Railway Road Bridge across the Danube in Novi Sad

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Azvi // TADDEI S.p.A. HORTA COSLADA Construcciones Metálicas

DEL ING

Railway Road Bridge across the Danube in Novi Sad

Content

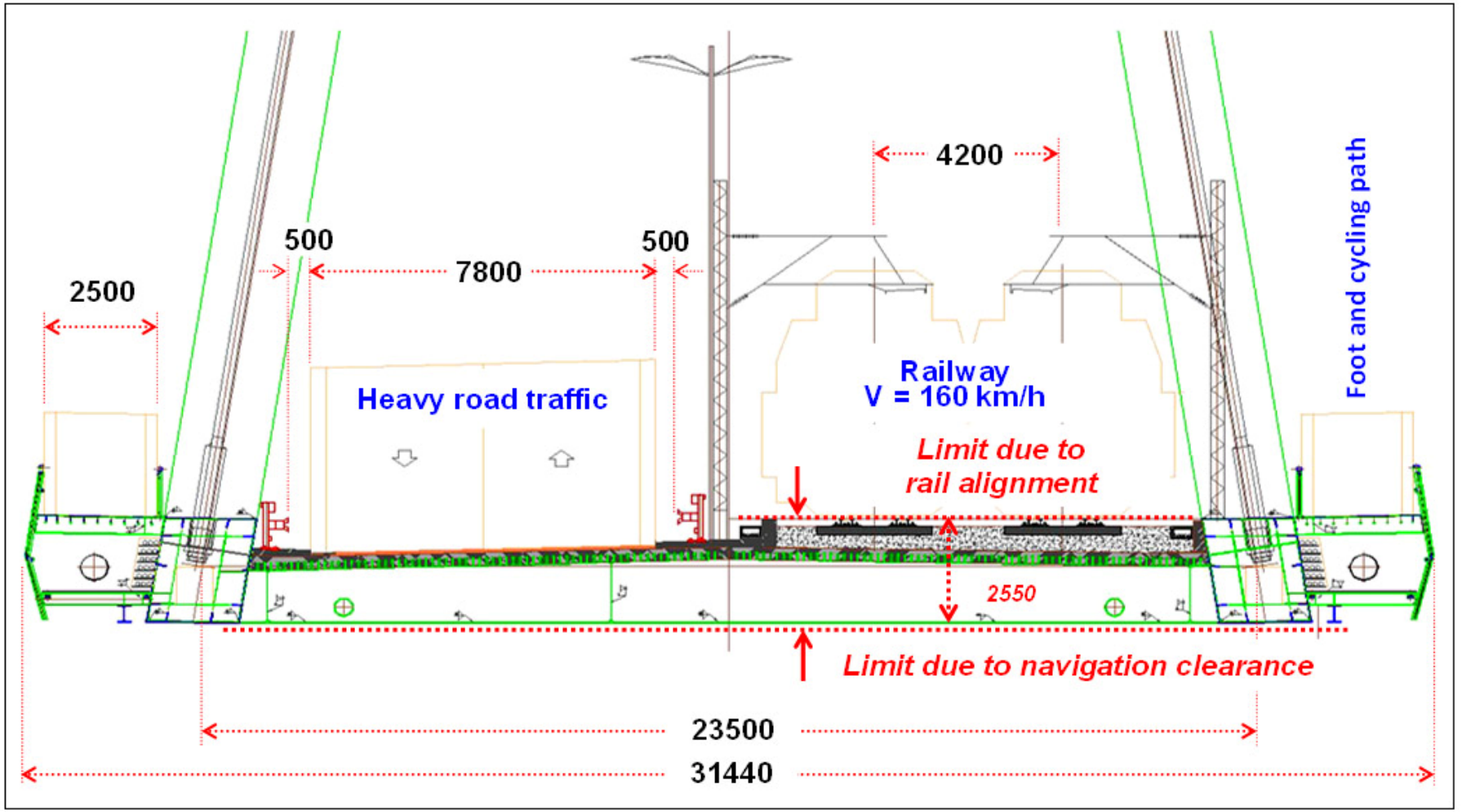
- Terms of Reference and basic technical requirements
- Bridge structure
- Structural analysis – loads, models, results
- Workshop and erection
- Bridge appearance – 3D-pictures
- Comparison to similar bridges in the world
- Participants

Terms of Reference and basic technical requirements

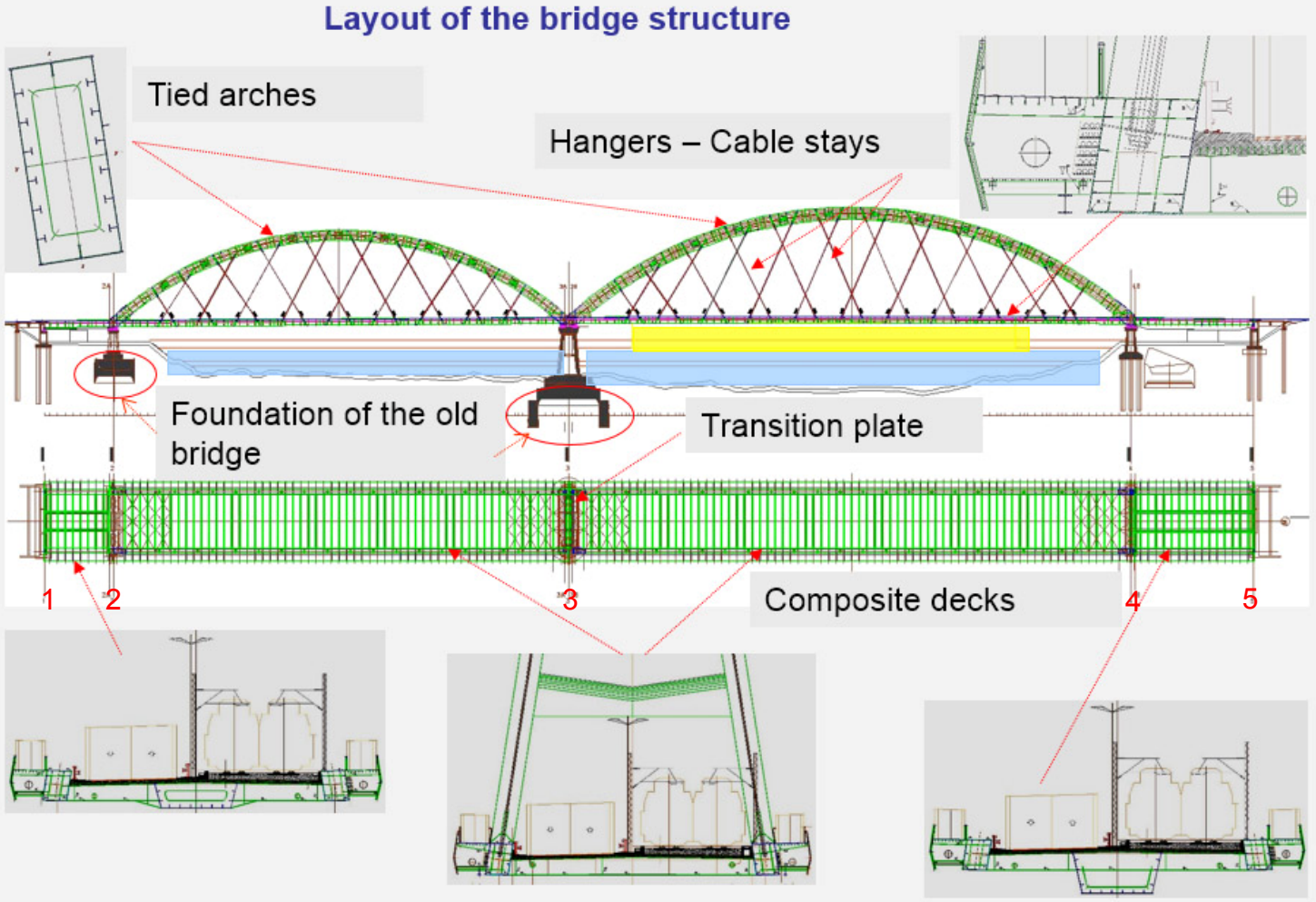
Rail alignment accommodated:
- to actual navigation clearance about 1,5 m higher than previous;
- to approach existent track.
(*Done in Preliminary Design*)

Location	**Location of the old bridge**, (finished 1961, destroyed 1999).
Traffic on bridge	**2 tracks** (e = 4,20m) + **2 road lanes** (2 x(3,50+0,35)m) + **2 foot- and bicycle lanes** (2 x 2,50m).
Train velocities	**Max line speeds 160 i 120 km/h** (passenger and freight trains)
Vertical acceleration	**max 1,3 m/s^2**
Trains for dynamic analysis	**Type 2 and Type 5**. (DIN-Fb 101:2009, EN 1991-2:2005)
Foundation	Use existing foundation structures from the previous bridge, as much as possible.
Accessories and equipment on bridge	According to beneficiaries requirements: railway equipment, water pipes, electrical accessories, inspection platforms, illumination.
Norms for designing	**German Guideline for railway bridges Ril 804:2003 + + norms DIN-Fb 101to104 and EN 1991to1994, 1998**.

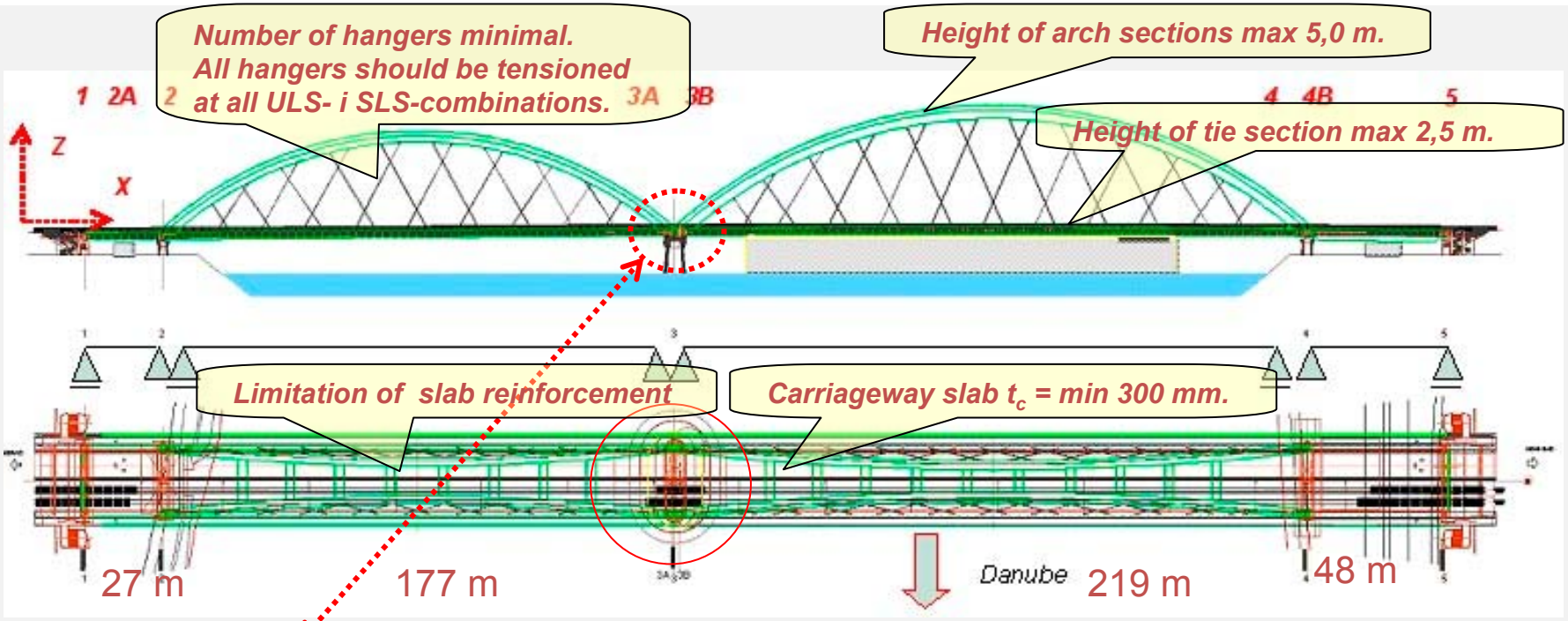
Typical cross-section of the bridge

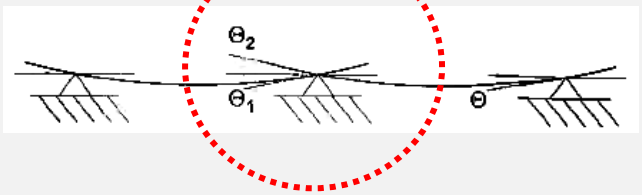


Bridge structure generally



Most important limitations at designing





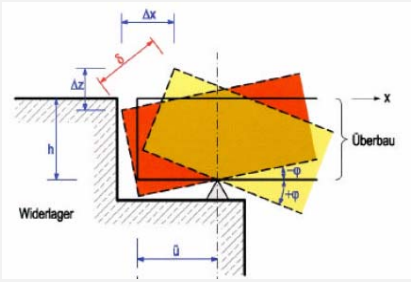
Most critical condition:

$\theta_1 + \theta_2$ (LM71/1 track+ΔT_M) ≤ 5 mrad

also

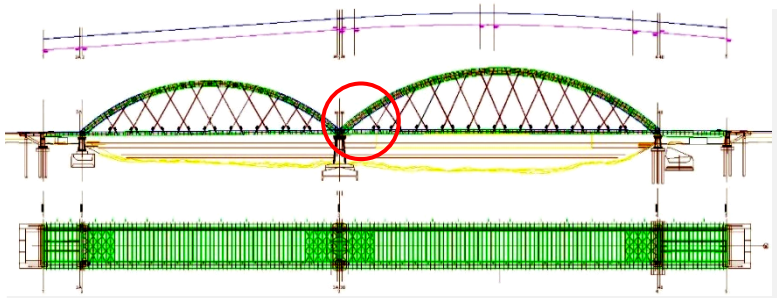
$\delta \leq 9$ mm (sum of rotations at axis 3)

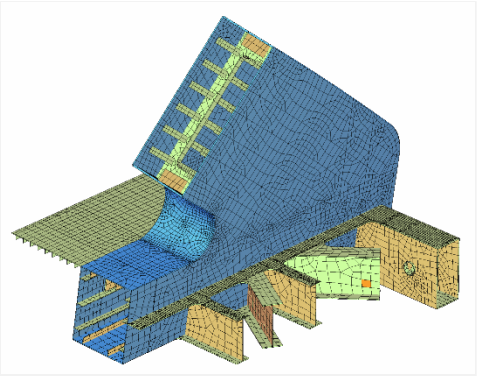
(DIN-Fb 101:2009 request)

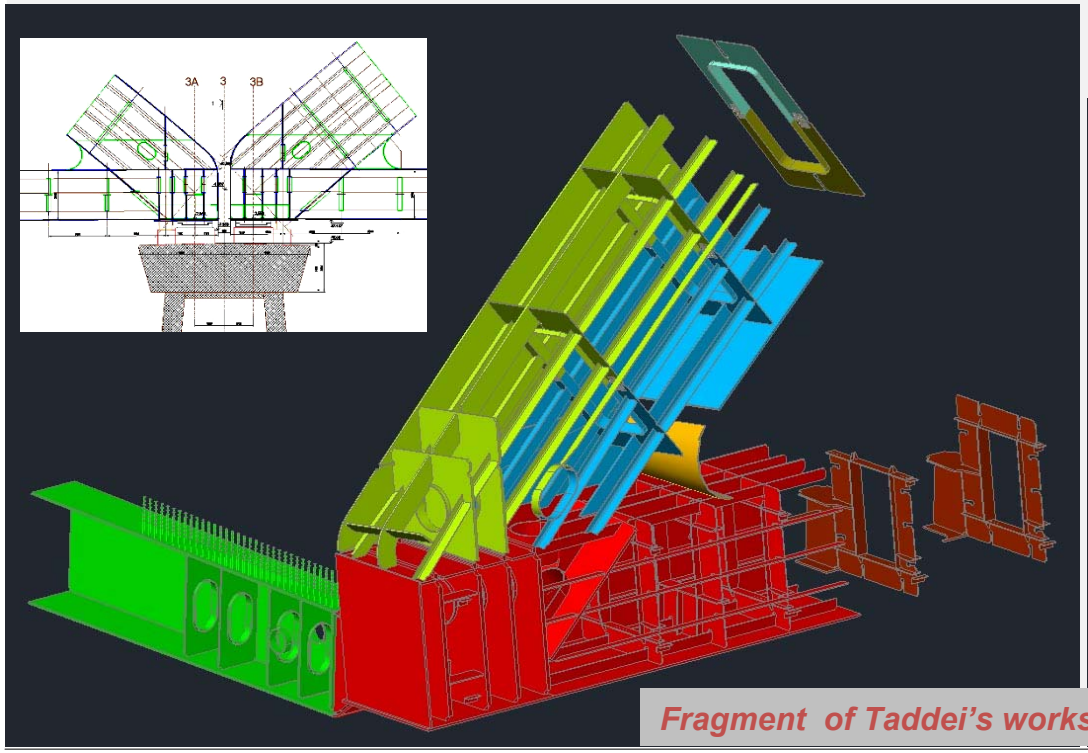


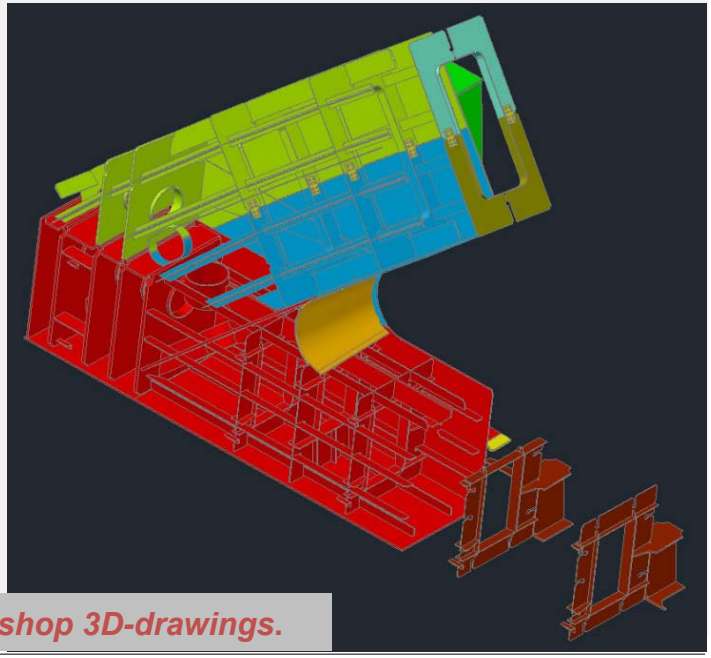
Steel structure details

Node arch / tie / end cross beam





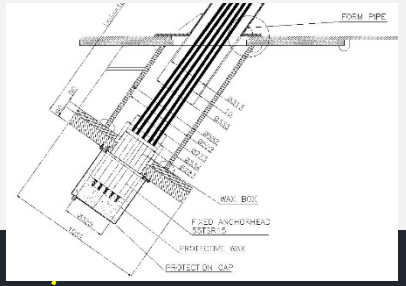


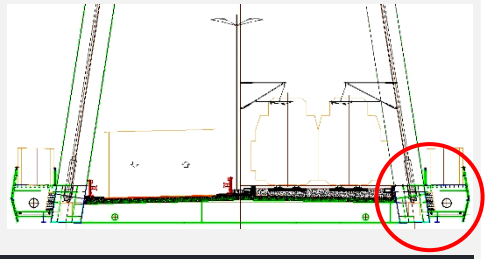


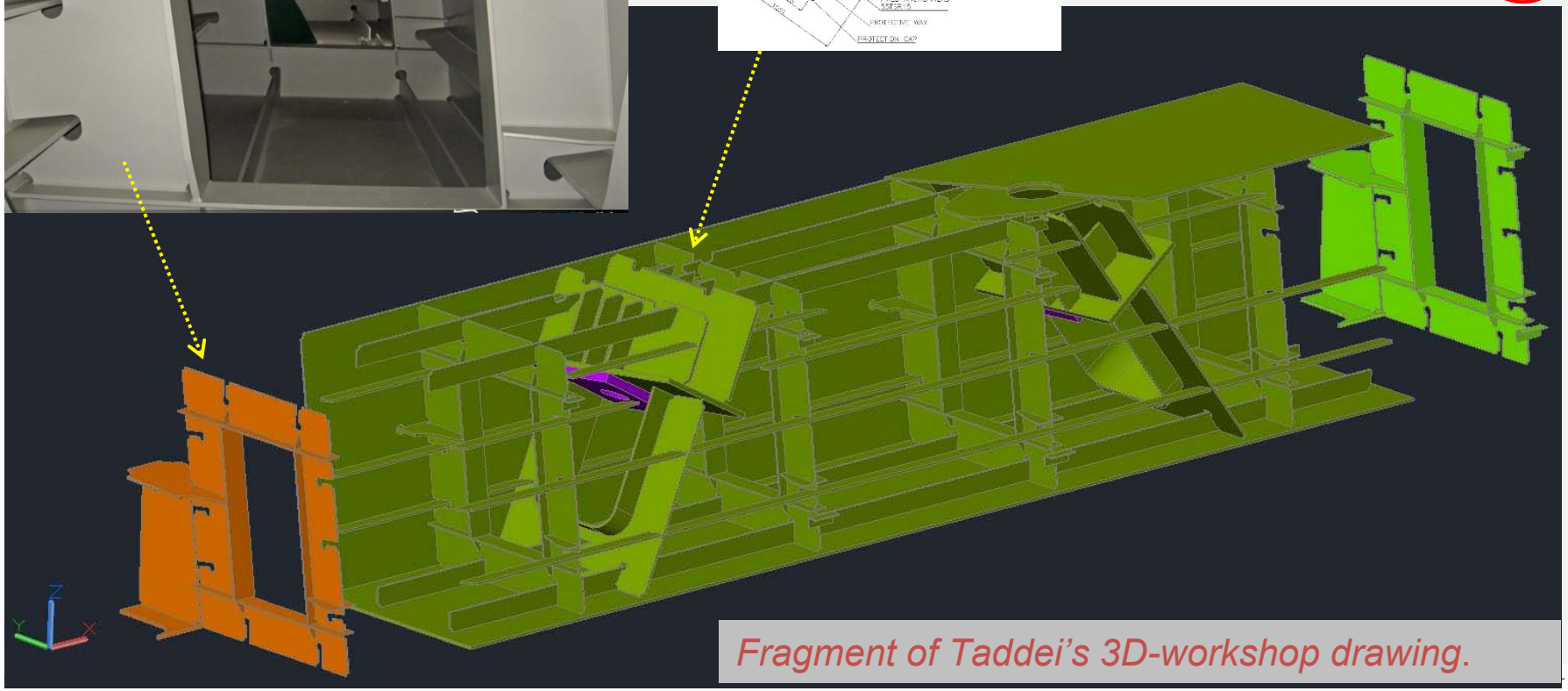
Fragment of Taddei's workshop 3D-drawings.

Steel structure details

Tie with hangers anchorages



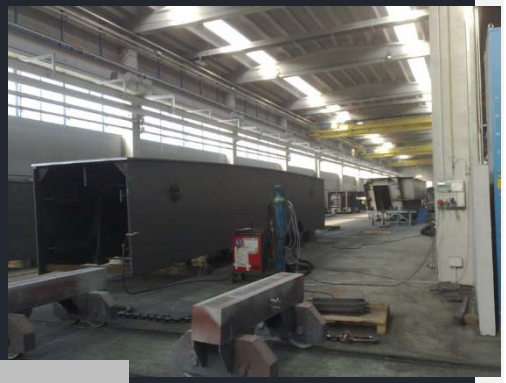




Fragment of Taddei's 3D-workshop drawing.

Steel structure details

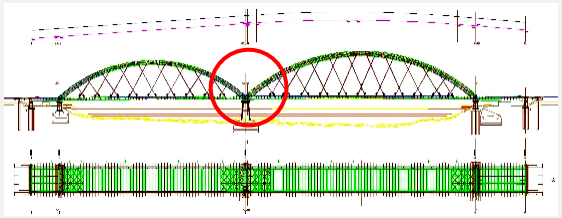
Arch with hangers anchorages

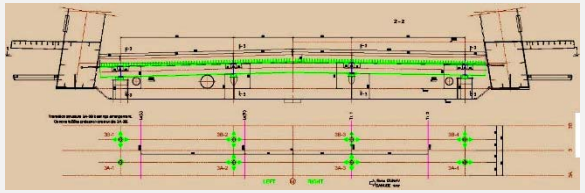


Fragment of Taddei's 3D-workshop drawing.

Steel structure details

Transition structure between arch bridges

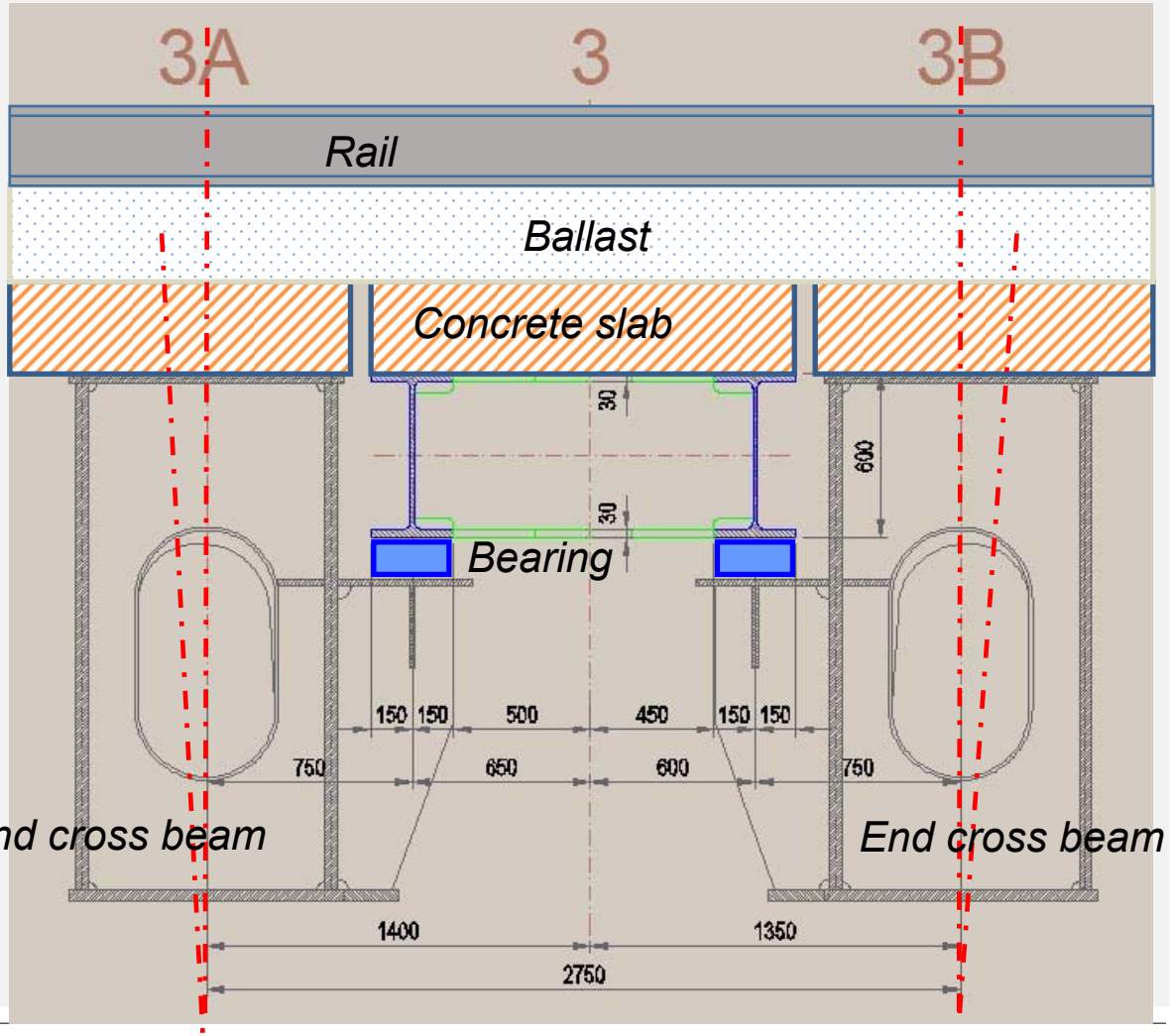




End cross beam

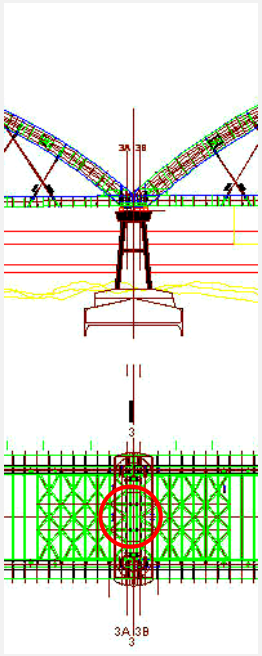
Requirement for the sum of support rotations of the next arch bridges is fulfilled.

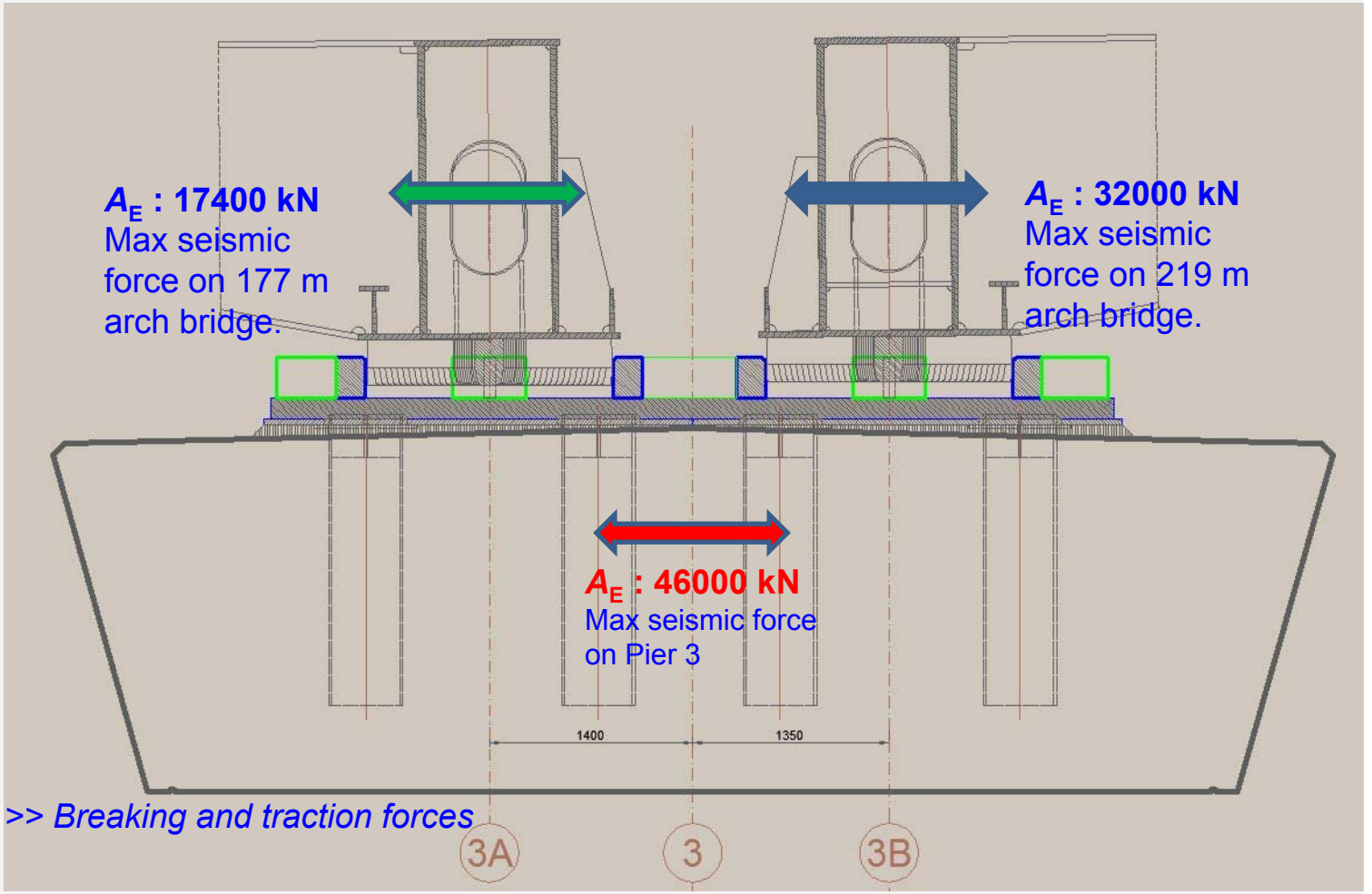
The transition structure improves the state of rails bending.



Steel structure details

Fixed horizontal supports on central pier



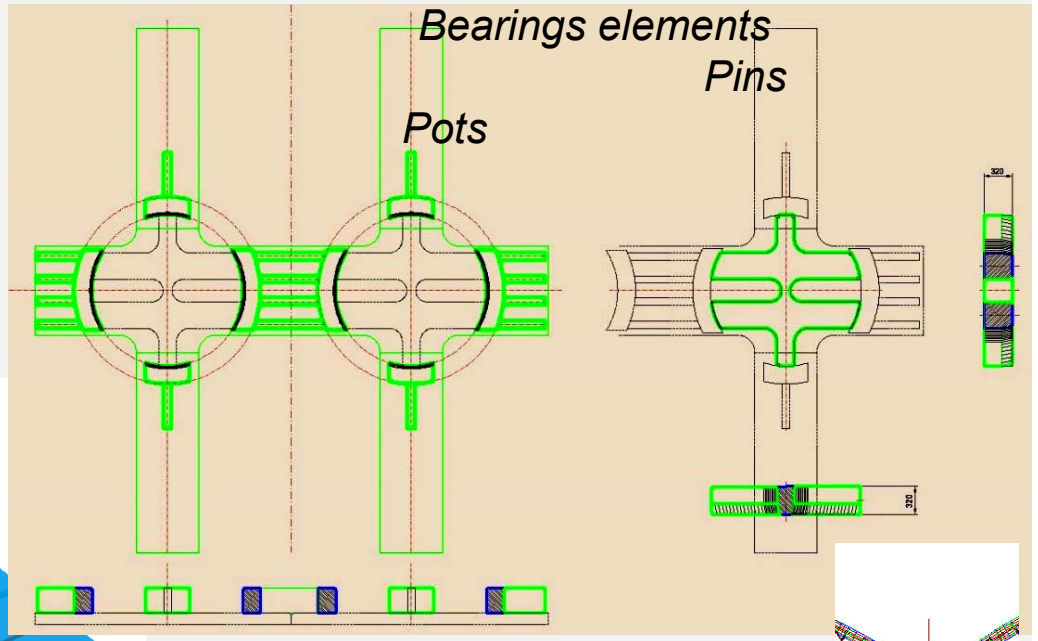


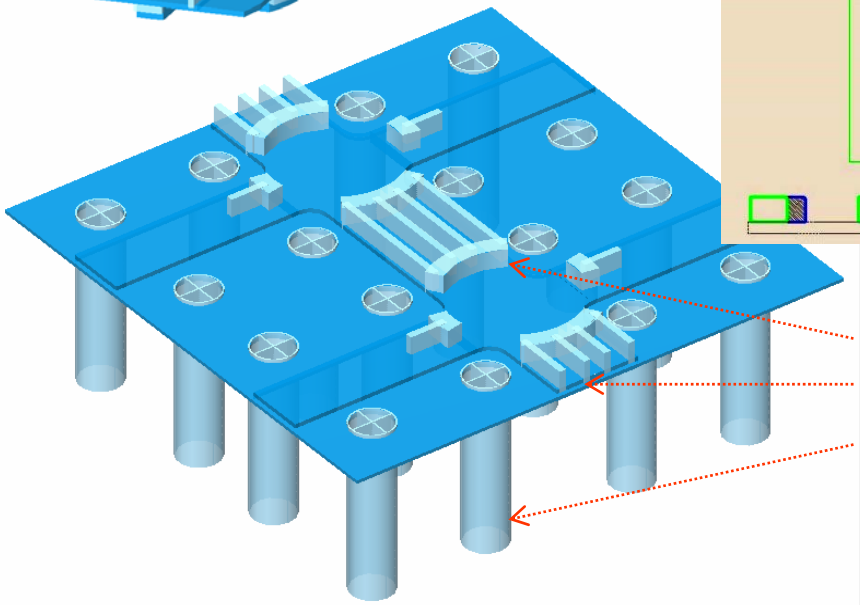
Seismic forces >> Breaking and traction forces

Steel structure details

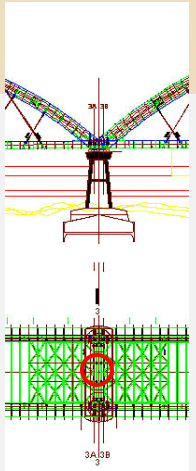
Fixed horizontal bearings on central pier

End cross beam fragment



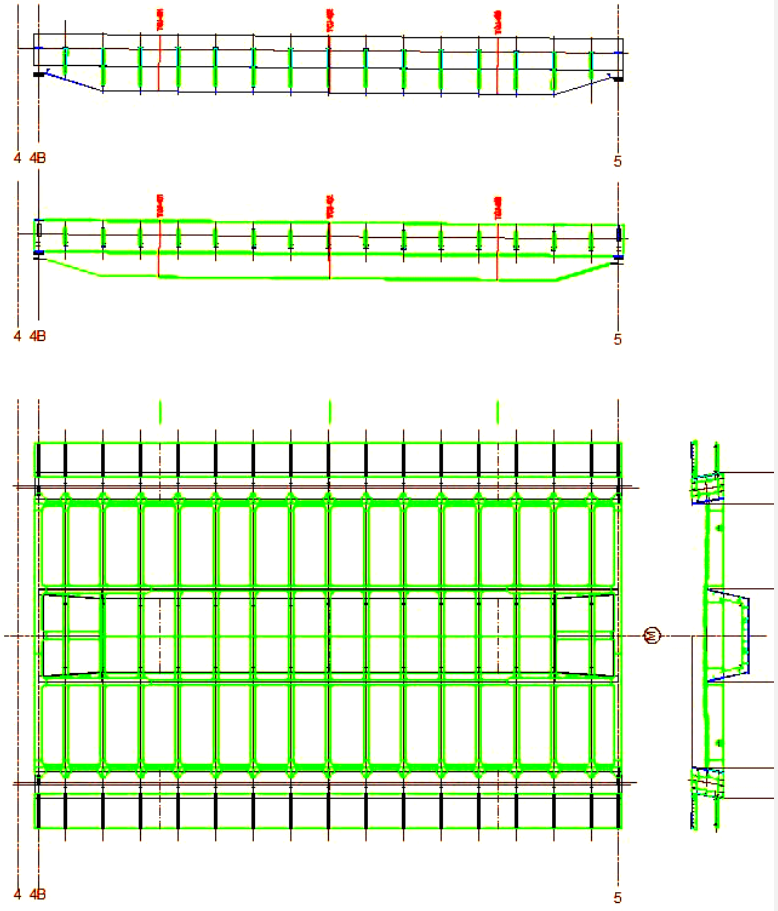


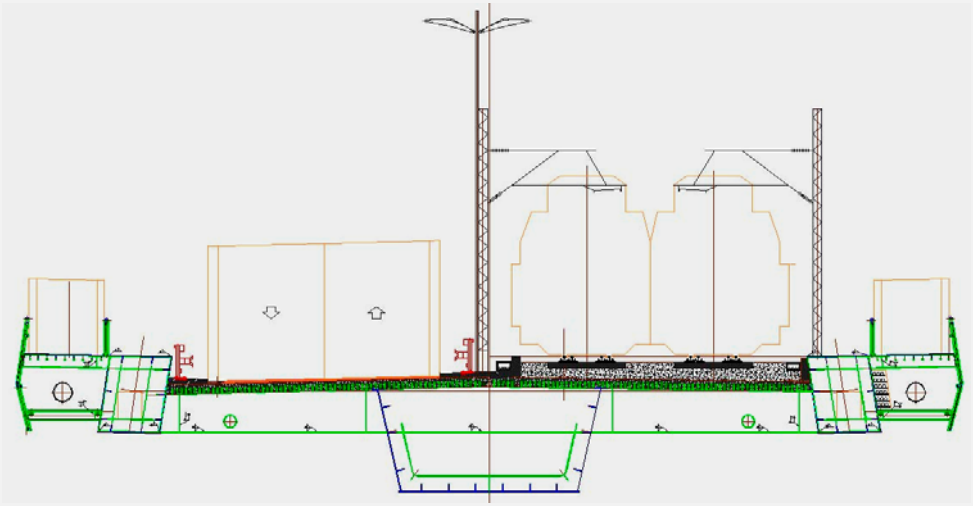
Bearings pots
Bearing plate on pier top
Pipe pins in pier concrete

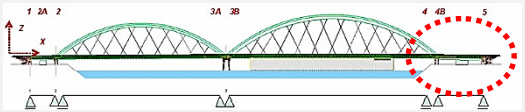


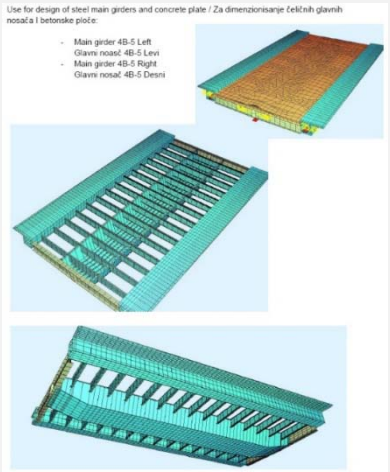
Steel structure details

Bridge *4B-5* (48 m span) as simple composite beam



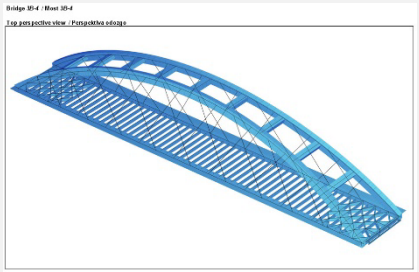


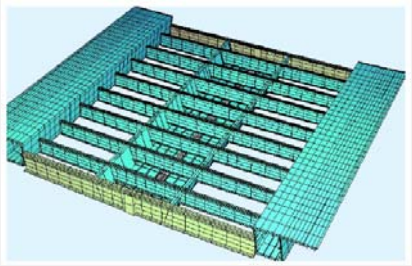


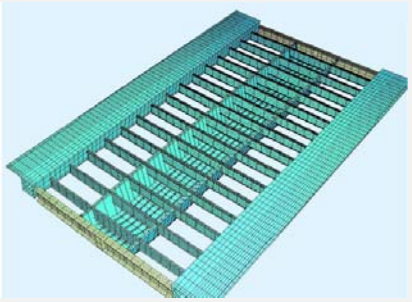


Structural Analysis
Loads

Models / Programs	Global: **Sofistik**, parallel also SAP. Structural details: Sofistik, Tower, SAP.
Loads	Weights: $G_{1,a,k}$ = Steel structure $G_{1,c,k}$ = Concrete slab = 181 and 232 kN/m $G_{2,k}$ = Permanent weights = 223 kN/m
EN 1991-2:2003	Traffic loads: Rail: LM71, SW/2; Type 2, Type 5 . Road: LM1, LM3 .
EN 1991-1-4:2005 +AC1:2010 EN 1991-1-5:2003	Wind: $v_{b,0}$ = 20,8 m/s. Thermal actions: $\Delta T_{N,pos,neg}$, $\Delta T_{M,pos,neg}$, and combinations (10).
EN 1991-2:2003	Traction and braking forces: Q_{lbk} i Q_{lk}.
EN 1998-2:2005 +AC1:2009	Seismic actions: In accordance to soil characteristics: Soil spring characteristics (X,Y,Z) and stifnesses 0,5K i 2,0K. Analysis: Multimodal analysis and Time history analysis.

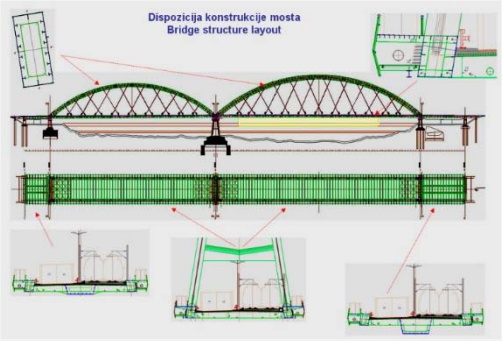




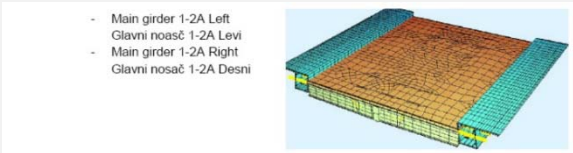


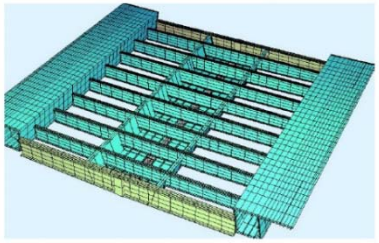
Structural Analysis

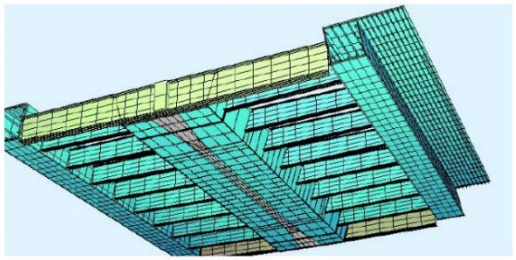
Structural models

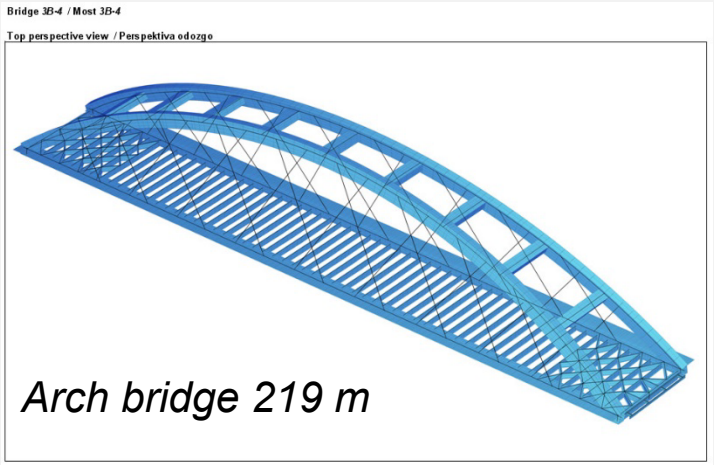


Approach bridge 25,3 m
Finite elements model

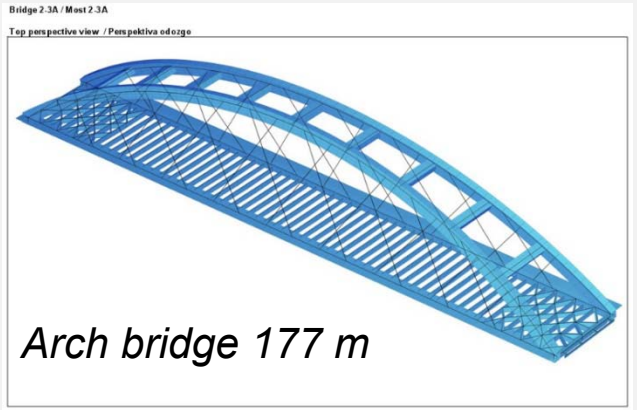




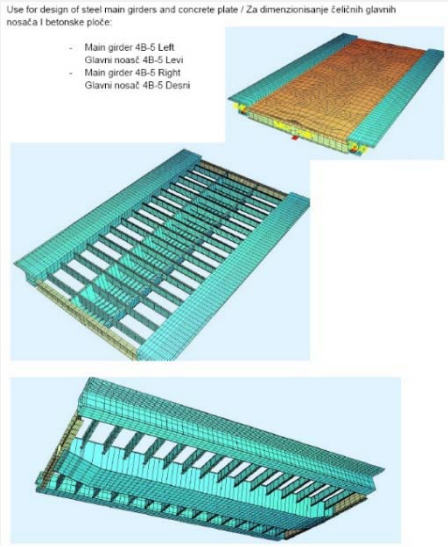




Arch bridge 219 m



Arch bridge 177 m



Approach bridge 46,3 m
Finite elements model

Structural Analysis
Section forces

1-2A:

L
M
R
} x **8** sect.

2-3A:

Arches: L+R, **2x64** sect.

Ties: L+R, **2x64** sect.

Hangers: **2x18** elements

3B-4:

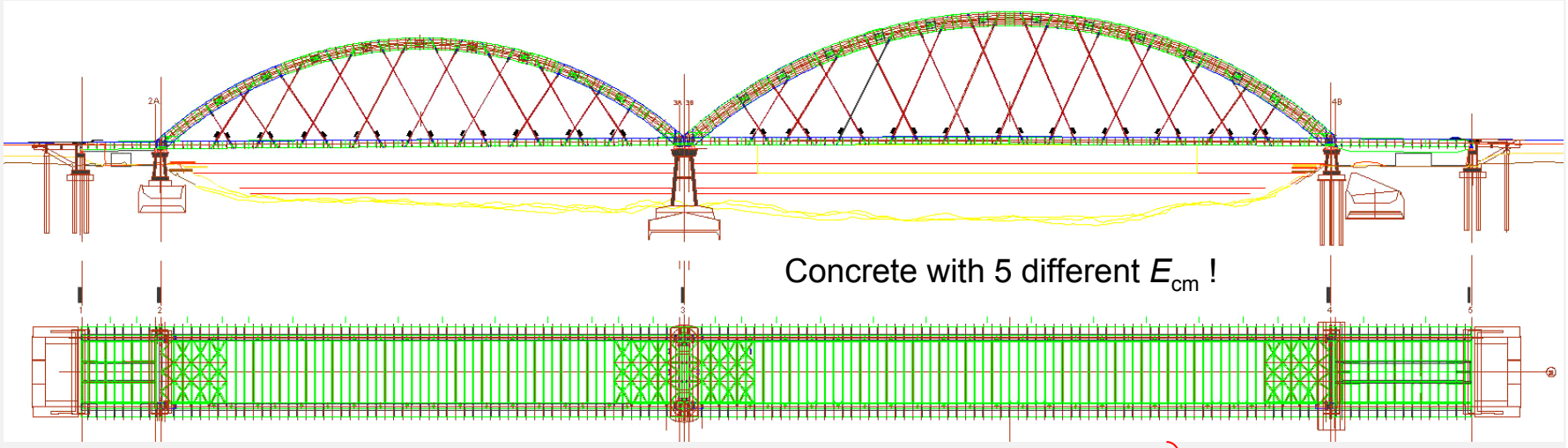
Arches: L+R, **2x80** sect.

Ties: L+R, **2x77** sect.

Hangers: **2x22** elements

1-2A:

L
M
R
} **x 15 sect.**

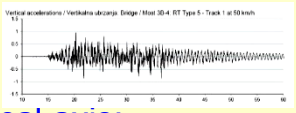
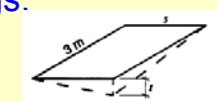
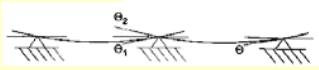
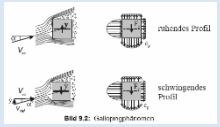
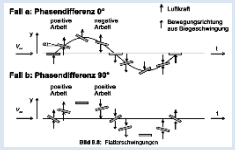


max/min N_x + corr. V_y, V_z, M_x, M_y, M_z.
max/min M_y + corr. N_x, V_y, V_z, M_x, M_z.
max/min M_z + corr. N_x, V_y, V_z, M_x, M_y.
} *for*

7 railway load combinations
6 road load combinations
10 thermal combinations
2 wind combinations
} *for*

ULS
SLS
Fatigue

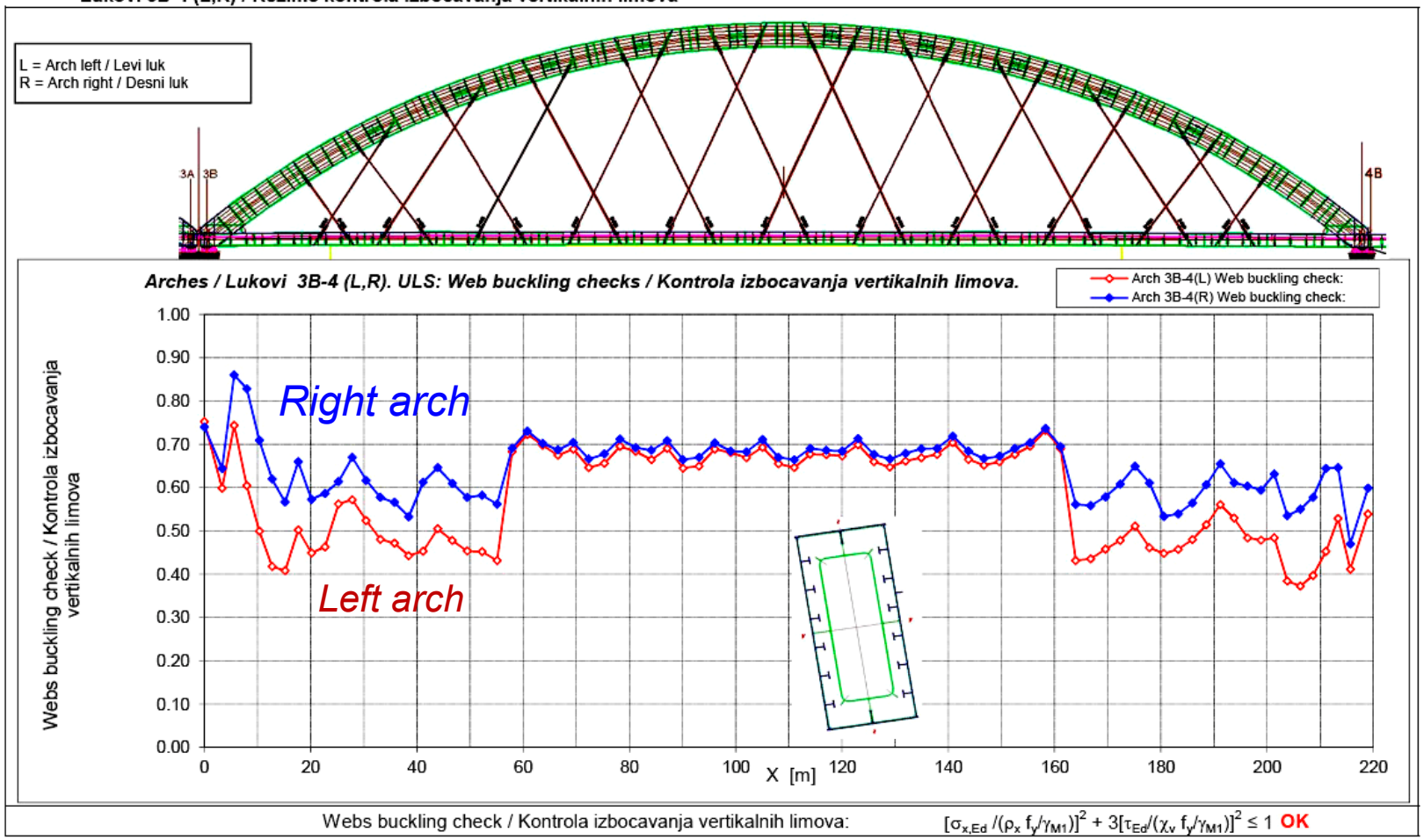
Structural Analysis
Scope of checks

ULS Ultimate limit states $\sum_{j\geq 1} \gamma_{Gj} \cdot G_{kj} \,"+"\, \gamma_P \cdot P_k \,"+"\, \gamma_{Q1} \cdot Q_{k1} \,"+"\, \sum_{i>1} \gamma_{Qi} \cdot \psi_{0i} \cdot Q_{k1}$	• Static analysis; • Dynamic analysis; • Cross-sections resistance: σ_{Ed}, τ_{Ed}, $\sigma_{V,Ed}$; • Local stability – buckling of plates (reduced stress method) and flange induced buckling; • Global stability of arches (out of plane buckling).
SLS Serviceability limit states $\sum_{j\geq 1} G_{kj} \,"+"\, P_k \,"+"\, Q_{k1} \,"+"\, \sum_{i>1} \psi_{0i} \cdot Q_{ki}$	• Vertical accelerations of deck structures; • Vertical deflections; • Horizontal deflections and rotations about vertical axis; • Longitudinal displacements of deck beyond bearings; • Extreme angular rotations on bearings; • Twist of decks; • Cracks of concrete carriageway deck.   
Fatigue	• Arches, ties, steel elements of deck structures; • Hangers (cable stays); • Concrete carriageway deck: concrete, reinforcements bars.
Aerodinamic effects  	• Girder: aerodynamic susceptibility, vortex shedding, flatter, turbulence. • Hangers: vortex shedding, galloping, rain and wind vibrations.

Structural Analysis

Example of checks: **Web buckling stability, arches 219 m**

(6) **Arches 3B-4 (L,R) / Resume of web buckling checks**
Lukovi 3B-4 (L,R) / Rezime kontrola izbocavanja vertikalnih limova

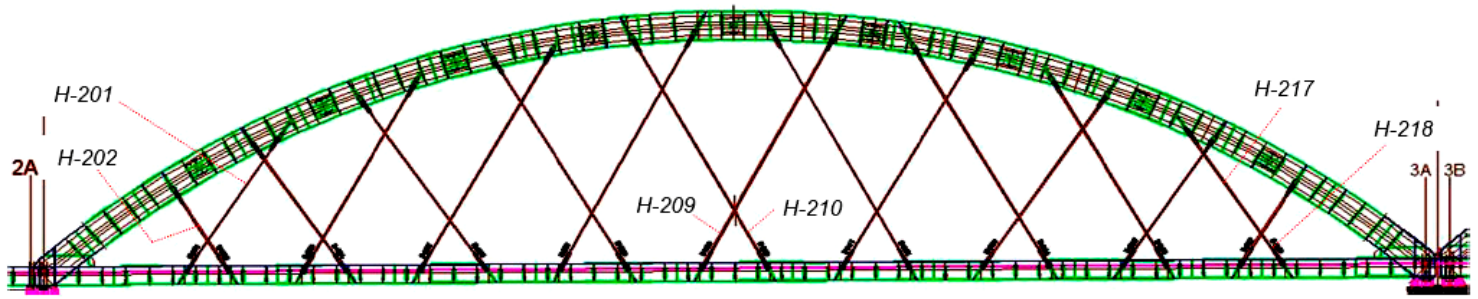


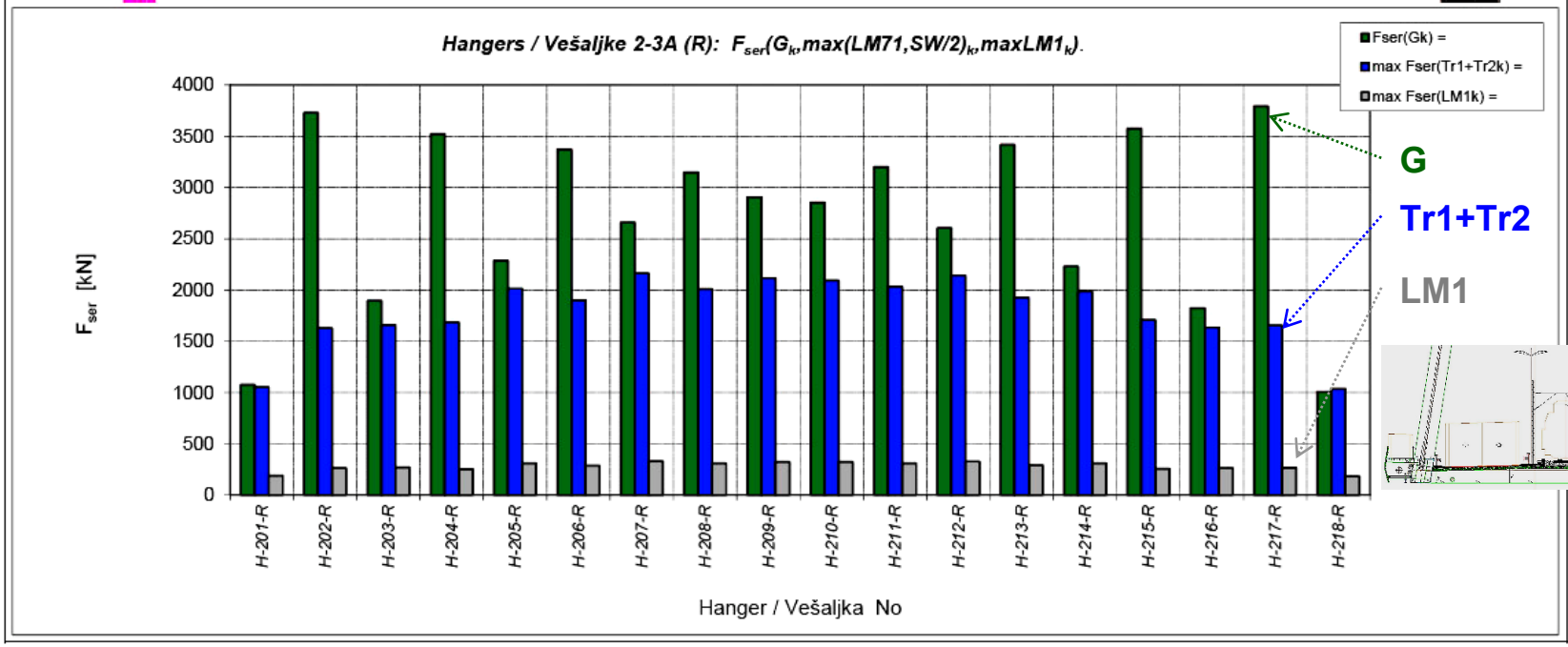
Webs buckling check / Kontrola izbocavanja vertikalnih limova: $[\sigma_{x,Ed}/(\rho_x f_y/\gamma_{M1})]^2 + 3[\tau_{Ed}/(\chi_v f_y/\gamma_{M1})]^2 \le 1$ **OK**

Structural Analysis

Example of checks: **Extreme right hangers forces, bridge 177 m**

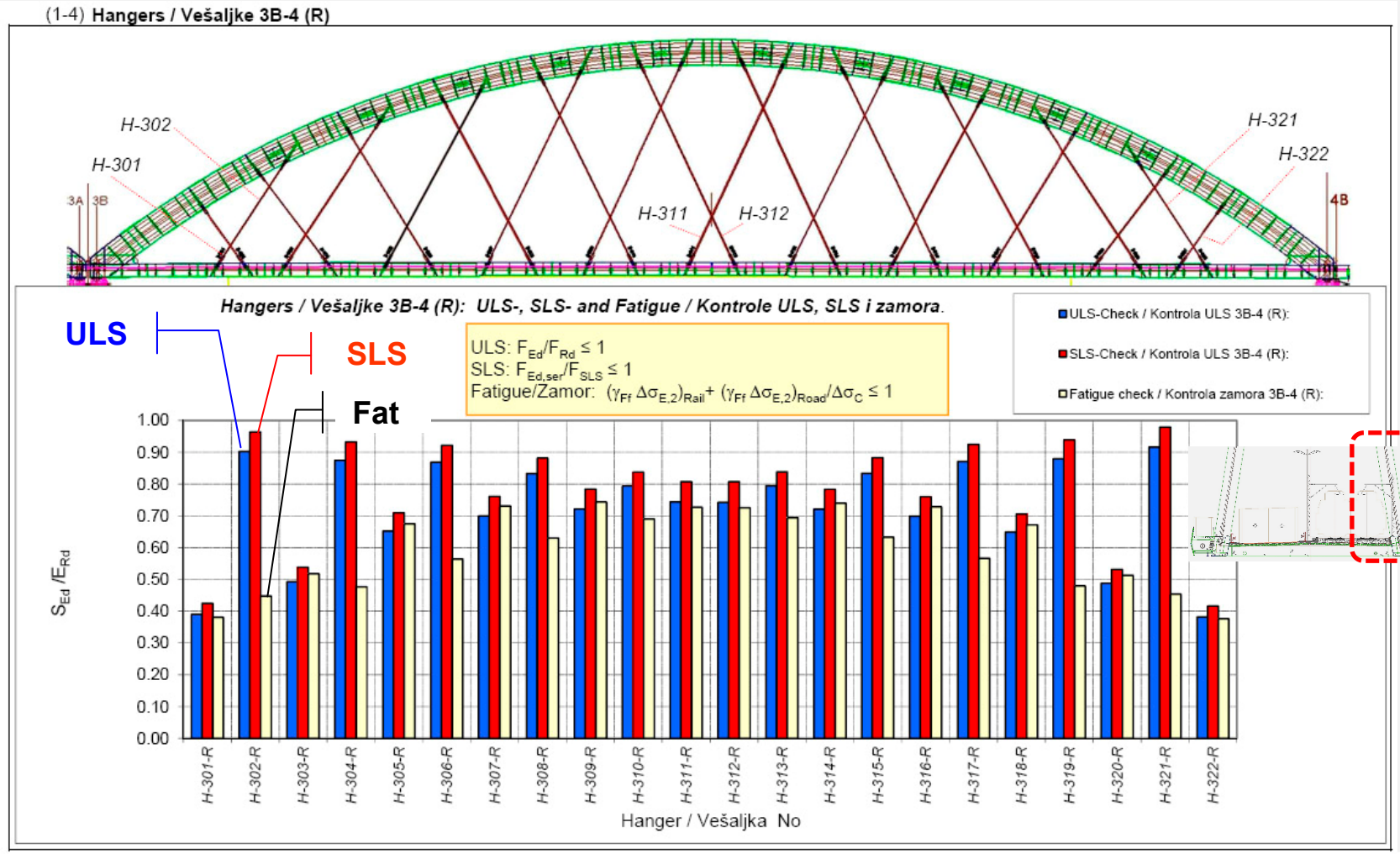
(2-2) **Hangers / Vešaljke 2-3A (R): $F_{ser}(G_k, max(LM71,SW/2)_k, maxLM1_k)$**





Structural Analysis

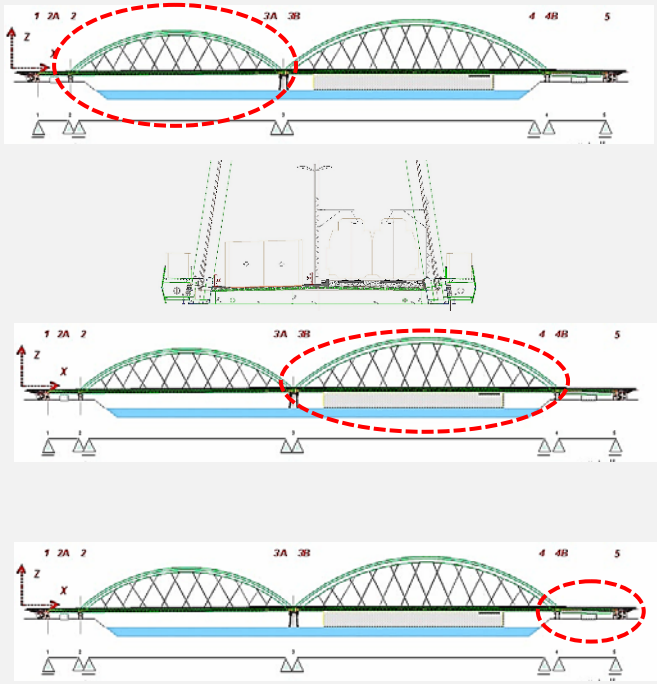
Example of checks: **ULS-, SLS-, Fatigue-checks of right hangers, bridge 219 m**



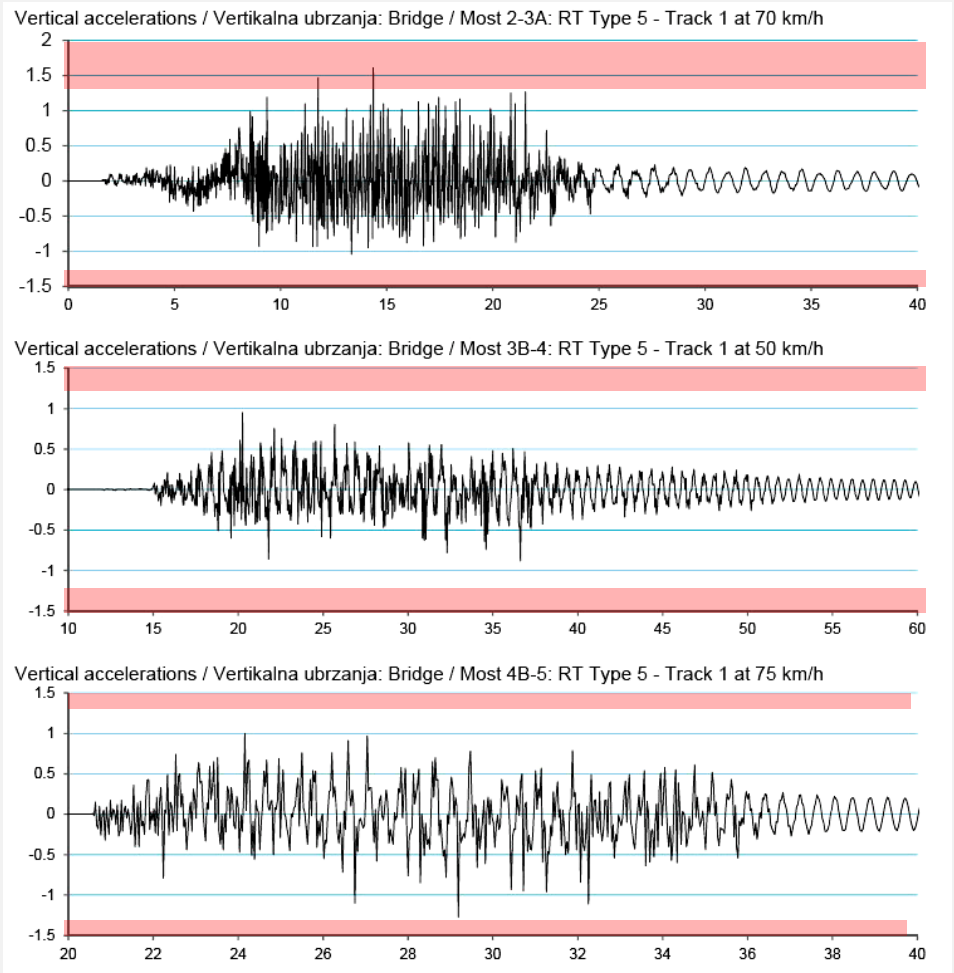
Structural Analysis

Example of checks: **Vertical accelerations of ties and girders**

Program Sofistik.
Train on non ballasted bridge structure.



Train Type 5, EN 1991-2:2003, Annex D:
V_{max} = 80 km/h, 16x(6x225kN) = 21600 kN



Production of the steel structure

Taddei S.p.A., L'Aquila, Italy, (member of JV)

Steel

Execution class: **EXC4**, **EN 1990-2:2011**.

Structural steel: **S355J0,J2,K2** , **EN 10025-2:2004**.

(small quantities: **S460Q,N,L** , **EN 10025-2:2004**)

Technical requirements:

Ril 804:2003 , **BN 918002:2000** , **SEL 072:1977**,

SEL 072/Beiblatt:1977 , **SEP 1390:1996**.

Headed studs

Automatic welded headed studs,

EN ISO 13918:2008, **EN ISO 14555:2006**.

Cable stays

Group C, Class 5, $f_{uk} \geq 1860{,}0$ N/mm^2 ,

EN 1993-1-11:2006, **SETRA:2002**, **fib:2005**.

Production of the steel structure

Inferior arch flange with hole for hanger's cable stay

Lower half of arch segment with hanger's anchorage structure

Tie box with hanger's anchorage structure

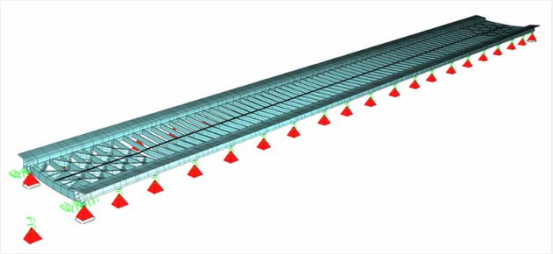
Trial assembly ties segments and end cross beams

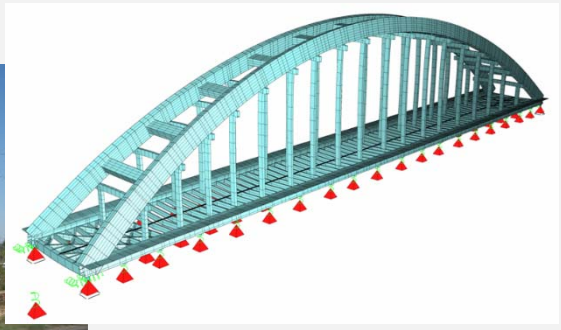
Assembling of the arch bridges steel structures

JV's Subcontractor: *Mostogradnja* a.d., Belgrade, Serbia

Assembling sequences:

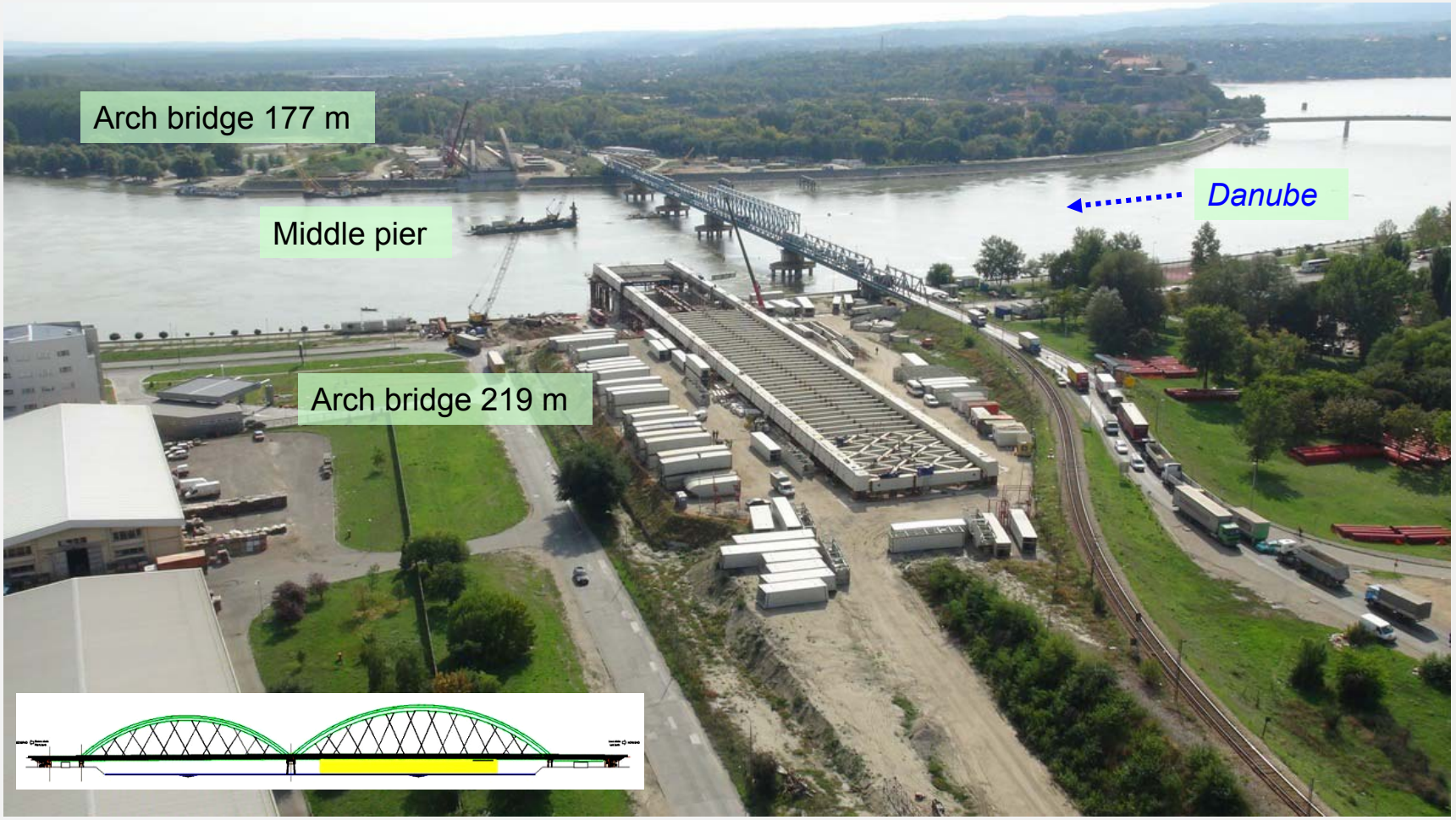
1) Ties, left and right,
2) Cross beams and bracings,
3) Temporary columns on ties for assembling of arches,
4) Arches.





Assembling of the arch bridges steel structures

State 2013-09-25



Assembling of the arch bridges steel structures

State 2013-09-25

Launching of the arch bridges steel structures

Global scope and participants

Global scope of launching:

1) Hangers installation;
2) Erection of temporary columns for launching;
3) Launching on banks: on skids and platforms;
4) Launching over river: barges;
5) Put on bearings.

Lead and coordination: **AZVI S.A., Sevill, Spain.**

Subcontractors:

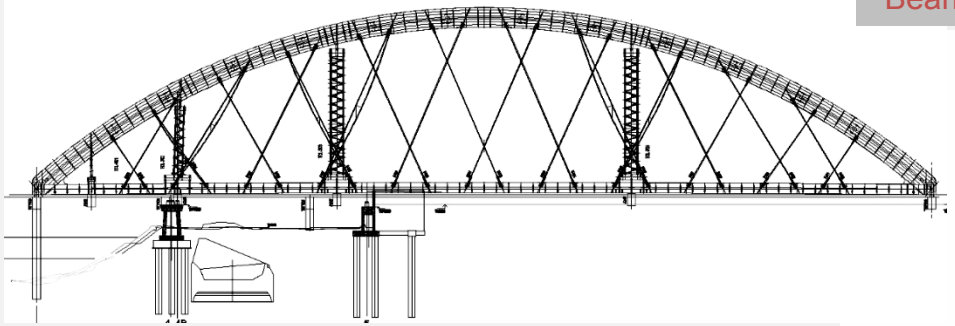
Launching analysis: **DEL ING d.o.o., Belgrade;**

Hangers: **VSL Ltd., Poland;**

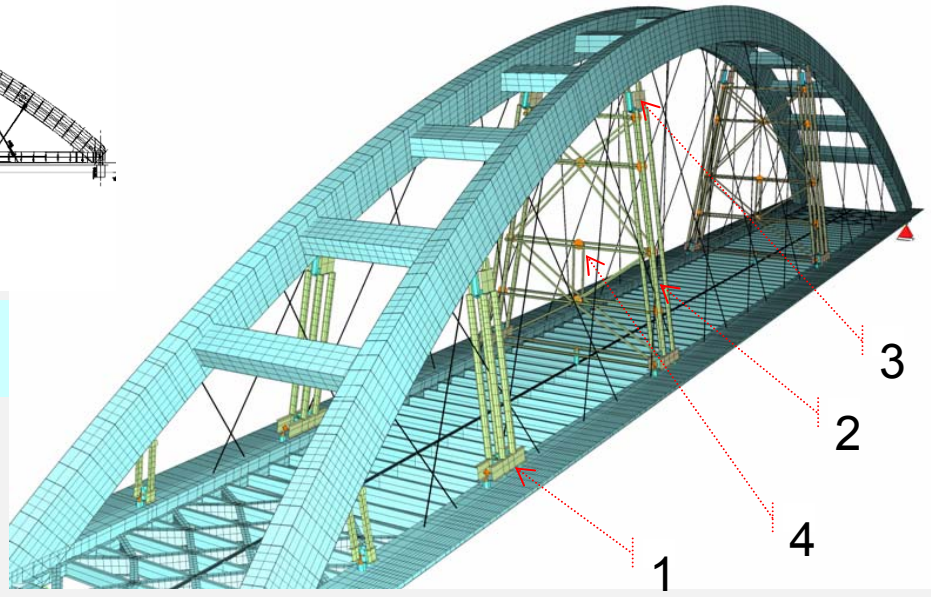
TCL: **Mostogradnja a.d., Belgrade, Serbia;**

Launching: **Mammoet, Rotterdam, Holand;**

Bearings: **FIP Industriale, Servazzano, Italy.**



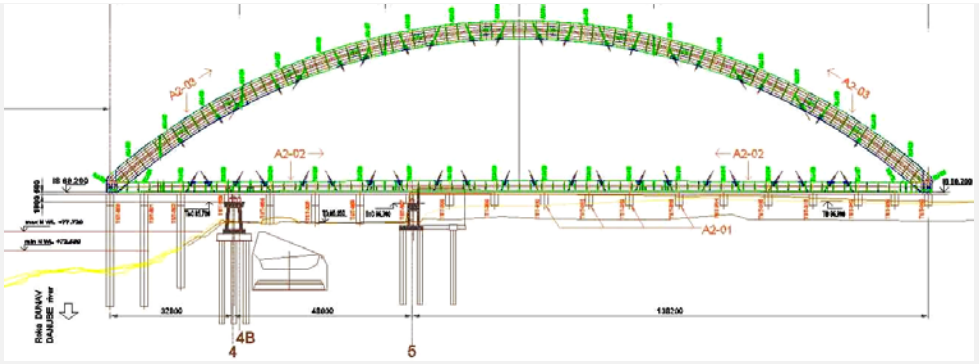
Bridge 3-4 (219 m): Bridge structure with temporary columns for launching (TCL).



1 = Inferior support beam, 2 = Column
3 = Superior support, 4 = Bracing

Launching of the arch bridges steel structures

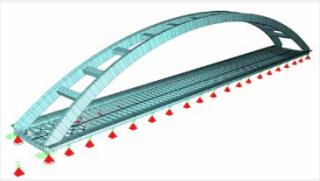
Launching of bridge *3B-4*, L = 319 m, (0,1)

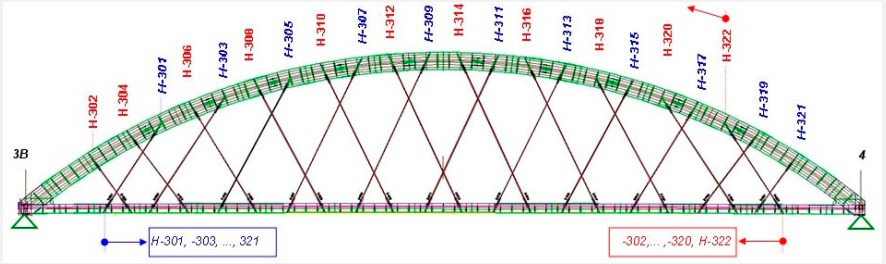


0) *Start state*:

bridge assembled, no hangers;

ties on temporary supports.





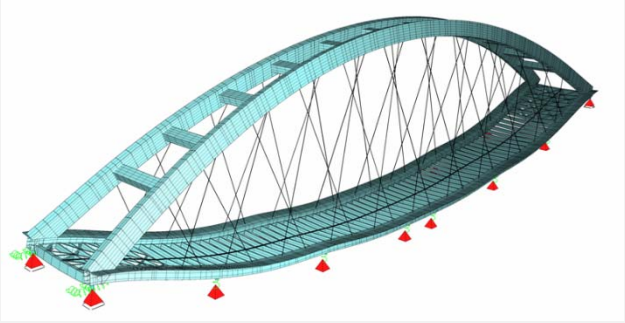
1) *Installation of hangers (cable stays)*:

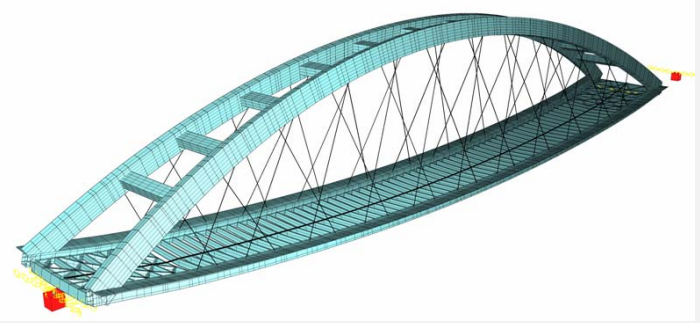
a) Descent of ties to level of expected deflections;

b) Installation of hangers with the slope to the right;

c) Installation of hangers with the slope to the left;

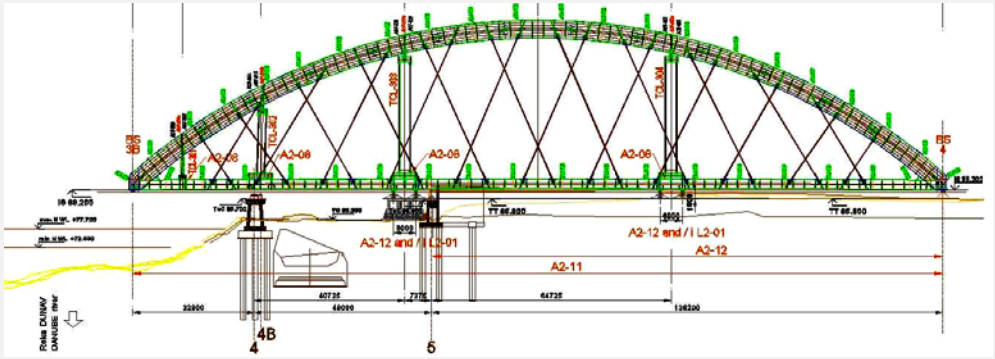
d) Bridge supported on four supports.

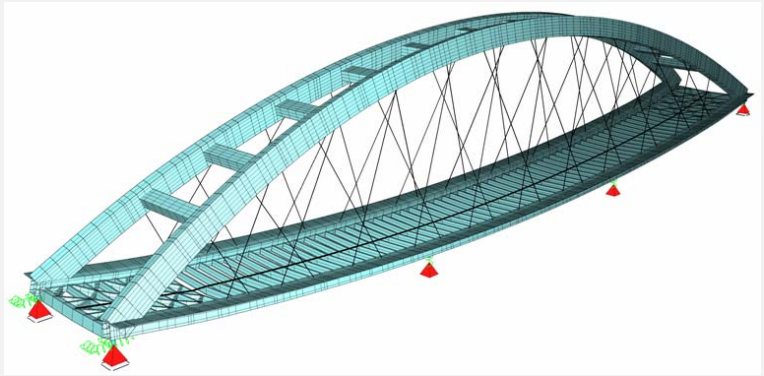


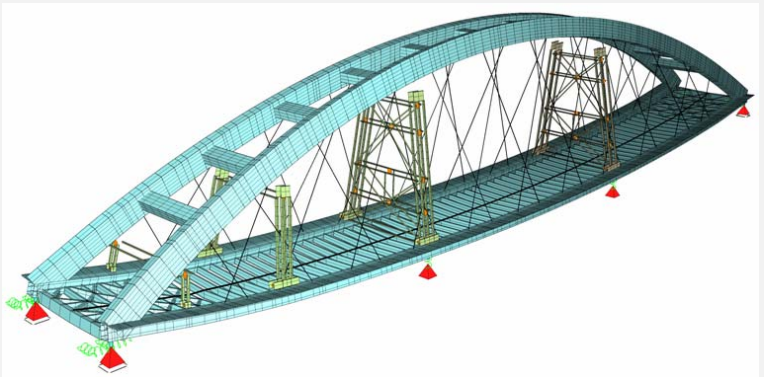


Launching of the arch bridges steel structures

Launching of bridge *3B-4*, L = 319 m, (2)







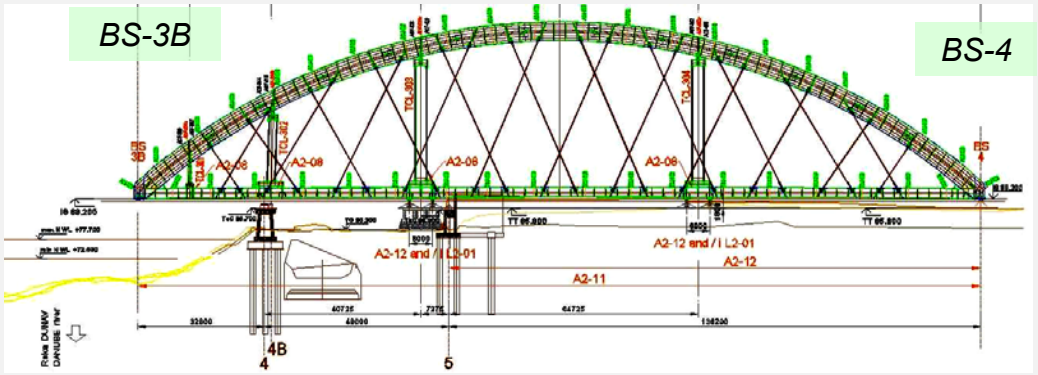
2) *Erection of temporary columns for launching (TCL)*:

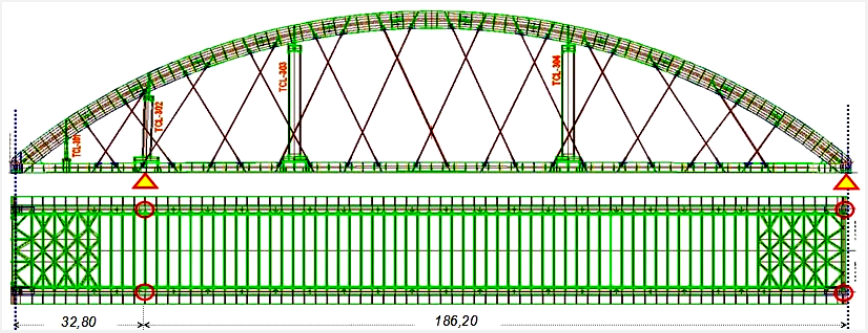
a) Installation of supports under the ties TCL locations;

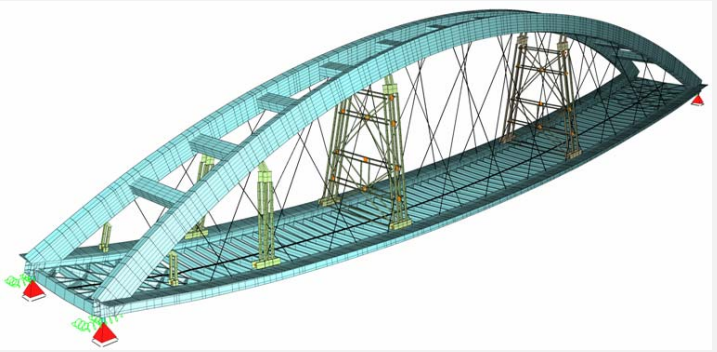
b) Installation of TCL around hangers.

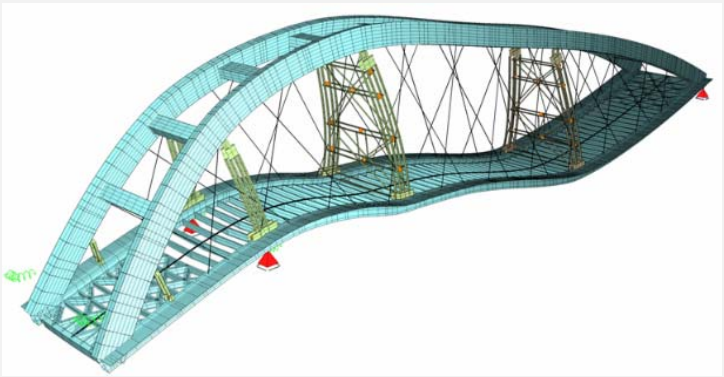
Launching of the arch bridges steel structures

Launching of bridge *3B-4*, L = 319 m, (3)









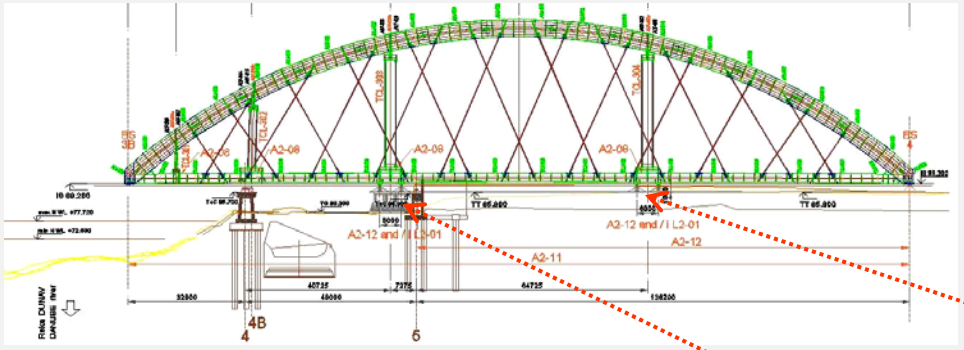
3) *Activating of supports on Pier 4 at axis BS-4*:

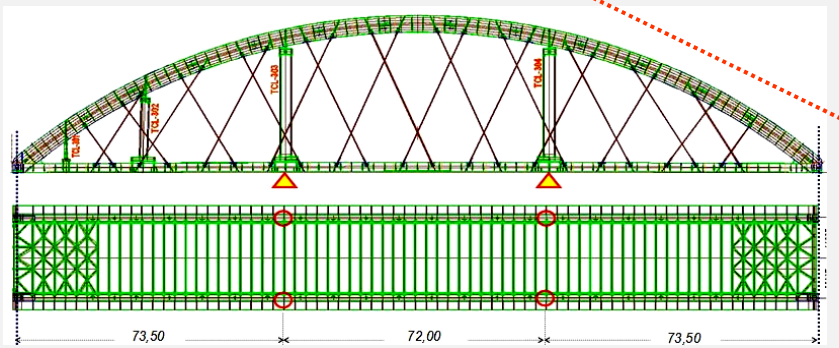
a) Removal of temporary supports under TCL;

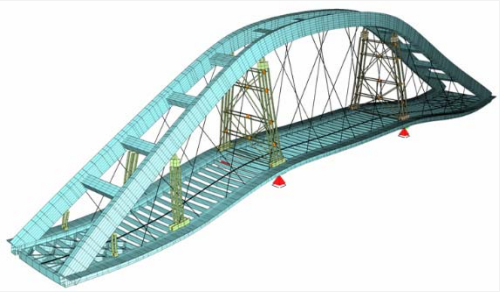
b) Activating of supports on Pier 4 at axis *BS-4*.

Launching of the arch bridges steel structures

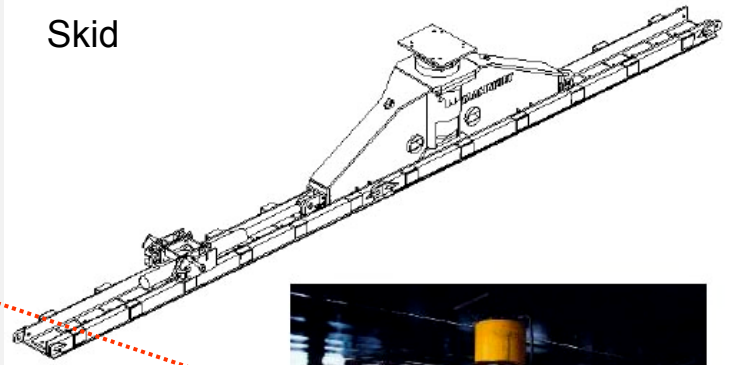
Launching of bridge *3B-4*, L = 319 m, (4)

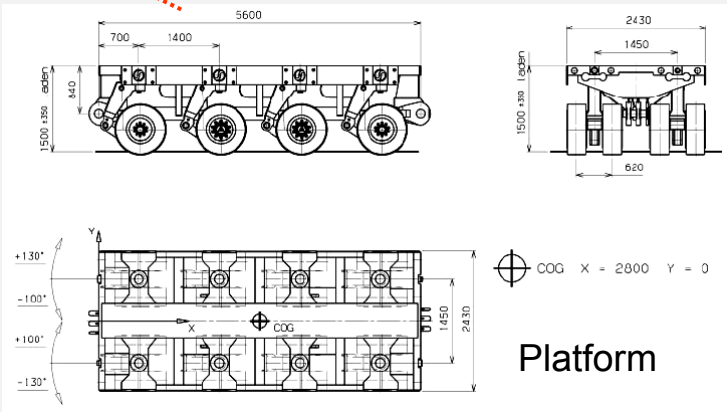






Skid



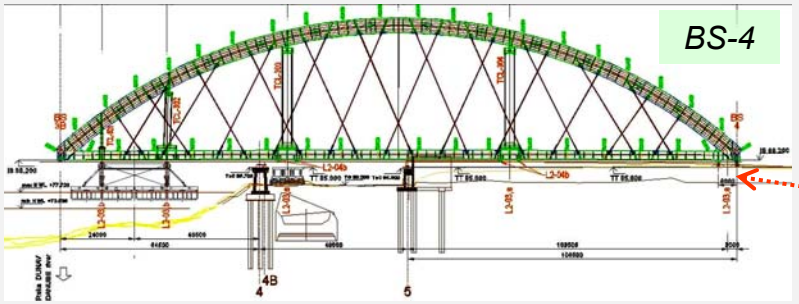


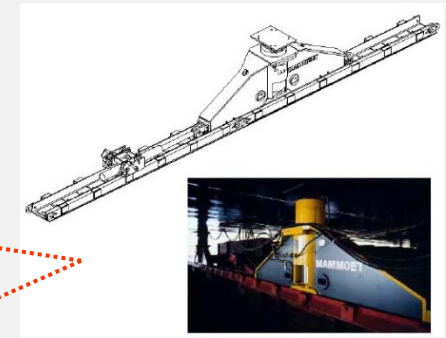
Platform

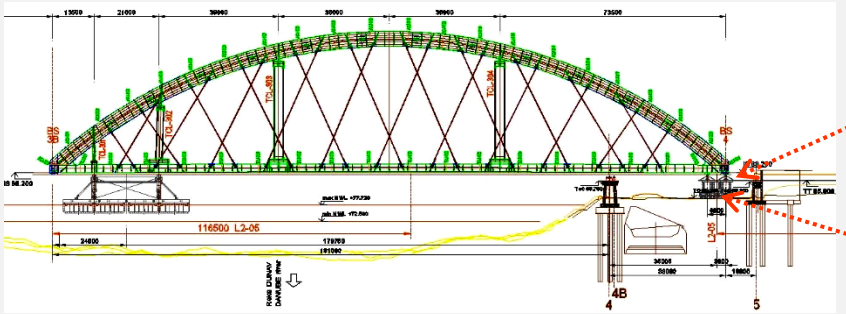
4) Activating of supports on skids and platforms.

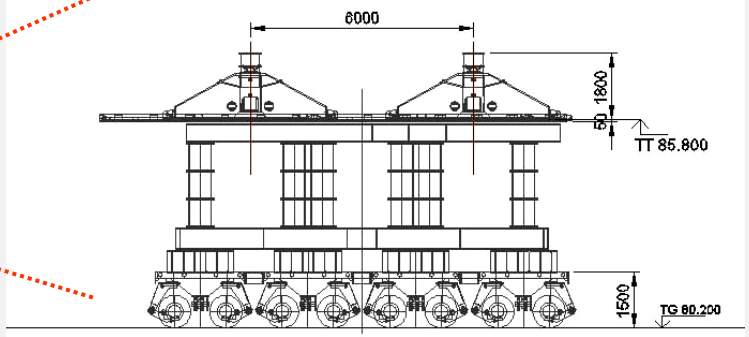
Launching of the arch bridges steel structures

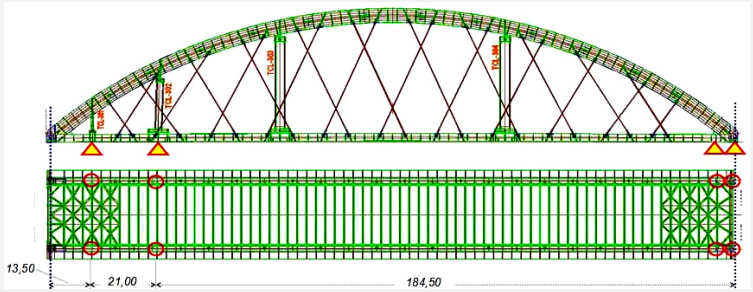
Launching of bridge *3B-4*, L = 319 m, (5)

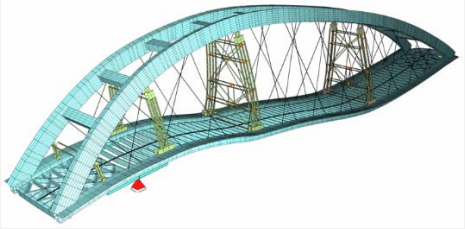








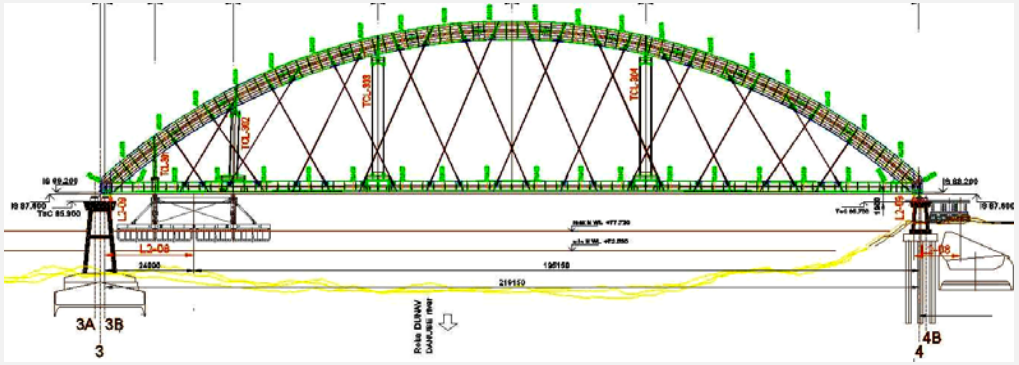


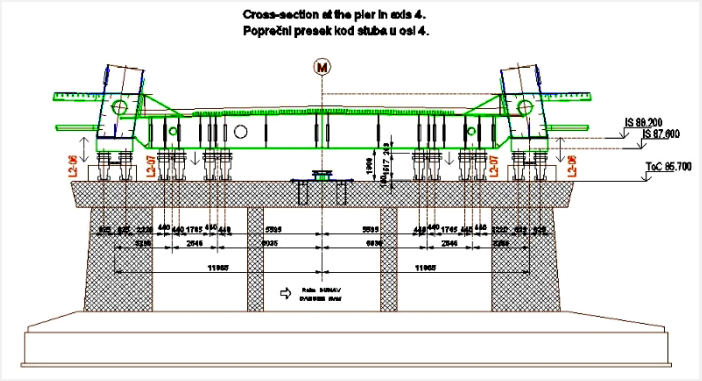


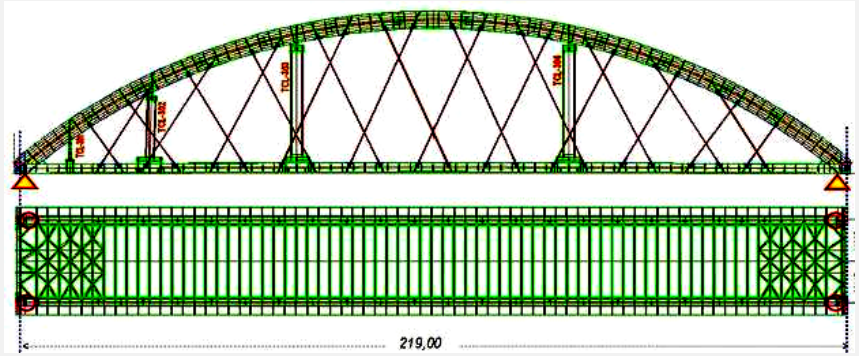
5) Activating of supports on barges and skids at axis BS-4.

Launching of the arch bridges steel structures

Launching of bridge *3B-4*, L = 319 m, (6,7)



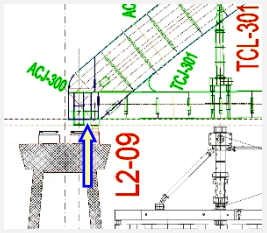


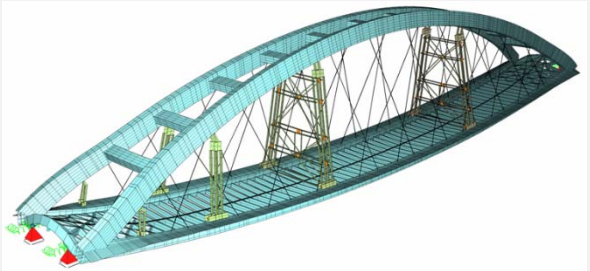


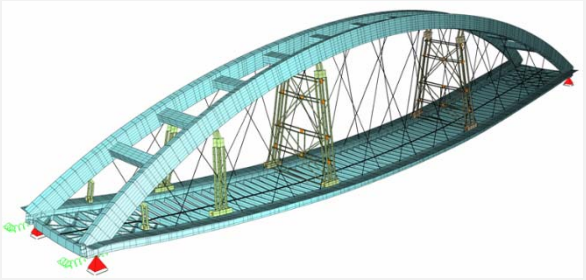
Longitudinally the structure is on final position.

6) ***Transfer of supports to end cross beams.***

7) ***Transfer of supports to temporary supports on locations of supports for bearings replacements.***

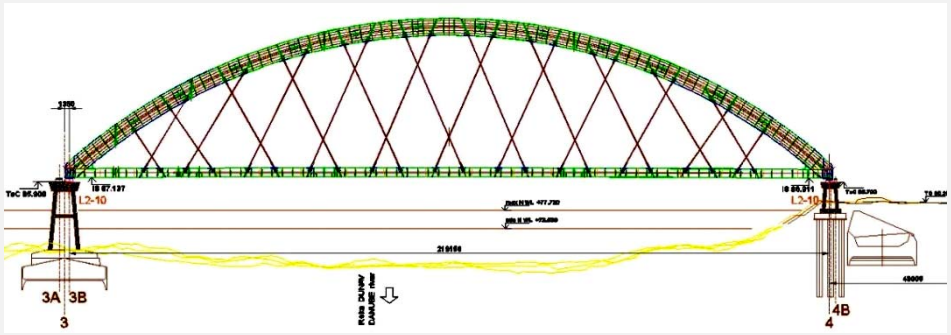


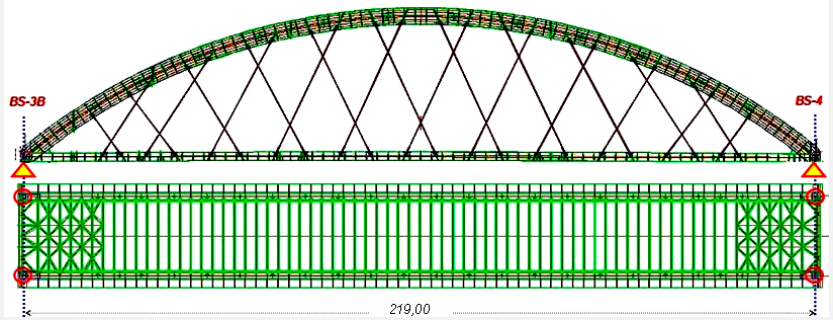


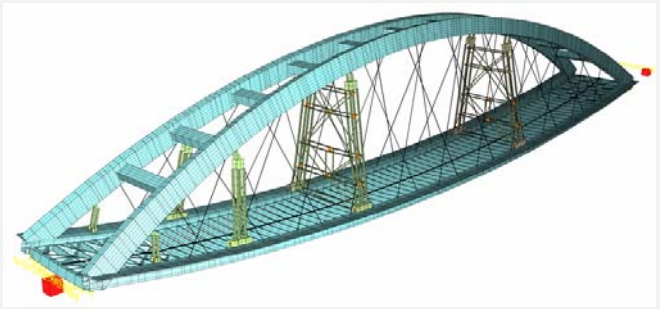


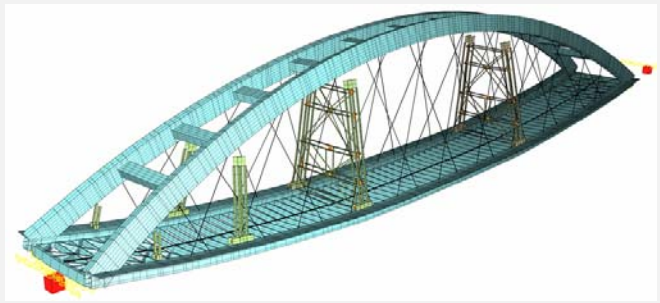
Launching of the arch bridges steel structures

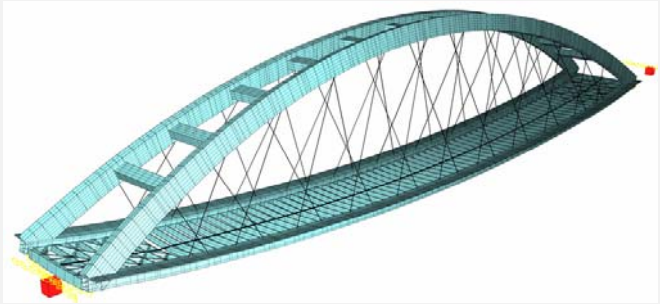
Launching of bridge *3B-4*, L = 319 m, (8-10)











8) *Final steps*:

a) Removal of TCL-301 to TCL-304;

b) Removal of all temporary supports on piers;

c) Bridge is on final position.

9) Concreting of carriageway slab.

10) Installation of ballast, asphalt layer, equipment, accessories.

Railway Road Bridge in Novi Sad on pictures.

Location and bridge

Railway Road Bridge in Novi Sad on pictures.

Bridge viewed from bank and river

Color of the steel structure and hangers:

RAL 9003 (signal white) BS ISO 4800:1998

Railway Road Bridge in Novi Sad on pictures.

Parapets and masks

View of masks in front of foothpath and accessories space.

Masks: Perforated metal, hot deep galvanized and coated.

Color: RAL 9003 (signal white).

Railway Road Bridge in Novi Sad on pictures.

Road lanes with safety barriers

Railway Road Bridge in Novi Sad on pictures.

Footpath with parapet and mask

Parapet height h_{Par} = 1200 mm according to German RIZ-ING:2012 and ZTV-ING-Teil 8:2010.

Bridge in Novi Sad and similar bridges in the world

Systems of steel arch railways bridges

Garabit Viaduct, Fr, 167 m, 1884

Hell Gate, USA, 298 m, 1918

True arches

carriageway above

carriageway down

Chaotianmen, Ch, 552 m, 2009

Dongping, Ch, 242 m, 2009

Trust tied arches

On the world list of **155** arch bridges with longest spans (208 to 552 m) there are **only 16 bridges with rail transport**, (railway, metro, light railway).

Hammer, G, 250 m, 1987

Merivale, Aus, 133 m, 1978

Arches with tie as girder

trussed girder

solid girder

Ayub, Pk, 246 m, 1962

Fehmarn, G, 248 m, 1963

Garde Adhemar, Fr, 2x115 m, 2000

Tied arches

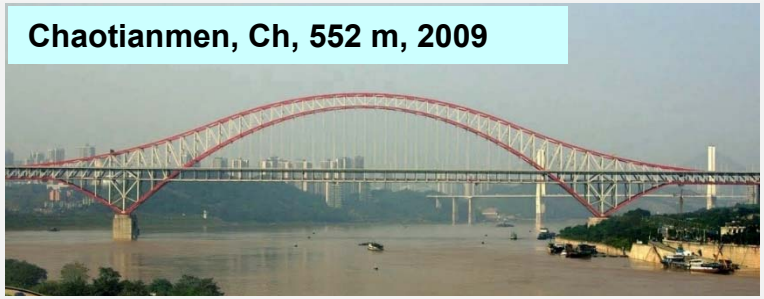
trussed arch

solid arch

Bridge in Novi Sad and similar bridges in the world

Trussed tie steel arch railways bridges with longest spans

Chaotianmen, Ch, 552 m, 2009



Wanzhou, Ch, 360 m, 2005

Rešetkasti lukovi sa zategom
Trussed tied arch bridges

	Foto	Name	Location	Opened	Type	Carries	Main span m
		**Chaotianmen Bridge**	Yangtzekiang River China	2009	Trussed tied arch bridges Steel	**2 tracks LR** 6 lanes	**552**
1		**Wanzhou Bridge**	Yangtzekiang River China	2005	Trussed tied arch bridges Steel	**2 tracks**	**360**
2		**Dashengguan Bridge**	Yangtzekiang River China	2009	Trussed tied arch bridges Steel	**6 tracks Metro**	**336**
3		**Hell Gate Bridge**	East River USA	1918	Trussed tied arch bridges Steel	**3 tracks**	**298**
4		**Ayub Bridge**	Indus River Pakistan	1962	Trussed tied arch bridges Steel	**2 tracks**	**246**
5		**Dongping Bridge**	Dongping Channel China	2009	Trussed tied arch bridges Steel	**2 tracks**	**242**

Bridge in Novi Sad and similar bridges in the world

Tied arch with girder steel railways bridges with longest spans

Caiyuanban, Ch, 420 m, 2007

Lukovi sa gredom
Tied arch bridges with girder (Bowstring-girder bridge)

	Foto	Name	Location	Opened	Type	Carries	Main span m
1		**Caiyuanba Bridge**	Yangtzekiang River China	2007	Arch steel/concrete Vertical hangers Trussed girder	**2 tracks Metro** 6 lanes	**420**
2		**Yiwan Bridge**	Yangtzekiang River China	2008	Steel arch Vertical hangers Concrete girder	**2 tracks**	**275**
3		**Hammer Bridge**	Rhein River Germany	1987	Steel arch Vertical hangers Trussed girder	**4 tracks** (2 S-Bahn)	**250**
4		**Kobe Bridge**	Kobe Japan	1970	Steel arch Vertical hangers Trussed girder	**2 tracks** 4 lanes	**217**
5		**Dintelhaven Railroad Bridge**	Rotterdam Netherland	1999	Steel arch Vertical hangers	**2 tracks**	**170**
6		**Neue Niederräder Brücke**	Frankfurt am Main Germany	1978	Steel arch Vertical hangers	**2 tracks** S-Bahn	**168**

Bridge in Novi Sad and similar bridges in the world

Tied arch steel railways one track bridges with longest spans

Fehmarn, G, 248 m, 1963

Železnički mostovi sistema sa lukova sa zategom - jedan kolosek
Tied arch railway bridges (Bowstring) - One track

	Foto	Name	Location	Opened	Type	Carries	Main span m
1		**Fehmarnsund Bridge**	Grossenbrode Fehmarnsund Germany	1963	Tied arch Network hangers Steel	**1 track** 2 lanes	**248**
2		**Main Bridge**	Main River Hanau Germany	1993	Tied arch Vertical hangers Steel	**1 track** (S-Bahn)	**160**
3		**Railway Bridge**	Vahldorf Germany	2005	Tied arch Vertical hangers Steel	**1 track**	**150**
4		**Flora Bridge**	Mitteland Canal Haldensleben Germany	2009	Tied arch Network hangers Steel	**1 track**	**133**
5		**Osaka Monorail Yodogawa Bridge**	Yodo River Osaka Japan	1997	Tied arch Network hangers Steel	**1 track** Monorail	**126**

Bridge in Novi Sad and similar bridges in the world

Tied arch steel railways two tracks bridges with longest spans

Železnički mostovi sistema sa lukova sa zategom - dva koloseka
Tied arch railway bridges (Bowstring) - Two tracks

	Foto	Name	Location	Opened	Type	Carries	Main span m
1		**Railway Road Bridge** 219 m span	Danube River Novi Sad Serbia	2014	Tied arch Network hangers Steel	**2 tracks** 2 lanes	**219**
2		**Railway Road Bridge** 177 m span	Danube River Novi Sad Serbia	2014	Tied arch Network hangers Steel	**2 tracks** 2 lanes	**177**
3		**Ogatayama Bridge**	Yamanashi Japan	1995	Tied arch Network hangers Steel	**2 tracks**	**139**
4		**Merivale Bridge**	Brisbane Queensland Australia	1978	Tied arch Network hangers Steel	**2 tracks**	**133**
5		**Bonpas Bridge**	Rhone River France	1998	Tied arch Vertical hangers Steel	**2 tracks HS**	**124**
6		**Vénéjan Mornas Viadukt**	Vénéjan Mornas Saint-Etienne-des-Sorts France	1999	Tied arch Vertical hangers Steel	**2 tracks HS**	**119**
7		**Garde Adhémar Viaduct**	Pierrelatte France	2000	Tied arch Vertical hangers Steel	**2 tracks HS**	**115**

Railway Road Bridge across the Danube in Novi Sad

Participants

Financing	**Delegation of the European Commission to the Rep. Serbia** **Autonomy Province of Vojvodina** **Municipality of Novi Sad.**	
Contractor	**JV Azvi, Taddei, Horta Coslada**	
	Azvi S.A., Seville, Spain **Taddei** S.p.A., L'Aquila, Italy **Horta Coslada** S.L., Madrid. Spain	www.azvi.es www.gruppoedimo.it/taddei
Subcontractors for designing	*Detailed design of the bridge structure*: **DEL ING** d.o.o., Belgrade, Serbia *Detailed design of the foundation and piers*: **ENCODE** d.o.o., Belgrade, Serbia	www.deling.rs
Subcontractors for construction	*Assembling of the steel structure*: **Mostogradnja** a.d., Belgrade, Serbia	www.mostogradnja.rs
	Cable stays: **VSL** Ltd., Poland	www.vsl.com
	Launching: **Mammoet**, Rotterdam, Netherland	www.mammoet.com
	Bearings and expansion joints: **FIP Industriale** S.p.A., Servazzano, Italy	www.fip-group.it