Assessment of a high-rise building under winds and rain

RISKADAPT · Asset Level Modelling of RISKs In the Face of Climate Induced Extreme Events and ADAPTation

RISKADAPT
Modeling of Risks and Adaptation

Workshop on "Risk assessment of structures under Climate Change "

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Wind and wind-driven rain load analysis

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Model of high-wind load on an high rise buildings

High-Impact Low-Probability Events:
Climate change often causes intense meteorological phenomena, such as extreme of temperature or precipitation or winds, the consequences of which can compromise the functionality and security of critical infrastructures such as buildings and bridges, which have a long-life expectancy.

Needs:
*Realistic estimation of the **atmospheric load (wind and rain)** on tall buildings under extreme weather wind and rain conditions in present and future scenarios.*

Methods:
High-resolved numerical simulations of the type Computational Fluid Dynamics for reproducing the wind field, i.e. models with low empirical content, high spatial resolution, and accurate of turbulent flows.

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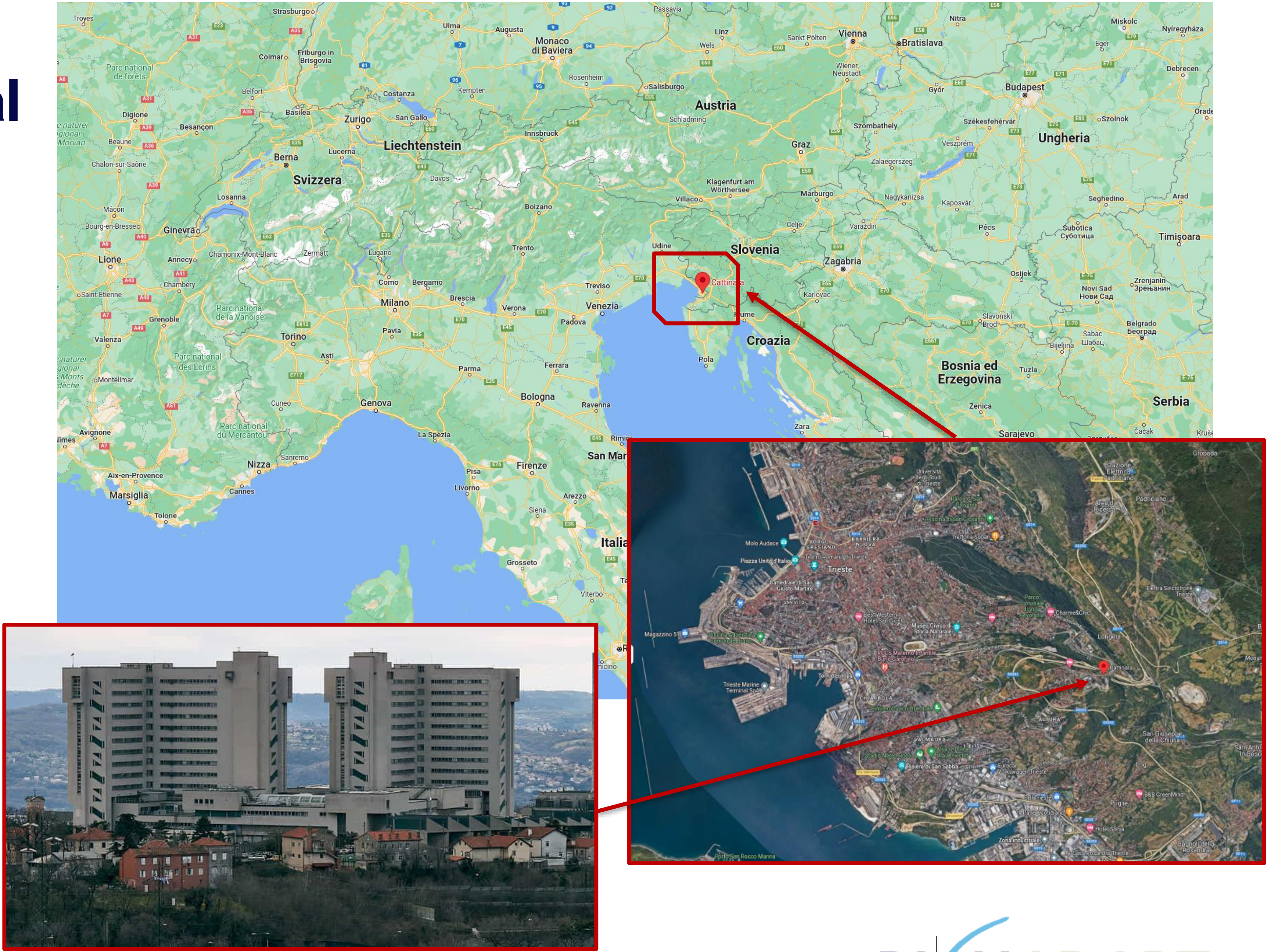
The Cattinara Hospital case study

Trieste (north of Italy, on the Adriatic Sea) is surrounded by the Carsic hills that make the city particularly **exposed to the Bora wind**, flowing from North/North-East
and characterized by sudden strong gusts that can reach 130-150 km/h.

A very strong Bora event from the recent past (11th Feb. 2012) was analysed in detail.
Wind gusts recorded in the Cattinara > 150 km/h.



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Computational domain

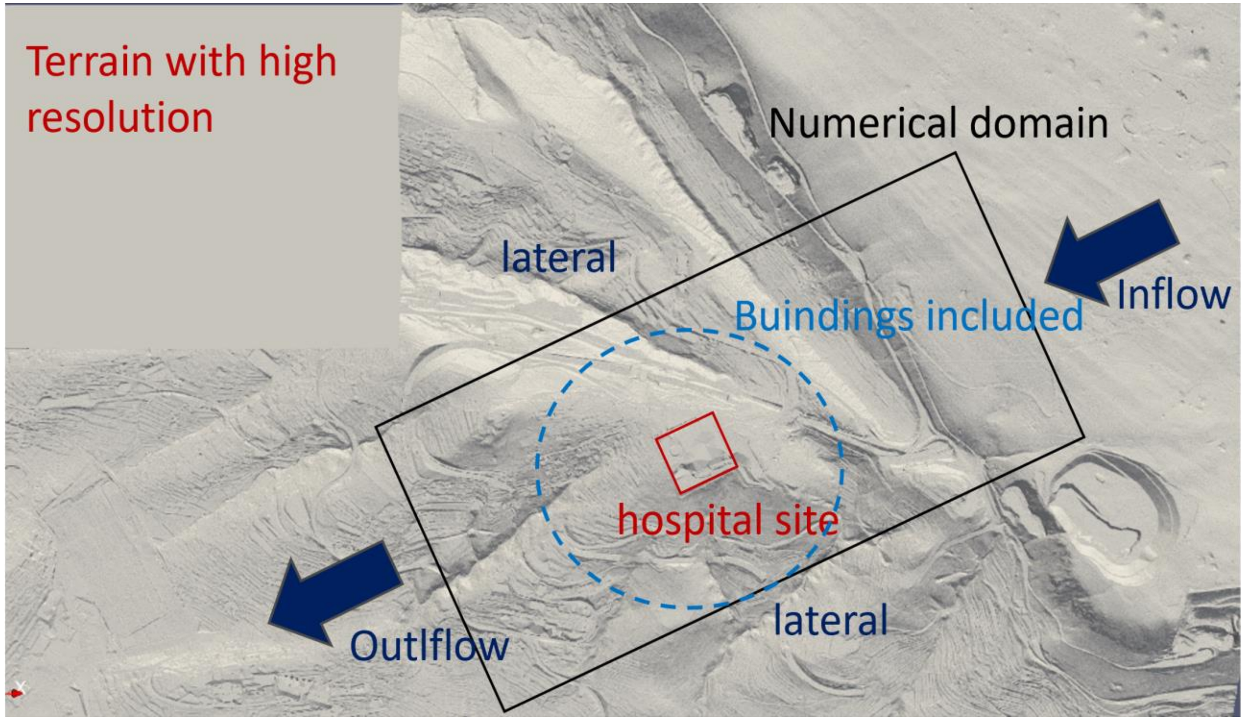
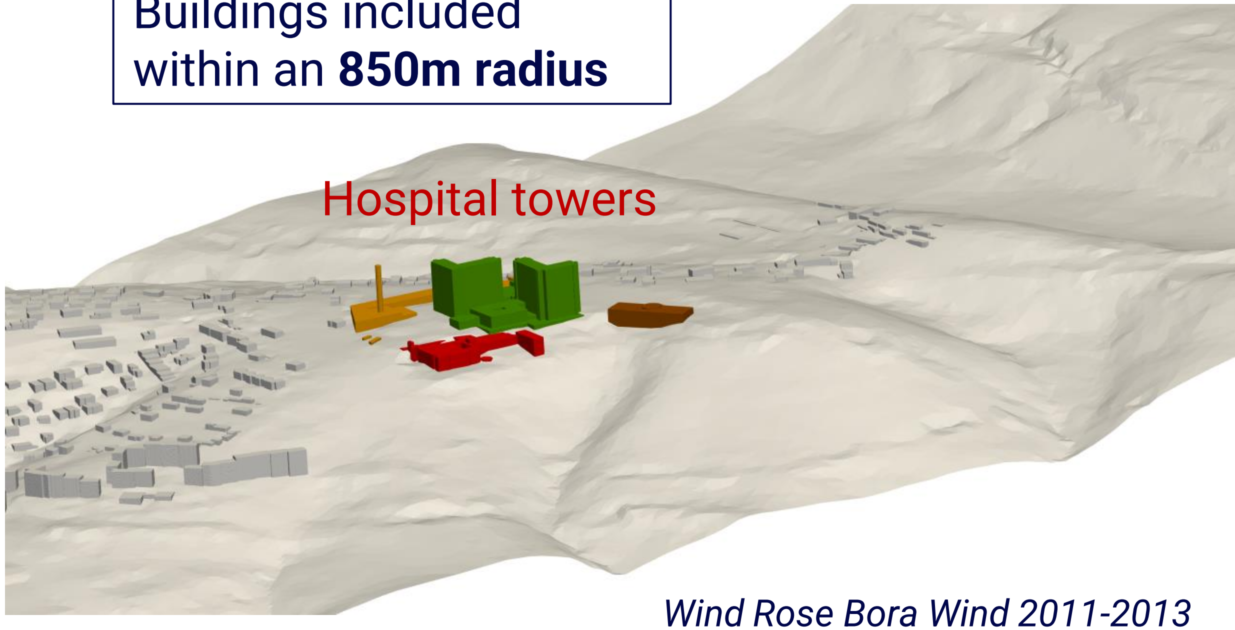
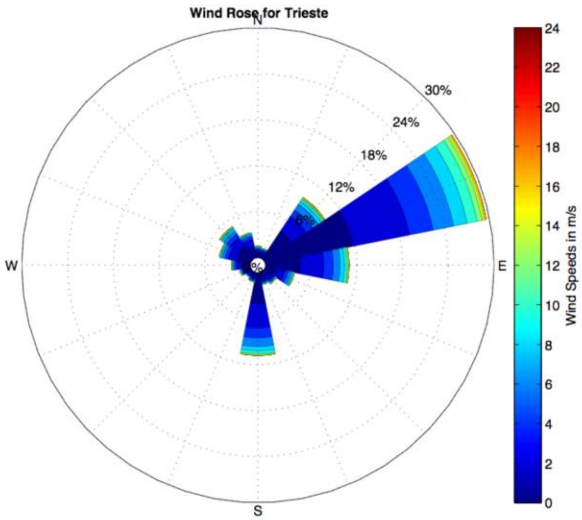


Fig. Orography sketch of the selected computational domain.

Buildings included within an **850m radius**



Wind Rose Bora Wind 2011-2013



Domain specification:

- Hospital height: 54m
- Domain height: 850m
- Domain **orientated E-NE** (22.5°)
- Spanwise: 600m + 300m buffer
- Upstream: 1100m (Carso flatland)
- Downstream: 700m + 200m buffer

Numerical set-up

OpenFOAM

open-source CFD library

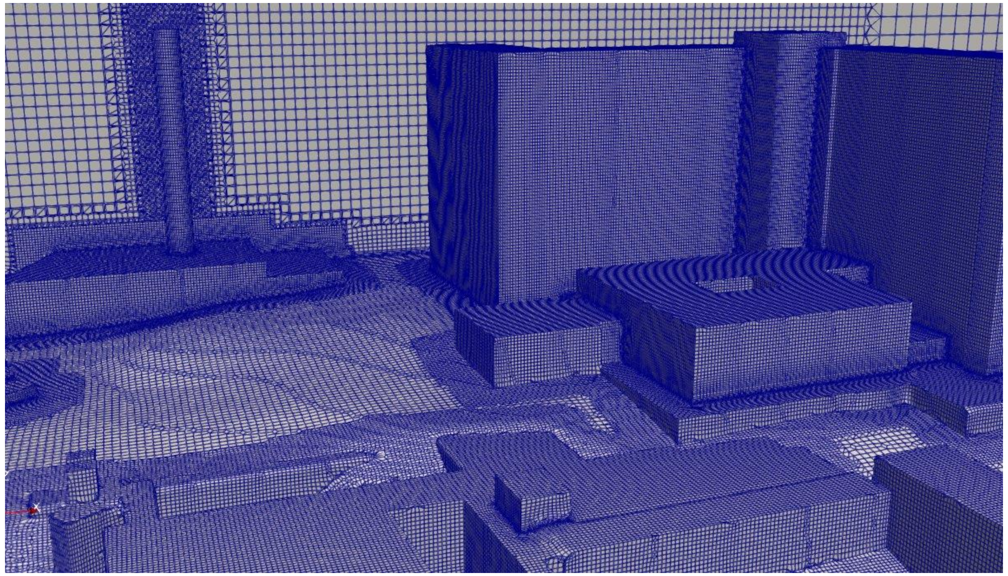
Reynolds-Averaged Navier Stokes (RANS),

k-epsilon turbulent model.

Reynolds number **Re = 1.4×10^8**

Computational grid **50 million cells,**

Near surface cells width 0.625m—**0.015m**



<u>Boundary conditions</u>

- **Inlet**: Uniform fixed velocity of Ux = **40 m/s** (Value close to the maximum wind gusts of the extreme 2012 event)
- Ground and buildings: **wall functions**

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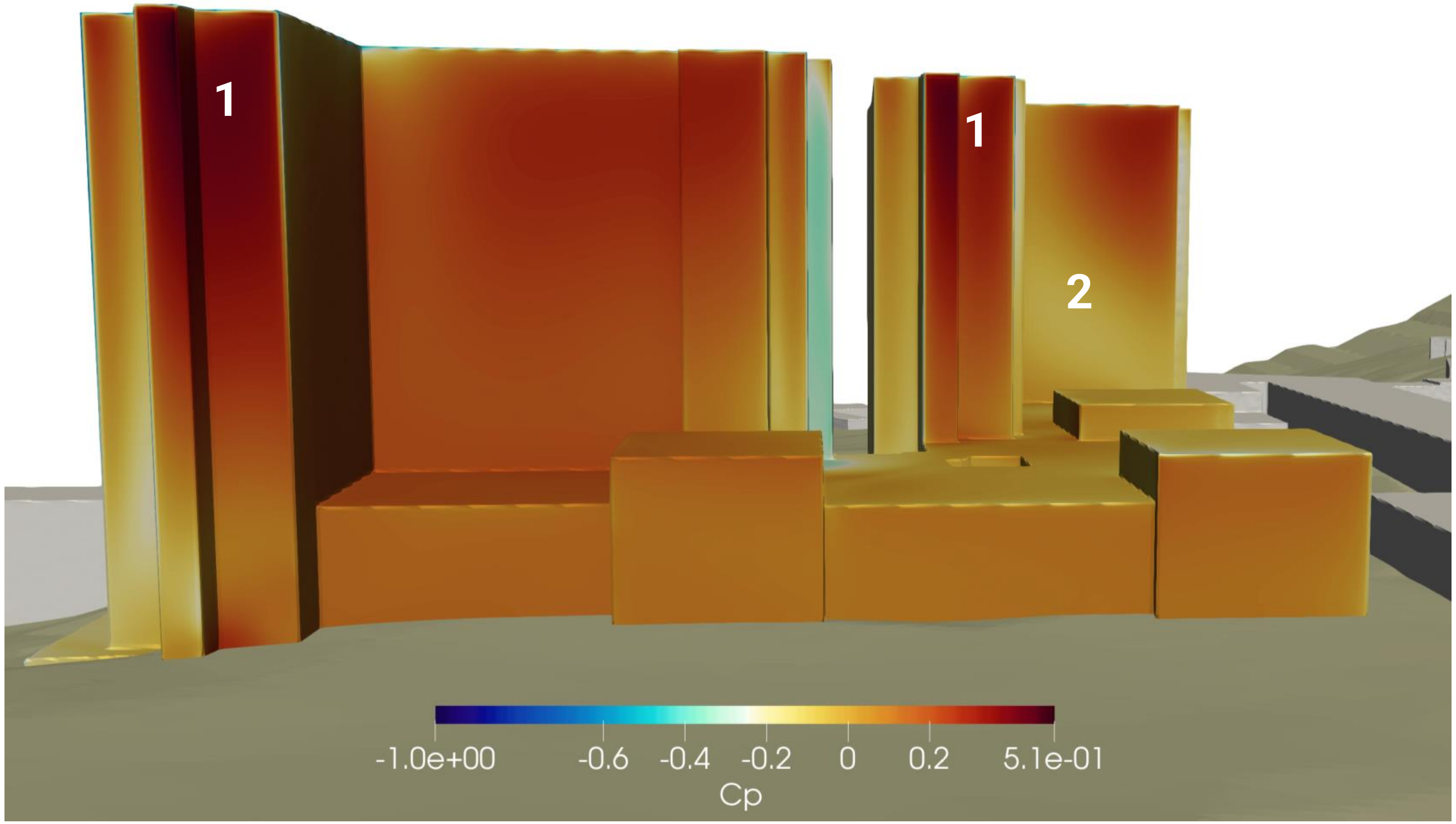
Pressure coefficient



1. **Increased pressure forces** at the front façades of both building.
2. **Decreased Cp** at the lower part of the second building
3. **Negative values** for the areas where there is a **recirculation** of the flow from the channel

$Cp = (p-p0)/(0.5\rho Uref^2)$

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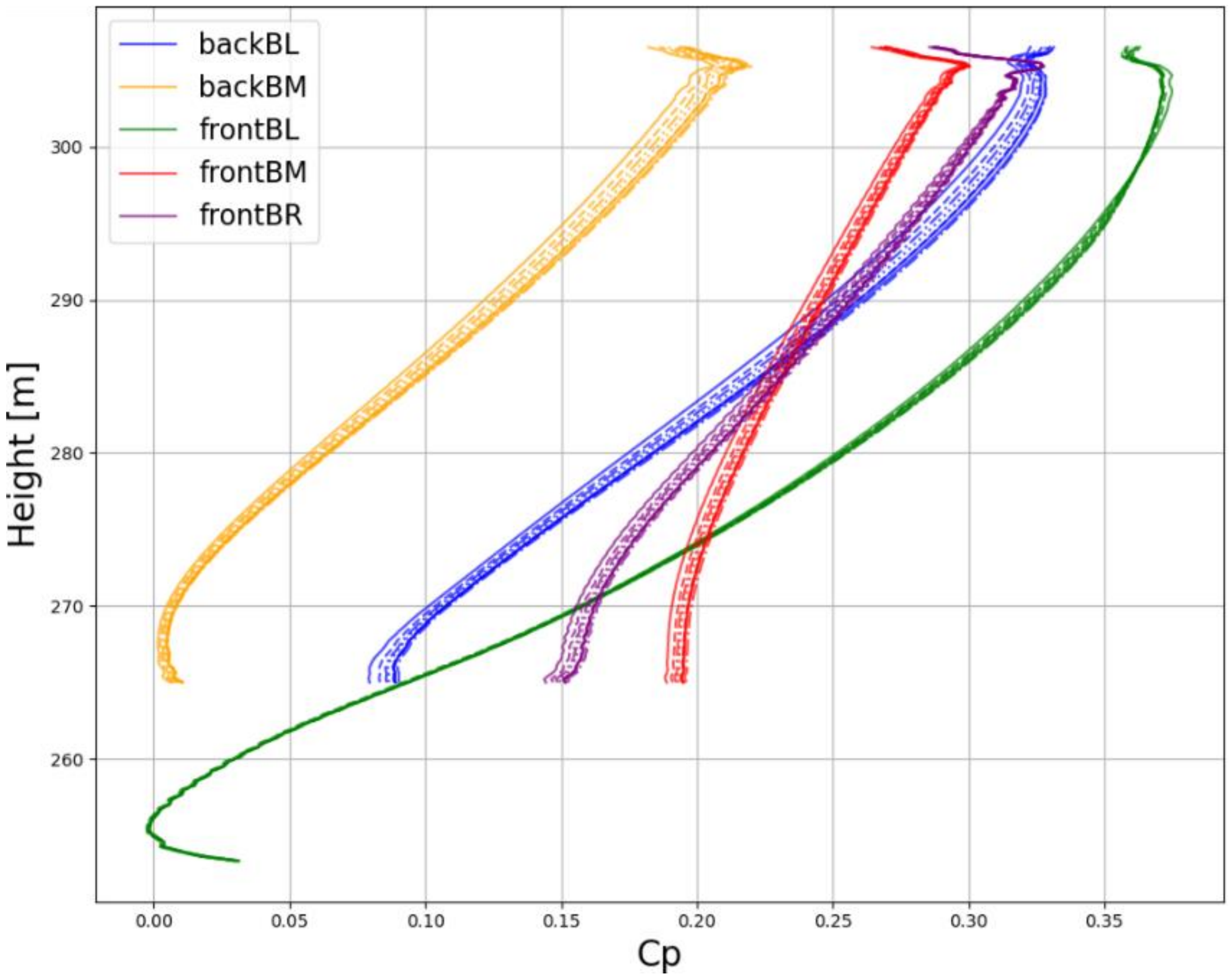
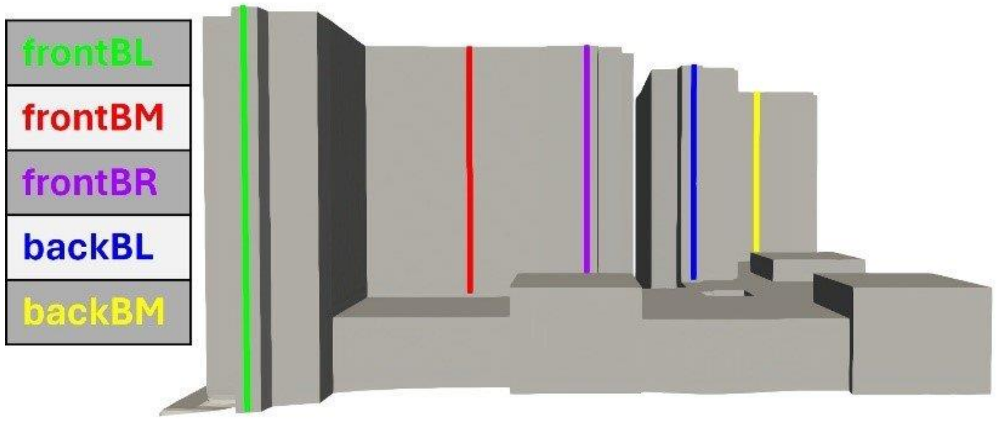
Pressure coefficient





Semi-empirical relations have been developed for estimate the wind and wind-driven load different locations at the upstream facade of the buildings.

(The contribution of rain is estimated from the wind spead using emiprial correlations).

RISKADAPT Modeling of Risks and Adaptation

Structural analysis,

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Cattinara Hospital Building – Trieste - Italy

- The Cattinara Hospital is located about 10 km from Trieste center, at an altitude of about 250m above sea level.
- According to the Italian rules, it is classified in class IV as building of “strategic importance”.
- The original design, started in 1969, was structurally foreseen with thick beams and slabs rigidly connected to the vertical columns, thus resulting in a typical frame structure.
- At the time of construction, Cattinara site was not yet classified as seismic but in 2010 was classified in category 3 (low seismicity).
- The above fact and the Italian updated wind loads in 2008, together to an exceptional wind forces in February 2012 of up to 180-200 km/h gusts imposed on the stakeholder to require an evaluation of the seismic capability and structural stability.
- The design review showed that the towers, which are about 60 meters tall, had problems. They were too close together and the joints can’t avoid pounding and hammering according to the relevant design rules. The solution chosen was to link structurally the two towers, through fluid dynamic devices the so called shock transmitters.

Cattinara Hospital Building – Trieste - Italy

- Definitively, all these revised loading systems, according to the new Italian Norms, were taken into consideration and imposed the refurbishment and upgrade of the structural capacity of the building.
- Since 2017 and following medical necessities, the Hospital has been upgraded spending 143 million Euro. Moreover the towers resulted in an excellent behavior during a recent catastrophic seismic event that occurred in 2021 in the Slovenian city of Petrinja far away of about 150 km, and of grade 6,4 Richter.
- The Complex covers actually an area of 110.000 sqm but at the end, will be of 165.000 sqm.
- The methodological process adopted in RISKADAPT was as follows:
  - Propose steel bar corrosion models and concrete degradation models to predict the evolution of the mechanical characteristics of the materials to provide the required quantitative input for structural assessment.
  - Develop a Structural Model based on the as-built drawings supported also by laboratory and in situ tests.
  - To define the Knowledge level and degree of confidence of the structure
  - To run the RISKADAPT Finite Element Model (FEM) in real situation and evaluate the internal forces on the structural elements under the imposed wind loadings
  - To analyze the results and identify the critical sections and finally estimate the safety factors and the eventual damage states.
  - Some of the results are summarized in the following slides

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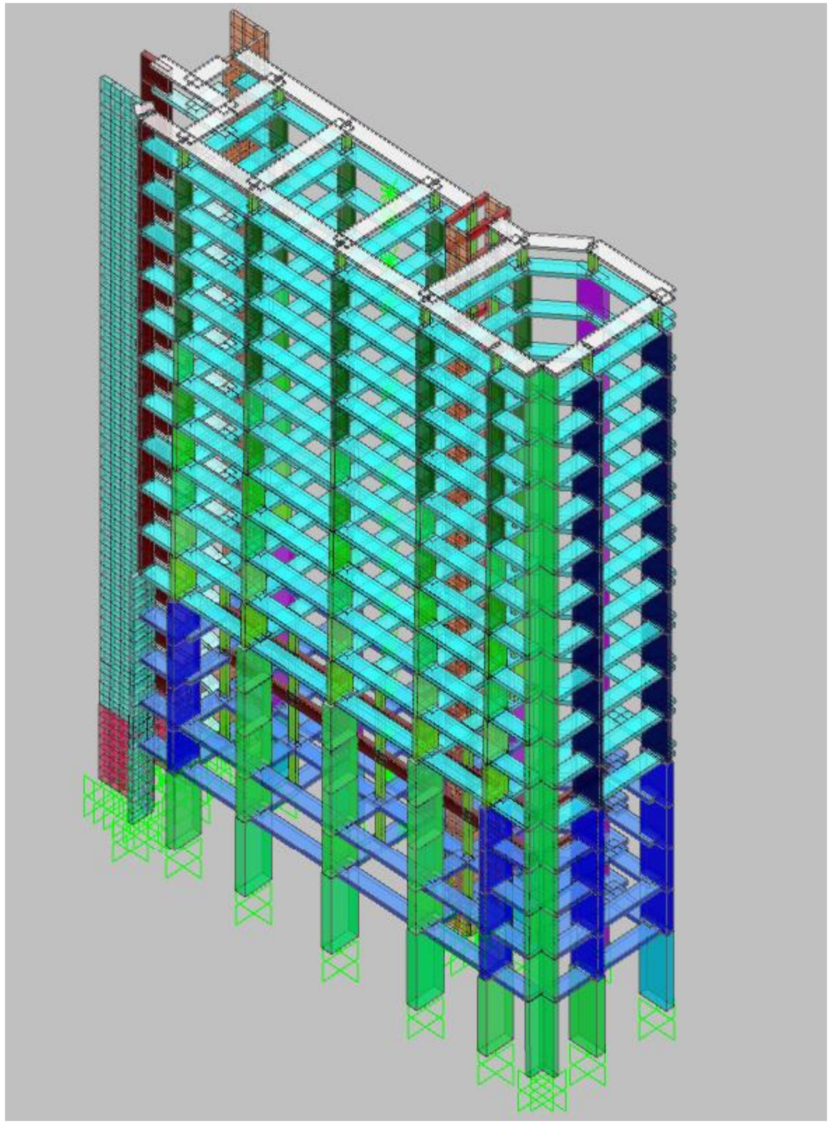
Cattinara Hospital Building – Trieste - Italy

- The RISKADAPT Built FEM model



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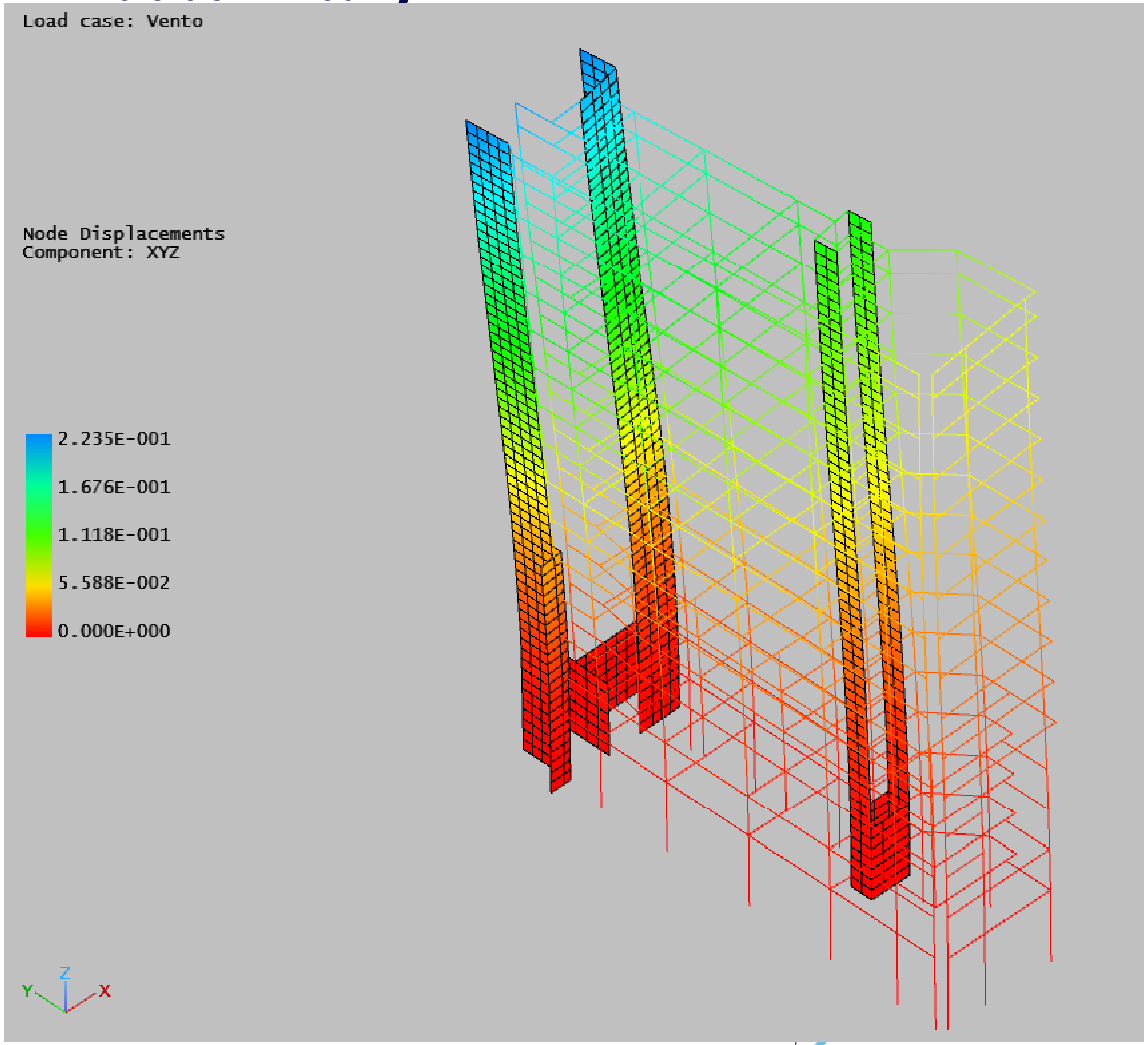
Cattinara Hospital Building – Trieste - Italy

- The RISKADAPT Built FEM model

The effects of the design by the codes wind load pressure for v= 30m/s – wind pressure for zmax of 60 m 2,50KN/sqm – for zmin of 4m 1,25KN/sqm

The displacements of the model [m]



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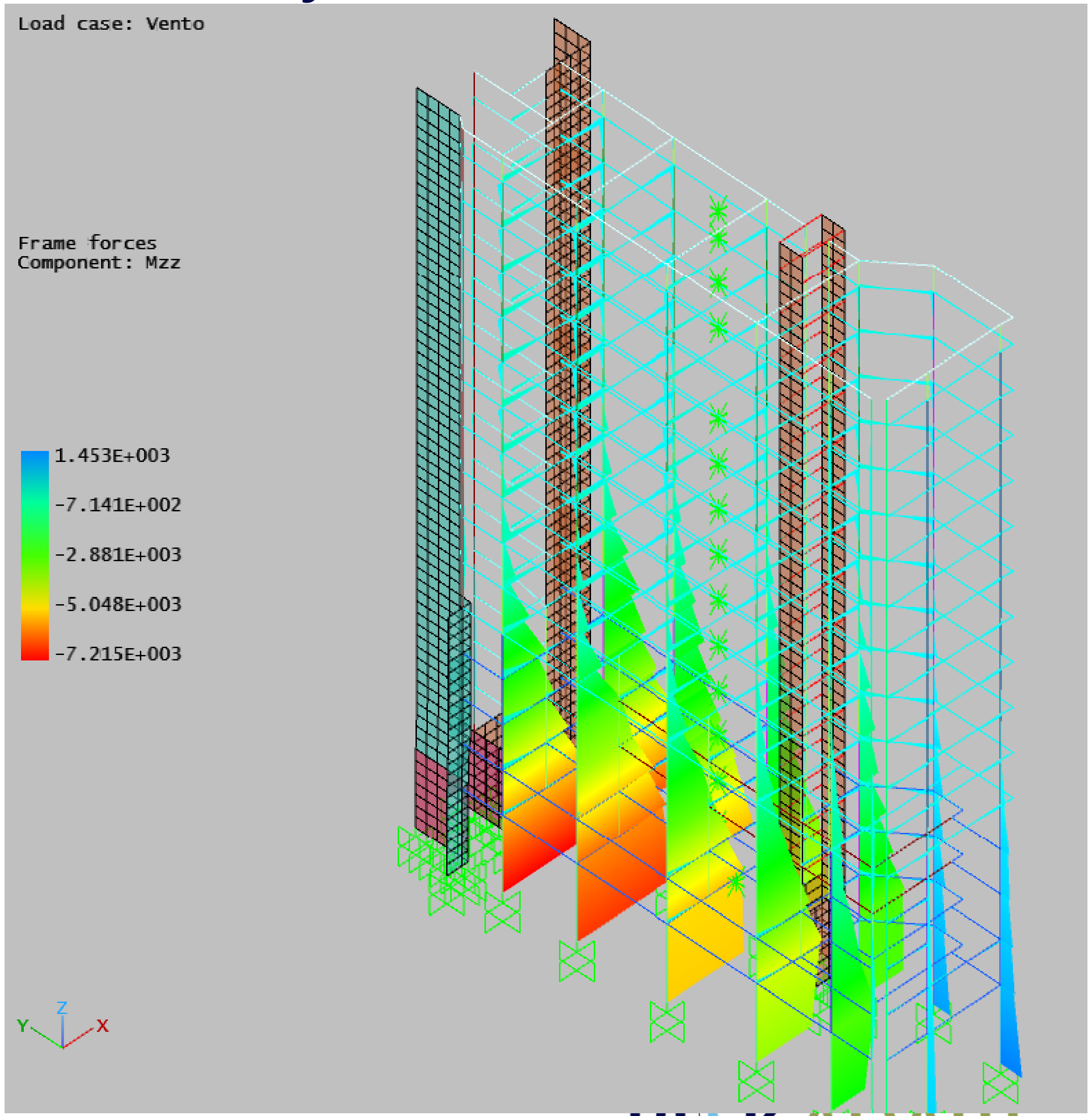
Cattinara Hospital Building – Trieste - Italy

- The RISKADAPT Built FEM model

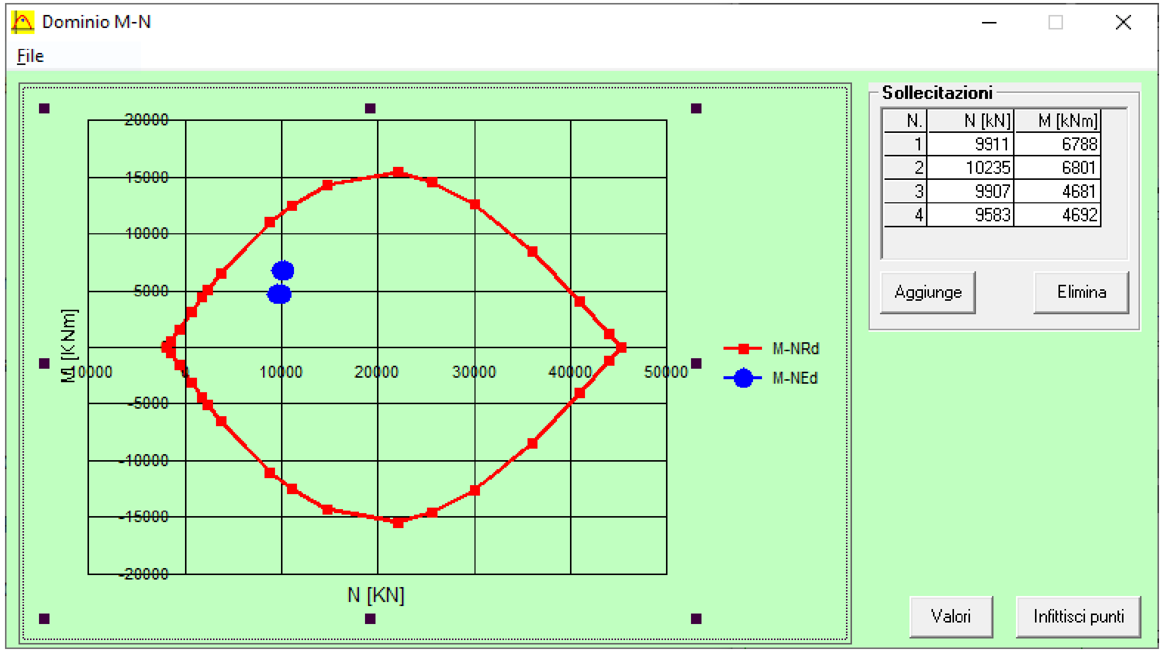
The bending moments (KNm) of the wind load case for v= 30m/s – wind pressure for zmax of 60m 2,50KN/sqm – for zmin of 4m 1,25KN/sqm.



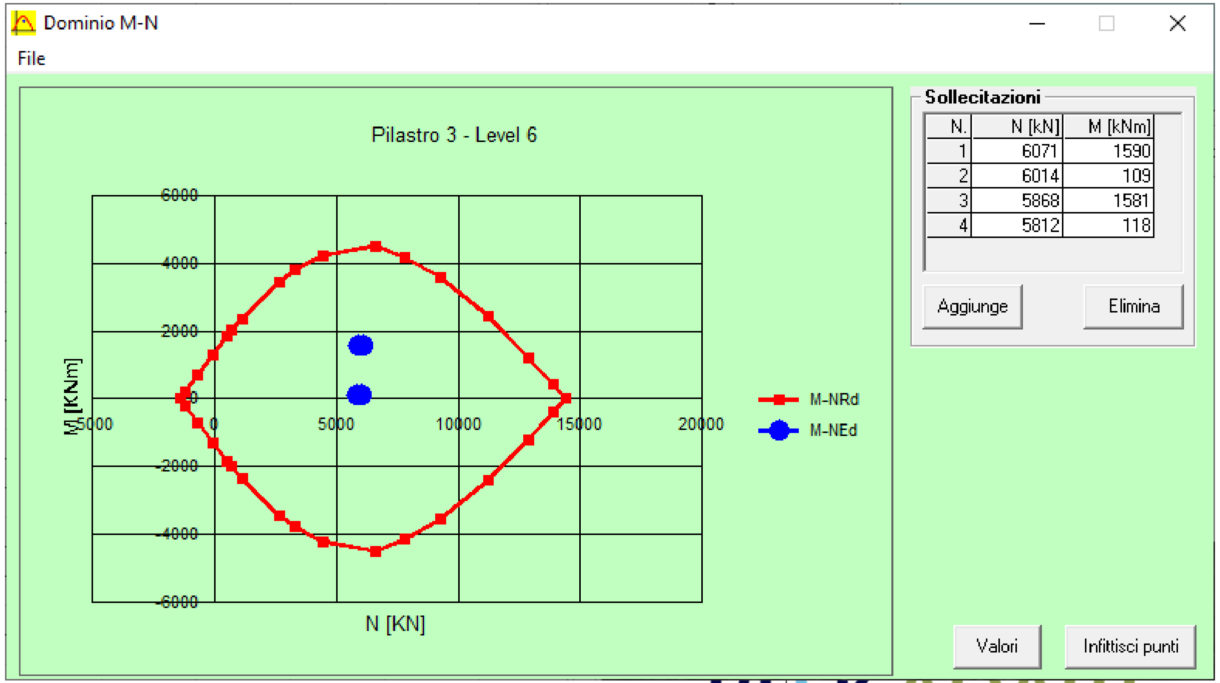
Cattinara Hospital Building – Trieste – Italy – The safety factors

- The wind velocity based on projections considering Climate Change for a 100-year return period is about 22 m/sec (i.e. less than design wind velocity of 30 m/sec).
- As an example, the results of the safety factors are here presented for column 3 level 1 the base column (safety factor 1,59) and level 6 (safety factor 2,66) with the design wind velocity of 30 m/sec.

Interaction domain M-N for column 3, Level 1



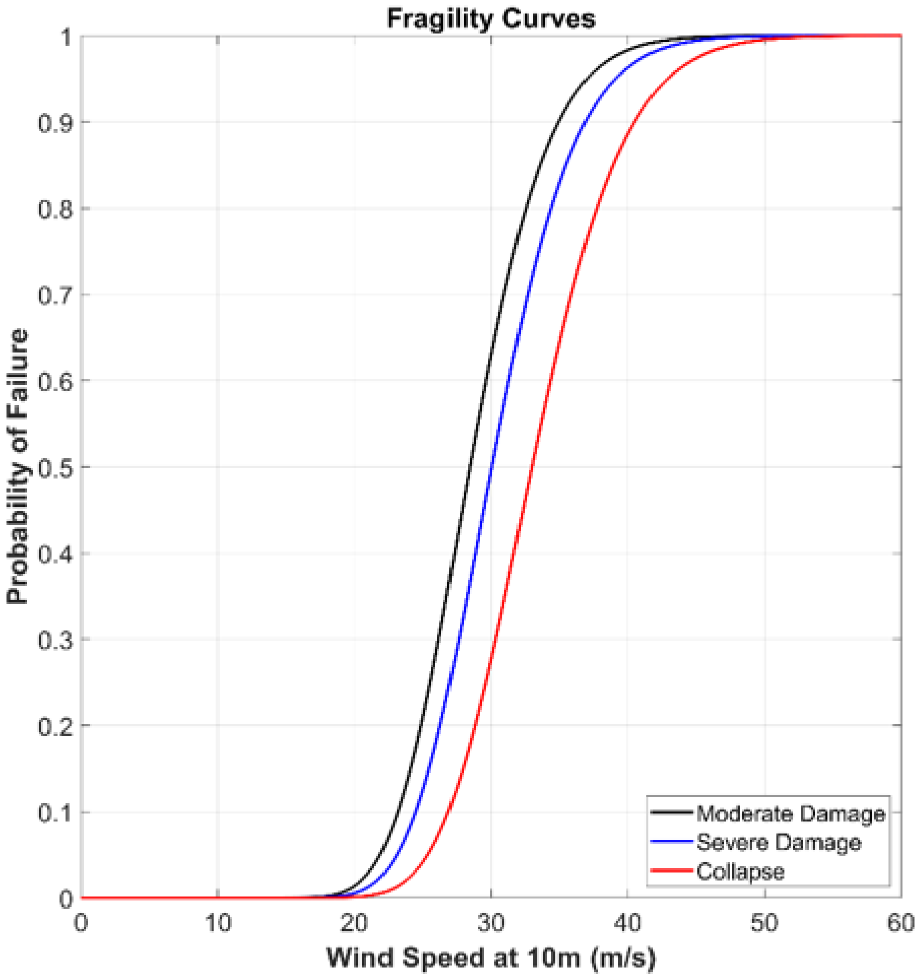
Interaction domain M-N for column 3, Level 6



Pilot 3 Cattinara Hospital Building–Trieste Italy–Probability of failure

- The fragility of the structure was estimated by running the FEM model iteratively for wind loads and Moment-curvature combinations.
- Moment-curvature for respective Tr and confidence factors calculated resulting in three different damage states (moderate, severe, collapse)
- Fragility curves for each damage state considered were developed assuming a lognormal distribution
- Annual probabilities of occurrence of each damage state:

$$P_{annual}^{moderate} = 0.0376, P_{annual}^{severe} = 0.0297, P_{annual}^{critical} = 0.0170$$



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Cattinara Hospital Building – Trieste – Italy – Remarks 1/2

- In the evaluation of the design wind codes the topography location of the building can produce an increase of the wind pressure of about 10 to 15% as occurred in Cattinara Hospital.
- Cattinara Hospital is absolutely a strategic infrastructure; the return period of 50 years is enough for the estimation of the design wind pressure for strategic buildings or needs to be increased.
- The actual Eurocodes of loadings is under revision; local and regional codes must be immediately adopted in accordance.
- In the evaluation of a structural reliability done in the design process there are uncertainties inherent with the values of the loads and the material properties which impose the introduction of more unfavourable situation through specified factors. The extended margins of the values permit the use of simplified and thus approximate analysis procedures for the design. In the real structural evaluation, a different approach could be used from that applied in the design since there could be obtained more realistic values coming out after the application of the strain sensors in selected sensitive locations i.e. the most critical sections of the columns in buildings. This procedure permits to avoid any underestimation or overestimation of the values of the stresses and consequently of the internal forces because the underestimation implies the ignorance of undesirable risk conditions, while the overestimation implies an unjustifiable high cost of repair and sometimes the demolition and replacement for parts of the structure.

Cattinara Hospital Building – Trieste – Italy – Remarks 2/2

- The procedure can take into consideration that the data input is coming from some in situ simulation operations as opposite to the typical classical approach in which the structural behaviour of the elements is evaluated based on the definition of the loading systems either established by the National Rules or by the Euro codes. Strain sensors measurements, can be used to assess the internal forces and structural adequacy of the concerned structural element and the procedure for the above structural assessment, in case the columns are defined as the critical points for the structural stability, includes the following steps:
  - evaluation of the axial strains and the curvatures around the defined x & y axes of the cross section of the column through strain sensors
  - evaluation of the strains at the nodes and at the positions of the reinforcing bars
  - consideration of only strains of negative value of the concrete (compressive strains)
  - determination of the stresses from the constitutive laws of the materials
  - consideration of a finite element mesh model of the section to calculate the structural capacity and the structural demand of the concerned concrete section

THANK YOU!

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