Modélisation des INformations INteropérables pour les INfrastructures Durables

IfcBridge

Consistency and Completeness Check

Auteurs / Organismes

Edouard BERTON (CEREMA)
Pierre BENNING (Bouygues TP)
Paul-Marie BOUVIER (ALLPLAN)
Pierre FONTAINE (CEREMA)
Guillermo RAMIREZ (VSL-Bouygues Construction)
Michel RIVES (Vianova Systems France)

Relecteur / Organisme

Christophe CASTAING

Thème de rattachement : Structuration des données

MINnDs2_GT1.1_ifc-bridge_consistency_completeness_check_003_2022_eng
LC/21/MINNDS2/061-062-063-064-065 & LC/22/MINNDS2/210
Avril 2023

Site internet : www.minnd.fr
Président : François ROBIDA Chefs **de Projet** : Pierre BENNING / Vincent KELLER
Gestion administrative et financière : IREX (www.irex.asso.fr), 9 rue de Berri 75008 PARIS, contact@irex.asso.fr

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, frame bridges, rigid frame bridges and culverts. The chosen scope set the limit to the interfaces with the other infrastructure domains: roads, rails, tunnels, geotechnics, and earthworks. The objectives of this deliverable are to verify the consistency and completeness of elements of the interfaces with the other infrastructures domains.

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. Le cadre de travail choisi fixait la limite aux interfaces avec les autres domaines des infrastructures : routes, rails, tunnels, géotechniques et terrassements. Ce livrable a pour objectifs de vérifier la cohérence et la complétude des éléments au regard des interfaces avec les autres domaines.

1.1 Abbreviations

Abbreviation	Signification
bSDD	buildingSMART Data Dictionary
bSI	buildingSMART International
IFC	Industry Foundation Classes
MoU	Memorandum of Understanding
MVD	Model View Definition
WG	Working Group
XML	eXtensible Markup Language

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

Deliverable key words (Eng) IfcBridge; IFC4.3; completeness check; consistency

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

Mots clés spécifiques au livrable (Fra) IfcBridge ; Ouvrage d'art ; Pont ; IFC4.3 ; complétude ; cohérence

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 or suspended 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.

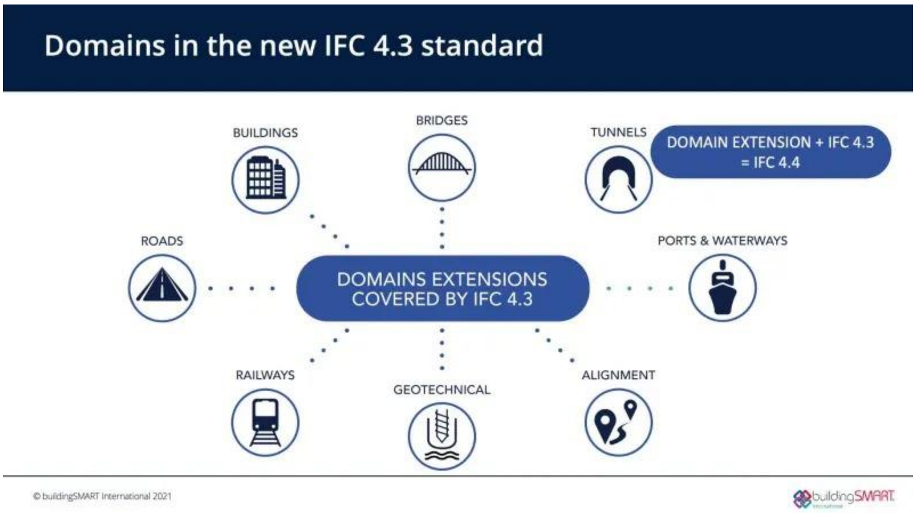

Fig.1 : Domain extensions covered by IFC 4.3

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

[MINnD UC03 04]

This document:

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

The Conceptual Model focused on the necessary data structures for modelling prestressing systems. 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

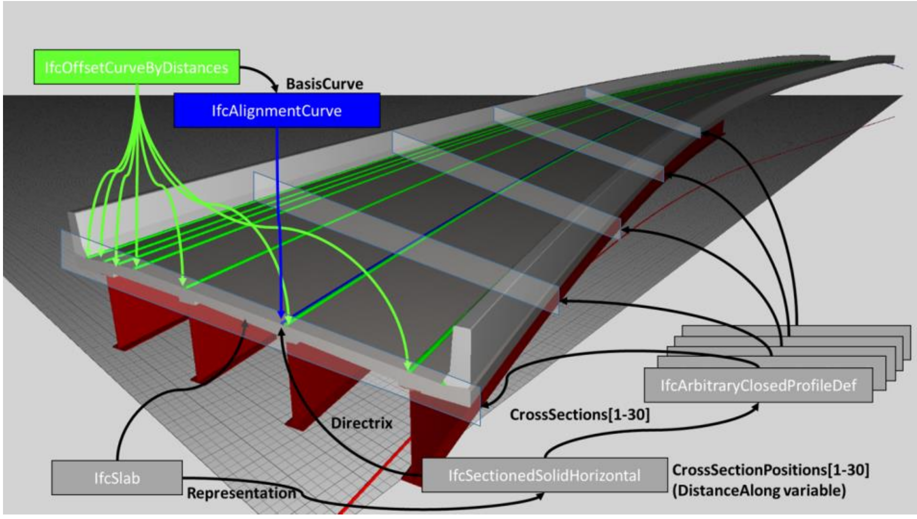

Fig.2 : The conceptual model included IFC extension requirements that were collected by the project teams.

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://ifc43-docs.standards.buildingsmart.org/

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.

This link leads to the different release specifications of IFC development.

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

It is important to note that the IFC4.X name incorporates the obligation to maintain continuity with IFC4.0, the latest ISO-approved version.

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 IfcBridge part 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 sweep 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.

Implementers forum

The IFC 4.3 Implementers Forum, coordinated by buildingSMART, is a joint testing effort between software developers, end-users and IFC experts. Its objective is to support the implementation of the IFC 4.3 standard and inform the community about its implementation progress.

Test instructions

bSI Projects, such as IFC Bridge, can create *test cases*, to challenge the IFC standard on a specific scenario. A test case generally includes test instructions, test dataset, validation criteria, and eventually a reference IFC file.
Thus, when a software vendor takes a test and produce an IFC file, this can be automatically checked using the bSI Validation Service. This process is illustrated in Fig.4 : Test cases process (www.buildingsmart.org). Test cases are the last step in validating a new version of the IFC format.

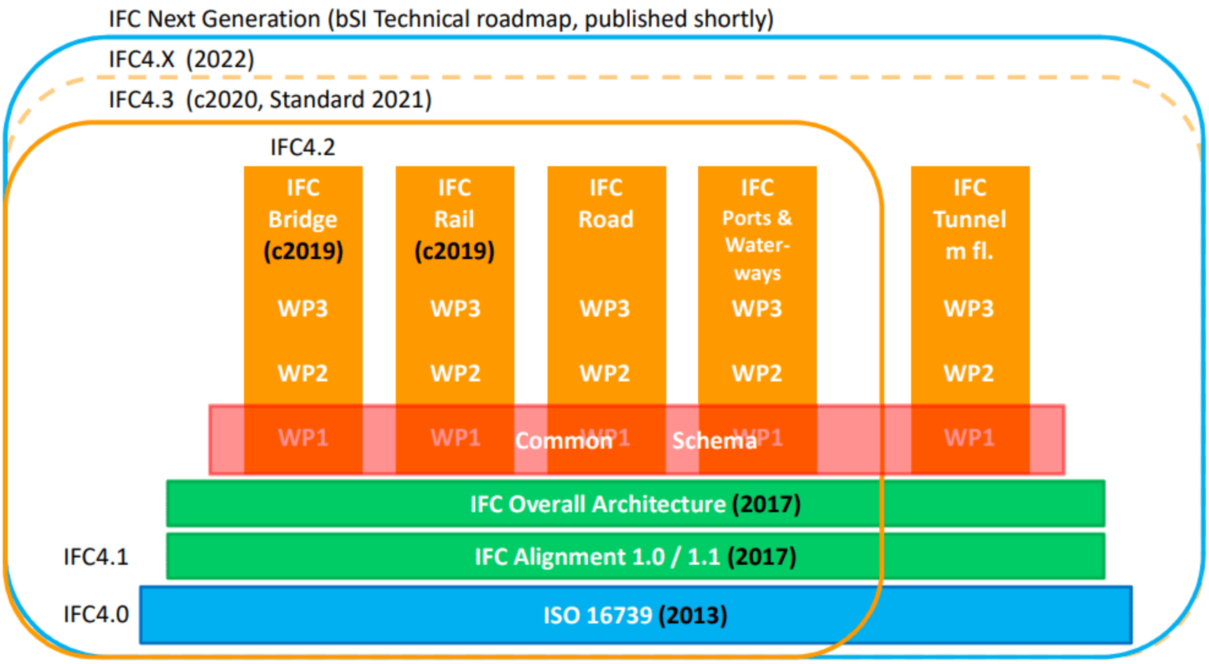

Fig.3 : buildingSMART International IFC-Infra roadmap

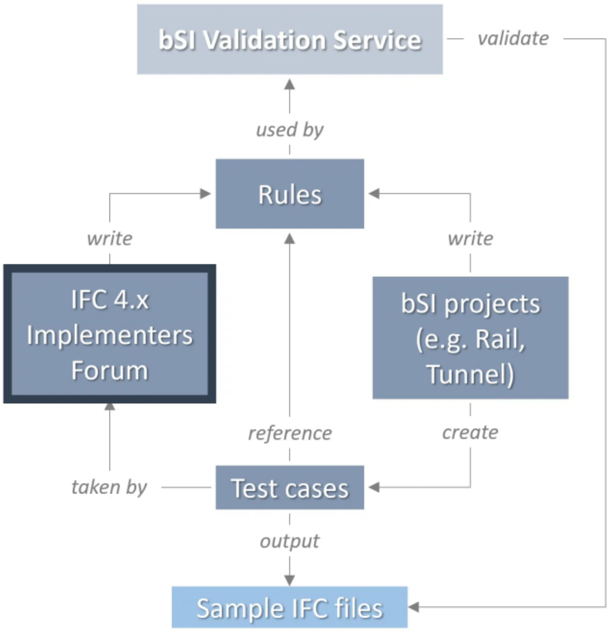

Fig.4 : Test cases process (www.buildingsmart.org)

3. Consistency

3.1 Bridge taxonomy

Bridge definition

A bridge is a construction that allows you to cross a natural or artificial obstacle (depression, stream, communication route, valley, ravine, canyon) by passing over it. The crossing supports the passage of humans and vehicles in the case of a road bridge, or water in the case of an aqueduct.

Five classes of bridges are defined according to their structure:

- vaulted bridges;
- girder bridges;
- arch bridges;
- suspension bridges;
- cable-stayed bridges.

Typical bridges

In the early development of IFC-Bridge, only typical bridges (80% of the assets) were considered, namely bridges without a prestressing system and without a cable-stay system, which are suitable for exceptional bridges of long range.

- Underpass typical bridge: closed frame reinforced concrete bridge;
- Overpass typical bridge: straight slab reinforced concrete bridge;

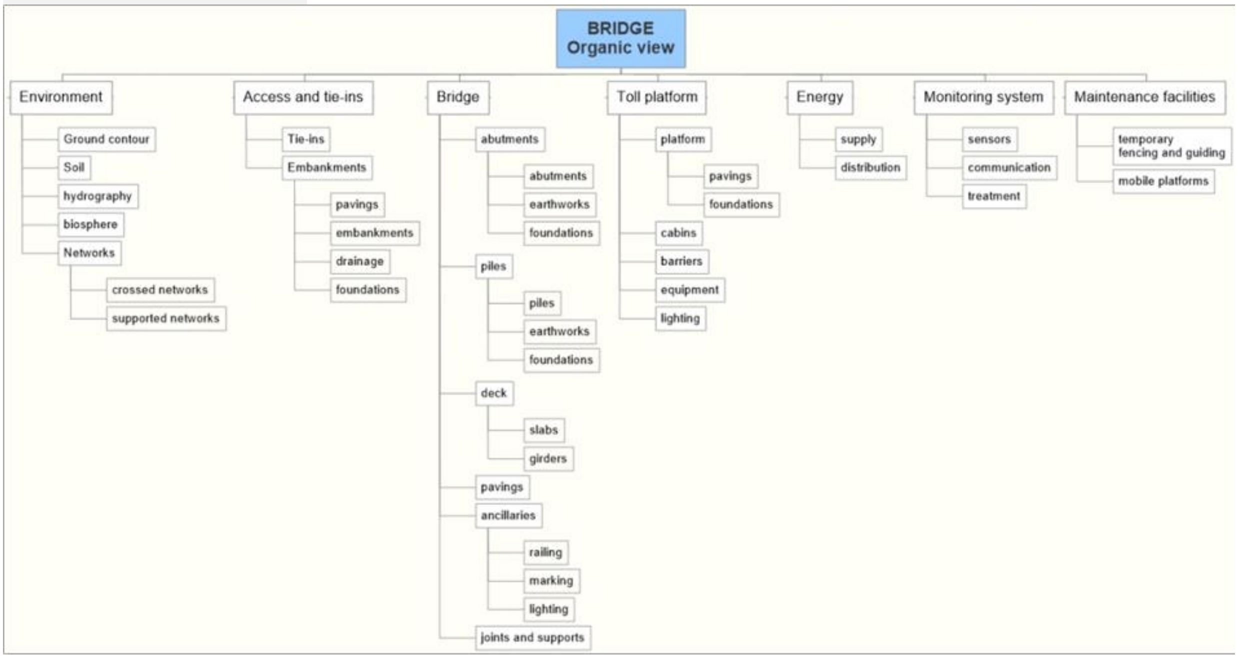

Fig.5 : List of component families of a typical bridge

Constituent systems of a bridge

A bridge consists of 4 main families of systems:

- Foundation system
- Vertical load-bearing system (vertical substructure)

	• Horizontal supporting system (horizontal substructure) • Carried system (superstructure)

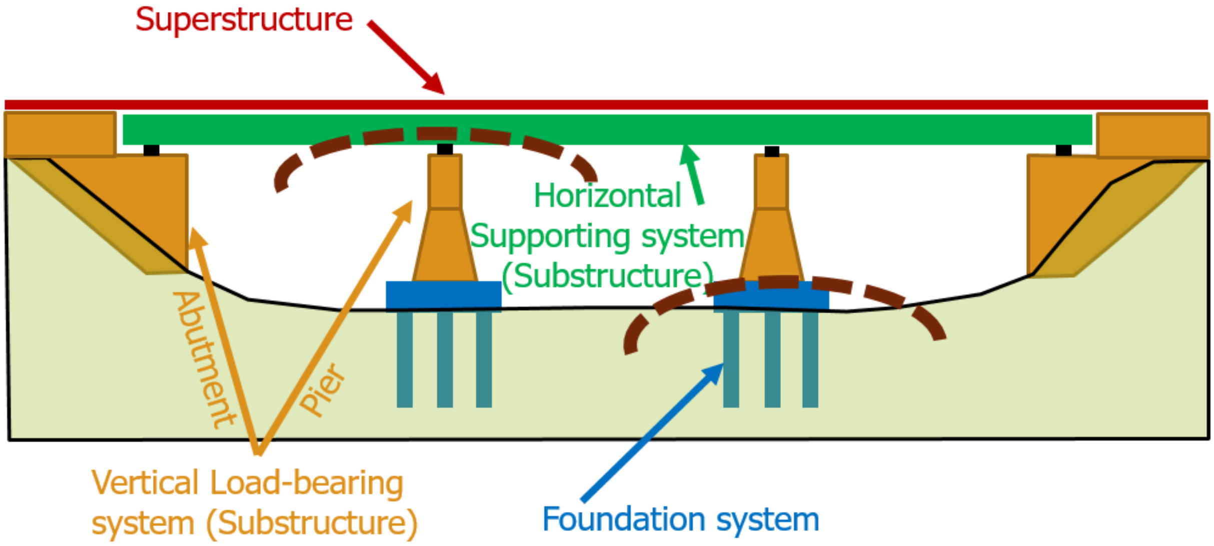

Fig.6 : Diagram of the different constituent systems of a bridge

Non-typical bridges	For the purposes of this document, exceptional (non-typical) bridges with a long range are considered: • prestressed bridges; • suspension bridges; • cable-stayed bridges.

3.2 Interfaces with other infrastructure domains

Interfaces with other domains	Bridges have many components that are not exclusive to them, such as retaining devices or retaining walls. The objective of this chapter is to define the exclusive scope of bridges and the "positioning" of the components necessary for their realization, but which it would be preferable to deal with in a more appropriate field.
Considered domains	The domains of infrastructure considered are as follows: • Carried systems or superstructures: – Road – Rail – Canal • The earthworks system
The specific domain of tunnels	The tunnel domain is rarely interfaced with the bridge domain. It was nevertheless considered in our analysis, because some components of tunnels and bridges are similar (such as drainage systems, safety systems...) and it is necessary to define which domain is in charge of defining these common and shared elements.
List of interfaces	The table below lists the components common to several domains of the infra-structure (box with a cross).

A cross in bold indicates the domain most concerned by the considered system.

Systems	French translation	Comments	Bridge	Tunnel	Earthworks	Road	Rail
Retaining wall	Murs de soutènement	List all differents walls	**X**	x	x		
Subvertical wall	Paroi sub-verticale				**X**		
Earthworks	Terrassement		x		**X**		
Platform	Plateformes	Sequences of platforms					
Excavation	Creusement			**X**	x		
Waste rock management	Gestion des déblais		x	x	**X**		
Earth moving	Mouvements de terres	with Time-Distance-Diagram	x	x	**X**		
Geotechnics / Foundations	Géotechnique / Fondations		x	x	x		
Clearance / Gauge width	Gabarit (espace circulé)		x	x		x	x
Signaling device	Signalisation		x	x		**X**	**X**
Miscellaneous equipment	Équipements divers	Security, lighting, fire hydrant ...	x	x		x	x
Inspection (sensors)	Inspection (capteurs)		x	x		x	x
Supervision (natural hazards)	Surveillance (dangers naturels)						
Access roads / Accessibility	Routes accès / accessibilité (Construction / Maintenance)	Track, Barrier, Gate, maneuver area, assembly point ...	x	x	**X**	x	x
Equipment for inspection	Equipements pour inspection	Staircase, Walkway, Lighting ...	x	x			
Variation of section	Variation section de l'ouvrage			x			
Way	Voie portée					**X**	**X**
Temporary objects	Objets provisoires	during construction	x	x	x	x	x
Deep Drainage Sanitation	Drainage Assainissement profond				**X**	x	x
Shallow Drainage Sanitation	Drainage Assainissement surface		x	x	x	**X**	**X**
Cut and cover	Tranchées couvertes et ouvertes			**X**	x		
Capping layer / subgrade	Couche de forme / Sous-couche				**X**	x	x
Networks	Réseaux	Lighting, telecom, power systems, etc.	**X**	**X**		X	X
Road restraints / Safety barriers	Dispositifs de retenues		**X**			X	X

Fig.7 : Infrastructure domain-to-domain interfaces

Location systems

An infrastructure carries lanes where vehicles travel. The environment and the traffic conditions impose a specific alignment of the lanes, called reference axis or alignment. IFC-Alignment (IFC 4.1) allows to describe these alignments in the classical orthonormal reference frame as well as the local reference frames associated with the alignments and the vehicles.

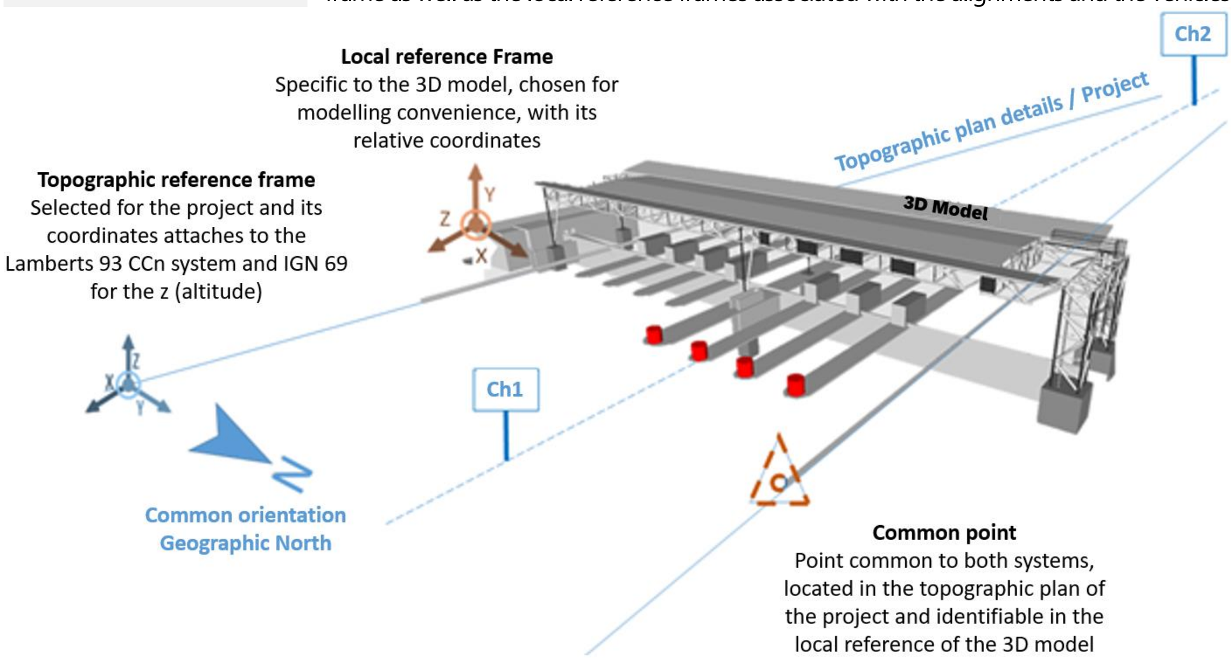

Fig.8 : The georeferencing of objects (MINnD S1)

IFC Alignment 4.1

The IFC-Alignment (IFC 4.1) conceptual model is now available and being implemented by software editors (buildingSMART 2020). It allows to position the works along the curvilinear abscissa of the project, with an offset on one side or the other of this reference axis (Fig.9).

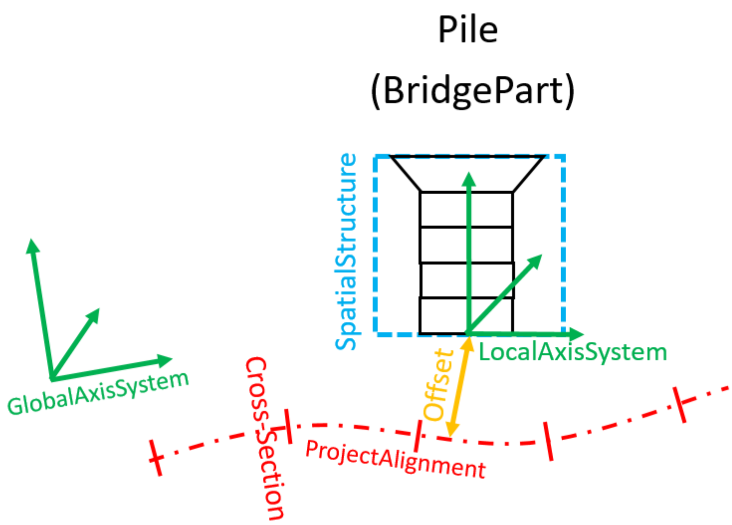

Fig.9 : The different location coordinate systems

Superstructure (Supported systems)

The superstructure (or supported systems) is defined by all the systems carried by the substructure (see Fig.6). Regarding supported systems, some specific elements depend on the nature of the bridge and others don't.

The scope of the IFC-Bridge stops at the level of the watertightness layer. All the components above this watertightness layer are therefore to be considered by the field of the carried superstructure.

IFC-Road

The components of road and pavements have been described in IFC 4.3.

IFC-Rail

The components of railroad tracks and ballast have been described and should be part of IFC 4.4.

Substructure

We consider a diversity of substructure that will support the superstructure. There is no specific substructure define only for road or rail bridges.

In the following list you will a find a diversity of substructures.

Prefabricated reinforced concrete beams

Precast reinforced concrete beams are generally prestressed, with rectangular or variable inertia section.

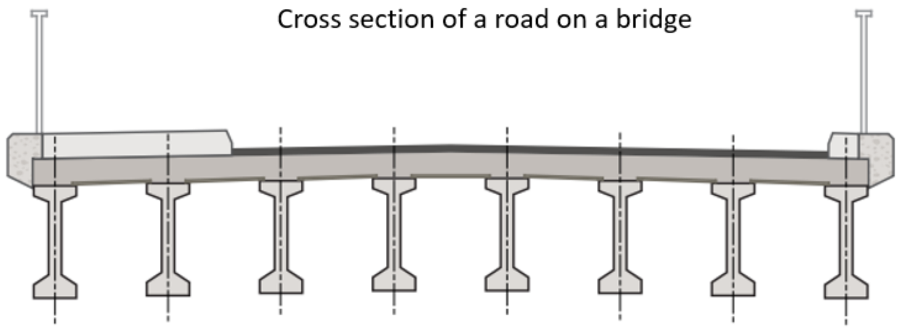

Fig.10 : Cross section of a road on a bridge (precast reinforced concrete beams)

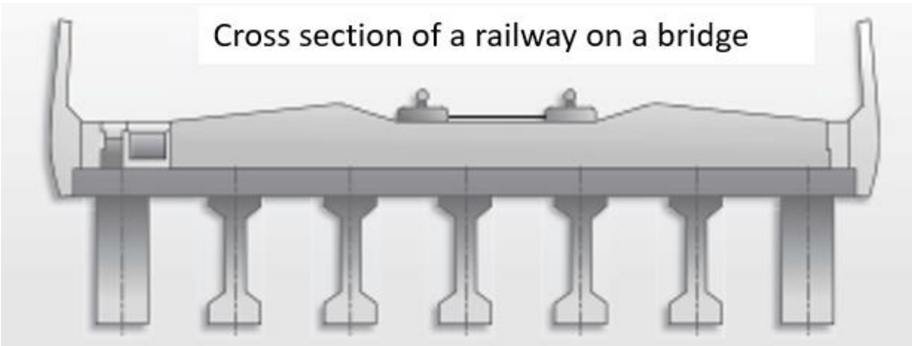

Fig.11 : Cross section of a railway on a bridge (precast reinforced concrete beams)

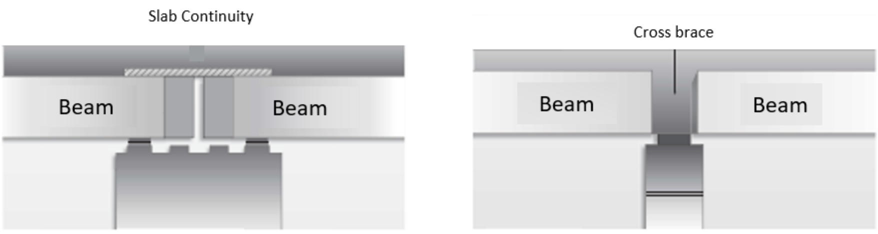

Fig.12 : Longitudinal section (precast reinforced concrete beams)

Beam Beam sections can have different geometries (Fig.13).

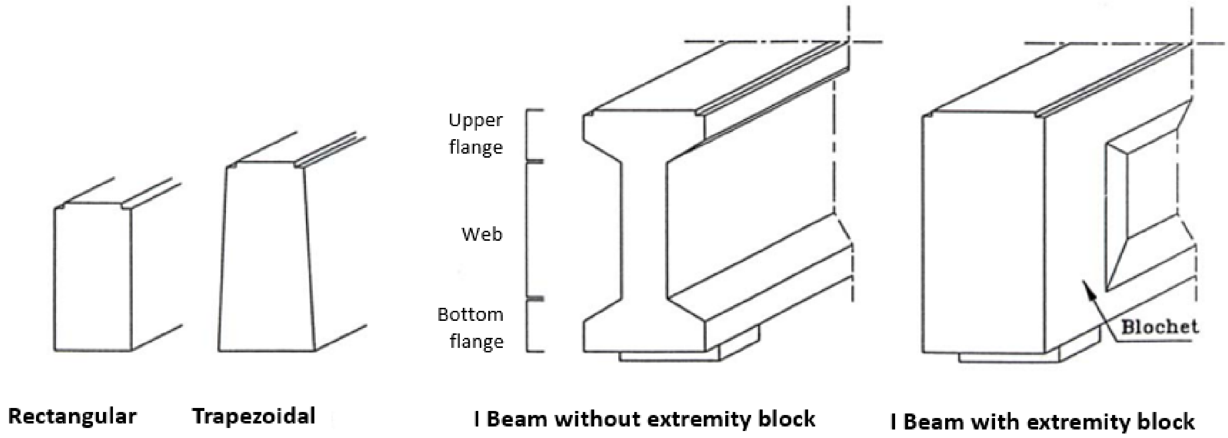

Fig.13 : Precast reinforced concrete beams sections

Slabs To carry out the bridge deck, concrete slabs are currently cast in place to connect the precast beams (Fig.14).

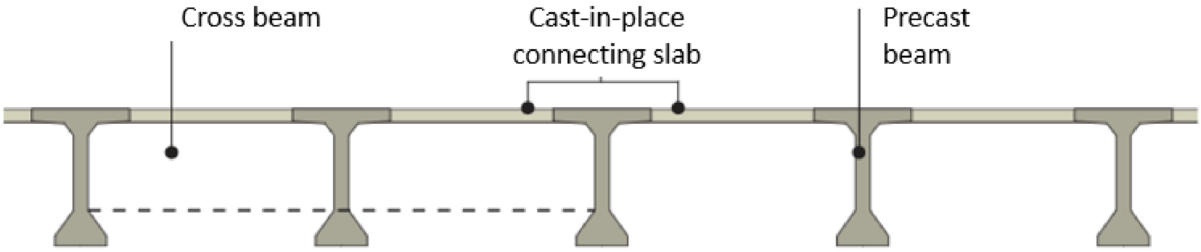

Fig.14 : Concrete slabs poured in place (on lost formwork)

Filer Beam A filer beam bridge is a slab bridge reinforced longitudinally by closely spaced steel beams and passive reinforcements (Fig.15).

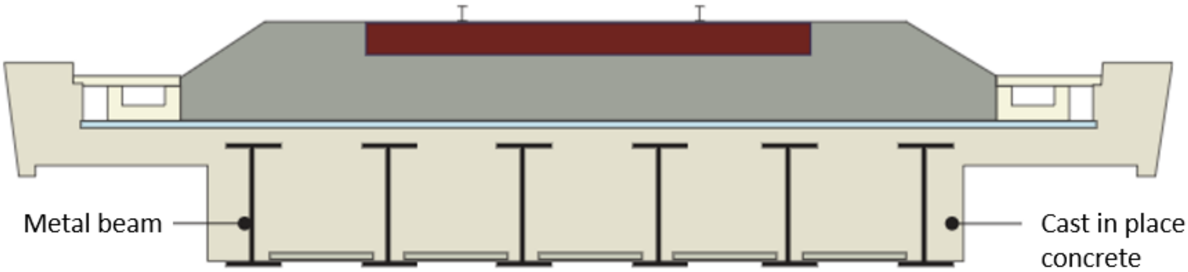

Fig.15 : Filer beam bridge

Box girder bridge A box girder bridge (or hollow box), is carried out by Cantilever construction or with precast hollow box segments (Fig.16 & Fig.17).

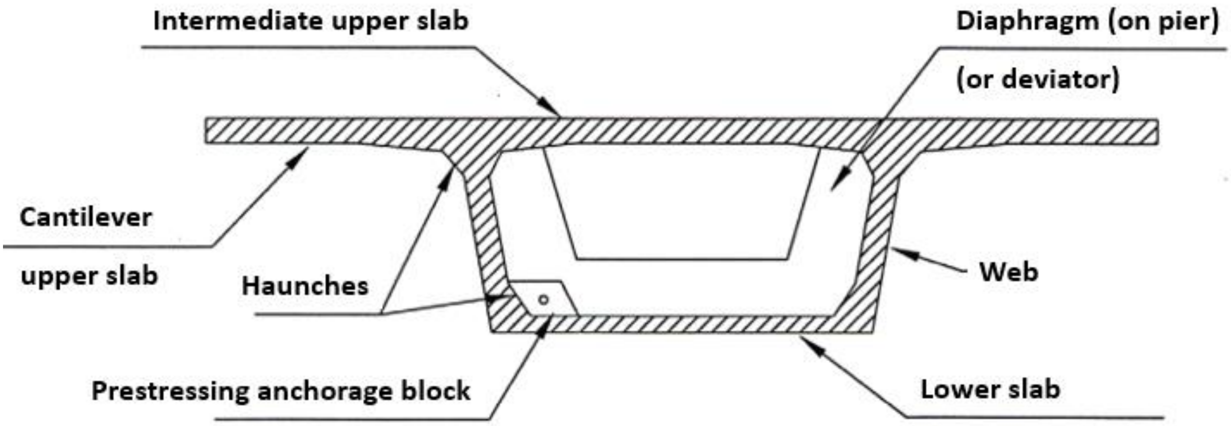

Fig.16 : Box girder (hollow box) bridge description

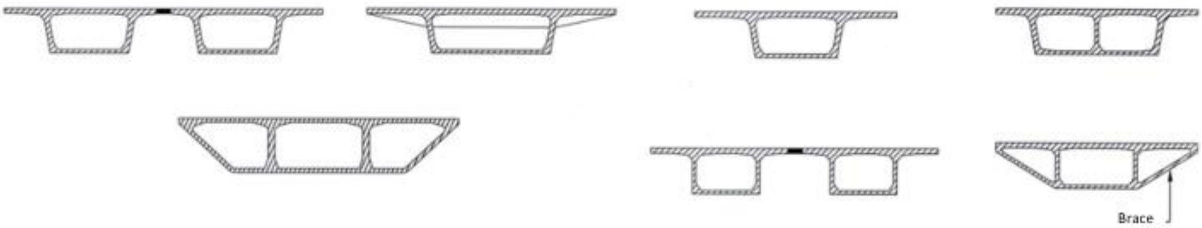

Fig.17 : Different types of hollow boxes

Slab bridge	Slab Bridge, with reinforced slabs, can be precast or not, with prestressing or not. The slabs can have several shapes with corbel or ribs.

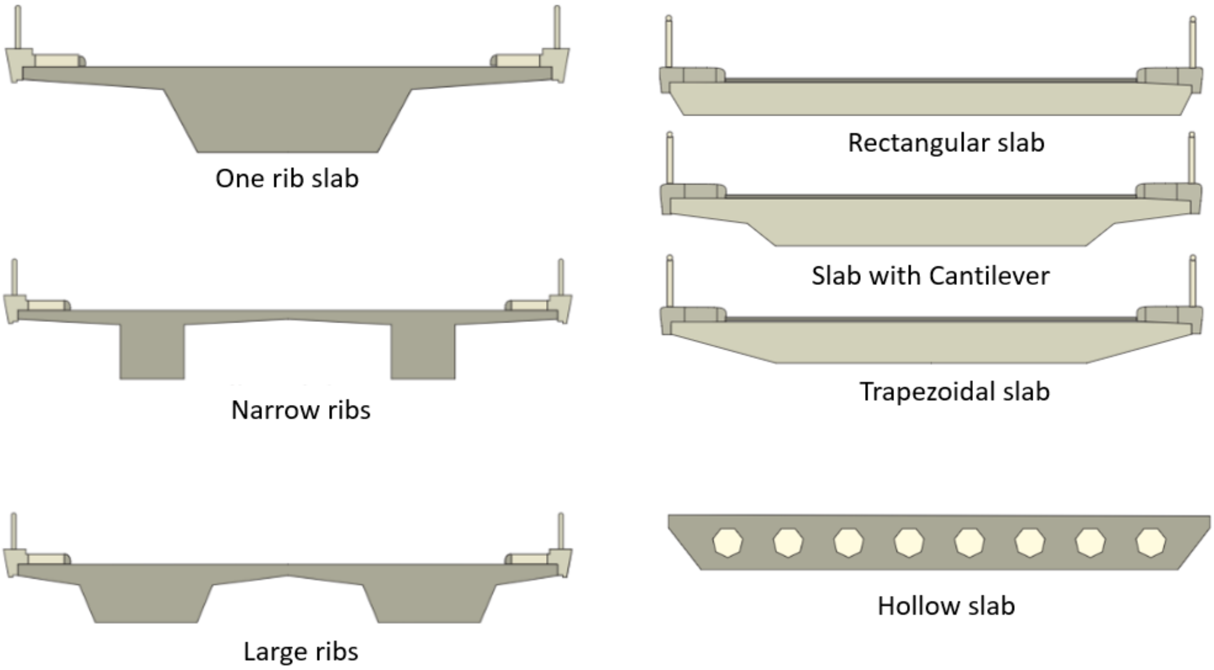

Fig.18 : Slab bridge sections

Composite bridge	A composite deck is a mixed frame made up of steel beams and a concrete poured slab.

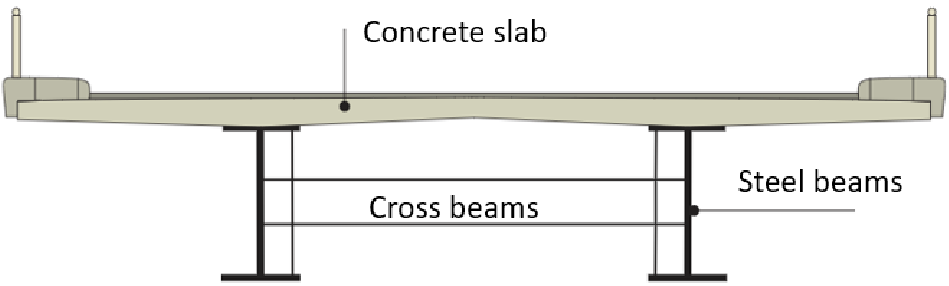

Fig.19 : Composite Bridge

Common components interfacing with IFC-Bridge

Here is a list of common components interfacing with IFC Bridge:

- Shallow Drainage Sanitation
- Sidewalk
- Safety slide
- Signaling device

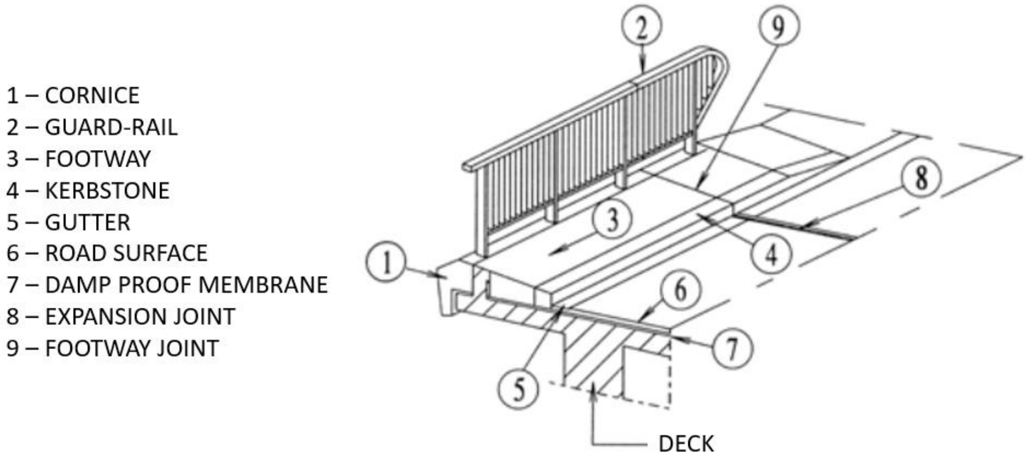

Fig.20 : Common components interfacing with IFC Bridge

Road bridge

Regarding road bridges, there is a waterproofing layer beneath the road surface

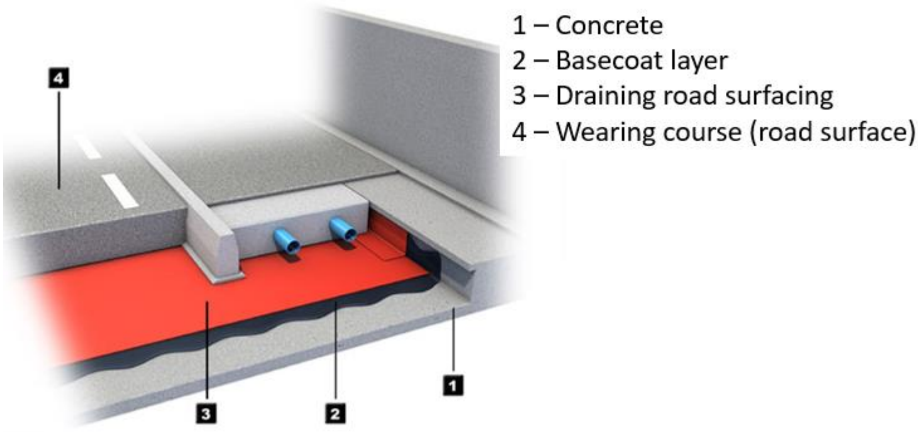

Fig.21 : Road bridge / Waterproofing course

Railway bridge

Regarding rail bridges, there is ballast and reinforced concrete slab.

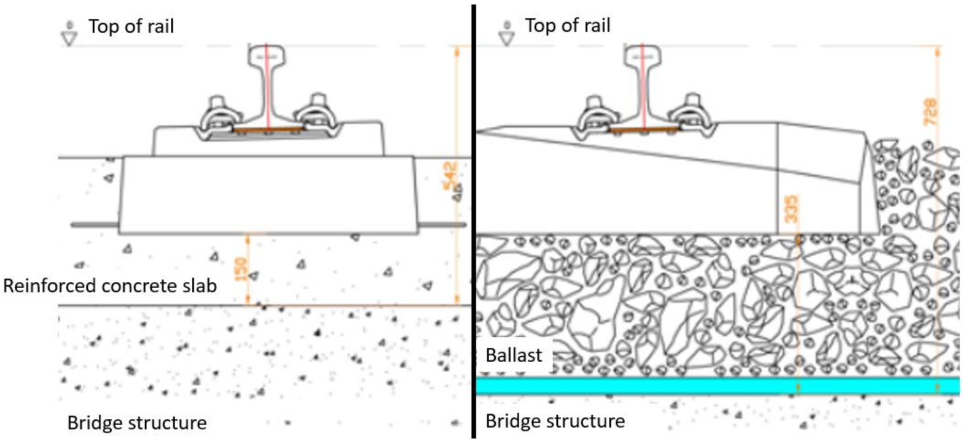

Fig.22 : Rail bridge / Supported system (ballast or concrete slabs for railways)

Foundation system

Bridge foundations can be divided into two main categories:

- Shallow foundations;
- Deep foundations.

Considering the variables B and D defined in Fig.23:

- Shallow foundations are defined by:
  - $D < 3m$
  - $D/B < 6m$
- Deep foundations are defined by:
  - $D > 3m$
  - $D/B > 6m$

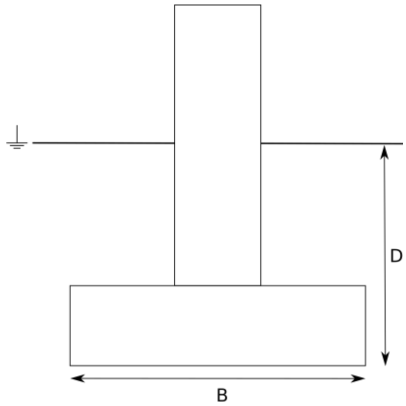

Fig.23 : Definition of a shallow foundation

Shallow foundations

Shallow foundations usually consist of a spread or shallow footing. Most typical configurations of shallow foundations are presented in Fig.24.

All shallow foundations mentioned above are covered by IfcFooting class.

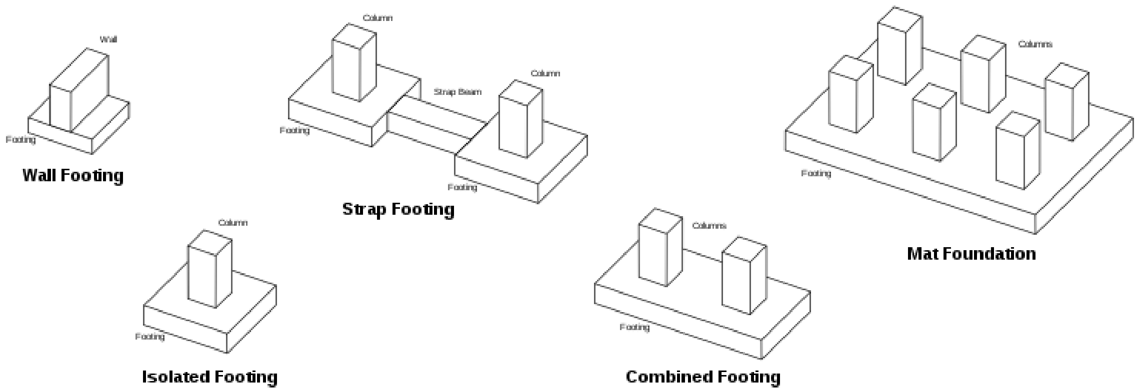

Fig.24 : Typical configurations of shallow foundations (Wikimedia Commons, by Jethrude Hipolito CC BY 2.0)

Deep foundations

Deep foundation transfers load deeper than shallow foundation, to reach soils capable of bearing the above structure.

According to French standard NF P94-262, piles can be put into categories according to their implementation methods:

- Bored pile;
- Screw pile;
- Driven pile;
- Micro-pile.

Bored piles

A bored pile is formed by excavating or boring a hole in the ground, with or without casing, and filling with plain or reinforced concrete, or with precast concrete sections which are grouted in place. Bored piles can take different forms:

- Bored pile.
- Cased bored pile.
- Bored pile using bentonite.
- hollow stem auger.
- etc.

Screw pile

Screw pile foundations are a type of pile foundation with a helix near the pile toe so that the piles can be screwed into the ground.

Fig.25 : Example of screw pile (Wikimedia Commons, licensed under CC BY-ND 2.0)

Driven piles A driven pile is precast pile "forced" into the ground by impact hammering or by vibrating. Driven piles are usually made of steel, pre-cast concrete, timber, or composite.

Micro-pile A micro-pile is a foundation pile with diameter below 250 mm.

Geotechnics

Knowledge of soil properties is crucial in bridge engineering, as it takes part in the design and the construction of every geotechnical infrastructure: foundations, retaining walls, excavations, etc.

The deliverable "MINnDs2_GT1.5_donnees_geotechniques_standard_openbim_018_2022" presents the results obtained by the MINnD GT1-5 working group and the proposal to extend the capacities of OpenBIM to manage the specificities of geotechnics.

Construction system

Earthworks consists of moving materials in large quantities to prepare the ground for construction. Based on three main actions:

- Extraction.
- Transport.
- Implementation.

General earthworks are large-scale works: road works, development of platforms, railway… The reorganization of the natural grounds entails a generally definitive modification of the topography and the landscape.

These notions have been studied by the MINnD GT1-6 working group and are discussed in the deliverable "MINnDs2_GT1.6_ifc_earthworks_021_2022".

Structures with similar requirements

Tunnels and bridges have in common the fact that they ensure the continuity of a roadway, a railway, or a waterway in the numerous configurations where these transportation paths need an overpass or an underground pass - in other words, in any situation where earthworks cuts and fills aren't sufficient to sustain the transportation path.

They notably share similar requirements in terms of:

- georeferencing, linear referencing and referencing technics relative to the hosted roadway/railway alignment(s);
- geotechnical conditions knowledge and uncertainties associated;
- non-linear transition in-between cross-sections;
- structural prefabricated components, e.g.: deck segments vs ring segments;
- cut and cover structures & immerged tunnels;
- specific characteristics of roadway/railway equipment in a bridge of a tunnel situation, e.g.: signalling, safety, lighting, platform waste-water drainage, energy/fibre networks.

Coordination with other working groups demonstrated the need for additional geometries to those already existing in IFC 4.3, as described below (coordinates, transitions, and value distribution).

Projected coordinate systems

Shared topics are:

- Documentation of the coordinate system used by a project to specify, using a tag, if:
  - it results from a projection (cylindrical, conic, etc.), and then it is able to manage distance distortion (distance on a sphere vs distance projected on a plan);
  - it is defined like an engineering cartesian system (like CAD), and then it cannot manage this distortion. This issue is shared with IfcRailway, IfcRoad and IfcTunnel.
- Specification of the transition between 2 specific profiles in case of a nonlinear variation (widening, cross-passage, shafts): nature of the transition (cubic, parabolic, etc.). This issue is shared with IfcTunnel.

Non-discrete variation

Representation of non-discrete variation of ground properties: specifications of 3D-grid georeferenced models (voxel), allowing the assignment of characteristic values (known or likely) to unit blocks constituting the model. This issue is shared with IfcBuilding (deep foundations), IfcTunnel (earthworks) and IfcEarthworks (cuts, fillings, etc.)

3.3 Shared elements

Transverses components

This section deals with elements shared with other infrastructures domains such as roads, railways, or tunnels

Road restraints / Safety barriers

Bridges must be equipped with restraint devices, to ensure the safety of users, vehicles, pedestrians or any other modes of transportation. The development of a restraining systems must be articulated with every other component of the project (geometry, earthworks, drainage, signage, etc.) to minimize the use of restraining devices.

Performance of a safety barrier is evaluated according to several criteria:

- Retention level, which depends on vehicle's mass, vehicle's speed, and angle of impact.
- Deformation of the restraining systems.
- Severity level of the collision.

Based on the desired performance, a road restraint is chosen:

- a guardrail for pedestrians and other active modes of travel.
- a level N barrier for light vehicles.
- a level H or L barrier for heavy goods vehicles (trucks).

The minimum level of restraint depends on the traffic and risks to users in case of collision. In some cases, a road restraint can be put in place even if the structure already has a device playing its role, example: in front of a masonry parapet. A few examples of guardrails and safety barriers are presented in Fig.26 Examples of guardrails and safety barriers (adapted from « Dictionnaire de l'entretien routier. Volume 5 : ouvrages d'art », Cerema, 2008).

Regarding the positioning of safety barriers, it is highly correlated to the road configuration: one-way, two-ways, divided, undivided, etc. Besides, to ensure an efficient performance of the retaining system, it must start before the bridge, and end after it. Hence, design of retaining systems depends to a large extent to the interface between the bridge and the supported system (road, rail, *etc.*).

Restraining systems are specific to linear infrastructures (roads, bridges, tunnels ...), and are not covered by IFC building classes. As of now, this subject has not been covered by any of the infrastructure working group of MINnD.

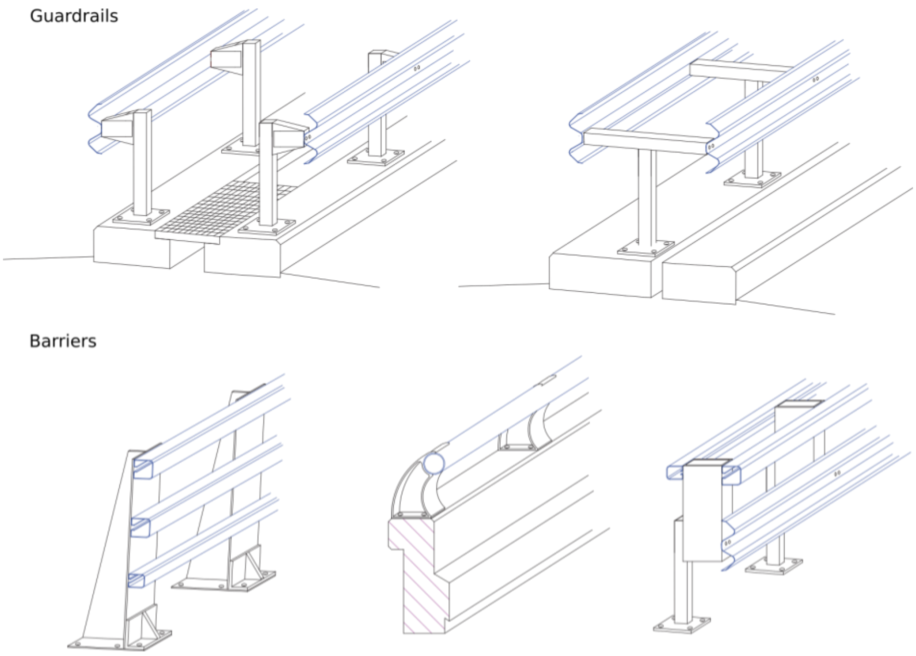

Fig.26 Examples of guardrails and safety barriers (adapted from « Dictionnaire de l'entretien routier. Volume 5 : ouvrages d'art », Cerema, 2008)

Drainage

Sewage and drainage systems are not structural elements. However, they are crucial to ensure the durability of the whole structure, by disposing of rain and wastewater.

Water on decks is evacuated thanks to several provisions and/or devices, usually:

- a transverse collecting, covered by an appropriate transverse slope of the carriageway (① in Fig.27 : Example Drainage system of a road bridge).
- a longitudinal collecting, usually with a gutter, sometimes put in a cornice (② in Fig.27 : Example Drainage system of a road bridge).

- punctual devices, such as floor drain or deck drains, to allow the freefall of water (drain can be called gargoyle), or to guide them toward a general evacuation system (③ in Fig.27 : Example Drainage system of a road bridge).

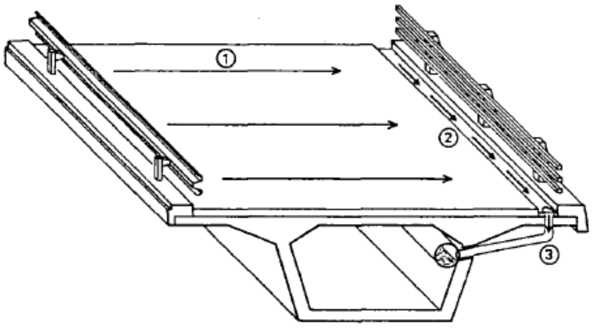

Fig.27 : Example Drainage system of a road bridge

Gutters

Gutters are covered by **IfcPipeSegment.** However, a further analysis of the IFC 4.3 schema is necessary to ensure that all draining elements are dealt with, particularly floor drains and weepholes.

Lighting, telecom, and power systems

Many non-structural equipment systems on bridges are shared with other infra-structures domains (roads, rails, and tunnels), such as:

- Lighting.
- Telecom.
- Power.
- Etc.

Regarding lighting columns (or streetlamps), according to NF EN 40-1, they are supports intended to hold one or more lanterns, consisting of one or more parts:

- A post.
- Possibly an extension piece.
- If necessary, a bracket, i.e., a component used to support a lantern at a definite distance from the axis of the lower straight portion of a column, of single, double, or multiple form and integral with or demountable from the column (NF EN 40-1).

Bridges and civil infrastructures can carry several networks: electrical, telecom, data, etc. These systems are very similar to those in use in buildings, and several prede-fined types of **IfcCableSegment** already exist in IFC 4.3:

- CABLESEGMENT;
- FIBERSEGMENT;
- OPTICALCABLESEGMENT;
- CONDUCTORSEGMENT;
- Etc.

4. Completeness

4.1 Complementary IFC classes

buildingSMART Italia analysis

The objectives of the working group of buildingSMART Italia dealing with IFC Bridge[1]:

- Analyse and understand the standard proposed by IFC Bridge International.
- Test the application of the standard to some of the bridge types that were not verified by the international Project.
- Identify deficiencies, solutions, and possible additions to the standard.
- Report the results of these activities to the international community.

Case studies

The working group identified 2 case studies (girder bridges) in order to challenge IFC Candidate Standard 4.2, with the main features:

- Minimized the number of new entities.
- Added new Enum to the existing classes.
- Defined a new Spatial Structure to capture an Infrastructure project organisation.

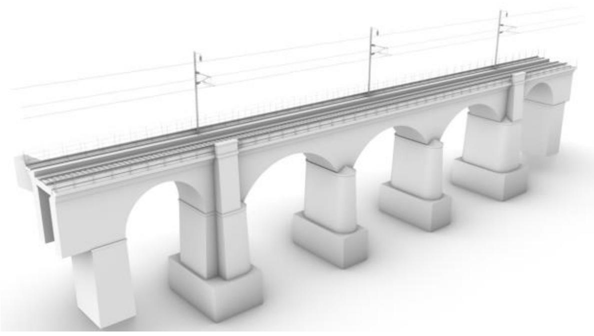

Fig.28 : Existing masonry arched bridge (A)

Fig.29 : Steel Concrete slab girder bridge design to construction (B)

	CASE STUDY "A"	CASE STUDY "B"
Owner	RFI Italian railway network manager	ANAS Italian government-owned company deputed to the construction and maintenance of Italian motorways and state highways
Bridge type	Arched bridge	Girder bridge
Construction type	Masonry	Slab-girder bridge
Superstructure geometry	Straight	(slightly) In curve
Materials	Masonry	Steel-Concrete
Condition	Existing	To be built
Model use cases	Degradation analysis	Design to construction
Modelling strategy	**A model used to identify the condition of the asset**	**Comparative approach between three different BIM authoring tools**
Modelling time	20 days	20 days
Software tested	1	3
Expected results	**Classes representation of complex elements (i.e., vaults). Relations between BIM-objects and condition.**	**Comparison between the IFC files exported from the different tools. Detailed model ready for tendering.**

Fig.30 : definition of the two case studies

[1] Working group pilots and writers: P. Borin, X. Fiorentinin, E. Alfieri, R. A.Bernardello, G. Scafetti, A. Basso, A. Ciccone

Reference documents	The documents are available on the Web site of buildingSMART Italia: [https ://www.buildingsmartitalia.org/utenti/pubblicazioni/guida-ifc-per-i-ponti/](https://www.buildingsmartitalia.org/utenti/pubblicazioni/guida-ifc-per-i-ponti/) • 01_Linea-guida-di-applicazione-dell'IFC-a-ponti-e-viadotti.pdf • casostudio-a-ponte-in-muratura • caso-studio-b-ponte-con-sezione-mista-acciaio-calcestruzzo
Classification phase	First, the implemented process is based on the analysis of the IFC classification: • Spatial Structure decomposition • Object IFC classification
Spatial Structure decomposition	The first classification aim is the Spatial Structure organization. It is based on: • Predefined types • Element composition of the classes
IfcBridgeTypeEnum reference	The IfcBridgeTypeEnum depends on the different bridge types: • Arched • Cable-stayed • Cantilever • Culvert • Framework • Girder • Suspension • Truss • Userdefined • Notdefined
IfcBridgePart	The case study A is an IfcBridge.ARCHED, with the following spatial decomposition:

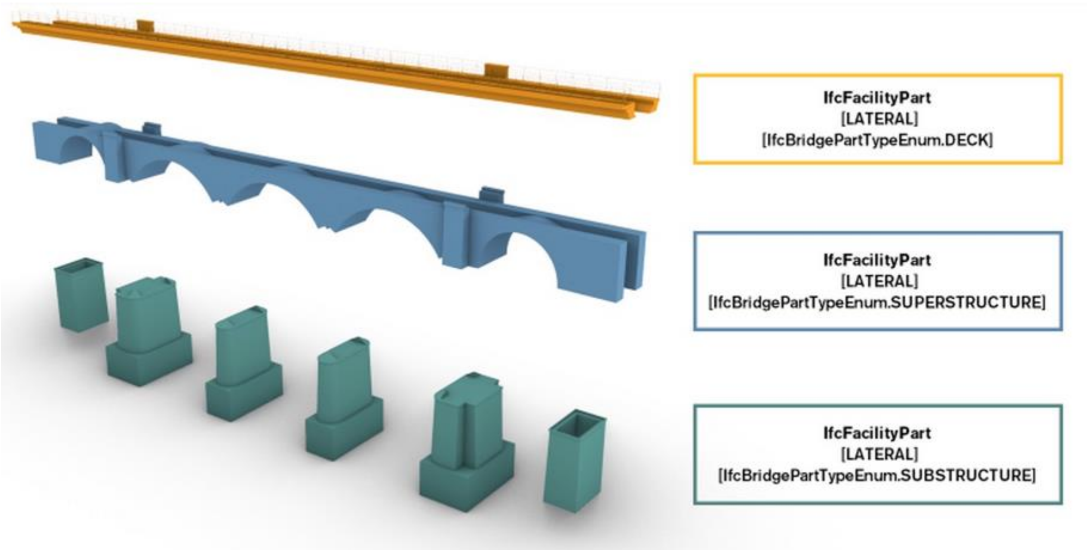

Fig.31 : Spatial organisation of an arched bridge

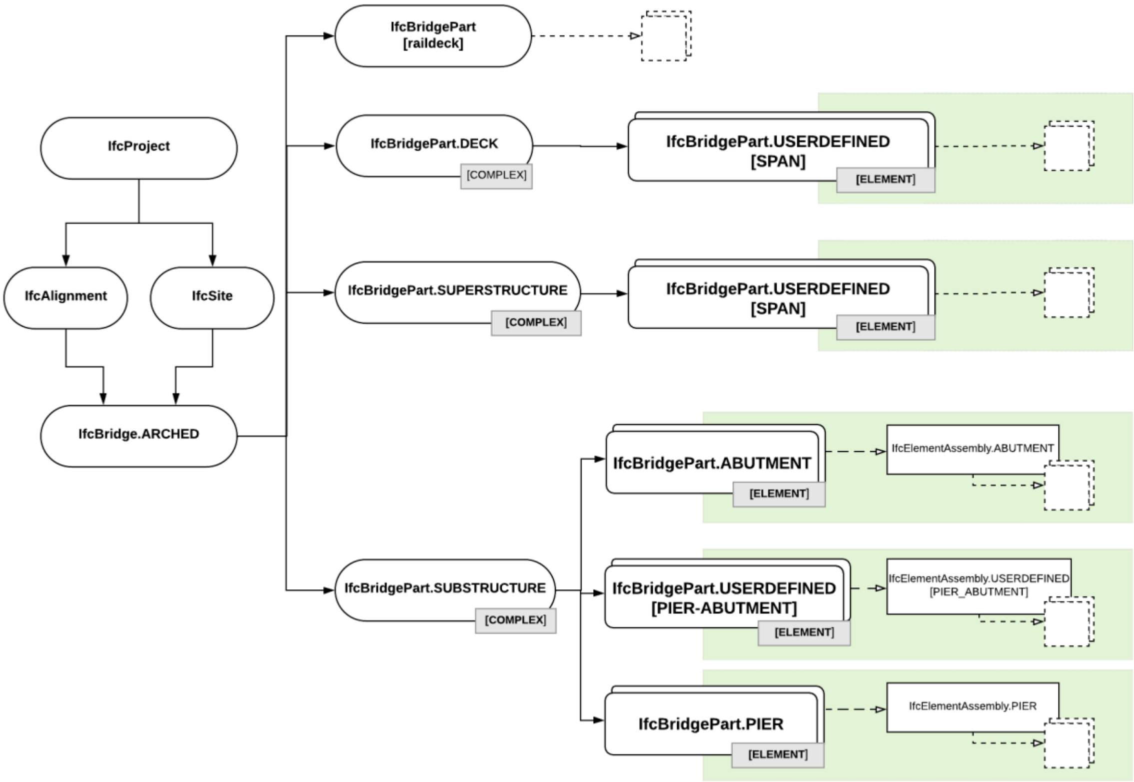

Fig.32 : IFC Spatial organisation of an arched bridge

Object IFC classification

After the setup of a spatial structure schema, each component of the structure is classified focusing on:

- Classes and Enum
- Relations between IfcObject

The component decompositions are based on:

- Use case of each model
- IFC logic

IFC class mapping

For the occurrence mapping, an in-depth analysis of the classification is carried out on two distinct levels:

- a higher level based on the definition of the classes.
- a lower level based on the definition of the Enum of the class.

Bridge structure interface

Some elements were not classified, because they belong to:

- the interface between the bridge structure and the linear infrastructure.
- the equipment of the linear infrastructures.

These elements are allocated in a specific spatial structure and the object classification is postponed to a second phase or to an integrated classification of the common schema.

Issues

Due to the intrinsic differences between the marked problems, they are organised in three main parts:

- Ifc classification issues
- Modelling issues
- Others Ifc related (like geometry export, etc.)

Some of the issues are common to all bridges, some others are bridge type dependant.

All issues are exposed in the document "01_Linea-guida-di-applicazione-dell'IFC-a-ponti-e-viadotti.pdf »[2] with a complete description and a proposed solution.

Missing IFC Classes

Here a sum up of the missing Ifc classes for bridges:

- IfcBridgePart.[SPAN], for the spatial organisation of a bridge.
- IfcElementAssembly.USERDEFINED:[PIERABUTMENT], for a masonry bridge.
- IfcBeam.[ARCH], for the head arch of a masonry bridge.
- IfcSlab_ enum userdefined:VAULT (/DOMED), for the vault of a masonry bridge.
- IfcBuildingElementProxy.USERDEFINED:[FILLING], for the filling material between the deck and the arched structure.
- IfcWall.USERDEFINED:[HAUNCH_FILLING], for the haunch filling.
- IfcPedestal, for the concrete blocks supporting the deck.
- ifcSlabTypeEnum, for the preslab components.
- IfcBridgePart:Equipment, to aggregate all the MEP equipment of a bridge.
- IfcElementAssembly:GIRDER, for a collection of beams forming a superstructure.

The Italian Working group proposed also new definitions of some existing IfcBridge classes, in order to fill some lacks.

Instrumentation

The monitoring of a structure is a set of controls and inspections revealing its condition and its possible evolution. It consists in following its evolution from a reference state. It includes two types of actions: periodic actions and actions related to particular events of the structure's life. In case of doubt or proven risks for the structure, other actions called reinforced surveillance or high surveillance can be added.

When it is necessary to verify the existence of disorders or to determine their mechanisms, when the monitoring of a structure can only be carried out by means of measurements (e.g., opening of cracks in prestressed concrete bridges) or when the structure is difficult to access, it is necessary to call upon instrumentation.

The most commonly used measurements are fissurometric, topometric or geometric. This is for example the case of monitoring the settlement of a pier, the tilting of an abutment, the deflection of a deck, the deplanation of a retaining wall, etc.

Other types of measurements can be made, some of which require the use of specialized techniques identical to those used in auscultation. This is the case of corrosion monitoring of reinforced concrete steels, detection of wire breaks by acoustic emission, monitoring of crack propagation in metal parts, etc.

The measurements directly necessary for the monitoring of a structure sometimes need to be accompanied by the measurement of parameters related to the environment in which the structure is located, either to be able to interpret the results or for the needs of corrections of the measuring devices. This is for example the case of piezometric readings, temperature readings, or even hygrometry measurements.

IFC 4.3

IFC 4.3 documentation defines a sensor as a device that measures a physical quantity and converts it into a signal which can be read by an observer or by an instrument. IFC Class **IfcSensor**, as a subtype of **IfcProduct**, allows the definition of sensors. A wide variety of predefined sensor types are available in IFC 4.3 schema:

[2] https ://www.buildingsmartitalia.org/utenti/pubblicazioni/guida-ifc-per-i-ponti/

- CO2SENSOR;
- CONDUCTANCESENSOR;
- FIRESENSOR;
- RAINSENSOR;
- WINDSENSOR;
- PRESSURESENSOR;
- Etc.

However, sensors currently used in structural health monitoring do not exists as predefined types:

- Crack meter.
- Strain gauge.
- Displacement transducer (linear or angular).
- Accelerometer.
- Etc.

Although these sensors can be embedded with USERDEFINED, it seems relevant to include them as predefined types in future evolutions of IFC schema, to efficiently cover the entire lifecycle of bridges.

Data storage

Instrumentation generates a massive amount of information. This raises issues about the storage and the security of the data. This topic is mentioned in MINnD deliverable "MINnDs2_GT3.2_vision_partagee_jumeau_numerique_027_2022".

Prestressing system

In the first season of the MINnD research project, only current bridges (which represent more than 80% of bridges carried out worldwide) were processed. The new deliverable "MINnDs2_GT1.1_IfcBridge_prestressing_suspension_systems_004_2022_eng" describes the post-tensioned bridge prestressing systems and lists the necessary objects to design and implement a prestressing system.

The list of objects is wide, but the sufficient IFC classes have been identified in order to define the main components of a prestressed bridge.

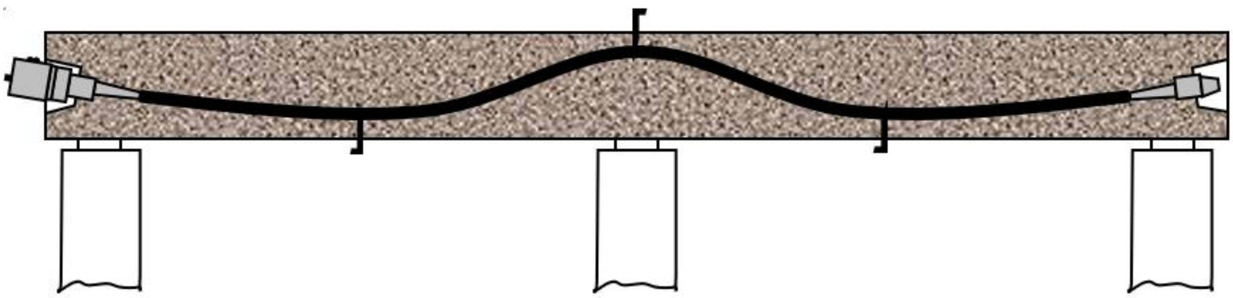

Fig.33 : Principle of a post-tensioning prestressing system

Suspension systems

In the first season of the MINnD research project, only current bridges (which represent more than 80% of bridges carried out worldwide) were processed. The new deliverable "MINnDs2_GT1.1_IfcBridge_prestressing_suspension_systems_004_2022_eng" describes the suspension systems and lists the necessary objects to design and implement a suspension bridge.

The list of objects is wide, but the sufficient IFC classes have been identified in order to define the main components of a suspension bridge.

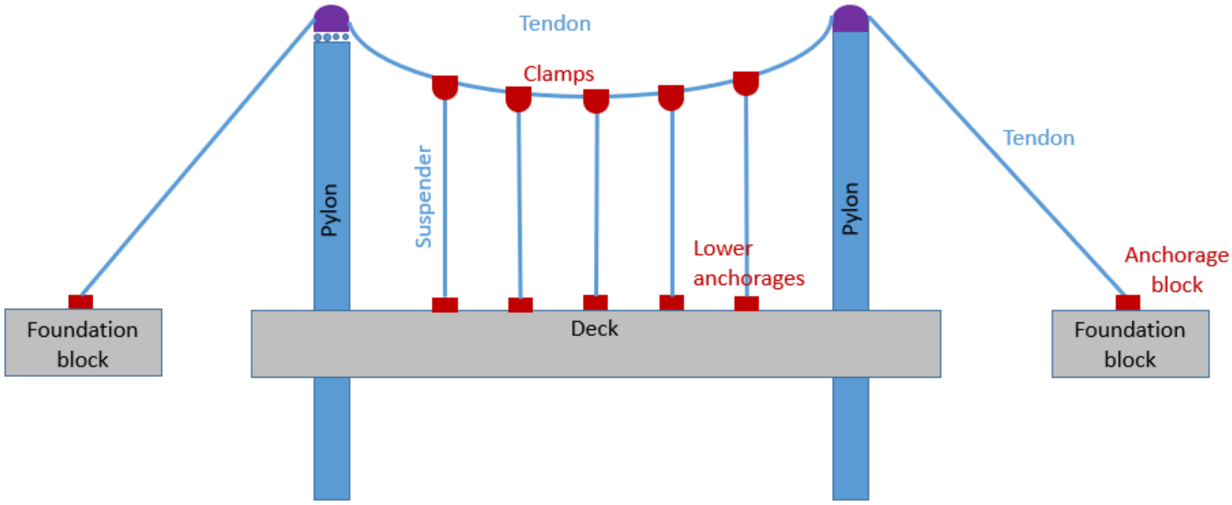

Fig.34 : Systems of a Suspension bridge

Cable systems

In the first season of the MINnD research project, only current bridges (which represent more than 80% of bridges carried out worldwide) were processed. The new deliverable "MINnDs2_GT1.1_IfcBridge_prestressing_suspension_systems_004_2022_eng" describes the cable-stayed systems and lists the necessary objects to design and implement a cable-stayed bridge.

The list of objects is wide, but the sufficient IFC classes have been identified in order to define the main components of a cable-stayed bridge.

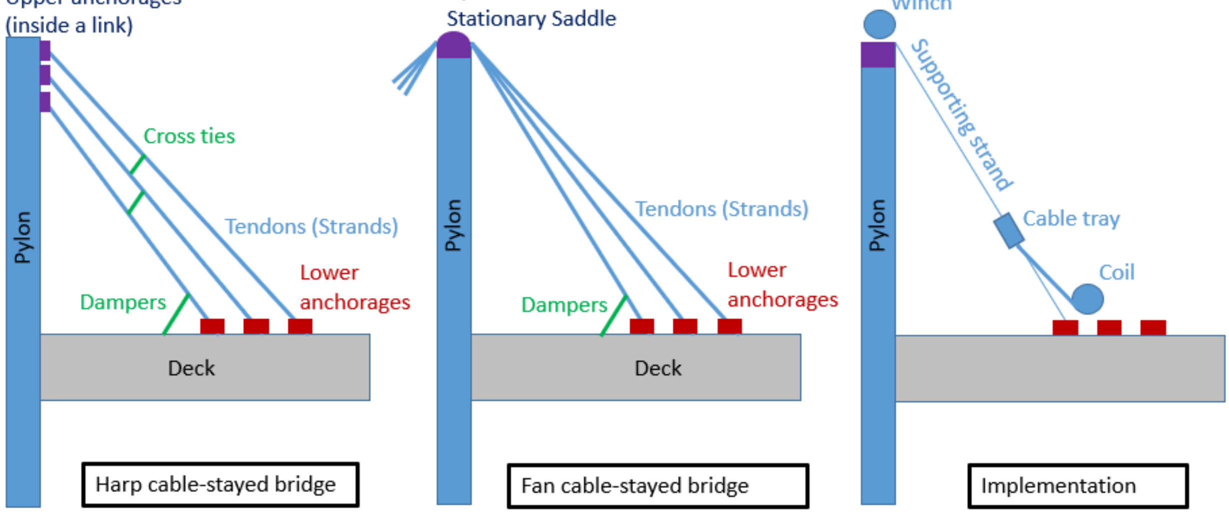

Fig.35 : Systems of a Cable-stayed bridge

Retaining walls

Retaining structures are designed to create a denivelation between upstream and downstream grounds. This denivelation can be achieved by placing backfill behind the retaining structure (embankment) or by extraction of land in front of the structure (cut). However, in practice, retaining structures are usually associated with a combination of cut and fills. Several types of retaining structures are presented in Fig.36. These structures differ from each other mainly by:

- their morphology (massive structures, reinforced concrete structures, curtains and walls, whether anchored or not, ...);
- their mode of operation and the sizing methods to which they relate;
- the materials which constitute them (masonry, reinforced concrete or not, ordinary steels or for prestressing, geosynthetics, added soils treated or not, ...);
- their method of execution, which can be very different depending on the type of structure concerned;
- their preferred field of employment, which naturally depends on many factors (work in backfill or cut, specific site conditions: land, urban, aquatic, mountainous, unstable, ..., special conditions of soil, environment, ...).

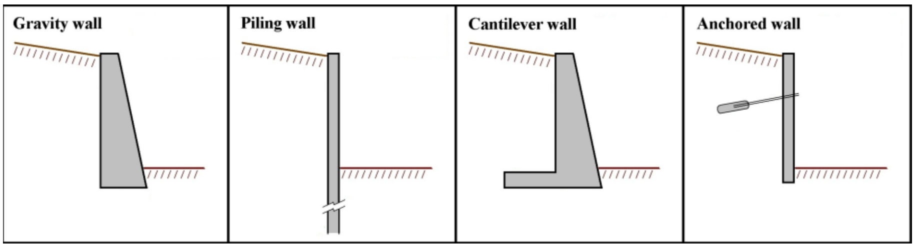

Fig.36 : Types of retraining walls (adapted from Wikipedia)

Regarding bridges, retaining walls are usually associated with abutments (wing wall, side wall), as illustrated in Fig.37. with a rigid frame example.

IfcWall class allows the definition of load-bearing walls, such as retaining walls (**IfcWallTypeEnum = RETAININGWALL**). According to IFC 4.3 documentation, a retaining wall is "a supporting wall used to protect against soil layers behind. Special types of a retaining wall may be e.g., Gabion wall and Grib wall. Examples of retaining walls are wing wall, headwall, stem wall, pierwall and protecting wall." This definition seems to comply with bridge requirements for retaining structures.

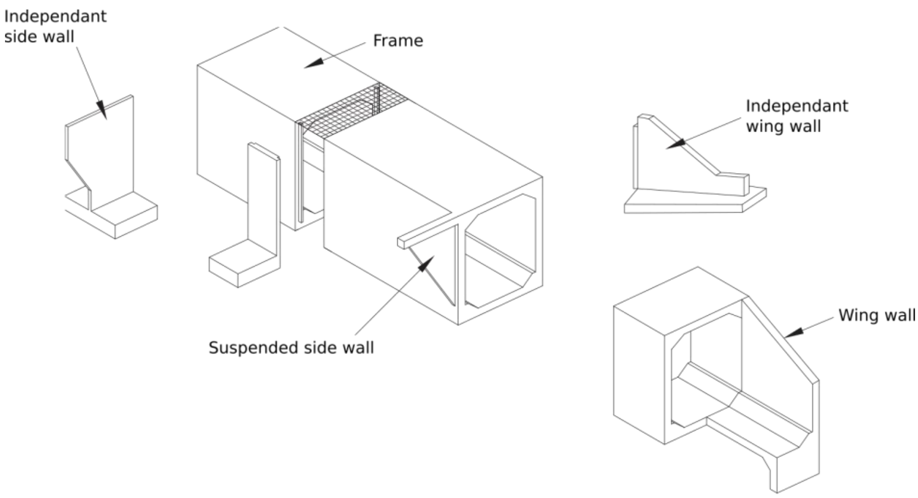

Fig.37 : Examples of retaining walls for a rigid frame (adapted from « Dictionnaire de l'entretien routier. Volume 5 : ouvrages d'art », Cerema, 2008)

5. Conclusions

Concluding remarks

This deliverable focused on the relationship between bridges and other infrastructure domains: roads, rails, tunnels, geotechnics, and earthworks. The precise definition of the scope of bridges allowed to identify: (i) elements at the interface between bridges and these other domains, and (ii) a list of systems or components necessary for the description of a bridge over its entire lifecycle but shared with other domains. The domain most concerned by these shared elements has been identified and should handle the consistency check of the IFC schema on this matter. This work was initiated in this deliverable for several systems: road restraints and safety barriers, drainage systems and lighting/telecom/ power systems. Finally, some complementary IFC classes were identified based on cases studies from BuildingSmart Italy and on the work carried out in the new deliverable “MINnDs2_GT1.1_IfcBridge_prestressing_suspension_systems_004_2022_eng”.

As mentioned in the introduction, the test cases put the finishing touches to the validation of a new version of the IFC format, in this case version 4.3. Work carried out within the buildingSmart International Implementers’ Forum confirms the great flexibility of the IFC format for spatial decomposition, which can vary according to the practices of each country. Besides, it is important to emphasize on the implementation of two key concepts in IFC 4.3: georeferencing as opposed to engineering coordinates systems. Again, with regard to the coordinate systems used in linear infrastructure projects, it's vital to consider linear positioning from the very first phase of design. These notions of co-existing coordinate systems within a single project are described in greater detail in the MINnDs2_GT1.1_ifcbridge_ifc4.3_validation_002_2023_eng deliverable.