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Vulnerability assessment and dynamic characterisation of a glass footbridge: on-site vibration tests and FE numerical modelling

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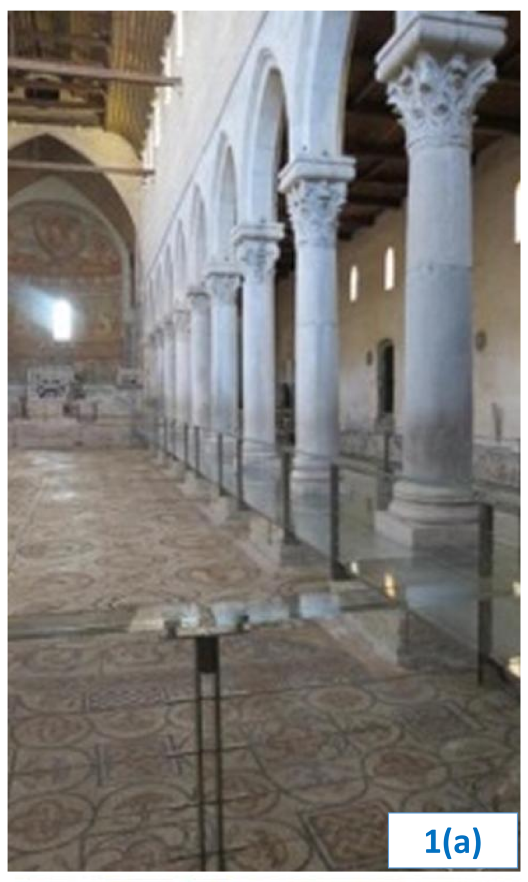
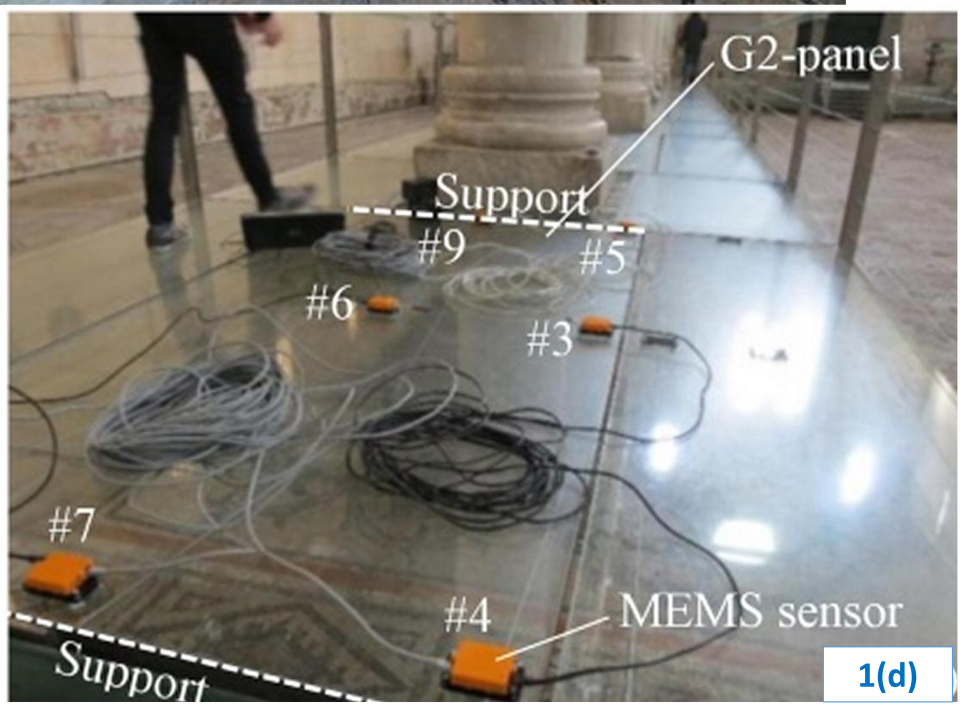
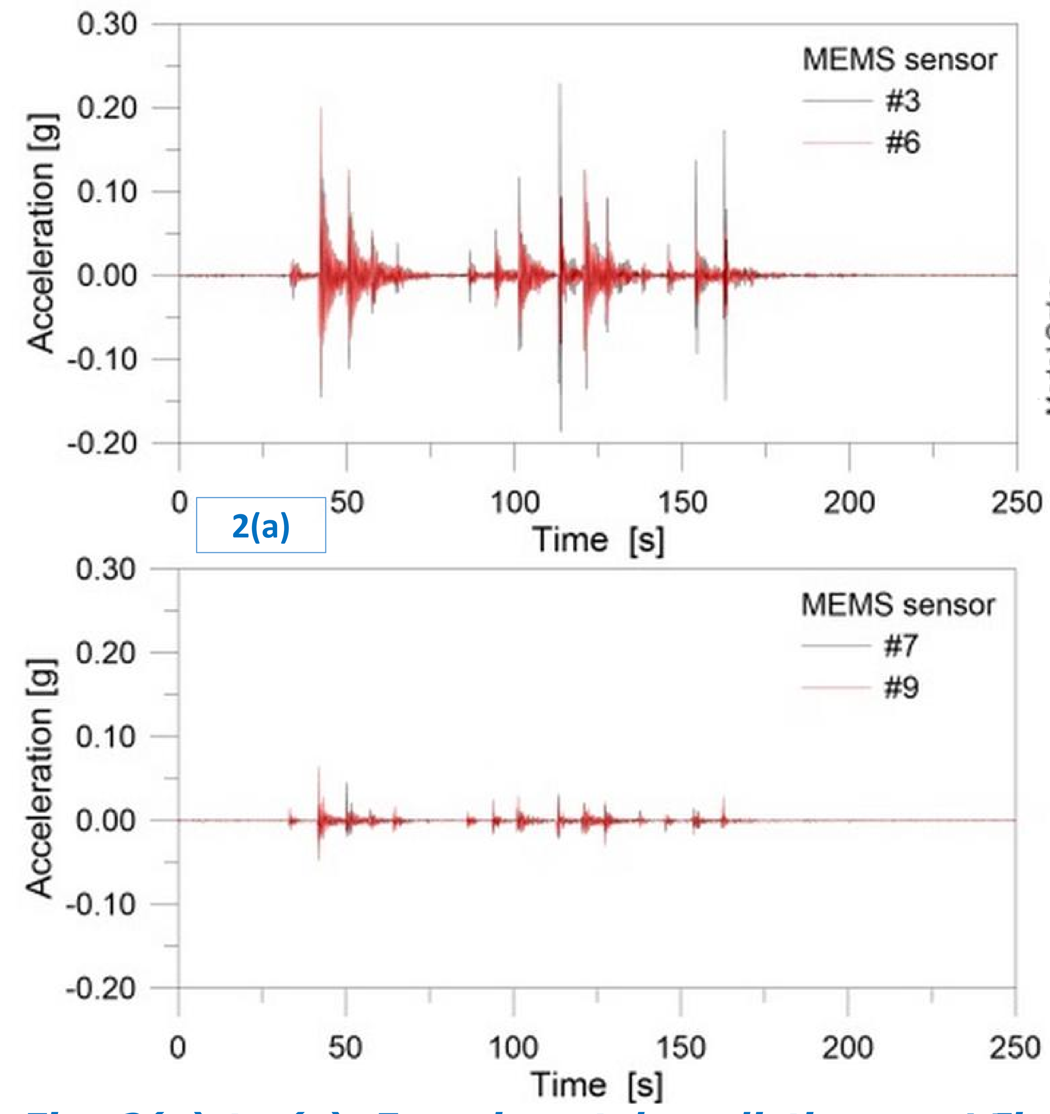


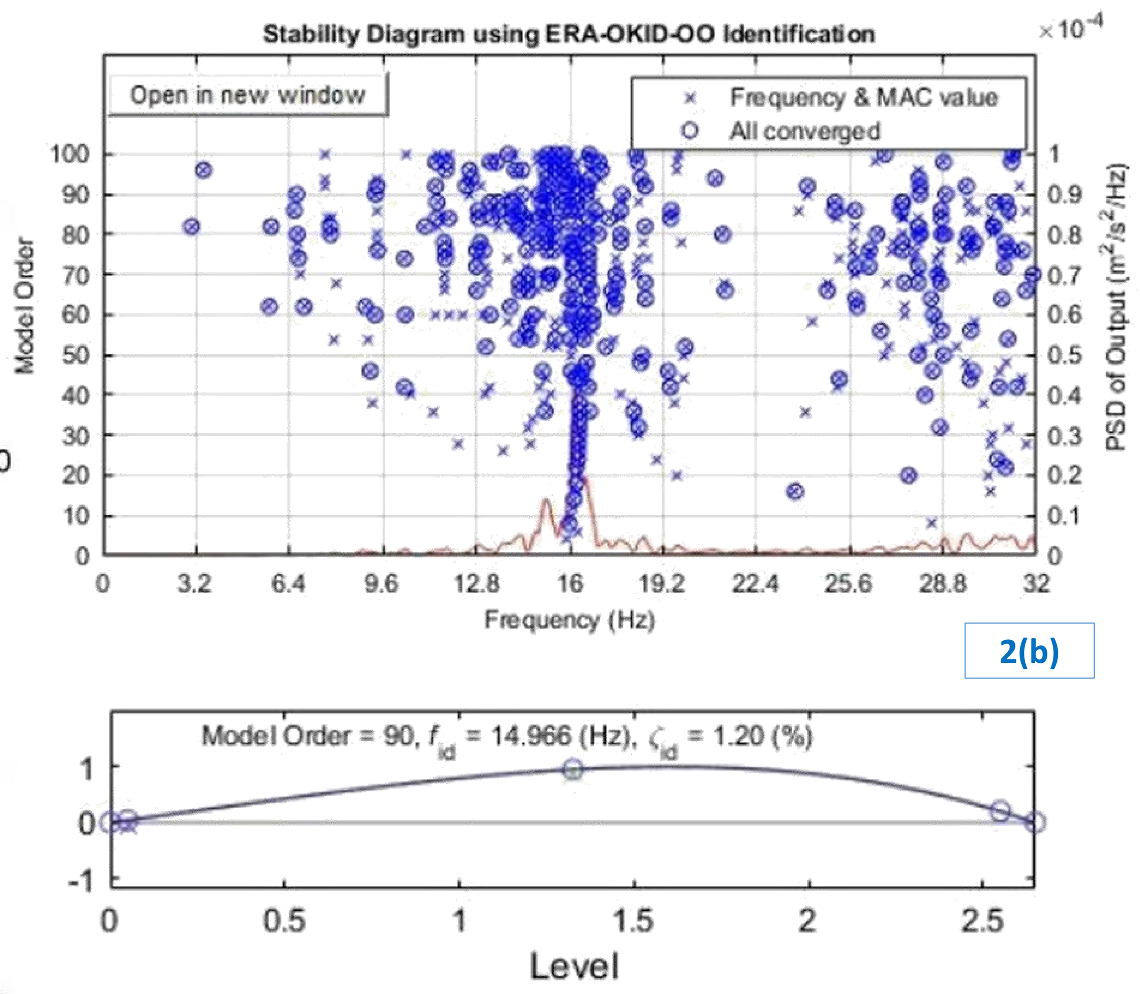
Figs.1(a)-to-(d): general view and details of the case study glass footbridge



In the last decades, the use of glass as a load-bearing material showed an exponential increase. Although it represents a relatively new construction material, requiring appropriate design methods and knowledge, glass is largely used for facades, roofs, footbridges. Given a series of intrinsic features, special care should be spent at the design stage, to ensure appropriate fail-safe requirements, but also in the life-time of these structures (**CNR-DT 210/2013**). The brittle behaviour and limited tensile resistance of glass, as well as the typical high flexibility of glazing assemblies, represent major issues. Further critical aspects may derive from time and ambient effects, due to the sensitivity of glass-related materials and components to long-term loads, humidity, fatigue, etc., or extreme loads. The vulnerability assessment of glazing systems under exceptional events (seismic scenarios, etc.) is hence an open topic, still requiring huge efforts.

In this paper, the preliminary dynamic characterisation of an existing glass suspension footbridge is presented. As a case-study, the walkway of the Basilica of Aquileia (UD) is taken into account. On-site vibration experiments are discussed, to estimate the fundamental parameters of the structure. A Finite Element (FE) numerical study is then carried out in ABAQUS, to further assess and explore the walkway performance and verify the suitability of FE models for diagnostic purposes.





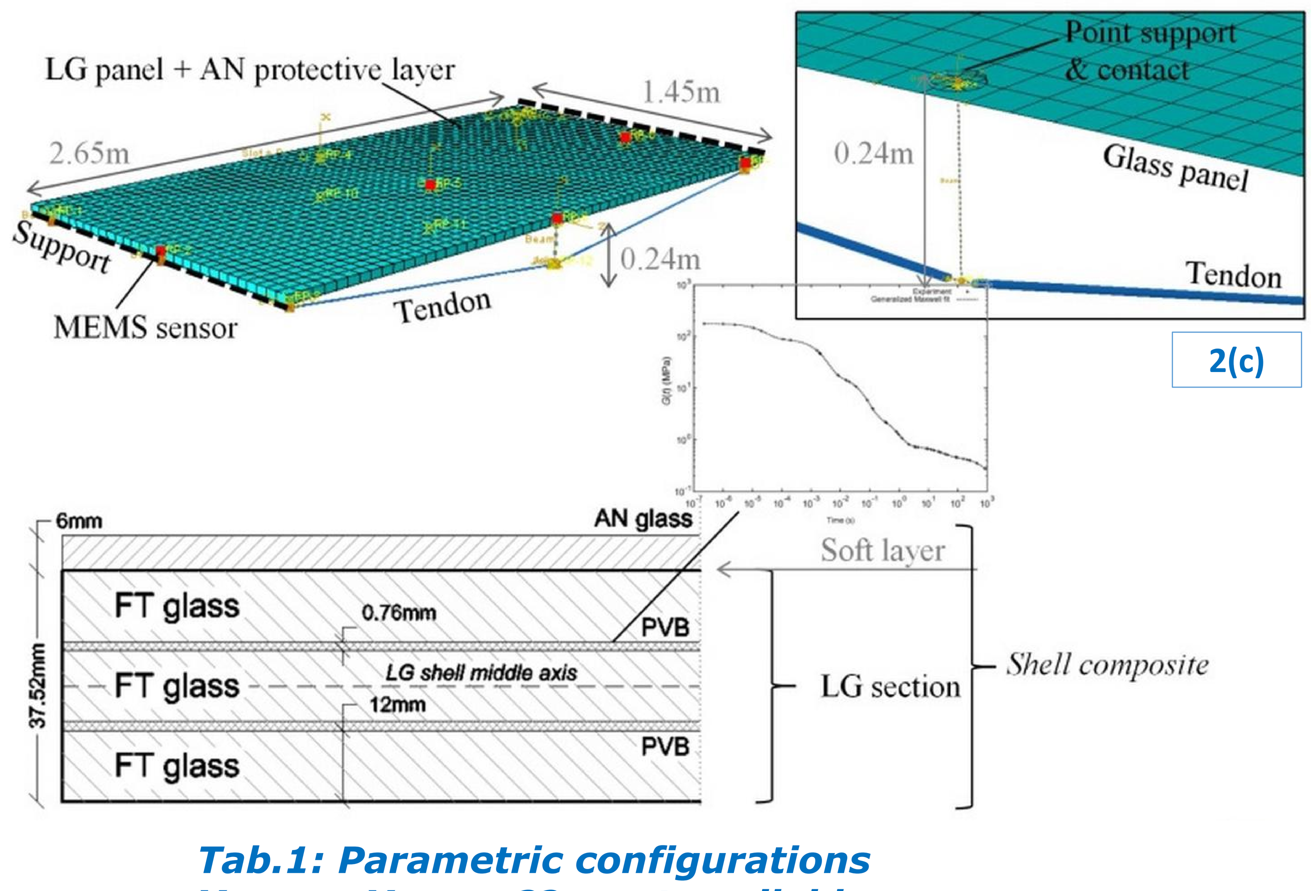
Figs.2(a)-to-(c): Experimental predictions and Finite Element numerical methods (ABAQUS)

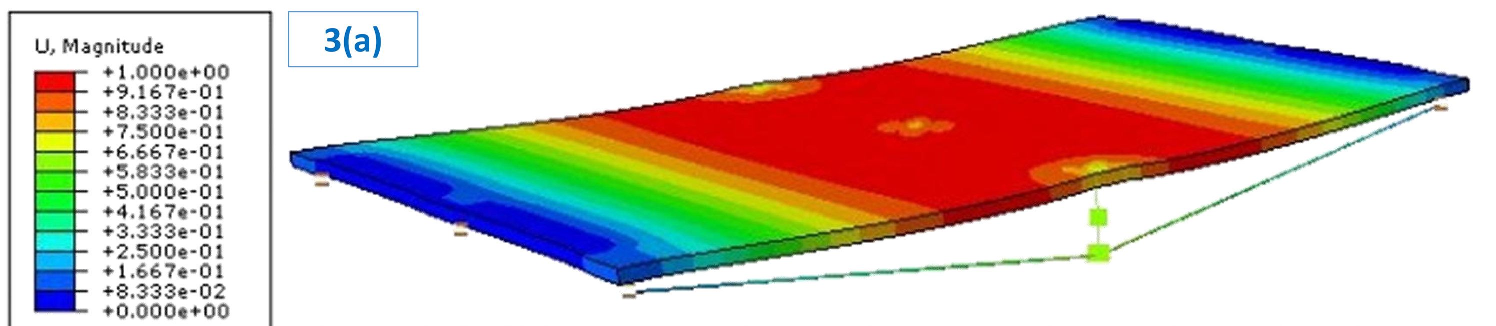
On-site experiments

The Experimental Modal Analysis of the Aquileia footbridge was carried out in November 2017. The full set of measurements was performed using the MEMS accelerometers prototyped in (**Bedon et al. 2018**). Given the average size of glass panels, six sensors were used and optimally located on the structure (i.e., #*n* sensors of **Fig.1(d)**). Output-only tests data were recorded, based on human induced vibrations (**Fig.2(a)**). The on-site experiments were performed on the footbridge panels characterised by maximum dimensions, and later on the panels with visible damage.

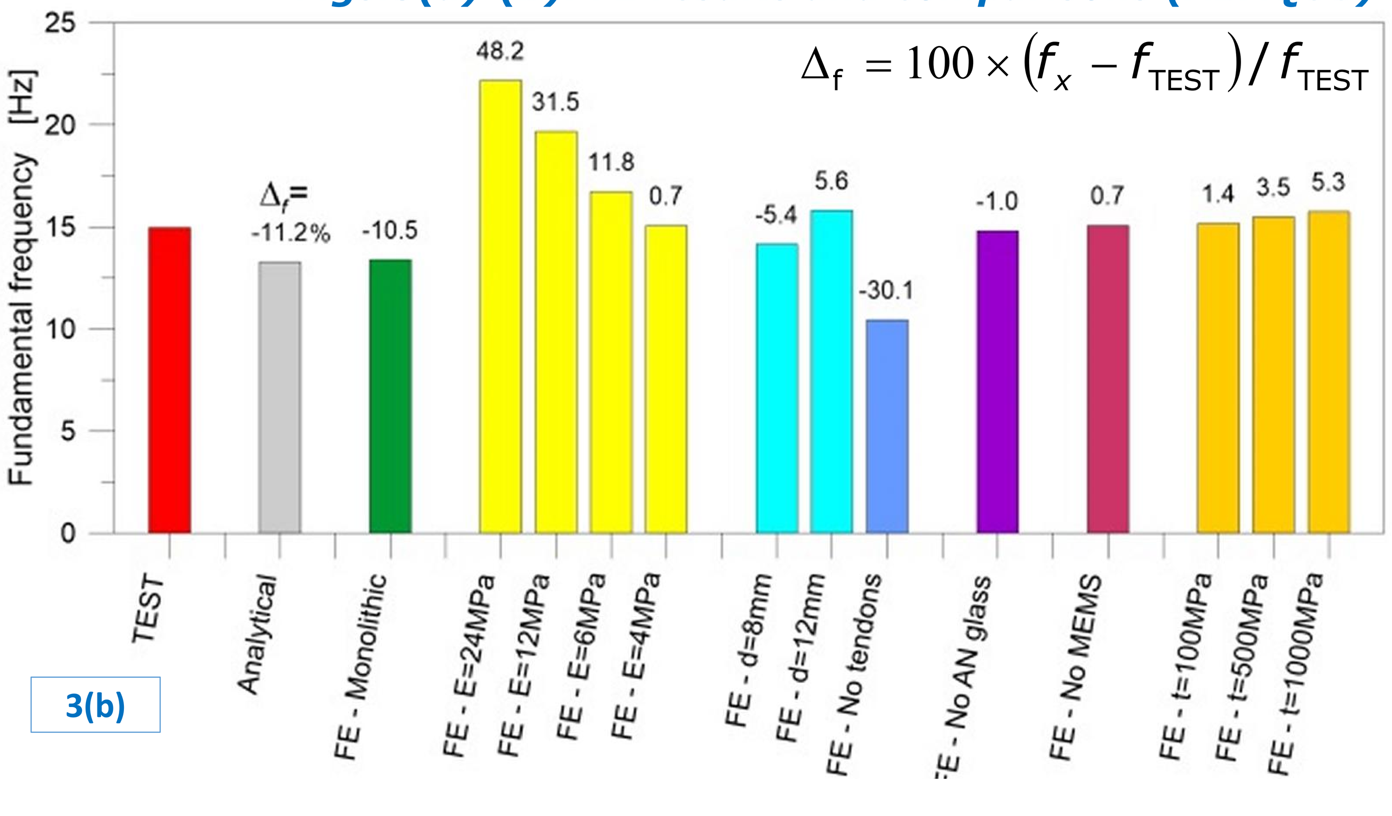
Preliminary observations carried out to qualitatively assess the state-of-the-art of the structure gave in fact evidence - for some of the panels only - of (d1) surface abrasion and minor glass cracks; (d2) condensation and debonding phenomena; (d3) dislodgement and pre-stress losses, for the steel supports and bracing tendons (**Fig.1(c)**).

All the test measurements were properly analysed (**SMIT**), to detect the fundamental mode of the footbridge (**Fig.2(b)**). Careful consideration was spent for the 1.45×2.65m G2-panel of the central nave. According to the test setup of **Fig.1(d)**, through the post-processing phase, the glass structure showed a beam-like bending response (**Fig.2(b)**), with f_{TEST}**=14.97Hz** the fundamental frequency and ξ_{TEST}**=1.20%** the modal damping.





Figs.3(a)-(b): FE results and comparisons (ABAQUS)



Tab.1: Parametric configurations
Y= yes; X= no; ??= not available

		Glass panel			MEMS	Steel tendons		
		LG section	E_{PVB} [MPa]	AN layer	Lumped mass [Kg]	Tendons	Diameter d [mm]	Pre-stress t [MPa]
	TEST	Y	??	Y	0.15	Y	10	??
	Analytical (Eq.(1))	X (36mm)	X	X	X	X	X	X
FE model #	Monolithic	X (36mm)	X	X	X	X	X	X
	E=24MPa	Y	24	Y	0.15	Y	10	X
	E=12MPa	Y	12	Y	0.15	Y	10	X
	E=6MPa	Y	6	Y	0.15	Y	10	X
	E=4MPa	**Y**	**4**	**Y**	**0.15**	**Y**	**10**	**X**
	d=8mm	Y	4	Y	0.15	Y	8	X
	d=12mm	Y	4	Y	0.15	Y	12	X
	No tendons	Y	4	Y	0.15	X	X	X
	No AN glass	Y	4	X	0.15	Y	10	X
	No MEMS	Y	4	Y	X	Y	10	X
	t=100MPa	Y	4	Y	0.15	Y	10	100
	t=500MPa	Y	4	Y	0.15	Y	10	500
	t=1000MPa	Y	4	Y	0.15	Y	10	1000

Acknowledgements

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Results and conclusions

The dynamic performance of the suspension structure was investigated via experimental measurements, parametric FE simulations and rough analytical calculations.

Worth of interest in **Tab.1** and **Fig.3(b)** is that the analytical model does not capture the vibration response of the footbridge (poor description of the LG section, lack of tendons, etc.). The FE model, conversely, can describe its bending behaviour and provide useful feedback. The actual role and interaction of structural components was also emphasised.

Severe FE frequency variations resulted especially from the PVB stiffness. Compared to design (E_{PVB}=24MPa, Δ_f=+48.2%), the optimal rigidity of PVB foils was found in E_{PVB}=4MPa (Δ_f=+0.7%), hence confirming a weak connection of the LG section, due to material degradation and possible debonding, to properly address. The AN layer resulted in minimum variations (Δ_f=-1%). Modifications of tendons size and pre-stress showed a Δ_f=±5% scatter. The full removal of bracing tendons from the FE assembly, finally, proved to largely underestimate the frequency of the footbridge (Δ_f=-30.1%), since disregarding the actual boundary conditions of the structure.

References

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