High Speed Bridges
Design & Construction Approaches

IDEAS FOR FAST, SAFE AND COST-EFFICIENT
BRIDGE CONSTRUCTION

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Lead Bridge Engineer at High Speed 2

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1. OVERVIEW

High Speed 2:

- Connects the major urban economies in the UK
- Phase 1 connects London and West Midlands
- Phase 2 connects West Midlands with Manchester and Leeds

- 135 Over bridges (bridges above the HS2 railway line)
- 185 Under bridges (bridges under the HS2 railway line)
- 70 Viaducts

The Efficiency Challenge Programme has the mission to support the delivery of HS2 infrastructure by realising significant cost savings through embedding the right sponsor, client and supply chain behaviours and processes.

The Efficiency Challenge Programme comprises 19 projects (Commercial/ Procurement, Skills development, Design strategy…). One of them is

Exploit Offsite prefabrication

The primary goal of Project 12 (Exploit Offsite prefabrication) is to maximize the benefits of Built off site over traditional methods of construction:

- *Improvement in Safety*
- *Programme reduction*
- *Cost reduction*
- *Predictable delivery and performance*
- *Reduced impact of construction on affected communities*
- *Improvement in Quality*
- *More Sustainable solutions*

Past experiences related to other programs show that if clients do not take the right steps in terms of design and procurement definition, the project will not benefit from the built off site full potential.

The Build off site Design Development Work Package include the following activities:

- Grouping all the structures into coherent standard families thereby reducing the number of different types of structures.

- Produce reports for each of the families, assessing the most common solutions against the following criteria:
  - Functional
  - Health & safety
  - Architectural
  - Economic (whole life cost)
  - Quality
  - Buildability
  - Sustainability
  - Durability/reliability
  - … <u>trying to promote or, at least, not to preclude offsite manufacture</u>.

- Develop the relevant sections of the "Project Requirement Specification", with the aim to allow innovation and address concerns deemed not properly covered by current standards.

- Develop architectural specification, including concepts for the elements likely to contribute noticeable to HS2 brand

HS2 DESIGN STAGES

FOR PHASE ONE INFRASTRUCTURE

hs2 engine for growth

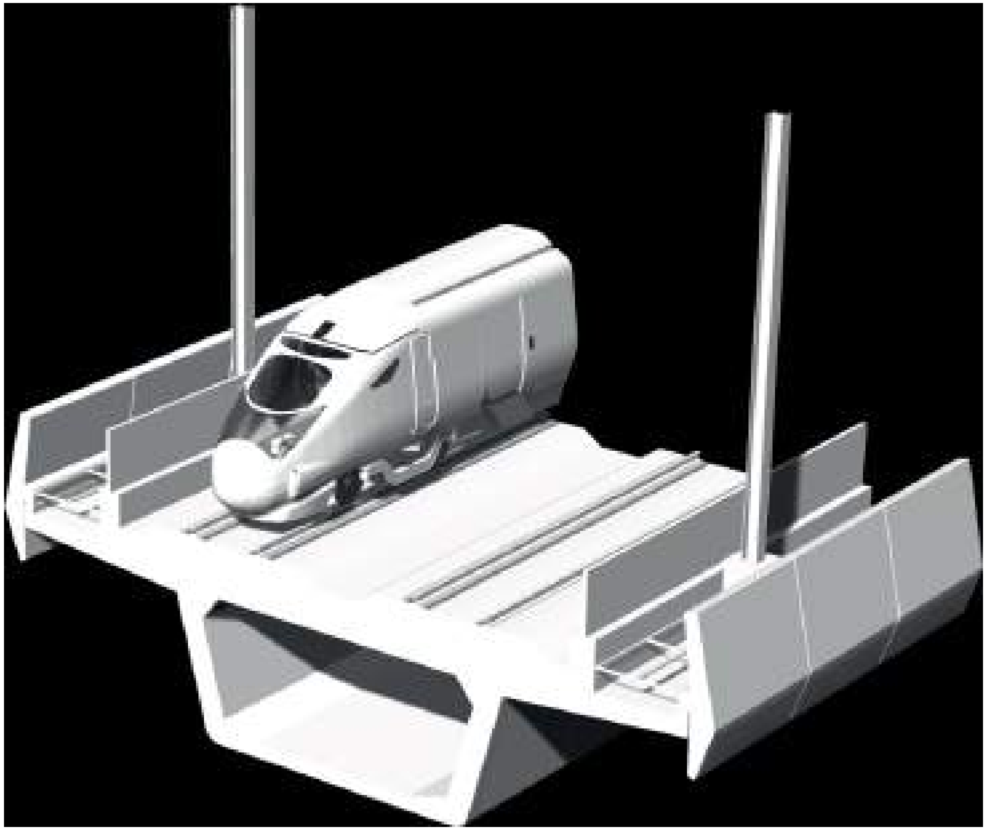
	Level 1	Level 2	Level 3	Level 4	Level 5
Name of design stage	**Parliamentary Design**	**Specification Design**	**Employer Requirements Design**	**Scheme Design**	**Detailed design**
Responsible directorate	Development Directorate (Parliamentary Team)	Technical Directorate	Phase 1 Infrastructure	Phase 1 Infrastructure	Phase 1 Infrastructure
Design carried out by	Professional Services Consultants (PSC)	Professional Services Consultants (PSC)	Multidisciplinary Design Consultants (MDC)	ECI Stage 1 Contractor	Stage 2 Design and Construction Contractor
Description	The design required to achieve Royal Assent. This includes the design for the preparation of a Hybrid Bill. This comprises a concept scheme capable of being built and operated, sufficiently developed to provide conservative limits of deviation, EIA and cost estimate.	The design required in order for HS2 Ltd to prepare Specifications for design and construction contracts consistent with the chosen procurement route.	The design required to provide sufficient scope definition to enter an ECI contract.	The design required to obtain approvals and permissions to construct, from statutory consultees, major utilities, planning authorities.	The design required to develop the Scheme Design to a stage where manufacture and construction/assembly can take place.

Note
These are the design stages for HS2, agreed between Technical Directorate and Phase 1 Infrastructure.
These stages supersede those in previous draft documents including: Design Strategy, Delivery Strategy, Schedule & Development Planning Review

eB: HS2-HS2-DS-PRO-000-000009 P02

High Speed specific constrains:

- Dynamic performance
- Noise



Typical HS2 viaduct cross section

2. DESCRIPTION

Typical case

- Fast
- Simple
- Inexpensive

...but

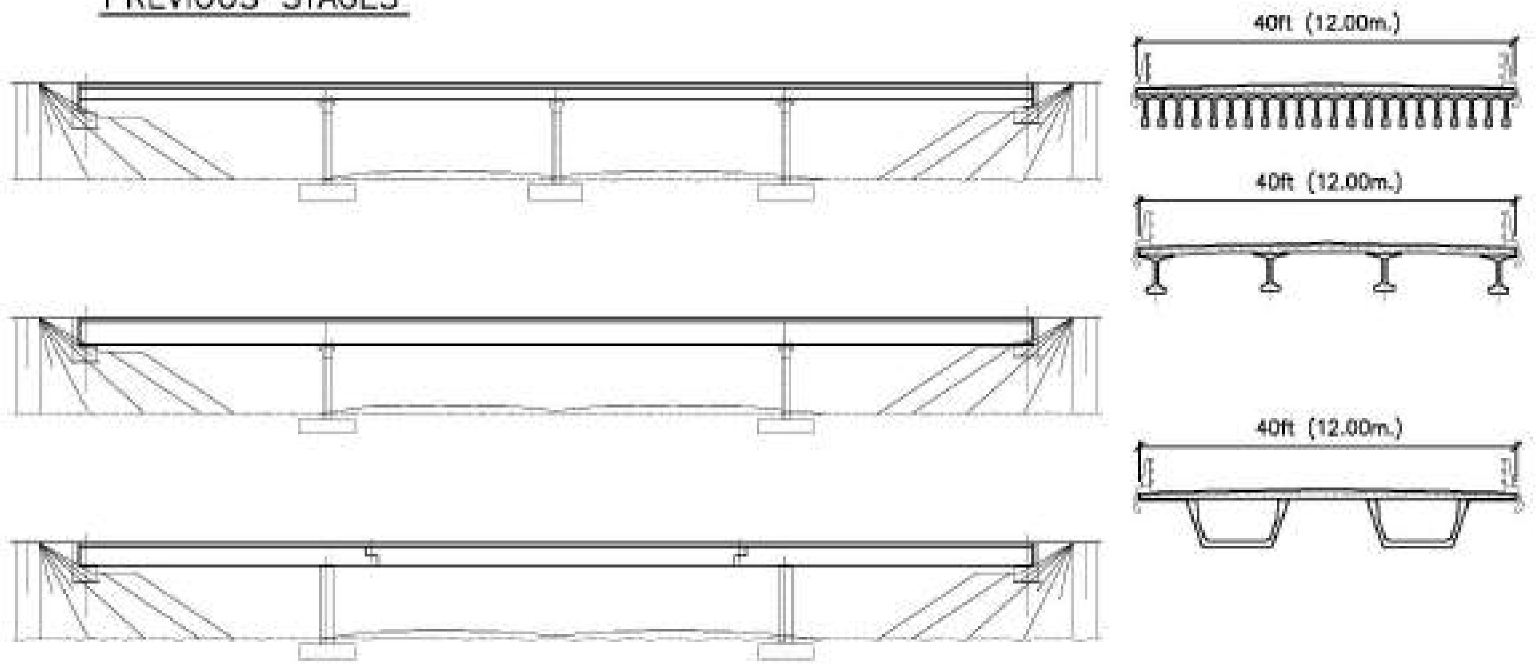
- Maintenance?
- Aesthetics?
- Functionality?

...Is there any other way?

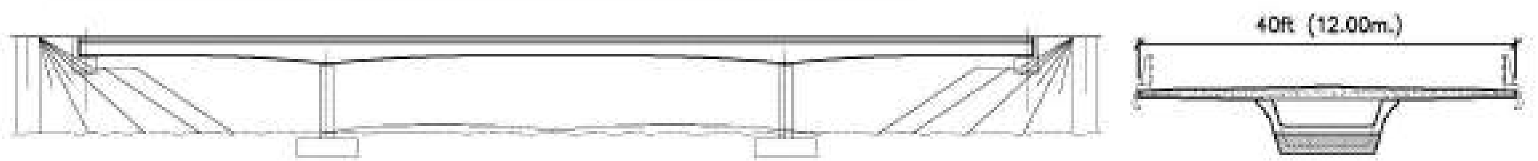
Different way to build continuous precast decks

Developments on Precast Concrete Bridge Decks: spliced U-beams by Short & "Straight" Tendons (BSST)

PREVIOUS STAGES



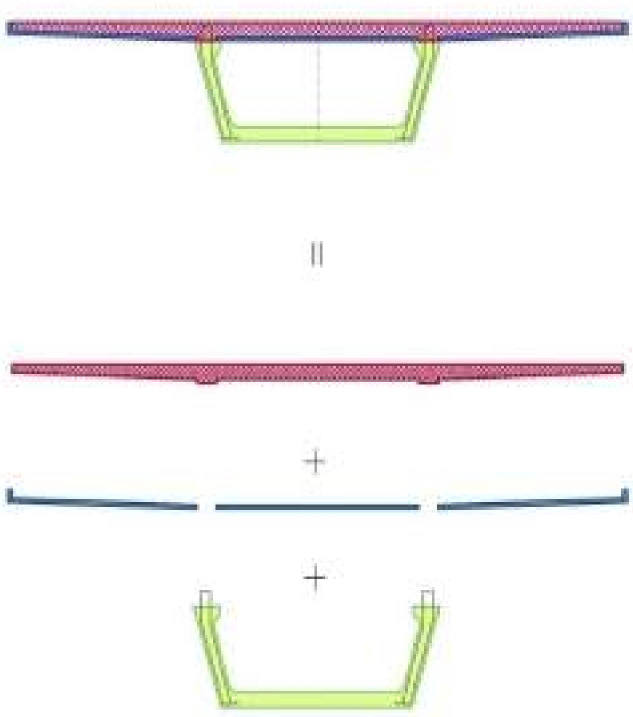
FINAL SOLUTION FOR CONTINUOUS PRECAST DECK



Main characteristics of BSST precast continuous bridges

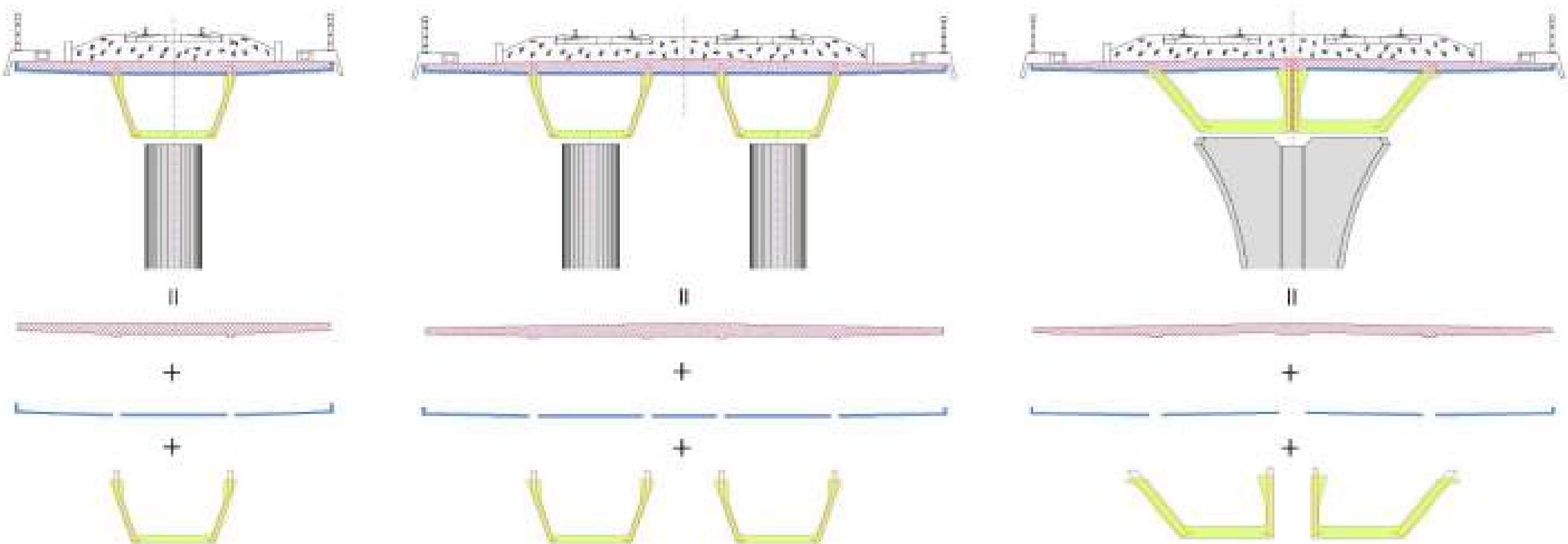
Continuous U-beam bridge decks, made up of:

- **Precast** prestressed **spliced** U-beams (pretensioned and/or post-tensioned)
- Cast-in-place **reinforced** and/or **post-tensioned** concrete top slab, using **free-standing planks**.



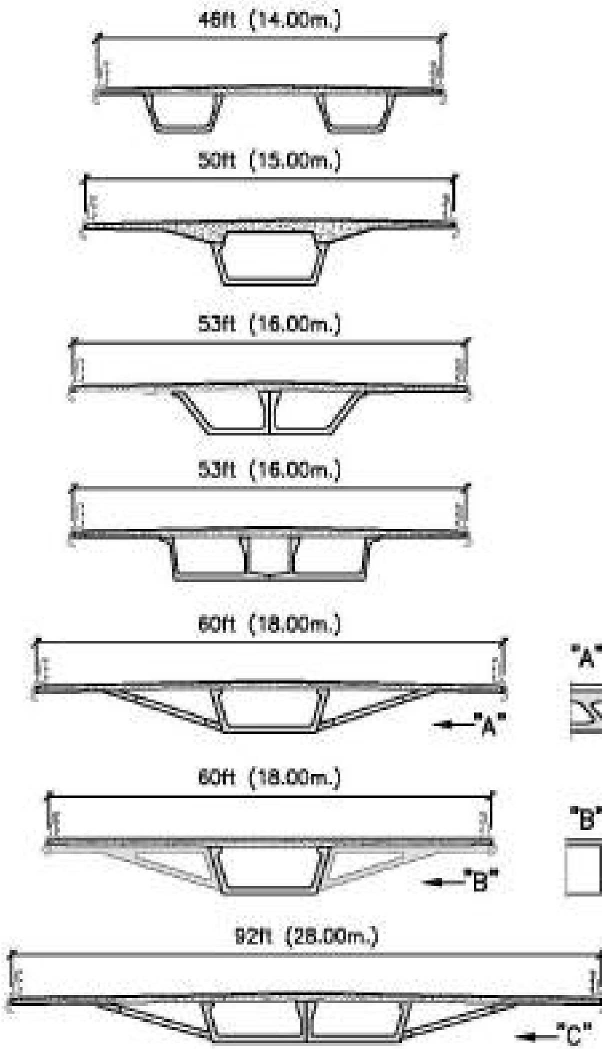
Main characteristics of BSST precast continuous bridges

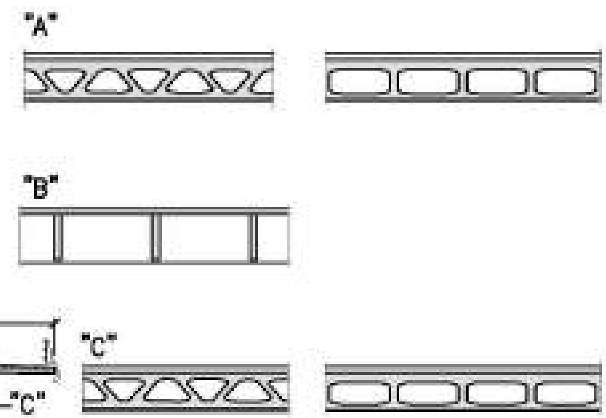
- Several U-beams or single/multiple cell box girder



- Attached U-beams: one single pier reduces occupation

Developments on Precast Concrete Bridge Decks: spliced U-girders by Short & “Straight” Tendons (BSST)





Evolution of cross-section for increasing width

First Bridge Decks using Spliced U-girders by Short & “Straight” Tendons (BSST)

- HS Railway Madrid – Sevilla (1989-1992):

  60-65% precast bridges (22/34) – simple supported

- **1992-1993:** First precast concrete continuous deck

  “La Barranca” Highway - Navarra

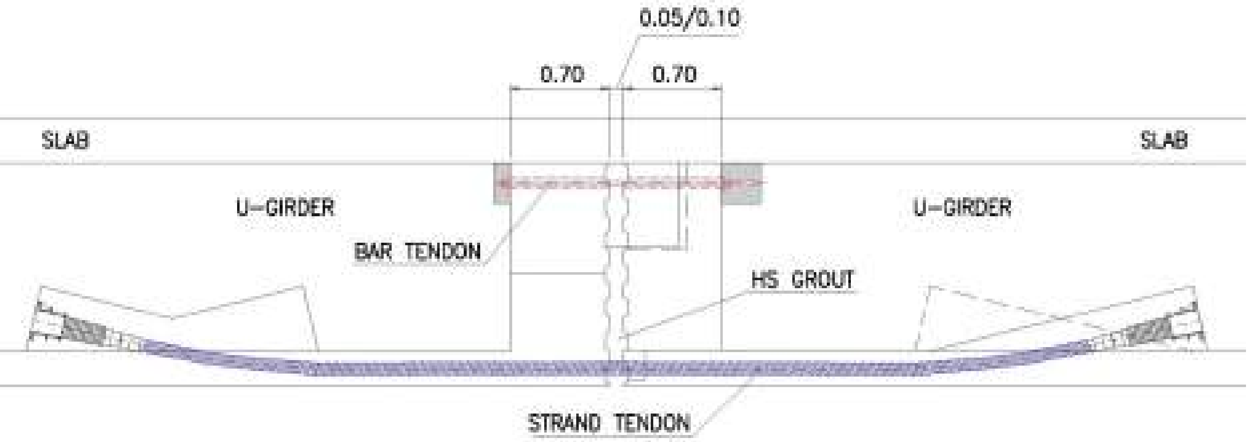
- **2001:** First precast concrete continuous deck for HS Railway

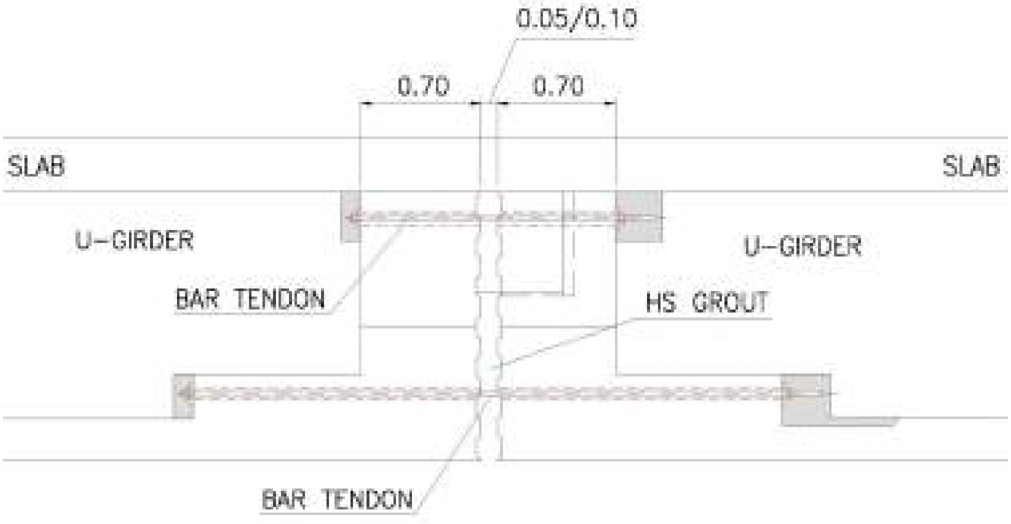
  HS Railway Madrid – Barcelona, in Zaragoza:

  - “Aguilar de Ebro” Viaduct
  - Viaduct over N-2 Road

Description of BSST system

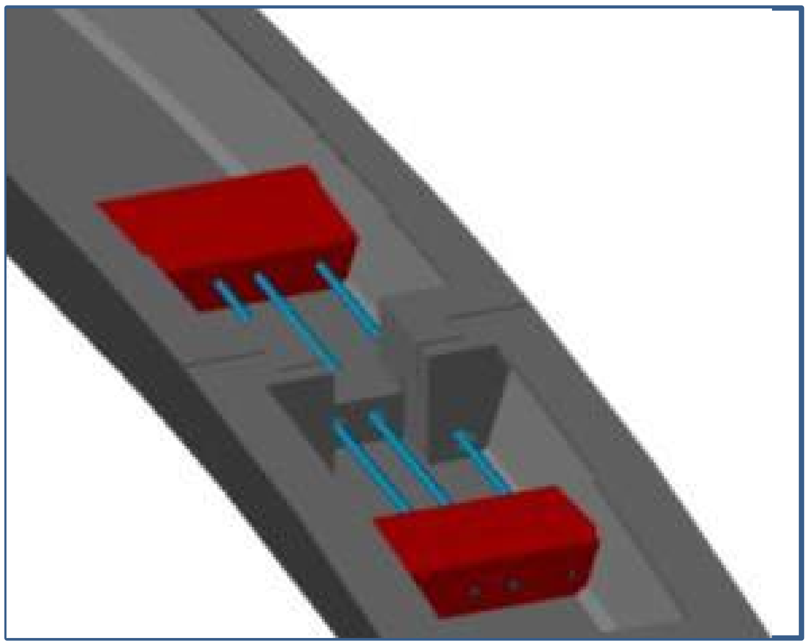
- Continuity by means of post-tensioning: tendon or bar





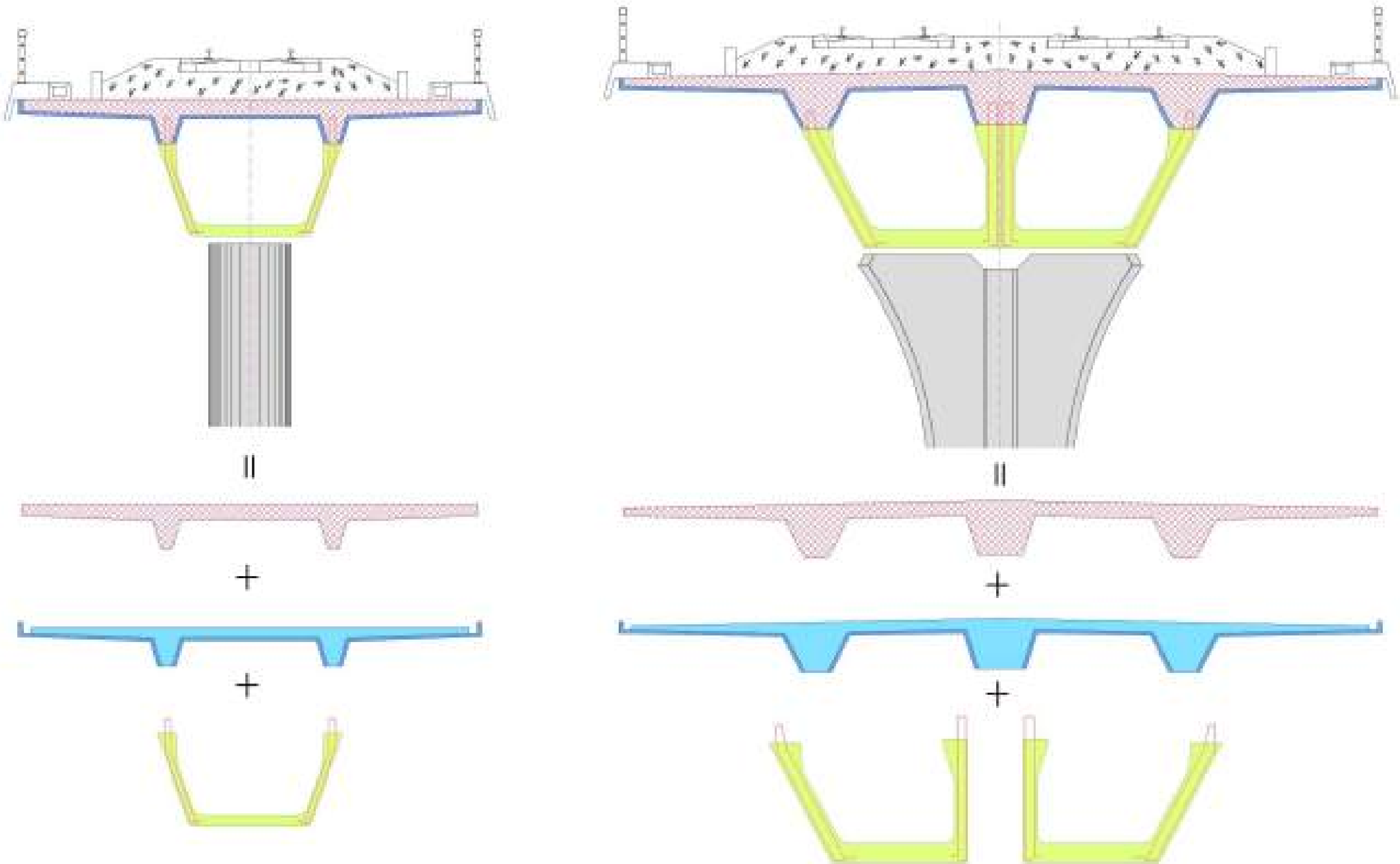
Continuity by

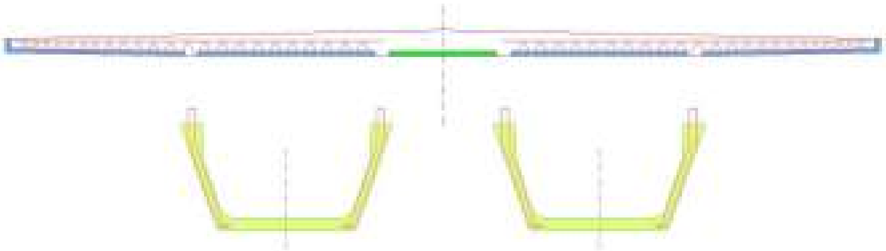
unbounded elements



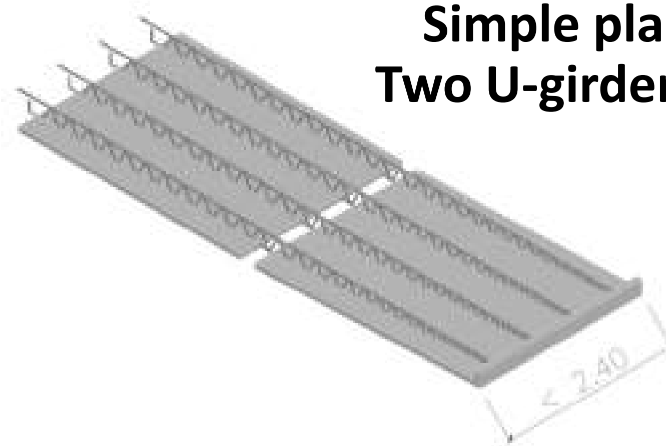
Main characteristics of BSST precast continuous bridges

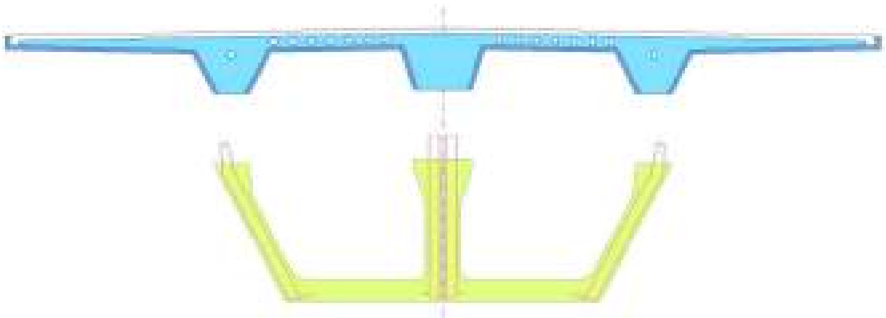
- Enhanced free-standing plank for long spans



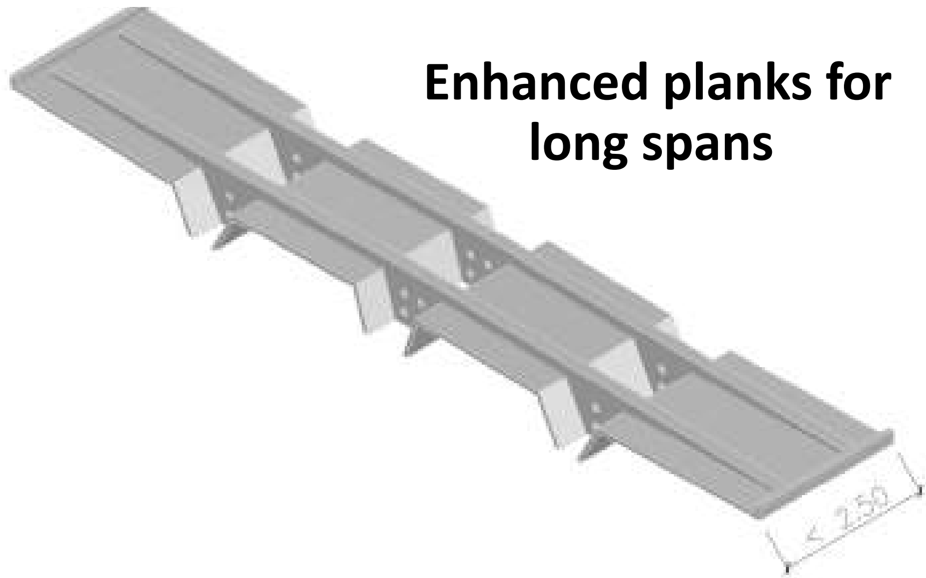


Simple planks for Two U-girder section





Enhanced planks for long spans



"LA BARRANCA" HW (Navarra) 1992-1995
Several overbridges with variable depth (Central span 35-40 m)

Examples

- Constant/variable depth

… SOME MORE DETAILS

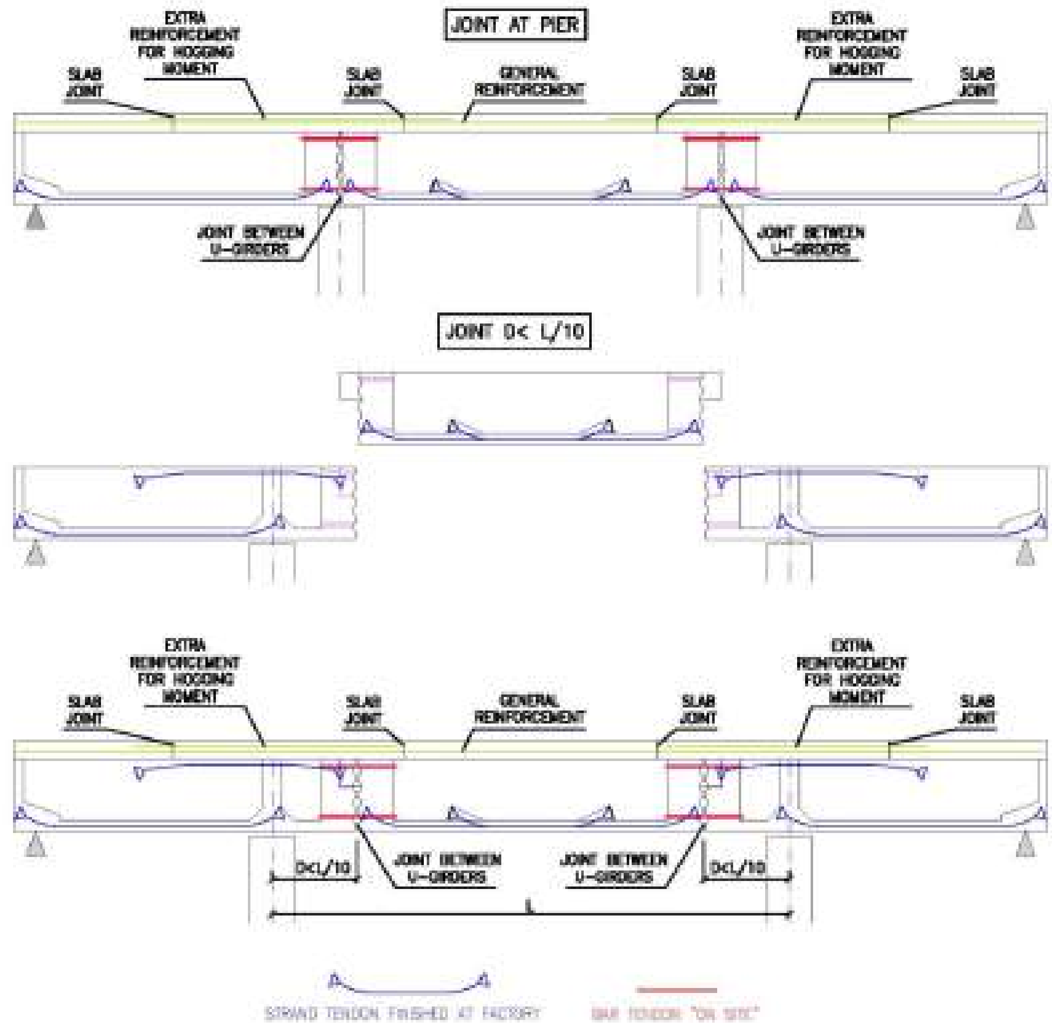
Description of BSST system

- **BSST system, four diferent solutions for continuity:**
  - Case 1: short span (up to 35 m)
  - Case 2: medium span (up to 45 m)
  - Case 3: medium-longer span (up to 55 m)
  - Case 4: long span (up to 65 m) = case 3 + enhanced planks
- **Common concepts for all cases**
  - Each U-beam has their own post-tensioning totally finished at factory
  - Splicing = wet joint
  - HS grout fills the gap (4cm – 12cm)
  - After grout setting → postensioning (joint ready to work in 2 days)
  - Slab joints never at splicing section → NEVER a whole section joint

Description of BSST system

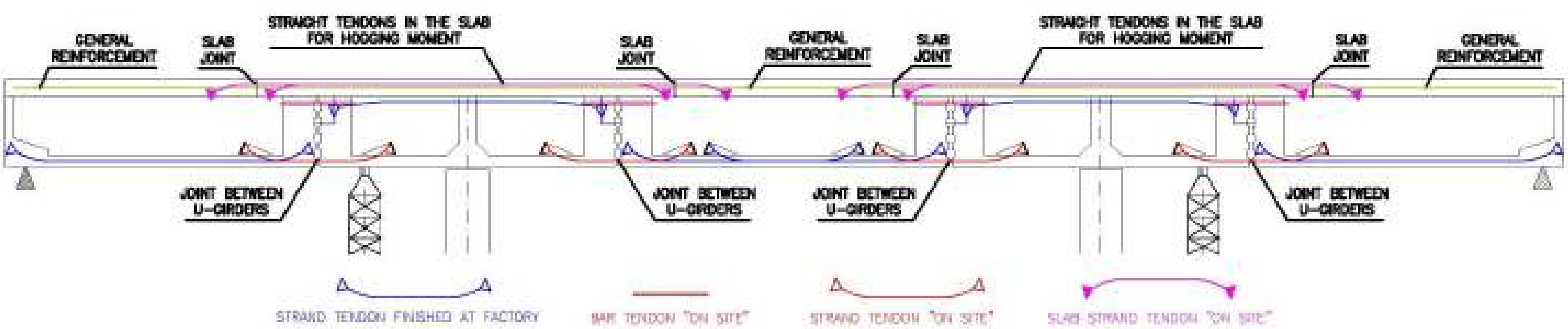
- **Case 1: short span (up to 35 m)**
  - Joint section at pier or D < L/10
  - Post-tensioning bars
  - Upper-slab with extra-reinforcement for hogging moment (if it's possible)

  - Reduction of <u>30-35%</u> on concrete compared to cast in place solutions.



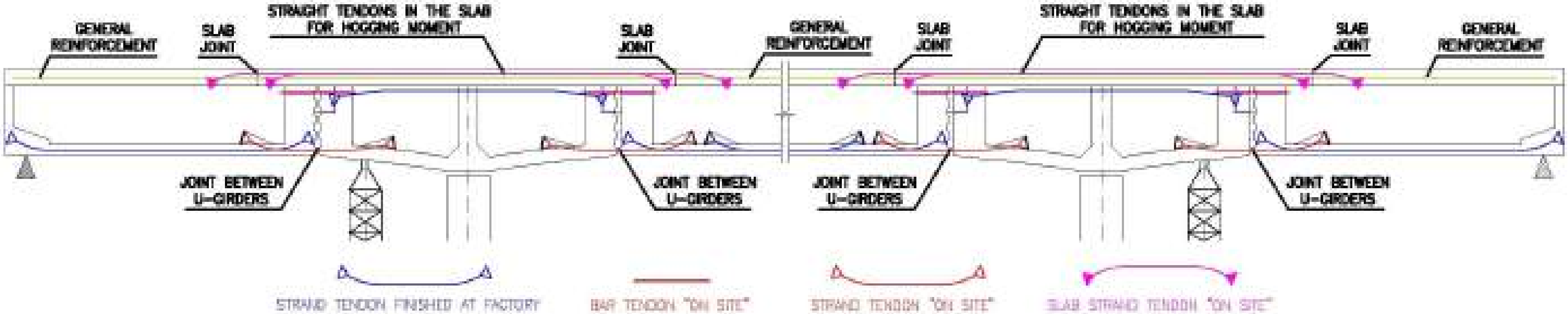
Description of BSST system

- **Case 2: medium span (up to 45 m)**
  - Joint section depends on U-girder proportions: length & weight
  - Lower post-tensioning → Strand tendon
  - Upper post-tensioning → Bar tendon
  - Upper-slab: post-tensioning strand tendon "on site" for hog moment
  - Temporary supports



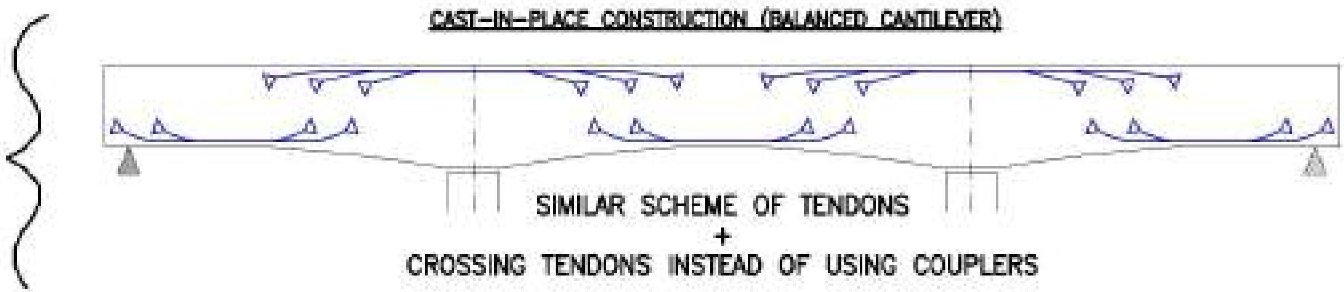
Description of BSST system

- **Case 3/4: medium-long span (up to 55 m / 65 m)**
  - Joint section depens on U-girder proportions: length & weight
  - Lower post-tensioning → Strand tendon
  - Upper post-tensioning → Bar tendon
  - Upper-slab: post-tensioning strand tendon "on site" for hog moment
  - Temporary supports
  - Variable depth & enhanced planks



BSST System ≡

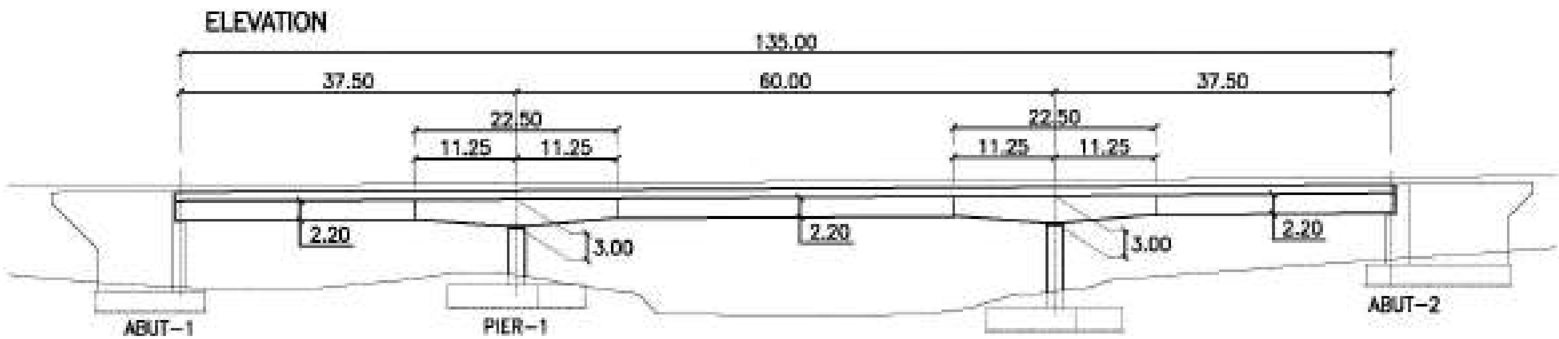
(No tendons in webs)

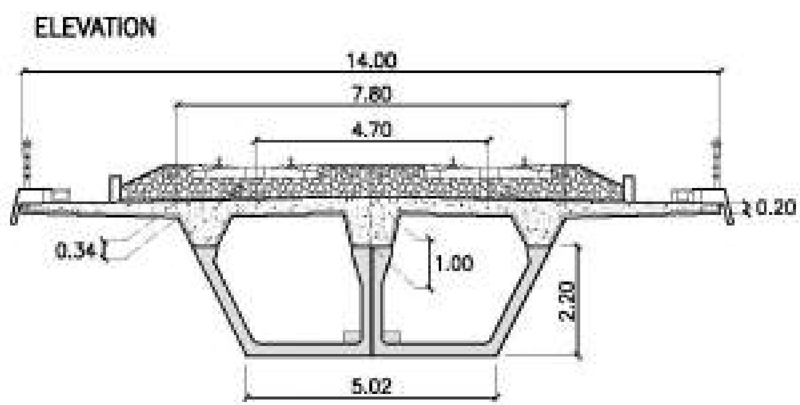


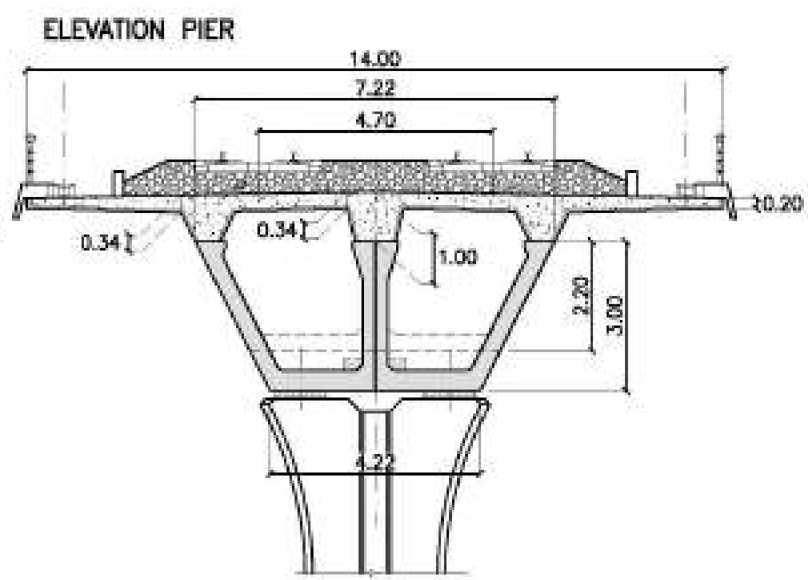
Details of slab reinforcement
and post-tensioning

Description of BSST system

- **Typical example:** general plan

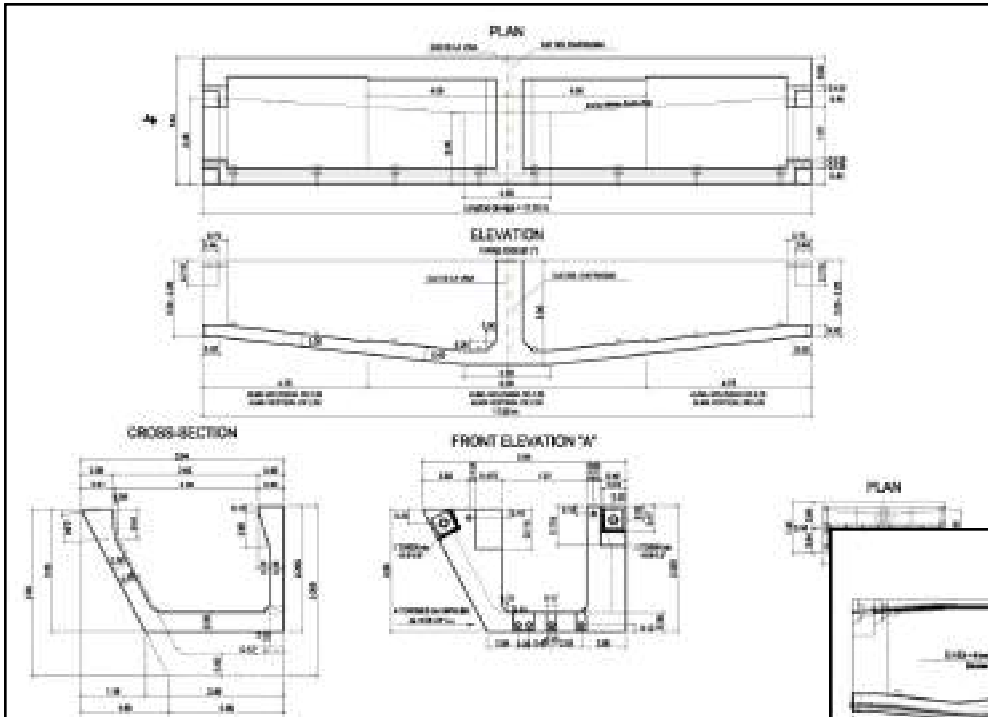


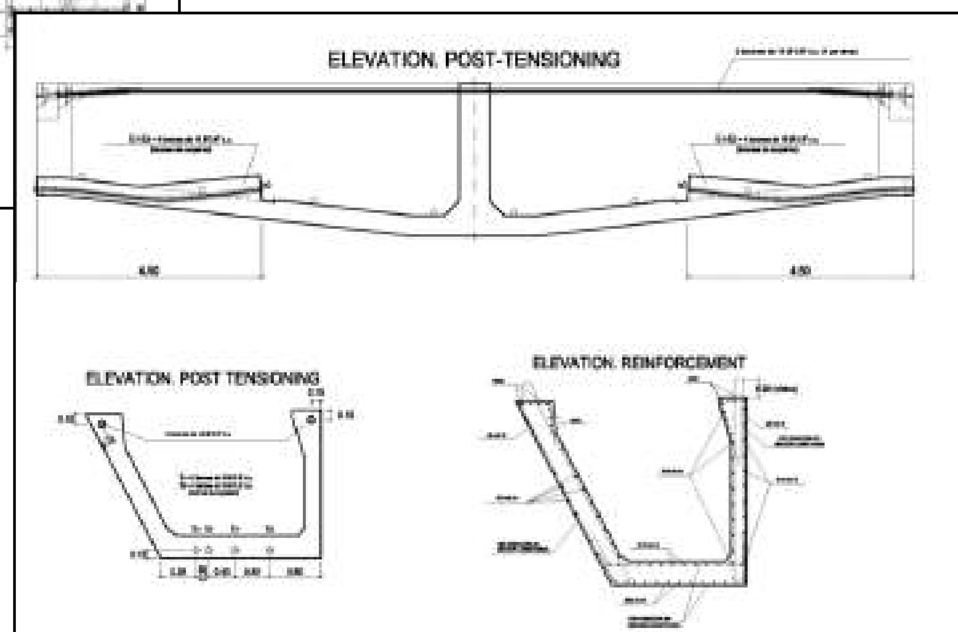




Description of BSST system

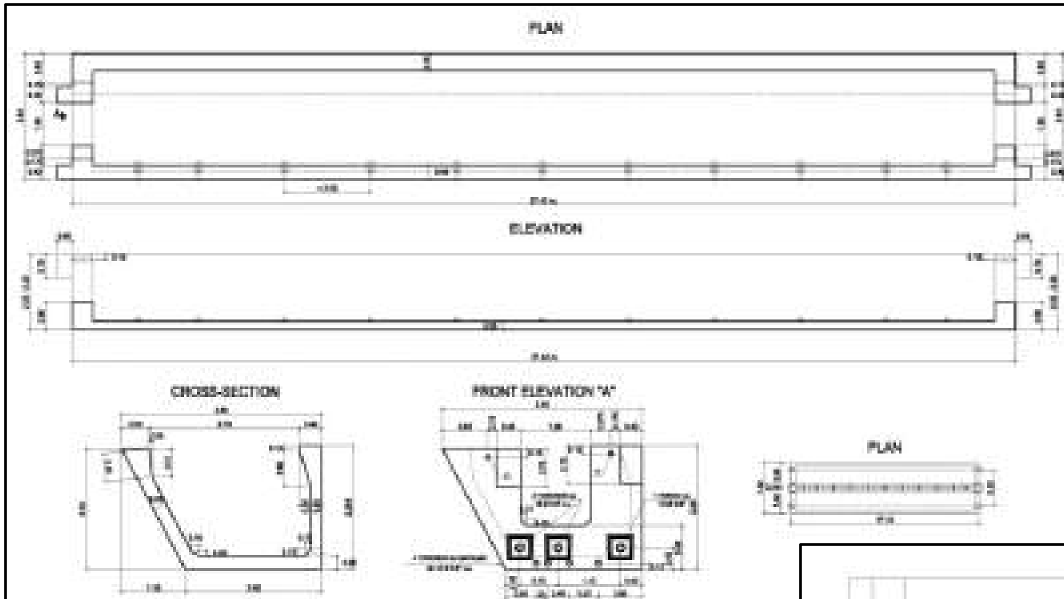
➢ **Typical example:** pier segment, post-tensioning and reinforcement



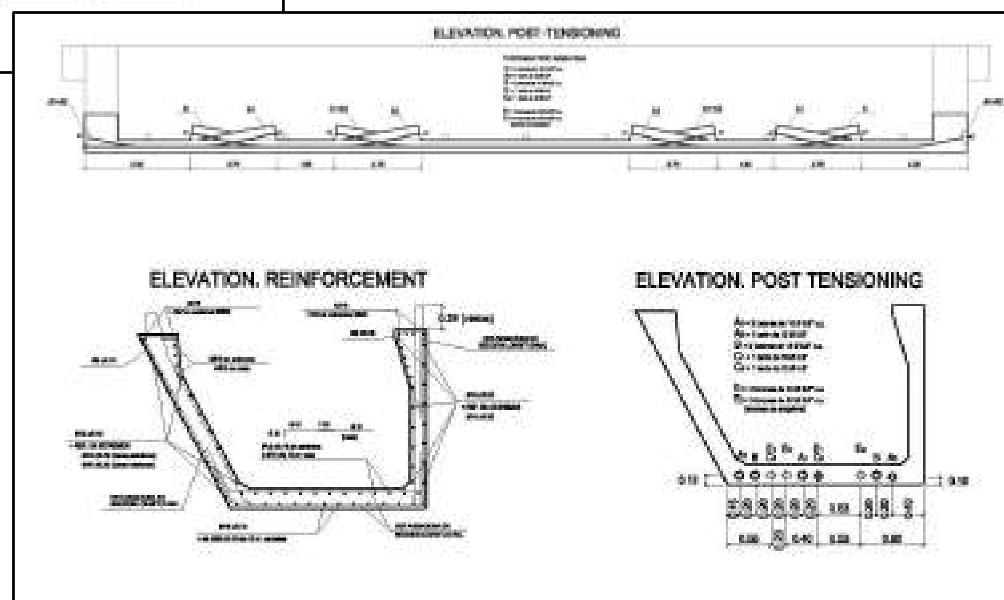


Description of BSST system

➢ **Typical example:** span segment, post-tensioning and reinforcement



Observe Concrete blocks
for post-tensioning anchorages



Description of BSST system

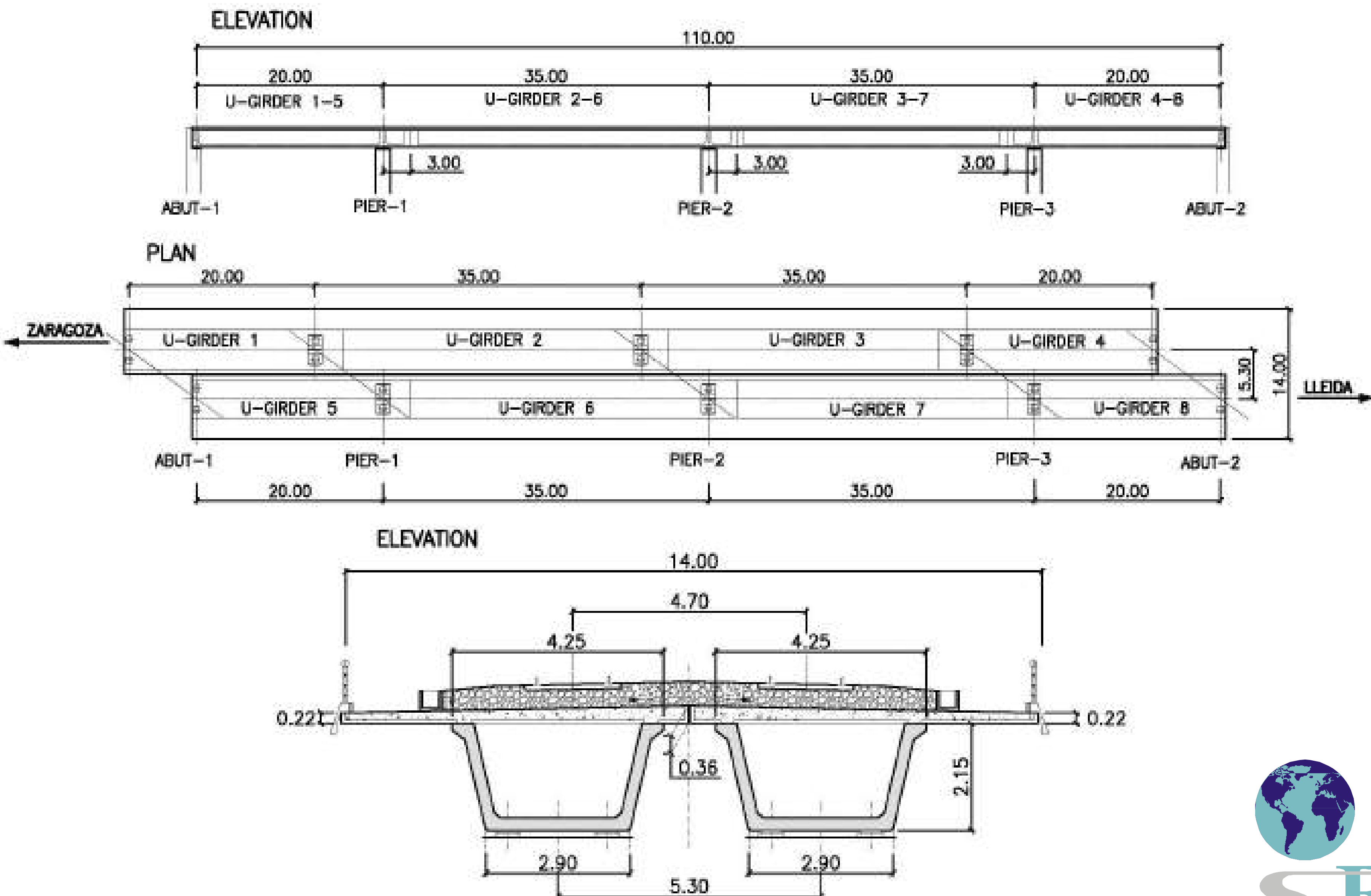
- "U" beams with end diaphragms and shear keys.
- Internal Corbels/Vertical joints.
- Conventional "wet joint" with HS grout
- Continuity by post-tensioning (short & simple)

… AND EXAMPLES

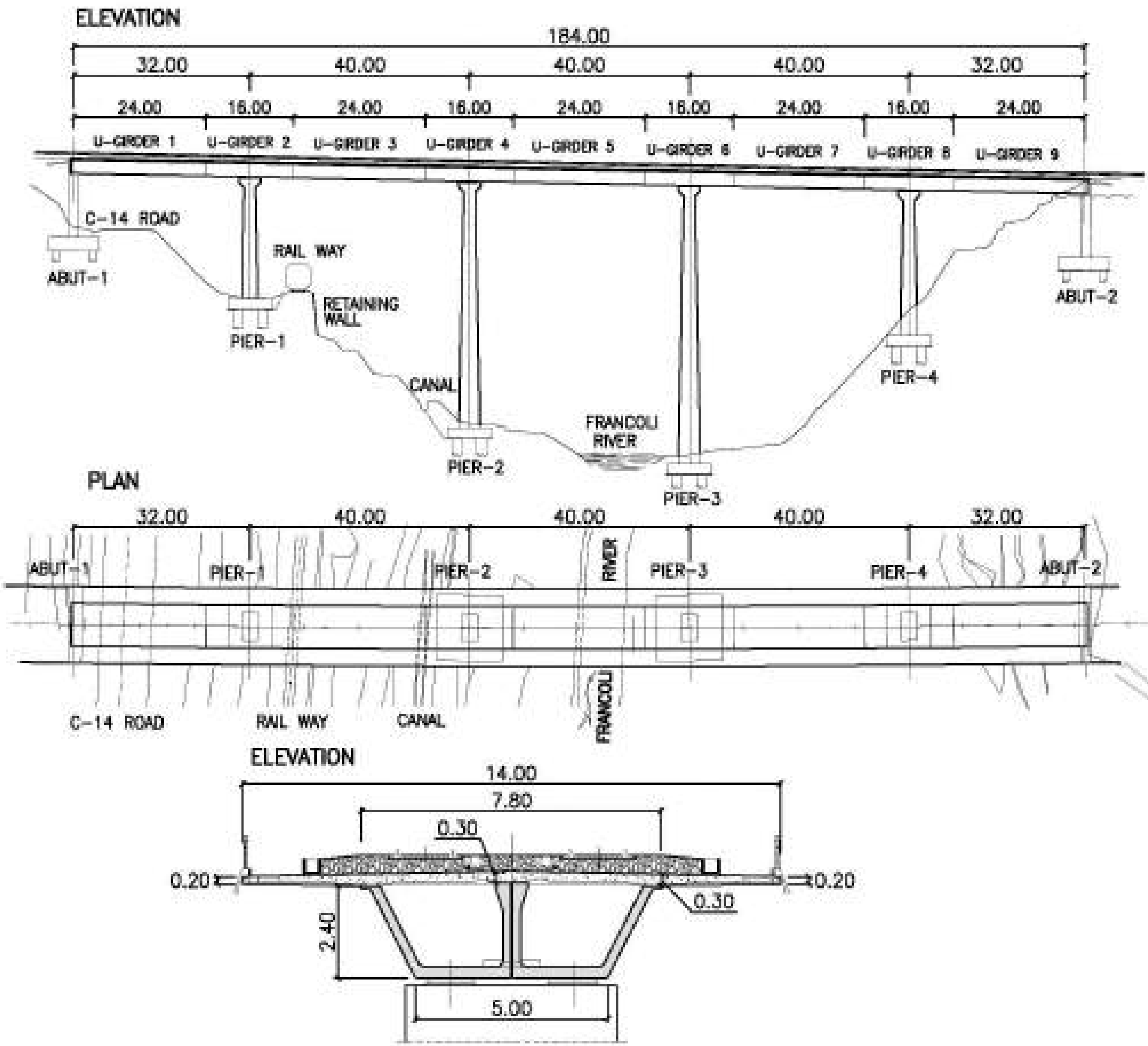
High Speed Rail Bridge Decks using BSST

- Some of the HS railway bridges built with BSST system

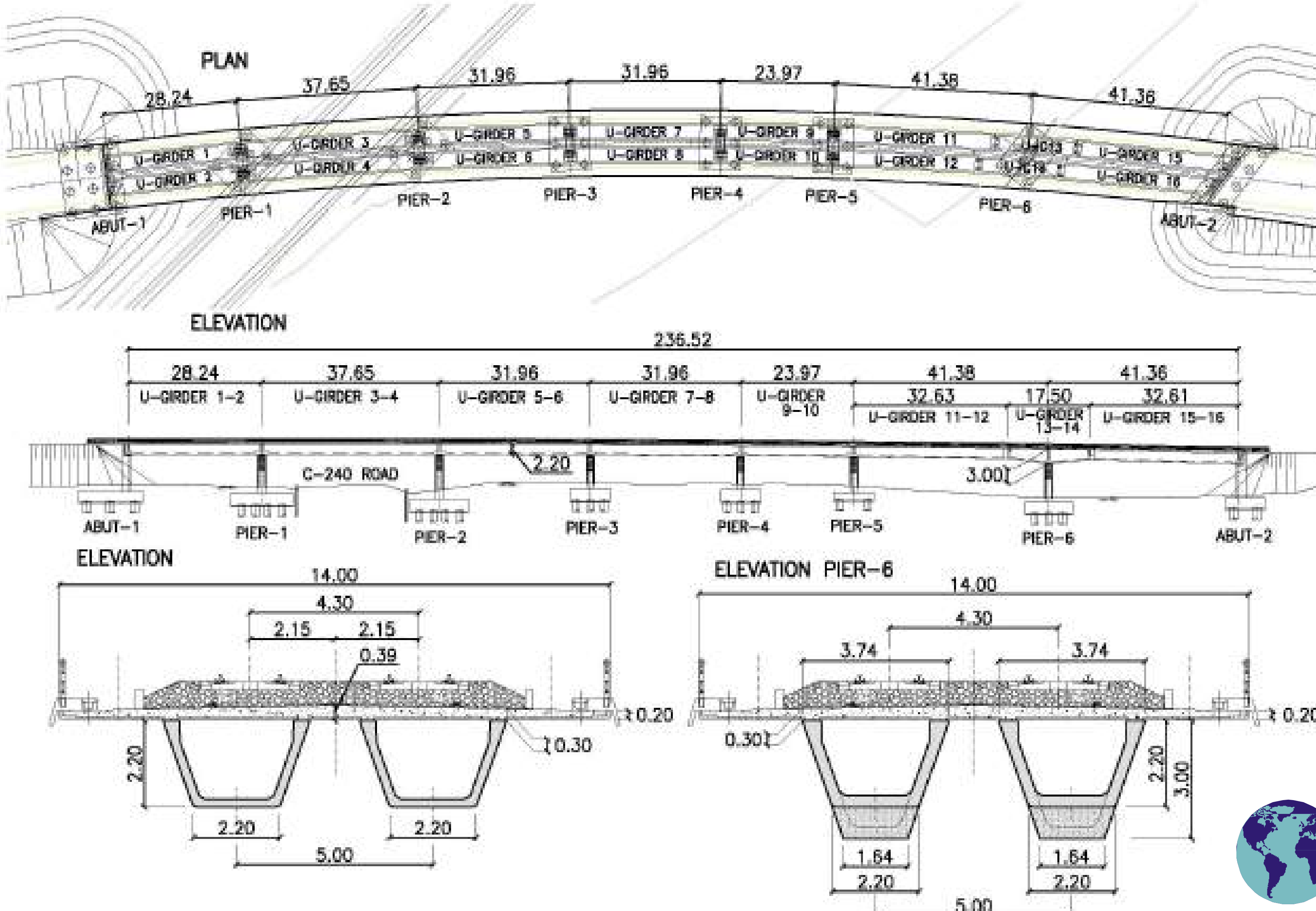
✓ VIADUCT OVER N-II ROAD IN ZARAGOZA (MADRID-BARCELONA)



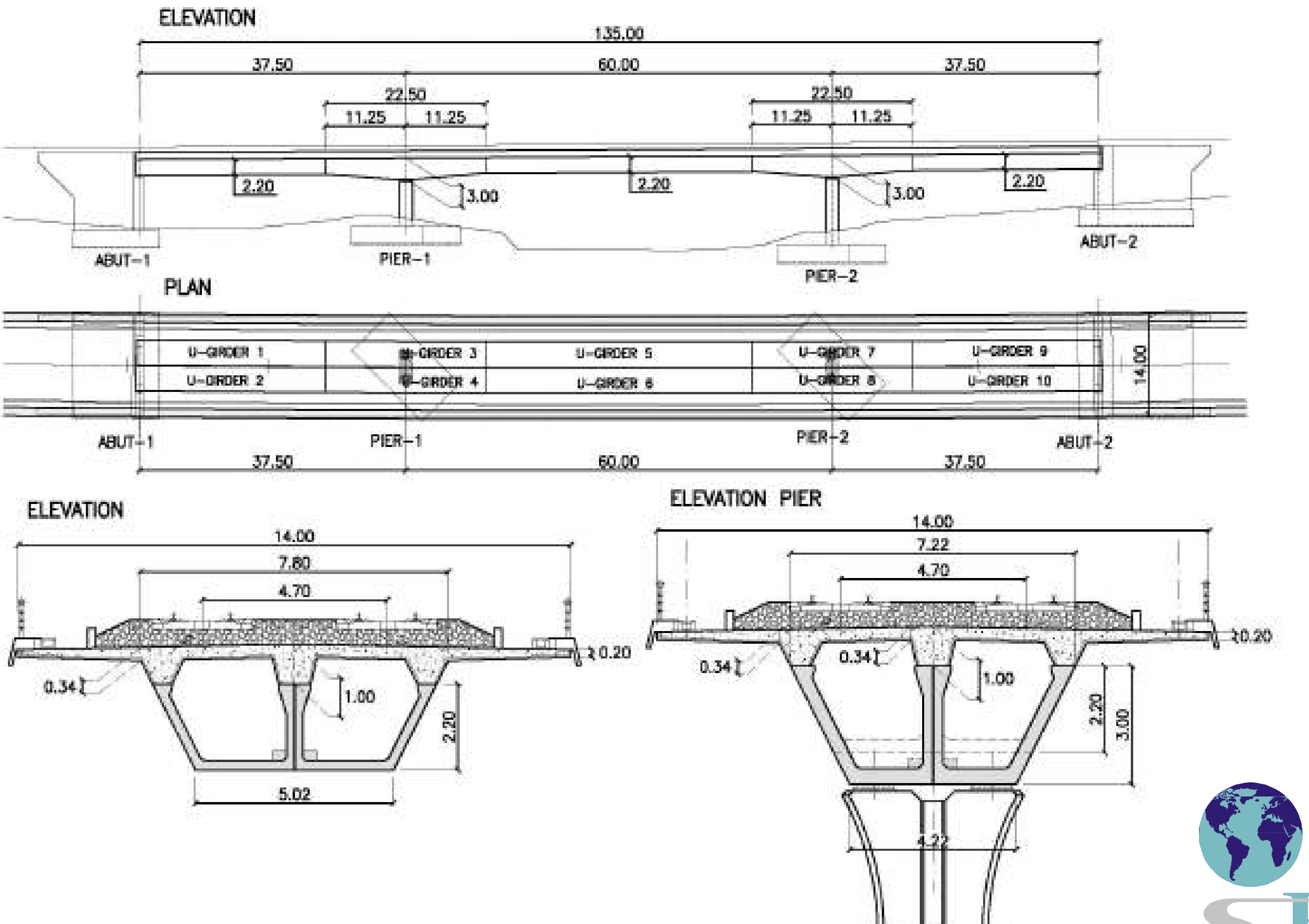
✓ VIADUCT OVER FRANCOLI RIVER IN TARRAGONA (MADRID – BARCELONA)



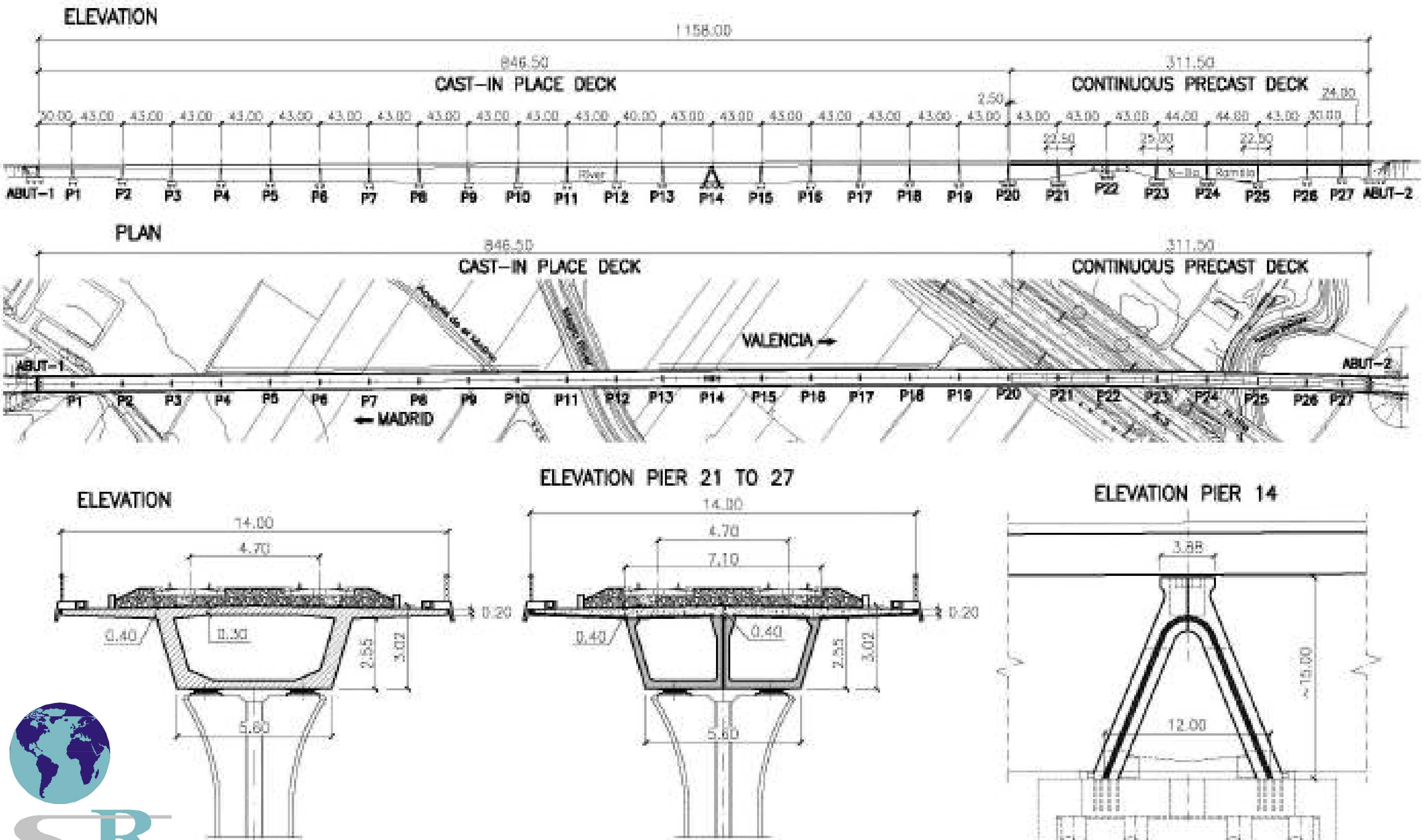
✓ VIADUCT OVER N-240 ROAD IN PERAFORT (MADRID – BARCELONA)

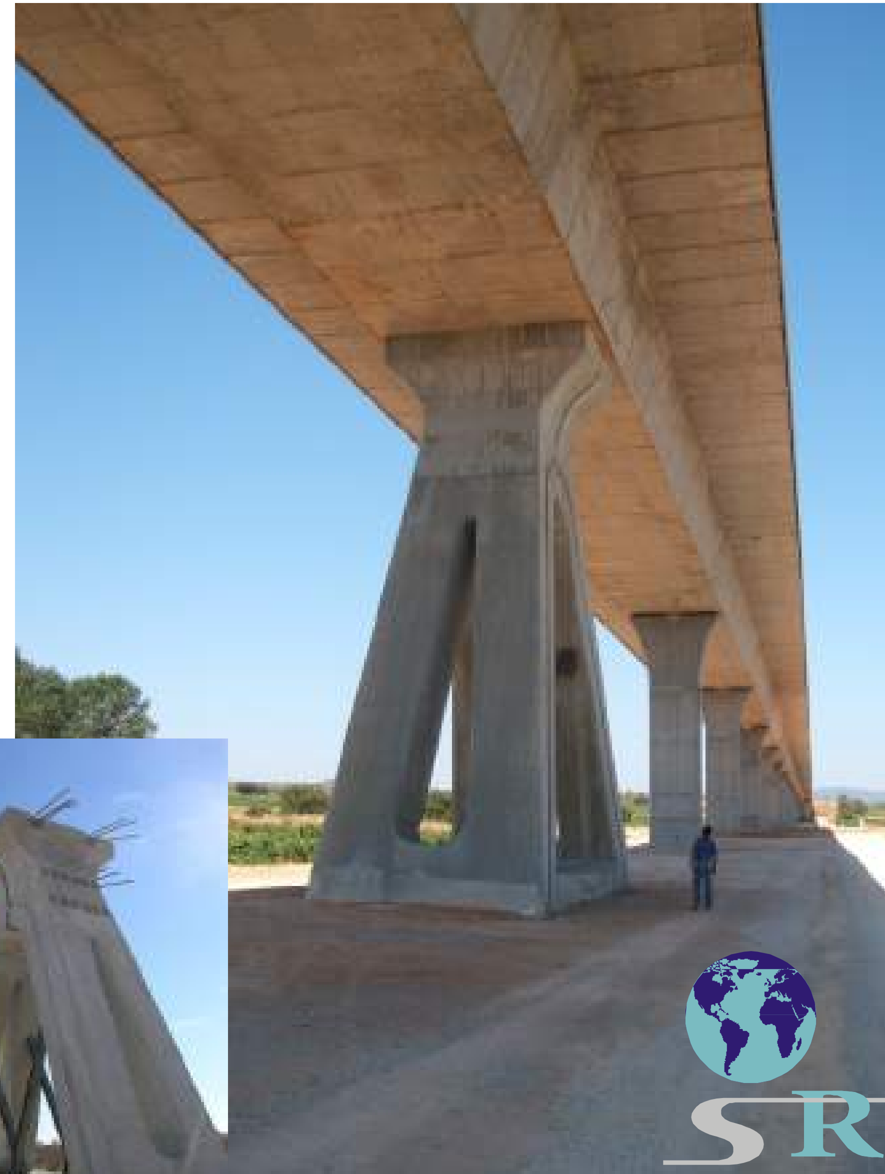


✓ BRIDGE OVER VALDEMEMBRA RIVER IN CUENCA - LEVANTE HS RAILWAY



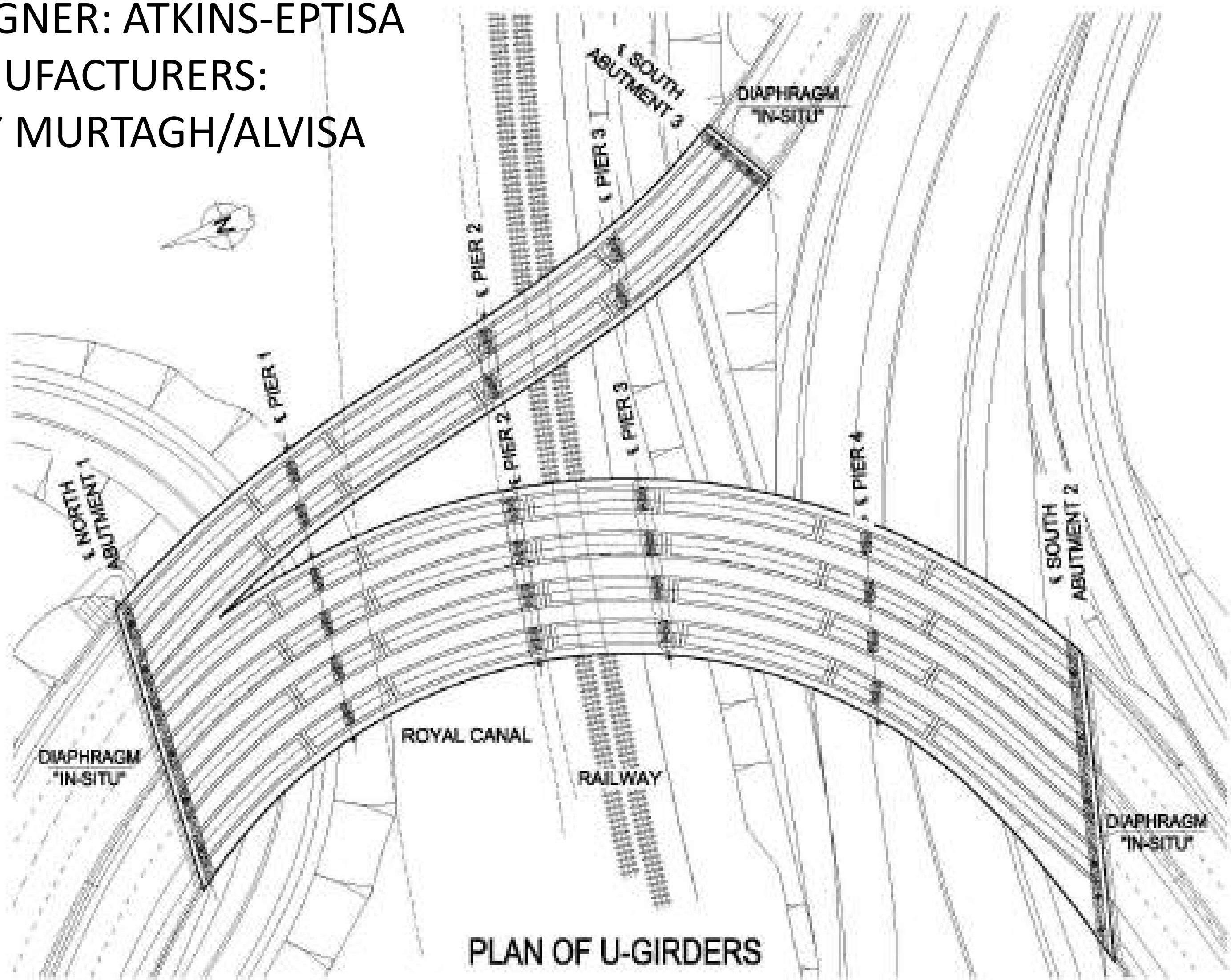
✓ VIADUCT OVER MAGRO RIVER & A-3 FREEWAY – LEVANTE HS RAILWAY





M50 motorway around Dublin (Ireland) -2010
Structure S17-N3 at junction 6 (Blanchardstown)

DESIGNER: ATKINS-EPTISA
MANUFACTURERS:
SHAY MURTAGH/ALVISA



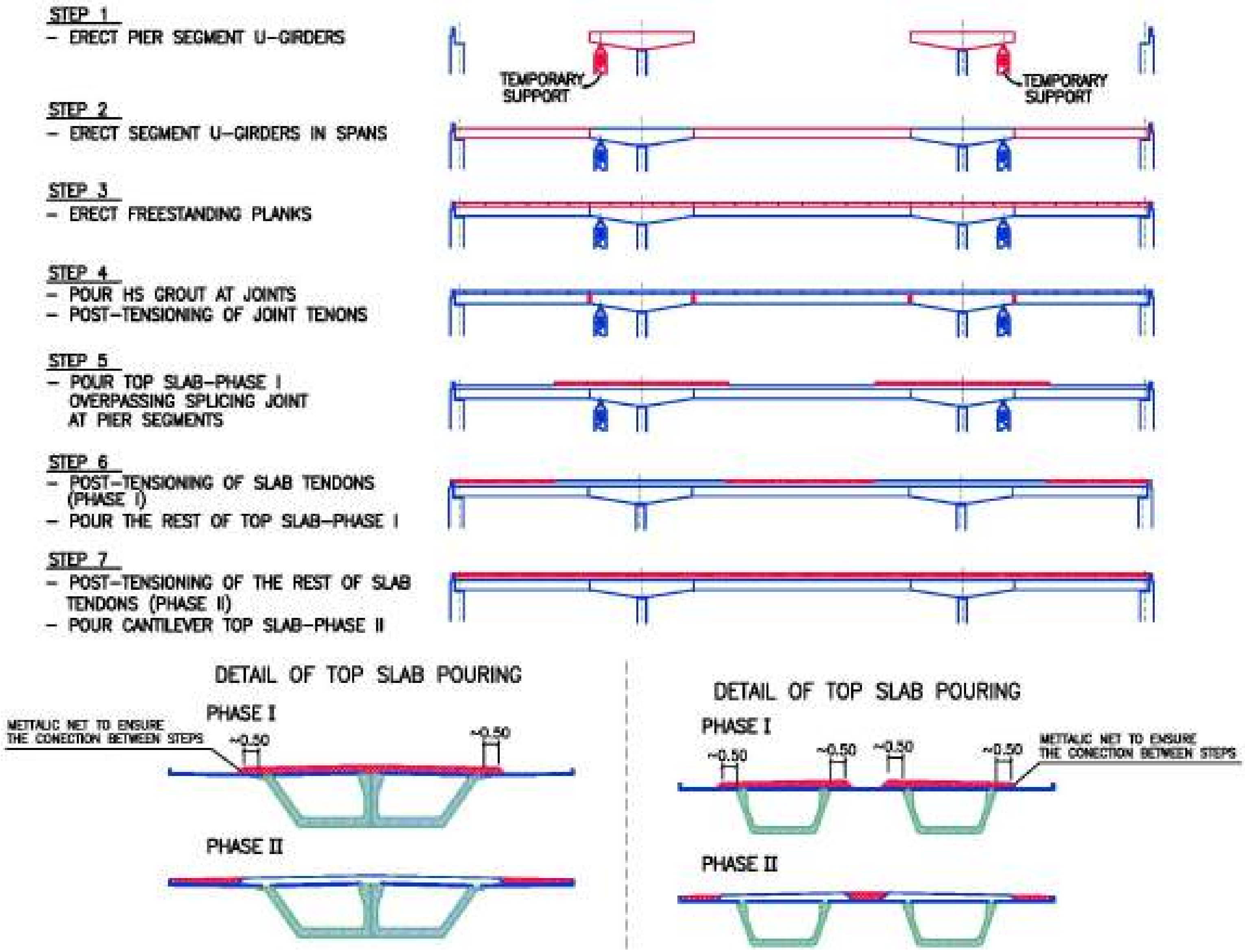
PLAN OF U-GIRDERS


29 4 2010

3. CONSTRUCTION SEQUENCE

Construction sequence of BSST

Standard construction sequence



Construction sequence of BSST

Precast pier

Construction sequence of BSST

Temporary girder support during assembly: pier segments

Temporary props

Temporary continuity pier segment - pier

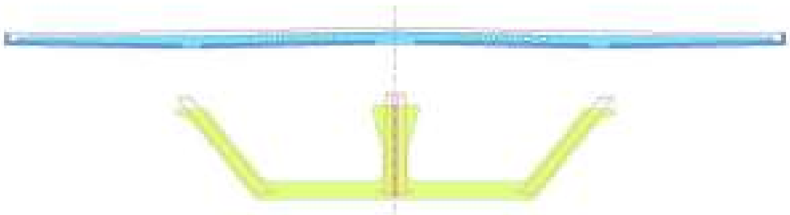
Construction sequence of BSST

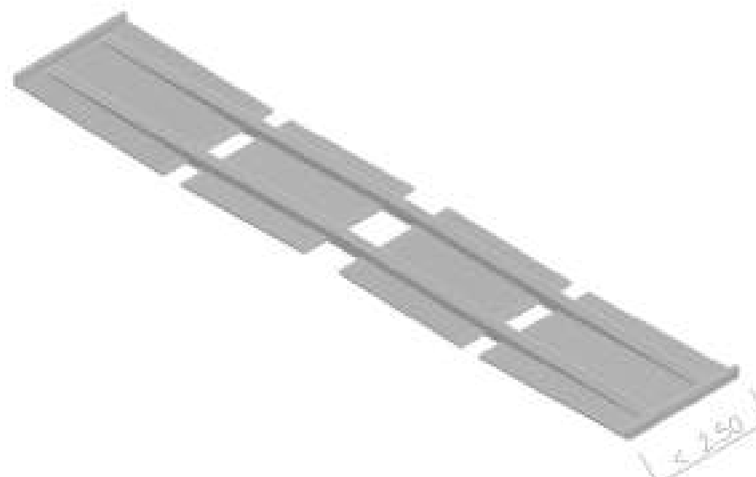
Temporary girder support during assembly:
“drop-in” segments with concrete corbels

Construction sequence of BSST

UPPER SLAB by FREE-STANDING PLANKS and pouring fresh concrete on site. ⇒

- get a fast surface to work on it
- increase of safety on top slab tasks





Construction sequence of BSST

LIFTING UP WITH CRANES

All-terrain mobile crane

LTM 1400-7.1

The seven-axle mobile crane LTM 1400-7.1 is the most compact representative of its class, and extraordinarily manoeuvrable due to the new active rear axle steering. Comprehensive electronics in the travel drive and in the crane control ensures increased safety, easy-to-use operation and a high availability of the 400 tonner. Hoisting heights of up to 122 m and a reach of up to 92 m characterise the range of applications.

▸ Technical data	Images	Downloads
max. lifting capacity		400 t at 3 m radius
Telescopic boom		15.4 m - 60 m
Lattice jib		7 m - 84 m
Carrier engine/output		Liebherr, 8-cylinder, turbo-Diesel, 490 kW
Crane engine/output		Liebherr, 6-cylinder, turbo-Diesel, 240 kW
Drive/steering		14 x 8 x 14
Travel speed		80 km/h
Operational weight		84 t
Total counterweight		140 t

Crawler crane

LR 1600/2

The crawler crane LR 1600/2 is convincing by its outstanding capacities, variable boom and derrick systems as well as by its optimized component dimensions for economical transportation. With the custom-made boom system the LR 1600/2 is ideal for the erection of wind power installations.

▸ Technical data	Images	Downloads
max. lifting capacity		600 t at 10 m
max. load moment		8,228 tm
Main boom, light/heavy		24 m - 144 m
Lattice jib		12 m - 99 m
Derrick mast		30 m - 36 m
Superstructure-/central ballast		190 t/65 t
Derrick ballast		350 t
Engine output		370 kW
Travel speed		0 - 1.35 km/h
Total counterweight		565 t

Liebherr mobile crane LTM 1400-7.1

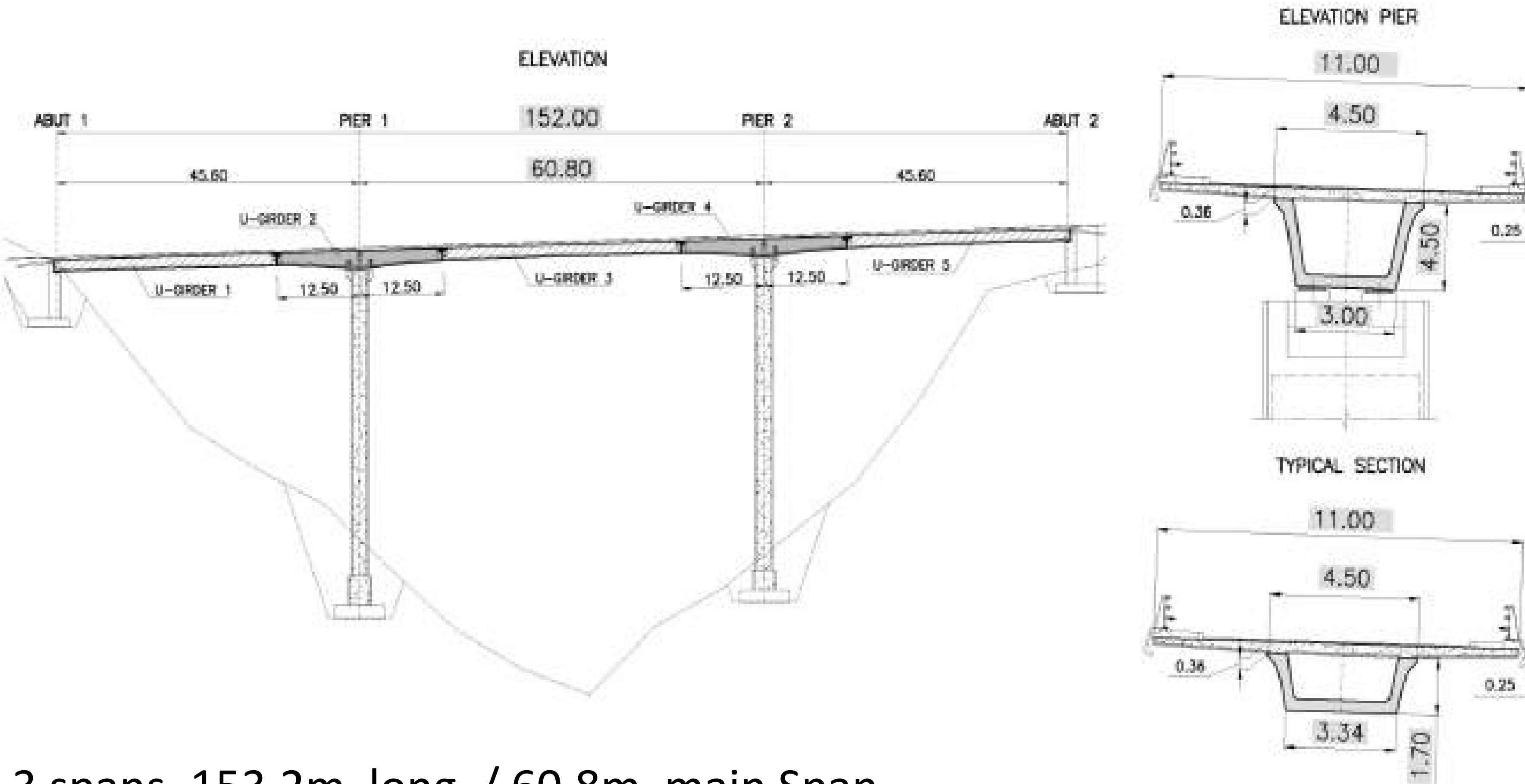
Liebherr crawler crane LR 1600/2

Construction sequence of BSST

Steel truss for beam launching

Capping beam launched

Construction sequence of BSST: “La Espluga” Bridge (2011)



3 spans, 153.2m long / 60.8m main Span

Pier 50m high / 60 m max. height from valley base

Deck was divided into 5 segments

Construction sequence of BSST: “La Espluga” Bridge (2011)

➔ 2m12s VIDEO

4. OTHER EXAMPLES

Alternative arrangements

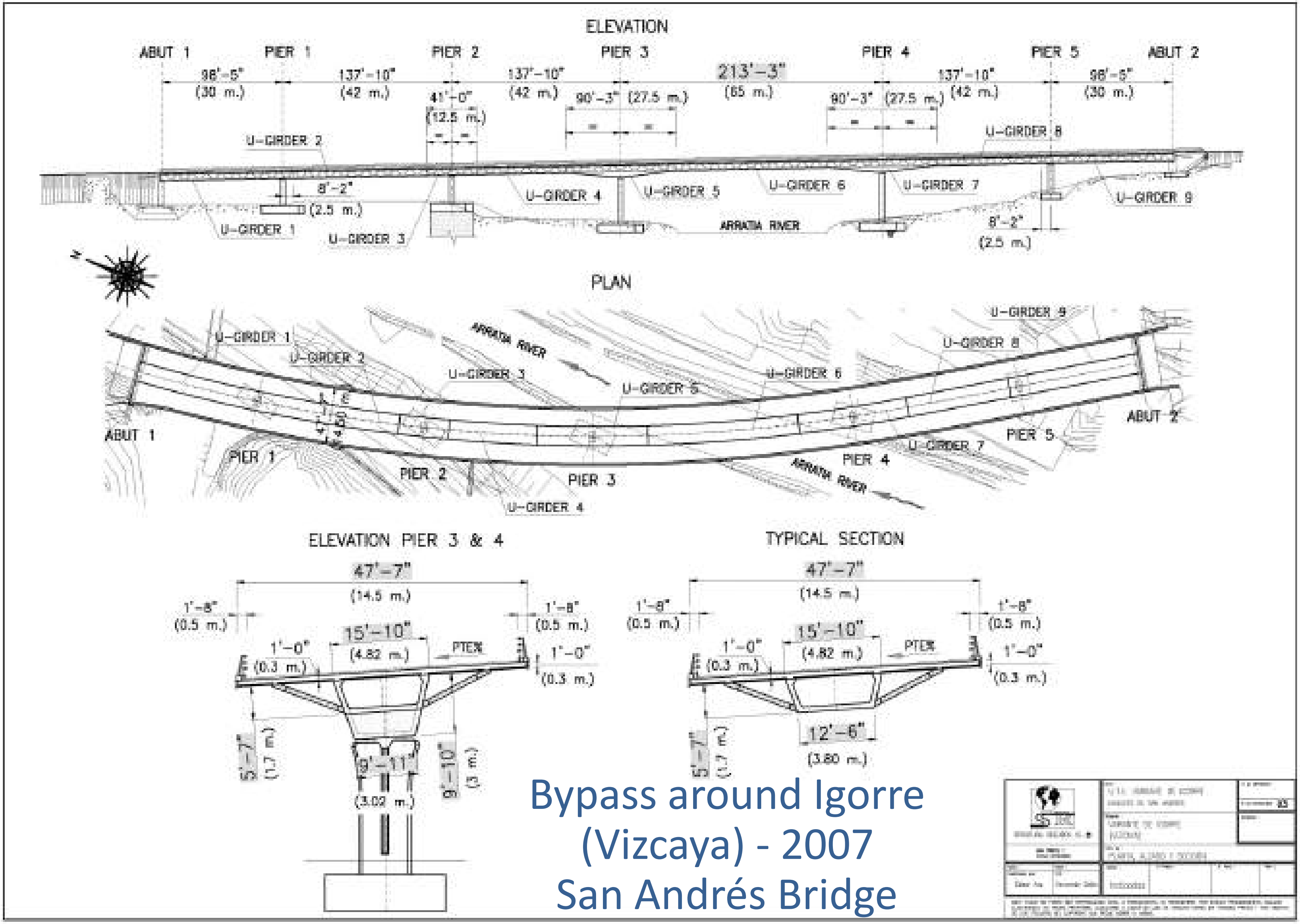
If required, monolithic connection to piers.

Alternative arrangements

- Monolithic capping beam, in extreme skewed crossings.

- Constant/variable depth or width (straight or curved haunches)
- Straight or curved beams

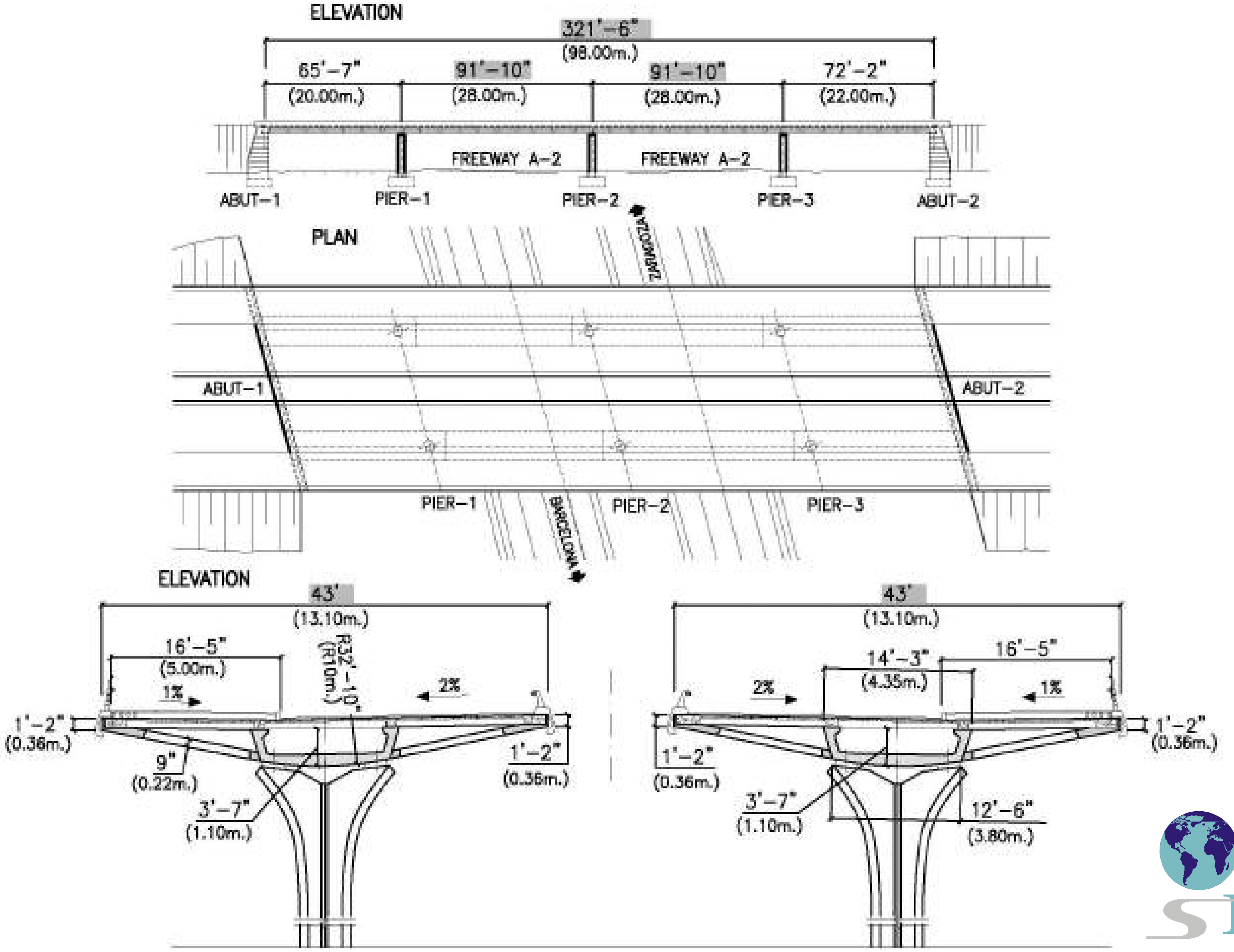
Transverse struts for wide bridges
(Width: up to 18 m
with only one beam)



Bypass around Igorre (Vizcaya) - 2007
San Andrés Bridge

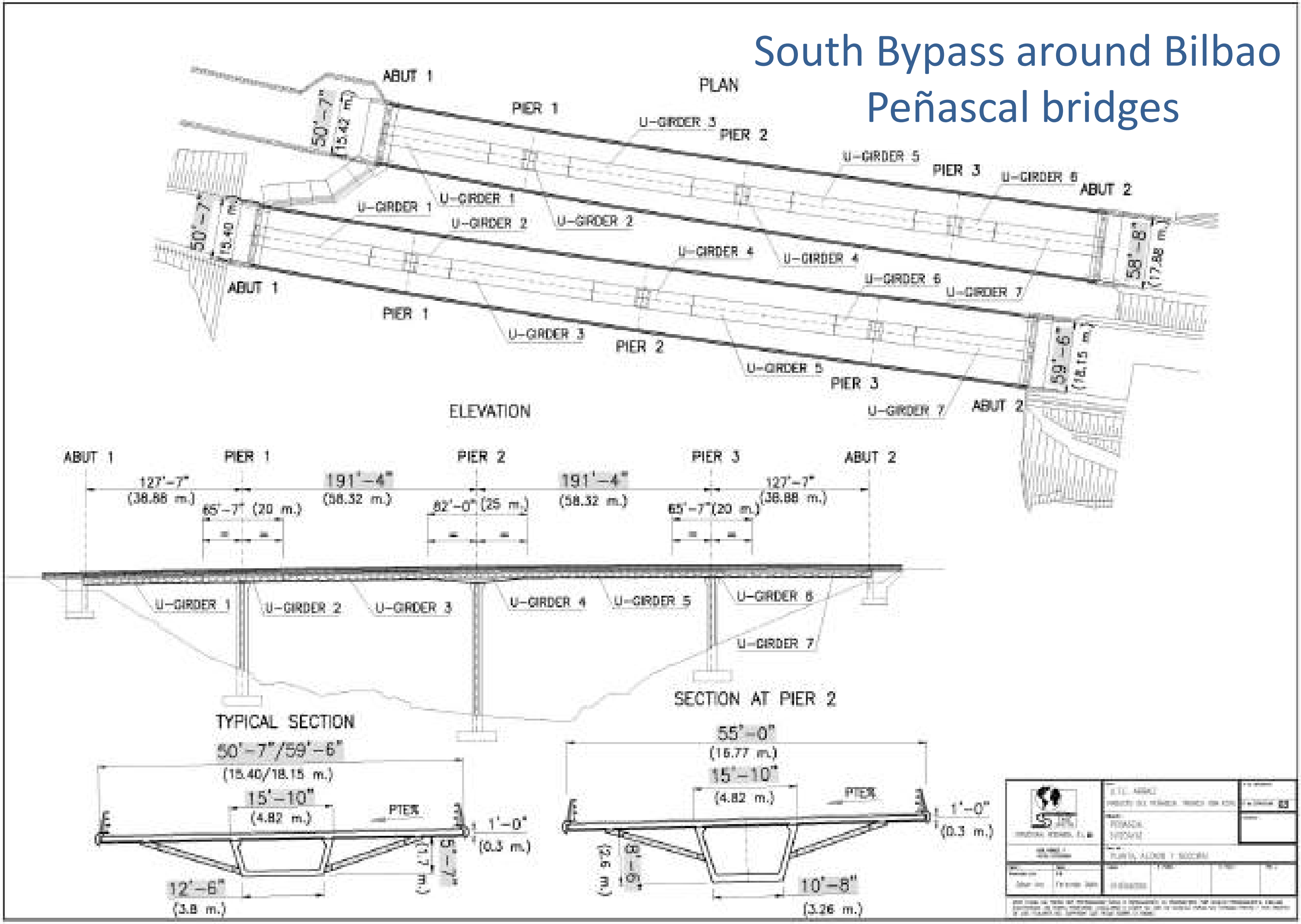

ARANZA

Bridge over Freeway A-2 Zaragoza



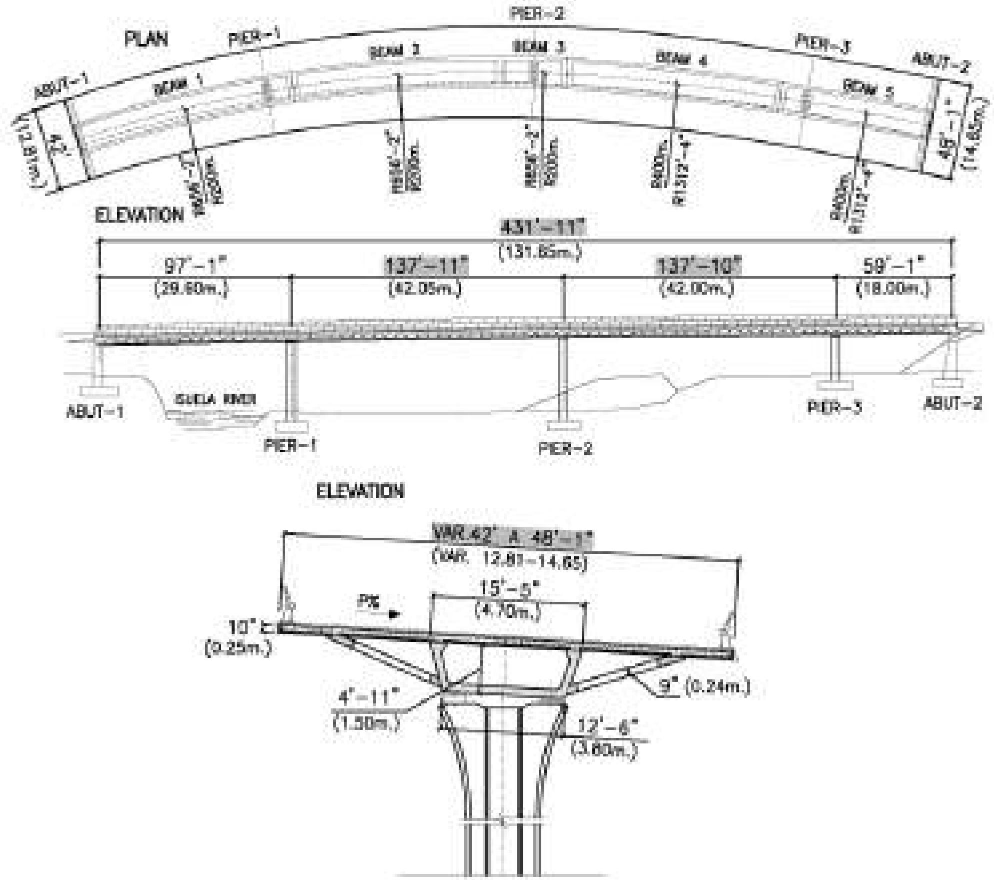

FINSA
SR

South Bypass around Bilbao
Peñascal bridges

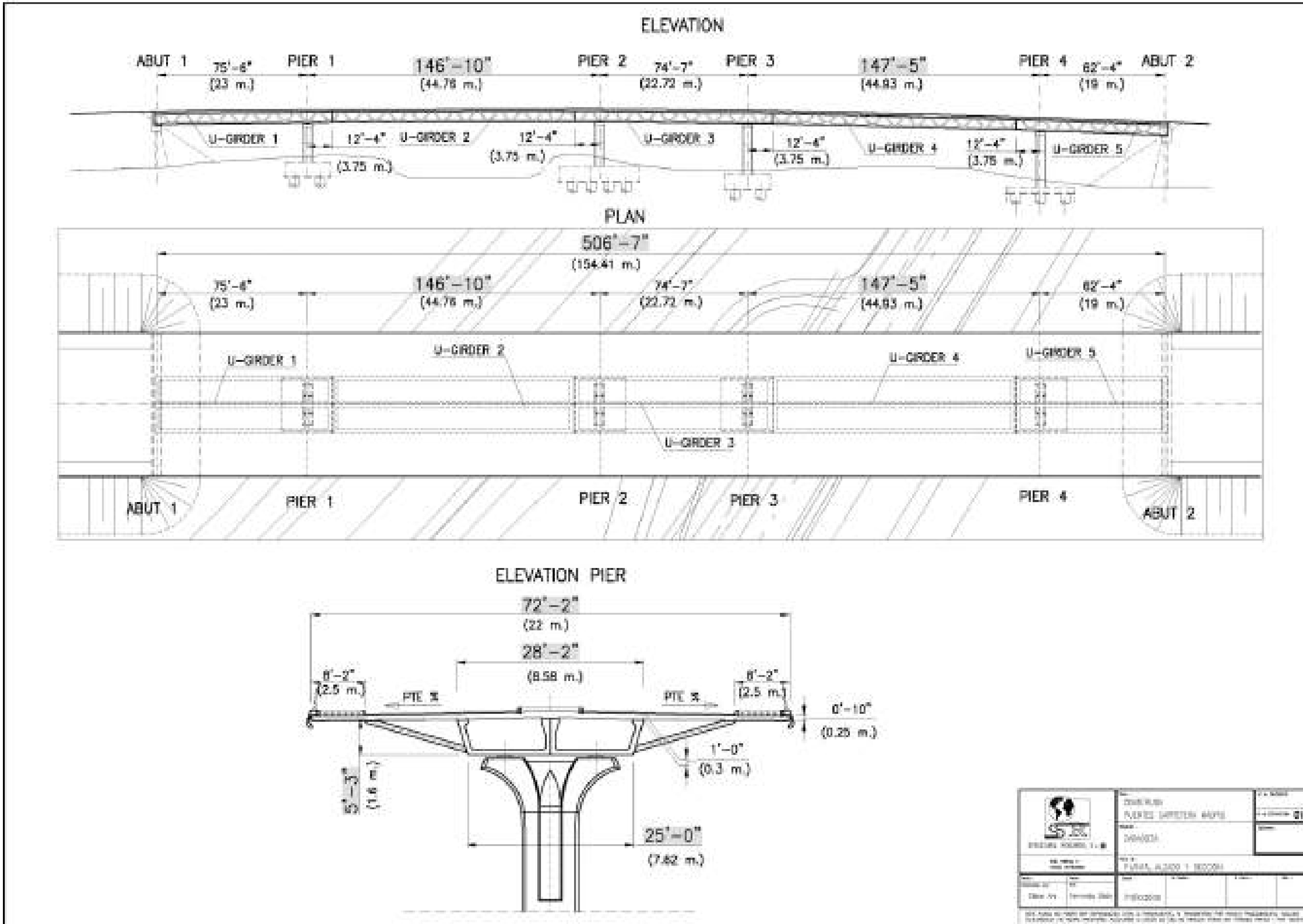





Brigde E-1 (2000)
North Bypass Huesca



Bridge over Madrid road (Zaragoza)

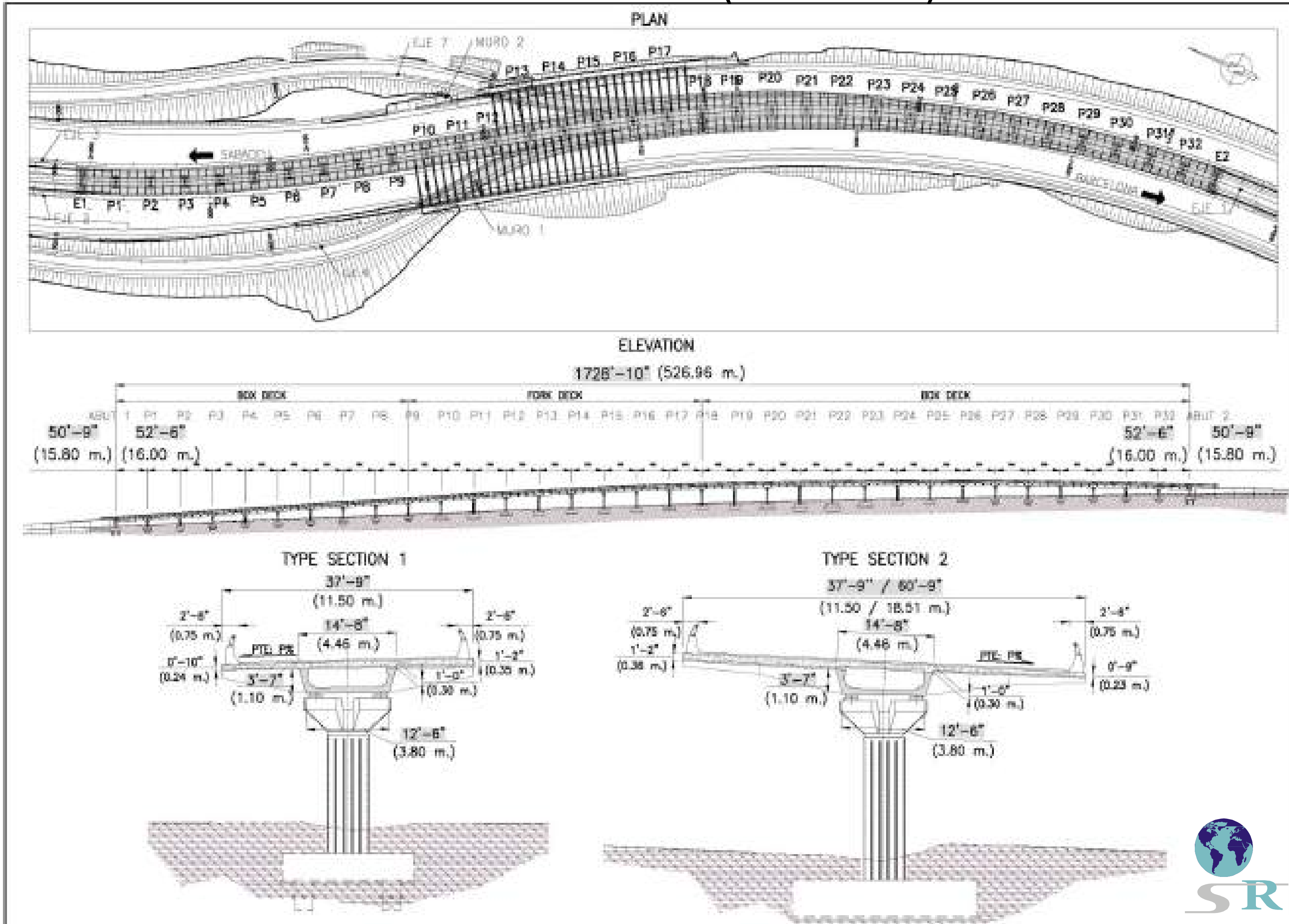


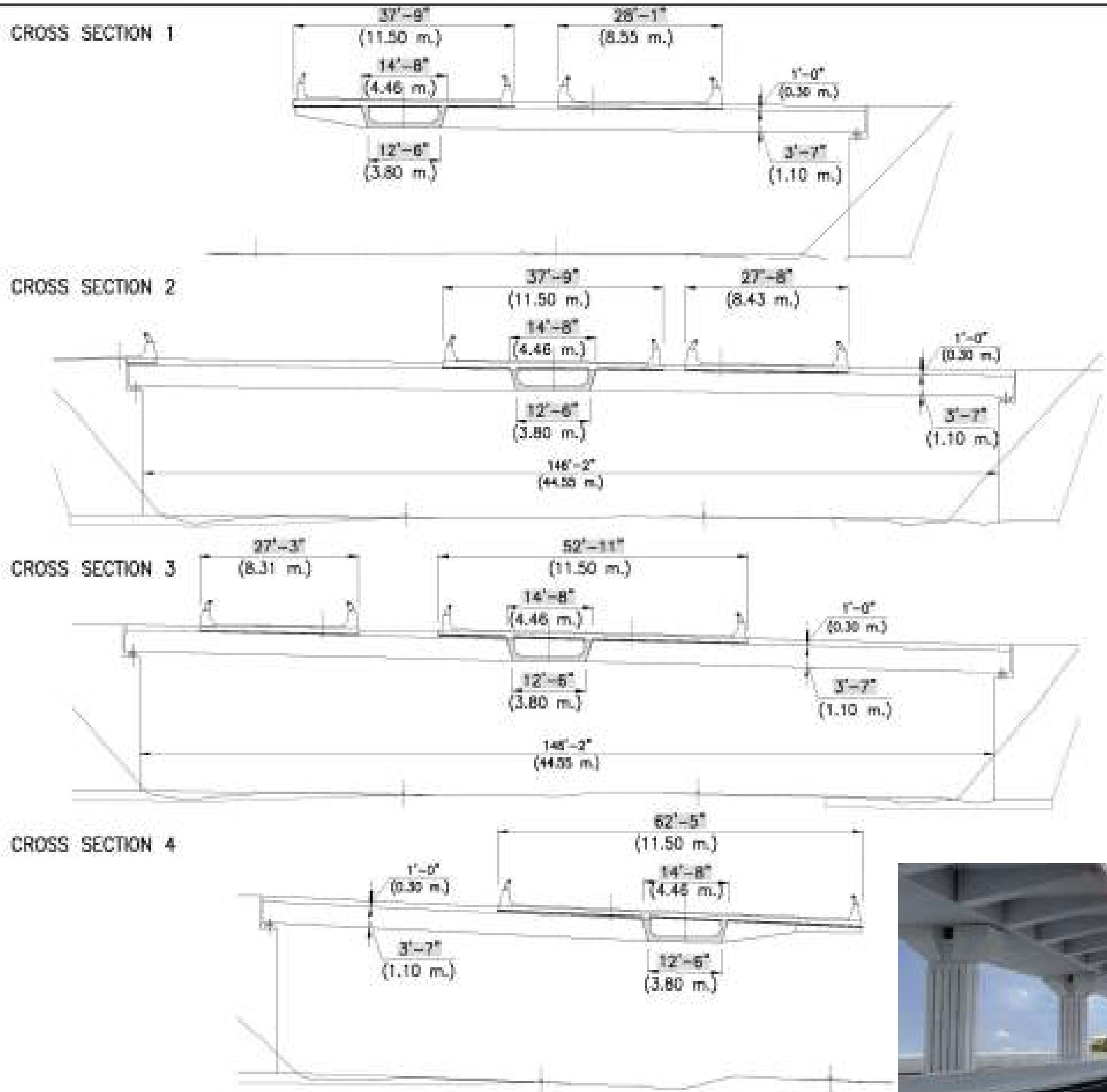
Design and construction solutions for complex geometries:

-“Fork” type decks

- Decks with a great variable width

New traffic lane BUS - VAO
Structure over C-58 (Barcelona)




CROSS SECTION 1
37'-9"
(11.50 m.)
28'-1"
(8.55 m.)
14'-8"
(4.46 m.)
1'-0"
(0.30 m.)
12'-6"
(3.80 m.)
3'-7"
(1.10 m.)
CROSS SECTION 2
37'-9"
(11.50 m.)
27'-8"
(8.43 m.)
14'-8"
(4.46 m.)
1'-0"
(0.30 m.)
12'-6"
(3.80 m.)
3'-7"
(1.10 m.)
146'-2"
(44.55 m.)
CROSS SECTION 3
27'-3"
(8.31 m.)
52'-11"
(11.50 m.)
14'-8"
(4.46 m.)
1'-0"
(0.30 m.)
12'-6"
(3.80 m.)
3'-7"
(1.10 m.)
146'-2"
(44.55 m.)
CROSS SECTION 4
62'-5"
(11.50 m.)
1'-0"
(0.30 m.)
14'-8"
(4.46 m.)
3'-7"
(1.10 m.)
12'-6"
(3.80 m.)


Adaptable to different structural systems:

- Arches:

  Foot bridge 67m span.
  Road bridge 47m span

- Portical frames

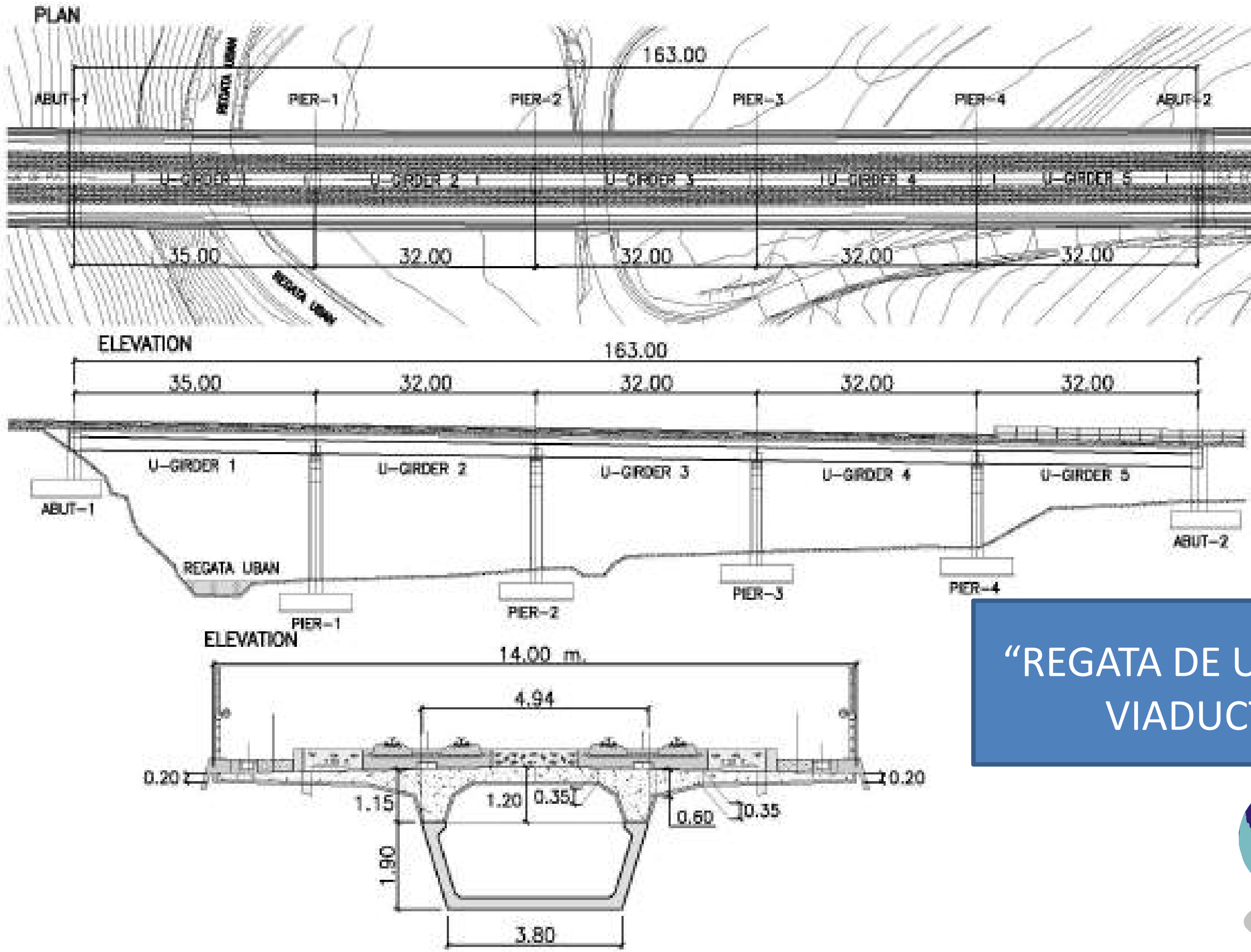
5. FUTURE DESIGNS

Future designs

- Only one U-girder for double track railway (under construction now)
- Large spans: railway bridges up to 80 m (designed)
- Large spans: road bridges up to 120 m (designed)

Future designs

- Only one U-girder for double track railway (under construction now)

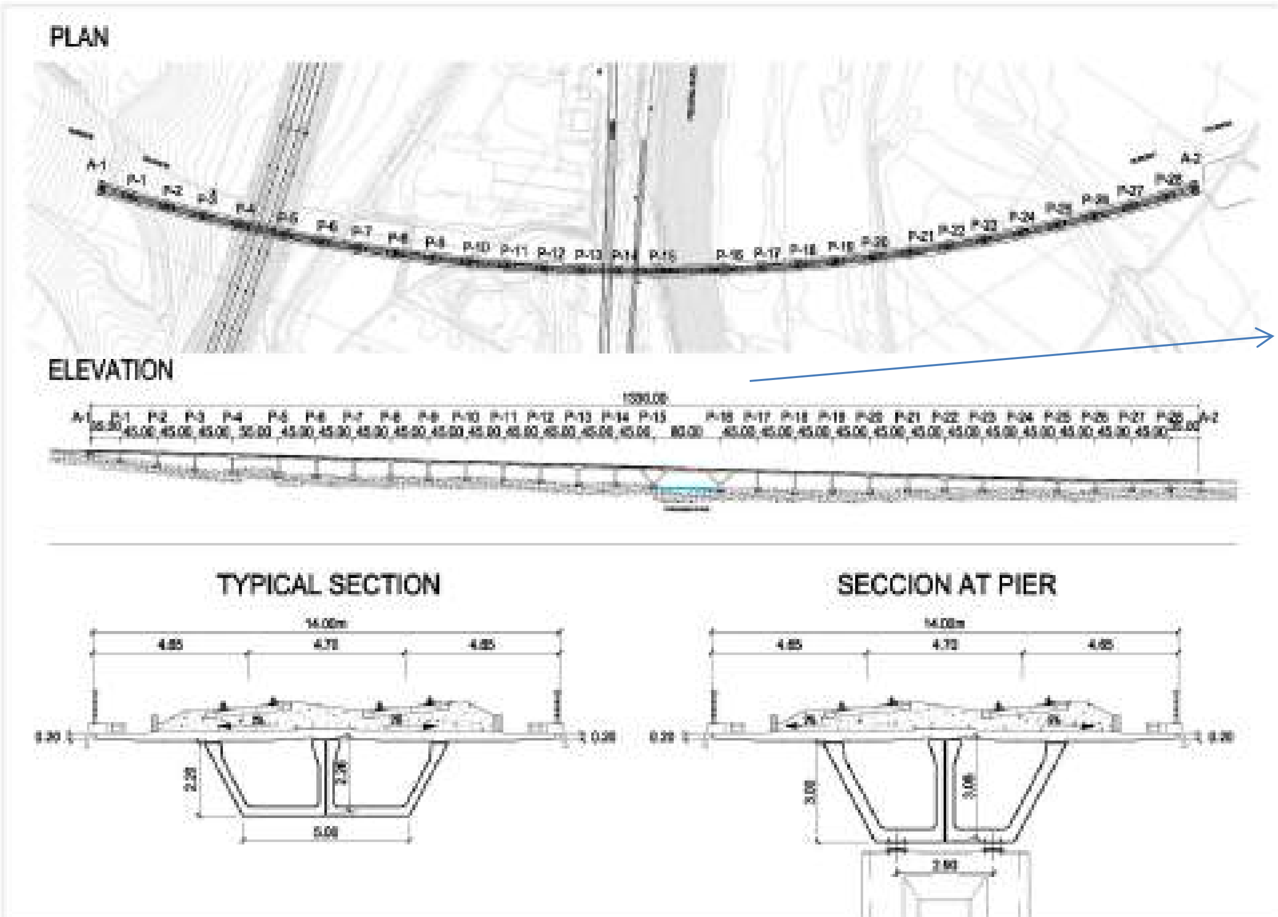


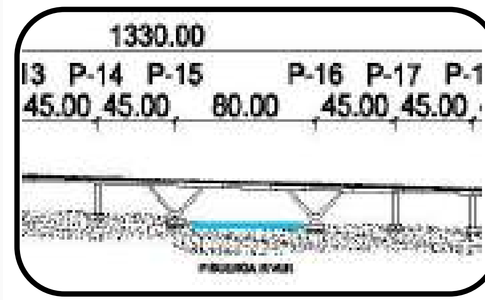
"REGATA DE UBAN"
VIADUCT

Future designs

- Large spans: railway bridges up to 80 m (designed)

VIADUCT OVER PISUERGA RIVER AND A-62 MOTORWAY

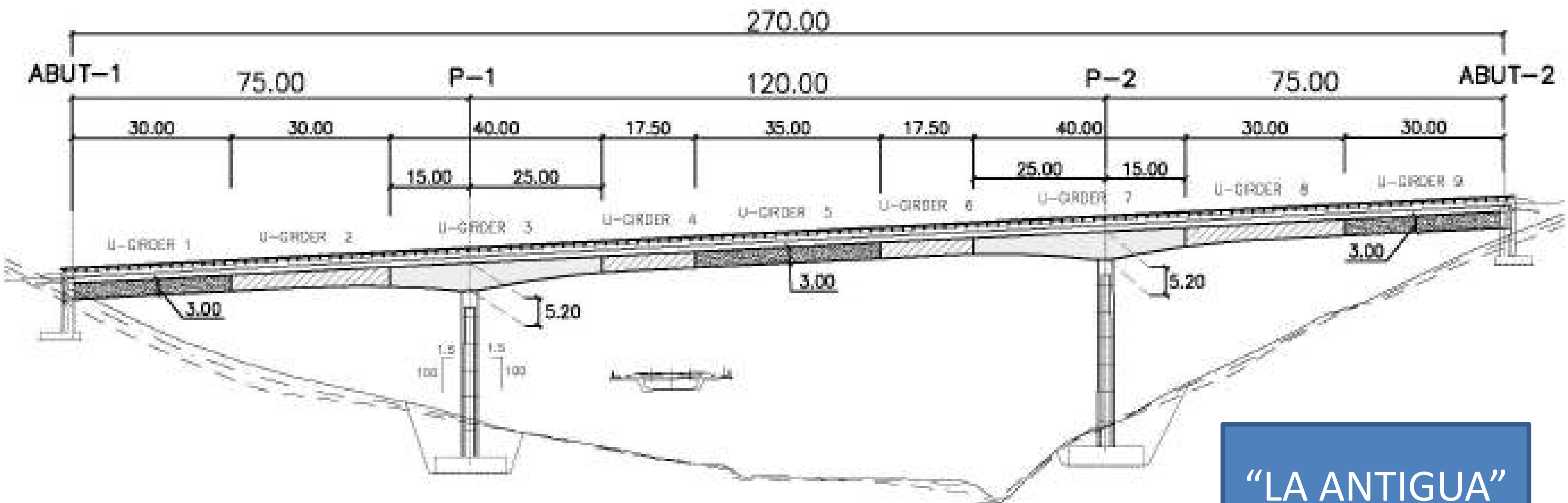




Main span detail

Future designs

- ➢ Large spans: road bridges up to 120 m (designed)



"LA ANTIGUA" VIADUCT

<u>**Deck is divided into 9 segments:**</u>

- **All 4.5m width.**
- **Constant depth 3.0m or haunched to 5.2m,**
- **…plus "Enhanced Plank", medium depth 1.18m:**

  Enlarged girder depth using a "double T" top slab.
- **U-girder maximum length: 40 m.**