ANALYSIS AND STRENGTHENING OF RC MANUFACTURING FRAME STRUCTURES DAMAGED BY EARTHQUAKE

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ABSTRACT

Reinforced concrete (RC) frame structures of manufacturing buildings have demonstrated high vulnerability and low shear capacity when exposed to seismic actions of recent earthquakes of 2016-17 in Italy. In this paper the behaviour of existing RC manufacturing frames invested by dynamic motion have been examined considering a series of industrial buildings located in a town of Central Italy invested by seismic actions particularly strong. RC structures of manufacturing buildings were built in different past periods so that any buildings were not designed to resist to earthquake and therefore collapse has interested some part of industrial buildings. Main damages have interested, however, many elements of the RC structures both roof and columns, together with beams and nodes of same frames. An analysis of damages of RC structures has been carried out in the paper to define the several effects of earthquake on the RC structures. A numerical analysis of existing RC structures has been developed under seismic forces and it has allowed to define the structural elements which are not able to support shear and/or bending actions without damages. Finally, rehabilitation technique adopted to improve the behaviour of RC frames and, more in general, of all structures subjected to seismic actions, has been described.

Keywords: RC frames, earthquake damage, rehabilitation, FE analysis.

INTRODUCTION

Recently, earthquakes in Italy have hit masonry and reinforced concrete (RC) structures significantly in many small historic centres of Italian regions such as: Marche – Umbria – Lazio [1, 2] ensuing dramatic consequences and destruction. Historic masonry structures have been, in many situations such as in the recent seismic events in Italy, subjected to exceptional combined shear and compressive stresses. Shear walls, whether solid or pierced by window and door openings in each storey, represent the basic structural elements of a masonry structure, resisting seismic loads [4,5]. In buildings with RC structures, normally built with

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RC frames, the response to seismic actions is linked to ductility of columns under bending and shear internal forces. Many damages have been recorded in civil buildings during recent earthquakes built with for RC frame structures and infilled masonry walls; dangerous damages interested column/column-beam nodes (Figs. 1(a),(b)). In this paper one study and strengthening of RC frames of a large manufacturing buildings located in small town of Matelica, damaged by recent earthquakes in Italy, have been analysed (Fig. 2). RC structures of manufacturing buildings were built in different past periods so that some buildings were not designed to resist to earthquake and therefore collapse has interested some part of industrial building. Main damages have interested however many elements of the RC structures both roof and columns together with beams and nodes of same RC frames. The study has been developed starting from the damages of frames and the collapse that has affected a part of buildings with RC frames and structures built in the seventies of last century utilizing an old Italian Code of Practise with few rules regarding the seismic actions. Because of the weakness of many RC structures, an investigation of concrete and steel bars used in the construction of RC structures has been considered as mostly important to define the elements with reduction capacity and need of strengthening. Although many non-destructive tests may be considered useful [6], in this investigation many specimens were subjected to compressive and tensile tests.

Fig. **1** – Damages in civil buildings in Arquata del Tronto, Italy (2016)

On the basis of experimental data of materials' strengths and recorded displacements of structures under earthquake actions, the authors have analyzed RC frames by finite element modelling. The project of strengthening and rehabilitation of frames have been developed by the authors considering both the weakness of materials and the lack of lateral force resisting systems on normal plans compared to the main plans of existing RC frames. The stability of RC frames was improved considering spatial steel truss beams as bracing elements, which allow to maintain the movements compatible between frames in direction normal to main plain under seismic actions. Finally, strengthening of columns has been projected using composite polymer materials.

Fig. **2** – Collapse of structures of manufacturing buildings in Matelica, Italy (2016)

SEISMIC ACTIONS IN CENTRAL REGIONS OF ITALY IN 2016

The Italian territory is particularly subject to seismic phenomena due to its geological nature. In Central Italy, already in 1997, high intensity seismic phenomena were recorded, involving the area between Marche Region and Umbria Region. Seismic events that affected central Italy repeated in 2016. They began on the night of 24 August 2016 and continued for several months with natural disasters, especially in October 2016. The 2016 earthquakes caused fatalities and extensive damage [7]. Figure 3 and 4 show the locations of the main seismic events from 24 August to 17 January 2017. The Italian accelerometer network has identified the hypocenter of the 24 August earthquake in the province of Rieti at a depth of 4 km, affecting the provinces of Perugia, Ascoli Piceno, L'Aquila and Teramo. Magnitude corresponds to an intensity between 6.0 and 6.2. The 30 October earthquake reached a magnitude intensity of about 7.0.

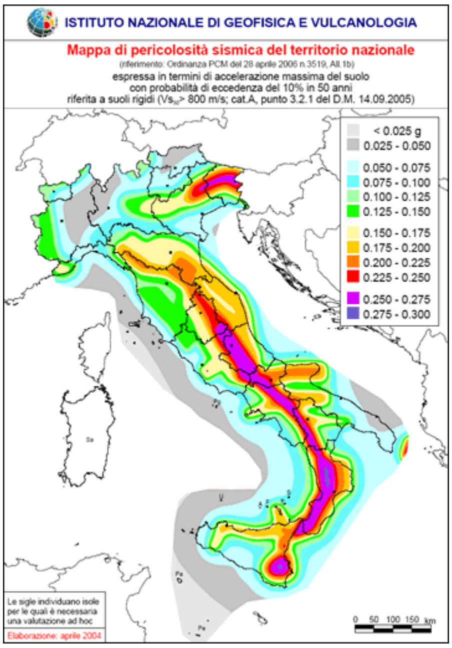
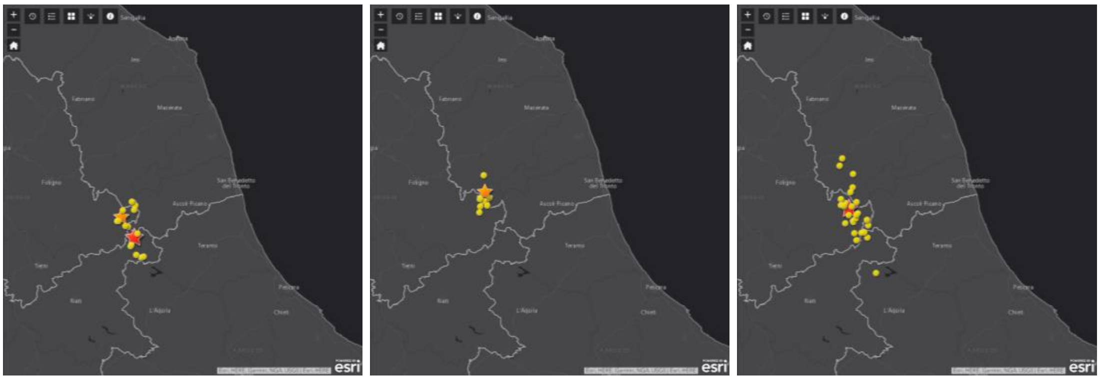


Fig. **3** - Italy seismic hazard map: horizontal PGA with 475-year return period.



(a) (b) (c)

Fig. **4** - (a) Map of Amatrice-Visso-Norcia seismic sequence from 24 August to 25 October 2016; (b) map of Amatrice-Visso-Norcia seismic sequence from 26 to 29 October 2016; (c) map of Amatrice-Visso-Norcia seismic sequence from 30 October 2016 to 17 January 2017.

Thanks to recordings it has been possible to evaluate the pick ground acceleration (PGA), the spectral acceleration (PSA), the spectral displacement (PSD) and, finally, duration of events. The elaboration is based on single degree of freedom system. It is particularly interesting to compare the values of the elastic spectrum of 30 August 2016 earthquake with the same values given by Italian Code of Practice (NTC08) [8], as showed in Figure 5.

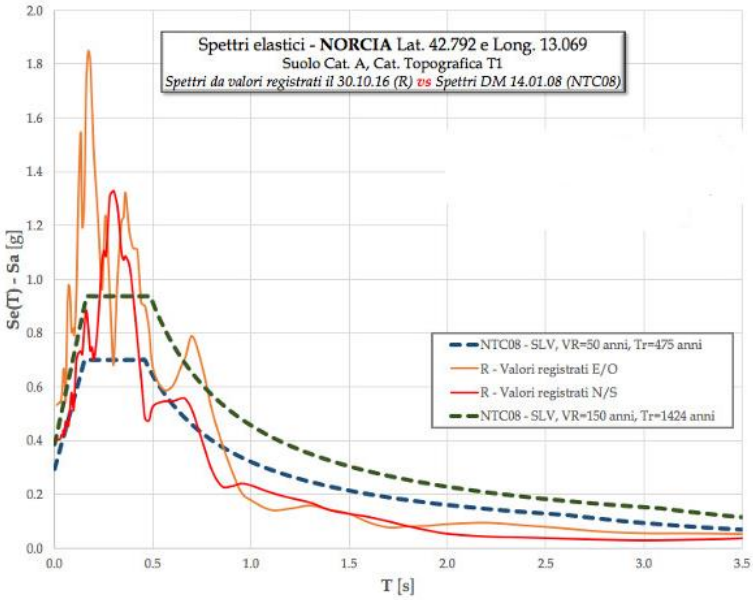
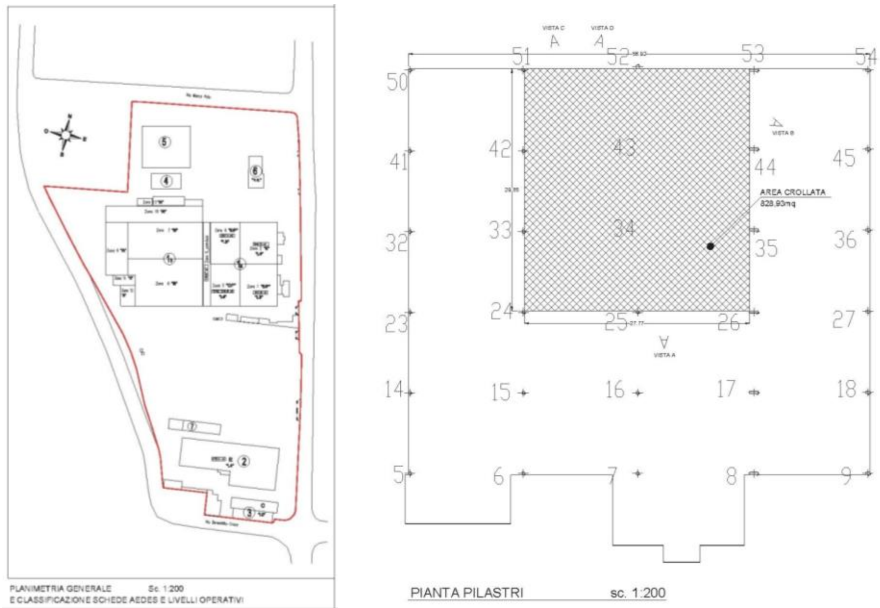


Fig. **5** - Comparison of elastic spectrum of Italian Code of Practice (NTC08) and spectrum recorded in Norcia during the event of 30th October 2016.

It is clear that seismic actions' intensity is very high (Fig.5), in particular on the east-west direction. Under the 30 August 2016 earthquake's action, some buildings of the industrial complex (Figs. 6(a), (b)) – object of this analysis – have suffered serious damages with structural collapse for some parts, as indicated in Figure 6(b).



(a)

(b)

Fig. **6** – (a) Plan of industrial buildings and collapsed zone; (b) details of damages.

EXPERIMENTAL TESTS ON RC BEAMS/COLUMNS

The objectives of the delivered experimental investigations have been analysis, check and qualification of materials – concrete and steel – which were sited into the structural elements of the complex.

The following on-site tests were carried out: non-destructive tests with magnetometric detection and direct tests for the location of the main and secondary reinforcing bars.

An electronic magnetometer produced by Elcometer "Inspection Equipment", model P331H, was used for the detection, equipped with an acoustic and visual check for the location and disposal of the reinforcement bars; pull-out tests on the columns and RC beams were used to evaluate the resistance of the concrete (Fig. 7).

Fig. **7** - Pull-out tests on RC columns

In the laboratory compression tests on cylindrical specimens obtained by drilling from structural elements in reinforced concrete (Fig. 8) and tensile tests on steel specimens obtained from structural elements in reinforced concrete (Fig. 9).
The experimental results/data have highlighted that steel has resistance to yield a generally adequate for the use in RC structure $f_y \approx 338.00 \div 465.00 N/mm^2$; instead, the recorded concrete values have highlighted high resistance differences among the specimens and nevertheless maximum resistance approximately not more than 20.0-22.0 N/mm^2.

(a) (b)

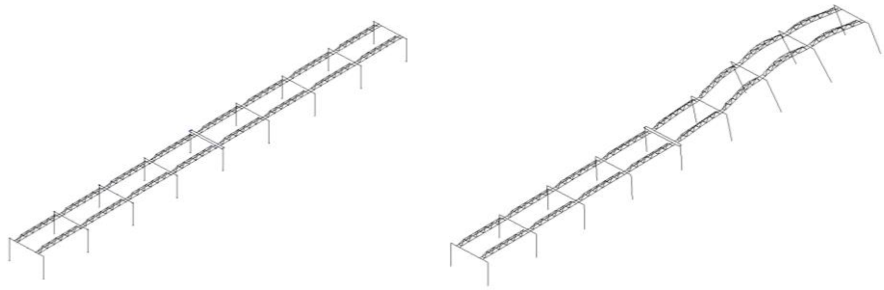
Fig. **8** – (a) Extraction of concrete sample and (b) element to test in laboratory.

Fig. **9** – Smooth steel bar collected in one RC column used to tensile test.

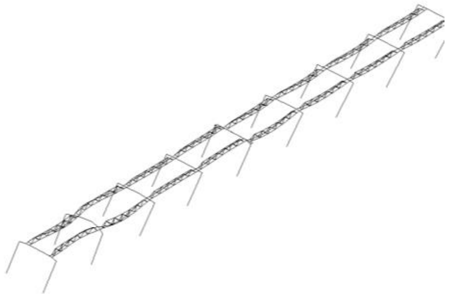
FE ANALYSIS OF FRAMES AND STRENGTHNING

The seismic vulnerability analysis of these industrial reinforced concrete building, has been achieved by analysis on a finite element model designed to be as close as possible to the real structure, in terms of stiffness, mass and strength distributions, by using commercial finite element software. Particular attention was put, during the modelling, at the choice of the finite element for simulating the connections between the structural elements, i.e. beam-column and beam-beam, by choosing rigid links and appropriate releases. Dynamic modal analysis was conducted.

The numerical analysis with finite elements models of RC structures has allowed to identify the most stressed elements under seismic action. Particularly interesting are the dynamic modal analysis of RC frames (Fig.10) where some examples of mode shapes for a series of RC frames put in a walking area among the various building of the industrial complex are showed.



(a) Three dimensions FE modelling (b) 1st vibration mode shape (Y direction)

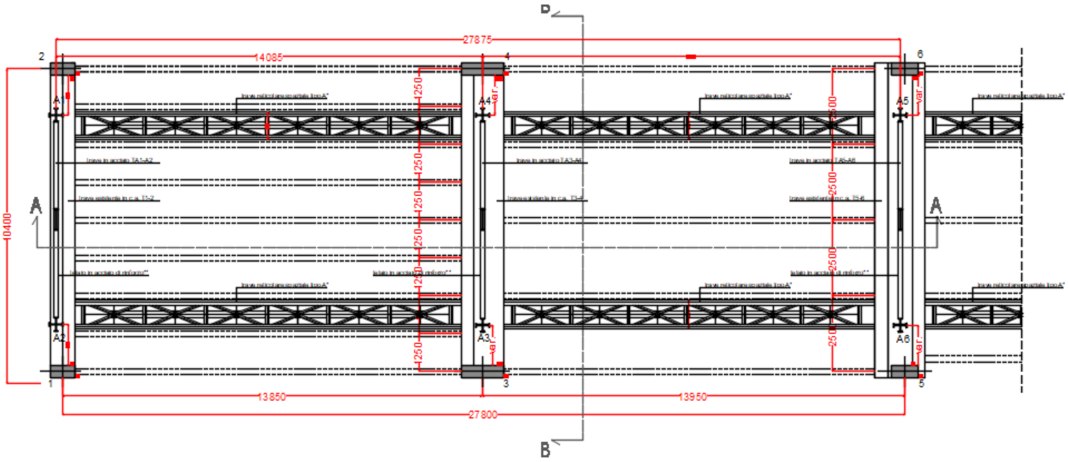


(c) 10th vibration mode shape (X direction)

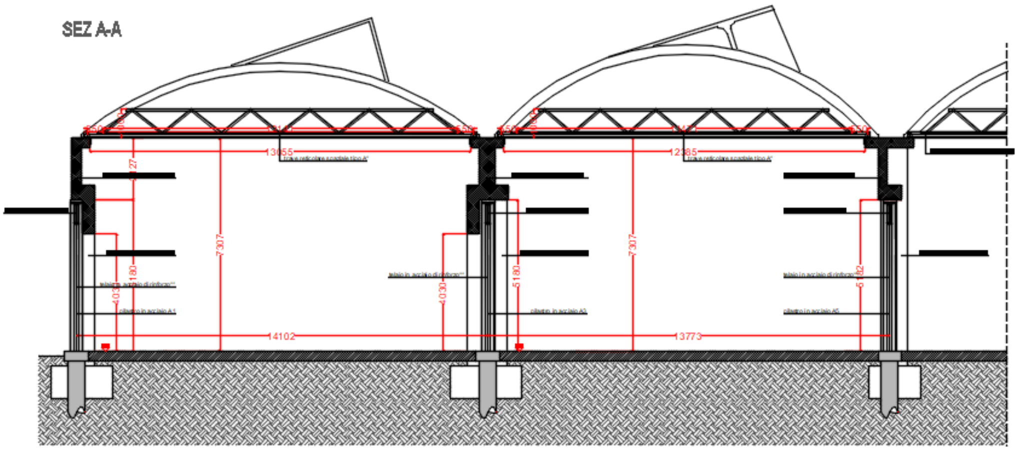
Fig. **10** – FE modelling and mode shapes of RC frames

With reference to frames in Figure 10, the project choices for the strengthening of RC frames has been described as follows. Numerical analysis and resistance tests have revealed the weakness of frames such as portal frames with three elements; all frames are parallel and connected by reticular curvilinear covering elements (Fig. 11(b)) of the three-hinge arc type with eliminated pressure.

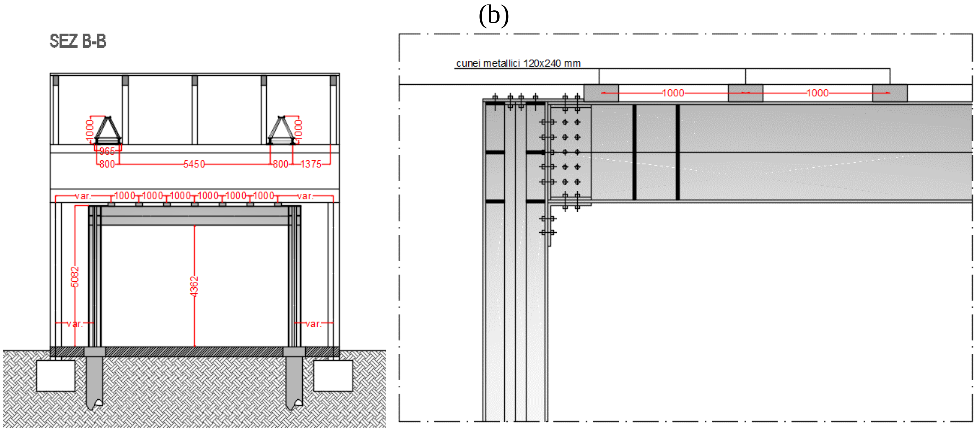
So that in the RC structures there is a lack of lateral force resisting systems. Therefore, in the direction perpendicular to the frames' plans and in the longitudinal direction to the intended walking area of the complex, steel spatial truss beams constrained with hinges to the extrados of main RC frames (Fig. 11(a)) were used.



(a)



(b)

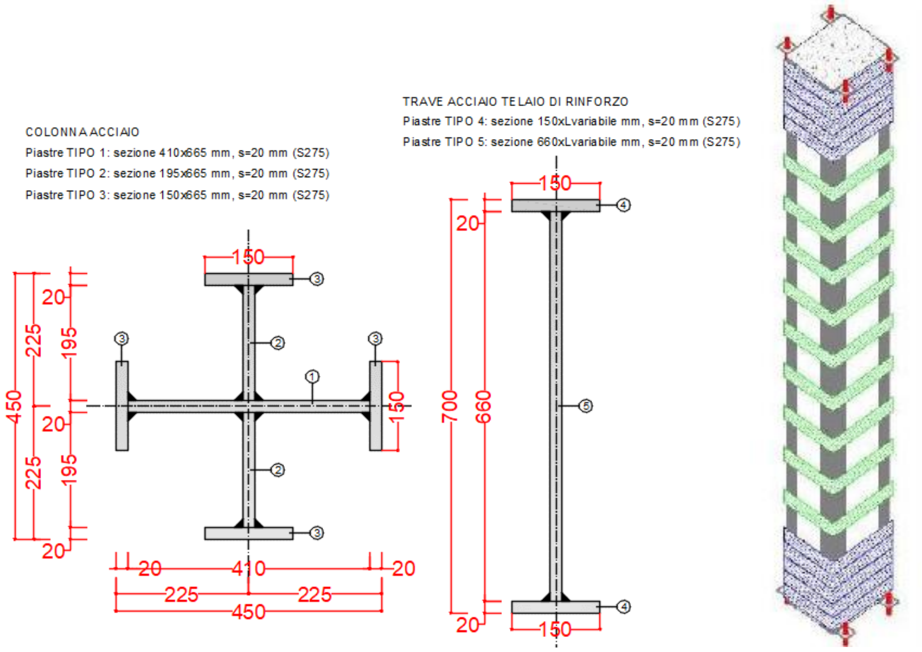


(c)

Fig. **11** – (a) View of plan with parallel RC frames and steel truss beams; (b) section and (c) details of steel frame.

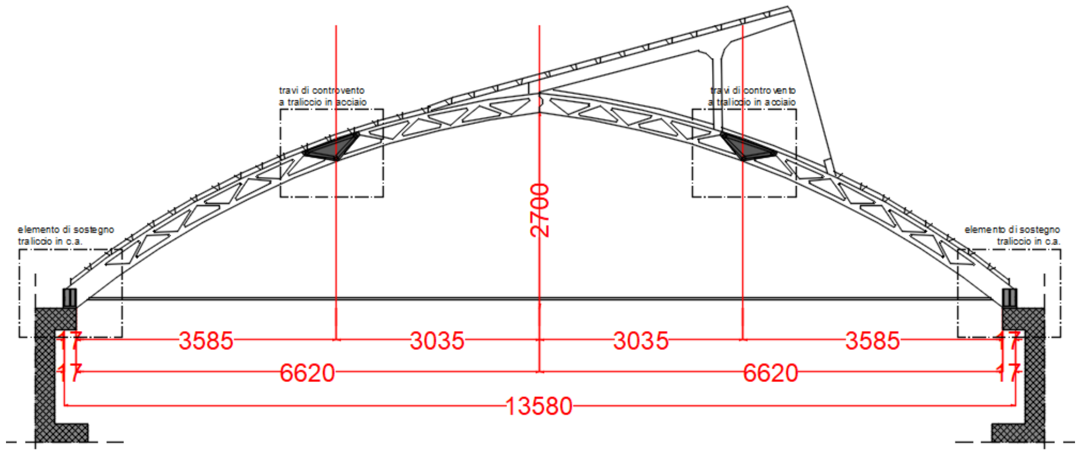
As it is possible to deduce from Figure 11 (c), a steel frame is inserted, as a support for the already existent RC beam necessary also for service loads, which are higher than those of the original project.

In Figure 12(a) the sections of both the steel frame's column reinforcing the RC beam and the same steel beam to put at the intrados of the RC beam, transmitting to that same beam a contrasting load in order to make it cooperate, are indicated.

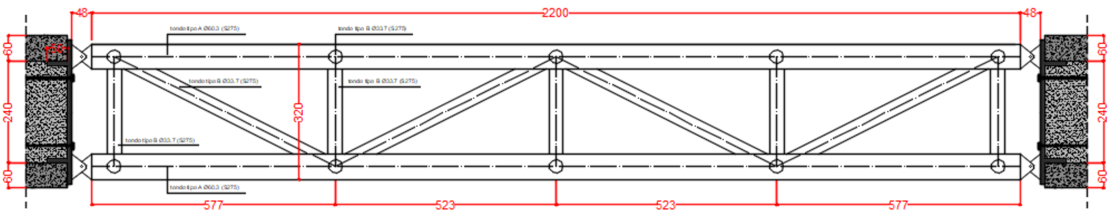


(a) (b)

Fig. **12** – (a) Sections of steel beams and columns.



(a)



(b)

Fig. **12** – (a) Section of RC truss arch structures of roof; (b) steel truss beams as lateral force system in roof.

A further intervention concerned the roof structures made up of RC three-hinges truss beams with eliminated pressure, as indicated in Figure 12. The reinforcement consists of a series of metal truss elements put in the interval between the RC arches, as shown in Figures 12 (a) and (b).

Also in this case, the design choice aims to give roof structures the capacity to endure perpendicular movements during a seismic event by introducing elements of bracing on a direction perpendicular to the plans of the roof arches.

In conclusion, a series of interventions for the improvement of already existent RC columns has been developed using composite material, such as carbon fibers reinforced polymers (CFRPs) and angular steel elements. Some columns examined during the on-site experimentation show low resistance of concrete and even the same disposal of stirrups turns out not to be adequated to contain the bending and shear stresses due to seismic actions. In Figure 12(b) the method used for the RC columns' reinforcement has been displayed.

CONCLUSIONS

In this paper the behaviour of existing RC manufacturing frames invested by dynamic motion have been examined considering a series of industrial buildings located in a town of Central Italy invested by seismic actions particularly strong. In particular the strengthening method has been described assuming that the weakness of existing structures under lateral seismic motion was due to lack of adequate structures in the direction perpendicular to the frames' plans and RC truss arches of roof. Using CFRP strips has been developed also a strengthening of RC columns with concrete of low experimental compressive strength.

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