



52nd ASECAP DAYS

Challenges of Future
Mobility | The Role of Road
Infrastructure

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Smart and Sustainable Precast Slabs for Modular Rigid Pavements made of an Industry-Friendly Geopolymer Concrete

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Acciona Construcción



Limitations of Rigid Pavements in the European Context

Flexible and semi-rigid pavements constitute the vast majority (over 94%) of European roads.



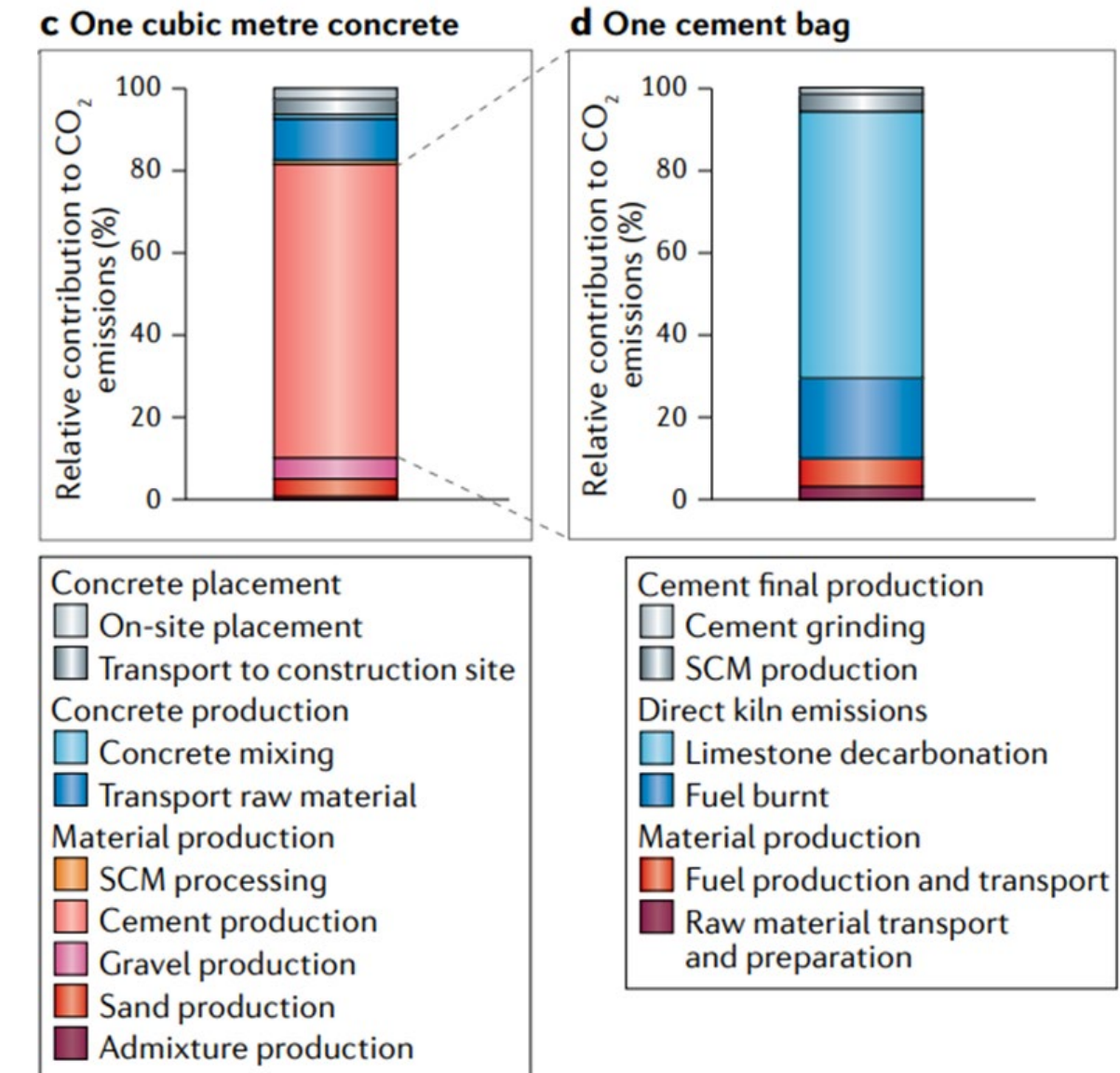
Rigid concrete pavements are mainly used in specific areas like urban areas and high-traffic zones.

The construction of in-situ rigid pavements requires paver machines.

Industry - friendly Geopolymer Concrete

Why use geopolymer instead of conventional concrete?

- Geopolymers reduce the quantity of CO₂ released during the manufacture of cement and concrete.
- Avoid increasing costs associated with energy sources from Portland cement production processes.
- 80% less polluting and require 50% less energy consumption in their manufacture.
- Employed industrial wastes do not require any thermal processing are used in their production.



Relative contribution to CO₂ emissions in one cubic meter of concrete (left) and one cement bag (right).

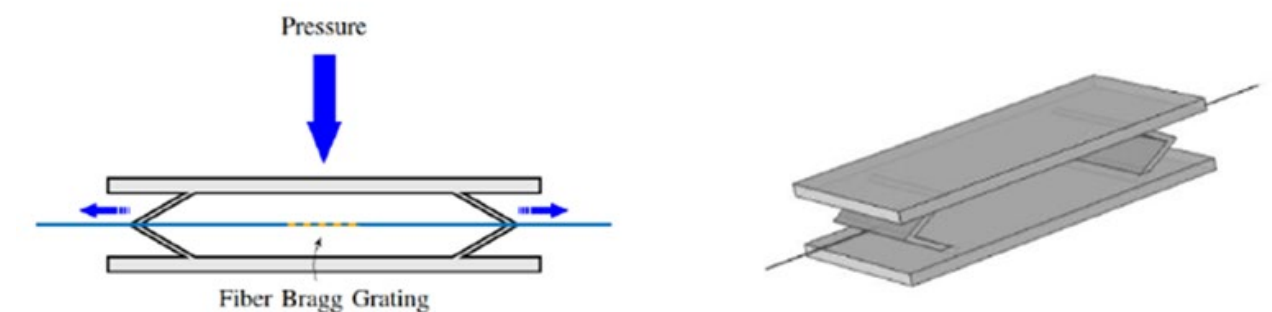
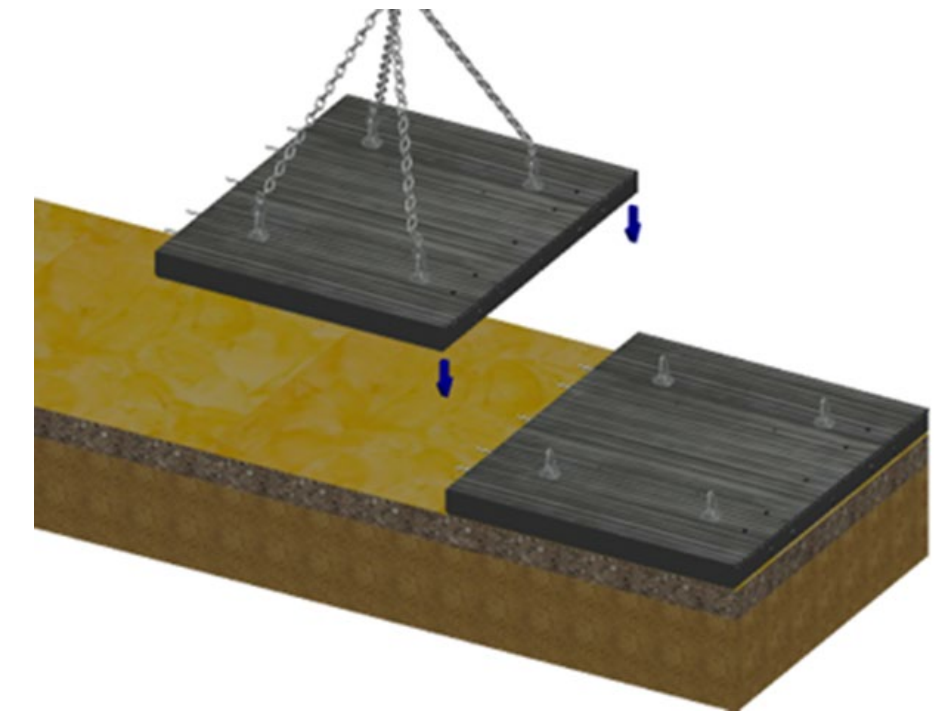
Source: Environmental impacts and decarbonization strategies in the cement and concrete industries (G. Habert et al., 2020)

● A Novel Solution to the Challenge

Smart and sustainable precast slabs for modular rigid pavements

Evaluation focused on the potential of a modular, digital, sustainable, and intelligent solution for road elements.

The developed solution is the design of smart modular road for rigid pavements made of an industry-friendly geopolymers concrete and integrating an innovative Weight In Motion (WIM) system for the real-time optimization of TI management.



Industry - friendly Geopolymer Concrete

Geopolymers are inorganic synthetic polymers of aluminosilicates, with an amorphous, three-dimensional structure, which result from a chemical reaction called geopolymerization. They are alkaline aluminosilicates that form tetrahedral units by means of random bonds formed by silicon and aluminum and hydrated alkaline cations such as K^+ or Na^+ located in the voids, (J. Davidovits).



Chemical Activator
Additive
Aggregates

GEOPOLYMER CONCRETE

Geopolymers offer a significant advantage of reducing environmental impact, and they also provide:

- High early strength
- Low drying shrinkage
- High sulphate resistance
- High temperature resistance
- High resistance to acid attack

A **user-friendly geopolymer concrete** is a sustainable concrete which can be produced in the construction site and can be cured under ambient conditions without any requirement of additional sources of energy or resources.

Industry - friendly Geopolymer Concrete

Different materials, originating from various sources, have been analyzed for the formulation of the mix design.

- Ground Granulated Blast Furnace Slag (GGBS) from iron and steel production
 - GGBS 1
 - GGBS 2
- Fly ash type F (FA) from carbon thermal power plants
 - FA1
 - FA 2.1
 - FA 2.2
 - FA 3

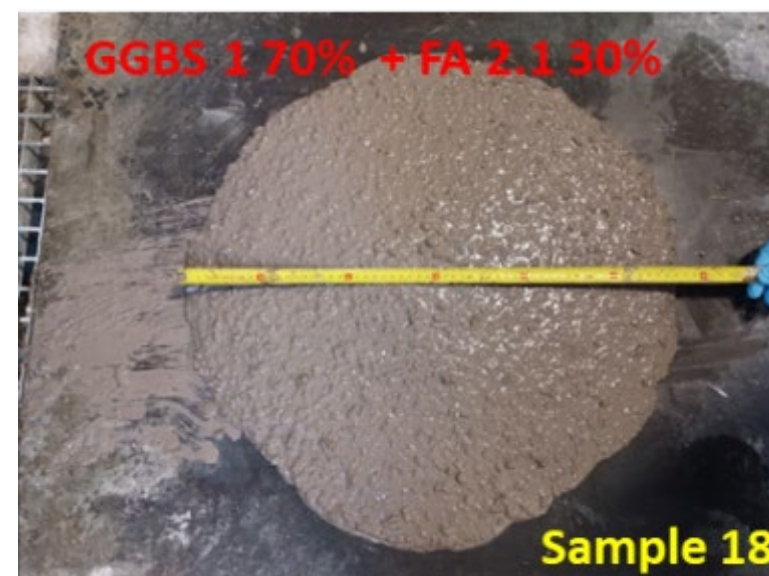
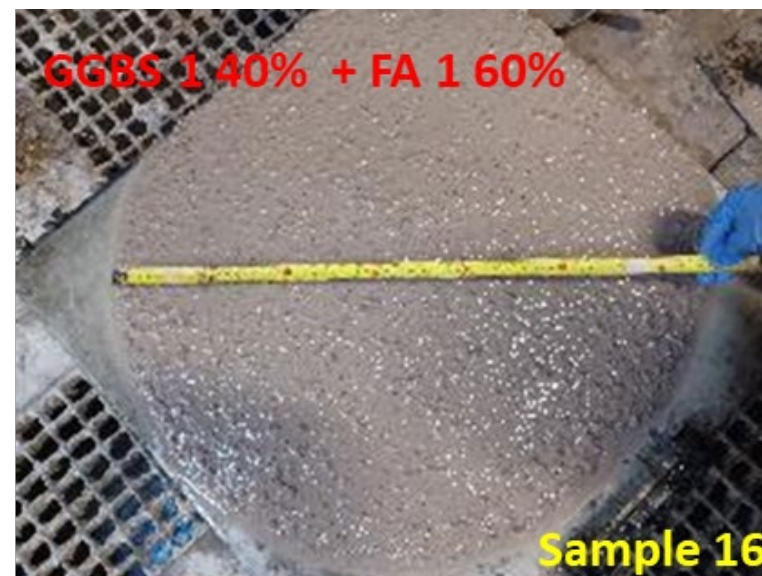
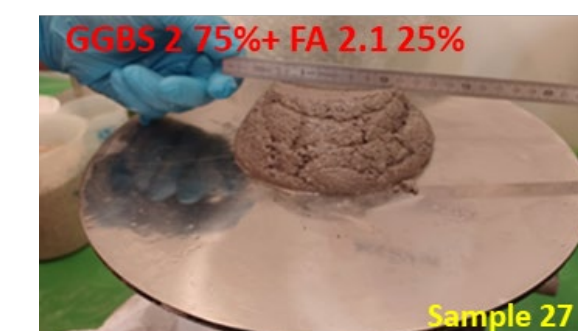
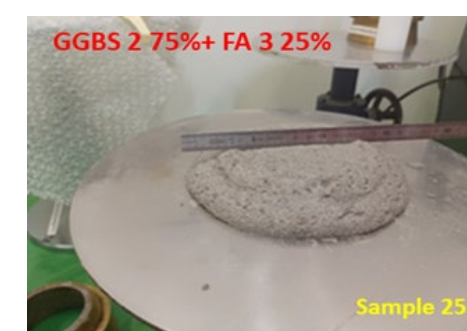
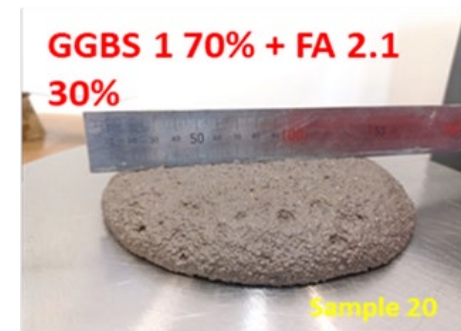
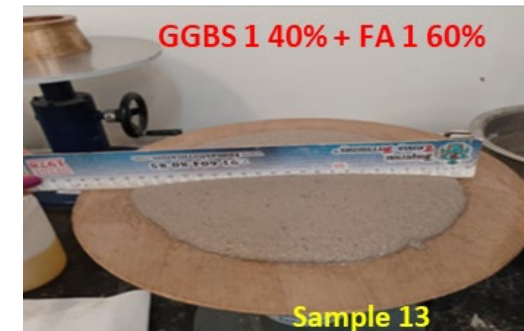
Parameter	Norm Requirements EN 450-1	FLY ASH FA 1	FLY ASH FA 2.1	FLY ASH FA 2.2	FLY ASH FA 3	Property	Norm Requirements 15167-1	GGBS 1	GGBS 2
Ignition losses	< 5 %	0,63	2,49	8,2	8,8	CaO+ MgO+ SiO2	≥66,7%	86,32	79,19
Cl-	≤0,1%		0,25	0,46	0,02	SiO2	-----	33,39	29,65
SO3	≤3%	0,62	7,16	7,02	0,3	CaO	-----	44,38	38,79
CaO (reactive)	≤10%	3,26	9,95	10,18	2,56	MgO	-----	8,55	10,75
SiO2+Al2O3+ Fe2O3	≥70%	86,89	69,49	64,33	83,48	Fe2O3	-----	0,28	0,61
SiO2	-----	60,99	37,06	34,73	60,53	Al2O3	-----	9,48	14,58
Fe2O3	-----	5,71	8,34	8,16	5,55	TiO2	-----	0,79	1,22
Al2O3	-----	20,19	24,09	21,44	17,4	Mn2O3	-----	0,17	0,24
Na2O	≤5%	2,27	2,91	2,77	0,62	SO3	≤2,5%	1,78	2,67
MgO	≤4%	2,38	2,51	2,37	0,84	Cl-	≤0,1%		0,03
P2O5	≤100 mg/kg	0,11	0,58	0,31	0,23	Na2O	-----	0,29	0,7
Pozzolanic activity index	After 28 days ≥ 75%	77,4	98,9	93,8	-	K2O	-----	0,56	0,53
Density	g/cm3	2,21	2,51	2,36	2,22				

Summary X- Ray Fluorescence XRF

Industry - friendly Geopolymer Concrete

Preliminary tests were conducted using a mortar matrix to screen variables before optimizing the concrete matrix:

- 8 dosages incorporating 100% of GGBS as binder in mortar matrix.
- 19 dosages with GGBS plus FA as binder in mortar matrix.
- 21 dosages with GGBS plus FA as binder in concrete matrix.

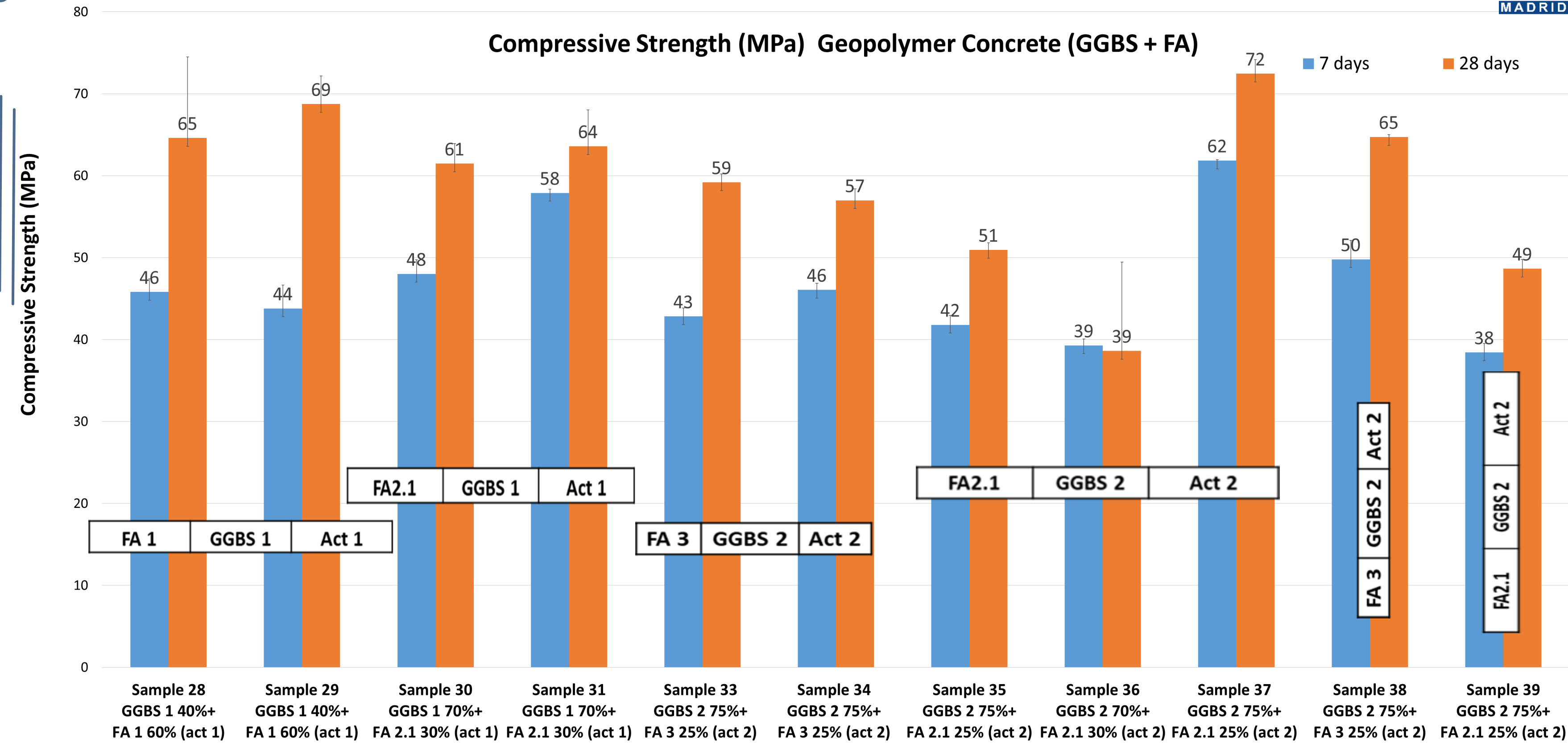


Compressive strength: C30/37

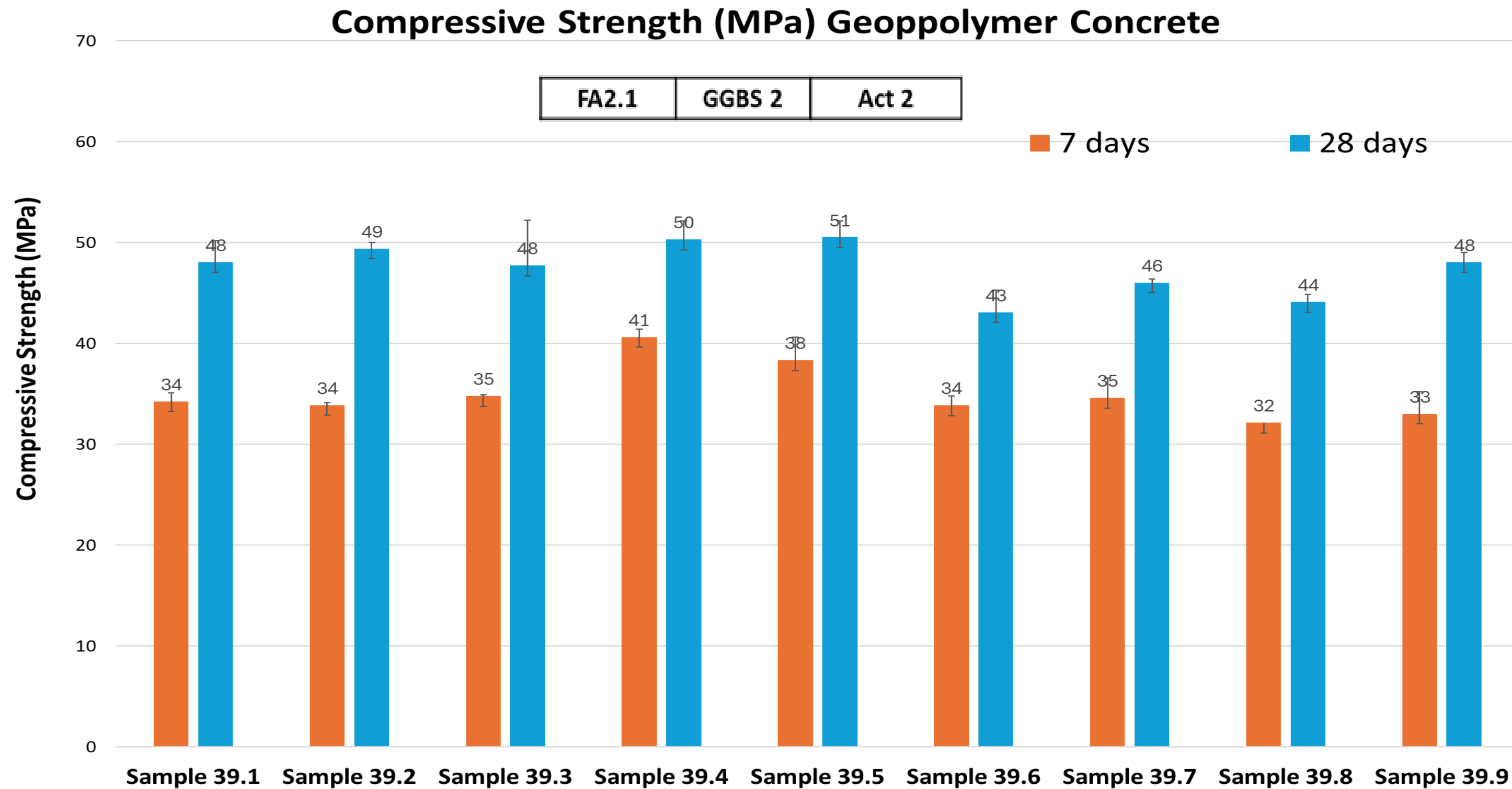


Compressive Strength (MPa) Geopolymer Concrete

Compressive Strength (MPa) Geopolymer Concrete (GGBS + FA)



Compressive Strength (MPa) Geopolymer Concrete

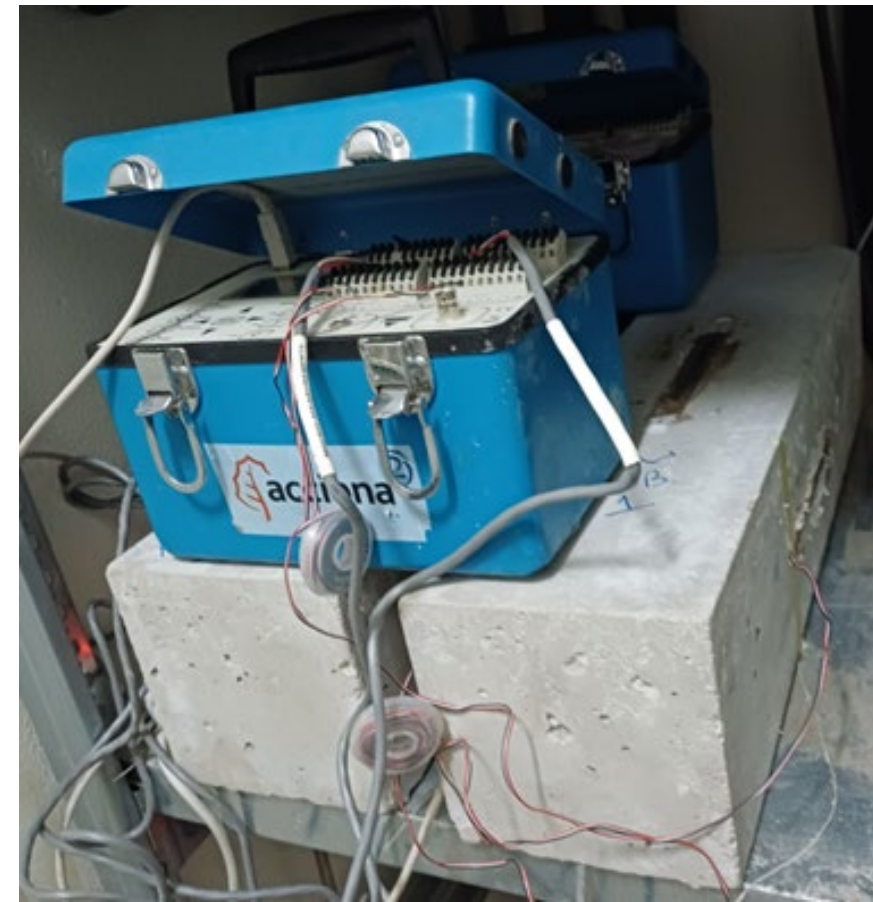


- Optimized Sample 39, using a different type of aggregate.

●●● Durability Test Geopolymer Concrete

As part of the efforts towards geopolymer development, durability tests have been performed to verify the advantages of this material.

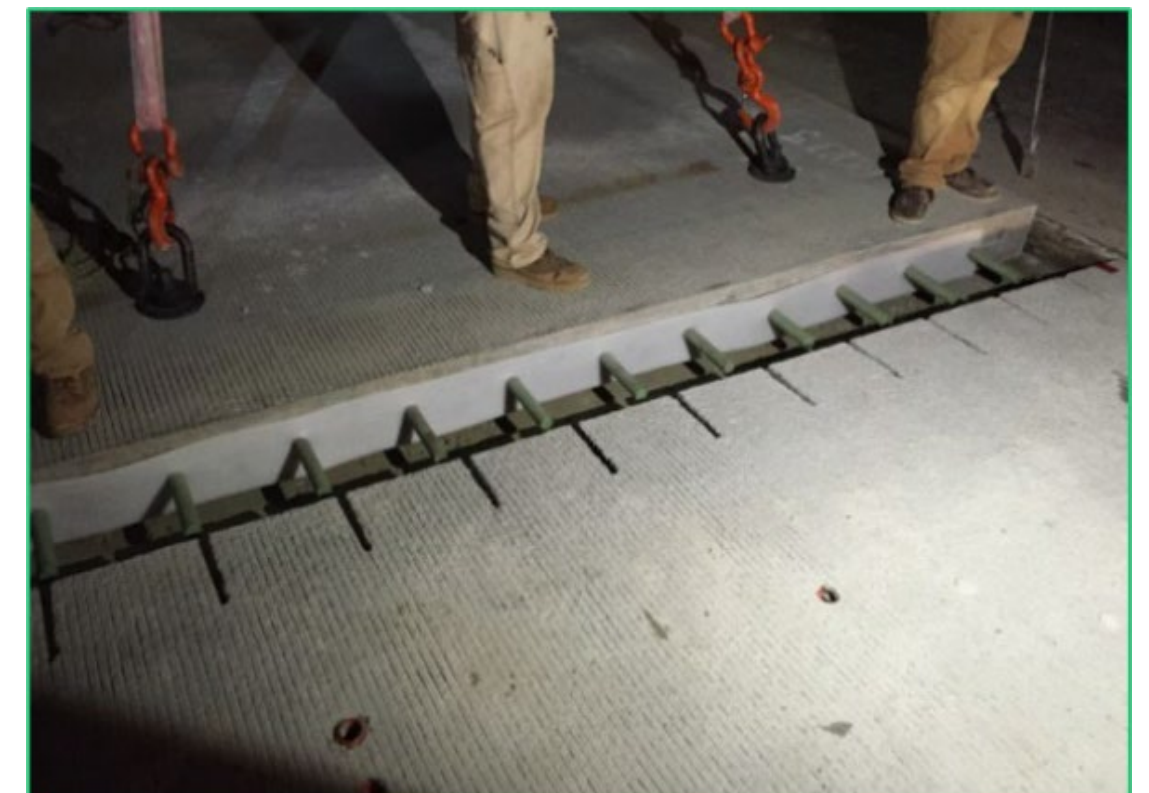
- Water penetration resistance (EN 12390-8). At 28 day and 3 month of age.
- Chloride penetration resistance (NT Build 492). At 28 day and 3 month of age.
- Shrinkage test.
- Freezing and Thawing (UNE-CEN/TS 12390-9).



● Structural Design and Industrial Manufacturing

DIFFERENCES TO EXISTING MODULAR RIGID PAVEMENTS

- Industry - friendly Geopolymer instead of concrete.
- Intelligent slabs: Weigh - in - motion system.
Failure detection and prediction maintenance.
- Reduction of execution time.
- Ease of repair.
- Extension of lifespan.
- Savings in construction and maintenance costs.

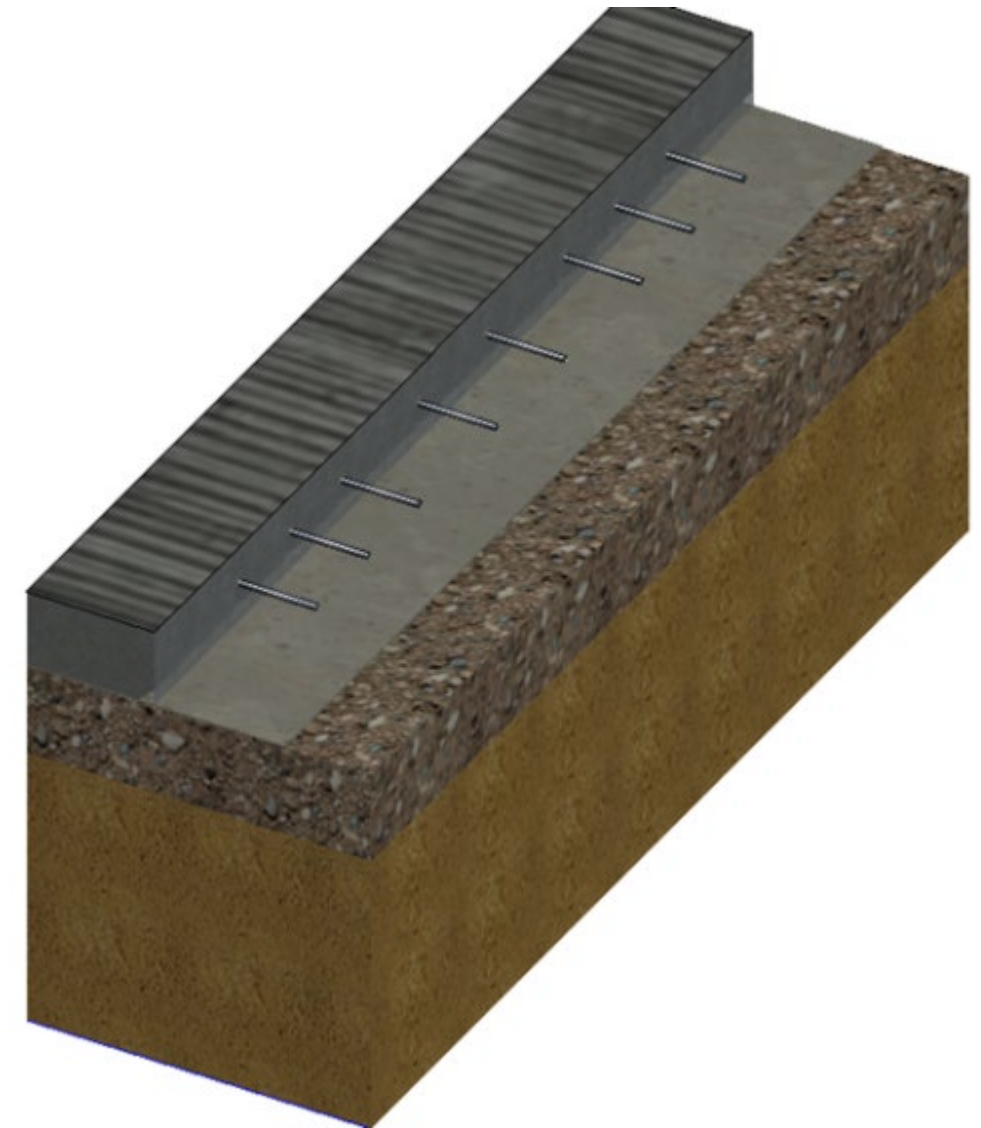


* National Precast Concrete Association (2013)
Complete Precast Concrete Paving Slab Installation.

Structural Design and Industrial Manufacturing

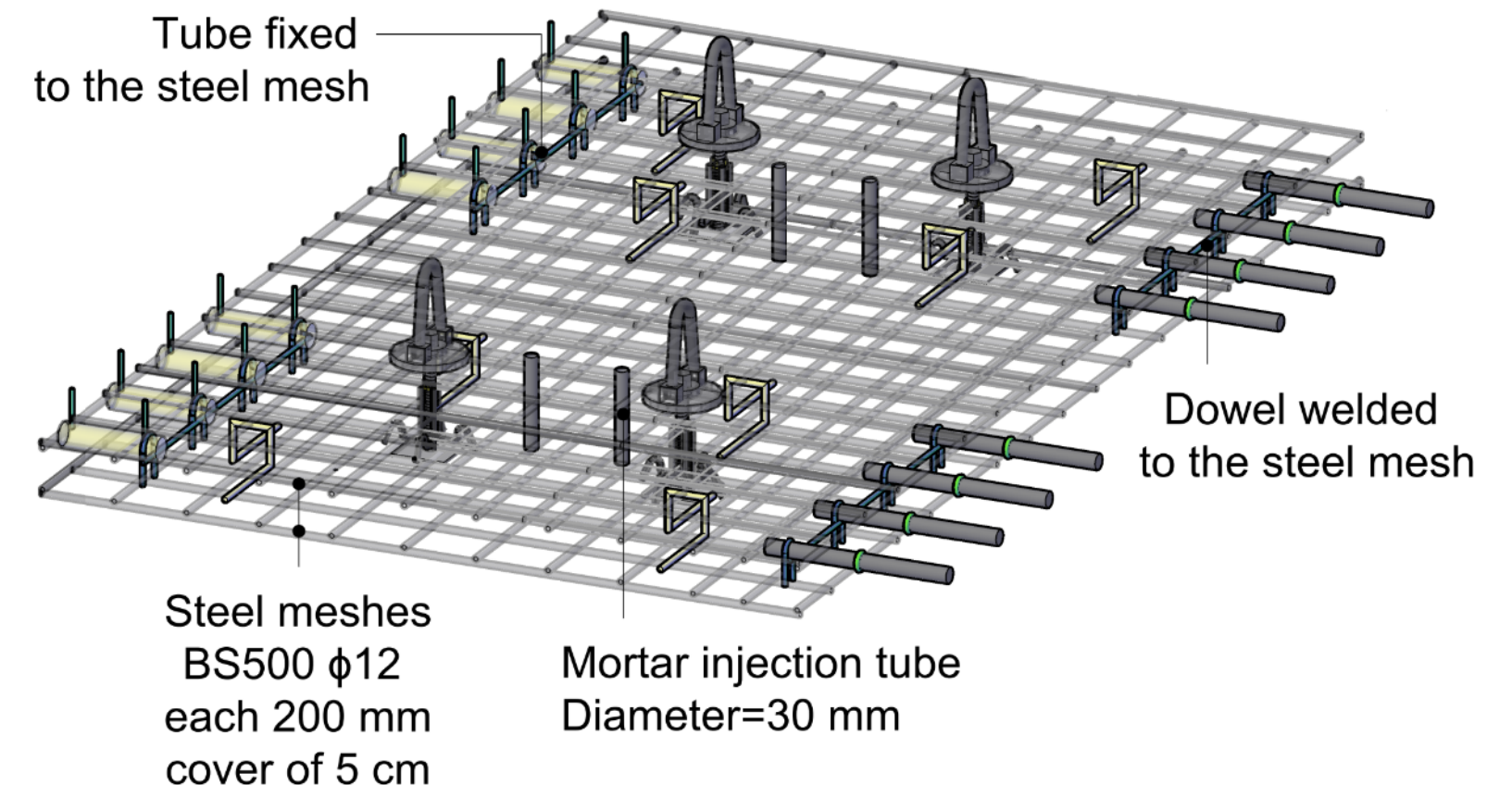
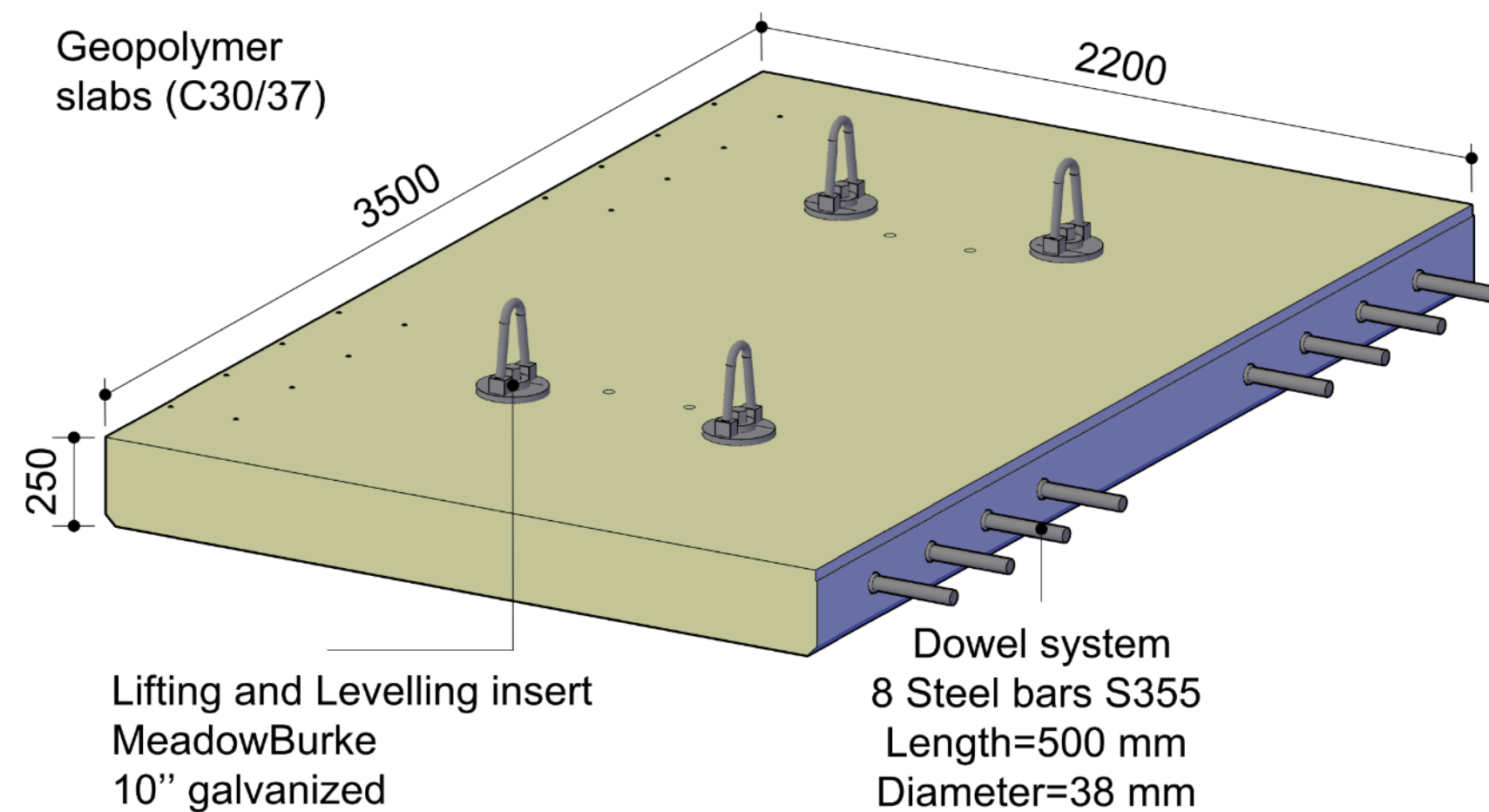
SLAB GEOMETRY AND COMPONENTS

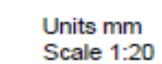
- Slab thickness = 0.25 m
- Gap between slabs = 2-6 mm → Prefabricated elastomeric joints
- Gap between slab and supporting surface = 20 mm (grouted)
- Dowel between slabs diameter = 38 mm
- Number of dowel = 8
- Position in depth of the dowel = 12.5 cm (at half thickness of the slab)
- Reinforcement steel diameter = 12 mm
- Reinforcement spacing = 20 cm
- Slabs dimensions = 3,50 x 2,20 x 0,25 m



Structural Design and Industrial Manufacturing

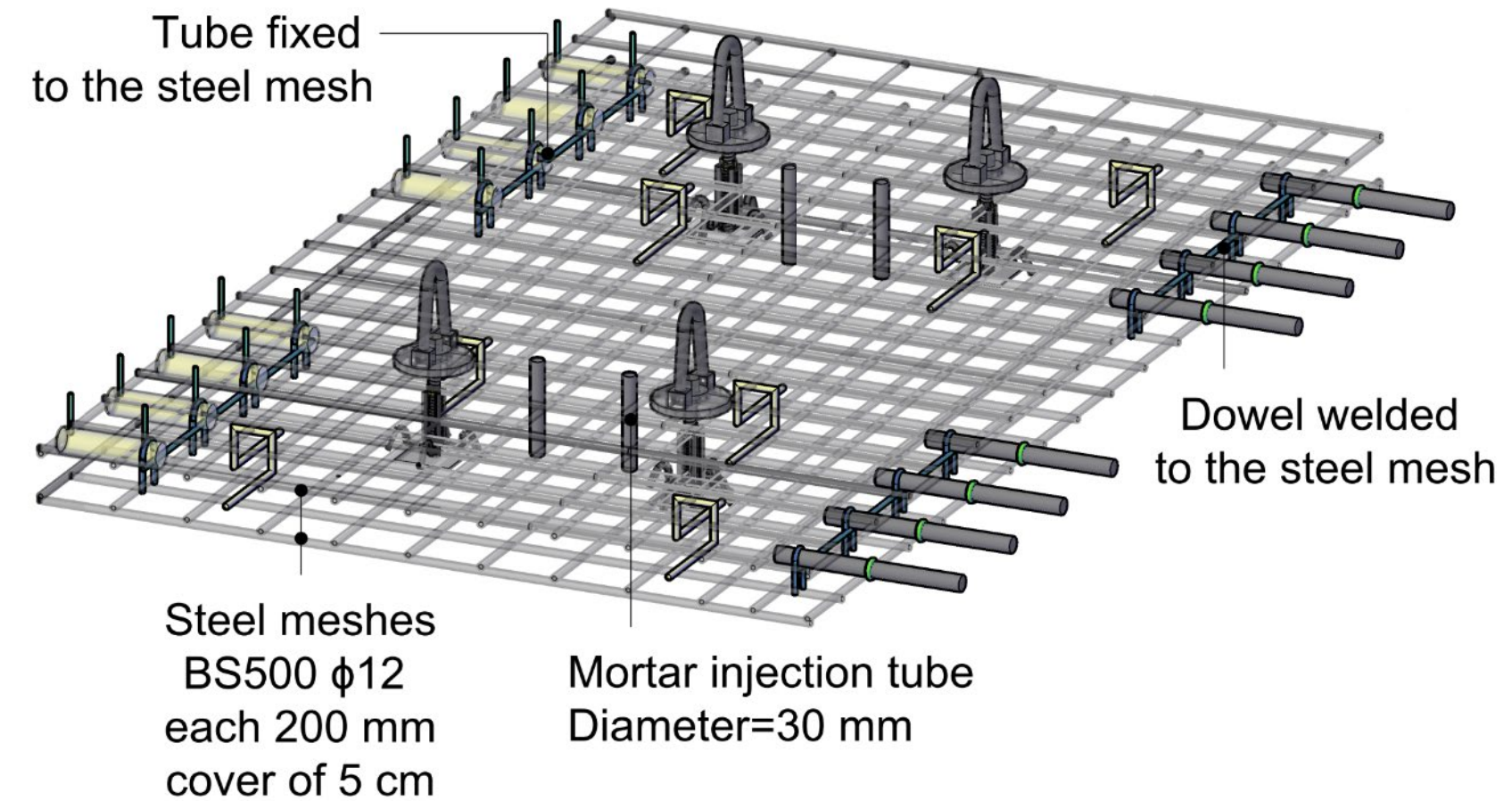
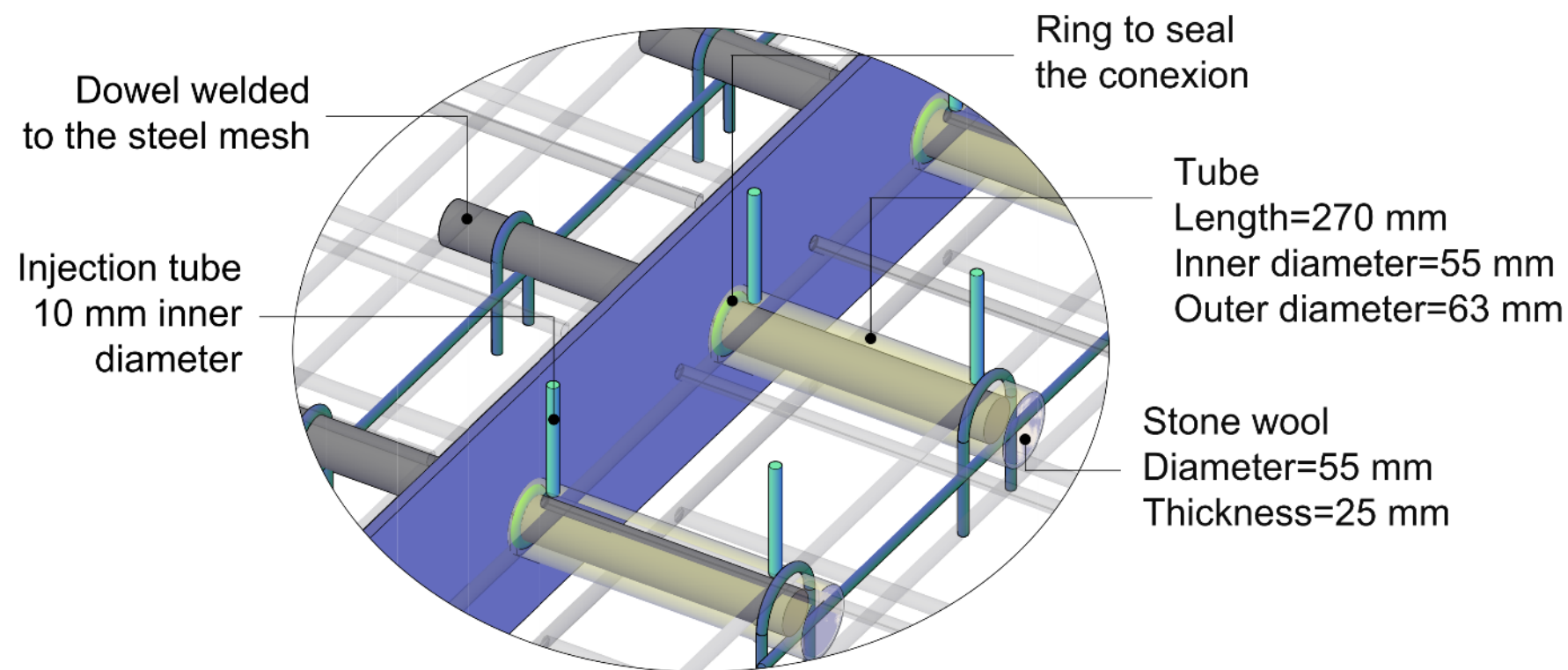
Technical drawings have been generated including general information, reinforcement detailing, positioning of secondary elements, definition of dowels between slabs, and lifting and leveling inserts.





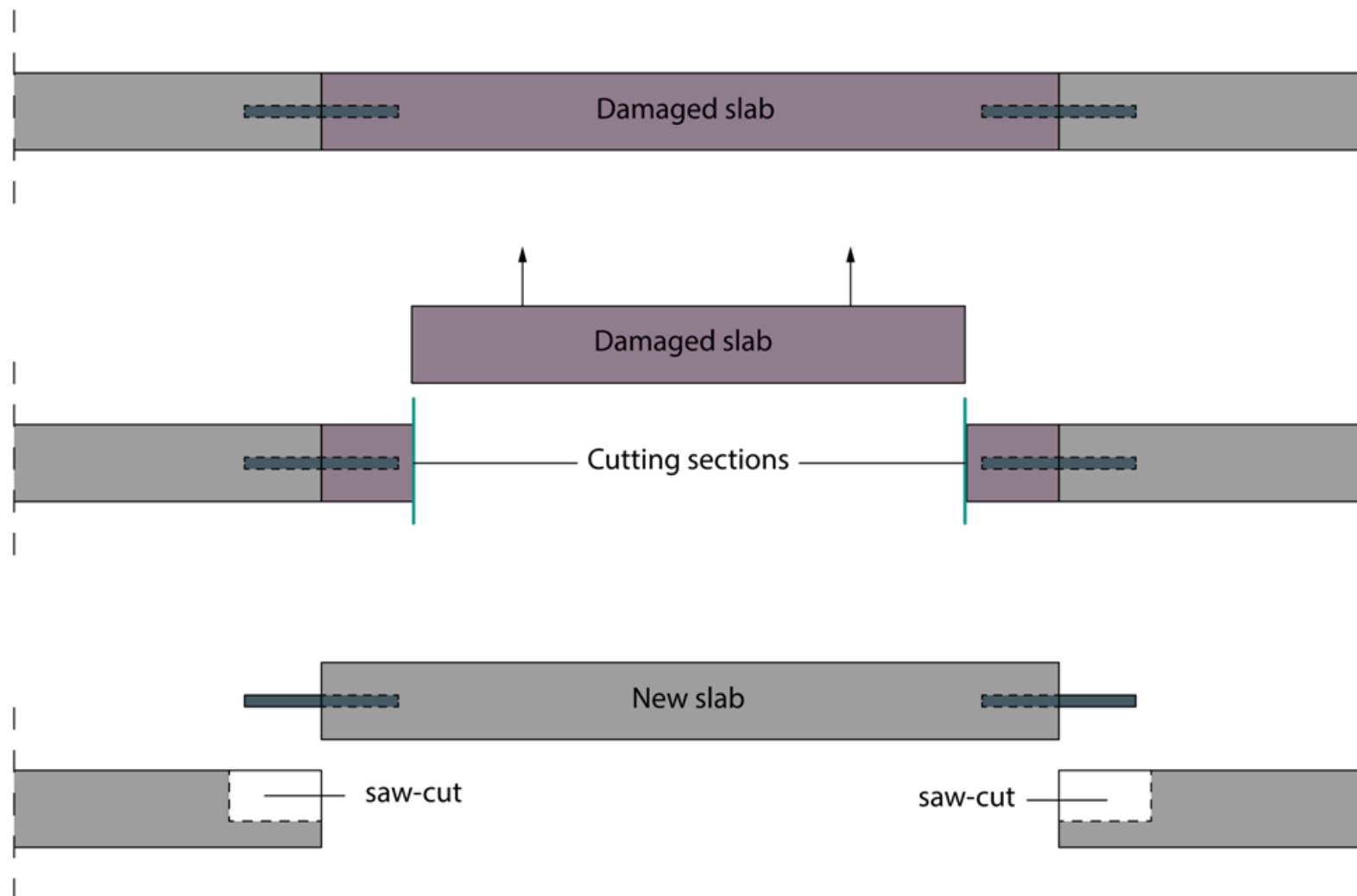
Slabs Design

Connection between slabs.



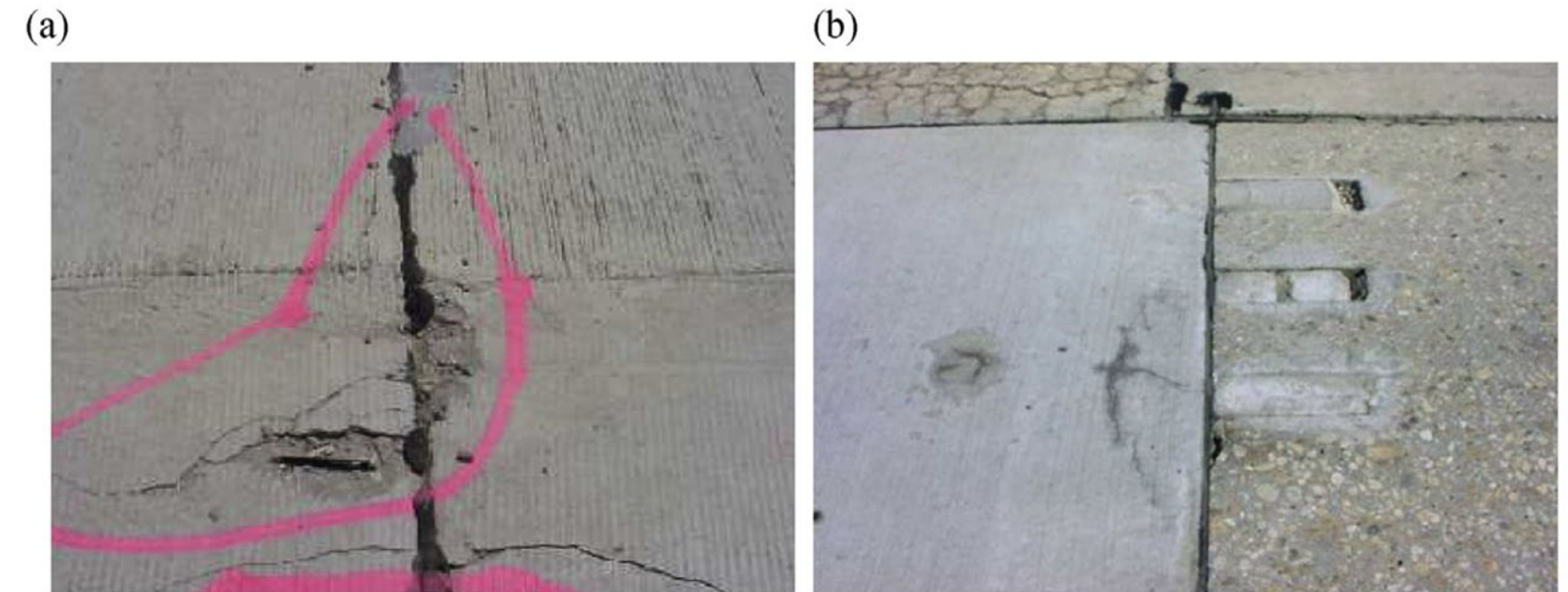
Slabs Substitution

The state of the art for slab replacement was evaluated. Idea from: NPCA National Precast Concrete Association, 2021, Manual for Jointed Precast Concrete Pavement, 3rd Ed



Best practices?

The most significant damage in case of replacement would be concentrated at the connection joints between the slabs

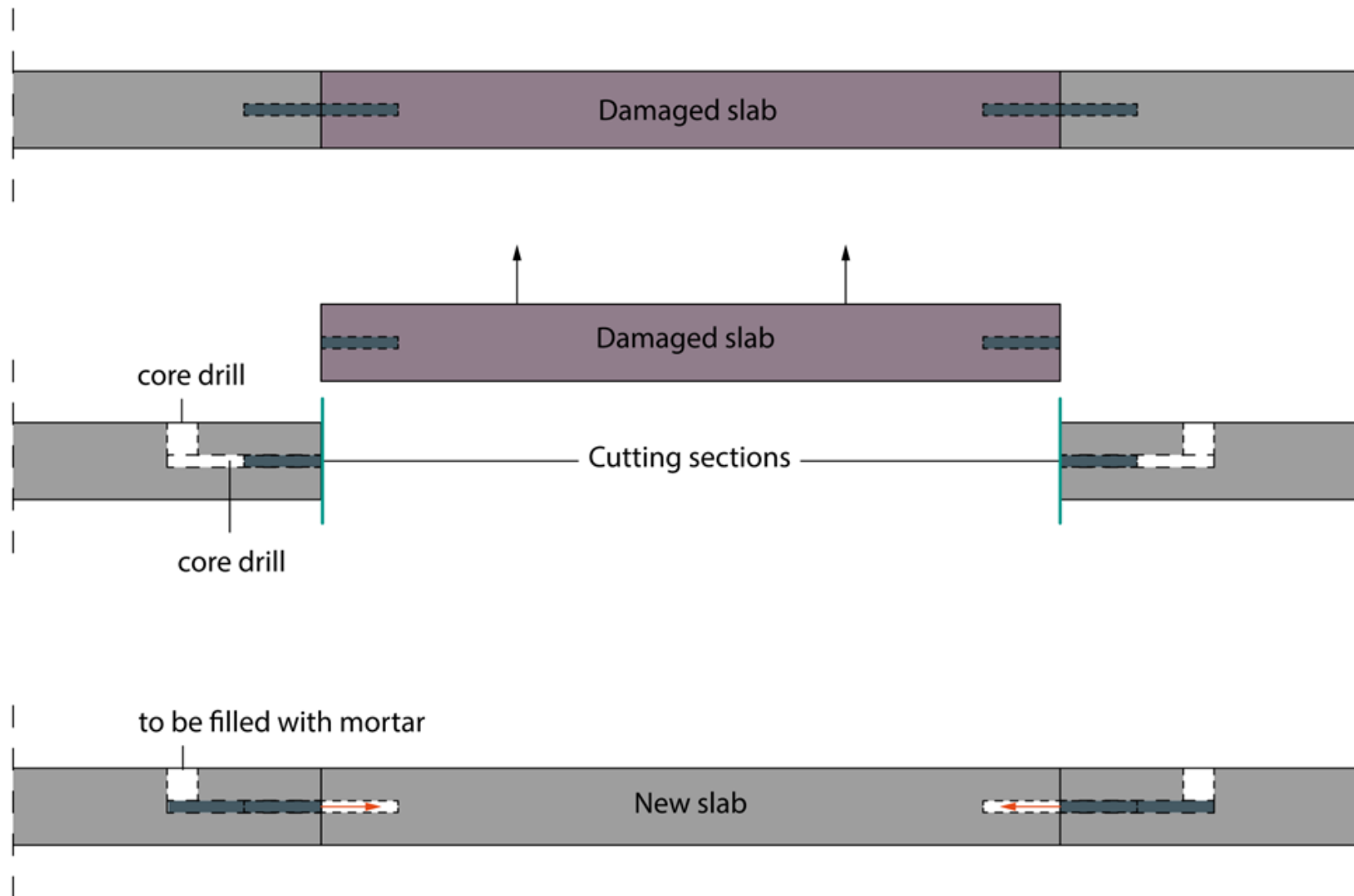


Typical damage form of joint (a) Corner cracking and spalling (Donahouse, 2009). (b) Typical panel distress (Shabbir and Celik, 2009).

* Fang, M., Zhou, R., Ke, W., Tian, B., Zhang, Y., & Liu, J. (2022). Precast system and assembly connection of cement concrete slabs for road pavement: A review. Journal of traffic and transportation engineering (english edition), 9(2), 208-222.

Slabs Substitution

State of the art: Idea from: The Fort Miller Co., Inc., 2016, Recent Innovations in Jointed Precast Concrete Pavement Systems.



Extracting Half Dowel



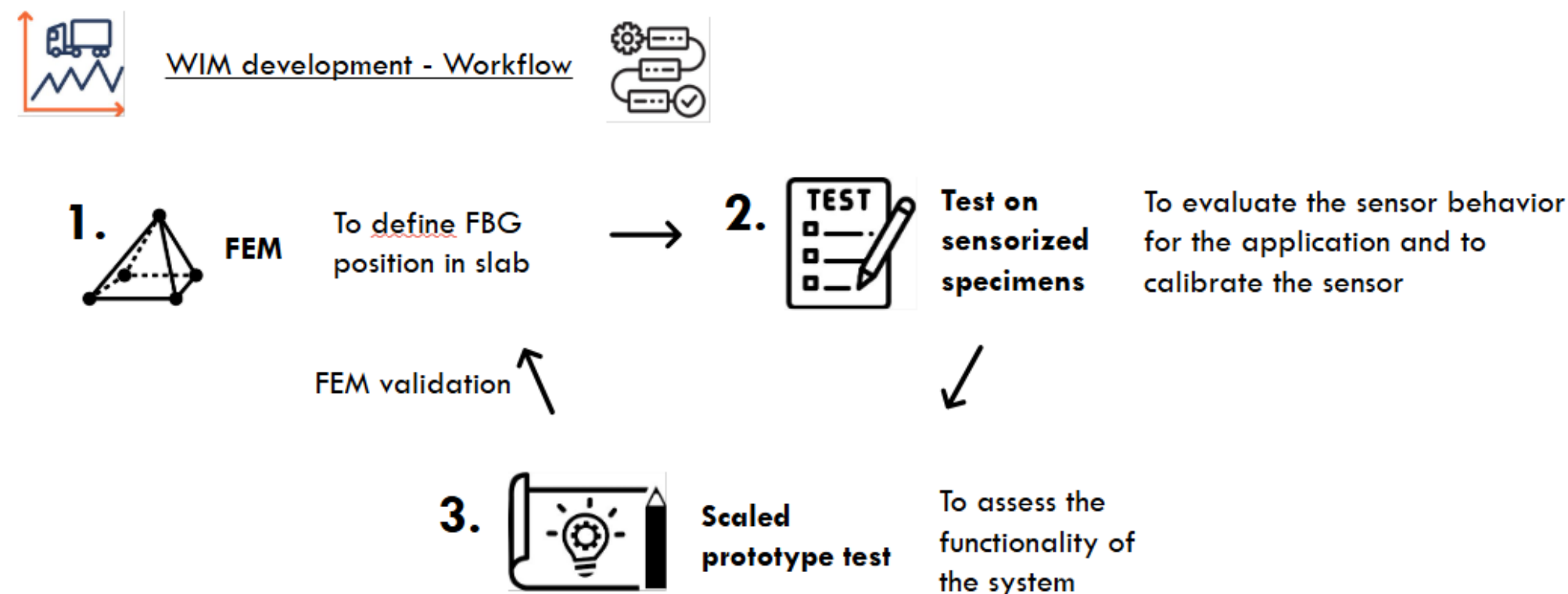
Restoring Tie Bars



* National Precast Concrete Association (2013)
Complete Precast Concrete Paving Slab Installation.

● Weigh In Motion in Slab

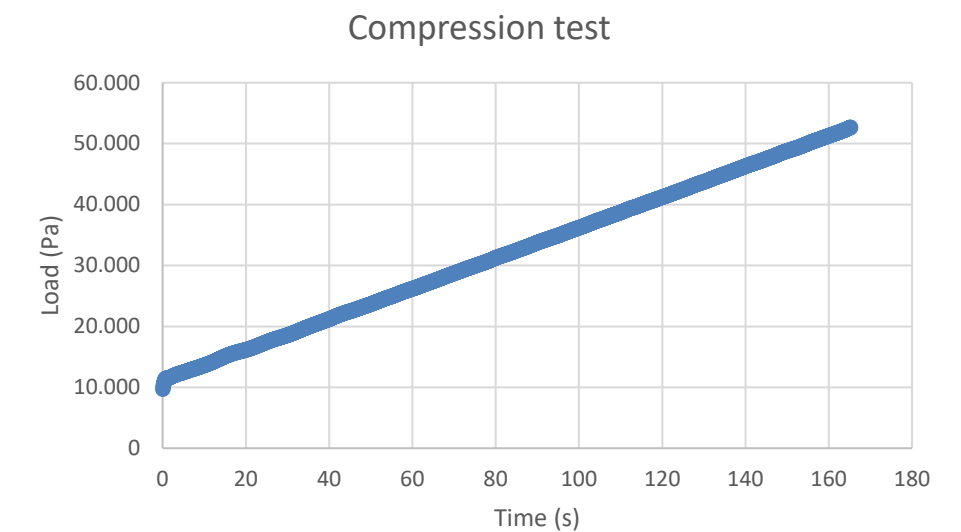
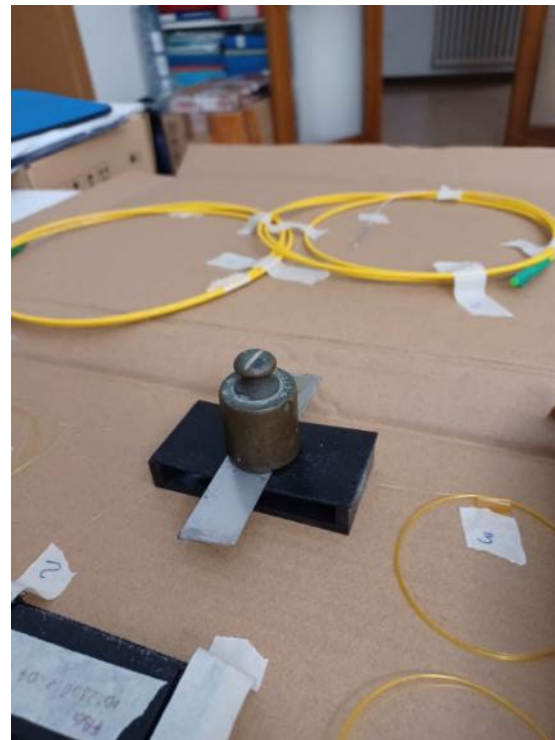
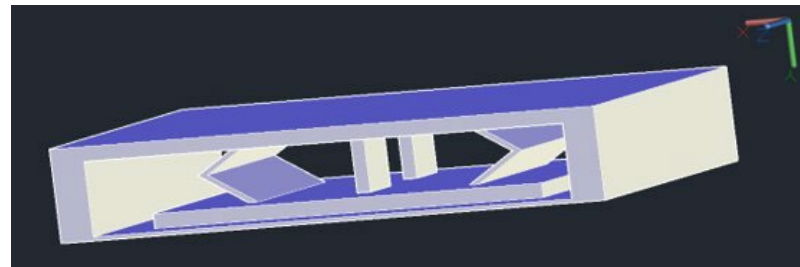
The integrated sensor is designed for controlled deformation (maximum 1 mm vertical), adapting perfectly to the slab and its reinforcement. Its ability to identify overloaded vehicles will not only extend the lifespan of the slab by 20% but also projects a 10-15% reduction in accidents. Furthermore, it will optimize heavy traffic flow, surpassing the limitations of traditional systems.



* RINA Consulting SPA

● Weigh In Motion in Slab

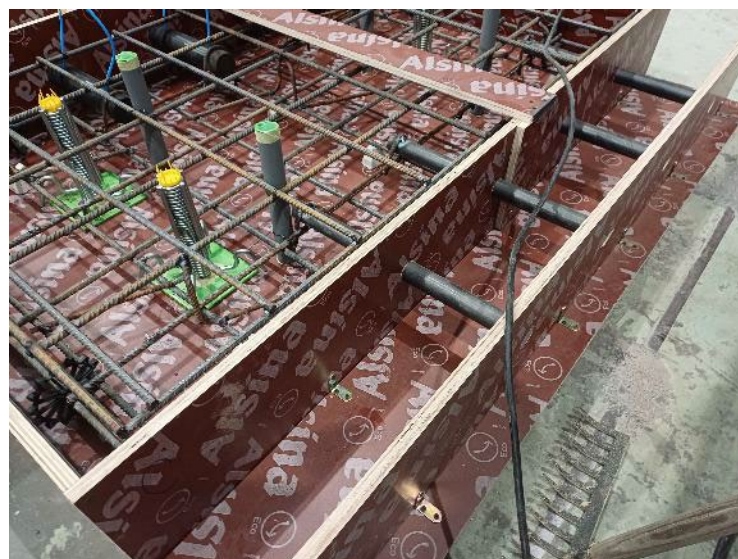
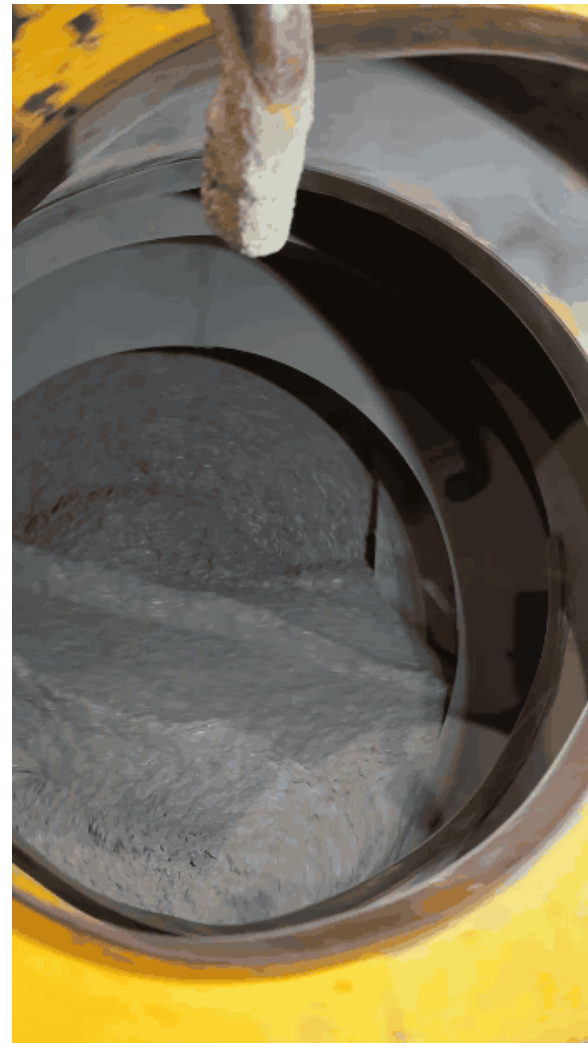
To achieve an optimized sensor design, 3D printing was utilized, which facilitated precise calibration tests with low loads. This was a fundamental stage in preparing the sensor for the subsequent and successful compression tests.



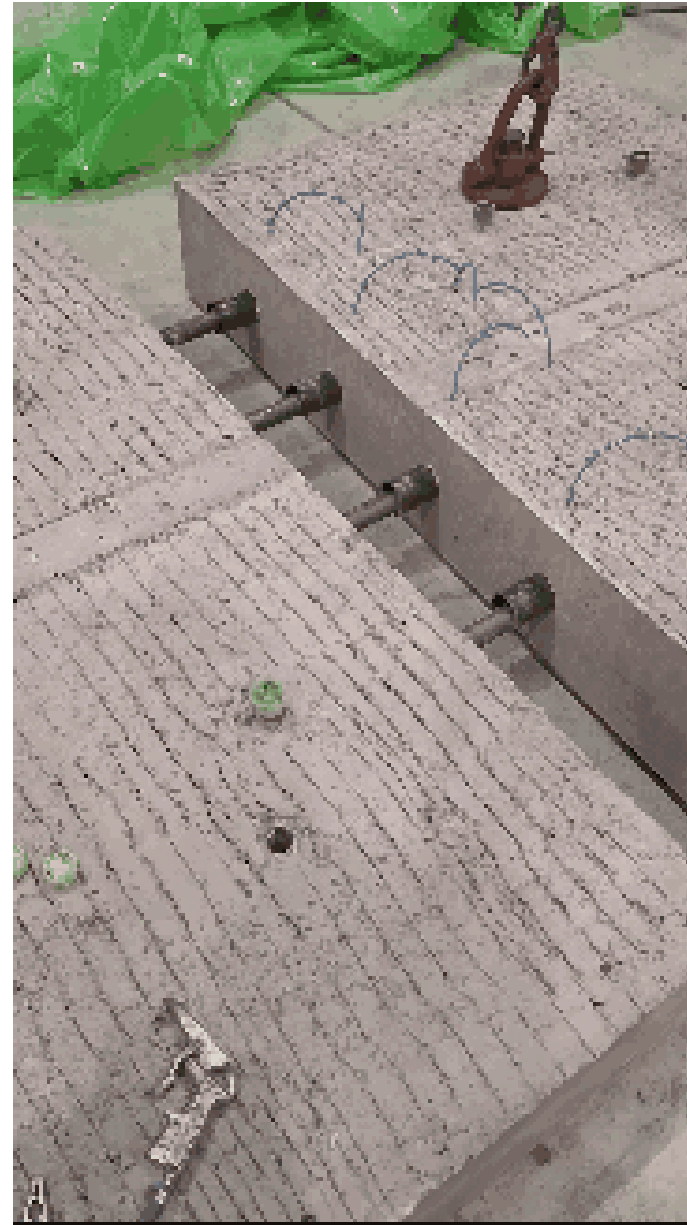
* RINA Consulting SPA

Where are we?

First step completed! We have manufactured initial test slabs, at a smaller scale than those that will form our demonstrator. This key milestone will allow us to precisely validate the manufacturing and installation process.

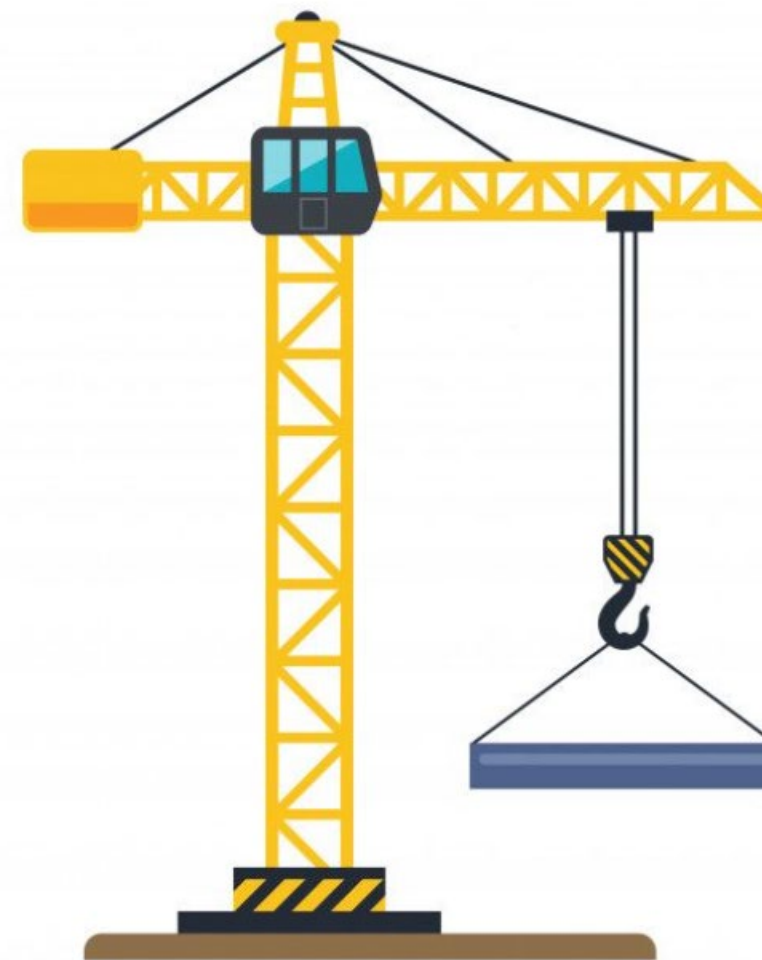


Where are we?



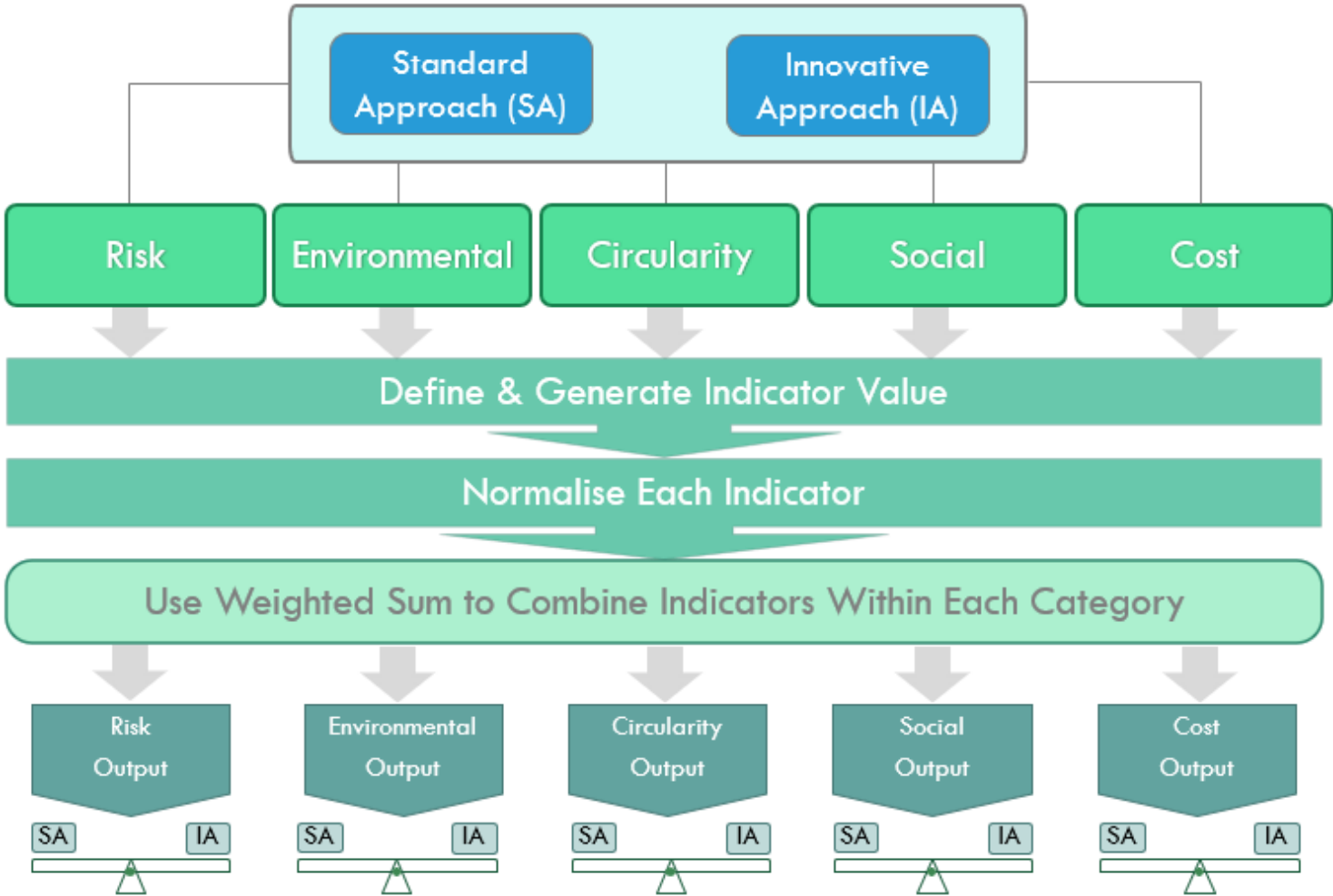
Our Next Milestone

Our project's next exciting phase: constructing a 30-meter test section composed of 14 pre-fabricated geopolymer concrete slabs. Notably, one of these slabs will feature an integrated Weigh In Motion System, enabling real-time monitoring of vehicle weights.



Tracking Progress: Quantifying Circularity

LIAISON project evaluate the success of our circular economy strategies for transport infrastructure construction through a defined quantitative methodology, Dynamic Multi-Infrastructure Governance Framework (DMIGF). This involves specific circular performance indicators that will allow us to track and measure our achievements.



POTENCIAL INDICATORS	
Risk	Strain Frost resistance
Environmental	Energy use Carbon emissions
Circularity	Use of virgin materials Re-use of materials Waste diverted from landfill
Social	User delays Comfort
Cost	Life cycle cost

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Thank You

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