

RAILWAY SLAB TRACK FORUM 2025

Zagreb 21-STT Slab Track Structure for Urban Tramway Construction

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Overview

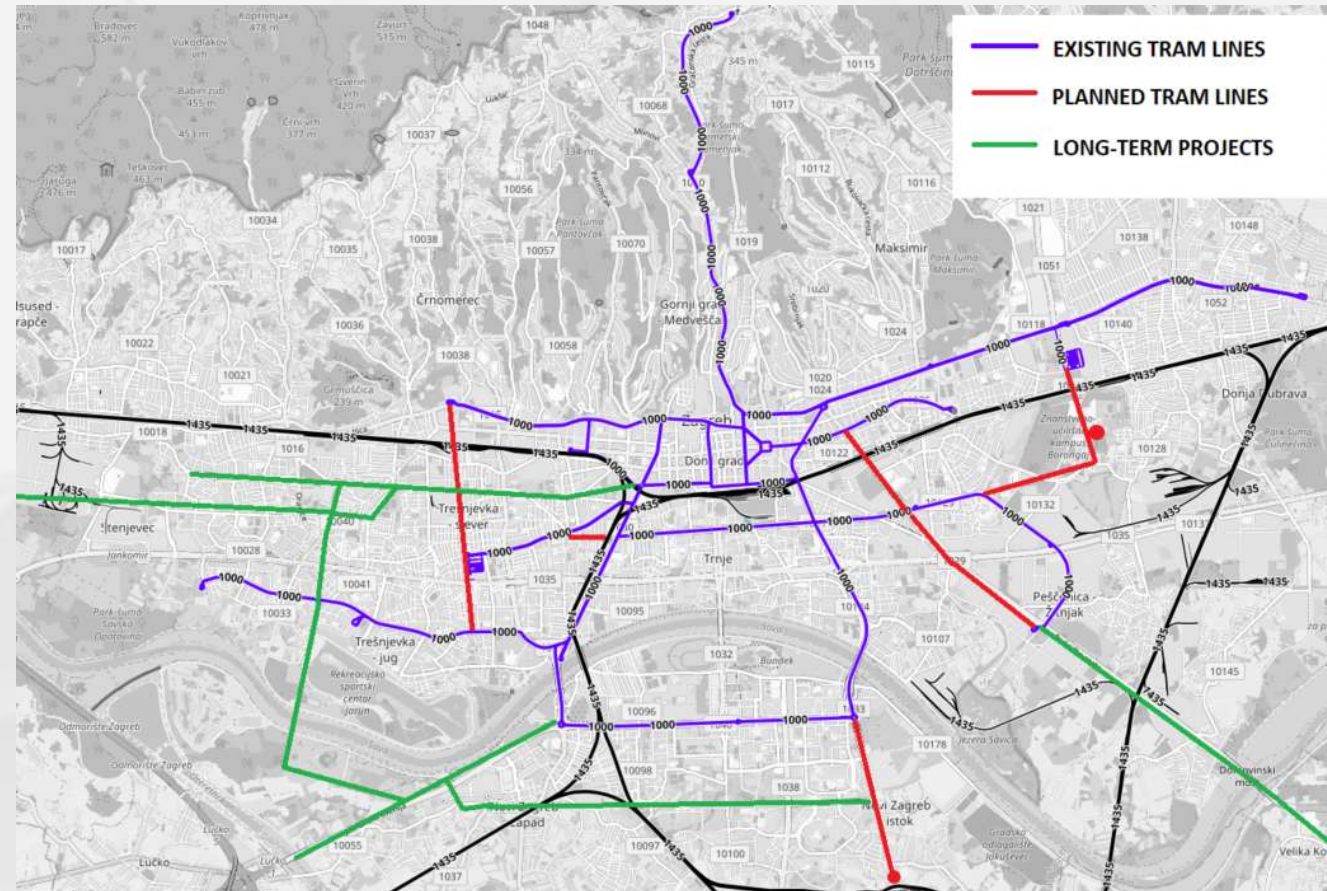
- Introduction
- Zagreb 21-STT slab track structure
 - Savska road test section
 - Sarajevska road implementation
- Future plans
- Concluding remarks



Introduction

Zagreb Tram Network

- Total length - **116,3 km**
- **15** day and **4** night lines – **180 trams** on the network every day
- Substructure:
 - ballasted track (5,9%)
 - **reinforced concrete slab track (94,1%)**
- Continuous reinforced concrete slab **25 cm thick**
- **Discretely supported** rails
- Sleeper spacing **1 m**
- Track gauge **1000 mm**



Introduction

Zagreb Tram Network

- 2005 – rolling stock renewal – **TMK 2200 introduced**

Before: a wheel load of **20 - 25 kN** per wheel

After: TMK 2200 tram - **33 kN per wheel**



- At the level of track structure operation, the main changes include:
 - **Increased axle load**
 - **Different load distribution on the structure**
 - Changed geometry of the wheel–rail contact surface due to the **different wheel profile**



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Introduction

Zagreb Tram Network

- **Track structure remained unchanged** → observed effects include:
 - Increased rail wear
 - Accelerated degradation of track geometry due to failure of fastening systems and rail supports
- In 2013, infrastructure manager requested the **development of adequate fastening system** that would meet the requirements:
 - Traffic load (up to **15 million gross tons**)
 - Vehicle passage frequency (intervals **<90 s**)
 - Wheel loads
 - Track gauge
 - Strict tolerances related to track geometry

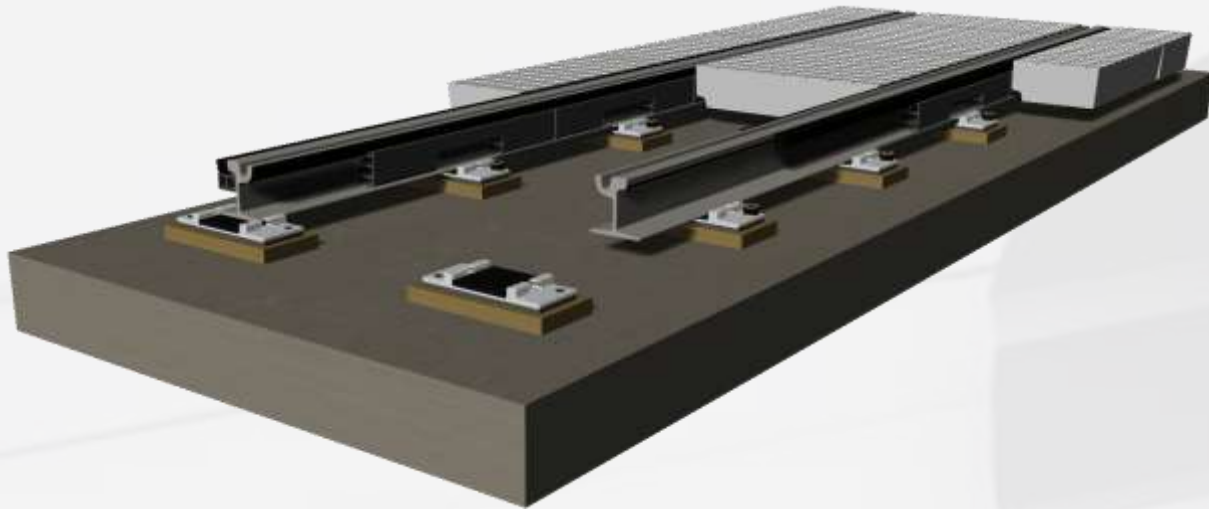


Introduction

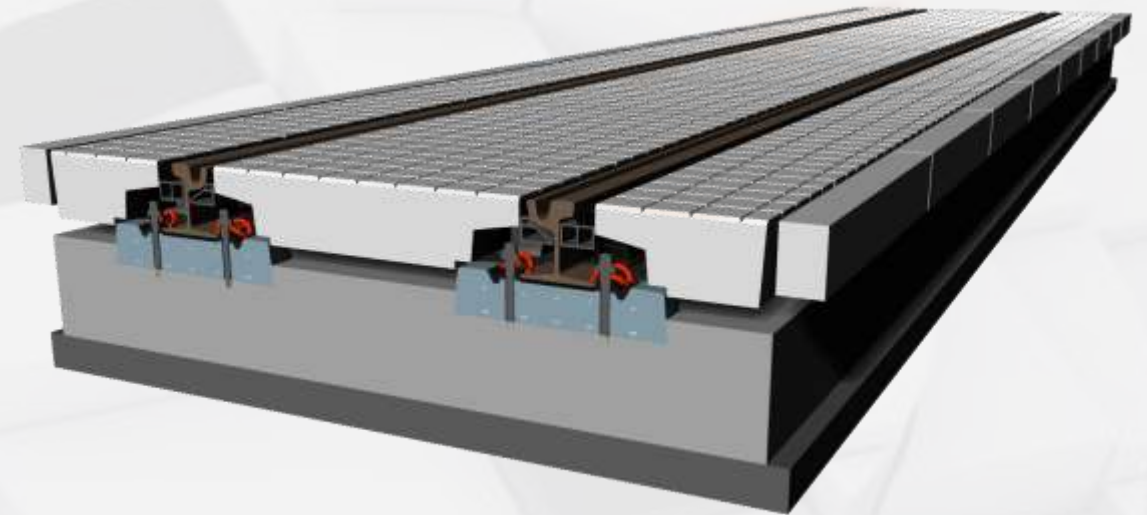
Zagreb Tram Network

- Faculty of Civil Engineering considered **5 fastening systems options**
- **2 track structures** were chosen for further development:

Zagreb 21-CTT (“Classic Tram Track”)

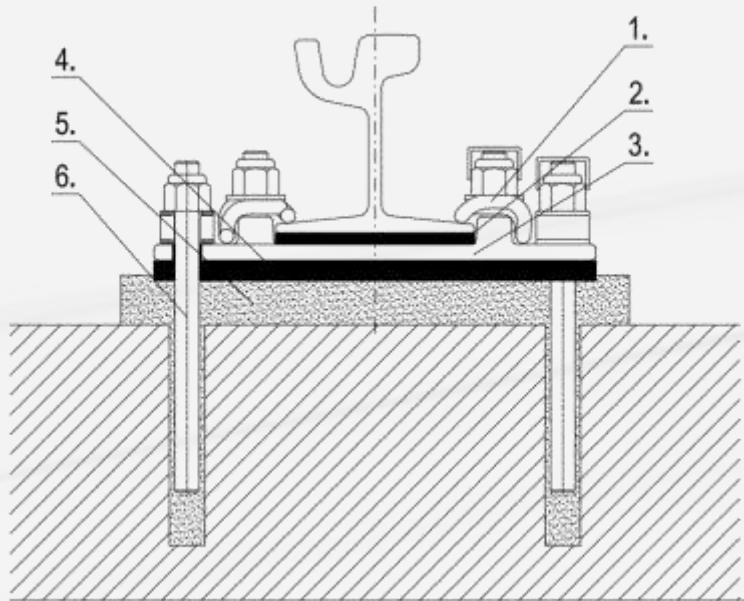


Zagreb 21-STT (“Slab Tram Track”)

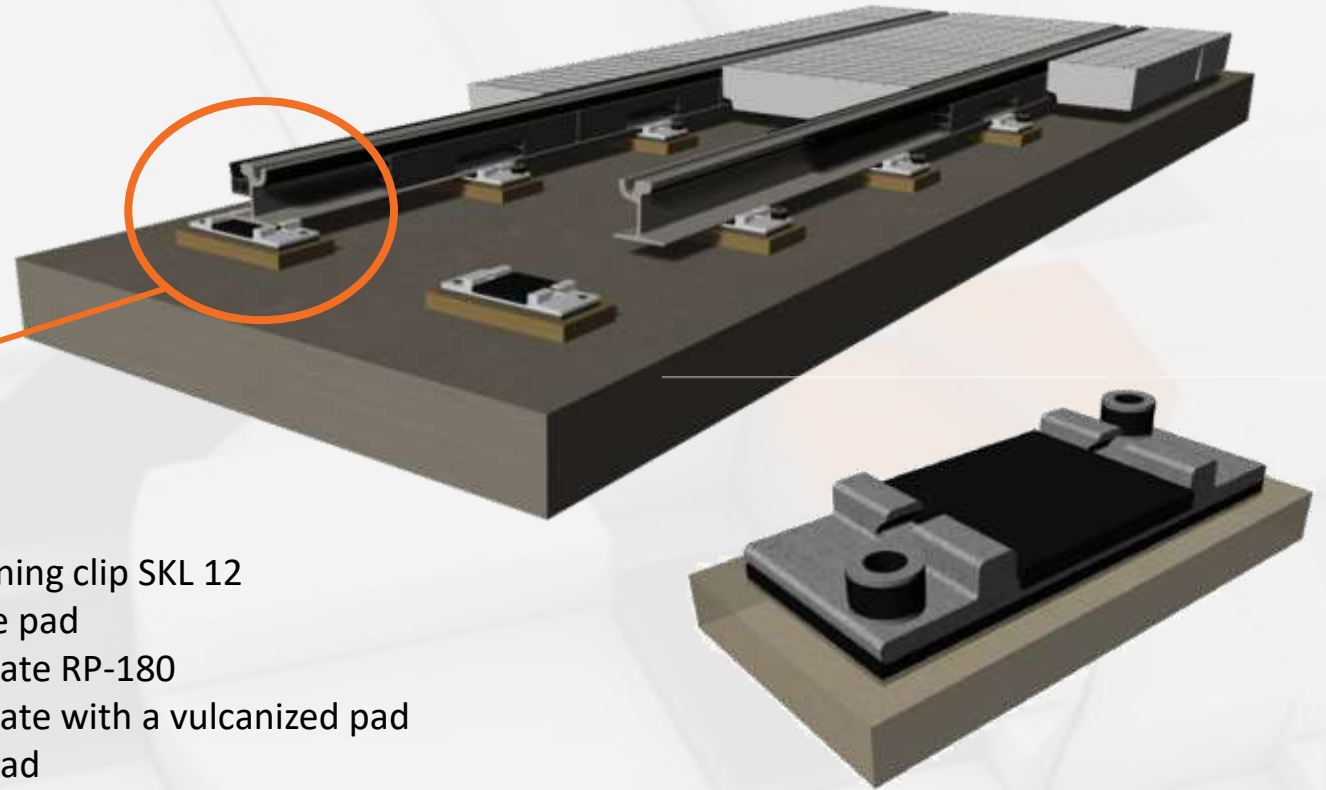


Zagreb 21-CTT structure

- Slab track structure with **discrete sleepers**
- Suitable for: **reconstruction of existing slab tracks + road/rail intersections + switch and terminus areas**
 - Upgrade of Zagreb 3/2 PPE fastening system
 - Easily available, standard railway components
 - Reduction of noise and vibrations
 - Protection against stray currents

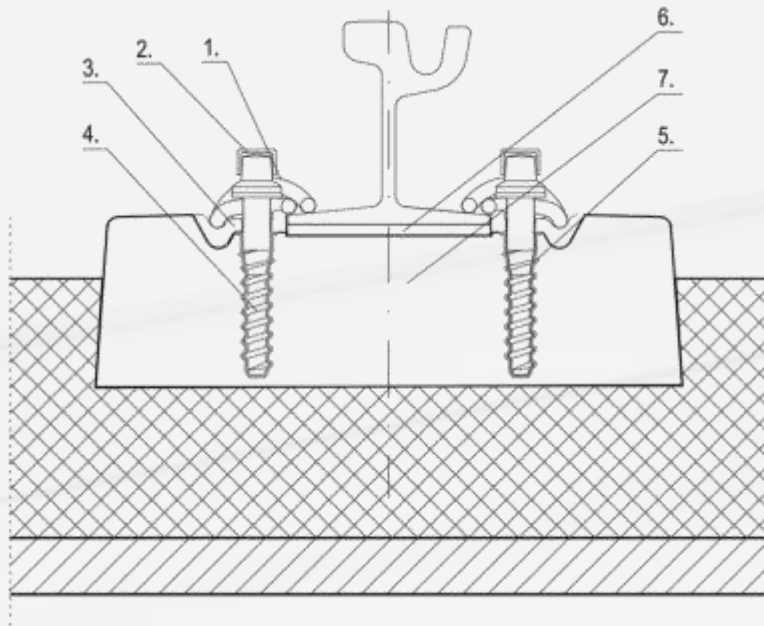


1. Rail fastening clip SKL 12
2. Neoprene pad
3. Ribbed plate RP-180
4. Ribbed plate with a vulcanized pad
5. Bearing pad
6. Indirectly fastened anchor bolt

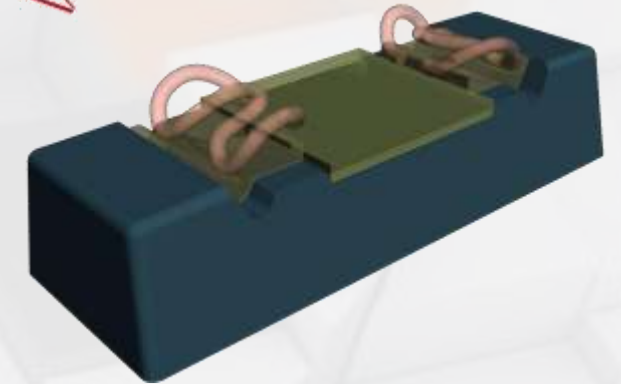


Zagreb 21-STT structure

- Slab track structure with **prefabricated, double-block concrete sleepers**
- Suitable for **open track segments** where higher speeds are achieved
 - Based on the Rheda 2000 track system
 - Adjusted track geometry, loads, vehicle speed



1. Rail fastening clip SKL 12
2. Protective plastic cap
3. Angle plate Wfp 14K
4. Tirfon screw Ss 35 with ULS7 washer
5. Tirfon screw dowel
6. Neoprene pad
7. Discrete concrete sleeper



Zagreb 21-STT structure

- Slab track structure with **prefabricated, double-block concrete sleepers**
 - Can be **pre-assembled (18 m segments)** with the corresponding fastening systems in the workshop, then delivered to the construction site
 - Developed tools for adjusting track alignment



Savska road – test section

- 2014 – 3 test sections
 - 55 m – Zagreb 3/2 PPE – reference track
 - 59 m – Zagreb 21-CTT – “Classic Tram Track”
 - 53 m – Zagreb 21-STT – “Slab Tram Track”
- Followed by 11 years of periodic monitoring



Savska road – test section

Zagreb 21-CTT – “Classic Tram Track”



Savska road – test section

Zagreb 21-STT – “Slab Tram Track”



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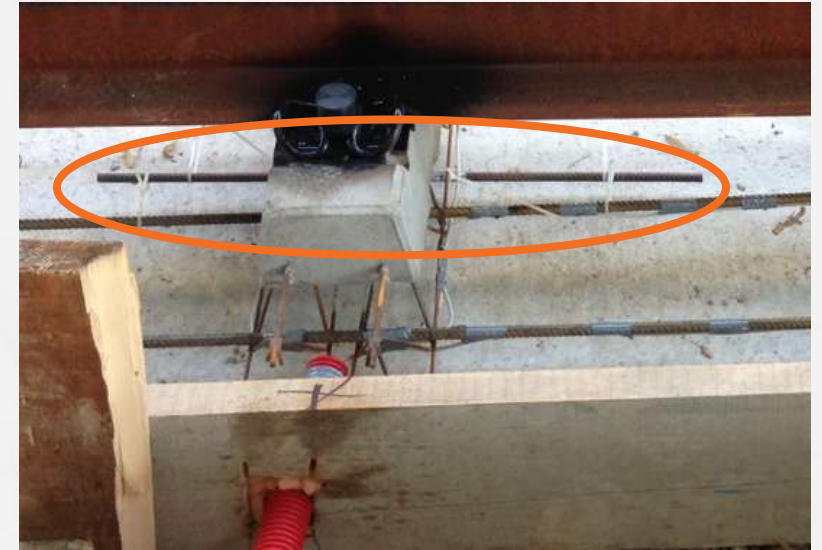
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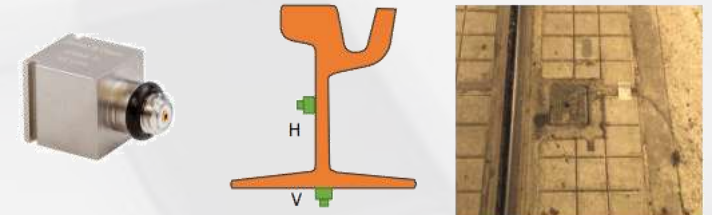
Savska road – test section

- **Measurements were taken:**

- immediately after installation – **8/2014**
- after 7 months of exploitation – **3/2015**
- after 4 years of exploitation – **10/2018**
(39,3 million gross tons)



- **Visual inspection** of the condition of the concrete slab, bearings, fastening components, rails, pavement, and elastomeric pads;
- **Measurements of:**
 - track geometry,
 - weld geometry,
 - stresses and deformations of the reinforced concrete slab → **strain gauges**
 - dynamic properties of the track (vibration damping) → **accelerometers**
 - noise generation



Savska road – monitoring results

Measurement	Results		
	PPE	CTT	STT
Track geometry [increase in track gauge (mm)]	1,18	1,61	0,92
Max. longitudinal stresses (MPa)	3,33	2,26	0,86
Max. transverse stresses (Mpa)	2,25	1,14	1,01
Track Decay Rate (dB/m)	+	++	+++
Noise generation [L_{Aeq} (dB)]	87,3	86,3	84,4



Savska road – monitoring results

- Results for **Zagreb 21-CTT system** were **similar** to those of **Zagreb 3/2 PPE** – coincidental with the fact that CTT is an upgrade of Zagreb 3/2 PPE fastening system

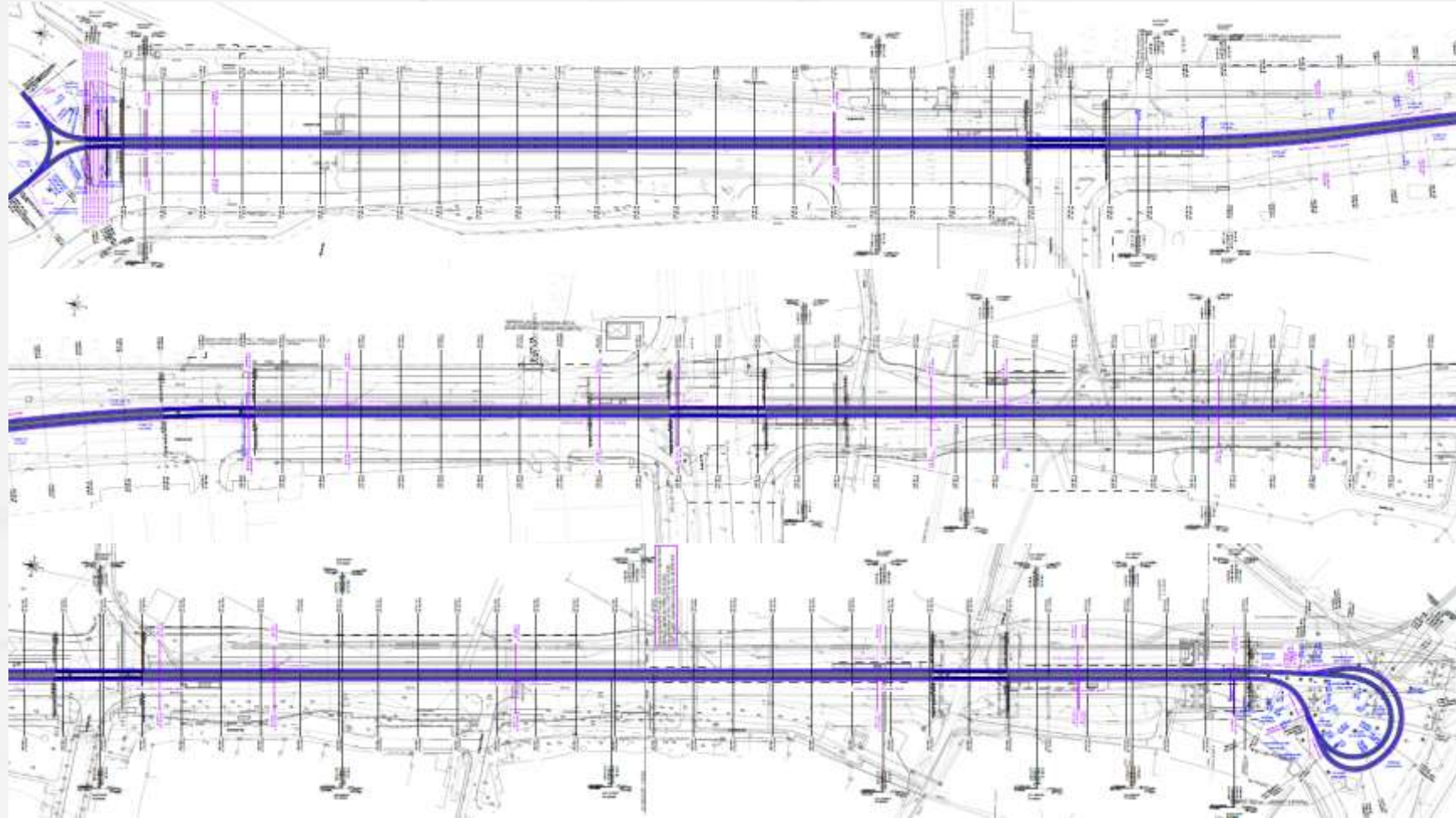
- Zagreb 21-STT exhibited the best results** regarding:
 - track geometry
 - maximum stresses
 - noise generation

Property	Zagreb 21-CTT	Zagreb 21-STT
Installation speed	=	+
Cost	+	++
Protection against stray currents	++	+
Maintenance	=	+
Durability	+	++
Vibration propagation	+	=
Noise propagation	+	+
= property similar to the PPE system		
+ positive improvement compared to the PPE system		

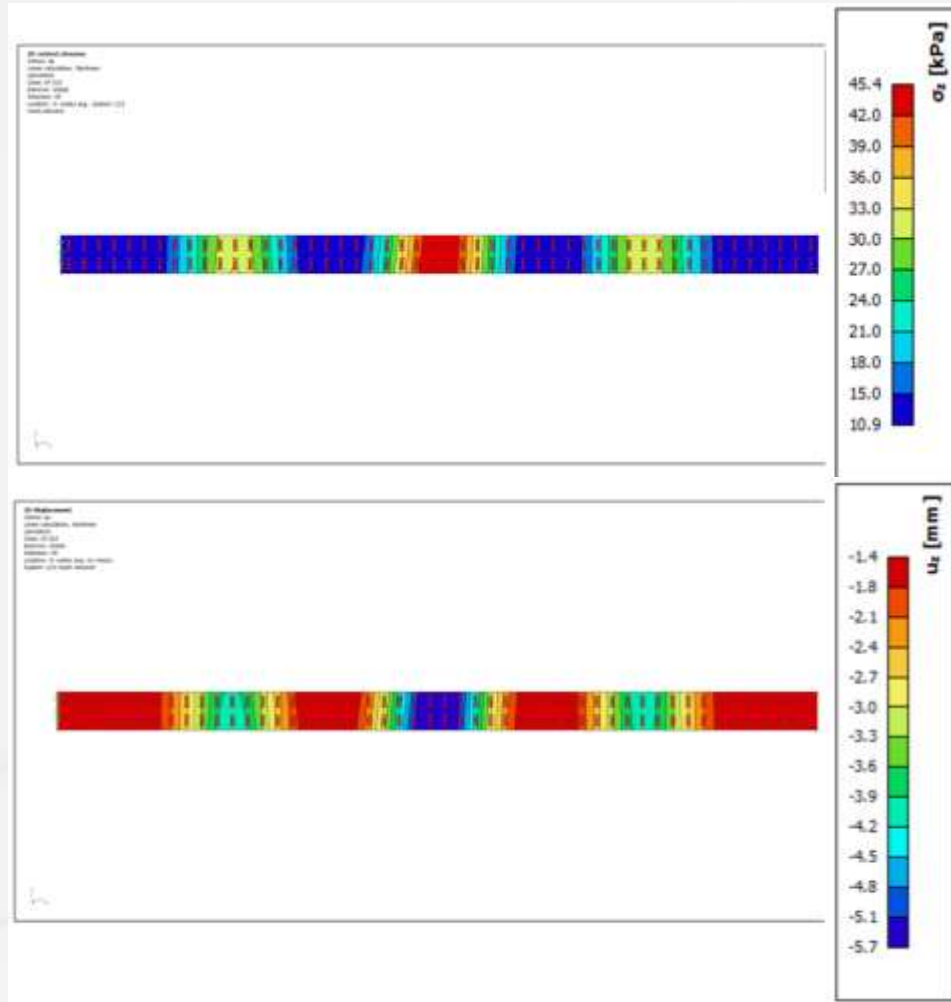


Sarajevska road - implementation

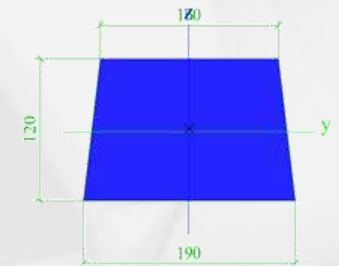
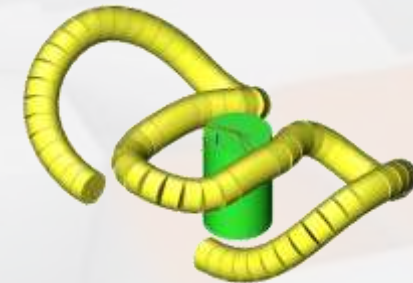
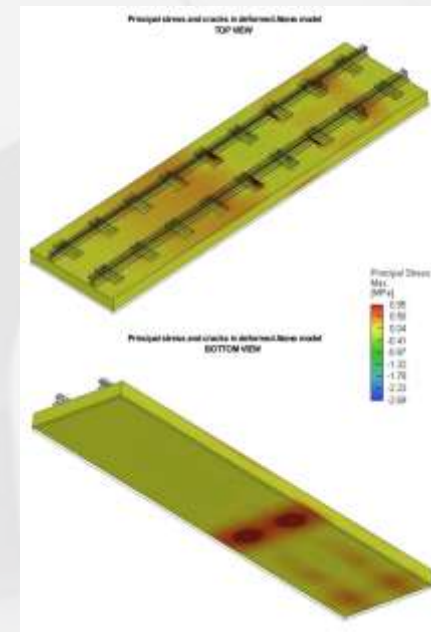
- Started in 3/2025
- The first expansion of the tram network after **20 years**
- **2,4 km** of tram track
- Min. radius **18 m**
- Max. slope **35 mm/m**
- **8 tram stops + new terminus**
- **4 switches**
- **3 track systems**
 - Zagreb 3/2 PPE – 2 %
 - **Zagreb 21-CTT – 10 %**
 - **Zagreb 21-STT – 88 %**



Sarajevska road - Calculation of the load-bearing capacity of the track structure



- Track structure with a reinforced concrete slab **23 cm thick** and **200 cm wide**
- The considered track section has a length of **40 m**
- Selected sleeper spacing **80 cm**
- Bottom slab reinforcement **B500B $\varnothing 14/20$ cm**
- Concrete slab reinforced with polypropylene microfibers (**5 kg/m³**)



Sarajevska road - implementation



Project URITMIS

Goal:

Implementation of digital twin technology for predictive maintenance of tram tracks in Zagreb

- Real-time vibration data is collected from an **in-service, sensor-equipped tram vehicle** operating on the Zagreb network
- Large datasets, machine learning techniques and digital twin technology → detection of irregularities and defects at various stages of degradation → **predictive maintenance**



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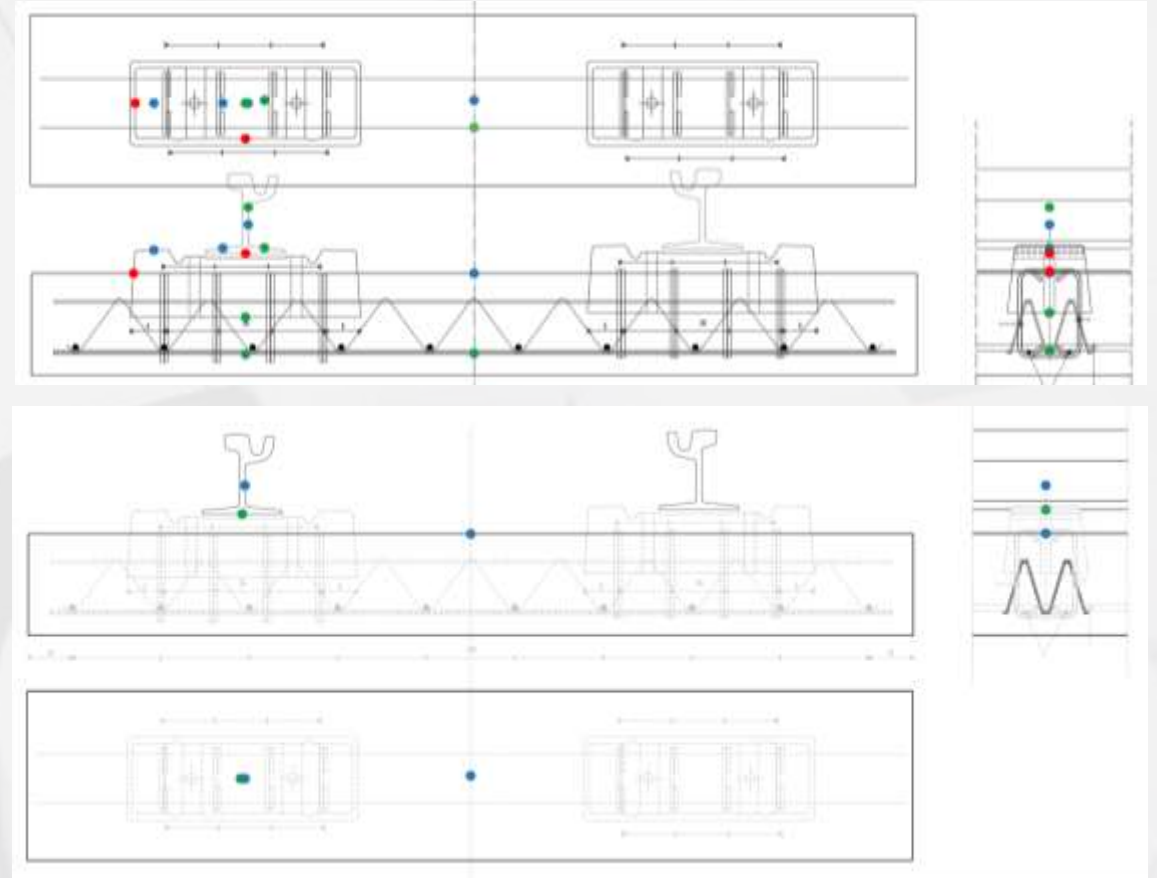
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Future plans

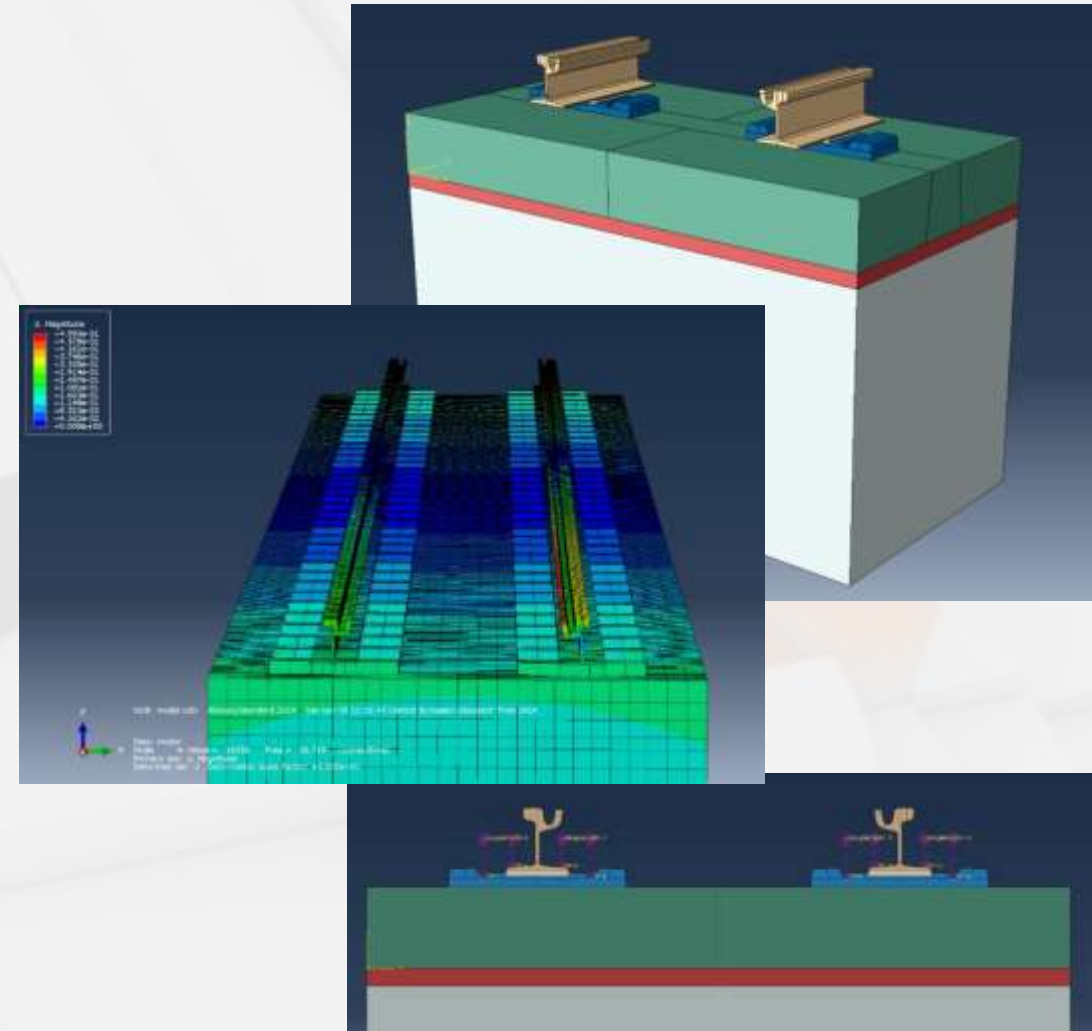
- Plan for continuous monitoring of Zagreb 21-STT slab track structure – **SMART SLEEPER**
- **Accelerometers, strain gauge, velostat → input information for the numerical model**
- Cross-section placement: **mid-span + the bearing**
- Appropriate track section for **sensor placement**

Measurements obtained with the in-service tram + track instrumentation → **comprehensive insight into track behavior**



Future plans

- Building a **numerical model of Zagreb 21-STT** track structure
- Model **verification** → currently in progress
 - **Parameter definition + Sensitivity analysis**
 - Slab thickness, stiffness/damping, sleeper spacing...
- Model **calibration** → using measurements obtained from continuous monitoring
- Model **validation** → verification of the model's predictive capability under new conditions → **predictive maintenance**



Concluding remarks

- Zagreb 21-STT system after 10 years of monitoring → **durable and resilient system**
- Prefabricated sleepers and modular 18 m segments → **efficient installation and maintenance**
- Supports **heavy, frequent traffic** → ideal for **urban tram networks**
- **Successful deployment** along Savska and Sarajevska roads → **scalability and cost-effectiveness**
- **Digital twin integration and continuous monitoring (will) enable predictive maintenance**
- **Cost reduction, increased operational safety, improved comfort and reliability of transport**



Thank You for Your attention! 😊

Comments, questions, advice...



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