Modélisation des INformations INteropérables pour les INfrastructures Durables

IfcBridge
Prestressing, Suspension and Cable systems

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I. ABSTRACT

Abstract

During the first season (2015-2018) of the MINnD research project, the IFC Bridge working group focused on common bridges: slab bridges, girder bridges, rigid frame bridges and culverts. All complex bridge's types such as prestressed, suspension or cable-stayed bridges were out of scope. This deliverable aims to fill this gap by identifying:

- systems, i.e., set of components responding to a specific function, related to these categories of bridges (prestressed, suspended or cable-stayed);
- objects composing these systems.

Reference documents and the methodology to identify systems and objects are first described.

This methodology is then applied to prestressed concrete bridges, then to suspension and cable-stayed bridges.

Résumé

Lors de la première saison (2015-2018) du projet de recherche MINnD, le groupe de travail dédié aux IFC Bridge s'est concentré sur les ouvrages dits « courants » : ponts-dalles, ponts à poutres, ponts cadres et ponceaux. Les ouvrages complexes comme les ponts en béton précontraint, les ponts suspendus ou haubanés n'ont pas été traités. Ce livrable vise à combler ce manque en identifiant :

- les systèmes, c'est-à-dire les ensembles de composants répondant à une fonction précise, spécifiques à ces typologies d'ouvrages (précontraints, suspendus ou haubanés) ;
- les objets qui composent ces systèmes.

Dans un premier temps, les documents de référence et la méthodologie de travail sont décrites.

La méthodologie est ensuite appliquée aux ouvrages en béton précontraints, puis aux ponts suspendus et haubanés.

1.1 Abbreviations

Abbreviation	Signification
bSI	buildingSMART International
IFC	Industry Foundation Class
HDPE	High Density Polyethylene
PCI	Precast/Prestressed Concrete Institute

Main key words (Eng) MINnD; Research; Construction; Infrastructure; BIM; Digital model;

Deliverable key words (Eng) IfcBridge; bridge; prestressing; suspension; cable stayed;

Mots clés principaux (Fra) MINnD ; Recherche ; Construction ; Infrastructures ; BIM ; Maquette numérique ;

Mots clés spécifiques au livrable (Fra) IfcBridge ; ouvrage d'art ; pont ; précontrainte ; câble ; suspension ; hauban ;

2. INTRODUCTION

2.1 Issues of the IFC-BRIDGE WG1.1 Working Group

MINnD S1 Continuity

In the first phase of the national MINnD research project, the working group dedicated to IFC Bridges was mainly interested in common bridges: slab bridges, girder bridges, frame bridges, rigid frame bridges and culverts. All complex bridge's types such as prestressed, suspended or cable-stayed bridges were out of scope.

MINnD project and other international initiatives contributed to the IFC-Bridge Fast Track Project led by buildingSMART International that aimed at extending the IFC data model to allow the precise description of the semantics and geometry of bridges: the IFC 4.2 schema specifications.

This present deliverable deals with the classes of objects necessary for the design and construction of non-current structures, i.e., prestressed concrete structures, suspension, or cable-stayed bridges.

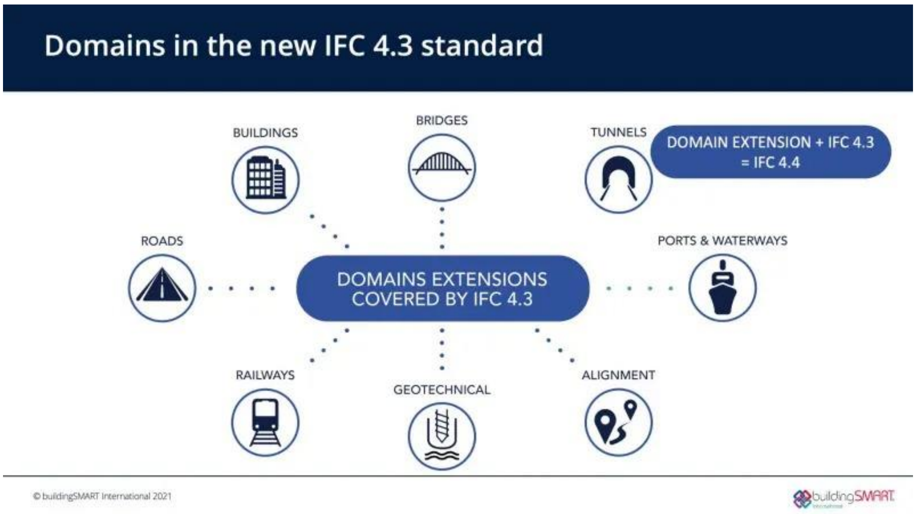


Fig.1 : Domain extensions covered by IFC 4.3

Since this initial work, which led to the development of IFC 4.2, then to IFC 4.3, some software editors have progressively started implementing these new classes of objects in their authoring tools. The second phase of the national research project must therefore continue its work in order to cover all types of structures, in particular prestressed and cable-stayed structures.

In addition, under the impetus of the development of IFC-Bridge, the other infrastructure domains (tunnel, road, rail, etc.) have mobilized to specify classes of complementary objects to cover all civil-engineering domains. This work in silos has made it possible to quickly mobilize the experts in each field, but now requires work on consistency and verification of the interfaces between the major fields of infrastructure (for example: a road or a railway line sometimes passes over a bridge or in a tunnel). It is therefore essential to identify the scope of study for each area, and to identify the topics that must absolutely be dealt with by the working group dedicated to the IFC Bridge. The goal is to ensure that the subjects essential to the field of bridges, and yet transverse to the other fields, have been correctly treated and correctly consider the particularities of this field.

In addition, since the development of IFC 4.1 (IFC Alignment) partly implemented by software vendors, some gaps and shortcomings have been identified during the first tests and first uses.

MINnD S1 deliverables dealing with IFC-Bridge

The first phase of the MINnD project took place from March 2014 to March 2016. The Use Case 3 "IFC Bridge" working group studied the state of art of the IFC. The latter is related to the field of the bridge design and construction. It identifies missing concepts and recommends a holistic approach to:

- Derive IFC definitions.
- Complete concepts used by users and stakeholders involved in the bridge's lifecycle.

The second phase of the MINnD project took place from March 2016 to December 2018. The working group goes deeper into the design process. It took the example of a typical bridge:

- Exhibiting a fair amount of all events and problematic that can be encountered during a bridge project.
- Considered from the complete lifecycle perspective.

The following deliverables were the first documents dedicated to IFC-Bridge development recommendations and were delivered to the buildingSMART IFC-Bridge dedicated team.

State of the art

[MINnD UC03 01]

This deliverable aims at providing a state of the art about the applicability of Industry Foundation Classes (IFC) entities to describe the data exchange model associated to a bridge under construction. The study is based on the knowledge of ISO 16739 standard (IFC) and the preparatory works for the IFC-Bridge extension. The study has also considered the results of Use Cases, in particular the analyses of the IFC files exported according to the ISO 16739 standard, with entities developed for buildings. As a conclusion, concepts not appropriately addressed have been listed and proposals have been given for developing the missing IFC entities.

Bridge data dictionary from conception to bSDD

[MINnD UC03 02]

This document presents the complete method to create a data dictionary (objects and their properties) dedicated to bridges.

It starts from existing documentation and standards, and go in detail through the methodology, till the transfer to the buildingSMART data dictionary (bSDD).

IDM Bridge design process

[MINnD UC03 03]

This document details the process of a typical bridge. It underlines how the conclusions and works carried out could be affected by other types of bridges.

During this process, the manipulated concepts are identified, and how they could be described within the framework of a theoretical and complete IFC. A final section defines globally the extensions required and places them into the more global contexts of the IFC extensions under discussion in the infraRoom of buildingSMART International.

Finally, the last part details the input data necessary for the design of a bridge whose geometry (architectural model) is strongly related to the computation (analytical model). This chapter specifies the mechanical properties related to the geometrical elements to be integrated in the IFC model.

Methodology to feed bSDD with a new Data Dictionary

This document:

- Presents the method used to add concepts of any domain into the buildingSMART Data Dictionary (bSDD).

[MINnD UC03 04]	• Shows the work on the data dictionary with the concepts related to the bridge domain added in the bSDD. • Aims to be used as a guide to manage a data dictionary by avoiding mistakes and loss of time.

buildingSMART deliverables	IFC Bridge became an official project in buildingSMART in October 2016 following the MoU supported by the Infrastructure Room. The project was initiated following the IFC alignment work and harmonization opportunity presented by the IFC4 release. The project team also recognized the importance of gaining support from software vendors, addressing missing property sets and the scope for overall extensions. The French organization MINnD was the driving force behind the technical requirements and deliverables in this phase, with 4 objectives: 1. Provide a description for the extension scope for IFC 4 related to bridges. 2. Develop a set of specifications for the extension of the IFC 4 conceptual model. 3. Create a dedicated space in the bSDD for bridge property sets including US specification. 4. Develop a set of specifications for bridge MVDs for machine readable bridge models.
Project Proposal	Capture the requirements for IFC Bridge project and align to the IFC 4 standard. This project plan was split into two parts and enabled cross-collaboration between different national requirements. https://app.box.com/s/3f4kc490jnfc6olo8f7nk3e128377ghd
Requirements Analysis	To analyse the requirements from the different stakeholders and look at the feasibility of the proposed project. This report focused on common use cases. https://app.box.com/s/5niaey8p2o7vhz6p4qfgpocigx0aggzw
Conceptual Model	The Conceptual Model focused on the necessary data structures for modelling prestressing systems (See Fig.2). This report covers the scope, use cases and bridge types that are covered by future extensions of IFC Bridge. https://app.box.com/s/w3r53huy4srhfg8t2vr0o12ot93hflsa

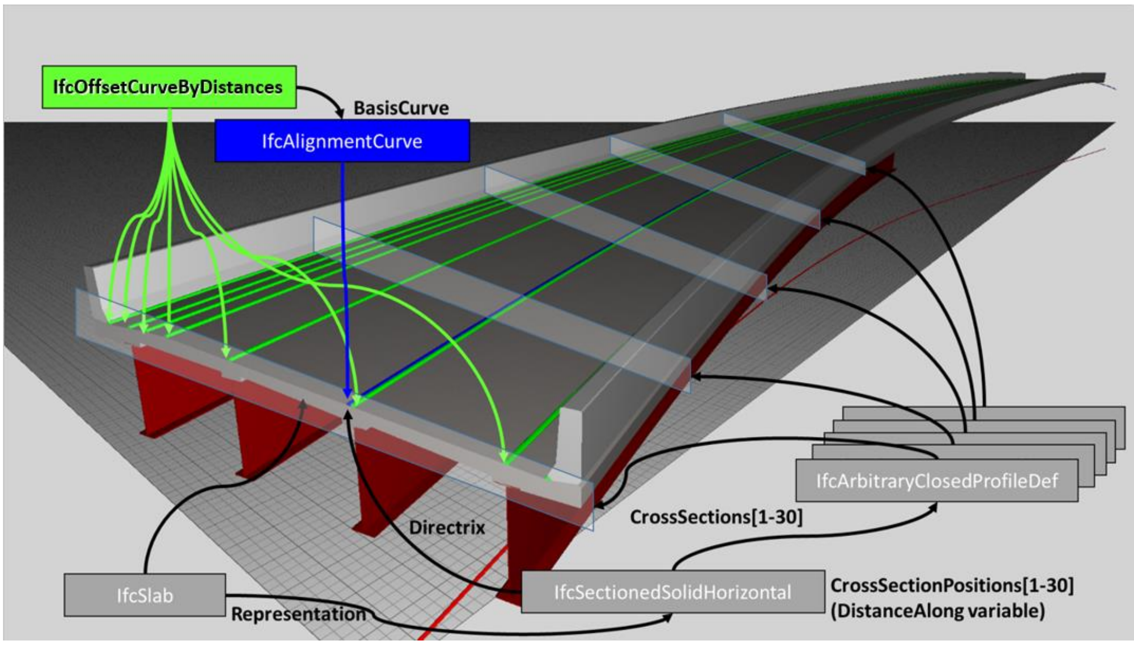


Fig.2 : The conceptual model included IFC extension requirements that were collected by the project teams.

Candidate Standard

The IFC Bridge Candidate Standard was delivered by the project team. This significant milestone brought together teams across the various projects to deliver this standard. You can read the standard below.

https://standards.buildingsmart.org/IFC/DEV/IFC4_2/FINAL/HTML/

IFC Bridge Information Exchange

This document contains the specification of the IFC standard. The specification consists of the data schema, in EXPRESS and as an XML Schema specification, and reference data represented as XML.

http://docs.buildingsmartalliance.org/IFC4x2_Bridge/

IFC Bridge

IFC-Bridge was one of the first identified infrastructure domains in the buildingSMART roadmap (Fig.3). This link leads to the different release specifications of IFC development.

https://technical.buildingsmart.org/standards/ifc/ifc-schema-specifications/ifc-release-notes/

IFC 4.1

The main purpose of IFC4.1 is to provide a basis for the various infrastructure domain extensions currently being developed (e.g., Rail, Road, Tunnel, Ports & Waterways). Extensions made to the IFC4 schema include:

- Description of alignment as a combination of horizontal and vertical alignment
- Linear Placement according to ISO 19148
- IfcSectionedSolidHorizontal as a new geometry representation particular useful for describing infrastructure facilities

IFC 4.2

The main purpose of IFC4.2 is to extend the IFC schema to include the description of bridge constructions. Extensions made to the IFC4.1 schema include:

- The spatial structure was extended by IfcFacility and IfcFacilityPart as a basis to describe the spatial breakdown structure of infrastructure facilities.

- IfcBridge and IfcBridgePart were added to represent bridges and bridge parts.
- Bridge elements have been integrated into a number of predefined types of building elements.
- IfcBearing, IfcDeepFoundation, IfcVibrationDamper and IfcTendonConduit were added to represent the respective bridge elements.
- IfcRelPositions was added to better support positioning along the alignment

IFC 4.3 RC1

The main purpose of IFC4.3 is to extend the IFC schema to cover the description of infrastructure constructions within the domains of Railways, Roads, Ports and Waterways including the elements that are common across those domains. The IFC4.3 schema has been developed to:

- enhance the current definition of alignment and linear positioning to include railway cant within its geometric representation and span placements to provide "from-to" positioning;
- enhance the current geometry definitions for advanced sweeps to add a sweeping operation taking cant into account, and for advanced surfaces to represent road surfaces;
- rationalize and enhance the definition of spatial structure to uniformly define a breakdown structure for all domains in question;
- rationalize and enhance the current specialization structure of products and product types to reflect the taxonomy of the new domains Railways, Roads, Ports and Waterways and common domains such as geotechnics and earthworks.

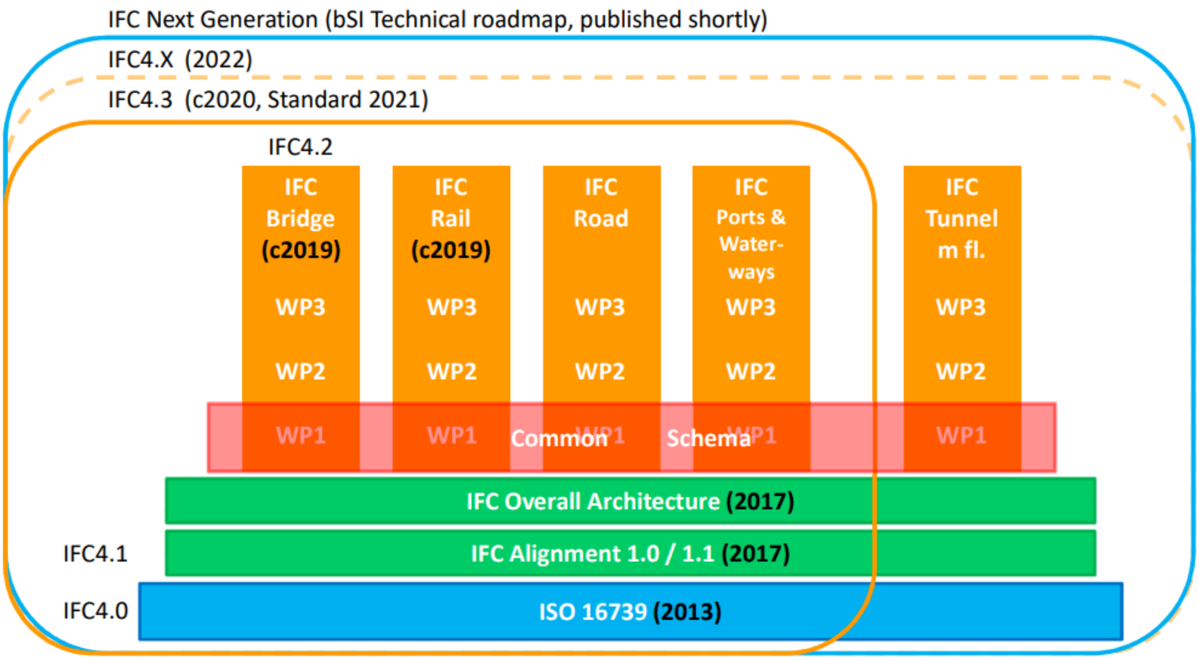


Fig.3 : buildingSMART International IFC-Infra roadmap

2.2 Existing documents

MINnD S1 deliverables	• MINnD_UC03_01_IFCBridge_State_of_the_art_002_2015 (December 2015) • MINnD_UC03_02_Bridge_DataDictionnary_from_concep-tion_to_bSDD_015A_2018 (November 2018) • MINnD_UC03_03_IDM_Bridge_design_process_015B_2019 (February 2019) • MINnD_UC03_04_Methodology_to_feed_bSDD_with_a_new_DataDiction-ary_015C_2018 (November 2018)

Reference documents	Reference documents of buildingSMART International: • IFC-Bridge Fast Track Project / WP1-Requirements analysis – May 2018 • IFC-Bridge Fast Track Project / WP2-Conceptual model – October 2018 Other reference documents: • "Post-Tensioning Terminology (PTT) Tab3-13"edited by PTI (Post-Tensioning Institute) - November 2013 • "Instruction technique pour la surveillance et l'entretien des ouvrages d'art, Fascicule 32, Ponts en béton précontraint", edited by Cerema, 2019 • "Conception des ponts à haubans – Un savoir-faire français", edited by Cerema, September 2016 • "Instruction technique pour la surveillance et l'entretien des ouvrages d'art, Fascicule 34-1, Ponts suspendus", edited by Cerema, 2021 • "Instruction technique pour la surveillance et l'entretien des ouvrages d'art, Fascicule 34-2, Ponts à haubans", edited by Cerema, 2008 • Dictionnaire de l'entretien routier - Volume 5 : ouvrages d'art du Cerema ?

2.3 Standards

EN-ISO 23386:2020	EN-ISO 23386 :2020 - Building information modelling and other digital processes used in construction - Methodology to describe, author and maintain properties in interconnected data dictionaries. This standard describes a standardisation method of concepts related to products and methods used in construction industry. This document defines and manages attributes related to each concept of a data dictionary. It is not a data dictionary! This standard is our reference document to create the bridge data dictionary, and all associated concepts.

Concept attributes

Each concept of the data dictionary of bridge terms has the following attributes:

Attributes	Details
Unique identifier	A character related to a single concept, which is convenient to precisely identify it (also called GUID – Global Unique IDentifier).
English name	
Description in English	
French name	Or another language
Description in French	
Visual representation	
Creation date	
Country where the concept is used	
Nature of the group	Domain, class, or group of concepts, depending on the hierarchy level of the concept
Group of concepts	Group's name in which the concept is. For a concept at the bottom of the hierarchy level
Relationship between groups	Group's name in which the concept is (parent) and the names of groups included in it (child), for a concept which is not at the bottom of the hierarchy level
Type	Kind of value. Integer, real or character
Cardinality	Number of values to describe the concept
	For example: three values are required for coordinates
Physical values	Length, speed, etc.
Unit	
Threshold values	

3. METHODOLOGY

3.1 System Identification

Systems	A system is a set of elements or components interacting with others, according to certain principles or rules. Each system responds to a function. A function responds to a requirement with an expected performance.
Objectives	The exhaustive identification of the systems makes it possible to check that the functions are treated in their context, because we have to consider the components of the system, but also the interactions with the external systems on which they depend or with which they have interfaces.
Stakes	In our study, the stakes are mainly to attach some properties to a complete system (such as performance attributes) and not to each object that composes it.
Links between systems	The links between systems also make it possible to propagate some properties by inheritance, that means some child attributes are the same as the parent attributes which govern them.

3.2 Object Identification

Exhaustive list of objects	Each system is therefore composed of objects, the list of which may vary depending on the type of project or the use of the system to meet a given function. Our goal is therefore to identify the exhaustive list of objects that make up a system, in all possible configurations, whether common or not.
Bridge Prestressing case study	As part of our study on prestressing, we must consider: • The prestressing components. • The geometry of the prestressing in its context. • The implementation of prestressing.
Suspension and cable-stayed bridges case study	As part of our study on suspension bridges and cable-stayed bridges, we must consider: • The suspension components. • The suspended or wired structure, whether concrete or steel structure. • The implementation of tendons and hangers.

4. Bridge Prestressing

4.1 Prestressing types

Prestressing definition

Prestressing is a construction technique for cement concrete structures which consists in creating favourable internal forces. These are carefully adjusted to reduce the effects of weak concrete in tension. Prestressing is mostly carried out using tension cables coated with concrete.

Pre-tensioning

In this case, steel wires are stretched between two benches. They pass through a formwork where fresh concrete is poured and set. After hardening, the threads are cut. At that time, the steels transfer part of their tension in the form of compression of the concrete: the compression of the concrete balances the tension in the steels. The wire / concrete contact exists all along the wire. The layout of the wires is most often straight.

The pre-tensioning is implemented in specialized workshops equipped with tensioning benches. It applies to the prefabrication of light fixtures, floor slabs and short bridge beams.

Post-tensioning

In this second case, the fresh concrete is poured into the formwork and sets. Wires (or cables) are then threaded into sheaths left waiting in the concrete. These wires are then tensioned using jacks and wedges. During the tensioning process, the wires transfer part of their tension in the form of compression of the concrete: the compression of the concrete balances the tension in the steels. The layout of the ducts is not necessarily straight; they can be curved so as to inject forces into carefully chosen areas.

Post-tensioning applies to larger structures such as bridges, but also tanks or nuclear power plants. This is the reason why this technique will be mainly treated in the following chapters.

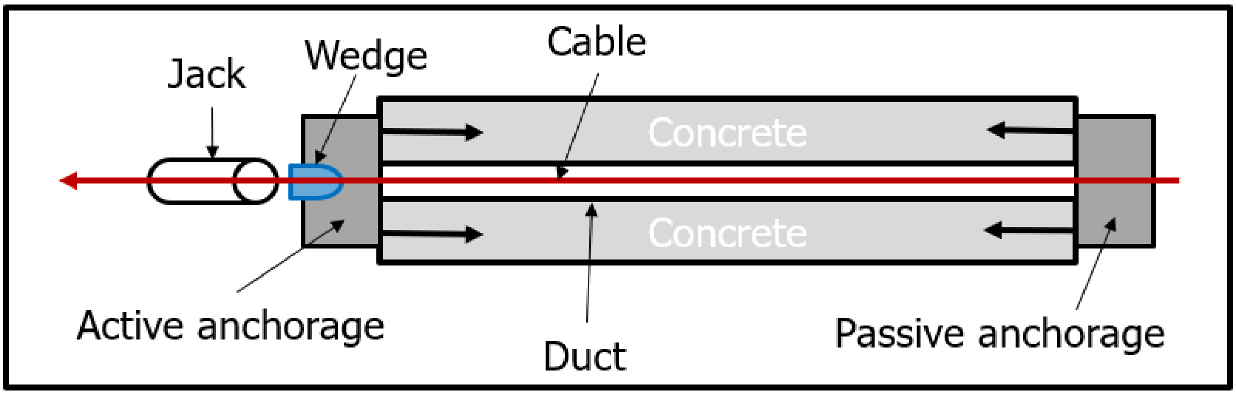


Fig.4: post-tensioned prestressing principle

Post-tensioned prestressing types

Here are the main characteristics of the different post-tensioned prestressing types:

Prestressing type	Characteristics	Comments
Internal prestressing (simply supported beam)	• Injected • Unremovable (in service) • Horizontal or Vertical (pylon)	• • Removable if wax is used •

Prestressing type	Characteristics	Comments
	• Longitudinal • Transversal	• Beam, continuity •
External prestressing (continuous beam)	• Injected • Removable • Longitudinal • Transversal	• • • •
Nailing	• Not injected • Removable	• • Temporary
Launching prestressing	• Incremental	• Temporary
Anchored wall	• Tendons or Thread bars	•

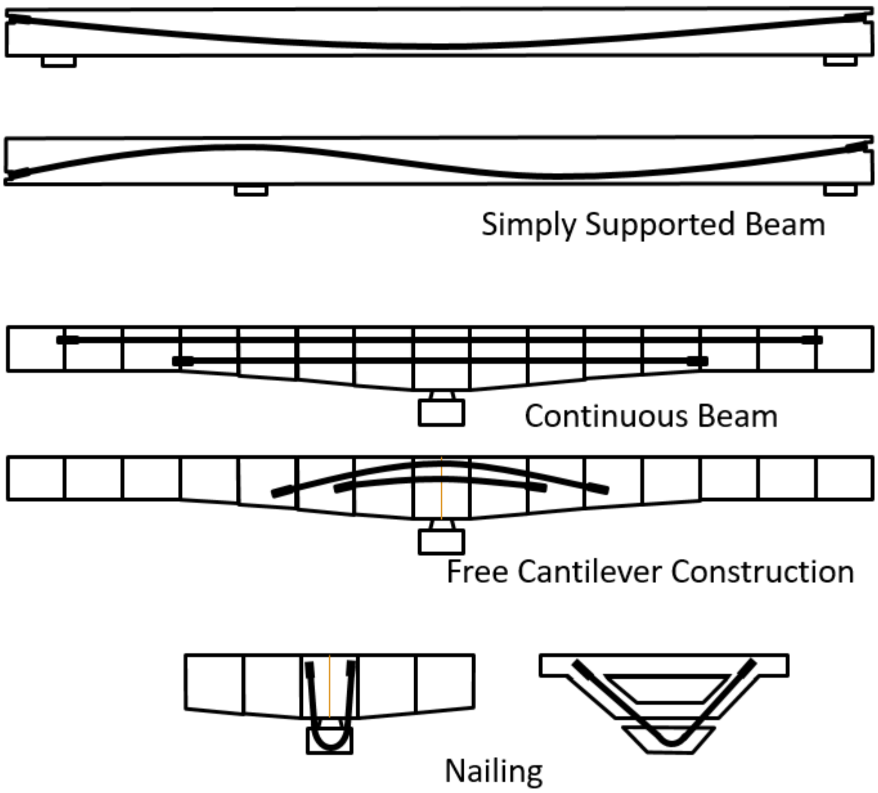


Fig.5 : Prestressing types

Prestressing systems

As proposed in the above methodology, the first stage is to identify the different systems for the prestressing of a bridge (see Fig.6 below).

Structure

The first system is the bridge itself (the concrete structure in which the prestressing elements will be installed), and mainly the "deviation zones".

Definitive systems (Tendon system)

In the "linear zone" of the concrete structure, the main systems concern the pre-stressing elements:

- Duct system (for post-tensioned prestressing only)
- Main tensile element system

The "anchorage zone" is at the end of each tendon:

- Anchorage system

Remark: specific elements to external prestressing (such as deflectors for external cables) are classified in the structure system (Concrete and Rebar).

Implementation system / Equipment

Then, the necessary systems for prestressing implementation are:

- Threading system
- Tensioning and monitoring systems
- Grouting system
- Other systems (Accessories, Tools...)

Interfaces between systems

All these systems have interaction between each other, by the means of some specific components. These interactions are shown on the Fig.6 below.

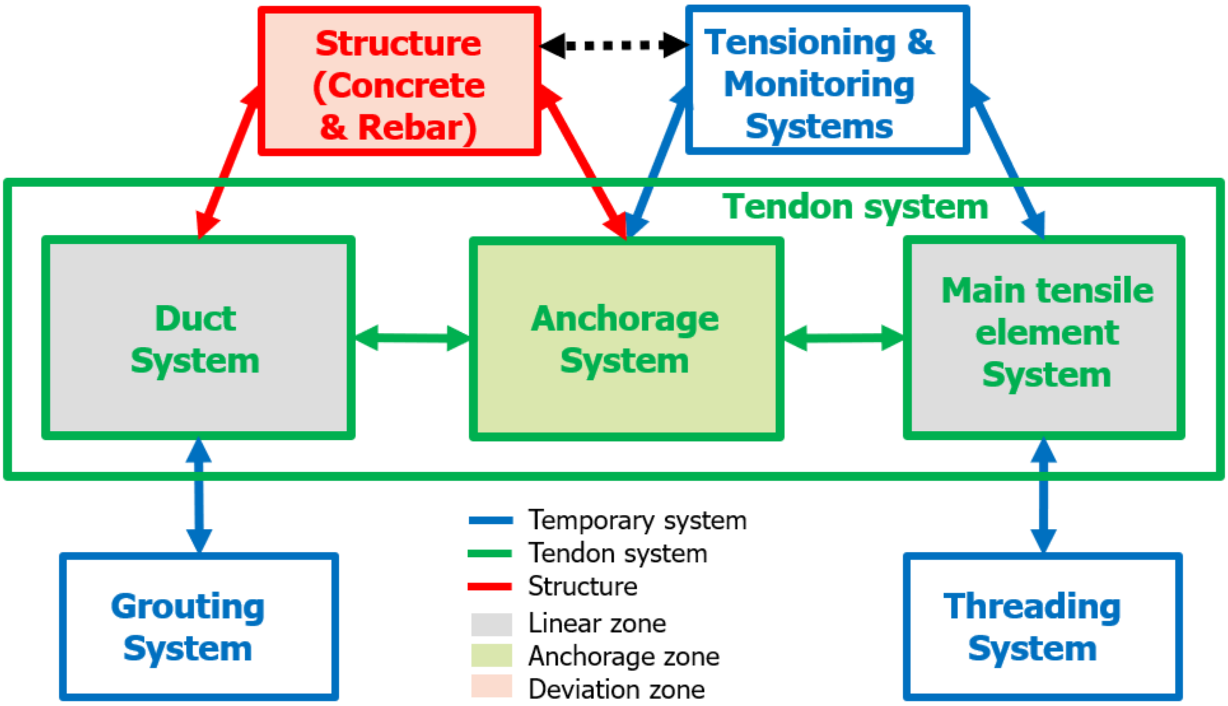


Fig.6 : Prestressing systems

Prestressing implemented components

For each definitive system, the components are the following ones:

Duct system

The ducts left waiting inside the concrete (internal prestressing) are placed in the formwork, generally fixed to the reinforcements. The ducts in which the cables will be inserted can be made using a sheath (metal strip, corrugated plastic) or a tube (HDPE, steel).

The ducts for temporary cables are not injected. Their role is to:

- facilitate the installation of cables,
- protect them against possible mechanical attacks.

Main tensile element system

Prestressing cables can be of several types:

- Wire: a flexible thread of steel used to bear mechanical loads, used in pre-stressed prefabricated elements (beams, slabs…) or some external tendons. Wires could be smooth or indented to allow a better grip.
- Bare strands: These strands are made up of several steel wires. They are smooth, without special protection or with a slight temporary lubrication provided in the factory and intended for the implementation of prestressing by post-tensioning.
- Protected strands: Protected strands are bare strands with additional protection (grease, wax, zinc or zinc-aluminium alloy coating, extruded high-density polyethylene (HDPE) sheathing in black colour or others, phosphating, epoxy and possible combinations) intended for interior or exterior prestressing of concrete.
- Prestressing bars: The bars can be threaded or ribbed over their entire length, or smooth in the main part and threaded at the ends. They are generally delivered without protection, but for certain uses, they can be fitted with special protection (marine protection, grease, wax, epoxy resin, HDPE sheathing, zinc plating, galvanization, stainless steel, etc.).

Anchorage system

In accordance with their function, there are several categories of anchorage systems:

- Live end or Active anchorage, mechanical device allowing the blocking of the cable at the end by which the tensioning is carried out.
- Dead end or Passive anchorage, fixed external mechanical device (the most common in bridges) or anchors embedded in concrete.
- Coupler, device used to connect adjacent sections of prestressing tendons.

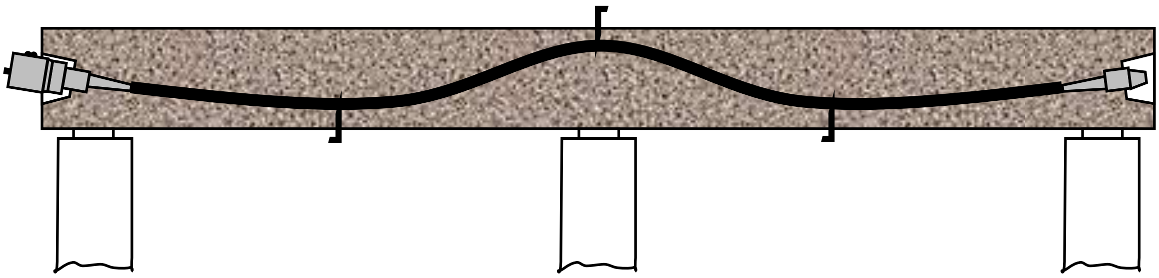


Fig.7 : Definitive prestressing objects

Prestressing Implementation components

Then the necessary components for prestressing implementation are the following ones:

Threading system

In accordance with the tendon type and geometry, the method has to be adapted:

- Some examples of implementation of main tensile elements:
  - threading by unitary pushing of the strands into the conduits (most cases)
  - towing in the case of strands that are difficult to thread or when difficulties are foreseeable (length, undulation, etc.).
- Protected sheathed strands: pulling of the strand, the reeling of the protected sheathed strand is carried out by the rotation of the reel mounted on an axis. Threading is generally manual or by pushing with a threader equipped with rubber rollers.

Tensioning & Monitoring system

The tensioning is carried out by means of a jack and its hydraulic pump, by successive pressure stages. The process is managed with pressure gauges and sensors. It can only be authorized when the structural concrete has sufficient resistance.

At each stage of tensioning, a keying operation allows the cables to be blocked.

Grouting system

The tensile elements must be permanently protected against corrosion in order to ensure the durability of the prestressing from the temporary protection to the final protection. The injection of conduits and anchors is intended to fill the voids in the conduits, to protect the strands against corrosive agents and to passivate the steel used.

Comment: Only cement grout passivates the steel. Not wax, not grease which allows to replace the main tensile elements if necessary.

Other systems

Lots of accessories and tools are needed to carry out the different tasks:

- Marking
- Duct assembly / welding
- Ducts and Casting installation
- Anti-bursting reinforcement installation
- Bar chairs installation
- Inspection
- Free Passing Test
- Concrete witnessing
- Equipment mobilisation
- Strand threading
- Strand cutting
- Strands bulging
- Compression fittings installation
- Anchorage installation
- Fitting of wedges
- Stressing Preparation
- Strand Stressing
- De-tensioning works
- Grouting preparation
- Pressure tightness test
- Grouting works
- Drilling works
- Chipping works
- Concrete patching

Prestressing External Objects (Structure and Tensioning systems)

Then, the necessary components to set prestressing in the concrete, or to stress tendons are the following ones:

Deflector

A deflector is a structural element, typically made out of concrete, capable of absorbing the forces exerted by the external cable in the deflection zone, and which

	ensures the geometry of the deflection. It can be reinforced with a curved steel duct or with a suitably shaped steel shell (diabolo).
End block	Device for anchoring a prestressing cable at an end or an intermediate point of a concrete structure.

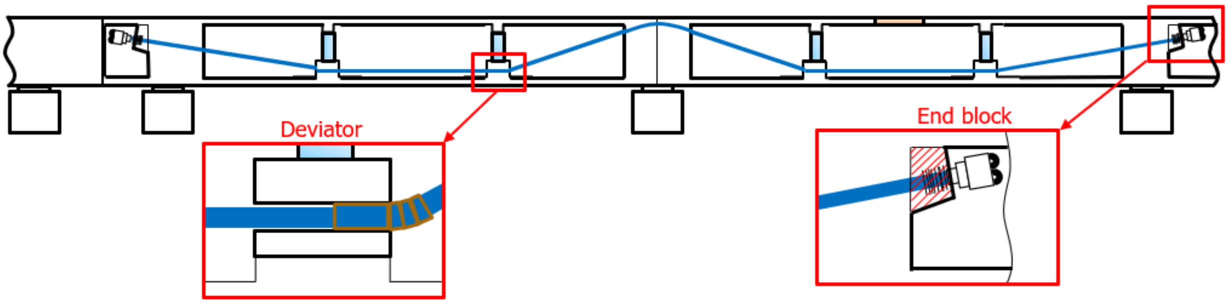


Fig.8 : Typical elevation of an external multistrand post-tensioning

4.2 Object Identification

Exhaustive list of objects	Exhaustive identification of the objects necessary for: • The prestressing: cables, anchors, ducts, etc. • The geometry of the prestressing: deviator, block, etc. • The implementation of prestressing: threading, tensioning jacks, etc.
Links between objects	The dependencies between objects are necessary to define interfaces between concepts (exhaustivity and scope).

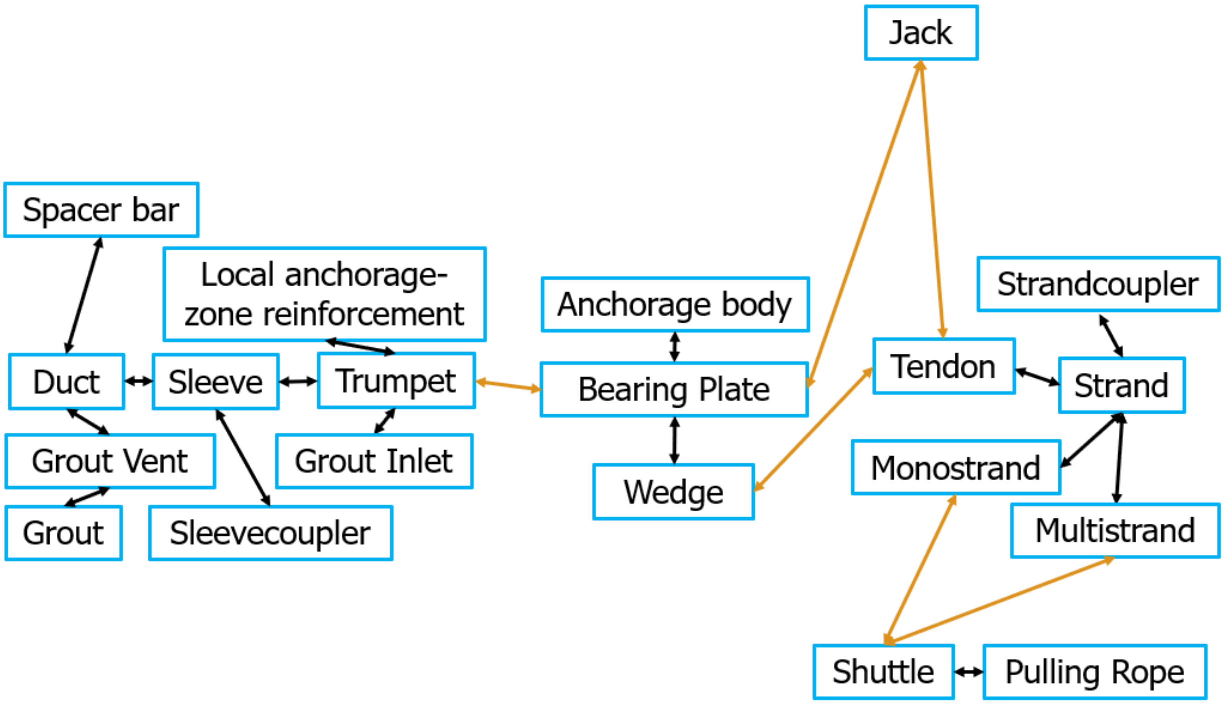


Fig.9 : Main objects of a Prestressing System with their dependencies

List of components Here is the list of the main components of a prestressing system.

Prestressing component / Object	Definition
Anchorage	Mechanical device, usually comprising several components, designed to retain the force in the stressed tendon, and to transmit the force to the structure.

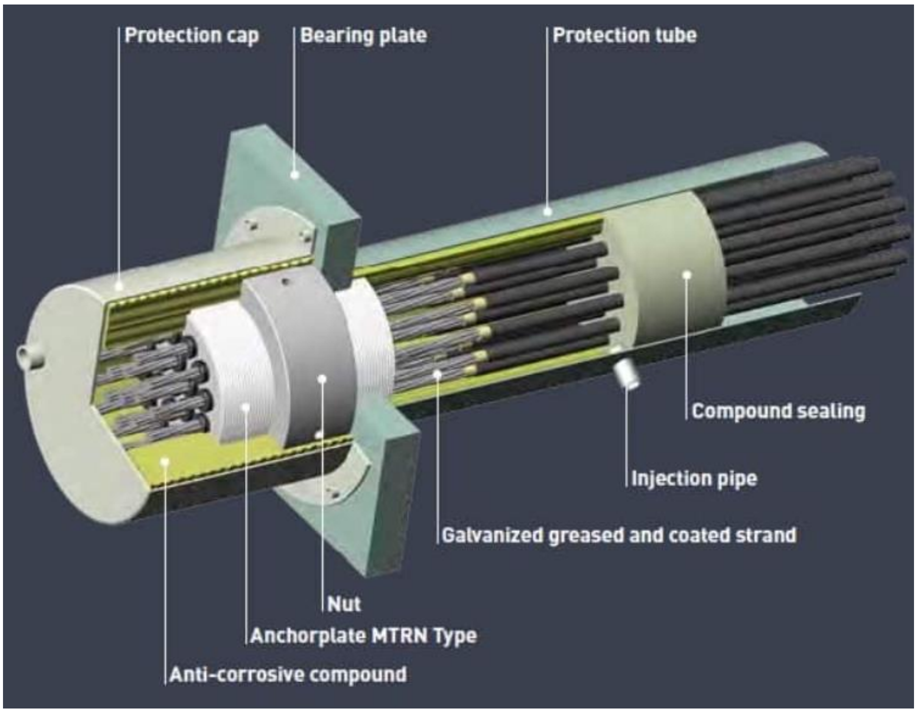


Fig.10 : Post-tensioning Anchorage

Anchor head (Wedge plate)	Part that holds one or several tensile elements by wedges/button heads/ nuts and transfers the prestressing load to the bearing plate, or for small tendon sizes directly into the structure. The anchor head is sometimes called a wedge plate.
Anchorage cap	Cap made of steel or plastic to encapsulate the end of the tensile elements at the anchorage.
Bearing plate	Part that supports the anchor head and transfers the prestressing load onto or into the structure. The bearing plate is sometimes called a "force transfer unit".
Bursting reinforcement	Reinforcement in the local anchorage zone, just adjacent to the anchorage, to confine the concrete, and to resist transverse tensile loads due to the introduction of the pre-stressing load.
Button head	Part that holds an individual tensile element, typically a wire, and transfers the pre-stressing force to the anchor head, or for an individual tensile element directly to the bearing plate.
Coil	Delivery unit of strands, monostrands or wires, generally made of a cylindrical shape.
Compression fitting	A cylindrical steel component that is extruded/cold over the tensile element such as to provide a tight fit with the tensile element allowing to anchor the tensile element force.

Connector	Special element to join individual duct lengths/sections between each other or to join a duct segment to the anchorage or trumpet.
Coupling / coupler	A device to join adjacent sections of tendons
Dead end anchorage	A "passive" end anchorage of a prestressing tendon that does not have any jacking operations undertaken at that end.
Deviator	A structural element where external tendons are deflected, and tendon forces are transmitted to the structure.
Duct	An enclosure in which tensile elements are placed and that temporarily or permanently allows relative movement between the tensile elements and the surrounding concrete. The remaining void within the duct can subsequently be filled with filling material.
Duct coupler or joiner	A component that securely connects separate segments of post tensioning ducting, commonly used when joining precast concrete segments in a prestressed structure.
Duct support	Device that supports and firmly holds a duct in position.
Filling Material	A material used to completely fill the space around the tensile elements inside a duct to provide corrosion protection and/or bond. A cementitious filling material is also called "grout".
Fixed anchorage	Anchorage that does not allow stressing, or anchorage formed by bond between tensile elements and concrete.
Fixed coupling	Coupling that allows joining of adjacent tendon sections stressed not at the same time
Grout	Cementitious filling material
Grout inlet (or Grout tube)	Tubular components connected to anchors or ducting through which grout is pumped during the process of grouting
Grout outlet (or Grout vent)	Tubular components or hose connected to anchors or ducting that permits air and water to escape the duct at high points and ends of the tendon profile during the process of grouting
Intermediate anchorage	Can be used when structures are built in steps. The intermediate anchorage anchors temporarily one strand in a first section before the second section is built and the whole strand is stressed from the other end of the second section. After stressing the whole strand from the second section, the anchorage remains in the structure without taking any forces. The anchorage can be used for internal bonded or internal unbonded tendons
Jack	A device that tensions prestressed concrete tendons.
Mono-strand	A prestressing system using tendons with single strands, or tendons able to be tensioned using a mono-strand jack
Multi-strand	A prestressing system using tendons with multiple strands, and are tensioned using a multi-strand jack
Movable coupling	Coupling that allows joining of adjacent tendon sections stressed at the same time
Nut	Piece that holds an individual tensile element, typically a bar, and transfers the prestressing force to the anchor head, or for an individual tensile element directly to the bearing plate. Nuts can also be components of anchorages or couplers

Pipe	A thick-walled smooth duct made of plastic or steel
Protection cap	Anchorage cap to protect the dead-end strands, injected with anti-corrosive compound
Sheathing	An enclosure encapsulating a single tensile element, usually separated by a thin layer of grease or wax from the tensile element. Typically, monostrands are equipped with polymer sheathing.
Shuttle	A specific temporary device set up at the end of a strand, used to facilitate pushing of strands in duct
Sleeve	Sheath joining duct and anchorage trumpet
Spacer bar	Specific bars or chairs to set up ducts in the concrete reinforcement system
Strand	Twisted steel cable composed of 2, 3, 7 or 19 high strength steel wires. Strands are galvanized, greased, and coated.

Fig.11 Different strand types (made of 3 or 7 steel wires)

Stressing anchorage	Anchorage allowing stressing of the tendon, usually a mechanical anchorage.
Tendon	A single tensile element or a bundle of tensile elements used for the prestressing of a structure, including the required protection and anchorages
Tendon tail	Protruding length of tendon, used for tendon tensioning implementation. This extra length is usually cut off after implementation, but is sometimes let in place in case of force adjustment or maintenance
Tensile element	Individual element such as strand, wire, or bar to impart prestressing
Trumpet	Device used to join bearing plate to duct providing the necessary leak tightness and allowing a reduction of the bundle diameter in the case of multi tensile elements anchorage
Trumplate	Steel part combining the functions of a trumpet and an anchor plate for prestressing reinforcement
Wedge	Part that holds and individual tensile element, typically a strand, and transfers the prestressing force to the anchor head, or, typically for a single tensile element but also feasible for several tensile elements, directly to the bearing plate
Wire	A flexible thread of steel used to bear mechanical loads

4.3 System Identification

System grouping

To match functions, the components are grouping by system (Fig.12).

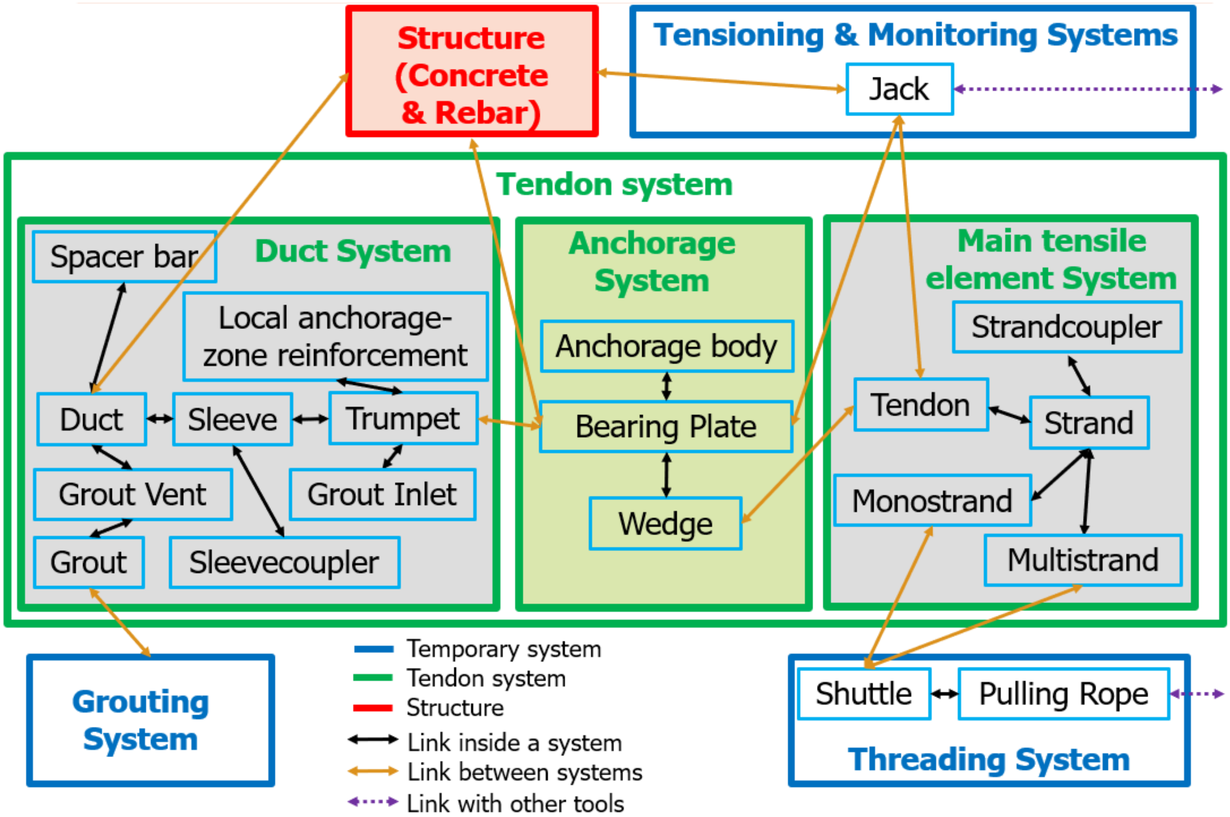


Fig.12 : Synthetic Prestressing system (organic view)

List of components per system

A complete list of prestressing components is detailed below, with the expected properties[1].

Implemented components

We can find hereafter the exhaustive list of implemented components:

- Tensile elements (Fig.13)
- Duct (Fig.13)
- Anchorage (Fig.14)
- Deviation (Fig.14)
- Dampers.

Comment

the completeness of the items in the list has been verified by:

- prestressing experts,
- comparison with catalogues of components offered by suppliers of prestressing equipment,
- research in specialized technical dictionaries.

[1] This Excel list is also available in deliverable: MINnDs2_GT1.1_ifc-bridge_taxonomy_prestressing_suspension_systems_005_2022.xlsx

Main system	Main System Properties	System	System Properties	Sub-system	Sub-System properties	Component / Object	Object Properties
Implemented components	*Bonded tendon*	**Linear Zone (Tensile element)**		Prestressing steel		Strand Coil	*Diameter* *Coiling sense (left/right)*
	Unbonded tendon					Stress bar	
						Wire	*Ultimate strenght*
	Longitudonal tendon					Strand	*Number of wires*
	Transversal tendon					Tendon tail	*Length*
						Tendon	*Monostrand* *Multistrand (Number of strands)* *Date of birth (implementation date)*
	Vertical tendon			Tendon Encapsulation		Sheathing	*PEHD*
						Wax	
	Internal tendon					Grease	
	External tendon			Continuity anchorage		Bar coupler	
	Hybrid tendon					Compression fittings	
	Exchangeable tendon (Y/N)					Movable Coupler block	
	Protection level:					Sleeve (=coupler casing)	
	Protection level 1 (PL1)					Trumpet	
	Protection level 2 (PL2)					Wedges	
	Protection level 3 (PL3)			Tendon support system		Chairs	
						Others	
				Local zone reinforcement (only with continuity anchorages)		Back-up bars	
						Bursting steel	
						Confinement reinforcement	
		Linear Zone (Duct)		Ducting system		Corrugated Duct	*Metal Protection level PL1* *PEHD ou PP: Protection Level PL2 PL3*
						Duct coupler (duct connector or joiner)	*Venting point (Yes / No)*
						Duct support	*coordinates x, y, z* *height*
						Duct Inlet	*coordinate z*
						Duct Outlet (= vent)	*coordinate z*
						Segmental coupler	
						Smooth pipe	
						Electrofusion socket	
						Sensor	*Acoustic sensor* *Accelerometer* *Void sensor*
				Duct Filling material		Grout	
						Wax	
						Grease	
						Gel	

Fig.13 : Prestressing - Implemented components of linear zone

Main system	Main System Properties	System	System Properties	Sub-system	Sub-System properties	Component / Object	Object Properties
Implemented components		**Anchorage zone**		**Anchorage (assembly)**	*Fixed anchorage* *Dead end anchorage*	Anchor	
						Anchor nut	
						Anchor, barrel	
						Bearing plate	*Basic or Special* *Number of strands* *Bolts for cap (Yes/No)* *Inspection port (Yes/No)* *Concrete strength*
						Bond length (in a passive anchorage)	
						Bulb (in a passive anchorage)	
			Anchorage zone volume			Button head	
			dimension x			Strand deviation soft interface	*Bushing* *Deviation plate*
			dimension y			Deviation plate (DSI)	
			dimension z			Electrical connection	
						Fixed Coupler block	
						Insulation plate	
						Lock nut	
						Pocket former (=recess former, stressing pan)	*x,y,z*
						Protection cap	*Temporary/ Permanent* *Material*
						Retaining plate	
						Sensor	
						Shims	
						Tension ring	
						Troubleshooting anchor	
						Trumpet	*Yes/No* *Material*
						Trumplate	
						Wedge	*Type of strand 13/15,2/15,7mm* *Number of segments (2/3)* *Clip/ No clip*
						Wedge plate (Anchor head)	*Number of holes* *Type of strand (0,5, 0,6, other)*
				Local zone reinforcement (end block)		Back-up bars	
						Bursting steel	*Bar diameter* *Grade of steel 400/500/670*
						Confinement reinforcement	*Bar diameter* *Grade of steel 400/500/670* *Helix/Stirrups* *Pitch/Spacing*
		Deviation zone		Deviator		Deviator tube	
						Diabolo	
						Matrix deviator	
				Nailing reinforcement		Reinforcement	

Fig.14 : Prestressing - Implemented components of Anchorage and deviation zones

Implementation components

We can find hereafter a non-exhaustive list of implementation components (Fig.15):

- Threading system
- Tensioning system

- Grouting system
- Installation and monitoring system
- Accessories and tools

Main system	Main System	System	System Properties	Sub-system	Sub-System	Component / Object	Object Properties
Implementation components – Equipment		**Threading system**		Strand pusher			*Hydraulic* *Electric*
				Uncoiler			*Horizontal* *Vertical*
				Dispenser / Strand drum			
				Hydraulic pump			
				Winch			*Electric* *Other*
				Hand tools and accesories		Shuttle (Push-through caps)	*Steel* *Plastic*
						Olive	
						Push tubes	
						Guiding hoses	
						Hydraulic cutter	
						Cable sock	
						Welded stirrup	
		Tensioning system		Hydraulic jack			*Single strand jack* *Multistrand jack* *Hollow jack (for bars)* *Jacking force*
				Hydraulic pump			
				Accessories		Guide forks / Strand Combs	
						Guide caps	
						Wedge seating tool	
						Fork / Spacer fork	
						Hydraulic cutter	
				Chairs		Stressing chair	
						Destressing chair	
						Jack chair	
						Curved chair	
		Grouting system	*For cement grout* *For wax/soft fillers*	Grouting station		Grout mixer	*Drum* *Colloidal*
						Agitation tank	
						Grout pump	
				Peristaltic pump			
				Wax pump			
				Vaccum pump			
				Heating tank			
		Installation monitoring system		Filling sensor			
				Force transducer / Load cell			
				Pressure gauge			
				Elongation			
				Displacement			
				Density			
				Insulation / Electrical resistance			
				Vibration / Accelerometer			
		Accessories		Gauges			
				Hoses			
				Coilers			
				Winches			
				Strand Coupler			
				Power Cables			
		Tools		Mirror Welding Machine			
				Internal debeader			
				Bundling Tool			
				Collars			
				Strand Preparation Bench			

Fig.15 : Prestressing - Implemented components - Equipment

Conclusion

Post-tensioning strand systems are far more complex than the elements developed in IFC4.3 may offer. They constitute sub-systems of the bridge system itself and it justifies introducing an **IfcSystem** to cover post-tensioning (and possibly other systems essential to the operation of the bridge such as the monitoring system, the lighting system etc.). Currently, without IFC classes dedicated to prestressing, post-tensioning systems designers call for elements that are often used in plumbing, piping, and electrical networks, but special entities are needed to cover all the prestressing scope, including deviators as well as anchoring points. For bridges constructed by segments, it is usual to plan internal (segment and creeping cables) and external cables (continuity). In the case of ducts, **IfcDuct** must allow being threaded in by an **IfcCable** or **IfcStrand** and its remaining void (the internal volume of the duct less the external volume of the cable) being later filled-in by an **IfcGrout**.

Perspectives

The prestressing objects described for structures are similar to those used for other prestressed structures (nuclear power plants, LNG tanks, gravity base of offshore wind turbines, etc.). Specific additional objects may therefore be required, but the main IFC classes have been described in this chapter.

5. SUSPENSION AND CABLE STAYED BRIDGES

5.1 Suspension bridges

Suspension bridge

Suspended bridge specificities are mainly the suspension cables and the hangers connected to the suspended structure and the deck. The suspension system is very flexible, and its shape is sensitive to the loads applied on the deck, the external temperature, and the construction sequencing. The reference of the geometric representation is the bridge with applied dead loads at the end of the construction. The detailed definition of this geometry is driven by the structural analysis of the construction steps. Specific parts are necessary to describe the components ensuring the connections between the deck and the hangers, between the hangers and the suspension cable, between the suspension cable and the saddle on the top of the pylon, between the suspension cable and the anchorages.

Suspension systems

As proposed in the previous methodology, the first stage is to identify the different systems for the suspension of a suspension bridge (see Fig.16 below).

Suspended Structure

The first system is the bridge itself, *i.e.* the suspended structure:

- The supporting system: deck, girders;
- The load bearing system: pylon, saddles, and anchorages;
- The foundation system (foundation under anchor block and under pylons).

The girder (rigidity beam) ensures aerodynamic stability and limits the local angle changes in the deck.

Suspension systems

The main systems deal with the suspension elements:

- Main suspension cable system;
- Hangers' system.

And the different fastener systems, binding systems together.

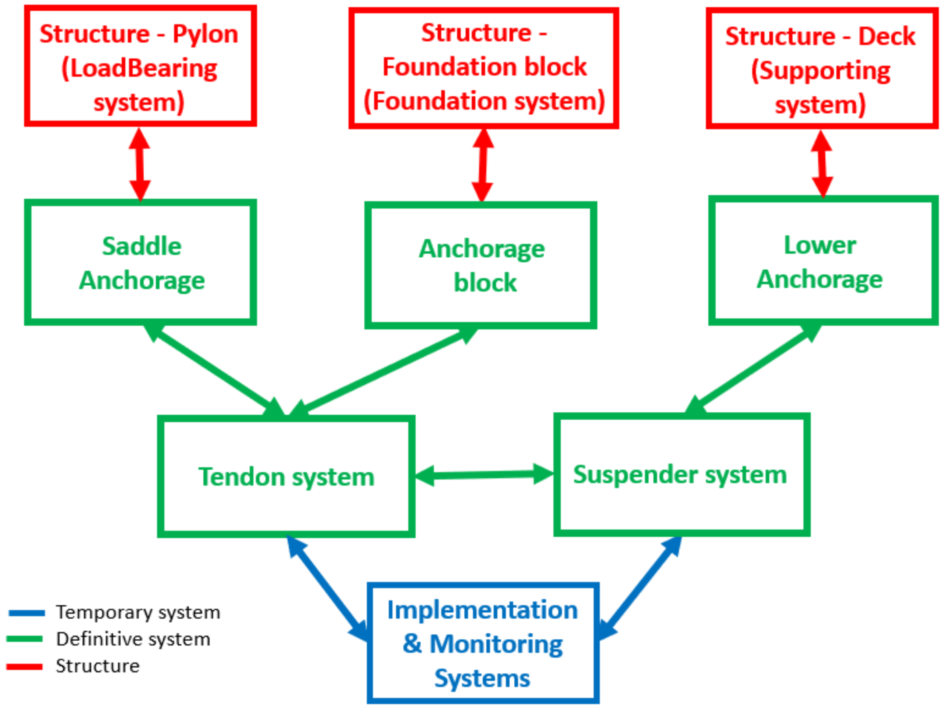
Implementation system / Equipment

The necessary system for cable implementation and tensioning:

- Lifting and guidance systems (saddles, splay saddle, splay collar);
- Tensioning and monitoring systems;
- Other systems (Accessories, Tools…).

Interfaces between systems

All these systems interact with each other, through some specific components. These interactions are shown on Fig.16.



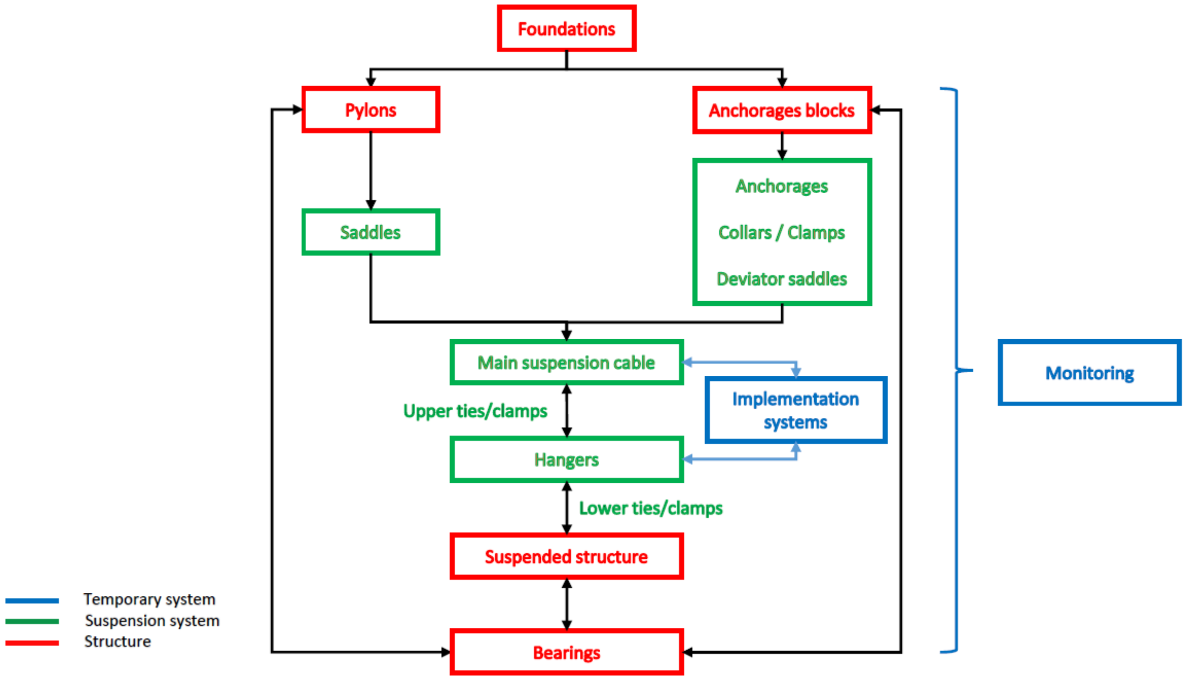


Fig.16 : Suspension bridge systems

Suspension bridge implemented components	For each definitive system, the components are the following ones (Fig.17):

Main suspension cable and hanger systems

The different types of cable are:

- Main suspension cable (MSC): the main cable, binding the pylons with the foundation blocks, supporting all hangers.
- Hanger (or suspender): cable binding the main suspension cable with the suspended structure, by means of anchorages and clamps.
- Cables-stays, involved in some specific hybrid configurations.
- Any other cable systems, such as horizontal cables between pylon heads to prevent large displacements of moving saddles.
- Vandal proof and explosion proof equipment.

Fastener systems

The different fastener systems, depending on their functions:

- Saddle and deviation system (mobile or stationary device on the pylon head).
- Lower and upper hangers' tie.
- Anchorage block system: linked to the foundation blocks, or directly to pylons for more specific configurations.

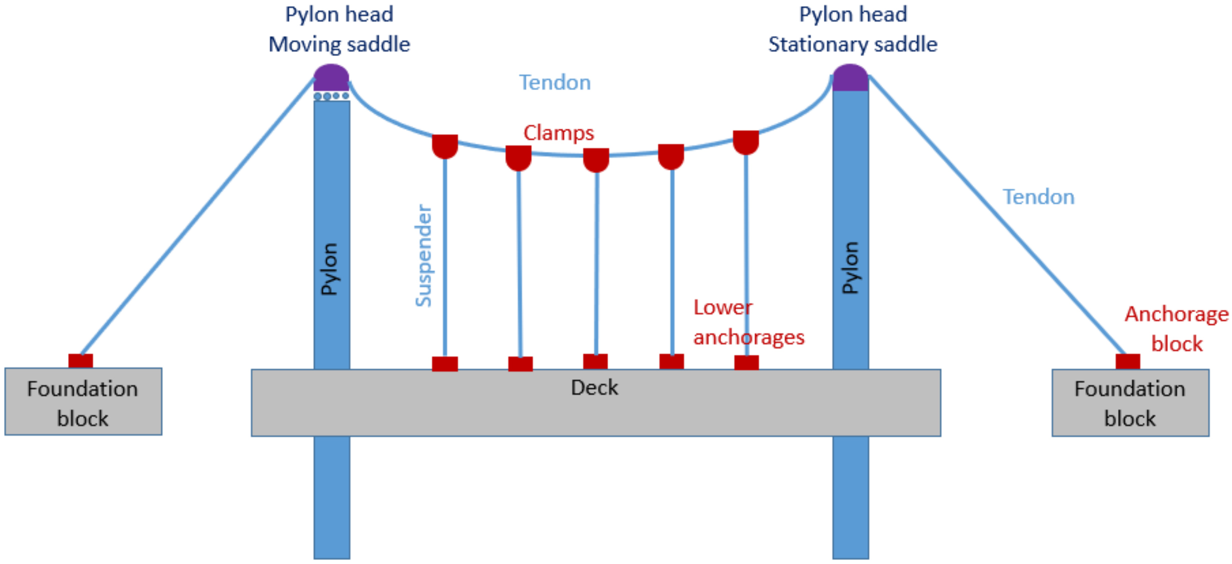


Fig.17 : Example of suspension bridge

Prestressing Implementation components

The necessary components for cable-stayed implementation for suspension bridges are the following ones (Fig.18):

Lifting and guidance system

To help lifting and guiding the main tendons, several devices are used:

- Catwalk: temporary cables with rollers to guide tendons implementation.
- Winch: device to lift tendons following the catwalk.

Tensioning & Monitoring system

The tensioning is carried out by means of a jack and its hydraulic pump. The process is managed with pressure gauges and sensors.

Other systems

Lots of accessories and tools are needed to carry out the different tasks:

- Saddle installation
- Anchorage installation
- Strand pre-cutting

- Strand threading
- Strand by strand stressing
- Strand by strand re-stressing
- Equalization
- Vibration testing
- Casing installation
- Catwalk installation
- Stay pipe closure
- Protection cap installation
- Anchorage injection
- Monitoring system installation
- Fire Protection installation
- Anchorage final inspection
- Bearings (strut, slides, wind block)
- Pendant bracket, pushcart
- Cable dehumidification system

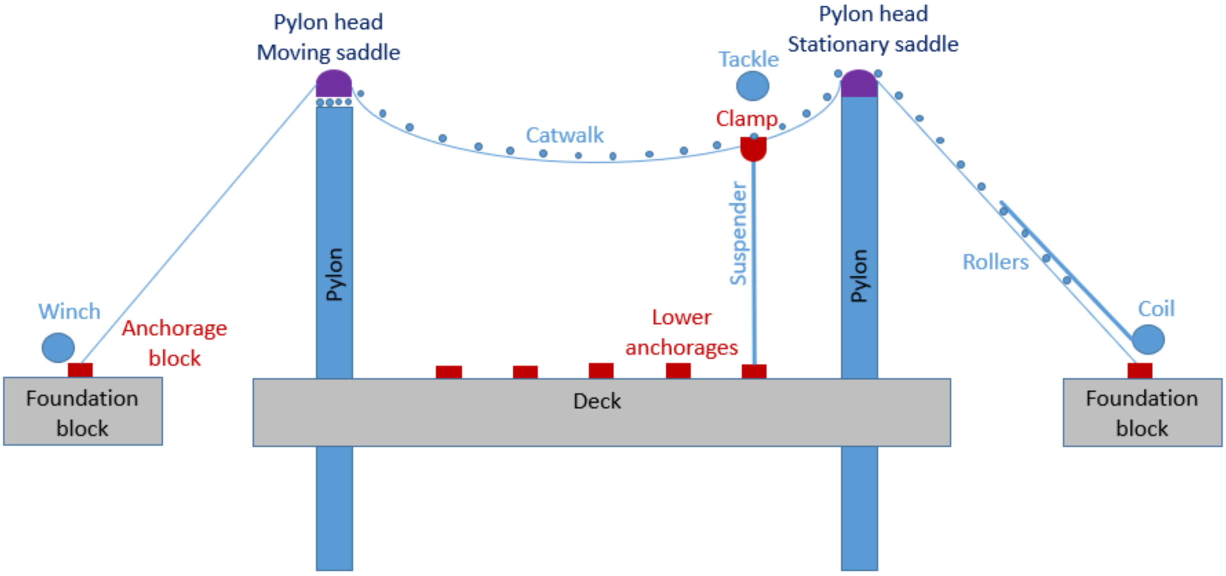


Fig.18 : Example of a suspension bridge implementation

List of components per system

A complete list of suspension bridge components is detailed below[2].

Implemented components

We can find hereafter the exhaustive list of implemented components:

- Anchorage Zone
- Transition Zone (Connectors)
- Free Length (Cables)

[2] This Excel list is also available in deliverable: MINnDs2_GT1.1_ifc-bridge_taxonomy_prestressing_suspension_systems_005_2022.xlsx

Implementation components

We can find hereafter a non-exhaustive list of implementation components:

- Cable installation system

Main system	System	Sub-system	Component / Object	Detail / Properties
Implemented components	Anchorage zone	Fixed anchorage (anchorage block)	Bearing plate	It can also be a steel structure with multiple plates and including the Guide pipe
			Guide pipe	
			Steel superstructure	
			Anchor head	
			Wedge	For strand tendons
			Anchorage nut	For bar tendons
			Protection cap	
			Transition pipe	Required to accomodate construction tolerances when cutting the strands. Depending on the system, it may or may not be present
			Sealing system	
			Soft filler	Wax, grease, gel or other polhymers
			Gusset plate	
			Fork/Clevis	
			Pin	
		Saddle system	Saddle	
			Sealing system	
			Roller	
	Transition zone	Connectors	Yoke	
			Socketed end fitting	
			Fastener	
			Grip ring	
			Tensioner	
		Damper	Rubber damper	
			Friction damper	
	Free length	Main tensile element	Load bearing stay (primary cable)	
			Stabilising stay (damping cable)	
			Rear stay	
			Wire	
		Pipe	Stay pipe	
		Hanger	Wrought iron hanger	
			Strand hanger	
			Steel rod hanger	
		Deck protection	Antivandalistic pipe	
		Fire protection system		
		Blast protection system		
Implementation components - Equipment	Strand implementation	Walkway		
		Winch		
		Gantry		
		Pulley		

Fig.19 : Suspension system - Implemented and implementation components

5.2 Cable-stayed bridge

Cable-stayed bridge

Cable-stayed bridge specificities are mainly the stay cables. Stay cables are elements of the structural analysis model. Their geometric representation is depending on the tension faced by the stay cables.

Cable systems

As proposed in the previous methodology, the first stage is to identify the different systems for the cabling of a cable-stayed bridge (see Fig.20 below).

Structure

The first system is the bridge itself, the cabled structure:

- The supporting system (deck):
  - girder ("rigidity beam");
  - bridge floor (stringer, transverse girder);
  - reinforced concrete slab.
- The load bearing system (pylon):
  - pylon;
  - saddle;
  - anchorages.

Definitive systems

The main systems concern the strand elements:

- Tendon system.

	• Damper system. And the different fastener systems, binding systems together.
Implementation system / Equipment	Then, the necessary system for cable implementation and tensioning: • Tensioning and monitoring systems. • Other systems (Accessories, Tools…).
Interfaces between systems	All these systems have interaction between each other, by the means of some specific components. These interactions are shown on the Fig.20 below.

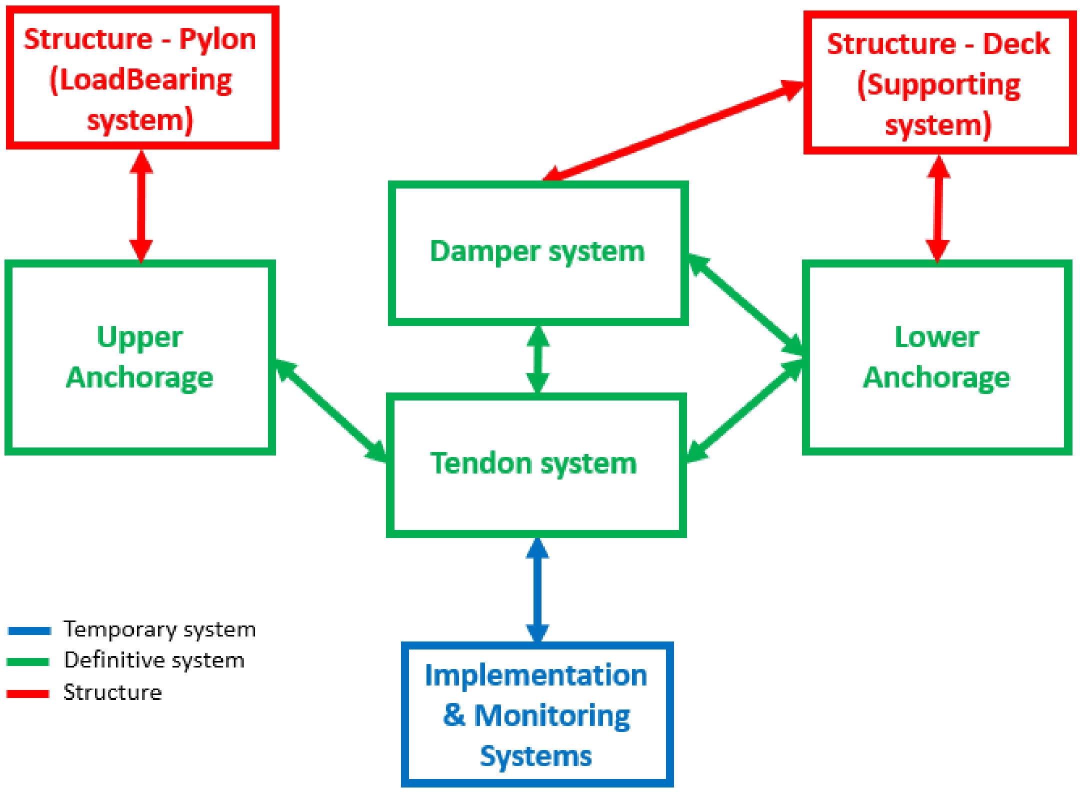


Fig.20 : Cable-stayed bridge systems

Cable stayed bridge implemented components	For each definitive system, the components are the following ones (Fig.21):
Tendon system	The collection of cables: • Tendon or strands, binding the pylons with the deck, by means of anchorages. • Stay pipe, the sheath of the different wires setting up each tendon. • Fire protection, vandal proof and explosion proof equipment.
Damper system	To absorb vibrations and avoid resonance, the devices are: • Dampers; binding tendons with the deck. • Cross ties: binding tendons together to avoid chocks in case of wide oscillations.
Anchorage systems	And the different fastener systems, depending on the cable-stayed bridge type:

- Lower anchorage system (linked to the deck).
- For a harp cable-stayed bridge (parallel attachment pattern - see Fig.21): upper anchorages or "link" set up in the pylon head.
- For a fan cable-stayed bridge (radial attachment pattern - see Fig.21): stationary saddle put above the pylon head.

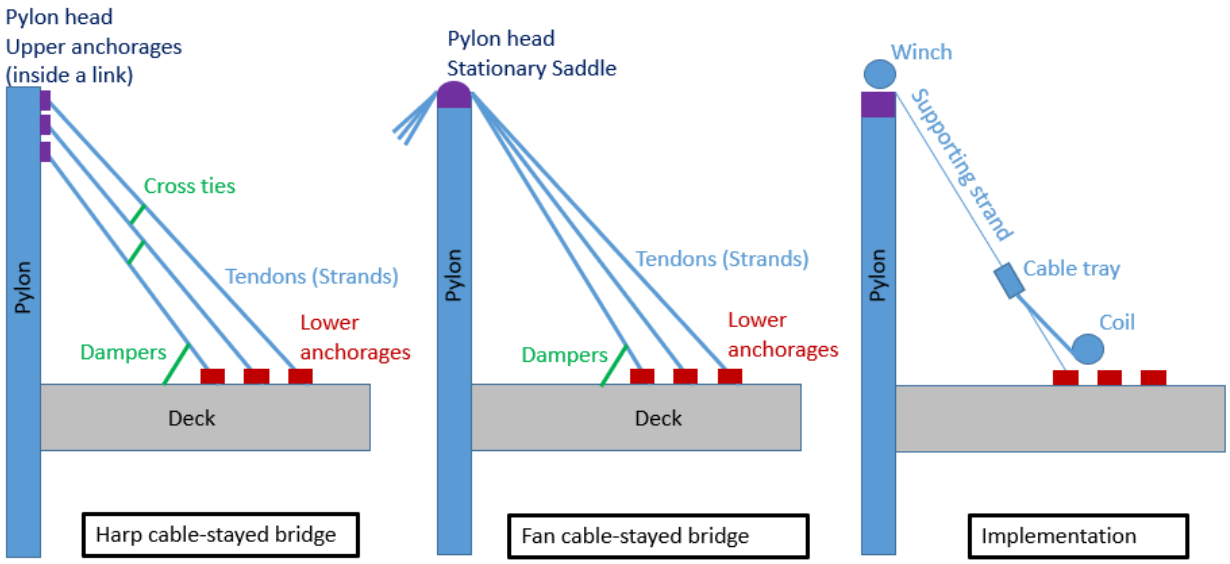


Fig.21 : Cable-stayed bridge

Cable Implementation components

Then the necessary components for cable-stayed implementation are (Fig.21):

Lifting and guidance system

To help lifting and guiding the strands (one by one), several temporary devices are used:

- Supporting strand: temporary cable between the deck and the pylon head, with a cable tray (guide pipe) to guide tendons implementation;
- Winch: device, put on the pylon head, to lift tendons following the supporting strand.

Tensioning & Monitoring system

The tensioning is carried out by means of a jack and its hydraulic pump. The process is managed with pressure gauges and sensors.

Other systems

Lots of accessories and tools are needed to carry out the different tasks:

- Guide pipe Installation
- Saddle Installation
- Link Installation
- Anchorage Installation
- First Strand pre-cutting
- Stay Pipe Handling
- Stay Pipe Lifting & Installation
- Strand pre-cutting
- Strand threading

	• Strand by strand Stressing • Strand by strand Re-stressing • Equalization • Multistrand stressing • Lift-off • Vibration testing • Damper installation • Damping Testing operation • Casing Installation • Guide deviator installation • Tension Ring installation • Dummy strands installation • Stay pipe closure • Protection cap Installation • Anchorage Injection • Cross tie Installation • Monitoring system Installation • Fire Protection Installation • Anchorage final Inspection • Damper final inspection

List of components per system	A complete list of suspension bridge components is detailed below[3].
Implemented components	We can find hereafter the exhaustive list of implemented components: • Anchorage Zone • Transition Zone (Connectors) • Free Length (Cables)
Implementation components	We can find hereafter a non-exhaustive list of implementation components: • Cable installation system

[3] This Excel list is also available in deliverable: MINnDs2_GT1.1_ifc-bridge_taxonomy_prestressing_suspension_systems_005_2022.xlsx

Main system	System	Sub-system	Component / Object	Detail / Properties
Implemented components	Anchorage zone	Fixed anchorage (It can be installed both on the pylon and on the deck)	Bearing plate	It can also be a steel structure with multiple plates and including the Guide pipe
			Guide pipe	
			Steel superstructure	
			Anchor head	
			Wedge	For strand tendons
			Anchorage nut	For bar tendons
			Protection cap	
			Transition pipe	Required to accomodate construction tolerances when cutting the strands. Depending on the system, it may or may not be present
			Sealing system	
			Soft filler	Wax, grease, gel or other polhymers
			Gusset plate	
			Fork/Clevis	
			Pin	
		Adjustable anchorage (It can be installed both on the pylon and on the deck)	Bearing plate	It can also be a steel structure with multiple plates and including the Guide pipe
			Guide pipe	
			Steel superstructure	
			Anchor head	
			Wedge	For strand tendons
			Anchorage nut	For bar tendons
			Protection cap	
			Ring nut	
			Threaded pipe	
			Transition pipe	Required to accomodate construction tolerances when cutting the strands. Depending on the system, it may or may not be present
			Sealing system	
			Soft filler	Wax, grease, gel or other polhymers
			Gusset plate	
			Fork/Clevis	
			Pin	
		Saddle system	Saddle	
			Sealing system	
	Transition zone	Compacting device	Tension ring/ Compaction clar	Free floating compacting device
			Guide deviator	Compacting device enclosed by the guide pipe
		Damper	Rubber damper	
			Friction damper	
			Viscous damper	
		Connectors	Pylon connection	HDPE pipe, slightly larger in diameter than the main HDPE pipe. It can be released from the pylon, and lowered to create a working window on the pylon.
			Deck connection	
	Free length	Main tensile element	Strand (stay)	radiating stays, fan stays, harp stays
			Wire	
			Bar	
			Bar coupler	
		Pipe	Stay pipe	
		Damper	Cross tie	
		Deck protection	Antivandalistic pipe	
		Fire protection system		
		Blast protection system		
Implementation components - Equipment	Strand implementation	Walkway		
		Winch		
		Gantry		
		Pulley		

Fig.22 : Cable-stayed - Implemented and implementation components

6. ATTRIBUTES AND PROPERTIES

6.1 Specific attributes

Attributes	Some additional attributes must be considered in the IFC classes, in particular the properties of the components (in particular, the tendons).

Considered system	Attributes	Definition
	Elongation	A change in the form or shape of a tendon which is subjected to stress
	Eccentricity	The distance of the geometric centre of the tendon from the axis of the duct
	Effective prestress	The stress remaining in concrete due to prestressing after loss of prestress
	Friction loss	The stress loss in a prestressing tendon resulting from friction between the tendon and other devices during stressing
	Ultimate strength	The highest load that a piece can sustain before failing

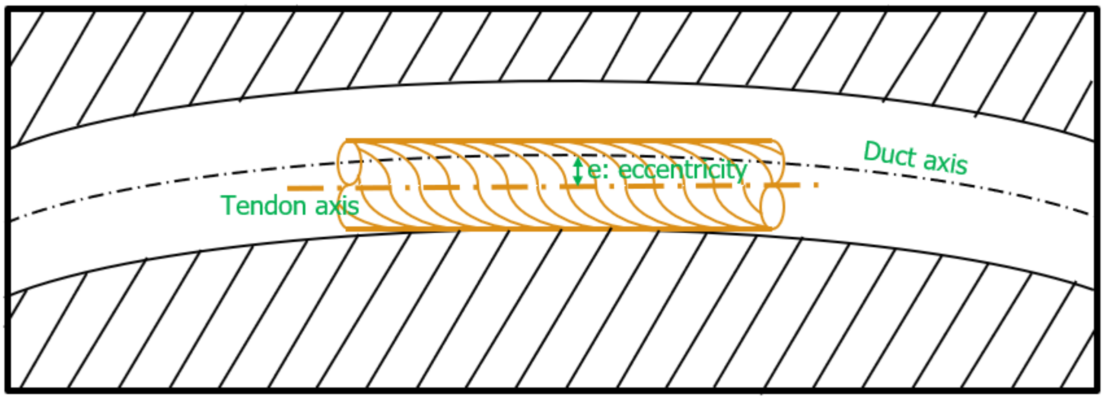


Fig.23 : Eccentricity

7. Conclusion

Concluding remarks

As the first season of MINnD focused on common bridges, this deliverable aimed to identify systems and objects specific to more complex structures, such as prestressed concrete, suspended and cable-stayed bridges.

Prestressing

Regarding prestressed concrete bridges, four main systems have been identified:

- the main structure itself (concrete and rebars);
- the tendon system, that can be decomposed in a duct system, an anchorage system, and the tensile system;
- the implementation/monitoring system;
- the threading and grouting system.

For every system, an exhaustive list of objects has been compiled.

Suspension and cable-stayed bridges

Concerning suspension and cable-stayed bridges, the decomposition in systems is similar to prestressed concrete bridges:

- main structure system;
- the tendon system, including tensile elements and anchorages;
- the implementation/monitoring system.

Objects composing these systems have been identified in this deliverable.

Implementation strategy

Even though suspension bridges and cable-stayed bridges are different, the structural concepts, cables and accessories used are very similar. We find many similarities in the presented enumerations, and it is imperative to treat these two types of bridges as an enveloping category.

Notice

As it was done for common structures in the UC3 MINnD s1 deliverable, it is necessary to decline the Excel file provided in the appendix with the attributes and properties necessary to establish the dictionary of data specific to structures non-current (prestressed, suspension and cable-stayed bridges). This data dictionary must comply with ISO 23386:2020 - Building information modelling and other digital processes used in construction - Methodology to describe, author and maintain properties in interconnected data dictionaries.

As a reminder, this standard establishes the rules for defining properties used in construction and a methodology for authoring and maintaining them, for a confident and seamless digital share among stakeholders following a BIM process.