

## RETROFITTING OF INDUSTRIAL STRUCTURE

Camillo Nuti

Ivo Vanzi

### Abstract

The paper presents damages and intervention policies and techniques adopted to retrofit industrial precast buildings after the sequence of earthquake that struck Emilia Romagna region in summer 2012. The region had been classified as seismic in 2012 only, therefore most of the buildings had not been built with seismic provisions. Notwithstanding this fact, due to the relatively small seismic intensity, the largest part of modern reinforced concrete buildings did not suffer damages, while large damages happened to precast industrial buildings, as well as to part of cultural heritage.

### Introduction

The last two Italian earthquakes, in l'Aquila 2009 and Emilia-Marche-Lombardia 2012 outlined various serious defects and dangers of past industrial constructions in large part in precast concrete. These have been built in large part before seismic design became mandatory in the specific sites, or before the introduction of modern seismic regulations, more severe and detailed. The consequences are large fragilities even for relatively small earthquakes and large direct and overall indirect costs. Even past international experiences have shown that, especially in in very industrially developed zones, earthquakes can even threaten local economies while the solution cannot relies on insurance for consequences, but a systematic prevention is the only method to guarantee owners as well as employees and in general the regional community. Due to this fact the Italian Ministry of Infrastructures has drawn guidelines for rapid assessment and repairing as well as guidelines for seismic retrofitting of existing industrial facilities [Consiglio superiore dei lavori pubblici 2012] [Consiglio superiore dei lavori pubblici 2013] in order to obtain the funds foreseen for post earthquake reconstruction or retrofitting after 2012 Earthquake. These guidelines are supposed to be the reference for precast industrial building retrofitting all over Italy. The Italian government has in fact disposed relevant benefits for whoever will retrofit building for seismic action. Some of the typical interventions are presented and discussed.

### The Industrial building stock in Italy: Emilia Romagna Region

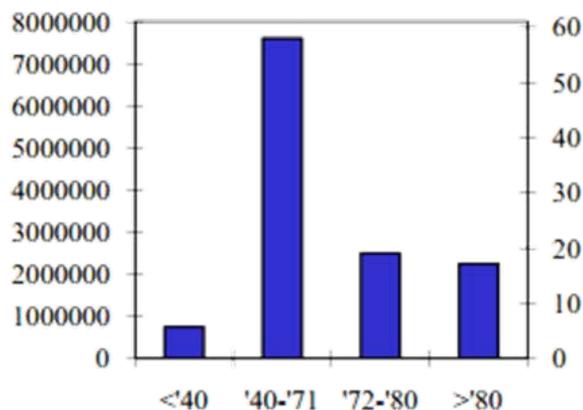
In May to July 2012 several seismic events hit the region of Emilia, in Northern Italy; the main shocks were recorded on May 20th ( $M_I = 5.9$  and  $M_w = 5.86$ ), and on May 29th ( $M_I = 5.9$  and  $M_w = 5.66$ ); significant aftershocks continued until July. These events caused 27 casualties, and produced heavy damage, mainly to the historic cultural heritage and to the industrial buildings.

A large part if not all precast industrial buildings suffered from large damages to total failure, as will be discussed later. These type of buildings represent the largest part of structural typologies. They in fact were not designed on the base of a seismic regulation. The largest part of the industrial structures was in fact designed to carry only gravity and wind loads, coherently with the structural code at the moment of design Fig. 1.

These structures, from the seismic point-of-view, had clear structural deficiencies, particularly in the beam-column and beam-roof connections. Due to this poor detailing, several collapses occurred during the second event in structures that had already been damaged during the first event. However collapses were observed also for structures in which no damage had occurred during the first event.

The main part of industrial buildings are single story precast reinforced concrete as one can see in Table 1 and Table 3. The typical layout is shown in Fig. 2. The mean surface of a building is about  $6000 \text{ m}^2$ , with an height of 6 m, Table 3. Based on the values of industrial buildings given on official documents, the mean value of industrial building in Emilia Romagna is  $613 \text{ €/m}^2 \times 6000 \text{ m}^2 = 3,678.000 \text{ €}$ . The annual industrial production of the region, based on official data is  $P = 106 \times 0.25 = 26.5$  billion €, therefore, given the total number of industrial buildings in Emilia Romagna region (see Table 2)Table 2, the yearly production per industrial building is  $P_c = 26.5 / 78644 = 744'795 \text{ €}$ . The yearly cost of interruption is larger than the yearly lost due to failure, which can be subdivided in about 30 (thirty) years. Furthermore past experience, and in part also the recent one, have

shown that due to the general failure in the epicentral area, there is also the risk that industries leave instead of rebuild their structure, to be able to restart the production in short time.



**Fig. 1 – Total Number o reinforced concrete building built in Italy (left), percentage (right) and year of construction. In 1980 Irpinia Earthquake. In 1939 introduction of design regulation for structures (no seismic action).**

USE	Masonry	RC	Precast RC	steel	RC-Steel	other	total
agriculture	13,0	31,2	30,4	9,1	8,2	8,0	100,0
industrial	1,9	18,6	67,4	4,4	4,9	2,8	100,0
Comm./tourism	2,7	37,2	51,0	1,7	5,4	1,8	100,0
Transportation	0,8	19,5	66,8	0,3	6,2	6,4	100,0
other	4,9	50,8	30,2	2,4	7,0	4,7	100,0
<b>Total</b>	<b>3,5</b>	<b>25,1</b>	<b>58,0</b>	<b>4,4</b>	<b>5,5</b>	<b>3,5</b>	<b>100,0</b>

**Table 1 - Percentage of non residential buildings as a function of structural typology and usage [Vanzi 2013]**

Damages to Industrial buildings due to 2012 Emilia Romagna Eathquake

After the earthquake of 2012 the following damages and failures were observed [Protezione Civile et al. 2012] [Fishinger et al. 2014] [Bournas et al. 2013] [Protezione civile et al 2012a]:

- a) Damages due to loss of support of beams and connections among structural elements
- b) Damages and failures to cladding
- c) Damages to columns
- d) Damages to racks and to the supported content
- e) Damages to foundations

The cost of damages was high notwithstanding the relatively low seismic level. Damages concentrated on industrial precast buildings and cultural heritage and not on modern cast in situ buildings even not built with seismic provisions (see Table 4Table 1).

Area	Regione	Stock	Quota %
Nord Est	Emilia-Romagna	78.644	12,0%
	Friuli Venezia Giulia	14.620	2,2%
	Veneto	84.181	12,9%
<b>Nord Est</b>		<b>177.445</b>	<b>27,1%</b>
Nord Ovest	Liguria	13.753	2,1%
	Lombardia	131.126	20,0%
	Piemonte	65.344	10,0%
	Valle d'Aosta	1.750	0,3%
<b>Nord Ovest</b>		<b>211.973</b>	<b>32,4%</b>
Centro	Lazio	33.028	5,0%
	Marche	28.694	4,4%
	Toscana	46.385	7,1%
	Umbria	11.621	1,8%
<b>Centro</b>		<b>119.728</b>	<b>18,3%</b>
Sud	Abruzzo	17.618	2,7%
	Basilicata	4.760	0,7%
	Calabria	14.660	2,2%
	Campania	29.689	4,5%
	Molise	4.319	0,7%
	Puglia	31.564	4,8%
<b>Sud</b>		<b>102.610</b>	<b>15,7%</b>
Isole	Sardegna	15.441	2,4%
	Sicilia	27.372	4,2%
<b>Isole</b>		<b>42.813</b>	<b>6,5%</b>
<b>Italia</b>		<b>654.569</b>	<b>100%</b>

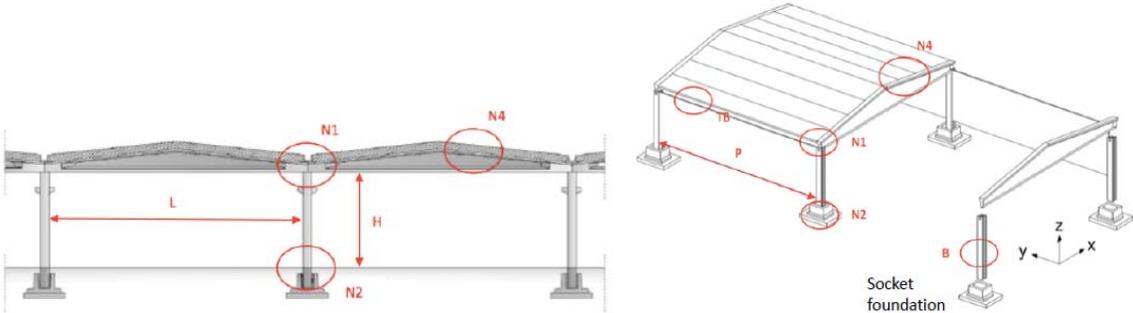
**Table 2 Industrial Buildings in Italy, subdivided per geographical location, region, giving total number and percentage of the total.**

Variable	Mean value	C.o.V (%)
P: frame spacing	9.40 m	42
L: beam span	15.0 m	34
H: height	6.2 m	42
Bx: column dimension in x dir	464 mm	22
By: column dimension in y dir	448 mm	22
Nt: number of plane frame (x dir)	10.2	200
Nc: number of span of the frame	5.2	154
A: construction year	1991	1

**Table 3 – main dimension of industrial buildings in Emilia Romagna [ Vanzi 2013]**

Valle del Belice - 1968	8.801	1968-2018	370	70.000
Friuli Venezia Giulia - 1976	17.776	1976-2006	989	45.000
Irpinia - 1980	49.882	1980-2023	2.914	280.000
Marche-Umbria 1997	12.909	1997-2024	11	32.000
Molise e Puglia - 2002	1.713	2002-2023	30	5.700
Abruzzo - 2009	9.809	2009-2033	308	67.500
Emilia Romagna, Lombardia e Veneto - 2012	9.131	2012-2026	27	15.000
<b>Totale</b>	<b>110.012</b>	<b>1968-2033</b>	<b>4.649</b>	<b>515.200</b>

**Table 4 – Reconstruction funding in millions of €, value at year 2011**

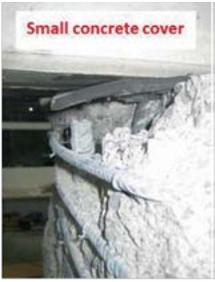


**Fig. 2 Typical layout of a precast industrial building**

The list is ordered for importance of the consequences of the number of cases observed. Those defects were essentially related to lack of seismic design or in clear mistakes in conceptual seismic design. However some important issues were underlined for precast buildings with seismic design:

- f) Failure of cladding connections
- g) Failure and damages due to unexpected structural constraints
- h) Failure of the structure due to the failure of the interior racks
- i) Rupture or large damages of the dowel between columns and beams

In case of absence of seismic design the following short descriptions can be given while for larger descriptions are given in the references. Type a) failures are essentially due to fact that the connections between beams and columns were just left to friction (the same usually holded among horizontal closure elements (which constituted the roof) and supporting beams. In many cases there were dowel of insufficient resistance. Usually the dowel caused failure of the cover losing any resistance to horizontal actions.



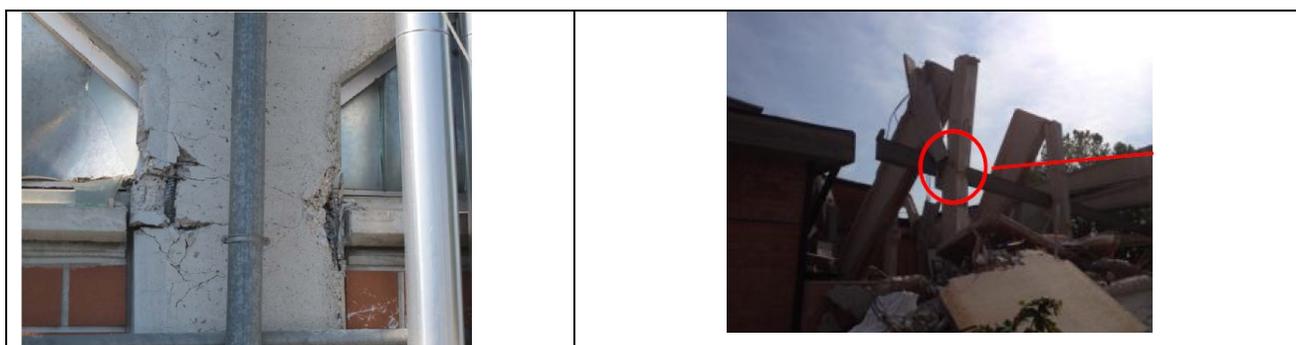
**Fig. 3 (left) failure due to loss of support (friction only) [Prtezione Civile 2012]; (right) failure of cover due to dowel action [Fishinger 2014]**

Type b) failure have been observed in case of precast vertical and horizontal panels as well as in case of masonry claddings, these latter usually utilized in the older buildings. For all type of failure, with the exception of out of plane masonry panel failure usually due to total lack of connection, the main cause of damage/failure was the excessive deformability of the structures which caused the panels and the connections to act as horizontal resisting systems. Connections were not able to have a sufficient ductility and failed in a brittle manner.



**Fig. 4 - Failure of hammer – head, Emilia Earthquake. Left [Fishinger 2014], right [ Protezione Civile 2012]**

Type c) failure and damages happened in columns, usually having socket foundations. They often lost the vertical asset due to plastic rotation at the base for insufficient resistance of the socket, or yielding of the column. In various cases the excessive spacing of stirrups caused buckling of longitudinal reinforcements. The industrial pavement in concrete represented sometimes an unexpected constraint with negative consequences for excessive shear or bending or stiffness of the column. In other cases the constraint of the pavement had a positive contribution. The hammering effect of the infill cladding as well as the horizontal elements have been causes of many damages and failures. The presence of an horizontal continuous windows at the top of the cladding, was the cause of shear failure in many situations.



**Fig. 5 Short column effect due to strip windows at cladding top and to the restraint of the rail of the crane [Protezione Civile 2012]**

Type d) represented a novelty for the large consequences in terms of induced industrial building failure or for the fact that they put out of use the buildings which were also difficult to be surveyed and repaired. The lost of the content was also a major problem due to the high value (for example in case of Parmigiano Cheese).



**Fig. 6 – Industrial building failure due to interior racks: left failure of the building due to the movement of racks (left), failure of the racks and of the building (right).**

Type e) were sometimes due to structural weakness (insufficient reinforcement of the walls of the socket), lack of connection between precast footing and the part of the footing cast in place, but many cases happened due to geotechnical problems: insufficient footing area or embedment in soil to resist vertical and/or horizontal actions. The absence of horizontal connection among footing had been often substituted (in a positive manner) by the industrial concrete floor, however the absence of connecting beams gave negative influences to bending resistance of the footings.

For building realized using previous seismic design:

Type f) happened for the fact that non structural element were generally disregarded in seismic design. In effect they were very stiff and not able to sustain large deformations typical single floor precast buildings. Therefore failure similar to type b) were observed.

Type g) failures were usually due to some errors in modelling or in construction details. A typical one is the absence of gap between concrete floor and columns. This fact reduced column free height and forced the plastic hinge to concentrate just above the floor, far from the attachment at the footing. In this latter position stirrups were probably placed at small spacing to comply with ductility design details for plastic hinge zones. The position above the floor were not considered a critical one, therefore stirrup spacing was large and buckling of compressed bar happened.

Type h) happened due to the fact that the content was not considered in structural design as well as for old structures Fig. 6.

Type i) failures happened even in case of seismic design for the excessive displacement of the structure or for poor details Fig. 7.



**Fig. 7 – (Left) compressed bar buckling due to plastic hinging over the concrete floor, for loose stirrups [ Protezione Civile 2012]; (right) failure of the zone around the plug for excessive deformation and insufficient stirrups in the support and cover in the beam [Fishinger 2014].**

#### Fragility and risk evaluation of Industrial Buildings in Emilia Romagna

In order to allow a quick assessment of the fragilities of the industrial buildings, a quantitative, though simple, procedure was set up to evaluate seismic fragility and understand the expected amount of retrofitting interventions. In fact the Italian Government decided that in a very short time, about six months, the screening of the structural situation of the industrial building should have been completed. As a first step, all industrial building, should have been quickly repaired for immediate practicability.

The check was quite easy: if no evidence of heavy structural deficiencies were found, or if they were solved for, the structure could be normally used, although for a maximum of six months. The checks on structural deficiencies were minimal, in order to make them simple and timely.

If either:

- i. no connections between vertical and horizontal structural elements, or between horizontal elements was found;
- ii. pre-cast infill elements were not adequately connected to the structure;
- iii. shelf systems (carrying heavy materials whose collapse may result in damage or collapse of the structure) were unbraced;

the deficiencies had to be solved for before using, even temporarily, the structure.

i., ii. and iii. are in fact the most frequent causes of seismic collapse; clearly they do not cover all possible vulnerabilities. The short term provision tried in fact to compromise between timely recovery and safety, accepting a lower level in the short term.

Then the final intervention to resist seismic forces not less than 60% of the new buildings, should be foreseen and than realized. Funding were provided by the Italian Government. However, for the epicentral zone, building who had experienced an earthquake intensity of about 70% of the design force for new structures, could not undergo any check and could continue to operate (for more details see on Braga et al. 2013).

Vanzi [2013] elaborated the cumulative distribution of expected ductility requested to Industrial buildings subjected to the design seismic action (60% of the 475 year return period earthquake) as shown in Fig. 8.

Interventions for seismic retrofitting should have been based on Chapter 8 of the National Italian Code [2008].

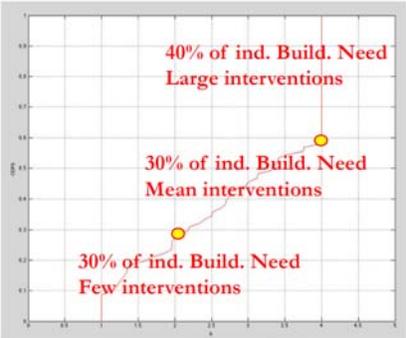


Fig. 8 – Cumulative distribution of expected ductility of industrial buildings in Emilia Romagna [Vanzi 2013]

Retrofitting of Industrial Buildings in Emilia Romagna

The final retrofitting usually came after a previous quick assessment and intervention for the use of the first six months, when possible: fix each other the precast structural elements of the roof to the supporting beams using steel cables , connect precast panels, create a bracing for the racks. For example Belleri et al. [2013] fixed the precast roof elements with cables and prevent rotation and out of plane loss of equilibrium of the high section roof beams due to torsion introducing steel elements at the support of the beams (see .

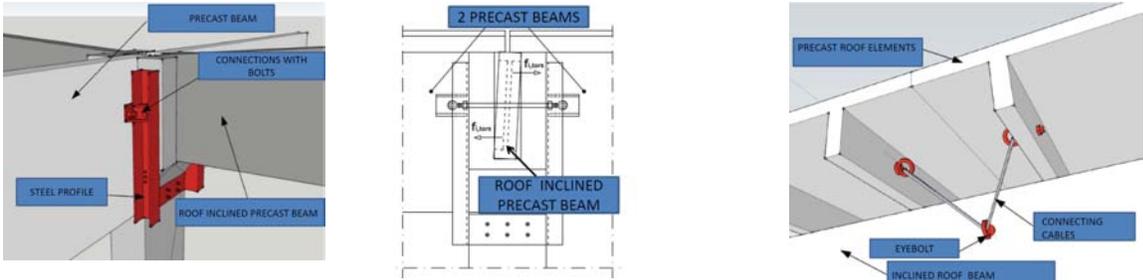


Fig. 9 – Quick retrofitting for the six months use of the Industrial building [Belleri et al. 2013].

Given the observed damages and failures discussed above, in order to obtain the prescribed seismic resistance, the following basic interventions can be considered quite standard:

- a) Confinement of column base (over the basement floor or at the foundation level)
- b) Reduction of top displacements to avoid loss of support and possibly reduce demand on non structural cladding
- c) Create new effective connections
- d) Exclude high beam out of plane rotations (in general in the roof)
- e) Fix precast and masonry walls from out of plane failure
- f) Create an efficient brace system for racks

Three basic strategies of interventions have been used:

1. To guarantee a sufficient ductility to the main structural system,
2. To reduce seismic demand increasing available dissipation,
3. To reduce seismic demand increasing the period (base isolation at roof level or other)

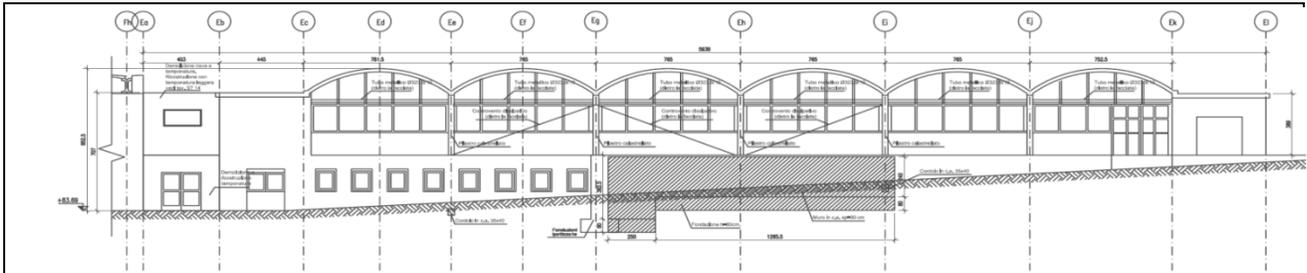
In all cases one has to intervene on all elements to let them undergo the related forces and displacements with adequate safety.

The third strategy will be treated first. The idea is to introduce isolation between the head of the columns and the roof, once this has been rendered sufficiently rigid in its plane. This is simpler after isolation, thanks to force

reduction. This technique become feasible if one can intervene without large supporting interventions in the phase of cut between column and roof to insert isolators.

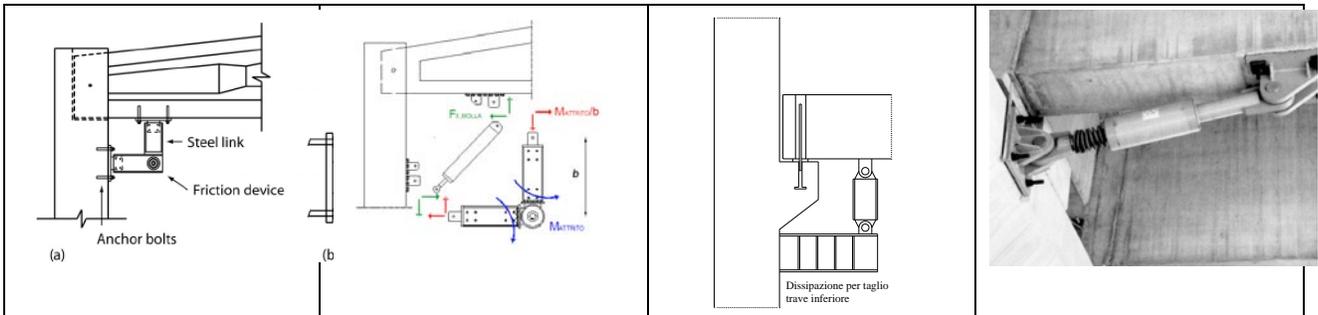
The second strategy is the more popular for these structures. There are two ways of increasing dissipation:

- a) using dissipative bracings, as for example in Fig. 10. This permits to stiffen the structure without a substantial increase of base shear, thanks to brace yielding and large cyclic dissipation. An efficient procedure to design retrofitting with the use of dissipative bracings (BRB) is given in [Bergami & Nuti 2013];



**Fig. 10 – Retrofitting of a single/double floor building using dissipative bracings [Nuti et al 2009, Nuti 2013]**

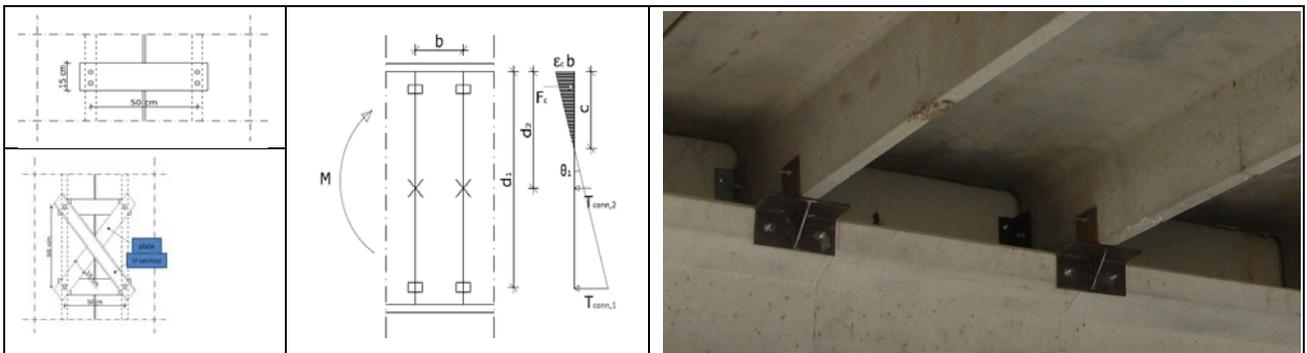
- b) introducing dissipative connections wherever possible. This solution has been adopted from various designer in Emilia [Riva 2014].



**Fig. 11 – Dissipative solutions at beam column connections**

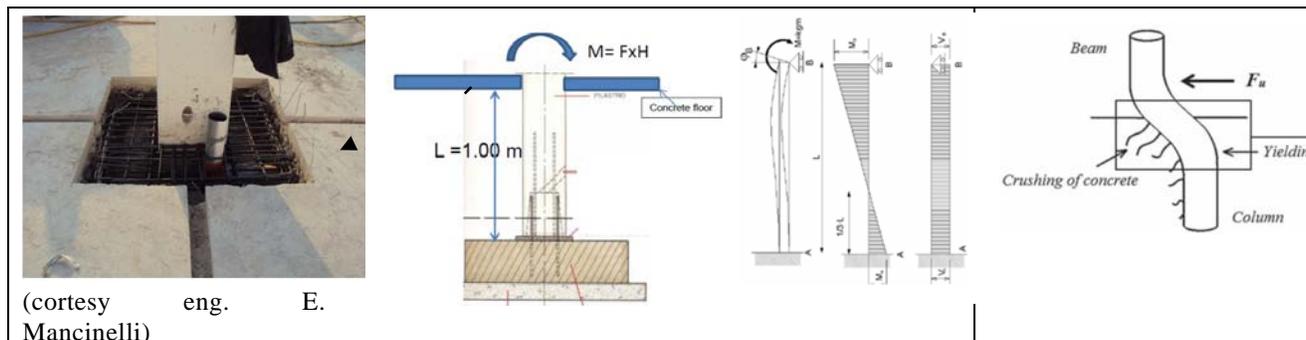
The first interventions, meant to increase ductility, is usually common to the three options. In fact this imply typical solutions to connect elements each other and to increase ductility for example by confining elements with FRP wrapping.

One basic point is the retrofitting of the roof precast elements. They must be fixed each other to obtain a slab of sufficient strength and stiffness. This can be usually obtained by connecting the horizontal part of the element to the adjacent. In the middle one should place a connection capable to resist shear, while at the two ends one can just place simple plate connected to each slab by bolts.



**Fig. 12 – Roofs and precast floor elements: connections between precast elements end with supporting beams**

It is interesting to note that in many cases instead of connecting the foundations, a connection has been imposed at floor level, about one meter (as a minimum) above foundation. This is an interesting and practical solution, however, if the connection between pavement slab and column is a hinge, than bending moment from the connection to the foundation will decrease in a very short length, therefore high shear action will develop in the column below the floor to the foundation and a very accurate check should be done with subsequent provisions if it is the case.



**Fig. 13 – (Left) Connections of column at the base using the concrete floor [Nuti 2013]; (right) connecting dowel between column and beams**

It is important to note that, when the expected seismic displacement is reduced, than the connection between prefabricated panels and structure works, in all other cases special provision should be taken to guarantee the structural behavior of these components.

Finally one should be aware of the recent research findings concerning connecting dowel between column and beams [Fishinger 2014]. The ultimate resistance of the dowel connection, in case it is far from the edge is:

$$R_{u,m} = F_{u,m} = \alpha_0 \cdot d_b^2 \cdot \sqrt{f_{cm} \cdot f_{ym}}$$

Where  $\alpha_0$  is 0.6. In case the dowel is near the edge, than one can have premature spitting and further evaluation are still needed to find accurate reliable solutions. Therefore the designer should be cautious and take large safety factors for such a critical component.

#### Conclusions

The paper shortly presents policies and technical interventions on industrial precast buildings after the Emilia Romagna sequence of Earthquakes which happened in summer 2012. Notwithstanding the small seismic intensity a lot of damages caused the interruption of the economy of large part of the region, one of the most developed in Italy. In fact the region has been classified as a seismic zone in recent time only and most of the buildings have been built without seismic provisions. It is a matter of fact however that that the majority of cast in situ buildings did not suffer important damages as the precast ones. We think that, at least in Italy, the experience of Emilia Romagna should be an important reference to reduce the seismic risk of Industrial Precast Buildings.

#### References

Andrea Belleri, Mauro Torquati, Paolo Riva Miglioramento e adeguamento sismico di edifici industriali: valutazione degli interventi e applicazione a un caso studio. Italian Conference of Earthquake Engineering, ANIDIS, Padua 2013 (in Italian)

Bergami A., Nuti C., 2013, A design procedure of dissipative braces for seismic upgrading structures. Earthquakes and Structures, Vol. 4, No. 1 (2013) 85-108

Bournas A, Negro P, Taucer FT (2013a) Performance of industrial buildings during the Emilia earthquakes in Northern Italy and recommendations for their strengthening. Bull Earthq Eng, published on-line, June 2013

Camillo Nuti; Ivo Vanzi. REDECON 2014: International Seminar and Exhibition on Recent Development in Design and Construction for Precast Concrete technology. Bangalore, India, 9-14 November 2014

F. Braga, R. Gigliotti, G. Monti, F. Morelli, C. Nuti, W. Salvatore, I. Vanzi, Speedup of post earthquake community recovery. The case of precast industrial buildings after the Emilia 2012 earthquake, Bulletin of Earthquake Engineering, Springer, DOI 10.1007/s10518-014-9583-3, 2014

Consiglio Superiore dei Lavori Pubblici: 22 Giugno 2012 - Linee Guida -Valutazione della vulnerabilità e interventi per le costruzioni ad uso produttivo in zona sismica (strumento per verifiche delle strutture produttive ai fini del rilascio, in via provvisoria, del certificato di agibilità sismica)

Consiglio Superiore dei Lavori Pubblici: In conclusione - Linee Guida - Valutazione della sicurezza e criteri di intervento per le costruzioni ad uso produttivo in zona sismica. Agibilità definitiva ai sensi della Legge 122 del 01.08.2012

Nuti C., 2013, Seismic behavior of precast Industrial buildings: Assessment and Prevention. Invited Keynote Lecture. Italian Conference of Earthquake Engineering, ANIDIS, Padua 2013 (in Italian)

Fishinger M., Zoubek B., Isakovic T., 2014, Seismic Response of Precast Industrial Buildings. Keynote Letcture. Proceedings of the 2nd European Conference on Earthquake Engineering & Seismology. Ed. A. Ansal (ed.), Perspectives on European Earthquake Engineering and Seismology, Geotechnical, Geological and Earthquake Engineering 34, DOI 10.1007/978-3-319-07118-3\_4, © The Author(s) 2014.

Governo Italiano, 2012. Decreto Legge 6 giugno 2012, n. 74, Interventi urgenti in favore delle popolazioni colpite dagli eventi sismici che hanno interessato il territorio delle province di Bologna, Modena, Ferrara, Mantova, Reggio Emilia e Rovigo, il 20 e il 29 maggio 2012, Gazzetta Ufficiale della Repubblica Italiana n.131 of June 7th.

Ministero delle Infrastrutture, (2008) Norme Tecniche per le Costruzioni, D.Min.Inf. 14 gennaio 2008, Gazzetta Ufficiale n. 29 of february 4th 2008 - Suppl. Ordinario n. 30.

Parlamento Italiano, 2012. Legge 1 agosto 2012 , n. 122, Conversione in legge, con modificazioni, del decreto-legge 6 giugno 2012, n. 74, recante interventi urgenti in favore delle popolazioni colpite dagli eventi sismici che hanno interessato il territorio delle province di Bologna, Modena, Ferrara, Mantova, Reggio Emilia e Rovigo, il 20 e il 29 maggio 2012, Gazzetta Ufficiale Ufficiale della Repubblica Italiana n. 180, August 3rd.

Protezione Civile, RELUIS, CNI, ASSOBECON, 2012, Linee di indirizzo per interventi locali e globali su edifici industriali monopiano non progettati con criteri antisismici.

Protezione Civile, AGI, Regione Emilia Romagna (Task Group coordinated by Michele Maugeri), 2012, Linee di indirizzo per gli interventi su edifici industriali monopiano colpiti dal terremoto della pianura padana emiliana del maggio 2012 non progettati con criteri antisismici: aspetti geotecnici.

Vanzi. I, 2013, Fast Evaluation of Industrial Building Fragility. Personal Communication.



Prof. Camillo Nuti

Full Professor of Civil Engineering at Roma Tre Univ., Dept. of Architecture  
Born in 1953 in Rome, Italy. Degree in Civil Engineering University of Rome la Sapienza March 1977. Research fields: Structural seismic design, seismic assessment and retrofitting of existing building, bridges, dams, base isolation and energy dissipation.

Publications: He has published more than 200 papers in the field of Structural Engineering on National and International Scientific Journals and Proceedings of Conferences.

E mail: camillo.nuti@uniroma3.it