How Lightweight Aggregate & Concrete can Reduce Global Warming Potential and Increase Sustainability of Concrete
Monday, November 4, 2024
Philadelphia, PA, USA

Eco-Mechanical Analysis of Lightweight Cement-Based Composites

Alessandro P. Fantilli

Politecnico di Torino
DISEG

Outline

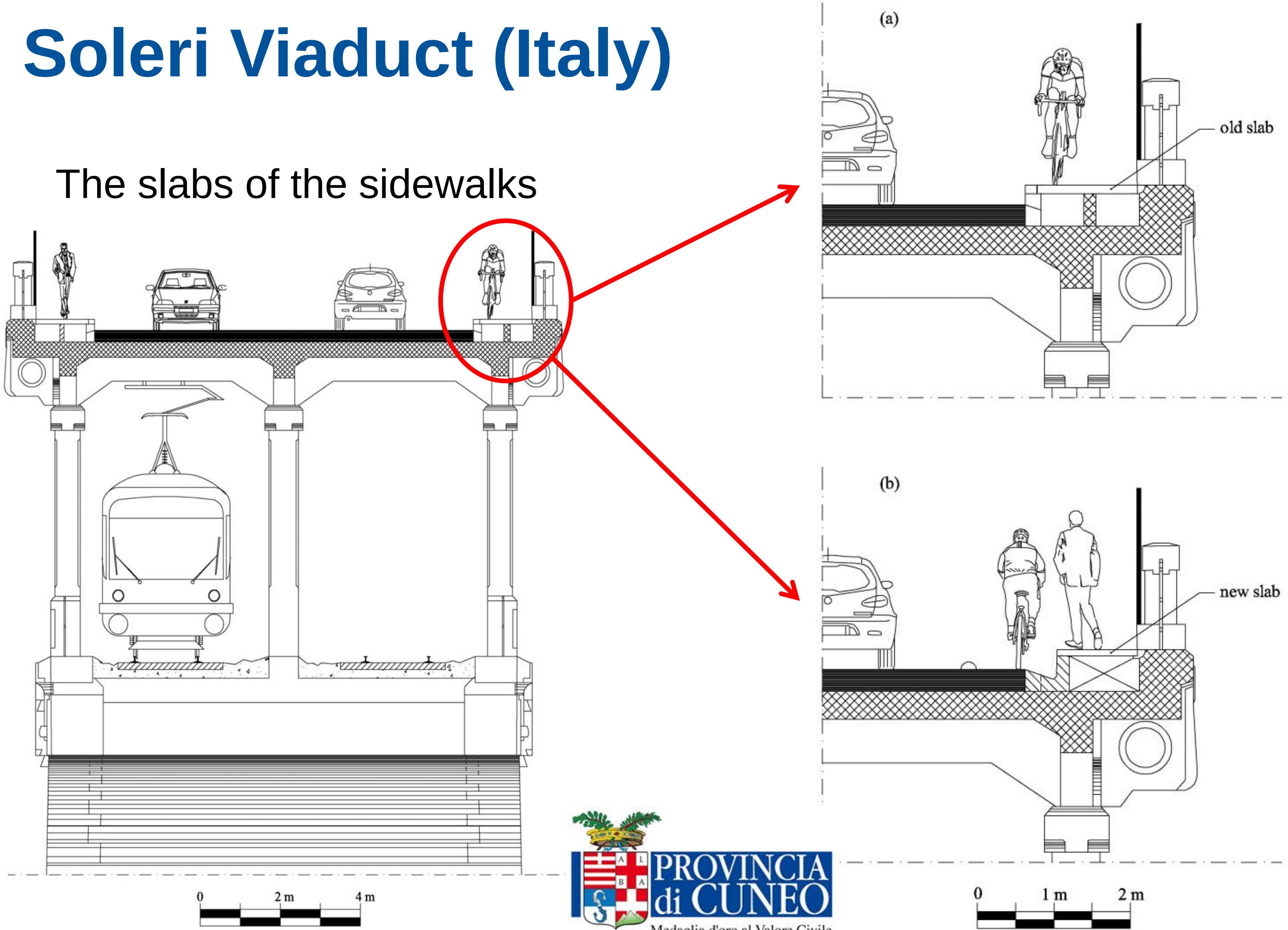
- Motivation
- Experimental campaign
  - Compression tests
  - Three point bending tests
- Eco-mechanical analysis
  - Material level
  - Structural level
- Conclusions

Soleri Viaduct (Italy)

Soleri bridge in Italy (1930).

Double-deck bridge on the Stura di Demonte River (Cuneo)

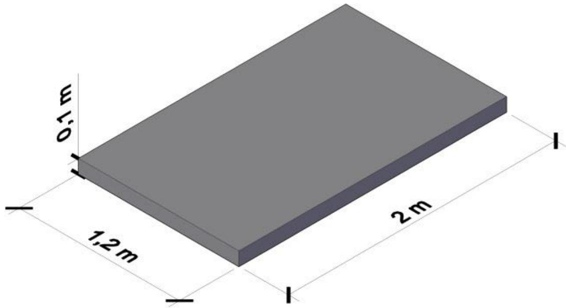
The slabs of the sidewalks



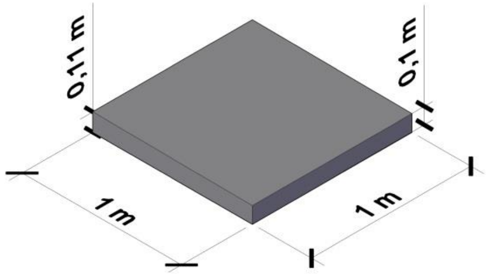
PROVINCIA di CUNEO
Medaglia d'oro al Valore Civile

Requirement (for live loads = 4 kN/m^2)

- Old slabs
  - 6 kN
  - Normal weight concrete
  - steel rebar



- New slabs
  - 1.6 kN
  - Lightweight concrete
  - **Can plastic fibers substitute rebar?**

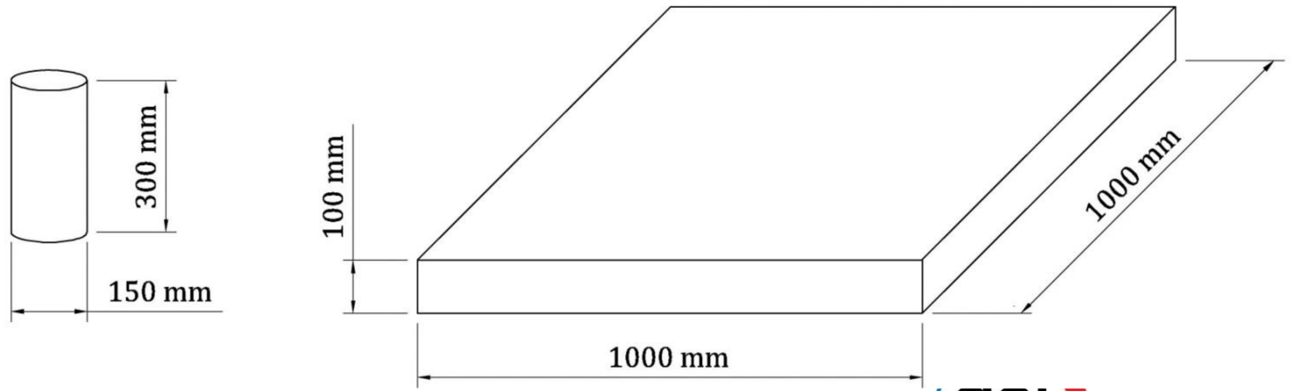


The feasibility of the solutions

- Materials

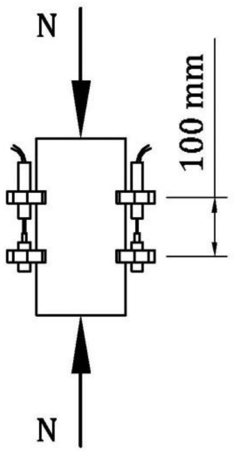
Component in 1 m^3	TLC_R	TLC_F
Water (kg)	140	140
Cement (kg)	500	500
Stone aggregate (kg)	700	700
Expanded clay – density 0.38 kg/dm^3 (kg)	300	300
Grinded rubber – density 0.90 kg/dm^3 (kg)	0	0
Superplasticizer (l)	3.6	3.6
Viscosity modifying agent (l)	1.2	1.2
Plastic fibers – density 0.91 kg/dm^3 (kg)	0	10

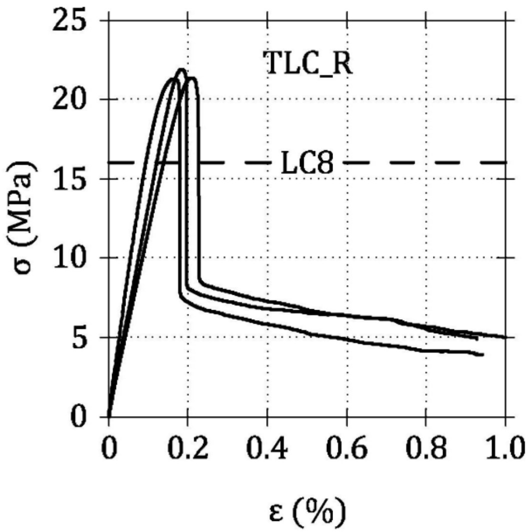
- Specimens for tests

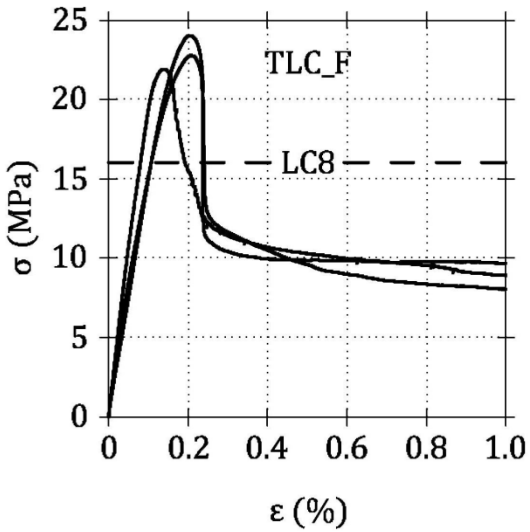


Mechanical behaviour of materials

- Measured with uniaxial compression tests on cylinders (diameter = 150 mm, height = 300 mm)





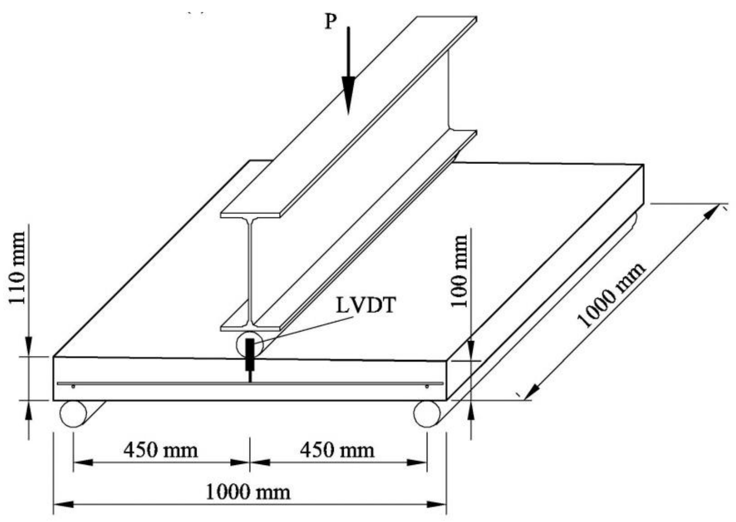


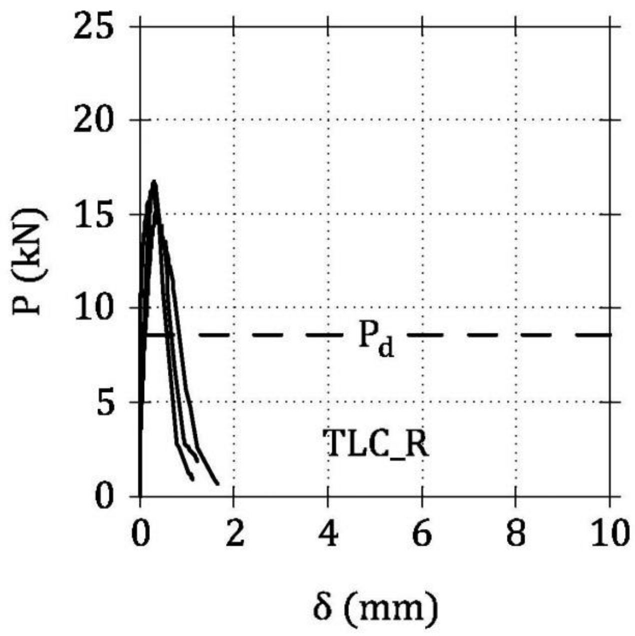
Mixture	f_{lc} (MPa)	E_{lc} (MPa)	ε_{lc1} (‰)	k_{lc}
TLC_R	21.51	15,070	1.84	1.27
TLC_F	22.91	18,868	1.82	1.47

- Same behaviour with and without fibers
- LC8 is the minimum required strength of structural concrete

Unreinforced slab

- Lightweight concrete (TLC) with expanded clay (density = 1500 kg/m^3)
- Three-point bending tests
  - In the real structure
  - P_{max} higher than factored loads P_d= 8kN
  - Very brittle behaviour



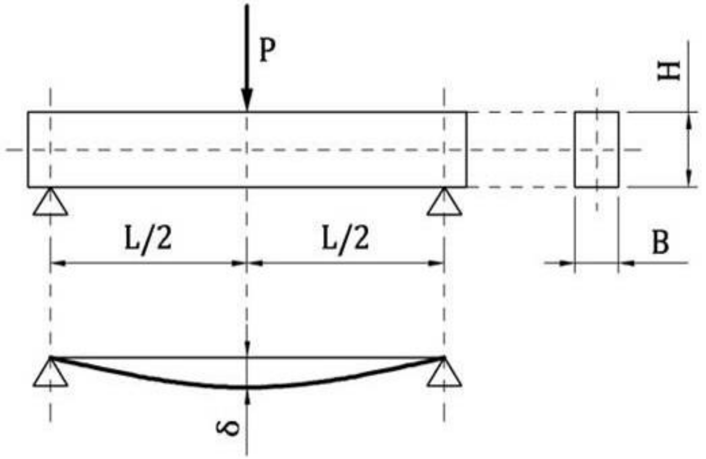


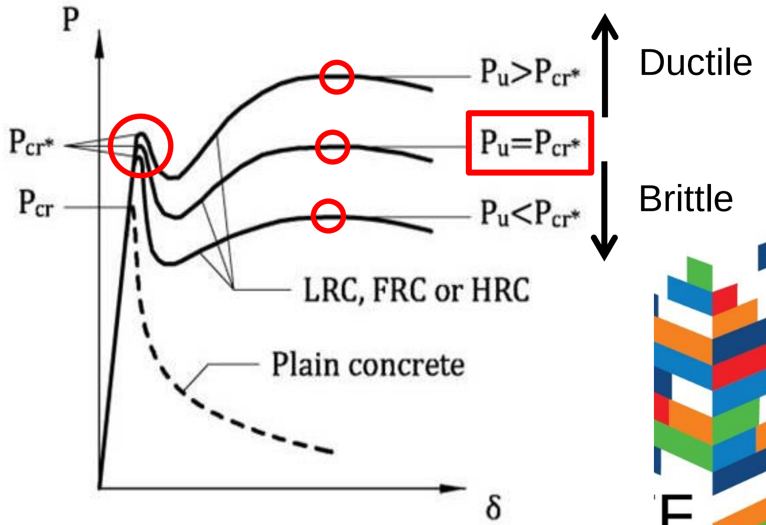
To have a ductile behavior a reinforcement is needed

Ductile vs. brittle behavior

- From flexural tests, it is possible to observe how the mechanical response depends on the amount of reinforcement (rebar or fibers)
- In statically determinate beams (or slabs) in bending, two stationary points can be observed in the load deflection diagram (P-δ)
  - P_{cr*} = Effective cracking load
  - P_u = Ultimate load

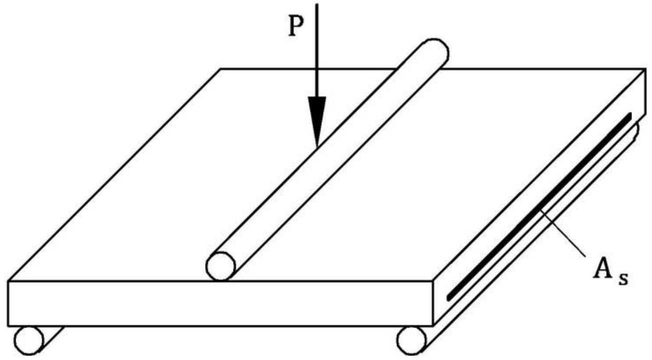
Ductile behavior when $P_u \geq P_{cr*}$





In the case of TLC_R

- To guarantee the ductility of the plate, a minimum reinforcement (made with traditional rebar) $A_s = A_{s,min}$ must be provided
- According to code MC 2010, $A_s = A_{s,min} = 4\ \Phi\ 5$
- By means of the moment-curvature relationship, it is possible to estimate the ratio δ_u / δ_{sls}



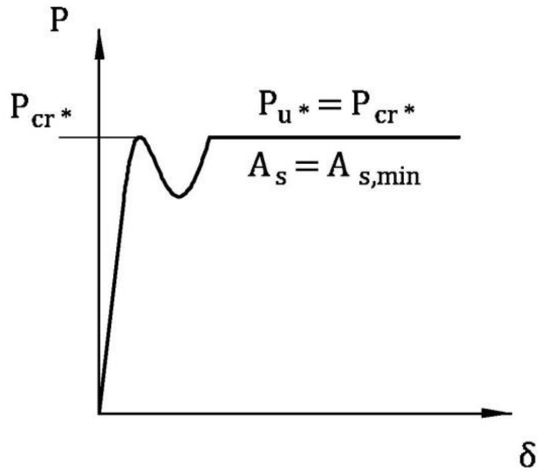
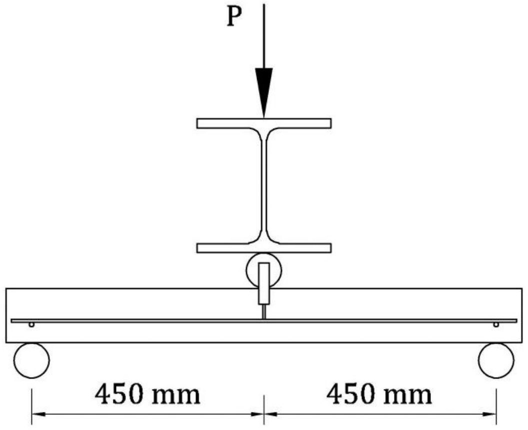


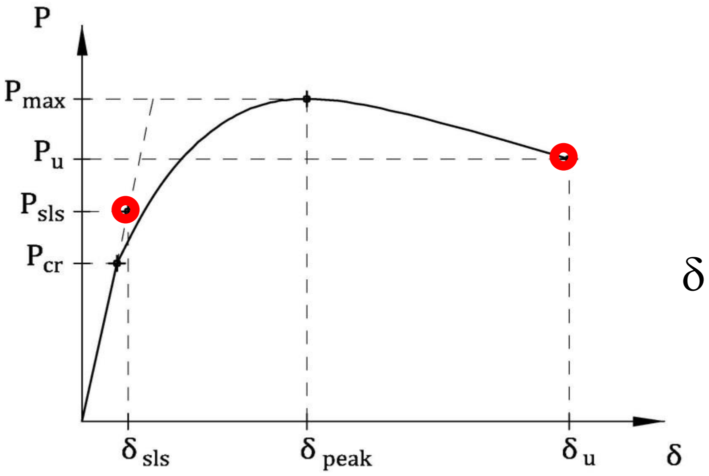
Plate	δ_u / δ_{sls}
TLC_R	6

In the case of TLC_F

- Ductility is defined in accordance with Model Code 2010:

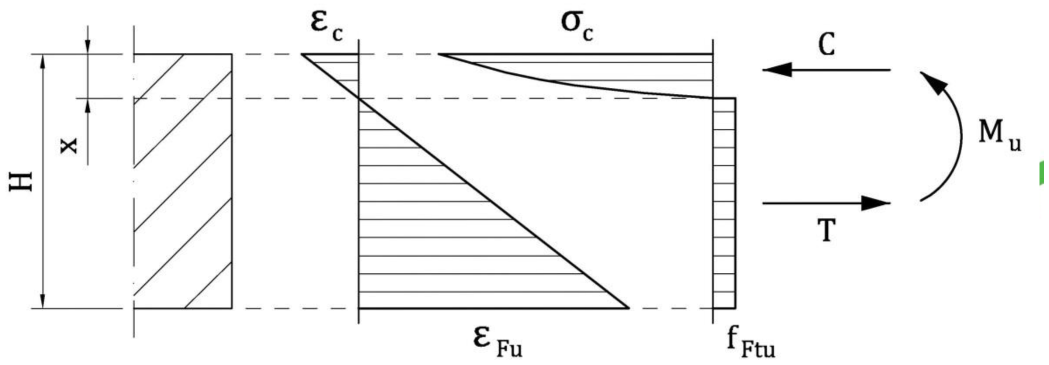
$$\delta_u \geq 20 \cdot \delta_{sls}$$





δ = midspan deflection

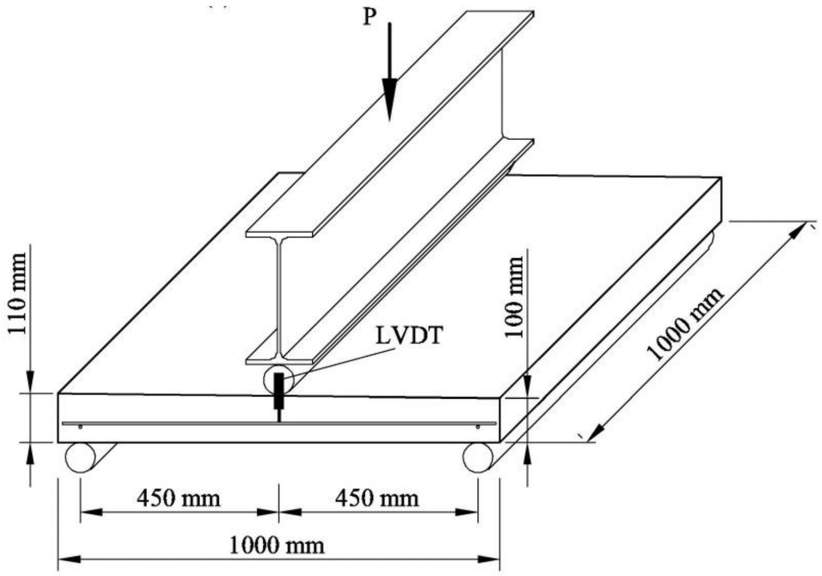
- The ultimate displacement δ_u of the structure is obtained when the ultimate bending, M_u , is reached in the midspan cross-section

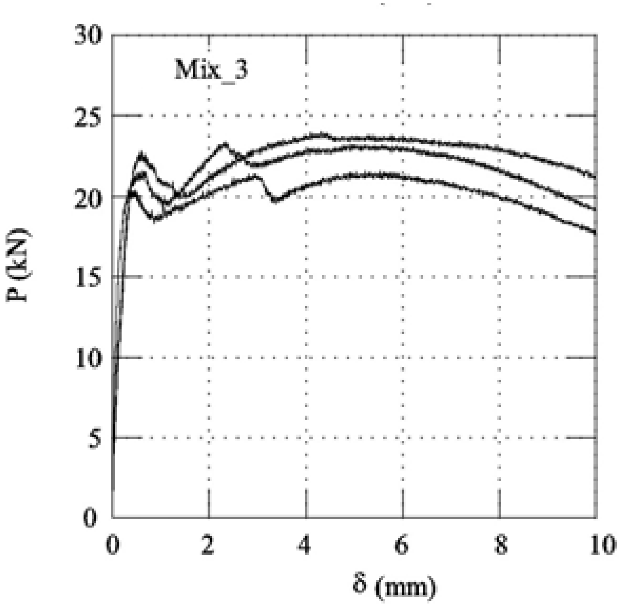


THE WORLD'S GATHERING PLACE FOR ADVANCING C

When $Q_f = 10\ kg/m^3$

- A ductile behavior can be observed ($P_{cr*} < P_u$)





$P_{cr*} = 21.6$ kN
$P_u = 22.9$ kN

- According to MC 2010, ductility can be evaluated (higher than TLC_R)

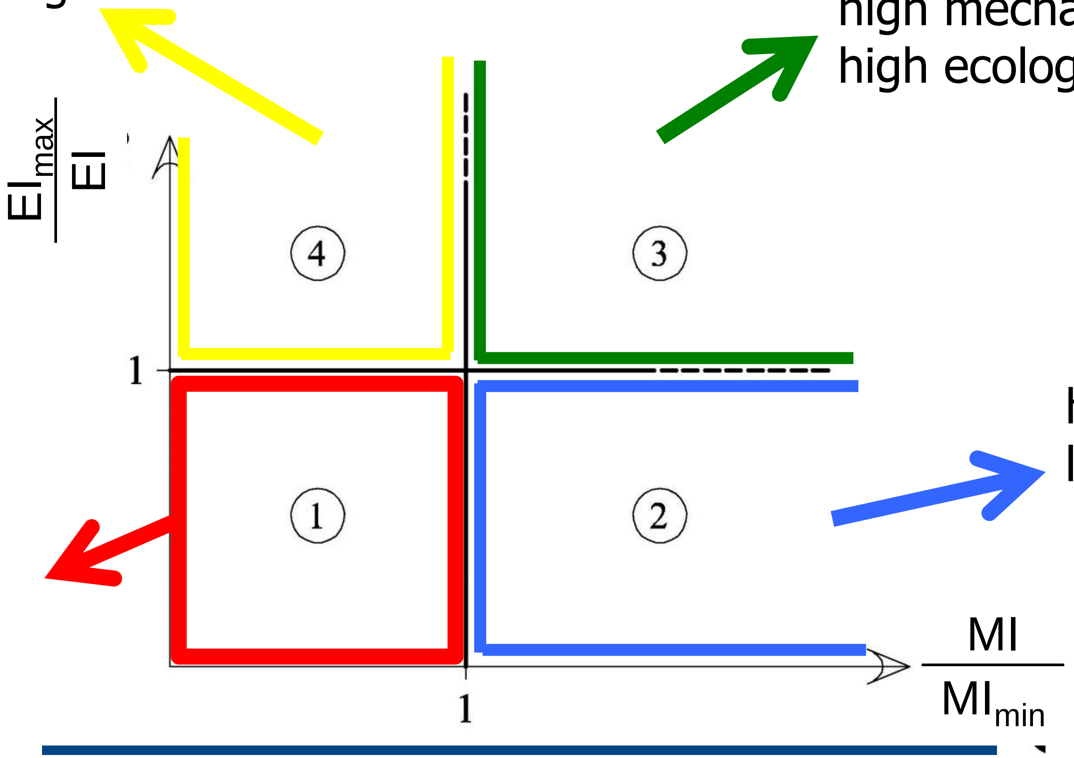
Plate	δ_u / δ_{sls}
TLC_R	6
TLC_F	486

To rate sustainability and mechanical performances

- A comparative analysis, after defining the lower bound value of MI (MI_{min}) and the upper bound value of EI (EI_{max})

low mechanical performances high ecological performances

high mechanical performances high ecological performances



high mechanical performances low ecological performances

low mechanical performances low ecological performances

Ecological and mechanical indexes

- The sum of the product of carbon footprint of each material times the content is EI

In cylinders carbon footprint (kg CO_2/m^3)	
TLC_R	TLC_F
453	480

In slabs carbon footprint (kg CO_2/slab)	
TLC_R	TLC_F
46	48

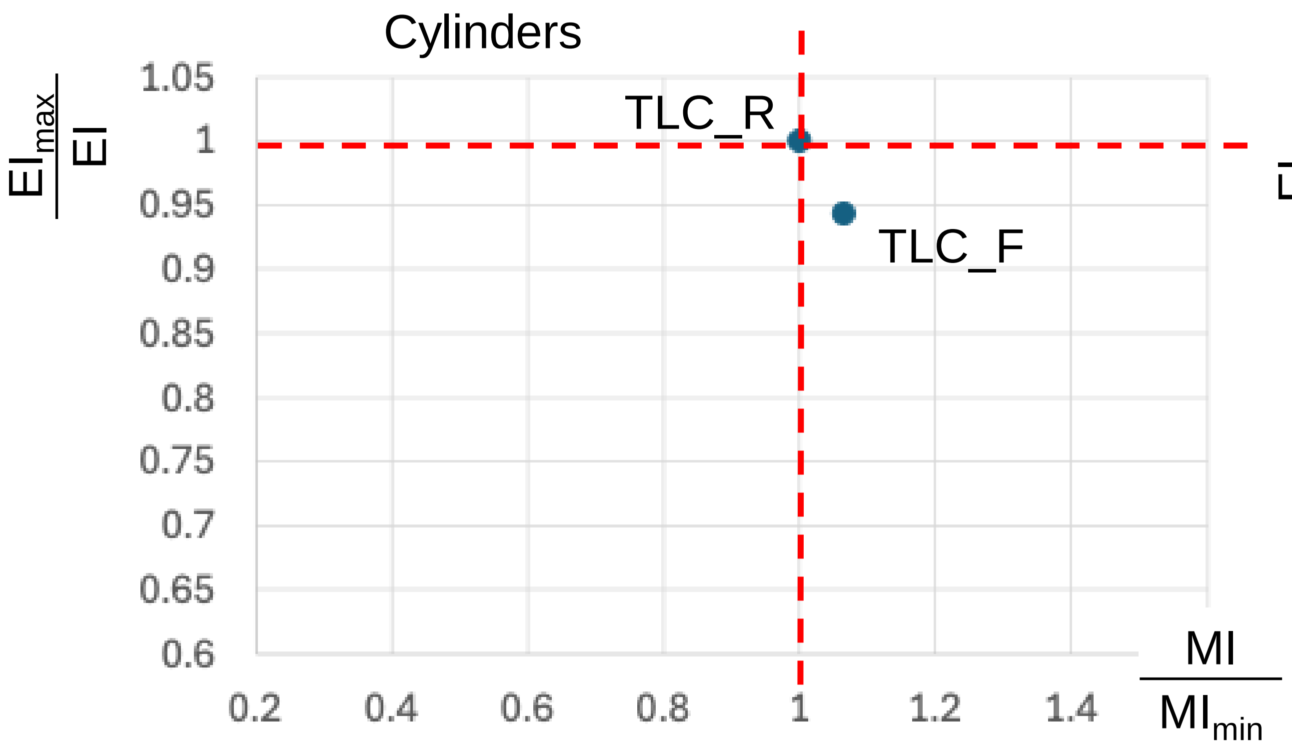
- Two mechanical index MI
  - Compressive strength
  - Ductility, measured as δ_u / δ_{sls}

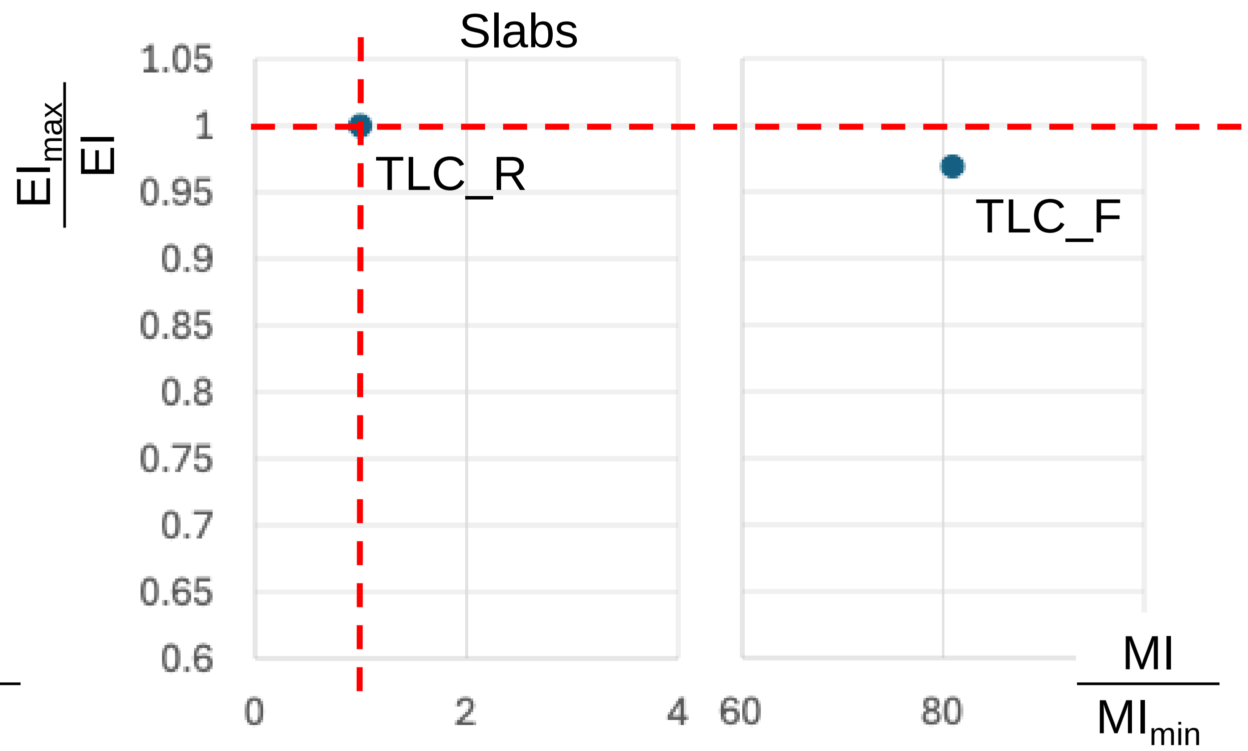
Cylinders	f_c (MPa)
TLC_R	21.51
TLC_F	22.91

Plate	δ_u / δ_{sls}
TLC_R	6
TLC_F	486

- Two eco-mechanical analyses
  - In cylinders, TLC_R the reference concrete with MI_{min}= compressive strength = 21.5 MPa, and EI_{max} = 453 kg/m^3
  - In slabs, TLC_R is the reference concrete with MI_{min}= δ_u / δ_{sls} = 6, and EI_{max} = 46 kg CO_2

Eco-mechanical chart





Although TLC_F has better mechanical performances,
TLC_R is the best solution (mechanical and ecological)

Conclusions

- TLC can substitute traditional normal-weight concrete in the sidewalks of the Soleri Bridge
- To select the type of reinforcement, among steel rebar and fibers, a, eco-mechanical analysis can be performed
- Although the presence of fibers increase the mechanical performances of TLC, the use of tradition rebar appears to be more sustainable when the carbon footprint for the material production is taken into account.