Seismic assessment and retrofit of «Artemio Franchi» Stadium of Pier Luigi Nervi in Florence

Scientific Responsible of the assessment study and the retrofit design:
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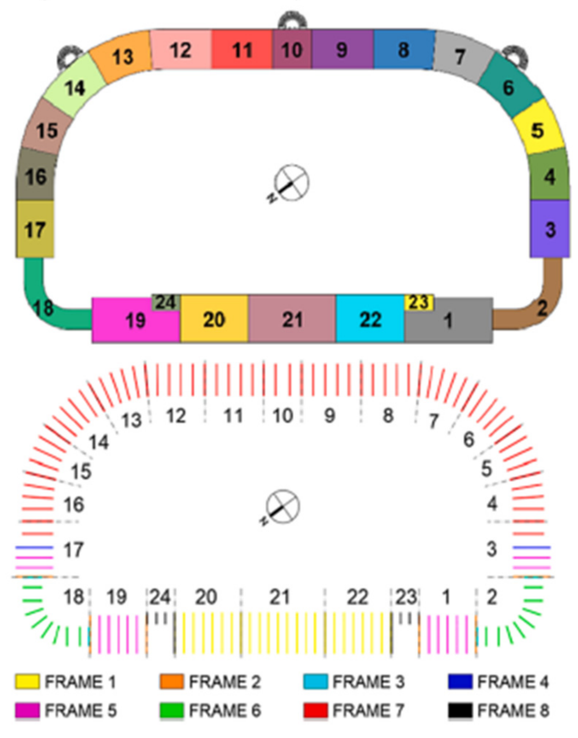
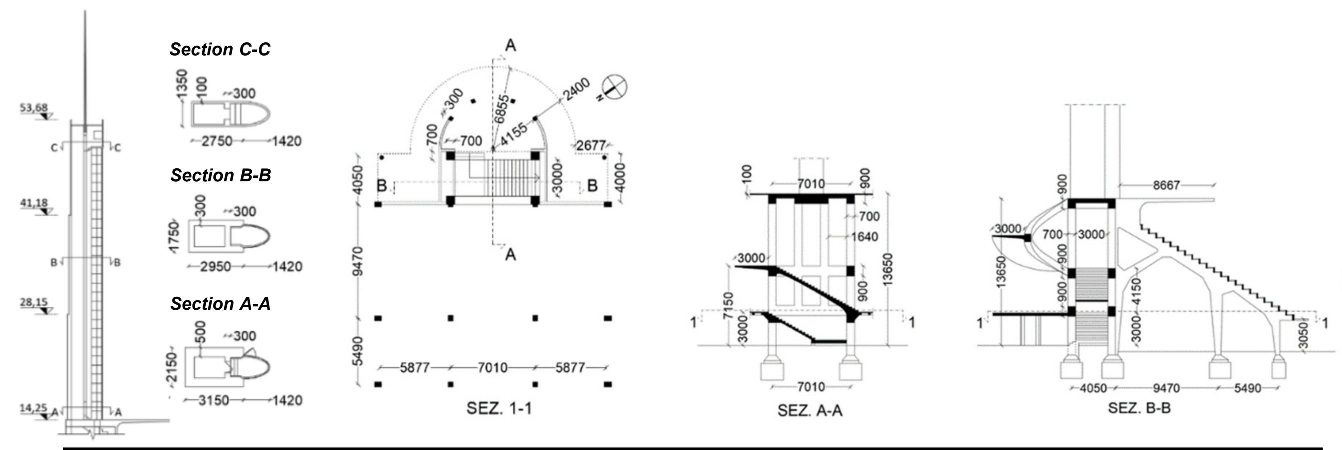
Artemio Franchi Stadium in Florence is <u>the first world-famous Nervi's design</u>, celebrated as a masterpiece of the Rationalist movement since its construction, carried out in 1930–1932. This acknowledgment derives from the innovative D-shaped plan and "telescope"-like appearance of the bleachers ring in perspective, and the neat exposed structure, constituted by elegant rhythmically repeated reinforced concrete (RC) sloped frames. Other prominent and distinguishing elements are represented by the Tribuna Centrale (main stand) cantilevered roof—exhibiting the widest RC free span worldwide at the time of construction and for the following twenty years, equal to 22.5 m—, the bold and aerial helical staircases giving access to Curva Fiesole, Curva Ferrovia stands and Maratona grandstand, the slender iconic Maratona Tower, and the elliptical balcony scenically jutting out of the elevation portion of the latter. Among the most recent international recognitions, in 2021 the Society of Architectural Historians—joined with ICOMOS—stated that the Stadium "is an outstanding example of 20th century architecture" and that it "was enormously influential on the design of other modern stadiums worldwide as well."

In view of this, the Stadium has been declared a work of <u>cultural and historical interest</u> by the Italian Ministry for Cultural Heritage and Activities (IMCHA), and included in the Italian <u>modern heritage listing</u>, <u>with several specific preservation restrictions on its most distinguishing structural and architectural elements</u>.

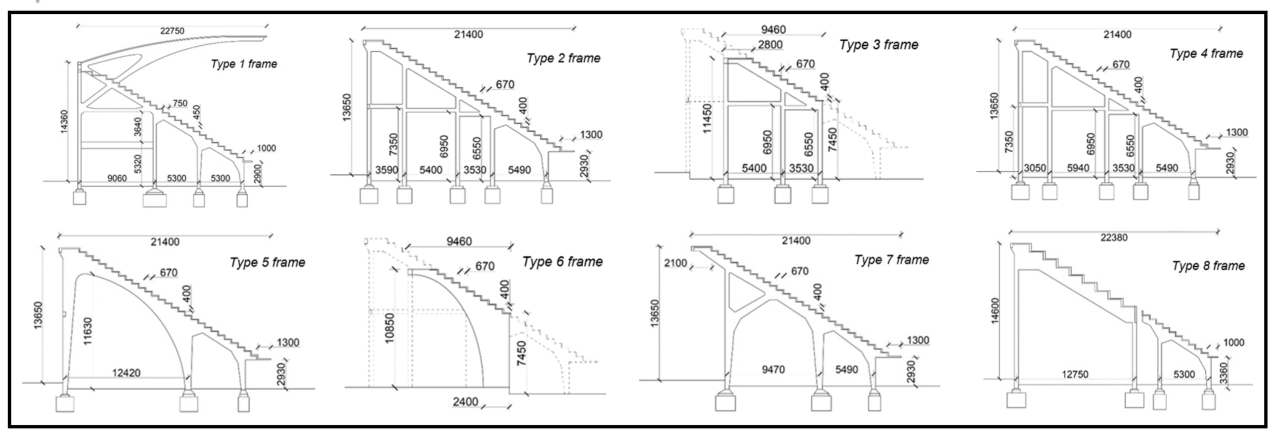
The structure of the Stadium consists of 24 blocks separated by technical gaps, constituted by eight different types of RC sloped frames, joined by a single walkway on the side of the field.



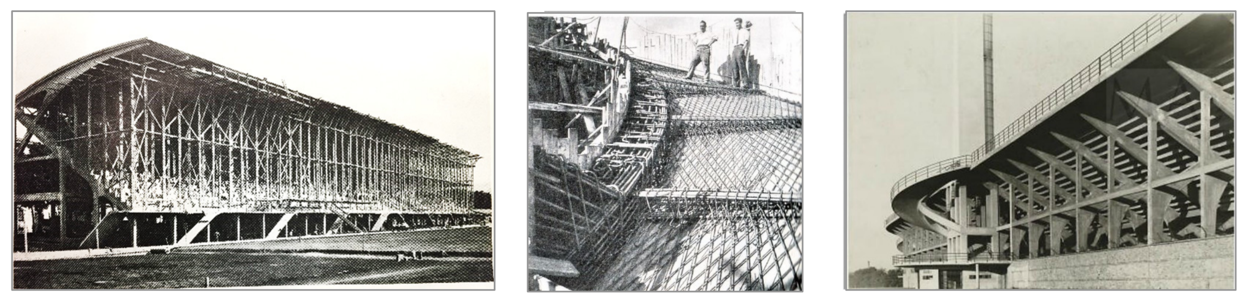
Blocks and RC frame types constituting the Stadium in plan



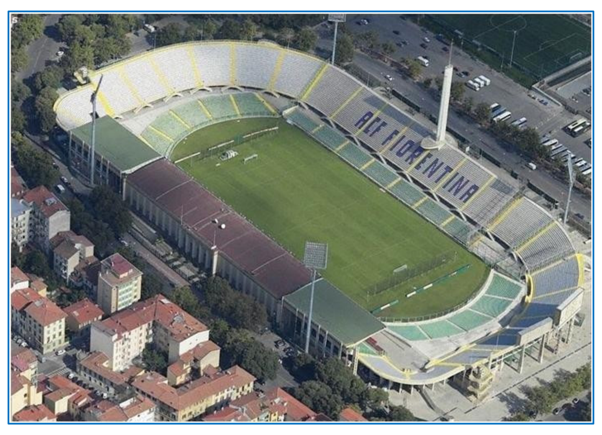
Lateral view and cross sections of Maratona Tower, and vertical sections of block 10 at the Tower base



Geometry of the eight types of frames



Views of cantilevered roof of Tribuna Centrale grand-stand and Maratona stand helical staircases during construction, and external view of the Stadium in 1932



Current aerial view of the Stadium

With a view to the planned restyling and modernization works, a diagnostic field survey and testing campaign (Pieraccini et al. 2019) and a static and seismic performance assessment study of the Stadium were commissioned by the Municipality of Florence to the Department of Civil and Environmental Engineering of the University of Florence (Scientific Responsible of the assessment study and the retrofit design proposal: Prof. Gloria Terenzi).

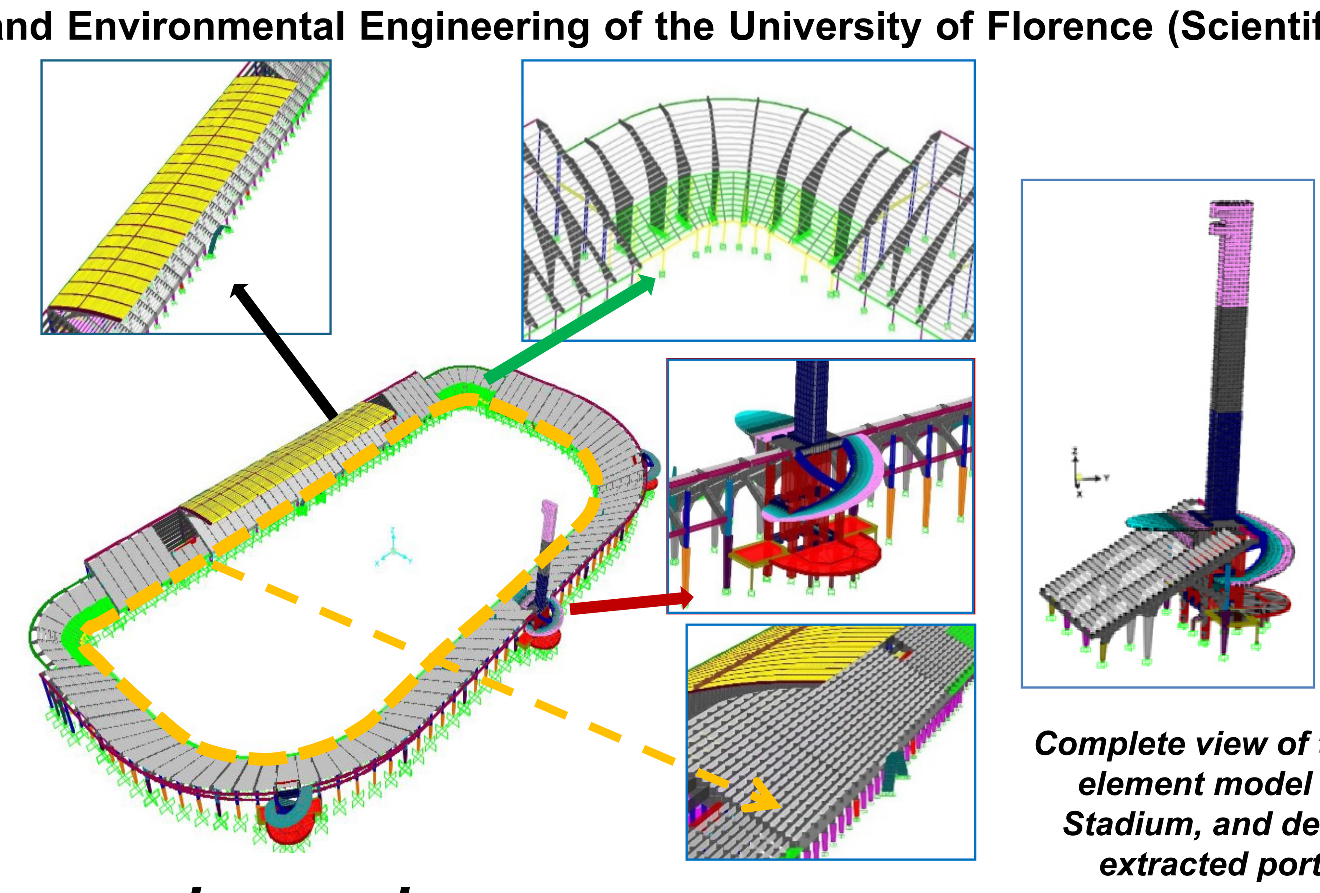
A GLOBAL FINITE ELEMENT MODEL of the Stadium was generated to carry out its static and time-history seismic analyses in current conditions, constituted by 8,747 frame elements and 32,904 shell elements (Terenzi et al. 2024).

The STATIC ANALYSES carried out at the ultimate limit state by referring to the normative dead and live gravity loads, and relevant combinations, highlight:

- **87 SECTIONS IN SLIGHTLY UNSAFE CONDITIONS in flexure or compression-flexure;**
- **demand/capacity ratios, $\alpha_{D/C}$, no greater than 1.5 for these members.**

The SEISMIC ANALYSES at the Basis Design Earthquake Level (BDE) highlight:

- **more than 500 SECTIONS IN UNSAFE CONDITIONS, with $\alpha_{D/C}$ ratio values up to 3;**
- **the generation of POUNDING EFFECTS between the blocks, constrained by a continuous walkway on the side of the field and free at the other end.**



Complete view of the finite element model of the Stadium, and details of extracted portions

RETROFIT SOLUTION by Pressurized Fluid Viscous spring-dampers and pure dampers

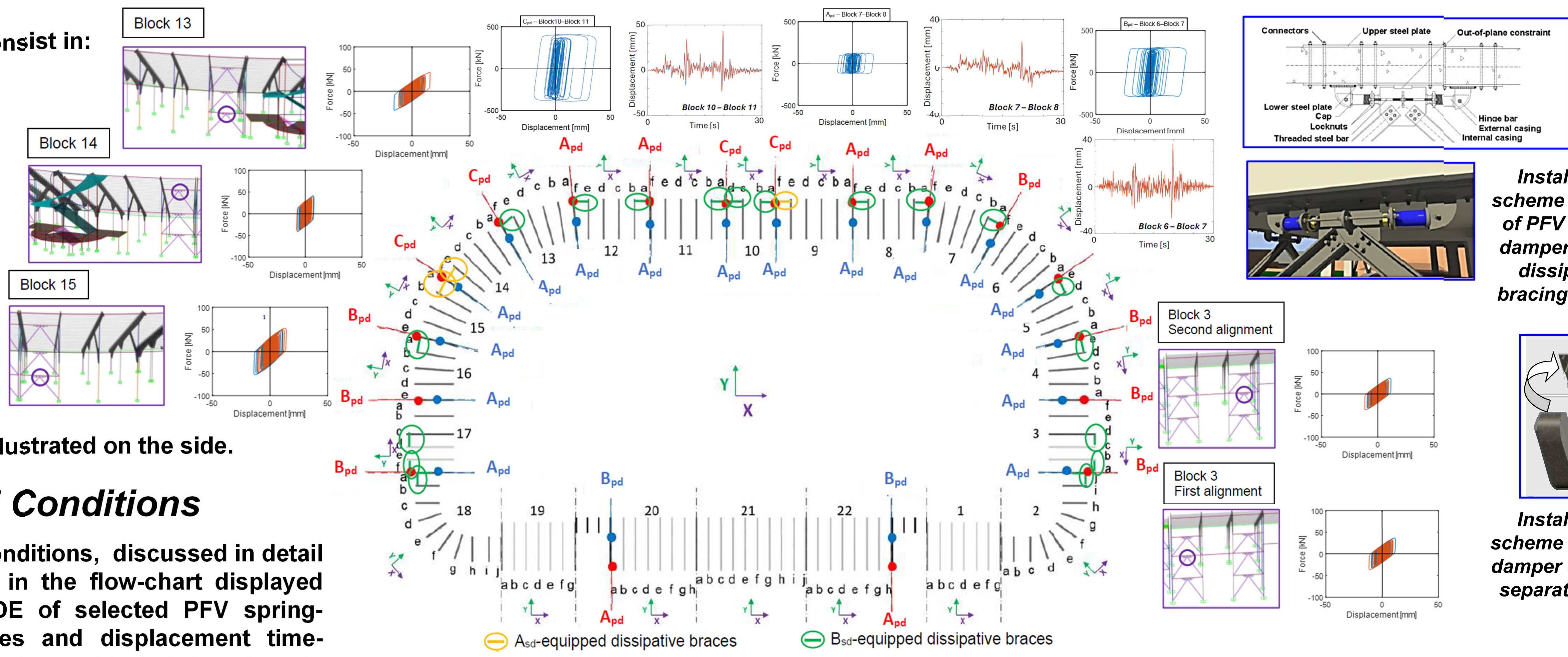
This retrofit design was aimed at guaranteeing a <u>safe use of the sports facility both in current conditions and after the upcoming restyling and modernization interventions</u>, whose structural additions are completely <u>independent</u> from the existing structures.

The proposed solution consists in incorporating <u>dissipative braces equipped with pressurized fluid viscous (PFV) spring-dampers in several spans</u> oriented in orthogonal direction to the bleacher frames, and installing <u>PFV pure dampers across the majority of the technical separation gaps between adjacent bleacher blocks</u> (properly cleaned and waterproofed), so as to prevent their mutual pounding. Among other typologies of dampers, PFVs were selected for their capacity of dissipating energy also for very small displacements. Moreover, the very low stiffness characterizing the spring-dampers installed in the dissipative braces allows keeping <u>almost unchanged the modal parameters of the retrofitted structure as compared to its current conditions</u>.

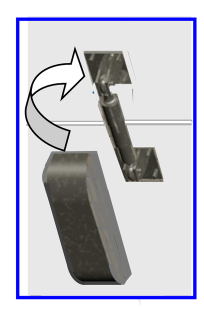
The essential steps of the intervention consist in:

- **Restoration of gaps (30 to 50 mm wide);**
- **Incorporation of 36 gap-crossing dampers avoiding pounding;**
- **Installation of dissipative braces to control displacements of blocks and significantly reduce member stress states, to be hidden behind movable walls (130 devices);**
- **Local strengthening of the statically unsafe and the most seismically vulnerable elements ($\alpha_{D/C}$ > 1,5) by FRP fabrics.**

The installation of the system in plan is illustrated on the side.



Installation scheme of a pair of PFV spring-dampers in the dissipative bracing system



Installation scheme of a PFV damper across a separation gap

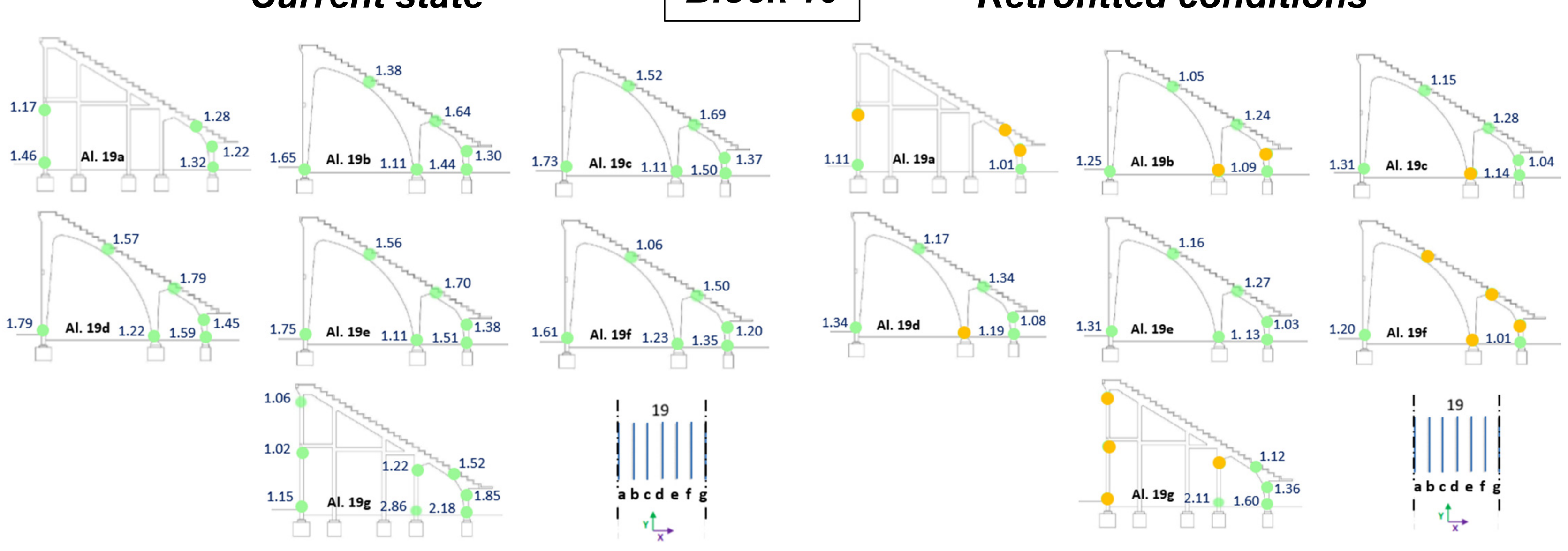
Performance in Retrofitted Conditions

The seismic performance in retrofitted conditions, discussed in detail in (Terenzi et al. 2024), is synthesized in the flow-chart displayed below. The response cycles at the BDE of selected PFV spring-damper pairs, and the response cycles and displacement time-histories of selected PFV pure dampers, along with their locations in the model, are shown around the plan of the Stadium on the side.

The results in terms of stress states highlight <u>reductions factors on the $\alpha_{D/C}$ ratios ranging from 1.09 to 1.83 for the 24 blocks</u>. Thanks to these reductions, the sections in unsafe conditions in compression-flexure decrease to 209 (i.e. 44.4 % of sections in current state), for columns, and 41 (39.4 %), for beams, with maximum $\alpha_{D/C}$ ratios of 2.17 (columns) and 1.79 (beams). By way of example of these results, the $\alpha_{D/C}$ ratios for Block 19 are compared below for current and retrofitted conditions. <u>Integrative local strengthening interventions</u> consisting in the application of one or two sheets of carbon fiber reinforced polymer fabrics allow achieving <u>safe stress states in all beams and columns</u>.

CURRENT STATE	RETROFITTED CONDITIONS
560 SECTIONS IN UNSAFE CONDITIONS WITH $\alpha_{D/C}$ UP TO 3	285 SECTIONS IN UNSAFE CONDITIONS WITH $\alpha_{D/C}$ LESS THAN 2
POUNDING	NO POUNDING

Current state — **Block 19** — *Retrofitted conditions*



Concluding Remarks

- **The intervention guarantees a substantial improvement of seismic performance with a minimal visual and functional impact on the existing structures, <u>meeting the preservation restrictions</u> imposed by the Ministry for Cultural Heritage and Activities;**
- **The <u>estimated cost of the structural works is 30 to 35% lower than the cost of conventional rehabilitation interventions</u> designed for the same objectives, which are also more visually impacting, as well as intrusive from an architectural viewpoint.**

Pieraccini M., Miccinesi L., Terenzi G., Costoli I., Spinelli P., Mazzieri G. (2019). Structural health monitoring of "Artemio Franchi" Stadium in Florence, Italy: measurement using interferometric radar. In: *Proc. of 5th Int. Conference SMAR 2019*, Postdam, Germany, 27-29 August 2019, Paper n. we.2.d.8, 8 pp.

Terenzi G., Fuso E., Sorace S. (2024). Structural performance study and improvement of Artemio Franchi Stadium in Florence. *Engineering Structures* 298, art. no. 117068.