



Fast strength-gaining SFR-SCC for tunnel retrofitting: a LCA comparison between traditional and innovative approaches

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Statement of the problem

EUR 5 bn: cumulated investments in heavy rehabilitation work on existing tunnels (equal to around 300 km estimated at an average cost of 15-20MEUR/km) estimated in 2022-26



HIGHWAYS

- 1,500 km:** Italian Tunnelling network (#1 in Europe)
- 1,000 km:** more than 20 yrs old and need heavy maintenance
- 500 km:** risk of collapse ² *² industry estimates*
- 210 Tunnels under watch:** high risk of collapse ³ *³ MIT/CSLP*

RAILWAYS

- 1,240 km:** built in 1870-1920 ²
- 1,000 km:** 70% of total railways tunnels not concrete ²

Statement of the problem

a lack of critical infrastructures in heavy populated and industrialized areas in Italy, generates as a loss in the GDP of the same area of **36,000 Eur/km/day** (Università Carlo Cattaneo)



Every year road interruptions and traffic congestion delays cost an average of > EUR 3500/household (ASCE)

Current «state of art» tunnel retrofitting

SCRAPING



TEMPORARY WORKS



Current «state of art» tunnel retrofitting

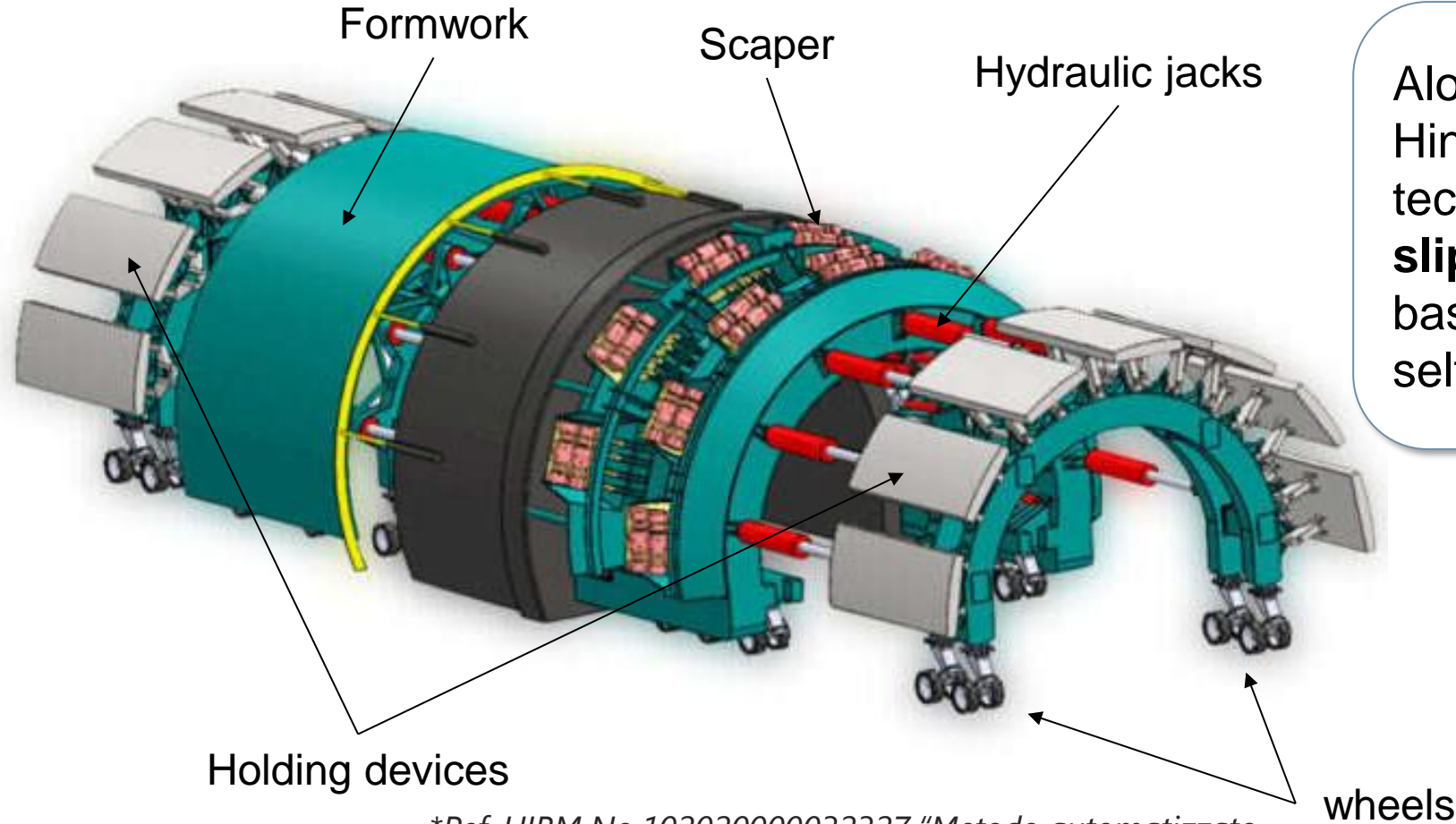
NEW LINING – CAST IN PLACE



NEW LINING – PARTIALLY PRECAST



“Horizontal slipforming” solution



Along with the start-up company Hinfra we have been developing a technology based on **horizontal slipforming** of **tunnel** linings, based of “fast strength gaining” self compacting FRC

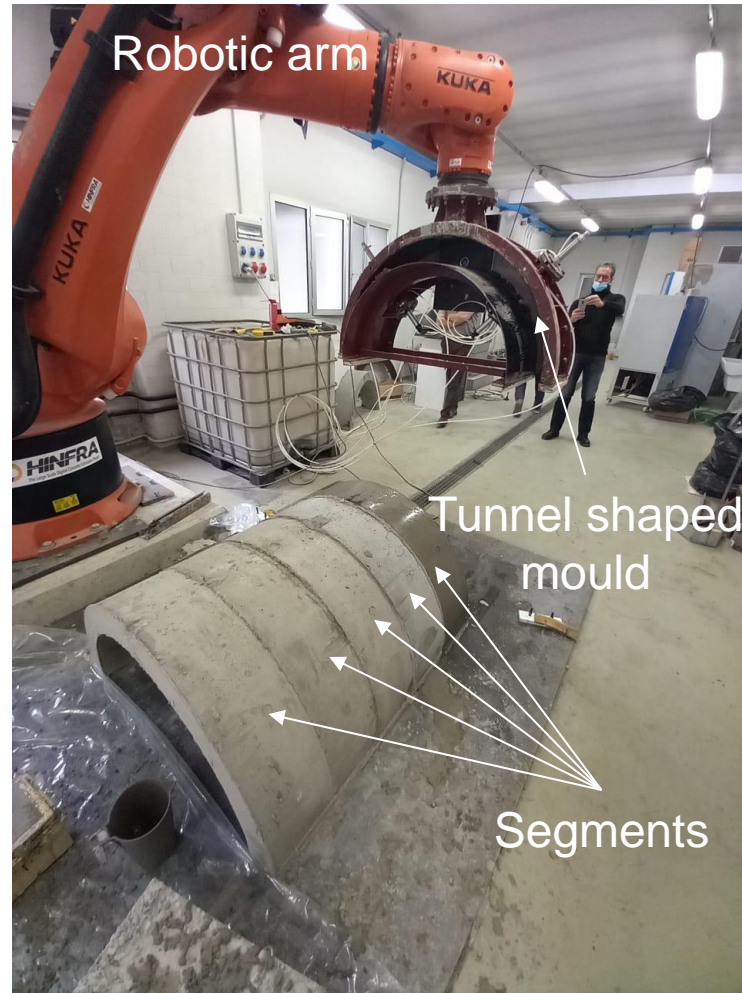


Patented technology* **Ref. UIBM No.102020000032327 “Metodo automatizzato e treno di lavorazione per il rivestimento gallerie”*

Small Scale Validation



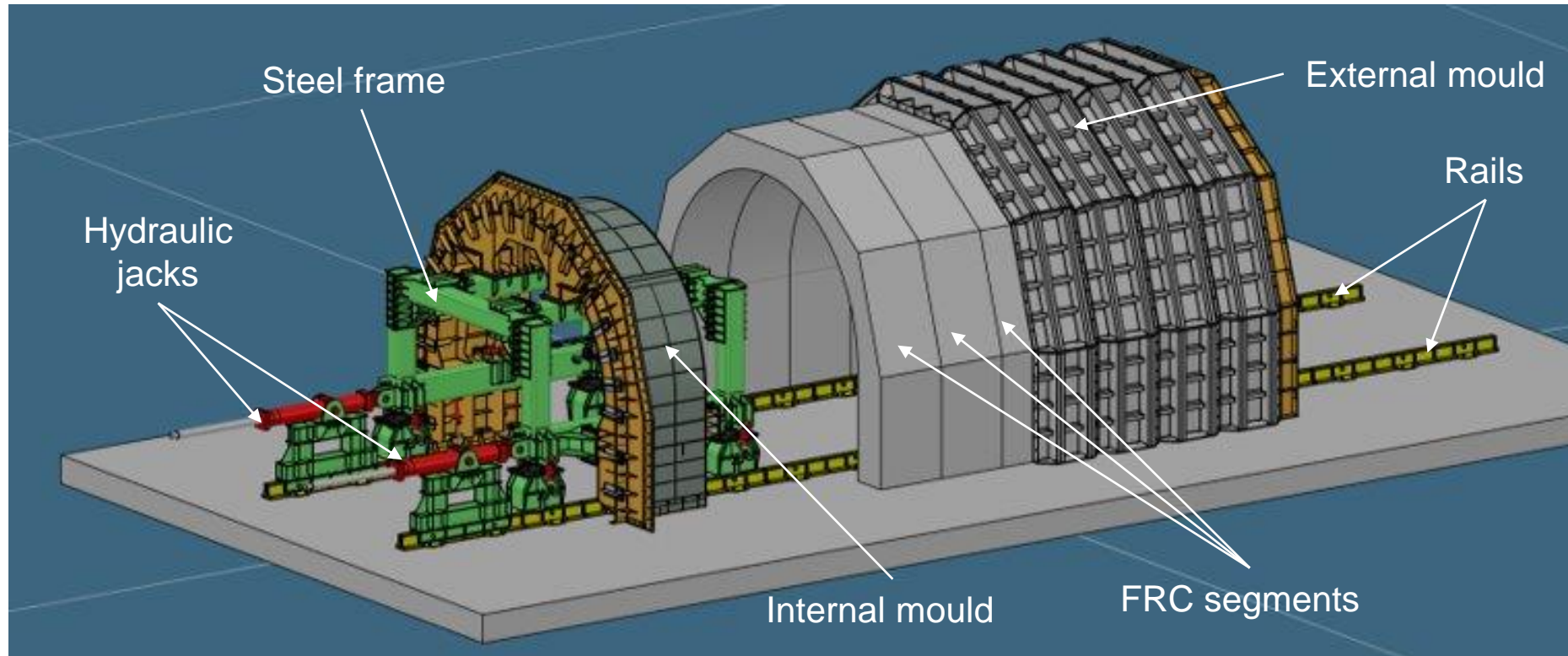
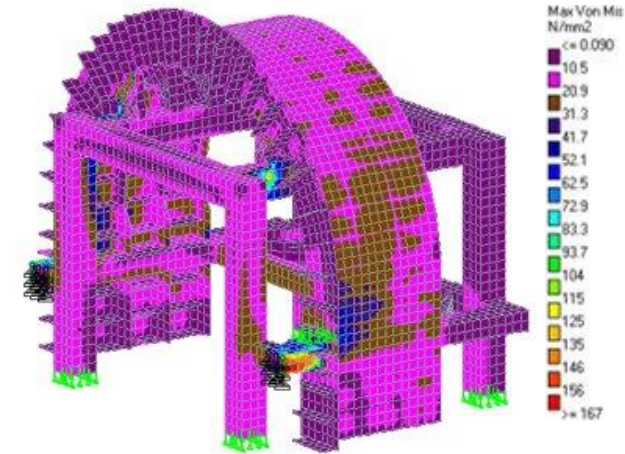
Preliminary small scale extrusions have been done by means of a **robotic arm** to validate the feasibility of the technology.



Full Scale Validation



“quasi full scale” mock-up validation on test - site



Process and material requirements

Material is **pumped** up to the key of the internal mould, from which it flows down to the bottom. As soon as the mould is filled and concrete has achieved a sufficient level of strength, the system moves, slip-forming **SFRC** tunnel segments.



«Very early age» mechanical characterization

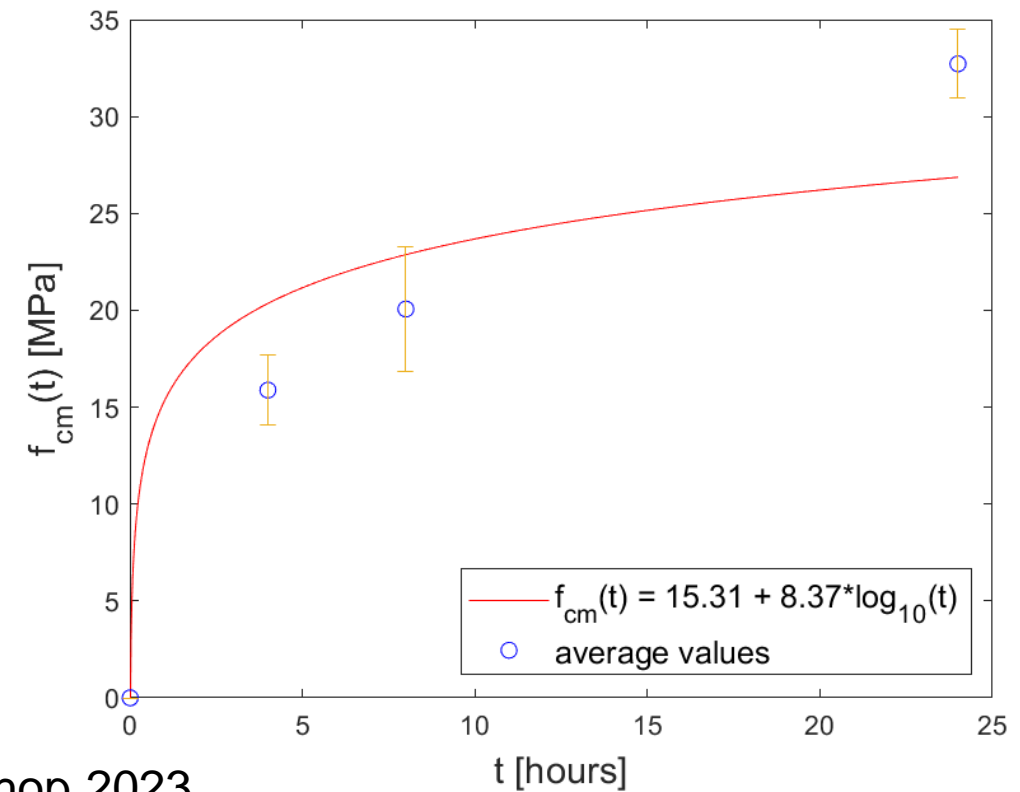
Due to the presence of CSA in the binder composition the concrete is characterized by a very **fast strength gain**.



1h

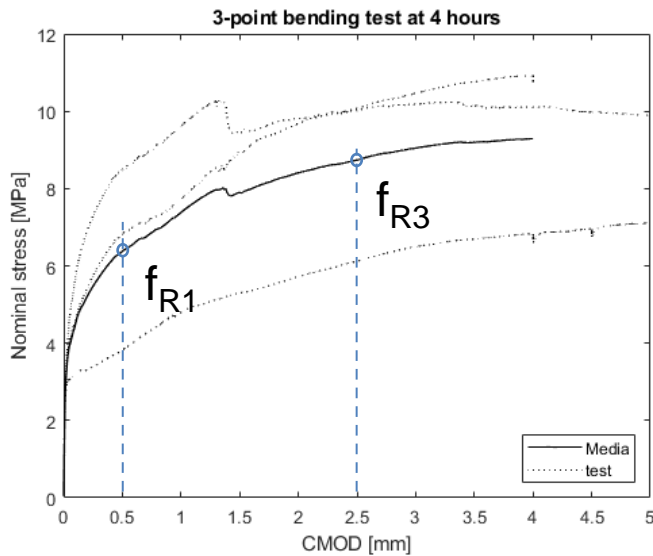


Ferrara et al., ACI-fib FRC workshop 2023

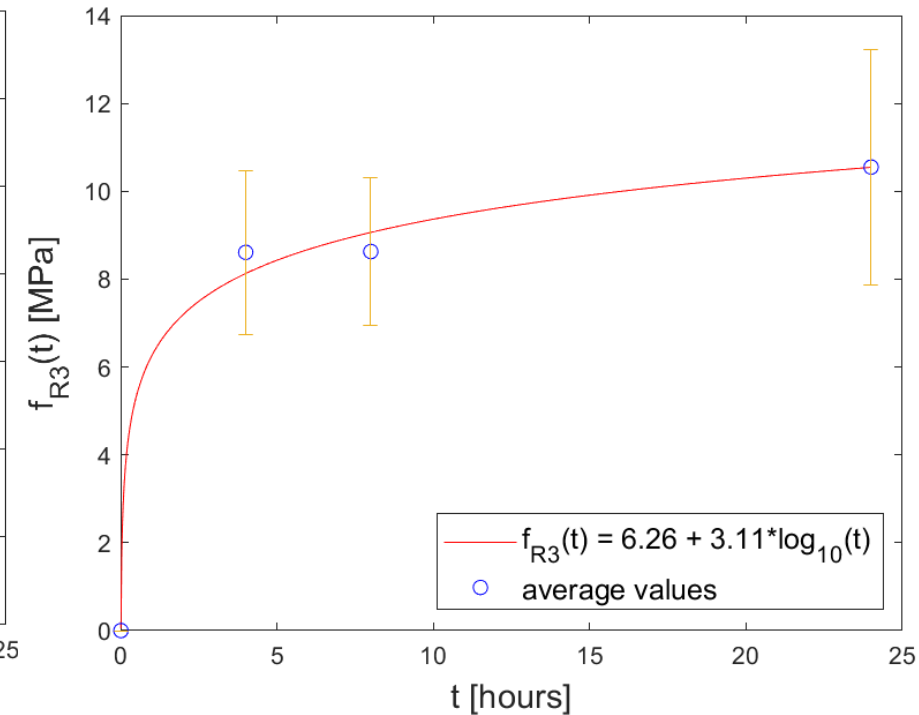
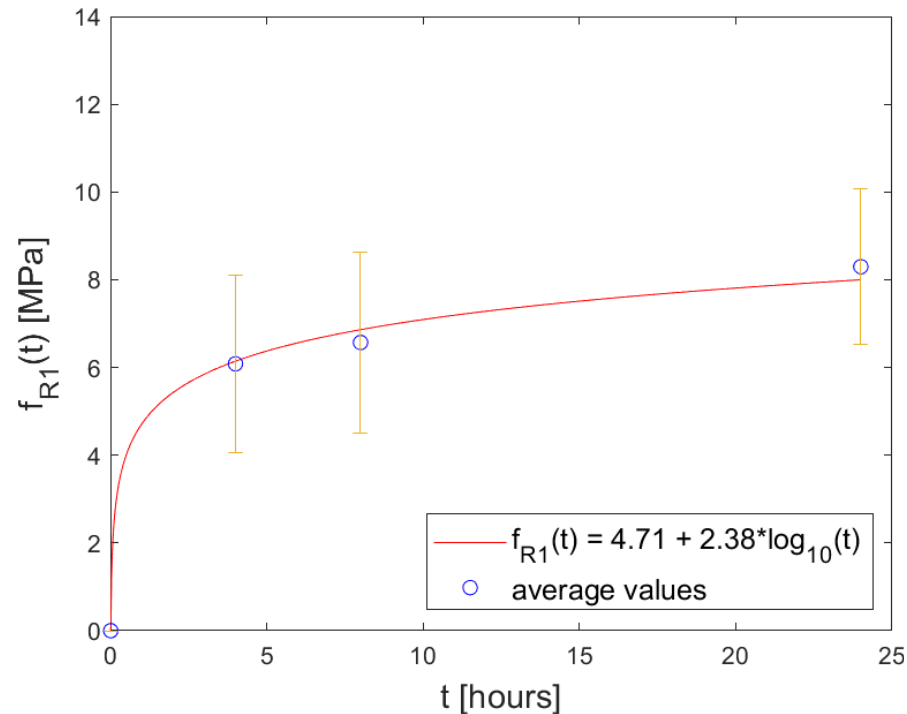


«Very early age» mechanical characterization

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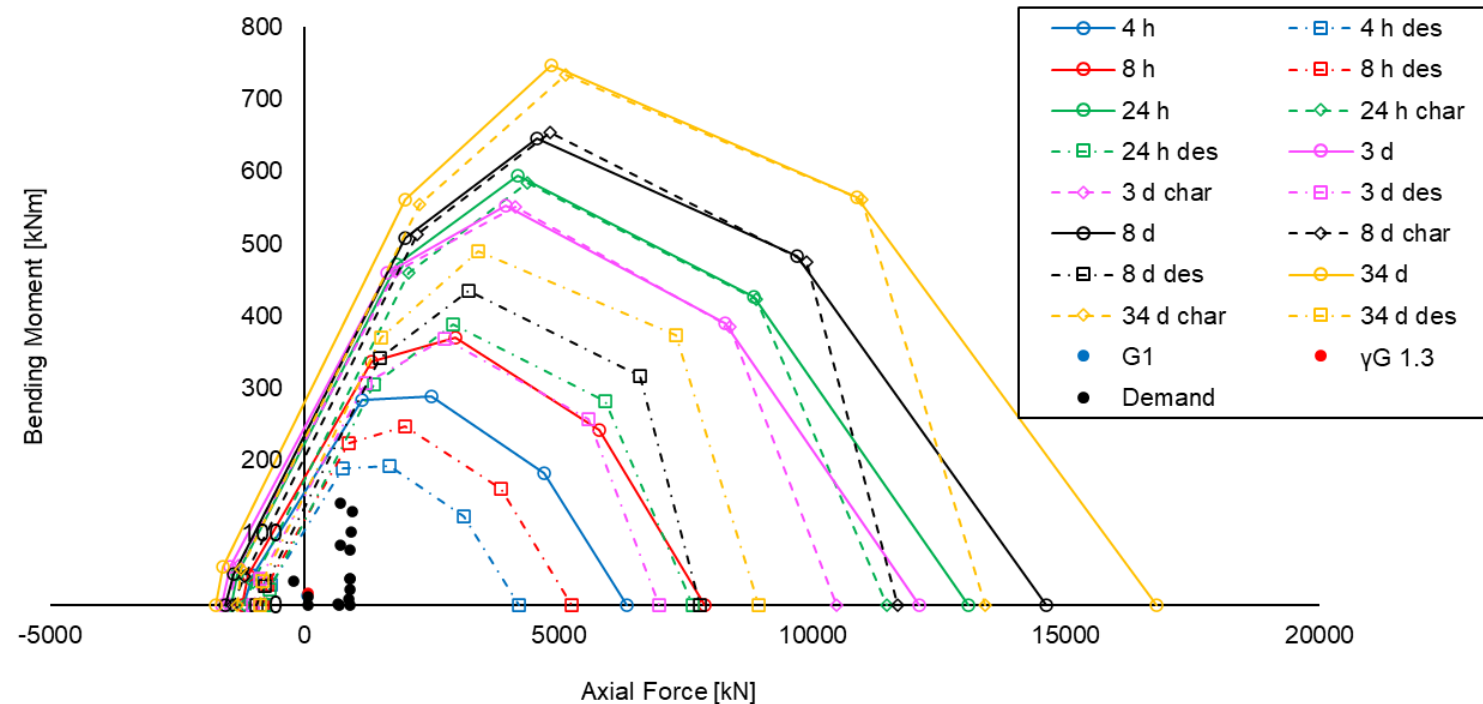
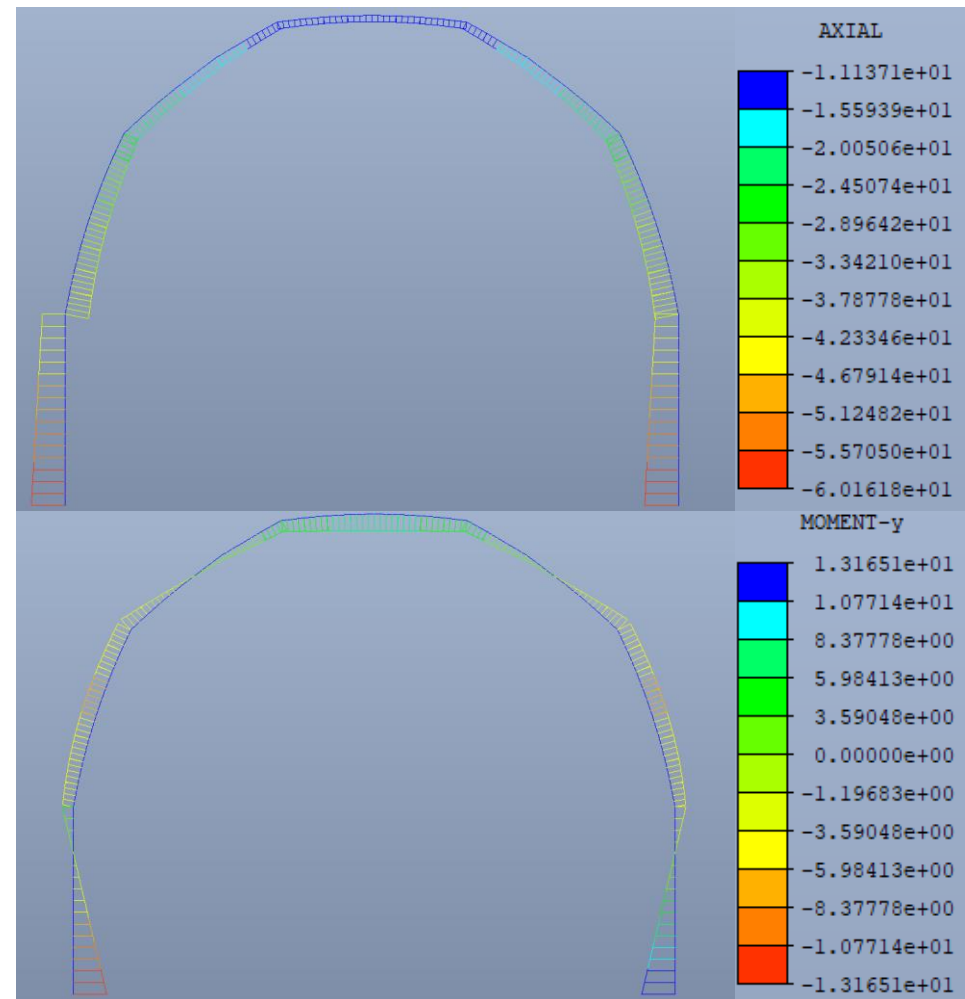


Class 3e at 4h
Class 4e at 8h
Class 6d at 24h



Ferrara et al., ACI-fib FRC workshop 2023

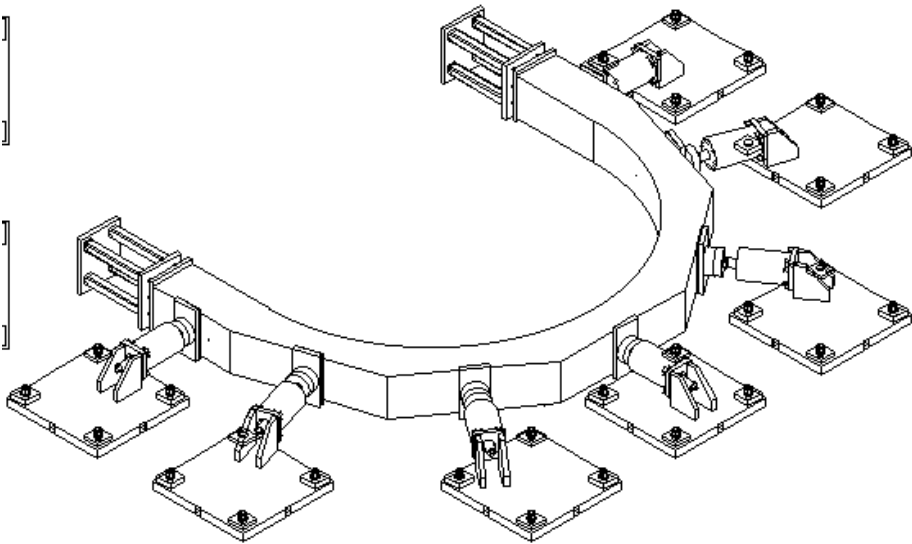
«Very early age» structural design



At 4h safety guaranteed for self-weight as well as for accidental failure of the existing lining (transmitting all the actions to the new one)

Ferrara et al., ACI-fib FRC workshop 2023

Full scale structural design validation



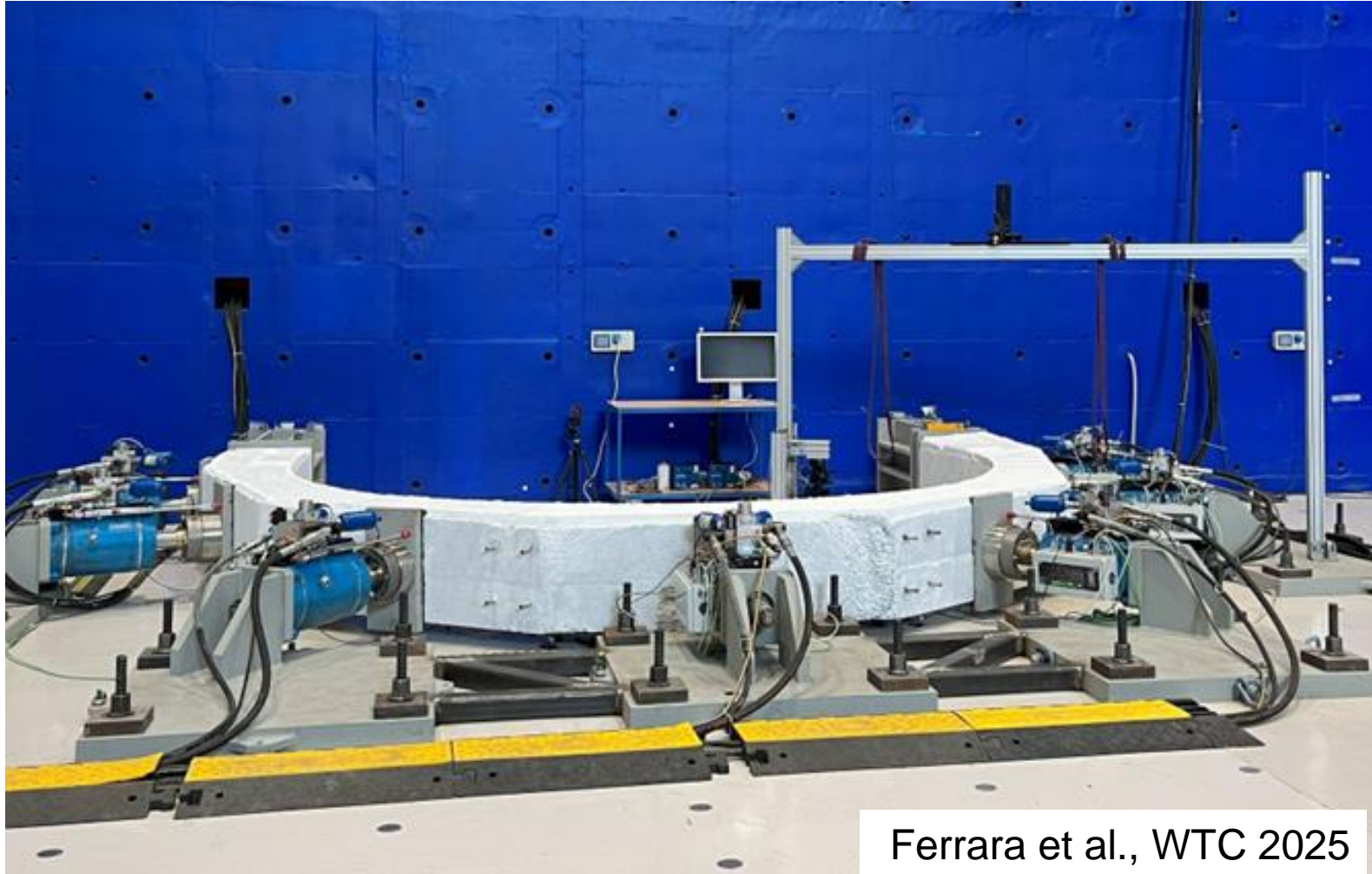
POLITECNICO
MILANO 1863



Politecnico
di Torino

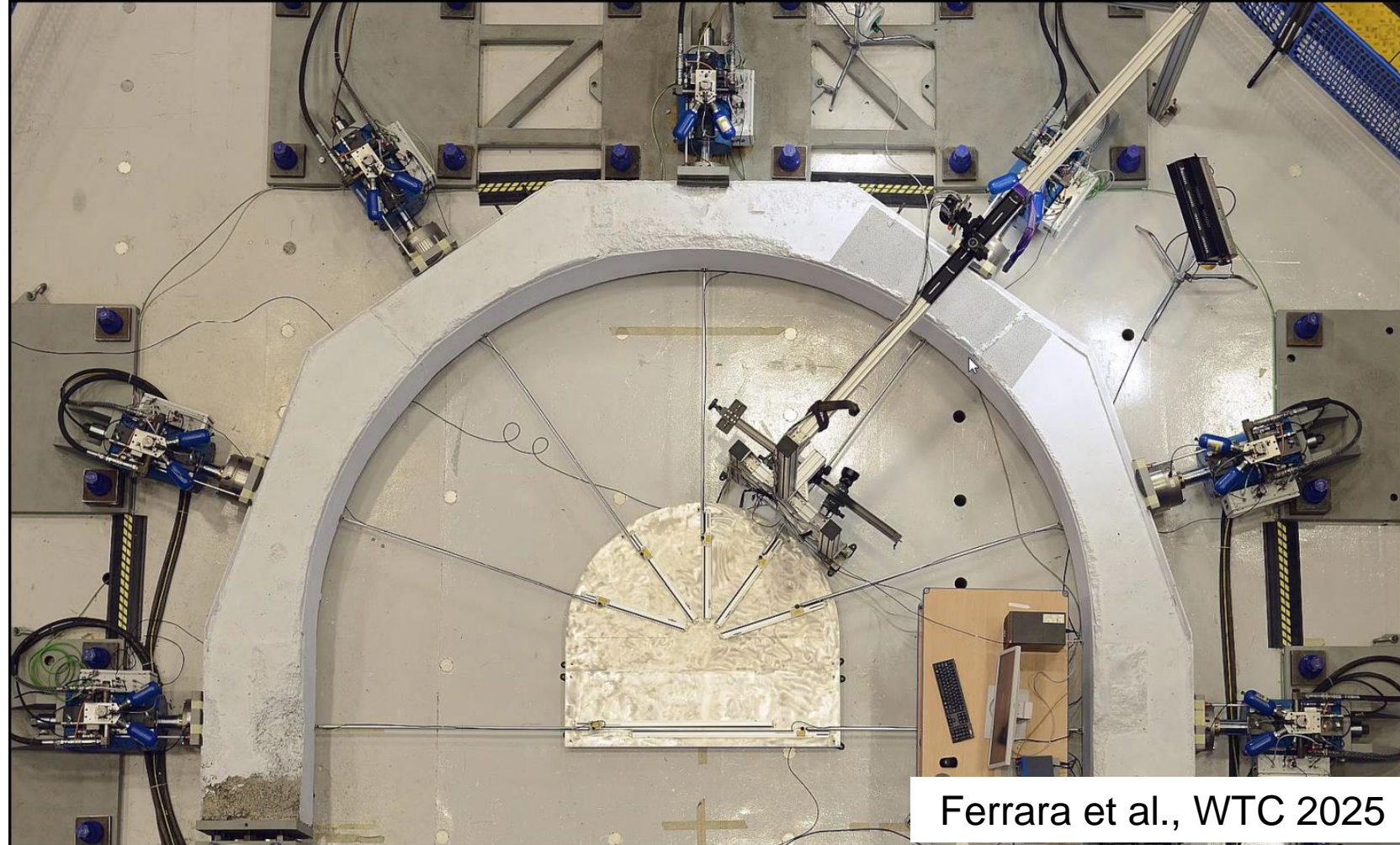
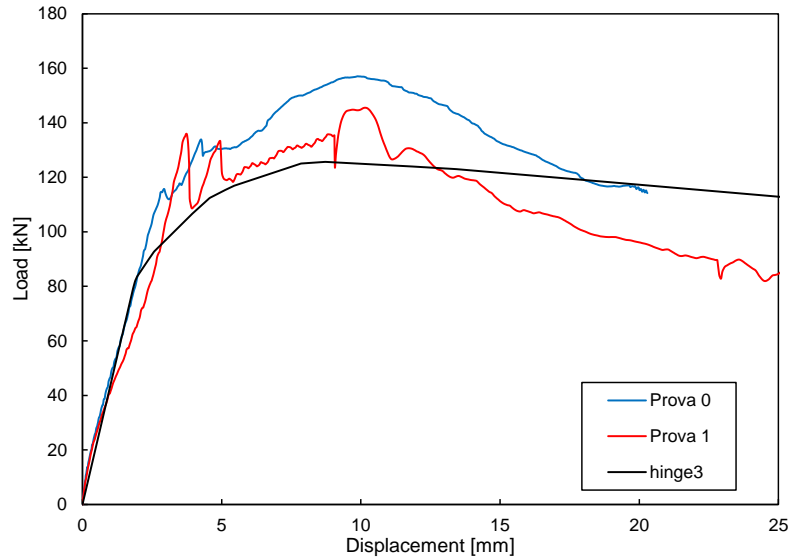


PROJECT OPENLAB ETLR 19-1



Ferrara et al., WTC 2025

Full scale structural design validation



Ferrara et al., WTC 2025



PROJECT OPENLAB ETLR 19-1

Full scale structural design validation



POLITECNICO
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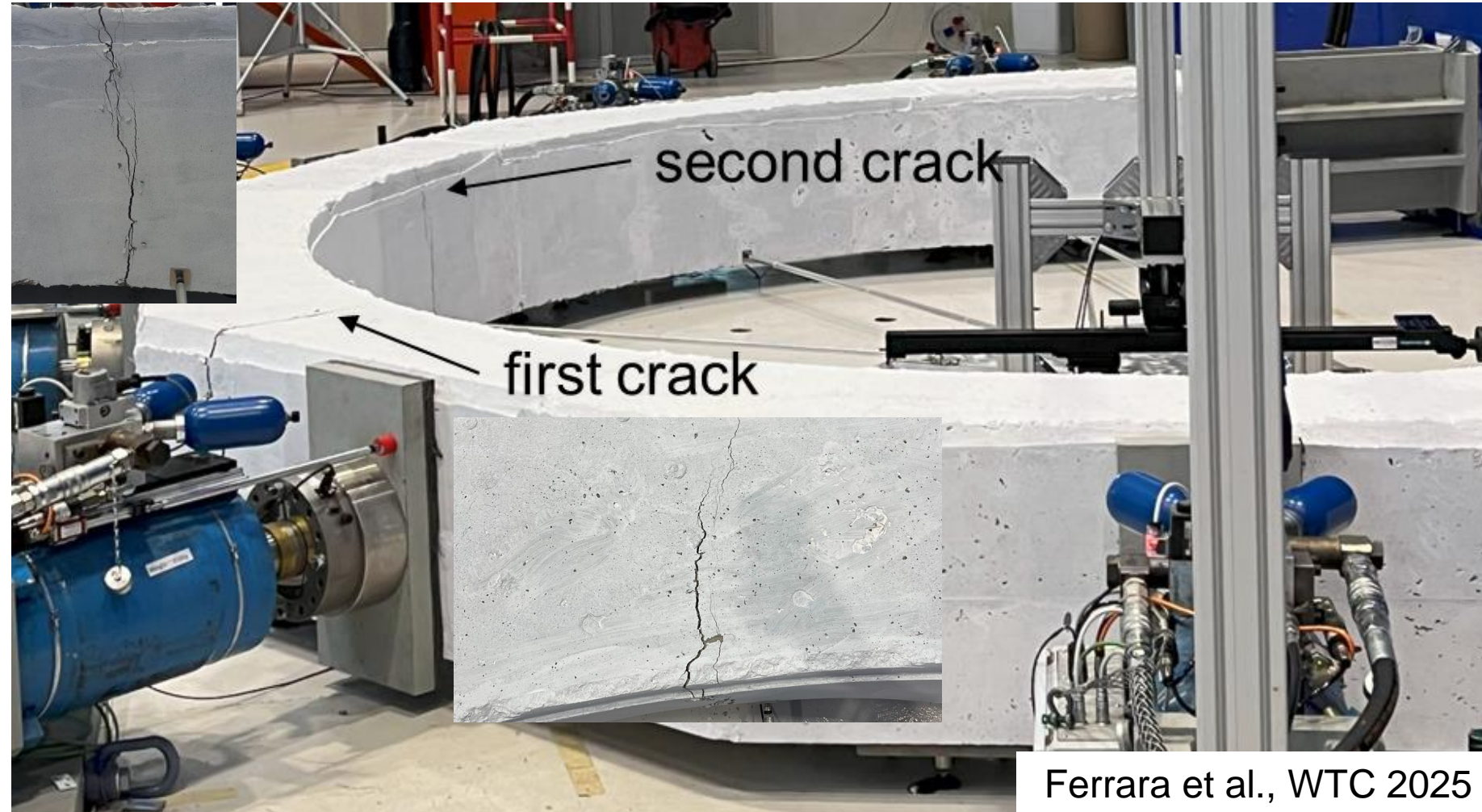


Joint Research Centre

The European Commission's science and knowledge service

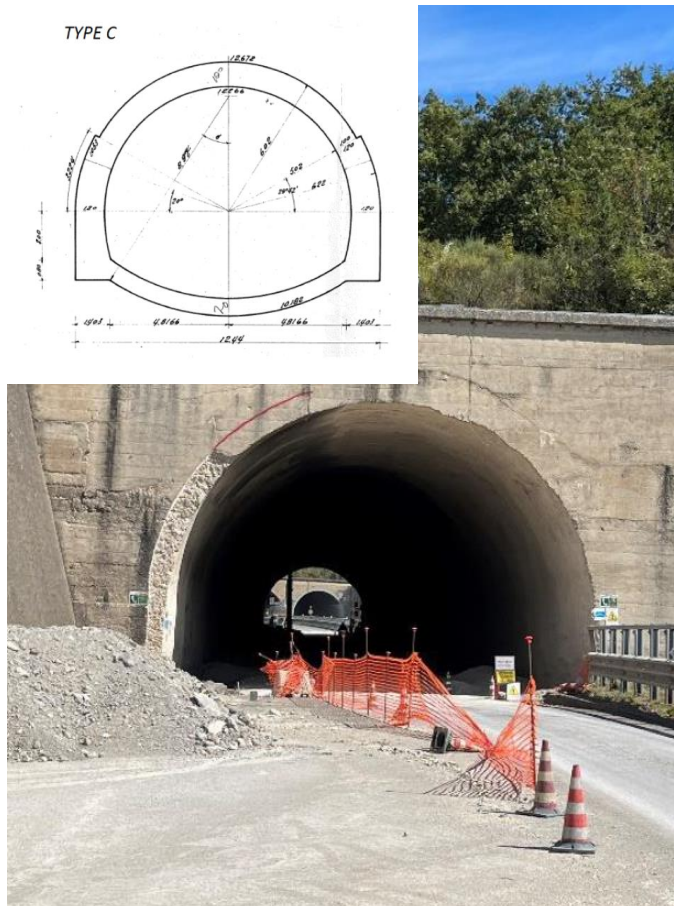
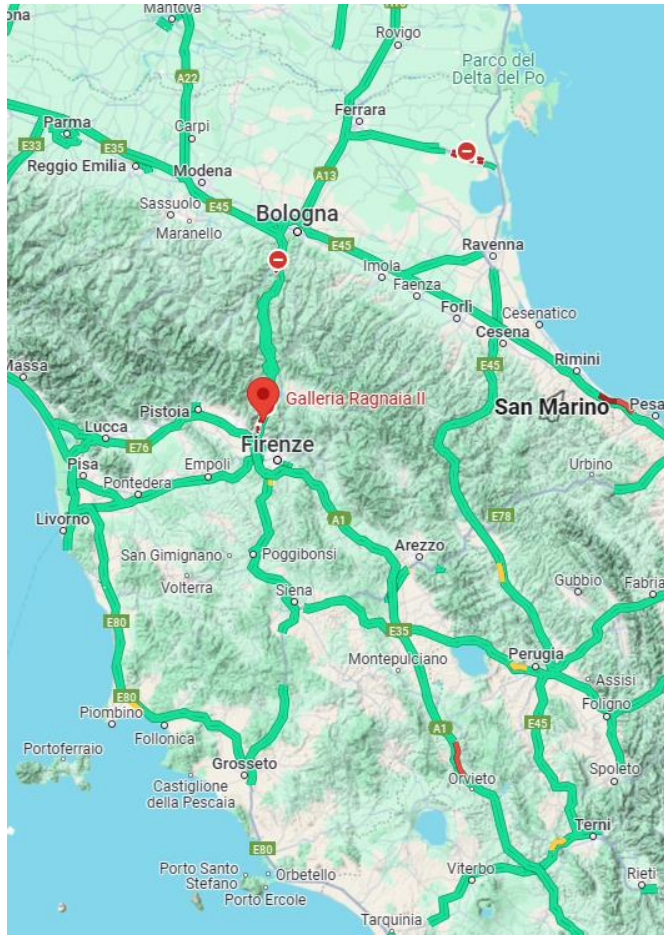


PROJECT
OPENLAB ETLR 19-1



Ferrara et al., WTC 2025

A real case study



Case of study: Ragnaia II, Tunnel of the A1 Italian highway.

128 m long and 60 years old concrete
12 m diameter excavated with traditional
method.



NEED OF MAINTENANCE INTERVENTION

Traditional

Innovative

Marcucci et al., RILEM Spring 2024

A real case study: traditional solution

Materials

Concrete C45/55

f_{ck}	45	MPa
Exposure class	XD1/XF2	-
Cover	40	mm

Steel reinforcements B450C

f_{yk}	450	MPa
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Construction phases

Phase	Description	Duration
0	Injection before milling	4 d
1	Demolition of sidewalks	24 d
2	Milling final coating	44 d
3	Levelling layer and foundation curb	24 d
4	Drainage system and waterproofing	28 d
5	Mounting of reinforcements	44 d
6	Casting concrete	44 d
7	Remaking sidewalks	28 d
8	Painting and road refurbishment	10 d
Total		250 d

Marcucci et al., RILEM Spring 2024

A real case study: fast strength-gaining FRCSCC

Material: SFRC —————> no concrete cover!!

Concrete C50/60		
f_{ck}	50	MPa
Exposure class	XD1/XF2	-
Toughness class	6.0d	-
Steel fibers 3D Dramix		
dosage	40	Kg/m ³

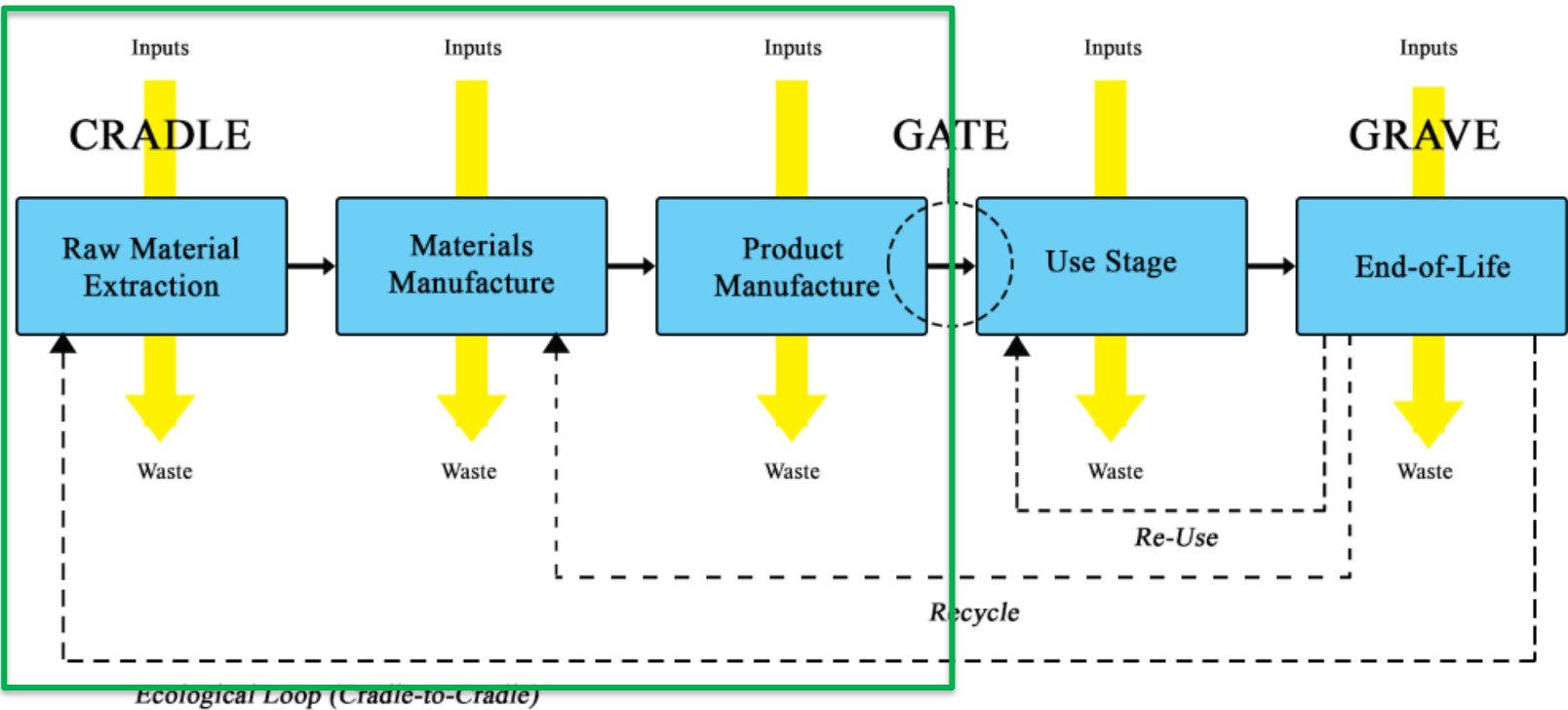
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Construction phases

Phase	Description	Duration
0	Injection before milling	4 d
1	Demolition of sidewalks	24 d
2	Milling final coating	44 d
3	Levelling layer and foundation curb	24 d
4	Drainage system and waterproofing	28 d
5	Mounting of reinforcements at pillars	15 d
6	Casting concrete	22 d
7	Remaking sidewalks	28 d
8	Painting and road refurbishment	10 d
Total		199 d

A real case study: comparative LCA

The material effect



4% saving on GWP?

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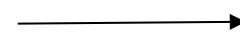
Impact category	GWP-total (kg CO2 eq)	Impact category	GWP-total (kg CO2 eq)
Reinforcing steel	1.56E+05	SFRC (HCA-1)	5.46E+05
Concrete classic solution	4.17E+05		
Waterproof surface	2.65E+04		
Grouting of steel bars	9.44E+03	Grouting of steel bars	9.44E+03
Protection for concrete surfaces	2.37E+04	Protection for concrete surfaces	2.37E+04
Pre-mixed mortar	1.17E+04	Pre-mixed mortar	1.17E+04
Formwork for single cast tunnel	3.07E+03	Formwork for single cast tunnel	3.07E+03
Formwork for tunnel head	1.00E+01	Formwork for tunnel head	1.00E+01
Geotextile sheets	3.12E+02	Geotextile sheets	3.12E+02
Painting cycle	5.99E+03	Painting cycle	5.99E+03
Sprayed concrete	5.00E+00	Sprayed concrete	5.00E+00
Profile for sealing joints	5.99E+00	Profile for sealing joints	5.99E+00
Total	6.53E+05	Total	6.27E+05

A real case study: comparative LCA

The duration of the job-site effect

TRADITIONAL

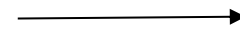
5	Mounting of reinforcements	44 d
6	Casting concrete	44 d



Duration of 88 days!

INNOVATIVE

5	Mounting of reinforcements at pillars	15 d
6	Casting concrete	22 d



Duration of 37 days!

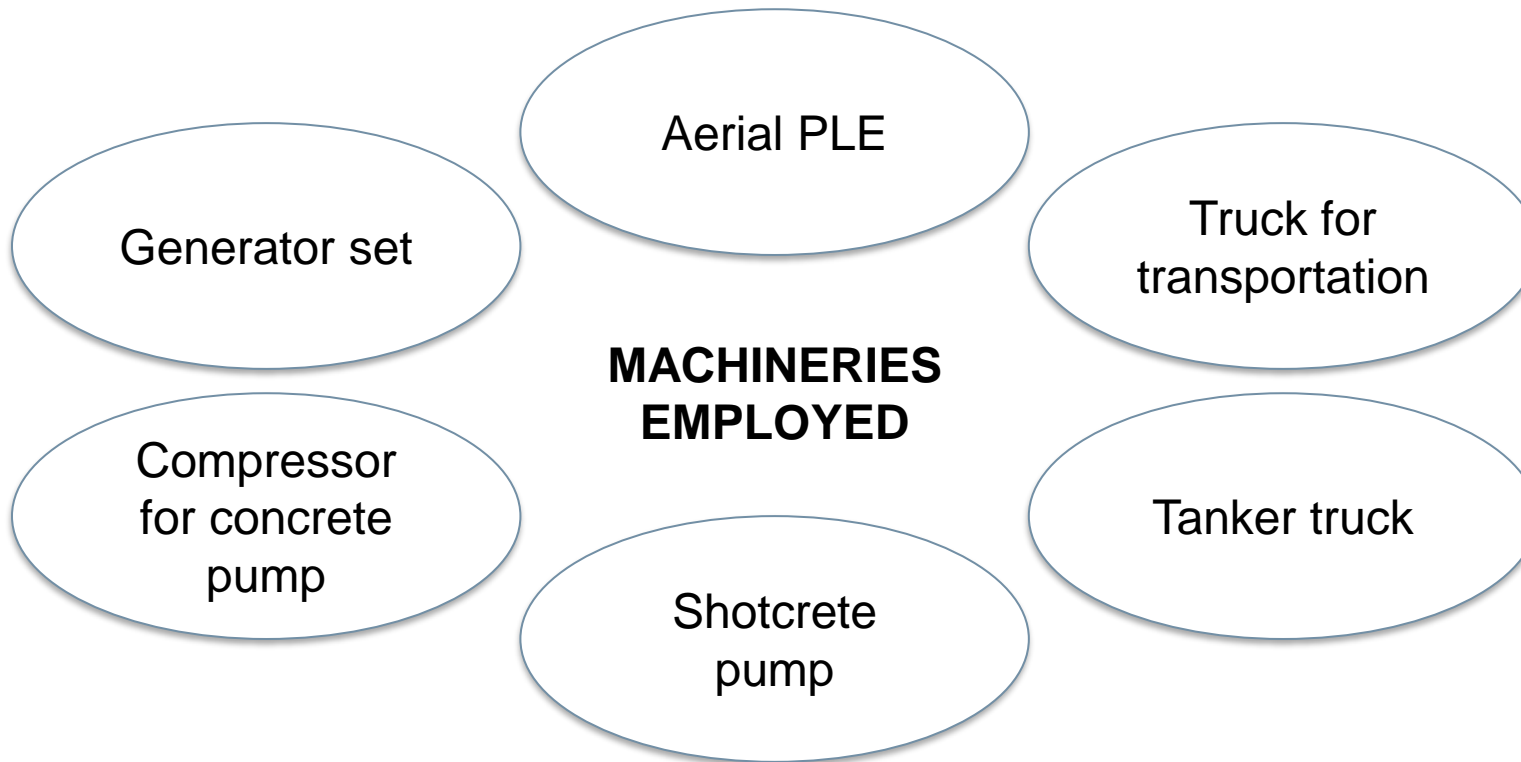
51 days reduction!!

Reduction of duration of phase **5** for the innovative solution is due to the time savings in the detailing and installation of the steel reinforcement thanks to the use of **steel fibers**, which also allows some temporary scaffolding savings. In phase **6** is tied to the **fast-setting** property of the binder.

Marcucci et al., RILEM Spring 2024

A real case study: comparative LCA

A **construction site** has been designed for completing **phases 5** and **6**, and the **consumptions** of the machineries employed has been evaluated for both the two solutions.

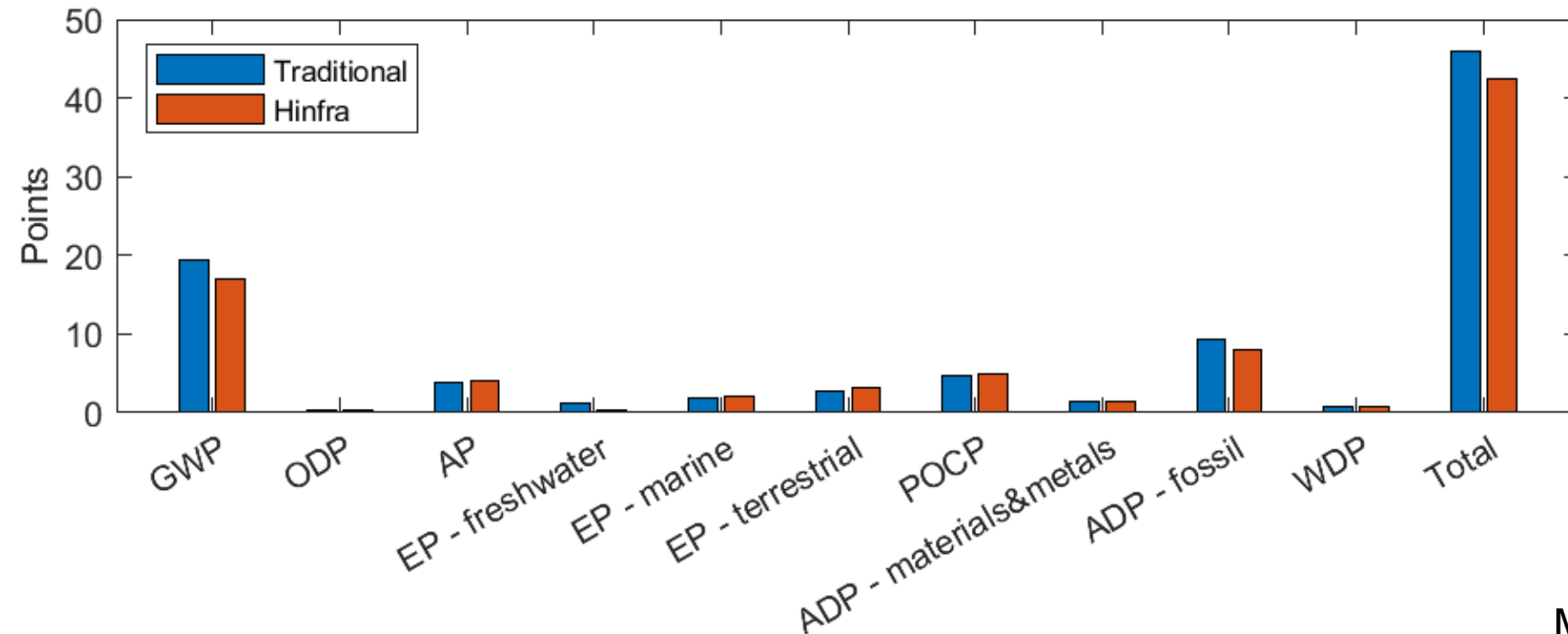


- Type and number of machineries
- Consumption of oil and diesel per hour
- Number of hours per workday

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A real case study: comparative LCA

Data are divided in background and foreground, first of which have been taken from **Ecoinvent** and the last provided by the specific **manufacturing plant** for the **patented** Hinfra SFRC mix. Calculation has been performed using the commercial software “SimaPro”.



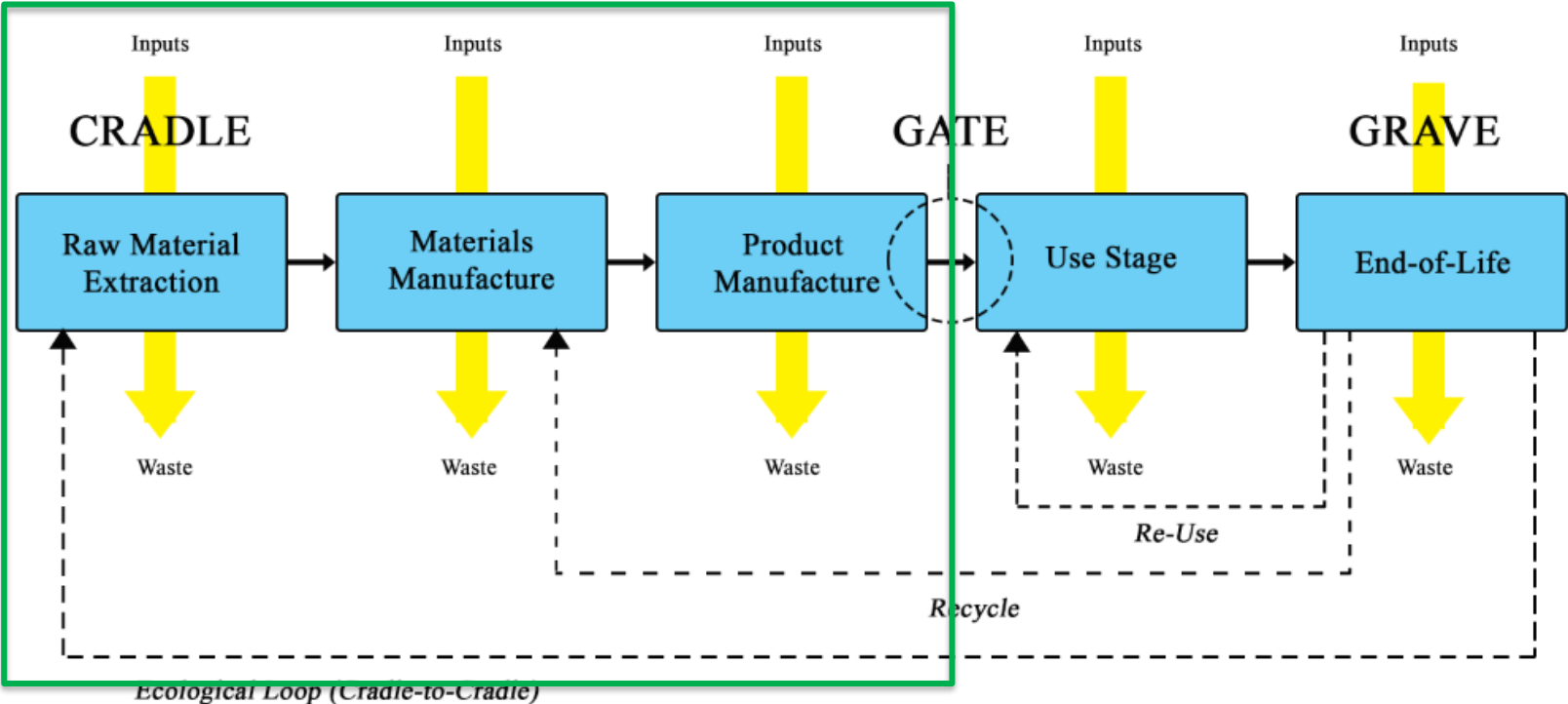
The values are given in terms of points (EN15804), which transform the impact of each category to a comparable quantity

↓
Total reduction of **8%**

Marcucci et al., RILEM Spring 2024

A real case study: comparative LCA

The job site effect



12% saving on GWP!

Marcucci et al., RILEM Spring 2024

Impact category	GWP-total (kg CO2 eq)	Impact category	GWP-total (kg CO2 eq)
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Geotextile sheets	3.12E+02	Geotextile sheets	3.12E+02
Painting cycle	5.99E+03	Painting cycle	5.99E+03
Sprayed concrete	5.00E+00	Sprayed concrete	5.00E+00
Profile for sealing joints	5.99E+00	Profile for sealing joints	5.99E+00
Construction site	9.94E+04	Construction site	3.51E+04
Total	7.53E+05	Total	6.62E+05

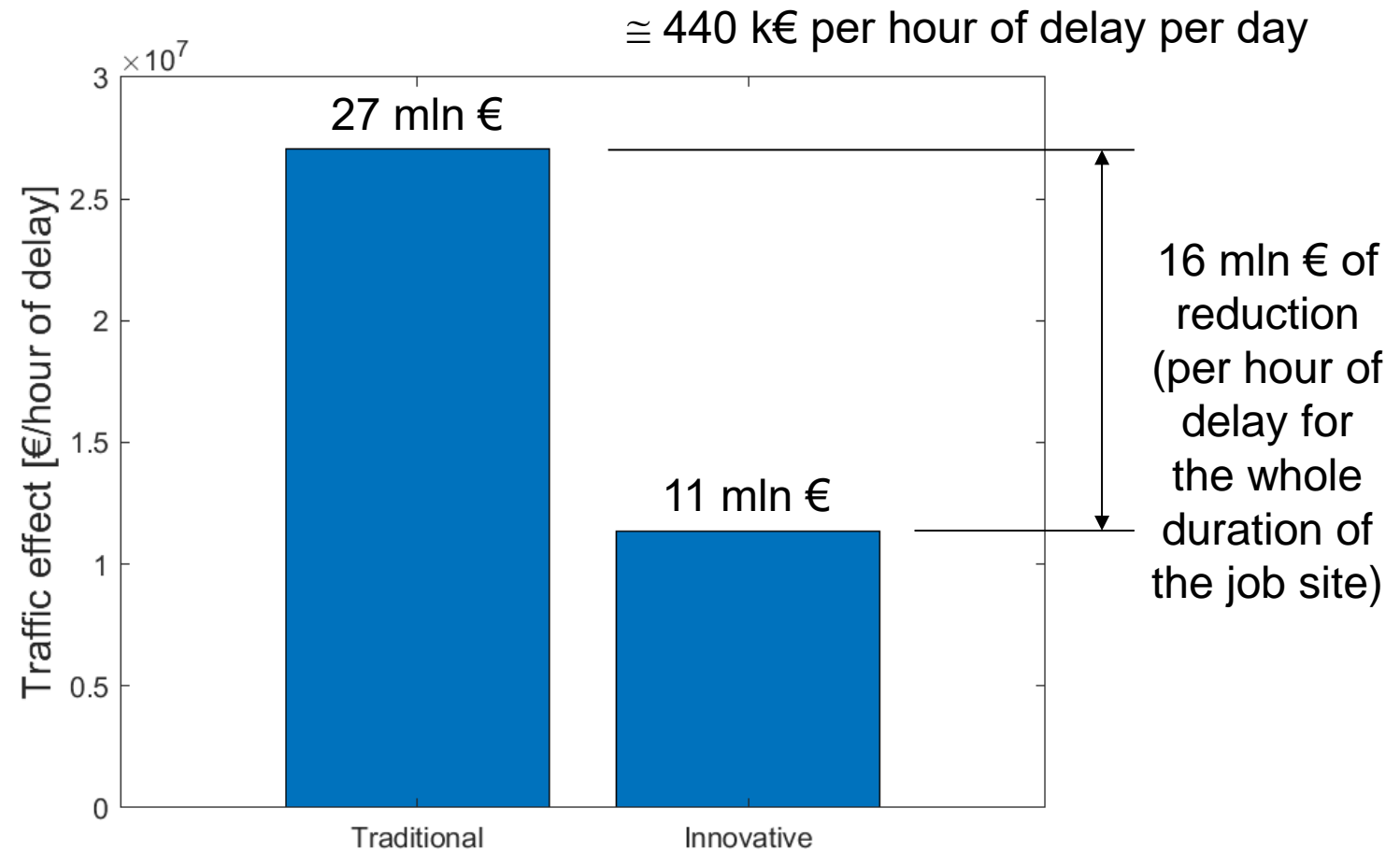
A real case study: comparative LCC

The traffic effect

Neglecting the effect of traffic leads to an underestimation of the social and economic impacts.

Value of Time (VOT) is around 8,99 €/passenger/hour for light vehicles, and around 34,49 €/hour for heavy goods vehicles.

It can be assumed a number of 30.000 light vehicles per day and 5.000 heavy goods vehicles per day for the A1 Italian highway



Conclusions

- The SFRC adopted in the innovative solution has excellent mechanical properties, which allow for the stability of a tunnel lining since the very early ages enhancing the overall productivity of the maintenance intervention.
- The use of steel fibers allows for a notable reduction of time related to construction by simplifying the mounting of steel reinforcement operation only for the pillars of the tunnel, and guaranteeing a sufficient structural bearing capacity.
- The LCA shows that the innovative solution is characterized by lower impacts. However, these impact reduction can be notably improved if taking into account for durability by extending the LCA beyond the gate.
- Considering the effects of traffic, the innovative solution reduces the social costs by 58% with respect to traditional solution thanks to the enhanced productivity of the intervention which saves 51 days of work.



Thank you for your attention!

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