Technical Annals

Vol 1, No 3 (2023)

Technical Annals

Seismic investigation and upgrading of disused industrial buildings a case study

Giovanna Longobardi, Antonio Davino, Antonio Formisano

doi: [10.12681/ta.34755](https://doi.org/10.12681/ta.34755)

To cite this article:

Longobardi, G., Davino, A., & Formisano, A. (2023). Seismic investigation and upgrading of disused industrial buildings a case study. *Technical Annals*, *1*(3). https://doi.org/10.12681/ta.34755

Seismic investigation and upgrading of disused industrial buildings: a case study

Giovanna Longobardi[1[0000-0003-2600-8417]], Antonio Davino[1[0000-0003-3509-3334]] and Antonio Formisano[1 [0000-0003-3592-4011]]

[1]Department of Structures for Engineering and Architecture,
School of Polytechnic and Basic Sciences,
University of Naples "Federico II", P.le V. Tecchio 80, 80125 Naples
giovanna.longobardi@unina.it, antonio.davino@unina.it,
antoform@unina.it

Abstract. In this paper, the evaluation of the seismic behaviour and the consolidation plan of a former industrial building are described.
After a short introduction regarding the value of industrial architecture, discovered only in the late '70s of the past century, and the necessity to intervene on this heritage, most of the time abandoned, the case study has been introduced. It is a former tobacco industry placed in a small village in the outskirt of Salerno, in the South Italy.
Firstly, the historical evolution of the property has been reconstructed. Then, the main structural and architectonical features of the building have been illustrated. After this knowledge phase, the seismic behaviour has been evaluated with regard both to local and global mechanisms. Based on the obtained results, retrofitting operations have been hypothesized to allow for the new functionalization and the reuse of the building.
In conclusion, the effectiveness of the consolidating interventions has been demonstrated by repeating the pushover analyses, whose results have enabled the complete seismic upgrading of the former tobacco industry.

Keywords: Industrial buildings, Tobacco factory, Pushover analyses, Retrofitting operation, Seismic upgrading.

1 Introduction

In Italy, most of the existing buildings were erected without any seismic criteria, since realization was made before the first national seismic regulations.

Among these structures, built to resist only to gravity loads, there were industrial edifices. A huge part of them, especially those built with a mixed structure (masonry and reinforced concrete), came back to the early '30s of 20th century, whereas the ones made of steel structure dated back around 1980s. [1]

However, both typologies seriously suffered seismic actions, as demonstrated by two recent earthquakes occurred in L'Aquila in 2009 and in the Emilia – Romagna region in 2012. In those occasions, seismic events highlighted not only the vulnerability of historical centres with their ancient buildings, but also the susceptibility of industrial constructions to undergo significant damages and failures [2].

Consequently, the Italian Project DPC-ReLUIS set up, in the period between 2019 and 2021, the CARTIS-GL form so to characterize, from typological and structural viewpoints, large span buildings on Italian territory[3, 4].

The form is divided into four parts that start from general information, like the consistency of the territory, and arrive to specific data, like the geometrical and structural features of the examined building. The collected data with the CARTIS form allow to obtain some important outcome, such as the prevailing construction period, covered area, number of floors, height, etc. of a set of industrial buildings in the studied area.

The interest in studying industrial areas and buildings was born in 1950 in England, where in the previous century the industrial revolution began. In Italy, this interest arrived later, mainly in ‘70s, when industry started to be considered as identity of the population. Thanks to an increasing interest on the factory buildings, in that decades, the “industrial archaeology” concept was born and many researchers began to study these particular architectures characterized by long spans [5, 6, 7, 8] after their abandonment due to the failure of industrial societies aiming at recovering purpose through reuse of their spaces for events and exhibitions.

On the basis of these premises, our work focused its attention on the study of a former tobacco industry abandoned after the bankrupt of the owner society. This industrial building is placed in a small village in the outskirt of Salerno in South Italy.

Starting from the description of the area where the building is located, firstly, the crack pattern achieved from in-situ visual surveys was defined and, then, its seismic behaviour was predicted by carrying out nonlinear analyses through the TreMuri computer program. Based on the results, recovery interventions were defined and the analyses on the retrofitted building was performed to evaluate their positive effect on the structure seismic behaviour.

2 The former tobacco factory: the case study

2.1 Placement and historical evolution

The case study herein introduced is a former tobacco factory placed in Cafasso - Borgo Nuovo, a small village, with less than 1000 inhabitants, in the municipality of Capaccio, within the province of Salerno in South Italy.

The municipality belongs to the Sele Plain, a very large flat area which extends for about 500 km^2. In **Fig. 1**the placement of the examined structure is observed.

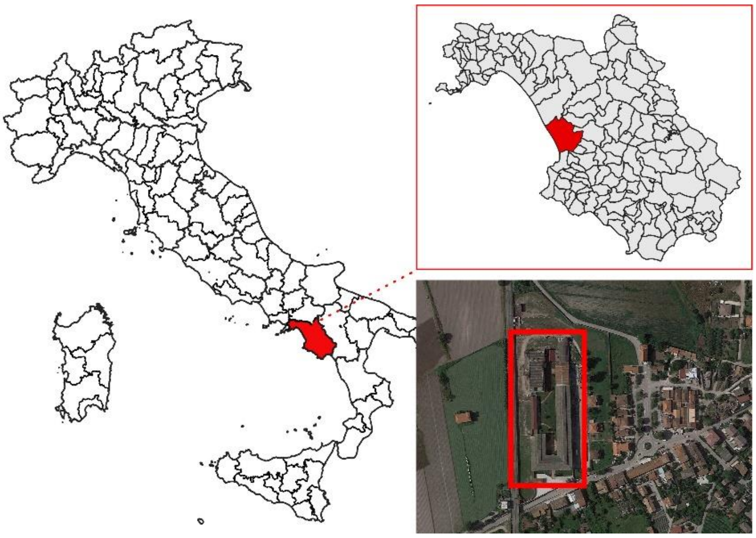

Fig. 1. Placement of the case study

The case study belongs to a network of other buildings having equivalent use spread in the Sele Plain, like the Farina or Fiocche tobacco factory. Most of them (except than the Carillia structure) was disused and abandoned in the '90s and now they are in a very advanced state of decay [9].

In **Fig. 2** a scheme of this factories network in the outskirt of Salerno is depicted.

These constructions have similar geometry distinguished by long spans and modest height. Their structures were realized with either load bearing masonry or reinforced concrete structures. Generally, the facades are characterized by a regular scan of openings useful for lighting of internal spaces and their ventilation.

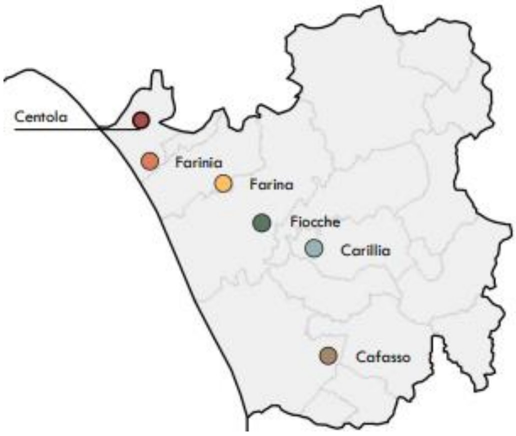

Fig. 2. Network of tobacco industries in the municipality of Capaccio (Salerno)

The case study named “Luigi Razza tobacco industry”, also known as “Cafasso tobacco factory”, was erected in a large property where about 26 structures dating back to different time periods were built.

The case study building takes its name from Luigi Razza, the last owner. Before his death, in 1935 he bought the property from Gaetano Bonvicini, who started the edification with the house of director and stables (Buildings with nr. 1 – 2 – 3 and 4 – 5 – 6, respectively, of **Fig. 3**).

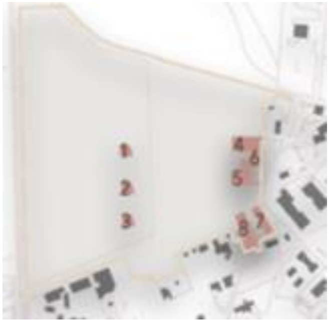

Fig. 3. The first buildings in the property (Late ‘20s)

In 1943, the property became a war warehouse and then returned to the Industrial Agricultural Society of Salerno a few years later until the '60s when the estate was sold to another tobacco industry society, and it was expanded with the construction of several houses for workers and dryers (Buildings nr. 9 – 15 and 24, respectively, of **Fig. 4**). In the early '70s, the entire area was sold to private entrepreneurs, who failed their activities in 2002.

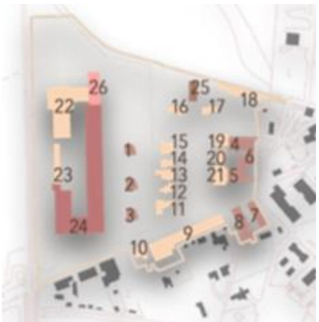

Fig. 4. A map of the property in the late ‘90s

Despite the efforts of Capaccio municipality, which tried to buy the grounds and its buildings, since 2020 the property is in abandoned state. In 2021, however, the procedure of remediation for the presence of asbestos is launched and the same municipality manages to win the lease for the organization of events and exhibitions.

Between the various and numerous buildings existing in the lot, in this work our attention is on the structure that one time hosted the dryers. Its main features are described in the following section.

2.2 Structural and architectural features of the former tobacco industry

The building under study, which within the large area examined is the one intended to the dryers' function when it was active. The drying phase in the processing of tobacco consisted in hanging the leaves on wooden structures, generally the gratings placed under the covers, to allow them to dry before the next production stages. **Fig. 5** shows a three-dimensional view of the edifice.

Fig. 5. A three-dimensional view of the building

It is articulated into three "arms" that, due to their configuration, individuate an internal courtyard. The structure reaches a maximum height of about 15m. **Fig. 6** reports the ground floor plan of the building.

Fig. 6. Ground floor layout

Its structure is of mixed type, composed of masonry and reinforced concrete (**Fig. 7**), the external masonry is realized with solid bricks, and it is interrupted by reinforced concrete pillars, placed at about 6 m each other, which develop from the ground to the building top (**Fig. 8**).

Internally, due to the old use required for the tobacco manufacturing, there are not vertical divisions, but only pillars which mark the spaces dividing them into standard modules.

There are not even internal horizontal floors, but only the roof structure having a double pitch configuration made of corrugated sheet metal placed so to replace the previous asbestos panels. This roof is sustained by a grid of wooden beams. (**Fig. 9**)The facades are characterized by a series of rectangular opening. Some of them have been closed with solid bricks after the abandonment of the factory in order to avoid the entrance of strangers (**Fig. 10**). All these features are highlighted in the following photographic documentation.

Fig. 7. Alternation of masonry walls and pillars on the façade

Fig. 8. Reinforced concrete pillar

Fig. 9. The structure of the roof

Fig. 10. Closure of the opening at ground floor

2.3 State of decay: the crack pattern

Due to the abandonment occurred at the beginning of the 20th century, the building under examination shows different types of injuries and failures, that could be grouped into four categories:

- Crushing of masonry walls;
- Poor connection among adjacent walls;
- Decay of wooden elements;
- Decay of reinforced concrete pillars.

With the regard to the first type of damage, at the base of the external masonry walls it is possible to individuate crushing phenomena. These could be related to the age of materials and the decay of the mortar. In some points of walls orthogonal to each other, there are a lack of connection between them, which give rise to the absence of the so-called “box-effect”. As a consequence, the structure could suffer local mechanisms. like overturning phenomenon [10].

Due to the humidity, numerous wooden elements of the roof grid are deteriorated. Instead, other elements show vertical lesions due to the loads increase during time.

Finally, some problems are found in reinforced concrete pillars, which exhibit in some parts the detachment of the concrete cover. As a result, the steel reinforcement bars are exposed and rusty. In **Fig. 11** the four typologies of damages above described are illustrated.

a) b) c) d)

Fig. 11. Injuries on the case study: a) Crushing of masonry walls, b) Poor connection between adjacent walls, c) Decay of wooden beams, d) Detachment of the cover concrete from the pillars

3 Seismic behaviour evaluation

3.1 Method

In order to evaluate the seismic behaviour of the dryers of the former tobacco factory, the TreMuri computer program, a calculation software developed by the STA.DATA company, is used. It is a software based on the Frame by Macro-Elements (FME) numerical modelling technique, where each masonry panel is composed of three macro-elements, namely piers, spandrels and rigid nodes. The first are placed next to the openings, the spandrels are above and under the openings, and rigid nodes, considered as infinitely igid, are at the intersection between piers and spandrels.

TreMuri program, which was extensively used in various literature works [11, 12], is herein used for the evaluation of the non – linear behaviour of the inspected masonry structure. The global analysis gives back the pushover (or capacity) curve, which is identified through the base shear-displacement diagram. According to the current Italian technical code [13, 14] in order to carry on the pushover analyses, two distributions of inertia forces must be considered as follows:

- Distribution proportional to the static forces (Group 1);
- Uniform distribution of forces, which is derived from a uniform distribution of accelerations over the height of the construction (Group 2).

3.2 Evaluation of local mechanisms

Before evaluating global behaviour of the tobacco fabric under study, it has been studied its tendency towards local mechanisms.

They are also known as first-way mechanisms, and they are defined as failure modes involving structurally independent parts of masonry named macro-elements experiencing behaviour outside their own plane. Among them, we recognize partial/total overturning and vertical/horizontal bending phenomena.

Generally, these failures interested structures which do not show the so-called "box – effect" due to a lack of connection either between vertical walls and horizontal floors or between two adjacent orthogonal masonry panels [15, 16, 17].

These local mechanisms have been assessed through the TreMuri software, used also in the next step for global analysis. The evaluation is based on the limit analysis method, that consider the masonry as a series of rigid macro-elements having unlimited compressive strength, but zero tensile resistance.

For each considered mechanism, the portion of masonry is transformed into a kinematic chain (unstable system), with the identification of rigid bodies capable of rotating or sliding among them.

Verifications have been conducted with reference to the Life Safety Limit State. They are satisfied if the spectral seismic acceleration of activation of the kinematics a^*_0 is greater than the peak ground seismic acceleration $a_{0,min}$:

$$a_0^* \geq a_{0,min} \tag{1}$$

In the case of ground floor constraint, a_0^* is calculated as follows :

$$a_0^* = \frac{\alpha_0 \cdot g}{e^* \cdot F_C} \tag{2}$$

in which:

- α_0 is the multiplier of the seismic action causing the collapse, obtained through the principle of virtual works;
- g is the gravity acceleration;
- e^* is the participating mass fraction related to the first vibration mode;
- Fc is the confidence factor (in this case assumed equal to 1,35).

$$a_{0,min} = \frac{S_e(0)}{q} \tag{3}$$

where:

- $S_e\,(0)$ is the ordinate of the elastic spectrum;
- q is the behaviour factor.

Contrary, for masonry walls having hinge at a certain altitude, the following expression is used:

$$a_{0,min} = \frac{S_e(T_1) \cdot \psi(Z) \cdot \Upsilon}{q} \tag{4}$$

where:

- S_e (T_1) is the ordinate of the elastic spectrum, which depends on the first vibration period T1;
- ψ is the first vibration mode in the considered direction;
- γ is the modal participation coefficient;
- q is the behaviour factor.

For the former dryers of tobacco factory, only the overturning phenomenon, considering both partial and global types, are evaluated.

In **Table 1** and **Table 2**, the achieved results obtained analysing the perimeter walls of the structure are summarised. It is seen that the structure has a high vulnerability towards local mechanisms, since all analyses are not verified.

Table 1. Results of evaluation of local mechanisms – Global type

Wall	Constraint	$\mathbf{a_0^*}$	$\mathbf{a_{0,min}}$	Check Result
-	-	[m/s^2]	[m/s^2]	[-]
1	Ground	0,4931	1,4171	Not Verified
2	Ground	0,0178	1,4171	Not Verified
3	Ground	0,5017	1,4171	Not Verified
4	Ground	0,5465	1,4171	Not Verified
5	Ground	0,4991	1,4171	Not Verified
6	Ground	0,5430	1,4171	Not Verified
7	Ground	0,5509	1,4171	Not Verified
8	Ground	0,5501	1,4171	Not Verified

Table 2. Results of evaluation of local mechanisms – Partial type

Wall	Constraint	$\mathbf{a_0^*}$	$\mathbf{a_{0,min}}$	Check Result
-	-	[m/s^2]	[m/s^2]	[-]
1	First-floor base	1,0950	2,5777	Not Verified
2	First-floor base	1,1248	2,5777	Not Verified
3	First-floor base	1,1793	2,5777	Not Verified
4	First-floor base	1,1806	2,5777	Not Verified
5	First-floor base	1,1332	2,5777	Not Verified
6	First-floor base	1,1799	2,5777	Not Verified
7	First-floor base	1,1104	2,5777	Not Verified
8	First-floor base	0,7632	2,5777	Not Verified

Fig. 12 represents one of the same perimeter walls (Wall nr. 3) analysed for the evaluation of the global overturning mechanism and the partial one.

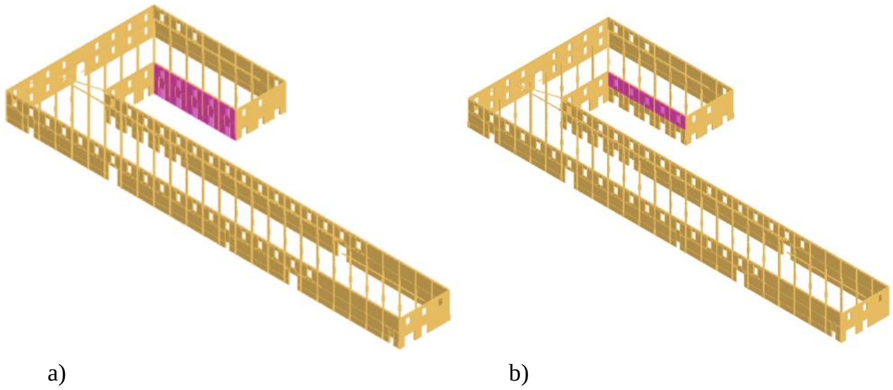

Fig. 12. Wall 3: a) Global overturning; b) Partial overturning

3.3 Pushover analyses

Once the evaluation of local mechanisms is done, pushover analyses are carried out in order to evaluate the global behaviour of the structure.

After geometrical modelling of the structure is executed, the properties of materials are defined selecting the lowest level of knowledge (LC1) according to the current Italian legislation. Therefore, the minimum values for resistance and medium ones for elastic modules are assumed for masonry. Finally, the roof structure is modelled over the masonry structure.

After the 3D model is generated, the mesh dividing each masonry panel in the three above-mentioned macro-elements is created. A view of both the three – dimensional model and the meshed one of the building is depicted in **Fig. 13**.

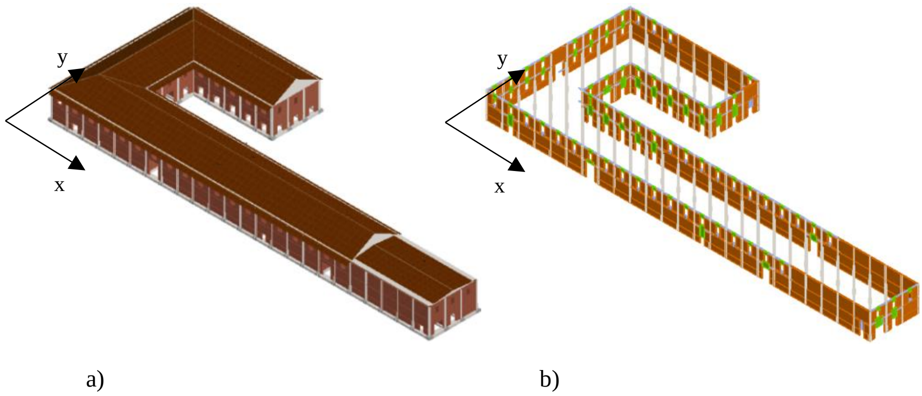

Fig. 13. Macro-elements modelling of the investigated structure:
(a) Three – dimensional model; (b) Meshed model

Firstly, modal analysis is performed and a first vibration period in y direction, equal to 0,57 s is achieved.

Subsequently, after the subsoil category type C is defined, pushover analyses monitoring the displacement of a “control node” at the roof level are performed. The results of the two worst analyses are shown in **Table 3**, where the seismic safety factor at Life Safety Limit State, intended as the ratio between the capacity acceleration and the demand one, is provided in each analysis direction.

Table 3. Results of pushover analyses

Nr.	Seismic direction	Seismic load	Eccentricity	α_{SLV}
16	-X	Modal distribution	-269,8	1,681
20	+Y	Modal distribution	-719,8	0,625

In **Fig. 14**, the main damage and failure mechanisms of masonry macro-elements are illustrated on the three-dimensional model of the building for the analysis in direction y.

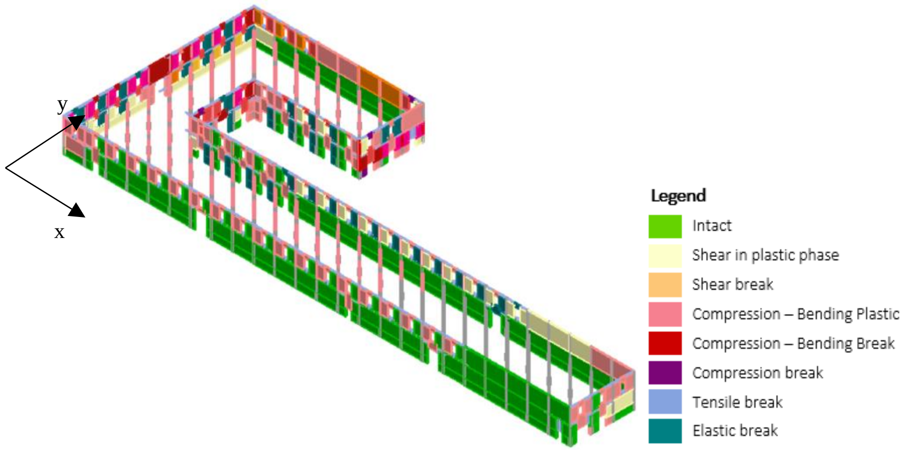

Fig. 14. Damage mechanisms of the structure loaded in direction y

As it is observed from the above figure, the main mechanisms affecting masonry piers are the shear failure (yellow elements) and compression – bending (pink elements) phenomena. Most of RC pillars undergo plastic behaviour under compression – bending actions (pink elements).

4 Retrofitting plan

4.1 Interventions

Following the analysis phase which underlined the deficient seismic behaviour of the building, especially in y direction, and its high vulnerability towards overturning phenomena, various consolidating operations are hypothesized aiming at the building reuse. In particular, based on the intentions of the municipality of Capaccio, the structure could be used for exhibitions and other events connected to the food industry.

The retrofitting plan foresees some specific interventions that are described as follows.

Metal chains

The first operation consists of the insertion of metal chains to contrast the overturning phenomena due to the lack of effective connections among orthogonal walls.

These chains, having circular cross-section with diameter of 20 mm and placed every 5/6 meters, arefirstly designed through the “Tie beams calculation” software, that allows to get the chain diameter, and then verified by means of “Kinematic Analysis” modulus of the TreMuri program. This latter calculation tool provides not only the verification of the local mechanism, but also the checks towards the following failure mechanisms:

- Masonry punching

The punching resistance of masonry in the anchoring zones is given by the following formula:

$$\tau_{pun} = f_v \cdot [2 \cdot (b + t) + 2 \cdot (a + t)] \cdot t \tag{5}$$

where:

- t: thickness of the masonry;
- b: width of the plate;
- a: height of the plate;
- fv: shear design resistance of the masonry.

- Anchor penetration

The penetration of the anchor in the masonry is given when the compressive strength of the masonry subjected to the contact pressure of the plate is exceeded. This resistance is given by the following formula:

$$\tau_{pen} = f_d \cdot a \cdot b \tag{6}$$

being f_d the design compressive resistance of the masonry.

- Chain yield strength

The verification of the chain is done by using the following expression:

$$\tau = f_y \cdot \frac{\Phi^2 \cdot \pi}{4} \tag{7}$$

where:

- Φ is the diameter of the metal chain;
- fy is the design tensile resistance of the chain.

Scuci and Cuci technique

Another intervention planned on the masonry walls is the scuci and cuci technique.

Thanks to this operation, the damaged stones are replaced with new ones of the same material in order to ensure a better organization and duration over the time of the masonry apparatus.

As a first step, the plaster covering the masonry (if present) and the damaged stones are removed. After, there is the cleaning of the masonry by removing debris and dust. Finally, the new blocks are inserted using a zero or slightly expansive shrinkage grout.

Re – styling of the joints

A further consolidating operation on the masonry apparatus foresees the re – styling of the joints using mortar having a similar chemical composition to the pre-existing one, so to avoid unsuccessful operations.

New steel frames around openings

Since the design idea includes the elimination of masonry brick walls used for the closure of openings after the abandonment of the structure, in order to restore the resistance and the stiffness of the structure, steel frames are hypothesized to be inserted around openings. They are made up of two steel columns per side and two beams of HEB type.

All the profiles are connected to the masonry walls by chemical anchors.

Interventions on the reinforced concrete elements

This category includes two types of operations. The first intervention consists of the enlargement of the cross-section of some pillars showing failures from pushover analyses. Existing pillars have cross-sections of 46x46 cm at the base and 36x36 cm at the top. These elements are reinforced to reach a final cross-section of 50x50 cm.

The second intervention is the reconstruction of the concrete cover in most cases detached due to the age of materials and the lack of maintenance over the time. Both operations can be performed according to the following phases:

- Removal of the degraded concrete;
- Removal of dust and debris and subsequent washing;
- Application of protective paints for steel bars;
- Placement of new steel bars for the reinforcement;
- Concrete casting in the first operation, reconstruction of the concrete cover in the second case.

Replacement of the roof

Since the current roof made of corrugated metal sheets is a temporary structure placed after the removal of the previous one realized in asbestos, its replacement is foreseen with a new "cold type" structure so to get a ventilation space between the coverage layers. Proceeding from the inside outwards, the new roofing structures is composed of wooden plank, vapour barrier, rock fibre panels for thermal insulation, waterproof coating, air space and final coverage.

4.2 Pushover analyses after interventions

After the planned retrofitting operations above described, reported in **Fig. 15**,are inserted in the TreMuri calculation model, both local (linear) and global (non-linear) seismic analyses are repeated.

From one side, local checks confirm the contrast of overturning phenomena thanks to the insertion of metal chains in the structure.

From the other side, global analyses show the effectiveness of the consolidating interventions. Indeed, all the 24 pushover analyses are verified in both analysis directions. The worst analysis results are depicted in **Table 4**, where it is noticed that, being the alfa coefficient greater than the unit in both analysis directions, the planned consolidation interventions allow the building to be completely retrofitted from seismic point of view.

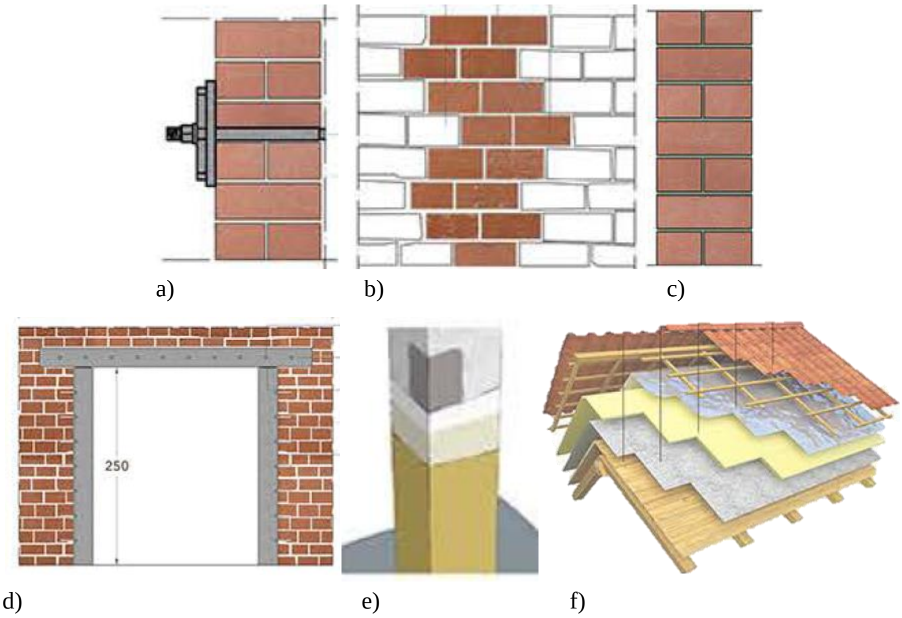

Fig. 15. Schematic representation of planned retrofitting operations: (a) Insertion of metal chain; (b) “Scuci and cuci” technique; (c) Re-styling of joints; (d) Steel frame around door; (e) Reinforcement of thereinforced concrete pillar; (f) New roof.

Table 4. Results of the two worst pushover analyses

Nr.	Seismic direction	Seismic load	Eccentricity	α_{SLV}
11	+X	Modal distribution	269,8	1,712
20	+Y	Modal distribution	-719,8	1,25

5 Conclusions

The work dealt with the seismic behaviour assessment and retrofit of a former tobacco industry located in the small village of Cafasso - Borgo Nuovo, in the province of Salerno of Southern Italy. Since interest in industrial archaeology began in the last decades of 21st century, the interest towards industrial buildings, which represent a huge heritage evidence of both the industrial revolution and the change of architecture adapted to new spaces and materials, is strongly felt by researchers and designers.

The case study is a typical example of this new way of doing architecture. The building has a mixed masonry-reinforced concrete structure, and it was abandoned after the bankruptcy of the industrial society in 2002. As a result, it is in a very advanced state of decay with widespread crushing phenomena of masonry walls and concrete cover spalling in the pillars.

In the current work, after the knowledge phase and the crack pattern survey of the building, its seismic behaviour with respect to both local and global mechanisms was evaluated. The unsatisfactory analysis results deriving from this assessment phase required the planification of anti-seismic interventions of different type, aimed to both enable overturning mechanisms and reinforce in terms of strength, stiffness and ductility the original structure, with the final goal to ensure its requalification and reuse.

The planned consolidation interventions proved their effectiveness, since local mechanisms were avoided by inserting metal chains and pushover analyses, thanks to operations on masonry walls, RC pillars and roofing structure, provided seismic safety factors greater than one in both analysis directions, allowing the former tobacco factory to be completely retrofitted from seismic viewpoint.

References

1. ANCE/CRESME report: The state of the Italian territory 2012: Settlement and seismic and hydrogeological risk, Rome (2012).
2. Formisano, A., Di Lorenzo, G., Iannuzzi, I., Landolfo, R..: Seismic vulnerability and fragility of existing Italian industrial steel buildings. The Open Civil Engineering Journal 11 (Suppl – 5, M7) 1122-1137 (2017).
3. Formisano, A., Meglio, E., Di Lorenzo, G., Landolfo, R.: Vulnerability curves of existing Italian industrial steel building designed without seismic criteria. In: Proceeding of the 10th International Conference on Behaviour of Steel Structures Areas. STESSA 2022, 872 – 880. Mazzolani, F.M., Dubina, D., Stratan, A. eds, Timisoara (2022).
4. PCM-DPC: Manual for the compilation of the form for the damage and post-seismic usability assessment for precast and large dimensions buildings (GL-AeDES), Rome (2014).
5. Formisano, A., Messineo, Y.: Seismic rehabilitation of abandoned RC industrial buildings: The case study of a former tobacco factory in the district of Avellino (Italy). Applied Sciences 12 (11) (2022).
6. Mainardi, M.: The preservation of industrial heritage in Italy: Traces of history, interpretation, methods. Stor. Futuro 2013. Available online: http://storiaefuturo.eu/la-conservazione-del-patrimonio-industriale-in-italia-tracce-di-storia-interpretazione-metodi/, last accessed 2022/12/13.
7. Negri, M.: To the origins of Italian industrial archaeology. In: Industrial Archaeology in Italy. Ciuffetti, A., Parisi, R., eds. Franco Angeli: Milano, Italy (2007).
8. Chiapparino, F.: Archaeology, heritage and landscape of industry. The genral evolution and the case of the Maches. In: Turismo e Sviluppo Locale. Novelli, R. Ed.. Cattedrale: Ancona, Italy, 2010, pp. 70 – 83.
9. https://webthesis.biblio.polito.it/7786/1/tesi.pdf, last accessed 2022/12/14.
10. Milano, L., Mannella, A., Morisi, C., Martinelli, A.: Illustrative sheets of the main local collapse mechanisms in buildings existing masonry and related kinematic model of

analysis, Annex to the Repair and Repair and Strengthening Guidelines of structural elements, infills and partitions, DPC – ReLUIS.

11. Longobardi, G., Formisano, A., Seismic vulnerability assessment and consolidation techniques of ancient masonry buildings: the case study of a Neapolitan Masseria. Engineering Failure Analysis 138 (1), 2022.
12. Davino, A., Longobardi, G., Meglio, E., Dallari, A., Formisano, A.: Seismic energy upgrading of an existing brick masonry building by a cold-formed steel envelopre system. Buildings 12 (11), 2022.
13. Ministry of Infrastructure and Transport. Technical Standards for Construction; Official Gazette (nr. 42 of 20-2-2018): Rome, Italy, 2018 (In Italian). [23] Ministerial Circular n.7/2019 (M. C., 02/01/2019).
14. Instructions for the application of the “Upgrading of Technical Codes for Constructions” (M. D: 17/01/ 2018). Official Gazette of the Italian Republic published on 2019 January 2nd
15. Milani, G., Tralli, A., Simple SQP approach for out-of-plane loaded homogenized brickwork panels, accounting for softening, Computers and Structure 89 (1-2) (2011) 201–215.
16. Chiozzi, A., Grillanda, N., Milani, G., Tralli, A.: UB-ALMANAC: An adaptive limit analysis NURBS-based program for the automatic assessment of partial failure mechanisms in masonry churches, Eng. Fail. Anal. 85 (2018) 201–220.
17. Milani, G.: Upper bound sequential linear programming mesh adaptation scheme for collapse analysis of masonry vaults, Advances in Engineering Software 79 (2015) 91–110.