A sustainable additive manufacturing system for the construction of new and regeneration of existing tunnels

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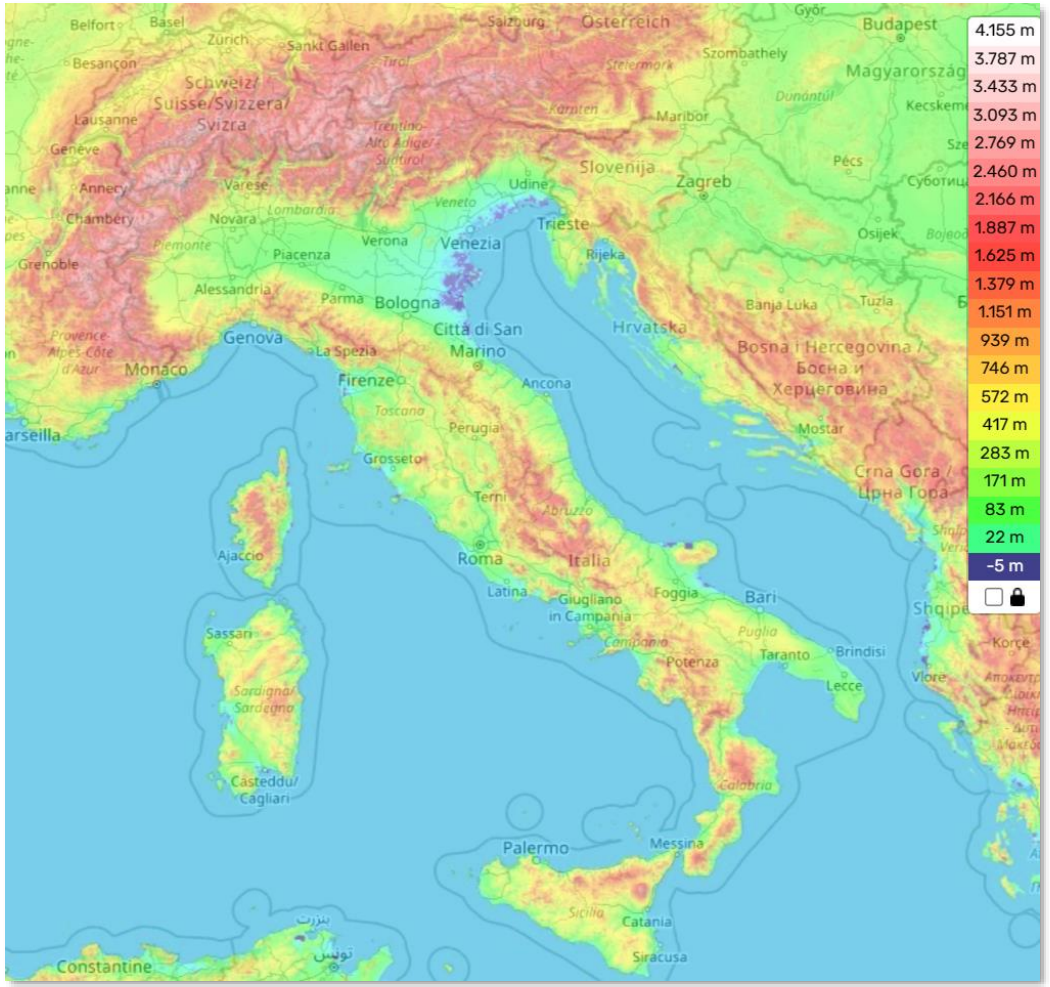
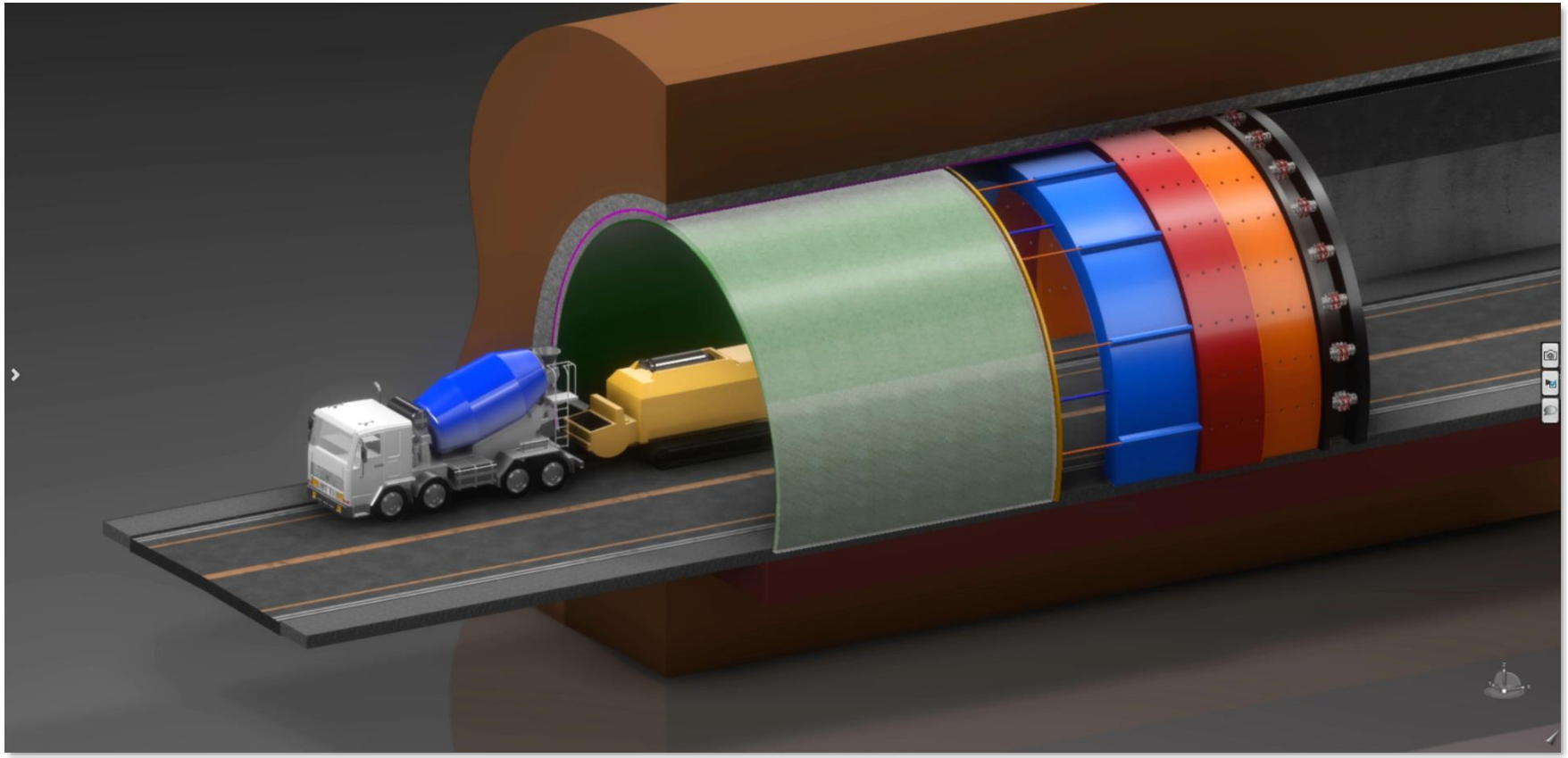
The current “tunnel issue” in Italy – Motivations



Due to its topography, Italy has a high number of tunnels in the roadway network (around **2000 km**). These were built around the 60s, thus they need maintenance in order to reduce the risk of collapse.

Nowadays there is still not any **maintenance** intervention able to provide the fair structure service-life that a **tunnel** deserves, due to its strategic importance for the roadway network.

The current “tunnel issue” in Italy – Hinfra proposal

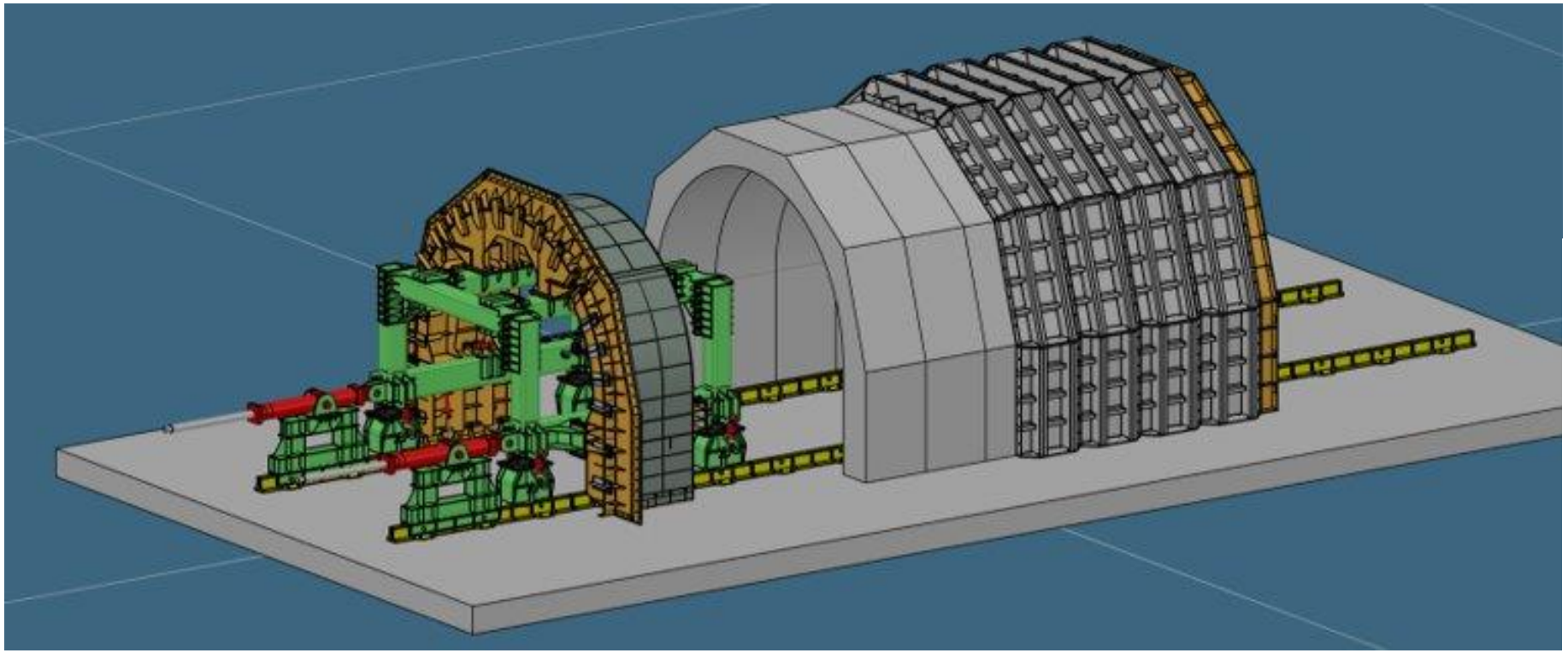


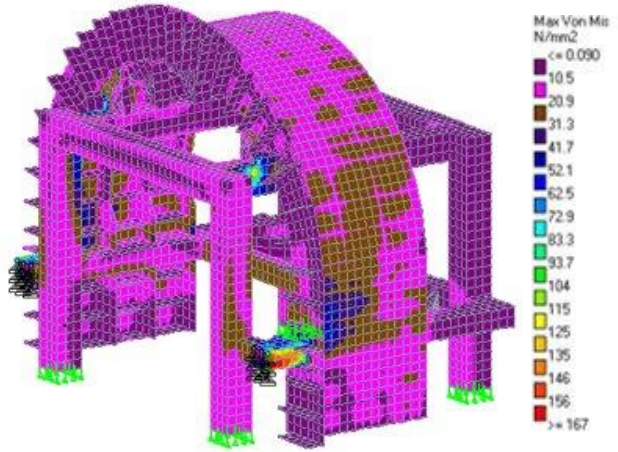
The start-up company Hinfra is developing a **slipforming** technology for the fabrication of **tunnel** segments, that can be the solution of the **maintenance** intervention for the refurbishment of existing tunnels (**ETLR** project).

Hinfra Senago site

eTLR
EXTRUDED TUNNEL LINING REGENERATION

HINFRA™
The Large Scale Digital Concrete Extrusion Project





THE WORLD'S GATHERING PLACE FOR ADVANCING CONCRETE

aci CONCRETE CONVENTION

Hinfra Senago site

First the material is **pumped** from the key of the internal mould, from which it flows until the ground. As soon as the mould is filled with concrete and the latter has achieved the sufficient level of strength, the system moves following the lining, slipping tunnel segments of **FRC**.

Process & material requirements for the new maintenance intervention

The Hinfra approach is an **Additive Manufacturing** application. Thus from the material point of view, some requirements have to be fulfilled, to be compatible with the process.

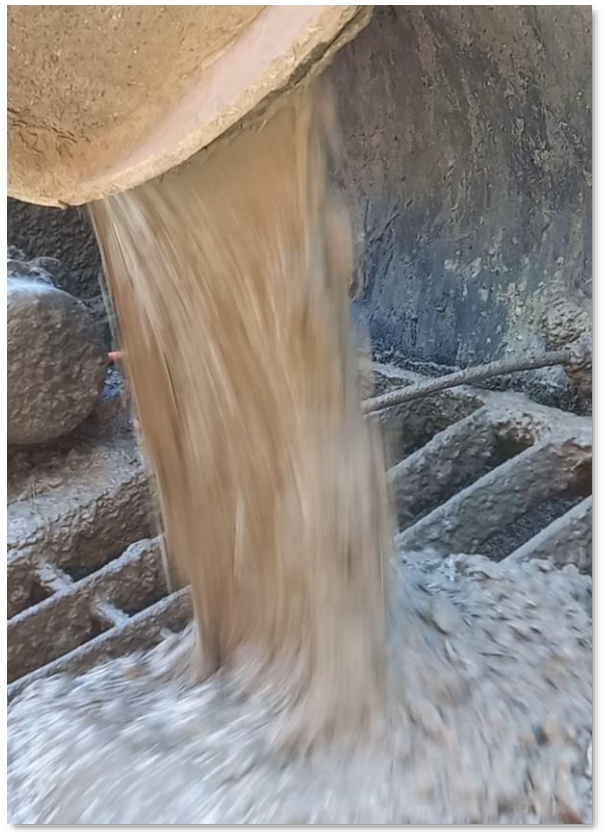
3DCP → ← Slipforming

- Pumpability
- Extrudability
- Buildability

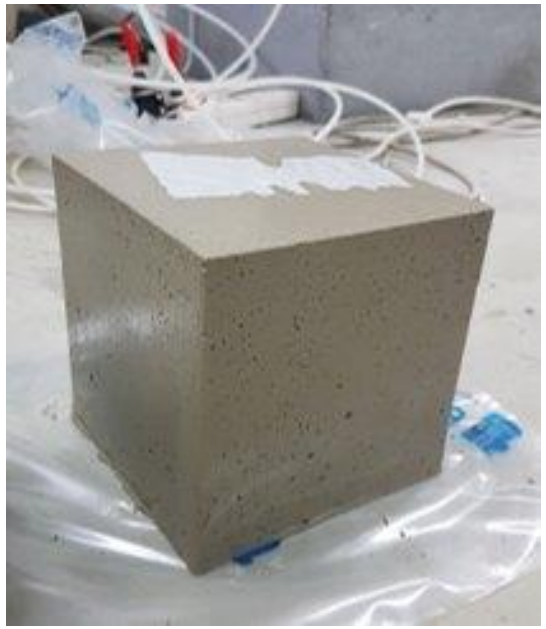
Process & material requirements for the new maintenance intervention

At the very beginning the mix must exhibit a high workability, as well as a Self Compacting Concrete (SCC), in such a way that, with a reduced **yield strength**, pumping until the key is allowed. Also this consistency enhances the quality of the fabrication process, guaranteeing a better fibre distribution along the tunnel lining.

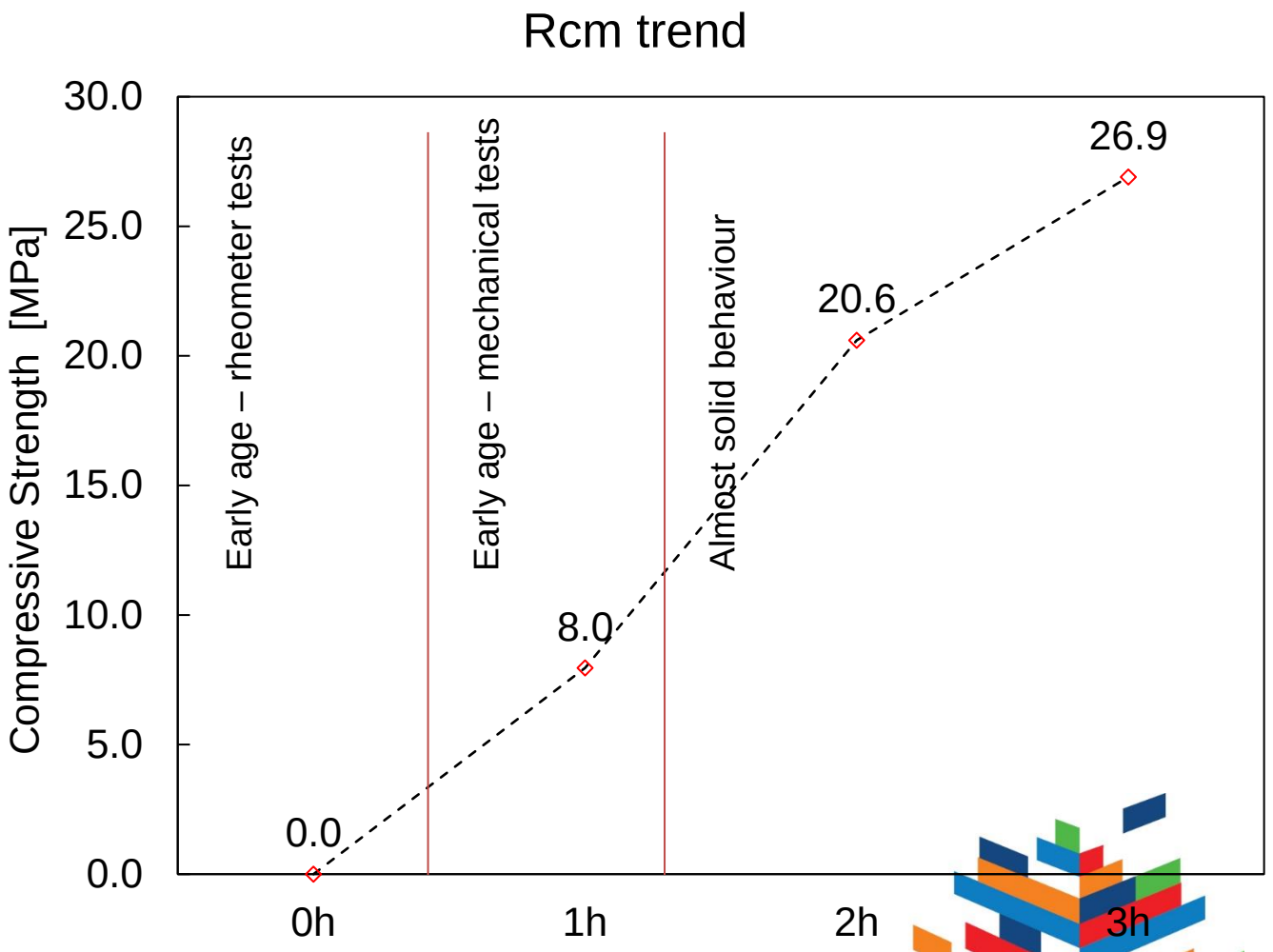
In order to increase the **productivity** of the intervention, thus reducing the time of the manufacturing process, the mix should have a **fast setting** in such a way it guarantees **buildability** in a very short time. In fact, when the mould slips the structure must withstand a value of load given by its own weights and part of what will be upon it.



Material characteristics



After some minutes



Traditional maintenance interventions for existing tunnels

SCRAPING

SPRAYING

Traditional maintenance interventions for existing tunnels

CAST IN PLACE

PARTIALLY PRECAST

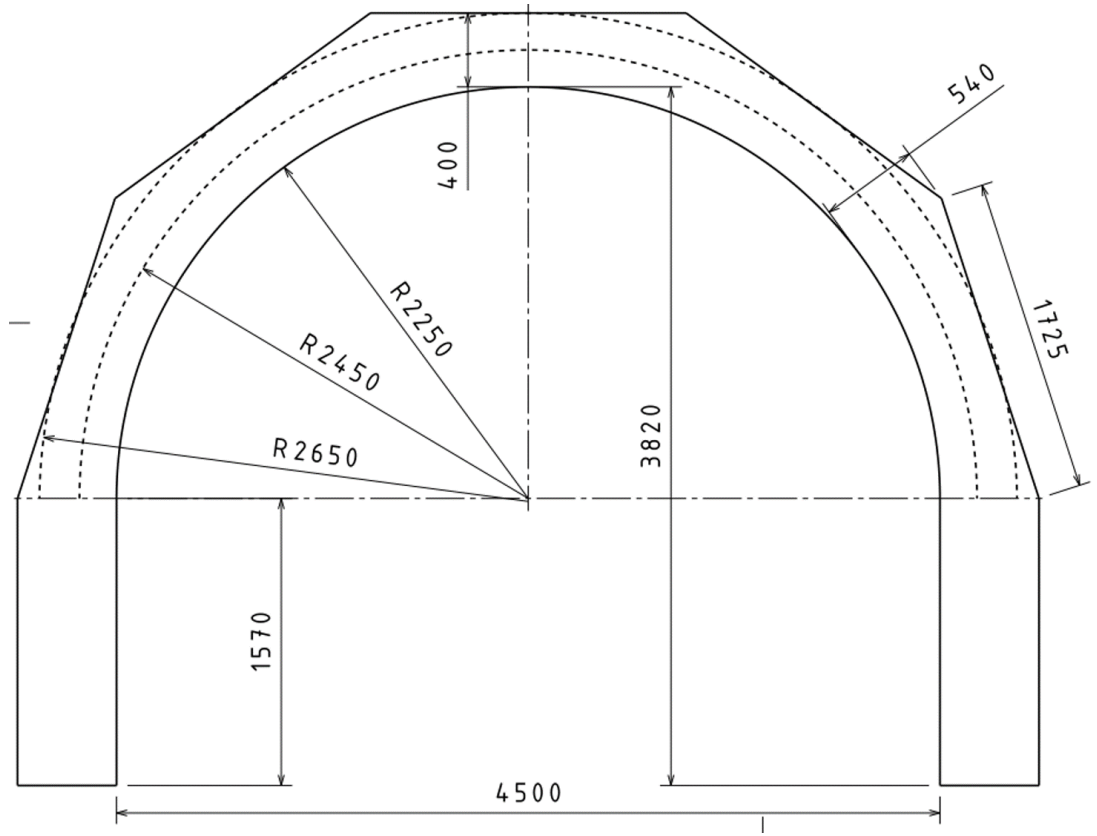
On the sustainability of the new maintenance intervention

Hinfra	Traditional	Differences	Explanations
		MATERIALS	
cement	cement	X	CSA based cement with reduction of CO2 emissions, with respect to OPC
aggregates	aggragates	-	-
water	water	-	-
admixtures	admixtures	X	Higher admixtures content due to special properties FRC
steel fibres	steel reinforcements	X	Quantity of steel can be lower for the same performance (M-N domains)
		CONSTRUCTION	
automated scraping	scraping	X	All of them contributes to a higher productivity of the Hinfra methodology, since process velocity is ten times higher, and number of workers is reduced
-	reinforcement placing	X	
concrete pumping	concrete pumping/spraying	X	
moving steel formwork	disposable formworks	X	
		PROCESS	
construction rate	construction rate	X	Rate is increased due to automation
number of workers	number of workers	X	Workers are reduced due to automation
		SERVICE LIFE	
use	use	-	-
maintenance	maintenance	X	They are reduced in terms of number of interventions needed as the expected service life is larger than 35 years with Hinfra
repair	repair	X	

Sustainability of the mix design

	Hinfra			Traditional		
unit	kg/m³	kg/m	GWP	kg/m³	kg/m	GWP
MATERIALS - volume of 1m segment						
cement	600	2600,856	1832,668	440	1907,295	1576,951
aggregates	1400	6068,665	15,35372	1570	6805,574	17,2181
water	210	910,2998	0,301309	180	780,2569	0,258265
admixtures	11,7	50,7167	138,553	9	39,01285	106,5792
steel	40	173,3904	421,9109	90	390,1285	977,4279

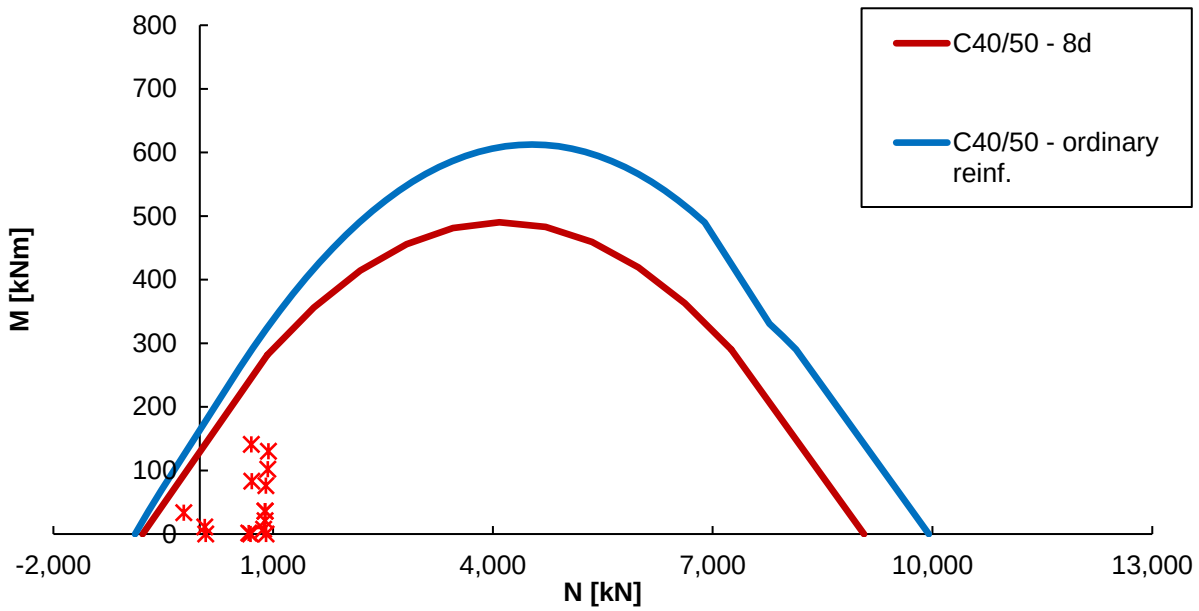
The Global Warming Potential (**GWP**) has been computed to check the sustainability from the material side, that indicates the equivalent kg of CO_2 emission. The values are referred to **1m segment of Senago site tunnel**, and taken from E. Gartner (2004), P. Hajek (2011) and M. Jolin (2003).

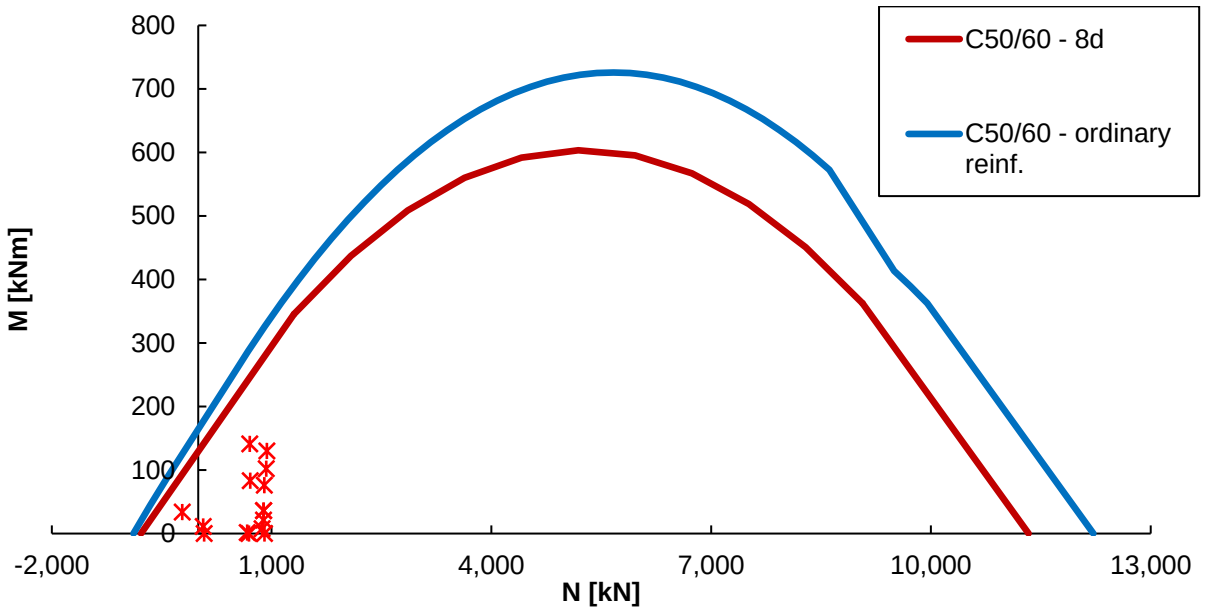


GWP:

HINFRA	**2409 kgCO2**
TRADITIONAL	**2678 kgCO2**

Sustainability of the mix design

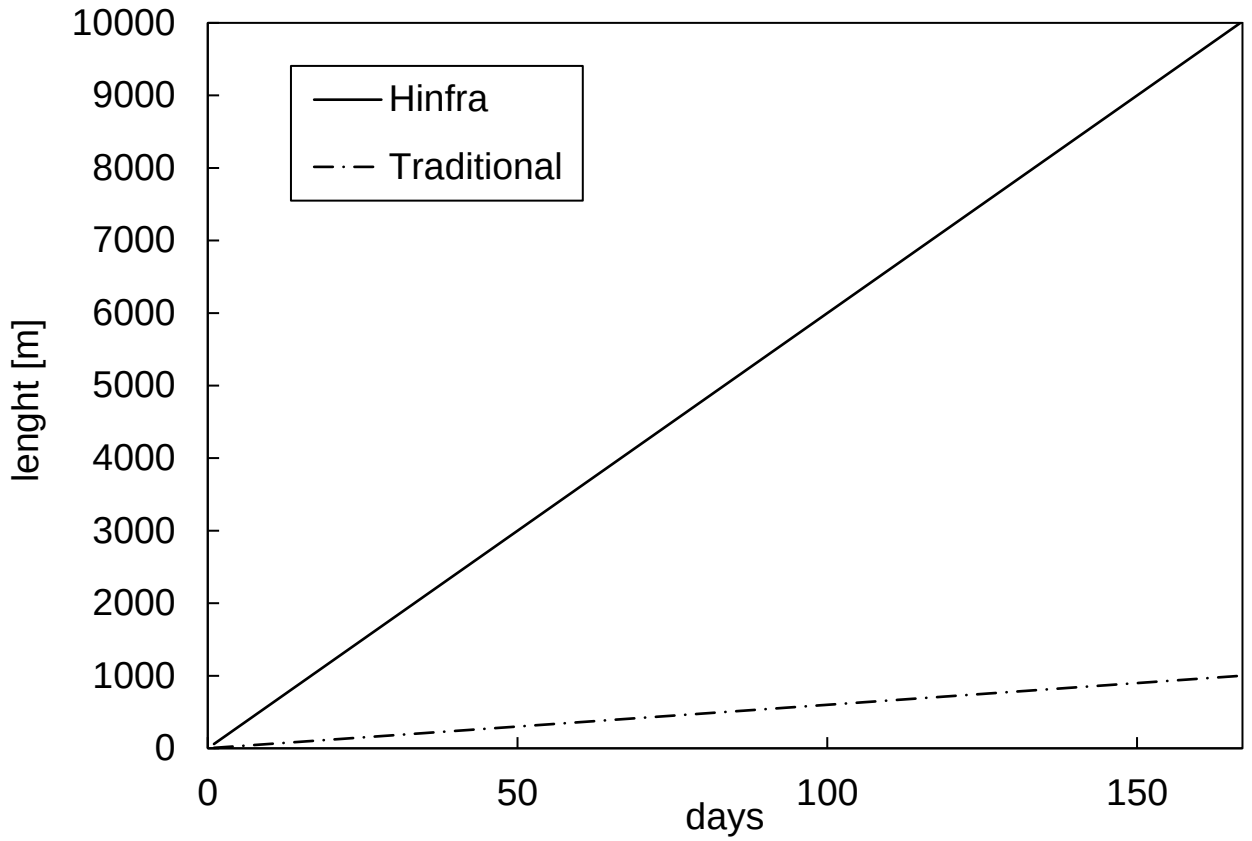




To obtain a comparison about the use of the steel in the construction, M-N domains have been computed with both the fixed dosage of 40 kg/m³ of fibers and a dosage of reinforcements such that the ultimate tensile strength of the cross-section would have remained the same, obtaining a 90 kg/m³ of steel rebars (mesh of Φ12/100, top and bottom).

Sustainability for process and service life

It results to be very difficult at this stage to give some numbers related to the overall sustainability through **LCA** of the Hinfra methodology for tunnel refurbishment, as the comparison will differ with the case of study.



Productivity largely increased:
Hinfra **60 meters/day**
Traditional **6 meters/day**

Comparison must be done for **costs**. These are also related to construction time.

Cost of **workers** reduced

Higher service life: **> 35 years**

Conclusions

- Hinfra is proposing a new maintenance intervention for existing tunnels, consisting of an automated slipforming process.
- Due to automation, the productivity of the intervention is increased as the construction time is highly reduced, as well as the need of workers.
- From the mix design, it is possible to observe a lower CO_2 content through the calculation of the GWP.
- For a similar capacity, more steel rebars are required compared to the fibers, that result to be the more sustainable solution.

Thank you for the attention!

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