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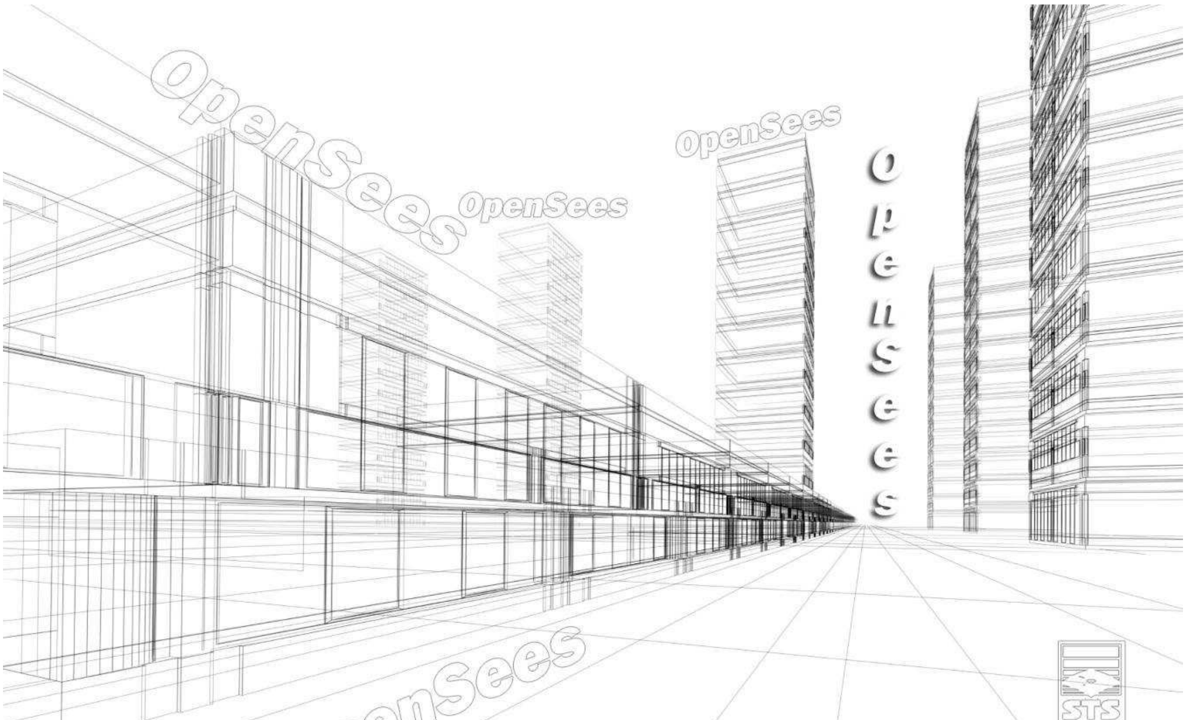

INFLUENCE OF CLADDING PANELS ON DYNAMIC BEHAVIOUR OF ONE-STOREY PRECAST BUILDING

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Abstract

Recent Italian seismic events, as L'Aquila earthquake (2009) and Emilia earthquake (2012), demonstrated the deficiency of the actual design approach of the cladding panels system in precast buildings. Collapse of these precast panels is observed due to the connection system failure.

Although cladding panels are designed as non-structural elements according to the actual code approach, i.e. no interaction with the structure is considered, a seismic excitations could make the panels collaborating with the resistant system.

In this paper the influence of vertical cladding panels on seismic behavior of one-story precast concrete buildings is investigated. A parametric study is carried out to judge the influence of the cladding presence on the dynamic characteristics of precast structures. At this purpose, modal analyses are performed on both bare and infilled models.

The parametric study shows a high influence of the panels on the first period of the structure, as well as the inadequacy of the code relationships for the evaluation of the natural period for such typology of structure. More suitable relations are proposed in order to evaluate the seismic demand of one story precast buildings both in the case of bare and infilled system.

KEYWORDS: Precast structures, Vertical Cladding Panels, Panel Connection System, Modal Analyses, Elastic Period.

1. Introduction

Precast structures have a very large diffusion and for some types of buildings represent a considerable estate. However, latest earthquakes, as L'Aquila earthquake (2009) and Emilia earthquake (2012), have pointed out some lacks in the design approach for the precast buildings, among which the inadequacy of the panel–to-structure connection systems. Indeed, most of the numerous damaged precast buildings showed the collapse of cladding panels, caused by the connection systems failure (1, 2, 3).

According to the actual code design approach, precast structures are usually considered as bare systems and the cladding panels are separately designed for actions deriving by itself weight and seismic or wind loadings; no interaction between panels and structure is then considered. However, during a seismic event, the panel-to-structure connections could make the panels collaborating with the structural system, increasing the structural stiffness and, hence, the seismic demand on the devices. Moreover, the failure of the cladding panels cannot be considered as the exceeding of the serviceability limit state but, to all intents and purposes, it must be considered as an indicator of ultimate limit state reaching, given its impact on the life human safety.

The described work investigates the vertical cladding panel influence on the seismic behavior of one-story precast concrete building. For this purpose, a parametric study is conducted to evaluate the dynamic response of typical precast industrial buildings, in case of both bare and infilled structures. A linear model of the structure which includes the stiffening action of panels is proposed. Bare and infilled buildings are modeled and implemented by means of OpenSees (4) analysis code and modal analyses are carried out to record fundamental vibrational periods.

2. One-story precast building

In Italy, the typical industrial building configuration consists of cantilevered columns, connected at the base through a monolithic connection, and hinged to prestressed beams, which support precast concrete roof elements. Horizontal or vertical precast concrete panels are typically employed as perimeter cladding elements. These panels (Figure 57) are made up of reinforced concrete flat slabs and other materials (i.e. polystyrene), for both reduction in weight and thermal insulation. This study refers only to the vertical panels case.

With regards to the cladding system, in seismic areas, connection must ensure panel stability, but also they must allow large inter-story drift, that occur during ground motions.

The vertical panel connection system is realized as shown in Figure 58 and it follows that there are three possible translational degrees of freedom: one is ensured by the slot in the plate (typically displacement of 50mm is allowed), and the other two ones are due to the embedded profile (the displacement magnitude depends on the profiles length). At the bottom, the panel connection can be ensured in different ways: clip-panel beams equipped with a fork, welded or bolted metal anchors.

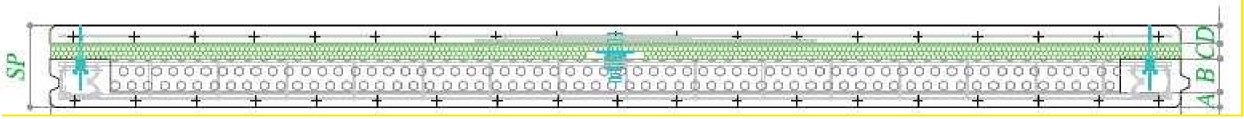

Figure 57. Typical transversal section of a precast vertical panel in one-storey precast structures

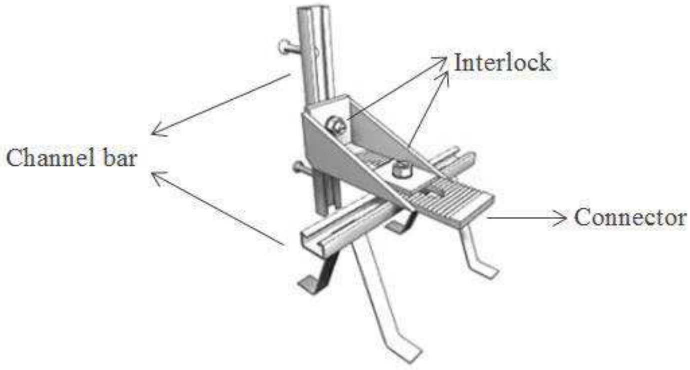

Figure 58. Connection of a precast vertical panel to the beam in one-storey precast structures

3. Fundamental period of one-story precast infill buildingS

A parametric study is performed in order to evaluate the fundamental vibration period of one-story precast building, including the infill system. The purpose of this work is the comparison of the infilled model results with the dynamic properties of the bare one.

The parametric study uses a benchmark structure (Figure 59, Figure 60, Figure 61), designed according to the actual seismic national code (4). The variable parameters are some geometrical characteristics, i.e. the columns height, the length and number of bays in transversal direction, the bays number in longitudinal direction. Table 1 shows the values of the variable parameters in the 288 cases studies. All facilities are considered to be located in a high seismicity area in Southern Italy. Response spectra of the concerned area are shown in Figure 62.

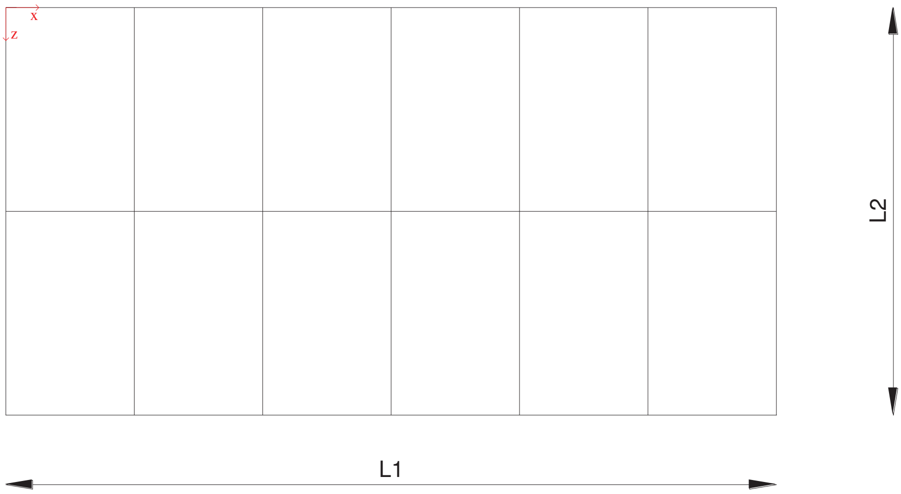

Figure 59. Benchmark building of the parametric study - plan view

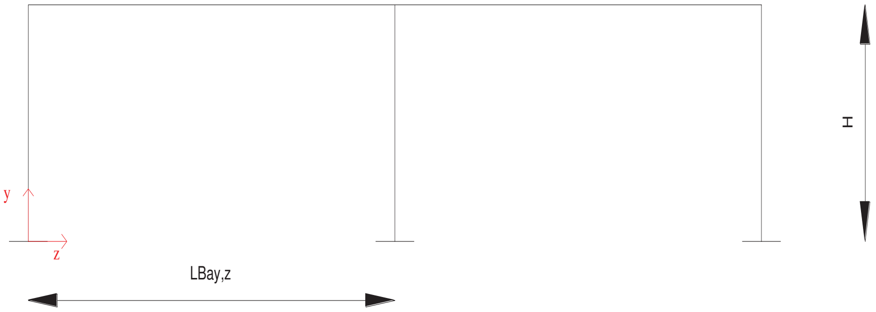

Figure 60. Benchmark building of the parametric study - transversal view

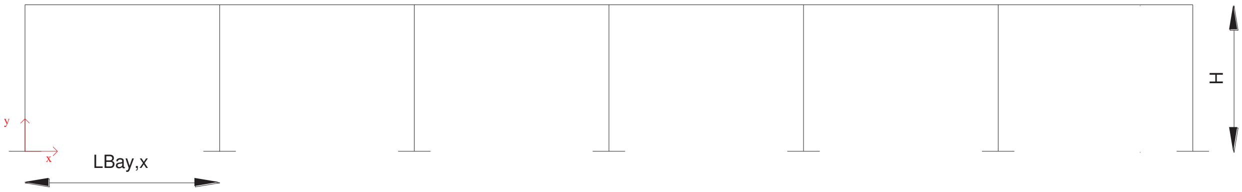

Figure 61. Benchmark building of the parametric study - longitudinal view

L_1	L_2	H	$L_{BAy,x}$	$L_{BAy,z}$	$N_{BAy,x}$	$N_{BAy,z}$
[m]	[m]	[m]	[-]	[-]	[-]	[-]
72	38	9	12	19	6	2

Table 2. Values of the variable parameters of the parametric study

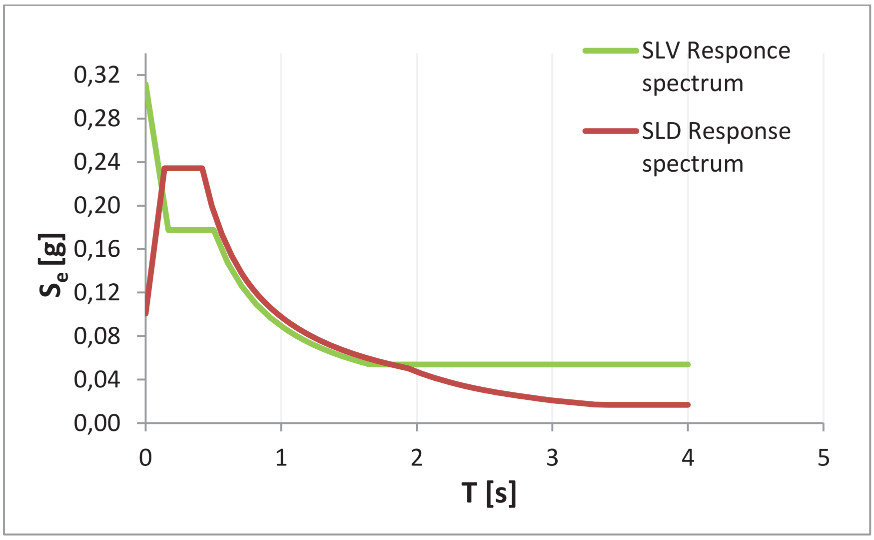

Figure 62. SLD and SLV design elastic response spectra of a site in Southern Italy, according to NTC 2008 (4)

3.1 Analytical model

The bare and infilled structures are modeled as three-dimensional structures in order to perform modal analyses.

Bare structure model consists of columns, girders (variable section beam) and secondary beams. Each of these elements is modeled as one-dimensional elastic element. The structural model does not include roof elements; anyway, they are included in the mass values (Figure 63).

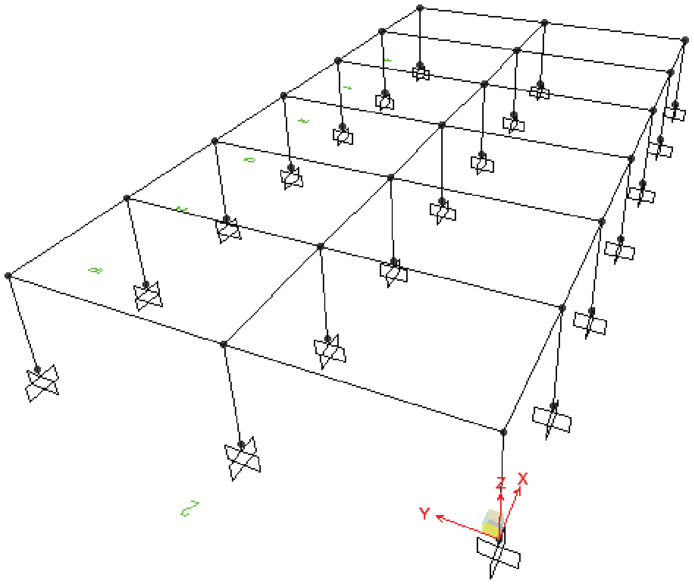

Figure 63. Bare precast structure model in SAP 2000.

In order to evaluate the cladding system influence on the seismic response of one-story precast structures, the cladding panels are modeled as a linear quadrilateral frame (5) in order to insert them in the bare system (Figure 64).

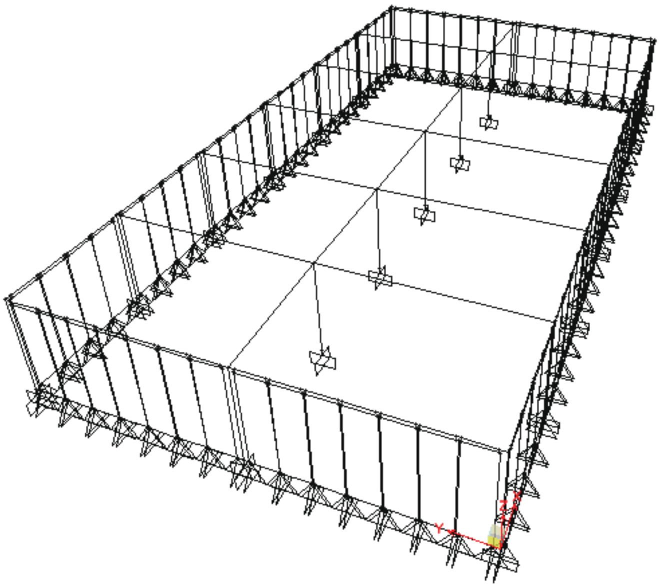

Figure 64. Infilled precast structure model in SAP 2000.

3.2 Linear modal analysis of study buildings

The performed parametric study provides the implementation of 288 bare and infilled building models. Due to the high number of analyses to be carried out, the models are implemented in the OpenSees (4) calculation program. Modal analyses of the above mentioned buildings are performed and Table 3 shows the first three vibrational periods of the bare and infilled benchmark building. As shown, the fundamental period reduces by about 75% if the cladding system is considered in the model, significantly influencing structural behavior in seismic conditions.

Model	T_1	T_2	T_3	Mode1	Mode2	Mode3
[-]	[sec]	[sec]	[sec]	[-]	[-]	[-]
Bare structure	0,982	0,982	0,793	Translational (transversal direction)	Translational (longitudinal direction)	Rotational
Infilled structure	0,213	0,172	0,117	Translational (transversal direction)	Translational (longitudinal direction)	Rotational

Table 3. Vibrational periods of bare and infilled precast benchmark building

3.2.1 Modal analysis results of bare structures

Figure 65 shows the first vibration period versus the columns height. The linear regression line shows an increasing trend with the building height, and a positive ratio of regression value.

In Figure 66 the same periods are plotted versus the NTC (4) relationship:

$$C_1 \cdot H^{3/4}$$

where H is the total height of the structure and C_1 is a coefficient that depends on the structural system and for the precast structure is assumed equal to 0.075. The trend shows that NTC relationship always returns lower values than those analytically obtained, considering a more flexible structure.

In order to define a more reliable coefficient C_1, first natural periods are plotted versus $H^{3/4}$ (Figure 67). The evaluated value of C_1 is equal to 0.18.

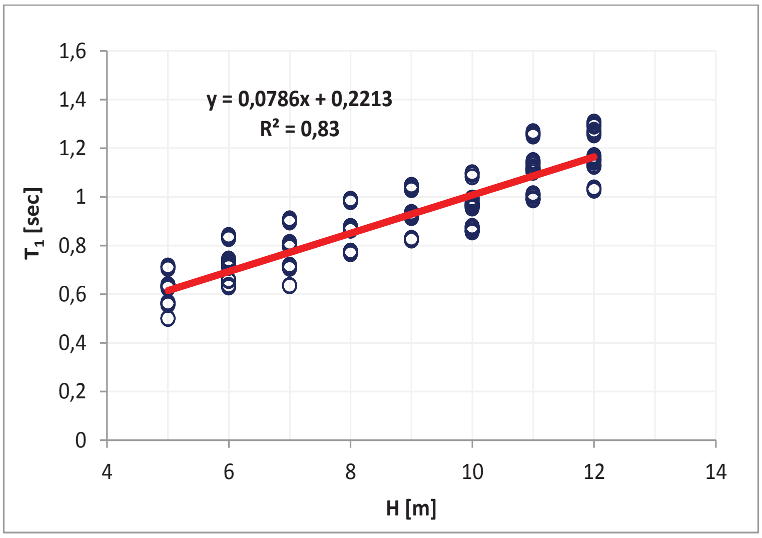

Figure 65. First natural vibrational period versus building height - bare structures

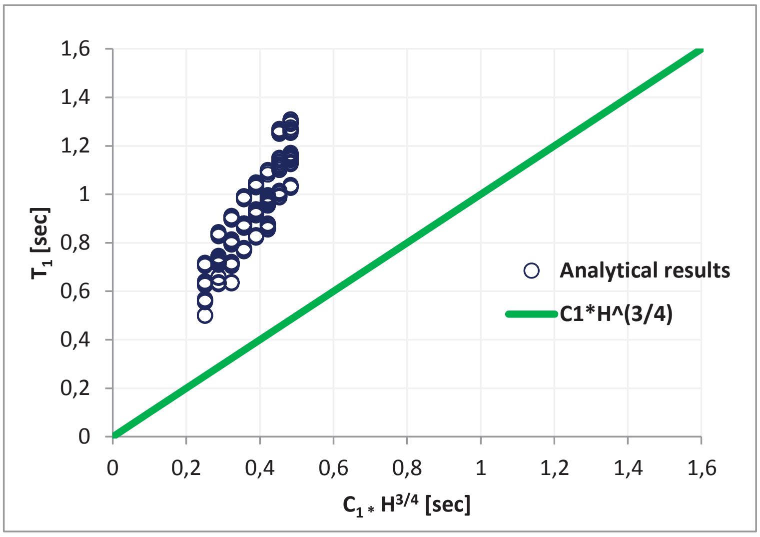

Figure 66. First natural vibrational period versus NTC formula ($C_1 H^{3/4}$) - bare structures

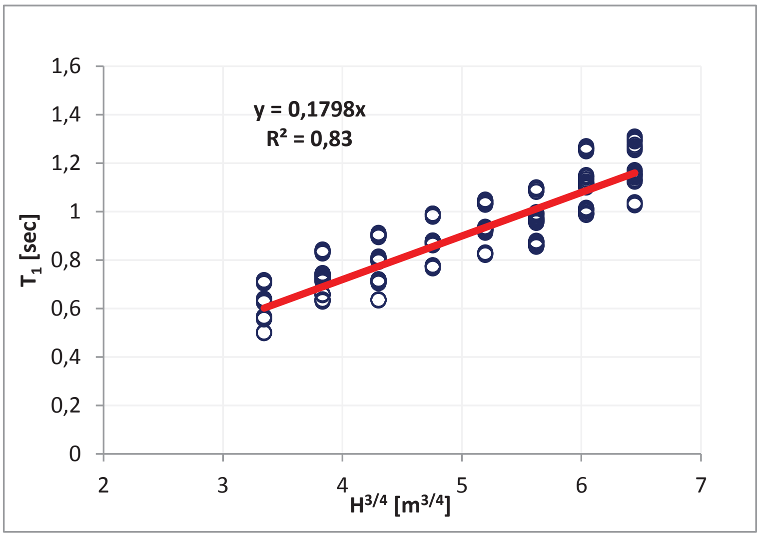

Figure 67. First natural vibrational period versus $H^{3/4}$ - bare structures

3.2.2 Modal analysis results of infilled structures

Figure 68, Figure 69 and Figure 70 show natural periods of the 288 case studies of the infilled structures.

Figure 68 shows the fundamental periods versus the height of the structure: the analytical results show an increasing trend with H, and are well predicted by the linear regression line.

Figure 69 finds a trend, that is opposite to that found for bare structures: the code formula considers stiffer structures.

The fundamental periods are also plotted versus $H^{3/4}$ (Figure 70). As the figure shows, the C_1 value is much lower than the one obtained for the bare cases, as well as lower than one proposed by NTC.

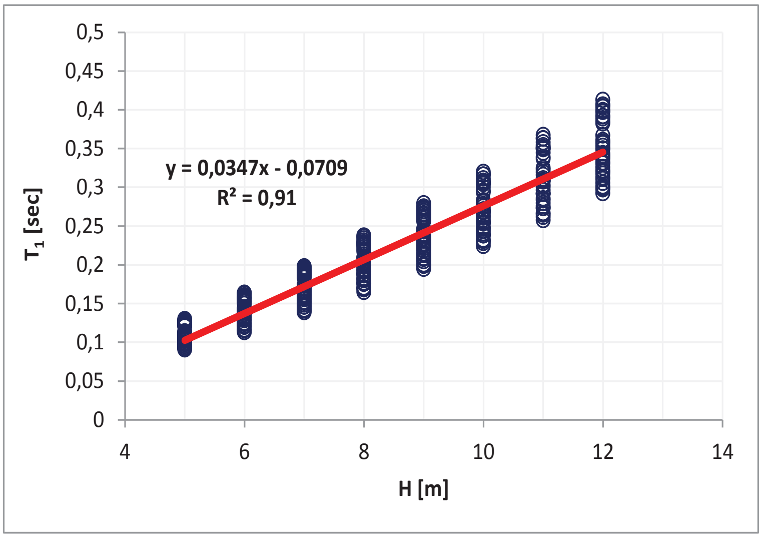

Figure 68. First natural vibrational period versus building height - infilled structures

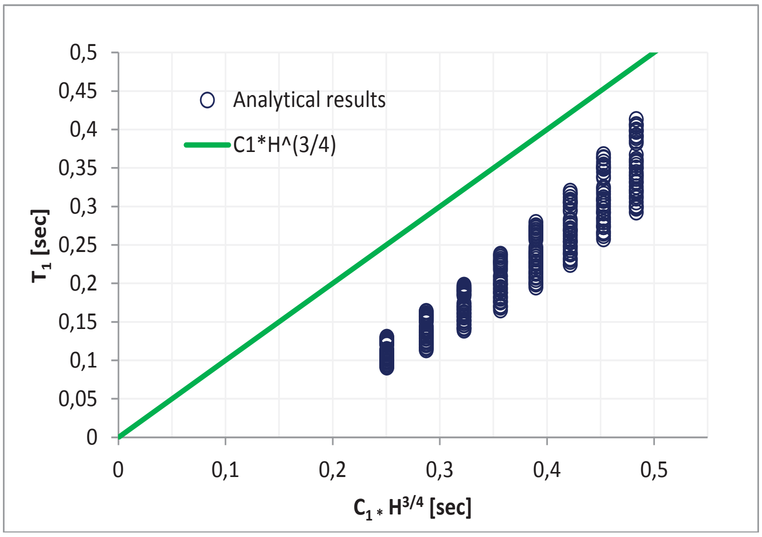

Figure 69. First natural vibrational period versus NTC formula (C_1 $H^{3/4}$) - infilled structures

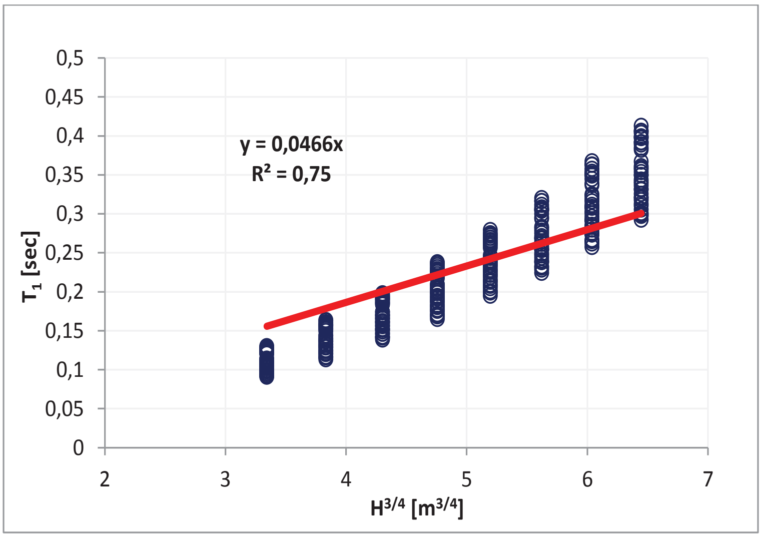

Figure 70. First natural vibrational period versus $H^{3/4}$ - infilled structures

4. Conclusions

The main purpose of the described work is the evaluation of the influence of cladding systems on the dynamic behaviour of one-story precast buildings.

Given a bare and an infilled structural model, i.e. including cladding panels, a parametric study was performed to determinate dynamic properties of 288 realistic buildings, designed according to NTC (4), in terms of natural vibration periods.

The considered variables in the parametric study are: columns height, number and width of bays in both main directions of the building.

From the analysis of natural periods of all investigated case studies, it can be concluded that:

- Vibrational period is significantly influenced by the presence of cladding system, presenting large variations with respect to the case of bare structure (reduction of 75%);
- The simplified NTC (4) formula to evaluate the fundamental vibration period $\left(C_1 H^{3/4} = 0.075 \cdot H^{3/4}\right)$, is not suitable either for bare structure case, or for infilled structure case. This relationship greatly underestimates bare structure periods, and overestimates infilled structure periods.
- With regards of the bare structures, a different C_1 value is evaluated on the basis of parametric study results. For the infilled structures, the C_1 value is found to be less than the NTC value.

5. References

1. Faggiano B, Iervolino I, Magliulo G, Manfredi G, Vanzi I. Le strutture industriali nel terremoto di L'Aquila. *Progettazione sismica 3* (2009), 207-213.
2. Ercolino M., Coppola O., Petrone C., Magliulo G. Report sui danni registrati a Mirandola (MO) in seguito all'evento sismico del 29 maggio 2012 – v.1.0 (2012a), available at http://www.reluis.it/images/stories/2012_05_29_report%20Mirandola.pdf. (in Italian)
3. Ercolino M., Petrone C., Coppola O., Magliulo G. Report sui danni registrati a San Felice sul Panaro (MO) in seguito agli eventi sismici del 20 e 29 maggio 2012 – v. 1.0 (2012b), available at http://www.reluis.it/images/stories/report_San-Felice-sul-Panaro_20-29maggio.pdf. (in Italian)
4. Decreto Ministeriale del 14/01/2008, 2008. *Approvazione delle nuove norme tecniche per le costruzioni.* G.U. n. 29 del 4/2/2008. (in Italian).
5. Hunt P J and Stojadinovic B. Seismic Performance Assessment and Probabilistic Repair Cost Analysis of Precast Concrete Cladding Systems for Multistory Buildings. PEER Report 2010/11 Pacific Earthquake Engineering Research Center, College of Engineering, University of California, Berkeley.
6. OpenSees. Pacific Earthquake Engineering Research Center, University of California, Berkeley 2007. http://opensees.berkeley.edu. Jaka Zevnik Seismic vulnerability of reinforced concrete viaducts with hollow piers (in Sloveno) - PhD Thesis - Ljubljana, Slovenia.