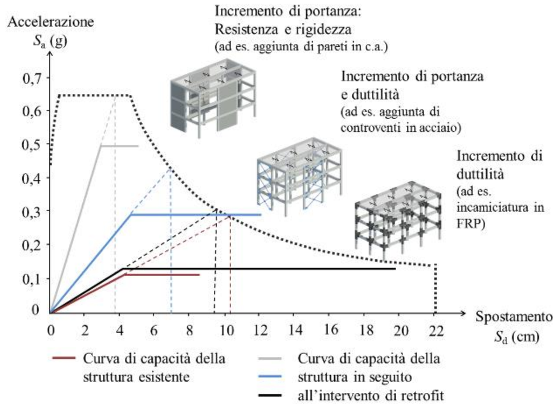
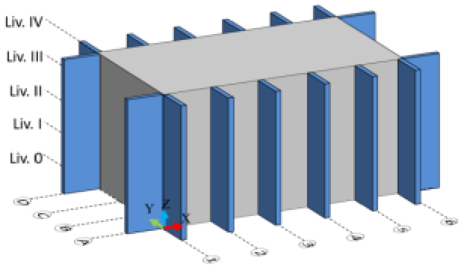
# SUMMARY

*Project objectives and goals*

Nowadays there are many strategies and intervention techniques that can be adopted for the seismic retrofitting of existing reinforced concrete buildings characterized by a high vulnerability due to the absence of seismic dictates and problems related to durability. The use of external seismic-resistant systems arranged along the perimeter of the structure, commonly called exoskeletons, are an excellent retrofit strategy to increase mainly resistance and stiffness of the structure.




Exoskeletons are shear walls made from metallic material. Their operation can be 2D or 3D and, in the 2D case, the walls can be arranged orthogonal or parallel to the building facades. In particular, this work refers to 2D systems orthogonal to the plan of the reinforced concrete building to be retrofitted. But what are the advantages and disadvantages of exoskeletons?

These systems have the advantage of being free from the structural grid, they can be easily industrialized, they meet the demand in terms of strength and overall stiffness by changing only their number, they can be designed to have a high level of accessibility, they do not restrict the passage of light, they can reduce the exposure class of the concrete of the existing structure, and due to their morphology these systems facilitate the lateral expansion of the existing structure. An additional advantage of this strategy lies in the fact that it is the only one that can be safely implemented without interrupting the operation/use of the building, but also because it can be effectively adopted, in cases where a structural expansion with lateral addition of volumes can be carried out, for the integrated retrofit (formal, energetic and functional) of the entire building. On the other hand, these systems, for essentially dimensional reasons, can be used for the retrofit of single and multi-storey buildings of modest height and require ex-novo foundations.

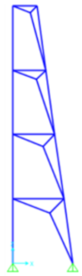

The main features of the system are:

- ability to have low impact to building users;
- ability to achieve high performance;
- low construction time and high costs but with the possibility of achieving economies of scale;
- variable accessibility from high to low depending on the type of system adopted.

*Description of method and result*

Focusing on the aspect of accessibility, weight and performance (stiffness, resistance, stability), a parametric study was carried out on the geometry of the wall within the global and local limits imposed, in order to obtain an optimization of the system itself. From the results, it can be seen that the optimum is reached with the lame system with "Y " diagonals (or semi portal), whose conformation gives the possibility to the people to pass underneath. The material, the arrangement exoskeletons in plan and the membranes sections, variable in base to the index of safety $\zeta_E$ (IS-V: ratio between the maximum seismic action the structure can withstand and the maximum seismic action that would be used in the design of a new construction) that is wanted to reach, have been determined through the methodology of plan articulated in five phases of continuation proposed:

- Phase 1 - choice of material and protection systems;
- Phase 2 - design of the shape;
- Phase 3 – walls arrangement in plan;
- Phase 4 - design of the elements and number of walls;
- Phase 5 - design of construction details and foundations;

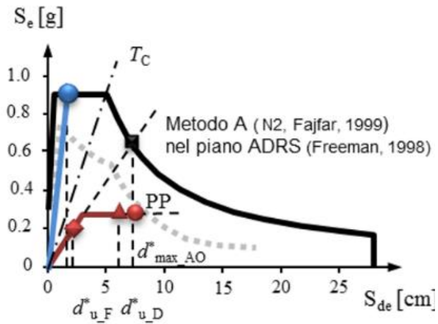


Some nomenclature was also adopted to classify the system:

EXO_S275-J2_2D_Orto_CBF_Y_IS

Then, an applicative case has been considered to evaluate also from a pratical point of view the study introduced above. The case study is a topic of the project WP5 2019-2021 of the consortium ReLUIS, in particular, this is the school P. Santini located in Loro Piceno (MC). A preliminary analysis identified, qualitatively, the following local and global deficiencies: frames in one direction, non-regular building, poor construction details, very poor concrete quality.

Subsequently, non-linear static analyses were carried out in order to catch and highlight the deficiencies at a quantitative level. Due to these deficiencies, a non-linear static analysis was performed as well, and the exoskeletons have been designed taking care to reach first an $\zeta_E$ = 0.80 and then an $\zeta_E$=1.00, guaranteeing however an elastic behavior to the exoskeletons.



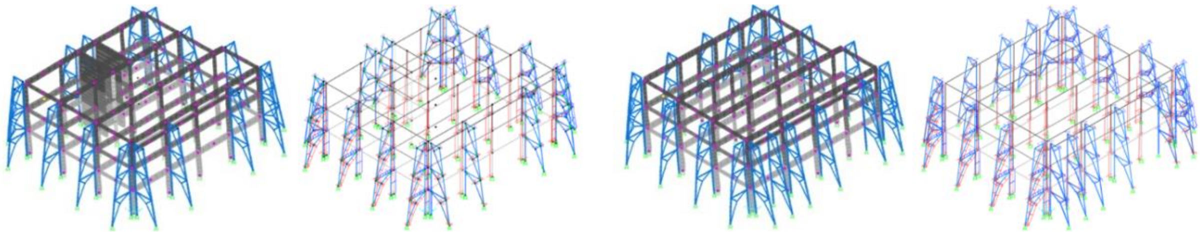

For $\zeta_E$=0.80, the sections obtained are:

- Currents: CHS 244.5x12.5 mm;
- Diagonals: CHS 139,7x10 mm;
- Crossbars: CHS 177,8x12 mm.

For $\zeta_E$=1.00 the sections obtained are:

- Currents: CHS 273x12.5 mm;
- Diagonals: CHS 177.8x12 mm;
- Transoms: CHS 193.7x12 mm.

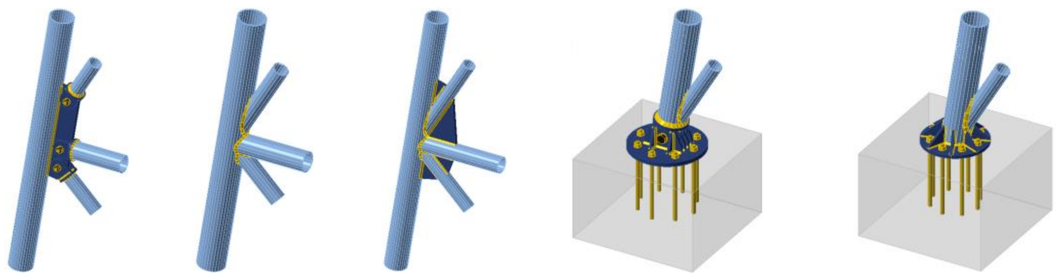
In addition, due to the presence of reinforced concrete wall that delimit the stairwell and due to their structural behavior is not well defined as it is not well known the degree of anchorage at floors level and the connection that it would have in the foundation, so it was considered two cases: the first one where the walls are collaborating in the seismic response of the building (case taken into account in the project ReLUIS WP5 2019-2021, then defined Benchmark System) and the second one in which they are assimilated as a infill wall (non-collaborating wall).



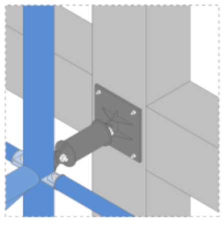
Comparing the results, it can be deduced that the exoskeleton is more stressed in the case of the structure with collaborating wall, which is another reason that lead to analyze the Benchmark System in detail.

When studying specific structures, it is often necessary not to limit oneself to the global analysis of the structure, since the behavior of some parts could be not considered in the analysis and, consequently, the criticality of these parts and the real behavior of the structure would be altered. Starting from the results of the Benchmark System, a local elastic-plastic analysis of the most characteristic nodes of the exoskeleton is carried out, parameterizing the material grade (S275 and S355) and the type of node according to its flexural stiffness (pinned, semi-rigid, rigid). The examinated nodes are the external one of the 1st deck, the external foundation one, link systems.

As far as concern the material, it was found that a S275 steel was insufficient for a local analysis of the nodes but, satisfactory for a global analysis of the structure. However, a S355 steel gave more performing and satisfactory results also for the local analysis. Regarding the node types, it was found that their variation returned very similar performances. Confirming this, there is the unchanged behavior of the retrofitted structure, after modeling it correctly with the correct initial flexural stiffnesses of the nodes. This occurs because the exoskeleton works mainly with axial stress, which is why changing the type of node, and therefore its rotational stiffness, is rather irrelevant.

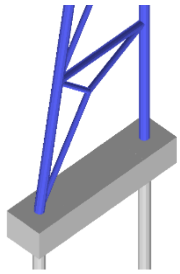


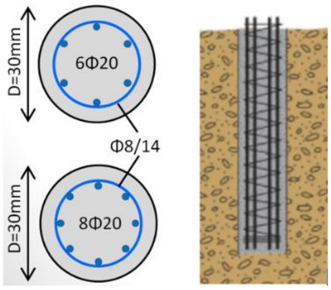
The local analysis of the nodes is very important to better capture the stress distribution at the nodes. In fact, independently of the $\zeta_E$ to be achieved, it can be observed that the material S275, as previously mentioned, is not sufficient in strength because there are large areas of concentrated stress which plasticize the node. In case of S355, the members have a lower work rate such that steel doesn't reach yield strength.



The connection between the exoskeleton and the existing structure can be made through simple rigid links or additional dissipation devices. It was chosen the first one. Given the low class of concrete of the school, it was considered to do a parameterization on the class of the concrete. If the existing structure does not have large nodes and does not have a good quality concrete (as in our case study), both the tensile verifications on the concrete side and the compressive verifications of the concrete basement, could be unverified, which is why local interventions are needed (local reinforcement with FRP, with FRCM, node ringing, lengthening of the plate on the elements adjacent to the affected node).

In addition, this thesis work analyzes also the aspect of foundations and soil-structure interaction through the support of structural calculation software ProSAP. The best foundations are the deep ones and, in the present case, micropiles are sufficient, which are cast in situ for gravity and without pressure. Parameterizing the category of subsoil, provided by NTC2018, and associating to each of them a design spectrum and a geotechnical characterization of the subsoil, a modal analysis was carried out with *behavior factor* q=1.5, limit to consider the structure as a substantially elastic system and to reason without the principle of hierarchy of resistance, both of the structure with collaborating reinforced concrete wall (Benchmark System) and of the structure with non-collaborating wall. That's why, it was possible to determine and associate, for each category, mechanical characteristics to the subsoil and then carry out the design and verification, both geotechnical and structural. Regarding geotechnical aspect, it can be inferred that, the diameter of the piles must be 30cm, while their length varies according to the structure, the $\zeta_E$ and the category of subsoil considered. Regarding structural aspect, the longitudinal bars and the spiral must have a diameter of 20mm, with a configuration ranging from 6 to 8 bars in the cross section, depending on the structure, the $\zeta_E$ and the category of subsoil.






*Potential for application of results*

The work was concluded by performing the estimation of the cost of the foundations and by comparing the values obtained with those already estimated of the superstructure, in order to understand if and how compatible they are with the incentives of the "Sismabonus". The results show that the intervention has a fairly high cost impact, especially with the addition of foundations. Comparing the results obtained, it can be deduced that there is an increase in cost ranging from 10%, for better subsoil categories (A), to 22% for poorer subsoil categories (D). It is easy to see that the costs related to the elevation part would decrease if non-tubular profiles was used. An excellent application of these systems is therefore expected to not interrupt the operation of the existing structure, to have an important improvement in terms of seismic risk (it's possible have a jump of 4-5 classes of seismic risk), then access the incentives of "Sismabonus" and "Superbonus", to take an holistic approach between structural (mitigating the risk), architectural (improving the appearance), environmental (making the envelope of the structure better from the energy point of view), all then in a perspective of life cycle thinking.

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