaped elements often used in combination with vault members to realize flat roofs in long-span buildings, or with shed elements (Figure 55).

Figure 48. On the left, roof with boomerang beam – Source: [37]. On the right, roof with double slope beam – Source: [7]

Figure 49. On the left, roof with glulam beam. On the right, roof with steel truss beam – Source: [7]

Figure 50. On the left, brace in roof plane. On the right, RC framework elements – Source: [7]

Figure 51. On the left, roof with hollow-core slab. On the right, RC roof – Source: [7]

Figure 52. On the left, horizontal panels – Source: [38]. On the right, vertical panels – Source: [7]

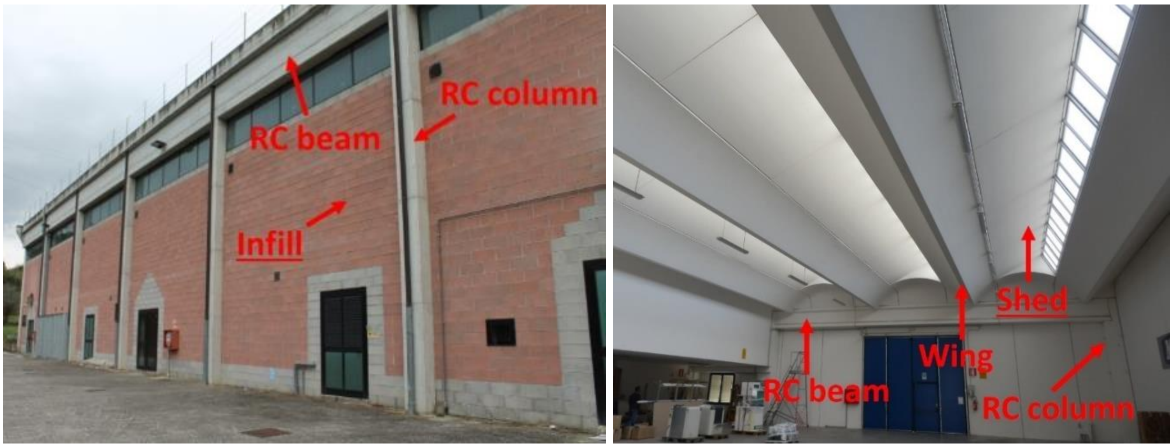


Figure 53. On the left, external view of a gymnasium with RC framework and infill. On the right, roof with shed elements – Source: [7]

Figure 54. On the left, T-T joist elements – Source: [7]. On the right, roof with vault elements – Source: [39]

Figure 55. Roof with wing, vault and shed elements – Source: [40]