MiCHe project

Multi-risk Hazard_ Norman Tower of Craco

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III. Multi-risk analysis

Italy is characterized by many heavily populated areas and a territory which, due to its specificities, is highly exposed to different natural risks, many of which concern the same area. In fact, the uncertainty of the occurrence of a natural event requires a study of risk analysis both single and multi-risk, as the territory, also due to its specific geomorphology, if involved in a natural event, could be subject to a cascade effect to further natural events, all linked together. The complexity of the possible scenarios that can occur is the result of the amplification of the effect of the events considered individually. In order to develop a model suitable for the prevention and minimization of effects, it is necessary to use algorithms that allow, once the probability intensity distribution of the natural trigger event is determined, to derive the probabilities of the sequences of possible events that constitute the waterfall.

Thus the need to use multi-risk methods is born: a careful analysis that considers the interaction between the events, the possible cascade effects and the evaluation of all the elements affected, represents a useful starting point for monitoring and planning the development of a territory, also in terms of post-event emergency management.

In the previous sections, the landslide and seismic risk analyzes were carried out individually. In this section we will try to identify a methodology that allows us to compare the results obtained, associating the specific PGA values for the Norman Tower with the landslide risk indices, obtained by mapping the territory.

III.1 Starting values

III.1.1 Landslide risk

The landslide risk of the Municipality of Craco presents a varied mapping, as it is possible to identify the areas representative of the three risk levels assessed: high, average or low. In particular, from the Pai cartography [29] and from the analysis carried out by ENEA [28], the Norman Tower falls within the area characterized by low level.

As explained in the introduction, the combination of different events could amplify the natural effects found on the territory and on the built heritage, therefore, for the sediment area of the Norman Tower positioned on the sheer rock of the north-eastern slope and in correspondence with a niche of detachment of a slow flow active in the past, it is interesting to consider the possible scenarios that can be triggered, assessable through different Degrees of Risk.

For this reason, in this study, the hypothesized scenarios provided for the activation of only the type of landslide, the "slow flow" one, present on the same side of the Tower. The activation of this phenomenon could occur due to a joint seismic event. Instead, the rotational-translational sliding type was excluded as it is present on the South side of the Municipality of Craco, too far from the subject of the research.

Once the type of landslide and its hazard have been defined, it is necessary to identify the parameters that describe and evaluate the risk connected to the type of event considered and that take into account the factor linked to the exposure. The methodology adopted hypothesizes several possible scenarios through the definition of three degrees of damage (Tab.16), at the basis of the multi-risk analysis.

Risk grade	Real estate	Activity
Low	Minor aesthetic or functional damage	Socio-economic activities are not interrupted
Average	Functionaldamage	Interruption of socio-economic activities
High	Slight and relevant Structural damage, until the total collapse	Destruction of socio-economic activities

TABLE 16 – CLASSIFICATION OF DAMAGE GRADE FOR LANDSLIDE RISK.

III.1.2 Seismic risk

In Chapter II, the seismic risk of the Norman Tower was analyzed using the conventional method, determining the peak ground acceleration (PGA) for each limit state, from which, subsequently, it was possible to obtain all the return times (T_{rC}) and the various annual average frequencies of exceedance (λ_{Sli}). Through the latter (λ_{Sli}) and the percentages, indicated by the code, relating to the cost of reconstruction for the achievement of each limit state of the structure, the curve representing direct economic losses is identified. The area underlying this curve represents the expected annual average loss PAM (Fig.65). Table 17 and Figure 70show that the proposed methodology divides the underlying area of the curve and therefore the possible damage scenarios, with respect to the achievement of the various Limit States, into three degrees of damage. This allows to distinguish the scenarios from structural and non-structural damage, in particular, the degree will be low if the scenarios foresee non-structural damage, average if they foresee non-structural damage and minor structural damage, high if they foresee serious structural damage leading to collapse or to the possible loss of human lives that benefit from the structure at the time of the seismic event.

Risk grade	State limit	Real estate	Activity
Low	SLID – SLO	No structural damage	Socio-economic activities are not interrupted
Average	SLO-SLD-SLV	Slight structural and unstructural damage	Interruption of socio-economic activities
High	SLV-SLC	Structural damage: from the human life preservation to close to collapse scenario	Destruction of socio-economic activities

TABLE 17 – CLASSIFICATION OF THE DAMAGE DEGREE FOR SEISMIC RISK.

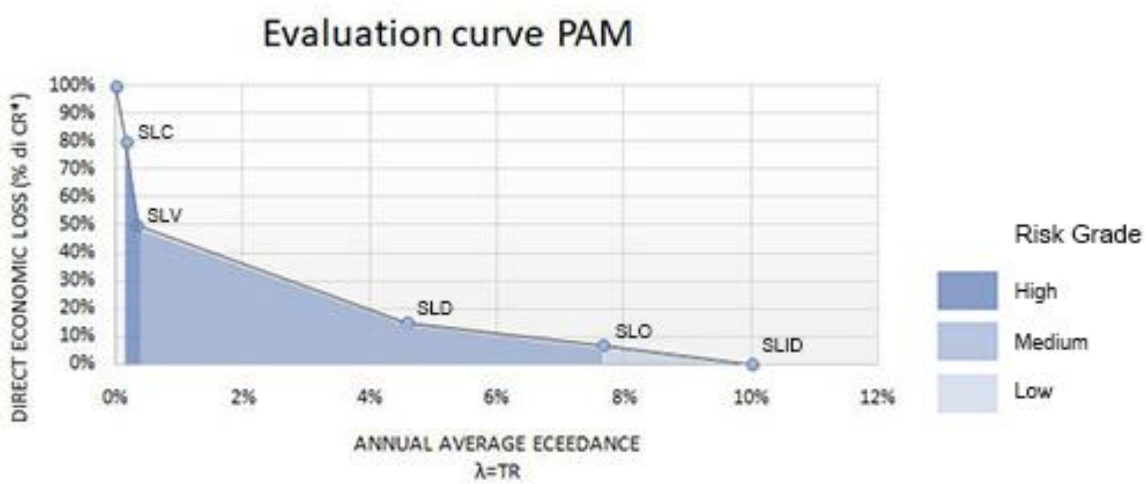


FIGURE 65– IDENTIFICATION OF THE DEGREES OF DAMAGE FOR SEISMIC RISK ON THE PAM CURVE.

Through this methodology, three degrees of damage were identified, attributable to the seismic risk, to be related to the multi-risk analysis with the three values emerged from the Landslide Risk.

III.2 Comparison of values

The comparison was made by taking the three degrees of possible damage, obtained previously, for both seismic and landslide risks.

The frequency and degree of the two individual risks were compared and combined, assessing the predominance of one risk over the other. This comparison made it possible to identify a "Multi-Risk Matrix" (table 18).

In any case, keep in mind that the Norman Tower suffers relatively the effects of the landslide risk. Therefore, the seismic risk, althoughnot high, isdominant.

Risk grade		**Landslide Hazard**		
		Low	Average	High
Earthquake Hazard	Low	El-Ll	El-La	El-Lh
	Average	Ea-Ll	Ea-La	Ea-Lh
	High	Eh-Ll	Eh-La	Eh-Lh

TABLE 18 – MULTI-RISK MATRIX.

Several scenarios are shown in the Table 18:

1. **El-Ll:** both Risks cause low level of damage, for which significant structural damage and interruption of use of the activity are not expected;
2. **Ea-Ll:** seismic risk is dominated by landslide risk, with slight structural and non-structural damage and the interruption of use;

3. **Eh-Ll:** the seismic risk is dominated by the landslide risk, with structural damage detected that could lead to the collapse and immediate interruption of use;
4. **El-La:**Average landslide risk predominant over the low seismic risk, the damages are only non-structural or functional, so there is only loss of ease;
5. **Ea-La:** the combination of both risks, seismic and landslide, at an average level leads to the non-use of the tower and to the presence of slight non-structural and structural damage;
6. **Eh-La:** the high seismic risk combined with a average landslide risk causes the non-use of the tower and the presence of significant structural damage up to the possible partial or total collapse of the structure;
7. **El-Lh:** the risk from high landslide predominated over the low seismic risk, for which the damages found are slight structural and lead to the non-usability of the tower;
8. **Ea-Lh:** High landslide risk and average seismic risk, the damages found are structurally significant and lead to the non-usability of the Tower;
9. **Eh-Lh:** both high Risks, the detectable damages are structural and significant up to the possible partial or total collapse of the structure and lead to the non-usability of the Tower.

III.3Hypothesis of involvement of the tower from the landslide front

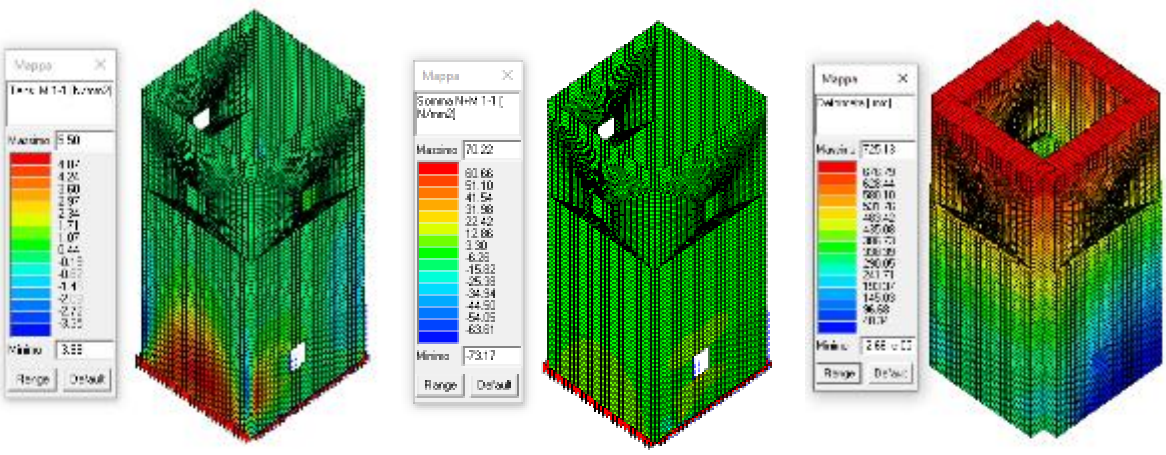
A linear analysis of the stress state of the tower was also carried out.Starting from the historical data of the instabilities suffered in Craco (deformations of the ground) collected and analyzed in [28], three imposed vertical displacementhave been hypothesized at the base, in correspondence with the South side, that is the one closest to the landslide front. These displacements can be associated with the three scenarios, which define in the previous chapter (III.1.1) the Damage Degrees of due to Landslide Risk:

- Low hazard: 200mm;
- Average hazard: 500 mm;
- High hazard: 1000 mm.

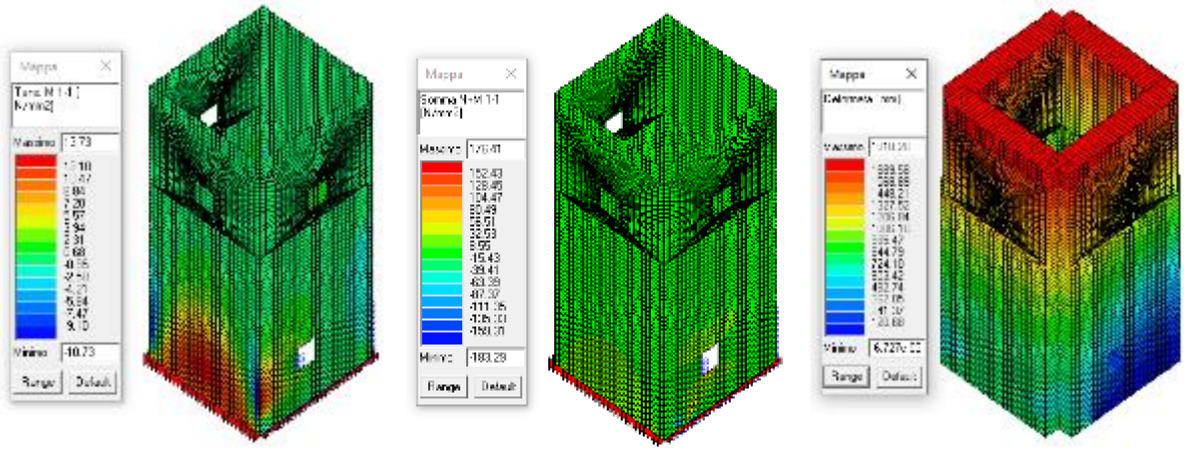
The model, visible in Fig. 66, has been subjected to a seismic analysis which also includes the three different displacements. Sothe results, visible fromFig. 67 for each displacement,outline the stress state of the tower in relation to the Linear Analysis carried out on Prosap [39] and highlight the combined behavior of the tower subjected to Heartquake Risk and a simulated Landslide Risk, or rather aMultirisk Analysis in the event of a determinate vertical displacement imposed on the basis of historical data collected.

FIGURE 66–PROSAP FE-MODEL OF THE TOWER WITH IMPOSED VERTICAL DISPLACEMENT

Vertical Displacement egual to 200mm



Vertical Displacement egual to 500mm



Vertical Displacement egual to 1000mm

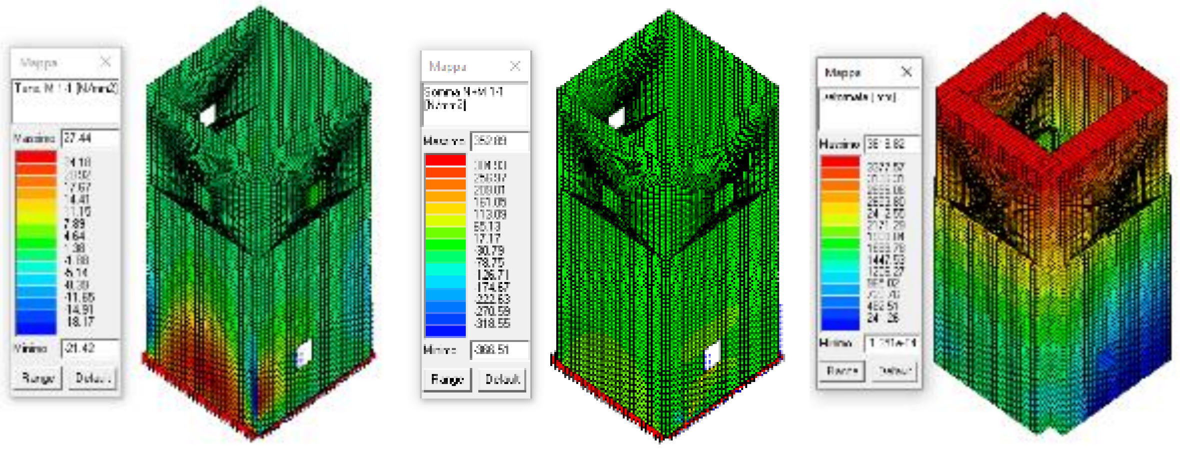


FIGURE 67–STRESS STATE AND DEFORMATION OF THE TOWER FOR DIFFERENT IMPOSED VERTICAL DISPLACEMENT.

In landslidecase,the hammering action of the tankRCfoundation on the masonry basement, could carry out possible scenarios.In particular, two different configuration were investigated in which several constraints at the base were partially removednear the landslide front. The figures 68-69outline, for each “constraint configuration”, the stress state of the tower in relation to the Linear Analysis carried out on Prosap [39] and highlight the combined behavior of the tower subjected to Heartquake Risk and a simulated Landslide Risk, or rather a Multirisk Analysis in the case of a determinated constraint configuartion imposed.

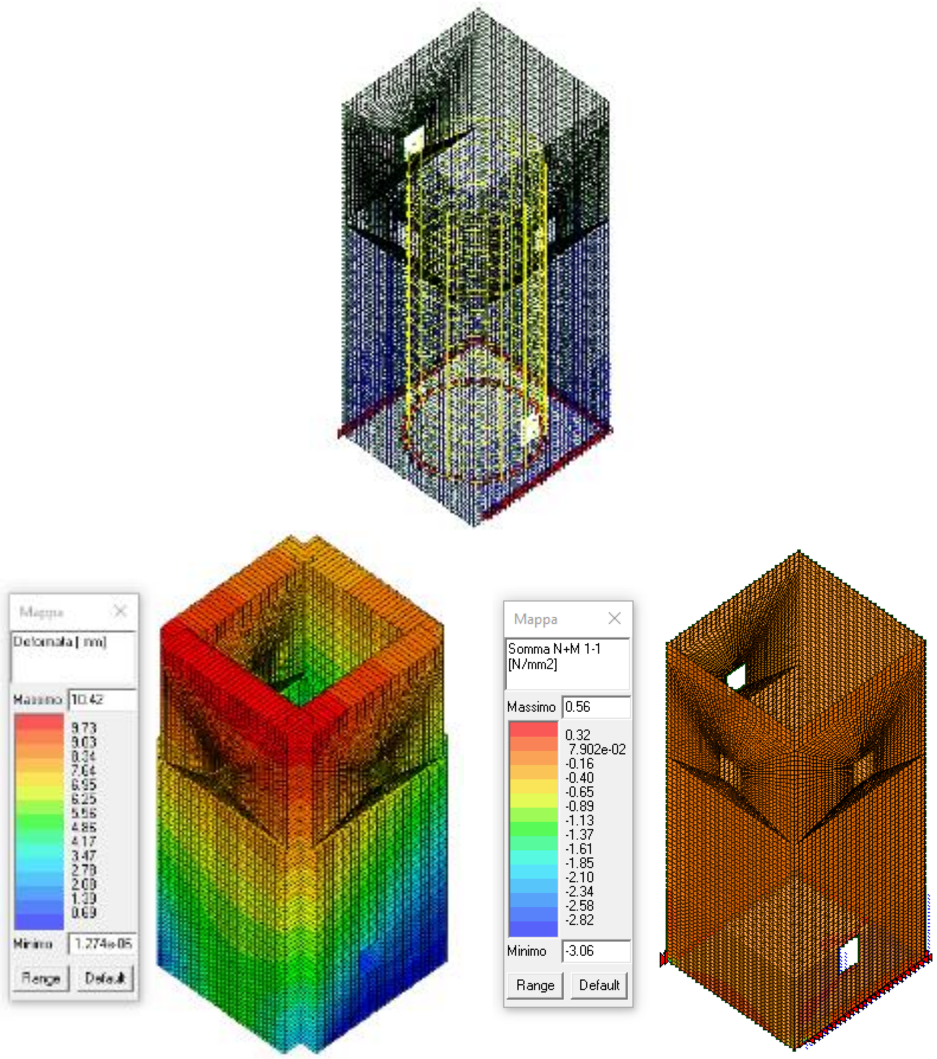


FIGURE 68–STRESS STATE AND DEFORMATION OF THE TOWER

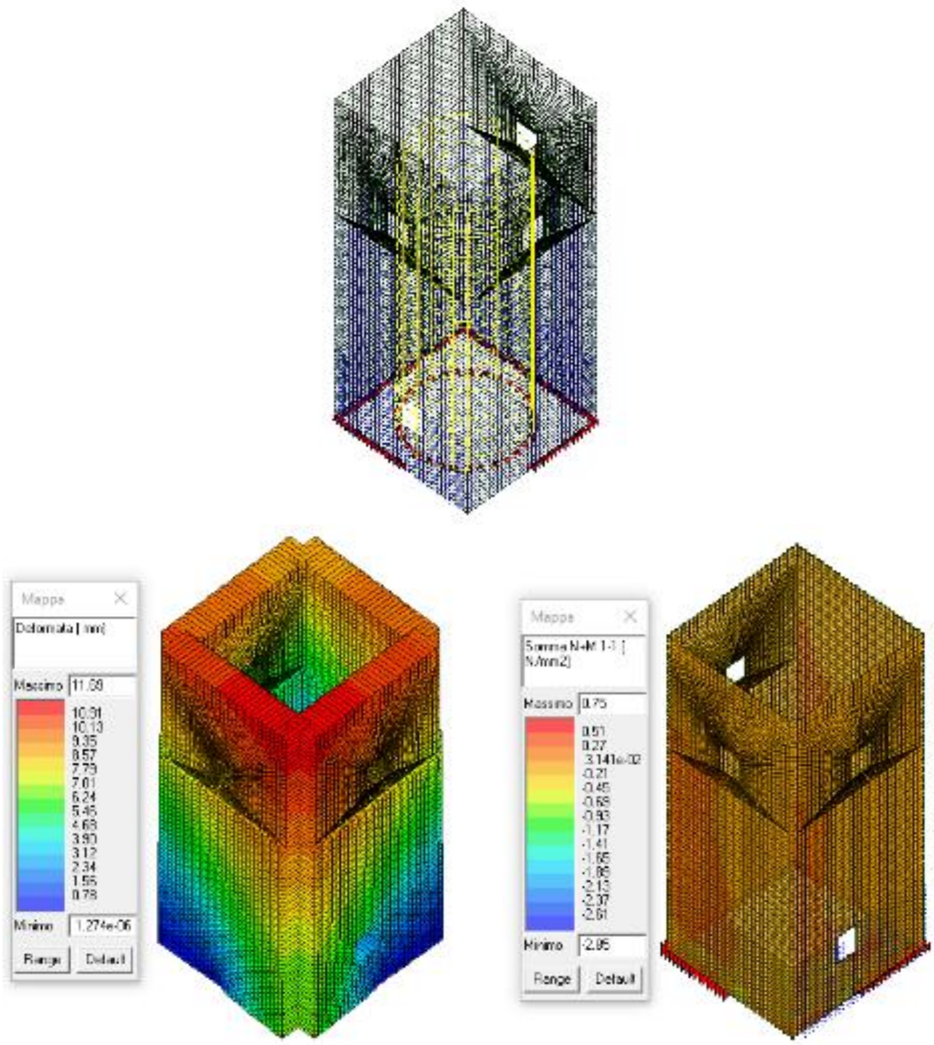


FIGURE 69–STRESS STATE AND DEFORMATION OF THE TOWER