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EVALUATION OF THE SEISMIC VULNERABILITY FOR P+4 RESIDENTIAL BUILDINGS FROM THE URBAN AREA OF IAŞI USING THE FINITE ELEMENT METHOD

BY

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Abstract. The analysis of the seismic vulnerability for a typical dwelling structure, existing in a developed urban area, subjected to repetitive seismic actions, is performed. This type of residential building is met all over Romania, making more than 50% from the total number of buildings constructed in residential areas, built between 1965 and 1985. The structure chosen for analysis is a P+4 building, made of precast concrete panels. This type of building was selected because many districts in Iaşi have been built using this type of project or similar ones, within the mentioned period.

The deterministic approach for evaluation is based on modelling and numerical simulations using ETABS *vs*. 9 software. The methodology uses two types of numerical models. In the deterministic approach, for the first model, the building is considered in its initial state and for the second model in its degraded state, after the structure was subjected to more than two or three major earthquakes. The degradations of the elements were introduced taking into account nine scenarios, considering consecutively the structural elements and the walls with openings having different degrees of damage, from 30%, 60% to 90%.

The obtained results study are used to classify the building structures based on their seismic risk and the degree of degradation, in order to fully comprehend and investigate the seismic vulnerability of the existing urban infrastructure.

Key words: seismic risk; Iaşi; precast panels; degradations.

1. Introduction

In order to support the capacity of an urban community in managing a possible coming disaster it is necessary to evaluate the risk and, respectively, the vulnerability that the potential danger holds. The seismic vulnerability represents the evaluation of the consequences that an earthquake has upon a community and the environment together with the time of response and recovery from the disaster [1]. When trying to prevent an earthquake there are two main factors that should be taken into account: the frequency of occurrence and the area affected by it.

In what follows the structural finite element analysis of a typical dwelling structure from the urban area of Iaşi, made of precast concrete panels, is presented. The finite element model has been made using a standard model for a P+4 building [2]. This type of building was selected because many districts from Iaşi city, like Nicolina, Tătăraşi, Oancea and others have been built using this type of project or similar ones (Fig. 1) [3].

Fig. 1 – A P+4 concrete panels building from Iaşi city.

2. The Deterministic Methodology for Vulnerability Evaluation

2.1 Finite Element Model Description

The deterministic approach of the evaluation is based on the modelling and numerical simulations using ETABS vs. 9 software [4]. The first step of the modelling was to define the grid data. In this case, for a P+4 building were necessary to use 7 grid lines on *X*-direction, 10 on *Y*-direction and 7 horizontal planes corresponding to the foundation level, first, second, third and fourth floor, the terrace and the attic level.

Taking into account that both the walls and the floors are made of precast concrete panels, the only type of structural element used in the model was the shell element. The only difference between them was their dimensions, exterior walls having the thickness of 27 cm, interior walls of 14 cm and the floors and ceilings, of 13 cm.

The construction is made all from concrete, but each type of structural element uses a different class of concrete. For example the exterior walls and the floors are made of C16/20 (B250) but the interior walls are of C12/15 (B200). When defining the material properties of the model, one has to define all the materials used in the structure, the concrete type and the type of reinforcement used together with that concrete, in this case OB37 and PC60.

2.2. Evaluation and Consideration of Load Scenarios

The structural analysis of the structure was made by subjecting the finite element model to three types of actions: dead load, live loads and repetitive seismic loads. The actions were defined in accordance with Romanian standards, in agreement with Eurocode 8 [5]. Table 1 presents the load cases defined by the code.

Table 1
Load Cases

The fundamental loading case	$1.35\sum_{j=1}^{n} G_{kj} + 1.5Q_{ki} + \sum_{i=1}^{m} 1.5\Psi_{0,i}Q_{k,i}$
The special loading case	$\sum_{j=1}^{n} G_{kj} + \gamma_I A_{Ek} + \sum_{i=1}^{m} \Psi_{2,i}Q_{k,i}$

G_{kj} – the dead load; Q_{ki} – the live load; Q_{kj} – the predominant live load; $\Psi_{0,1}$ – the live load factor equal to 0.7; A_{Ek} – the earthquake action for a recurrence interval of 100 years, P100 - 2005; $\Psi_{2,\mathrm{i}}$ – the live load coefficient equal to 0.4; γ_I – the coefficient of importance equal to 1.00 for importance class 3.

The seismic actions have been introduced in the program in the form of response acceleration diagrams, for 1986, 1990 and 2004 earthquakes (Tables 2 and 3) due to the fact that these types of structures were built starting from 1982 [6].

Table 2
The Defining Elements of Vrancea Earthquakes

No.	Earthquake	Lat. N	Long. E	Earthquake Code	h, [km]	Date	Mw
1	Vrancea M (G-R) = 7.0	45.53	26.47	861	133	1986.08.30	7.3
2	Vrancea M (G-R) = 6.7	45.82	26.90	901	91	1990.05.30	7.0
3	Vrancea M (G-R) = 6.1	45.83	26.89	902	79	1990.05.31	6.4
4	Vrancea M (W) = 6.0	45.79	26.71	O41	100	2004.10.27	6.0

Table 3
Vrancea Earthquake Codes

Station	Earthquake code	Station code	Axis	Orientation	Lat. N	Long. E
Iaşi	901, 902	IAS1	l	N150E	47.169	27.576
		IAS1	t	N60E		
Iași	861, 901, 902	IAS2	l	N–S	47.190	27.570
		IAS2	t	E–W		
Iaşi	861, 901, 902	IAS3	l	NS	47.193	27.562
		IAS3	t	EW		
Iaşi -ISC	O41	IAS4	l	NS	47.174	27.554
		IAS4	t	EW		

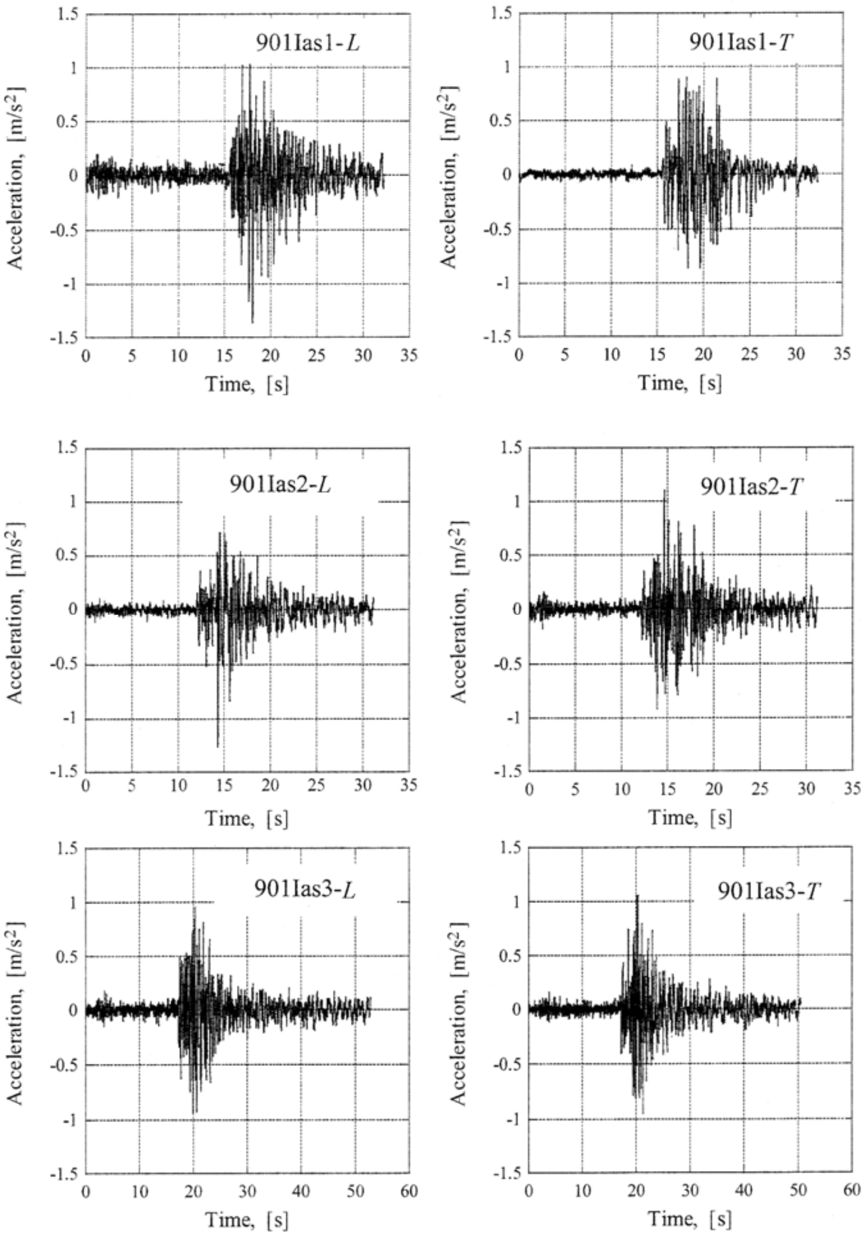

Fig. 2 – The Acceleration diagrams for 1990 Vrancea Earthquake recorded at the stations IAS1, IAS2and IAS3 (the longitudinal component, *L*; the transversal component, *T*).

The longitudinal and transversal components of the Vrancea 1990 (code 901) earthquake time history graphs are represented in Fig. 2. The other earthquakes are also taken into account in the paper, but their representation is not shown, due to the space limitation. The finite element program superposes the two components of the earthquake for a better representation of the real natural event.

3. Interpretation of the Obtained Results

Fig. 3 represents the deformed shape of the model subjected to the self weight. The deformations are displayed to a larger scale than the natural one for a better understanding of the deformation mode.

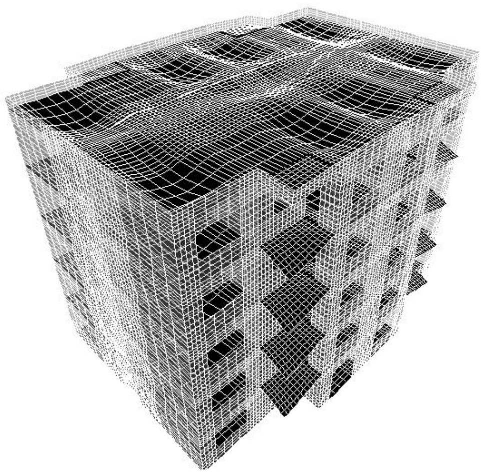

Fig. 3 – The deformed shape of the structure due to the self weight.

The finite element model was analysed both statically and dynamically, in order to determine the natural modes of vibration of the structure. The deformed shape of the structure corresponding with the first mode of vibration is presented in Fig. 4. The values of the natural periods and frequencies of vibration for the structure in its initial state have been synthesized in Table 4.

Table 4
Natural Periods and Frequencies of Vibration for the Structure in its Initial State

Mode of vibration	Natural period of vibration, [s]	Natural frequency of vibration, [s]
1	0.125131	7.9916
2	0.121001	8.2643
3	0.094191	10.6167
4	0.044625	22.4089

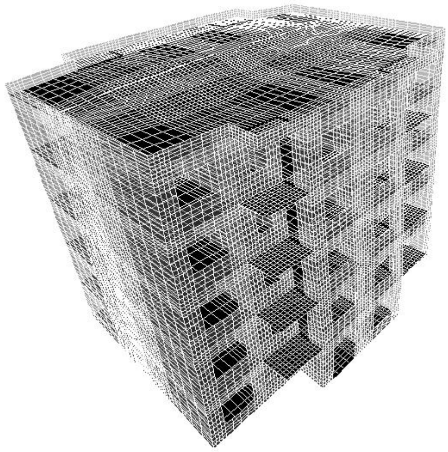

Fig. 4 – The deformed shape of the structure corresponding to the first mode of vibration with $T = 0.125131$ s.

The deformed shape of the structure due to 1986 Vrancea Earthquake has been presented in Fig. 5. Similar results were also obtained for the other considered earthquakes, all of them being gathered in tabular shape. These results have been used to analyse in detail the structural behaviour differences between the finite element models subjected to different types of seismic actions.

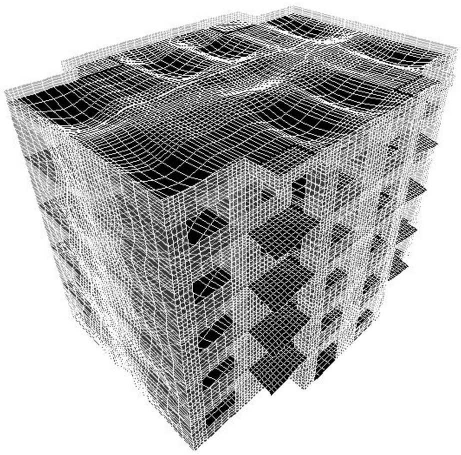

Fig. 5 – The deformed shape of the structure due to the 861IAS2 seismic action.

The main parameters of the present paper were the seismic load used in the study of the building structural behaviour and different degradation percentages applied to the structure. The degradation factors were considered by their effects on the structure taking into account different degradation percentages (30%, 60% and 90%), located on critical members of the building.

The considered scenarios were: a) the building with the degradations located at the openings panels level; b) degradations of the walls; c) degradations of all structural elements of the building. By combining these two parameters, it resulted a total of 81 analysis scenarios.

The interpretation of the obtained results has been made for each case of analysis, separately, taking into account the natural periods of vibration and the maximum level displacements. Fig. 6 shows the variation of the first natural period of vibration due to the position and the degradation percentage of the affected elements of the building, in case of a degraded structure.

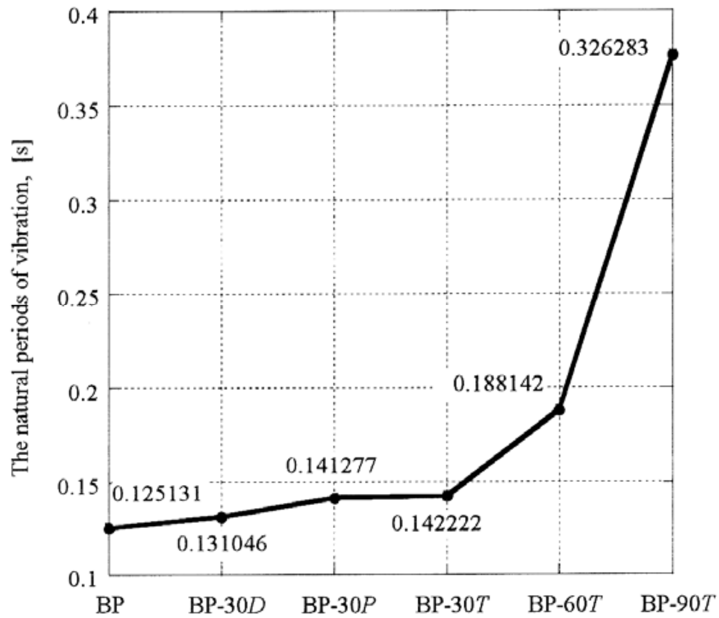

Fig. 6 – The variation of the first natural period of vibration due to the position and the degradation percentage of the affected elements of the building.

The notations from the following figures have been personalized by the authors in order to make the understanding of the diagrams easier for the reader. Due to this fact, the explanations of these notations are presented as follows: BP – the concrete panels building in its initial state. The numbers present in the name of the analysis cases show the considered degradation percentage from the structure. The last letter from the name symbolises the location of the degraded element in the structure: *D*, for the panels with openings (doors and windows); *P*, for when all the panels are considered with degradations and *T* for when the entire structure is considered degraded. For example BP-30*D* indicates the fact that the considered structure is a building made of concrete panels sustaining degradations of 30% in the panels with openings.

As the Fig. 6 points out, one can observe an increase of 5% in the natural period of vibration when the percentage of degradations of the structure in the panels with openings is 30%. When the same amount of 30% of degradations is considered affecting all the walls panels, the value of the natural period of vibration is significantly higher (13%). This phenomenon appears due to the fact that the lateral rigidity of the structure is highly diminished compared to BP-30*D* case scenario. Also, one can observe that when the structure sustains degradations of 30% in all its structural elements, the natural period of vibration doesn't increase considerable, but only with 0.06%.

An interesting aspect is that the natural period of vibration increases for different cases of degradations, as follows: the natural period of vibration has a 33% increase, from 0.142222 s for BP-30*T* to 0.188142 s for BP-60*T* and a 50% increase, from 0.125131 s, for BP, to 0.188142 s, for BP-60*T*.

In the case when the whole structure suffers degradations of 90% it has been observed that the natural period of vibration has a peak, increasing from 0.125131 s for BP to 0.326283 s for BP-90*T*. This behaviour has been expected, taking into account that the lateral rigidity of the structure is considerably diminished.

The coefficient of degradation was defined by Di Pasquale and Cakmak in 1990 as being dependent of the natural period of vibration of the structure in its initial state, T_0 , and of $T_{\mathrm{degr.}}$, the natural period of vibration of the structure in its degraded state [6]

$$\delta_M = 1 - \frac{T_0}{T_{\mathrm{degr.}}}. \tag{1}$$

The classification of the structures depending on the coefficient of degradation has been made according to the reference intervals shown in Table 5 [7].

Table 5

Reference Intervals for Classifying the Degraded Structures

Degradation state	Reference interval
Monitor degradations	0.0…0.2
Capital repairs needed	0.2…0.5
Irreparable	0.5…1.0
Total colaps	> 1.0

The results from Fig. 6 are summarized in Table 6, using relation (1) and the data from Table 5.

The numerical results for the maximum displacements on each floor are presented, for both longitudinal, *X*-, and transversal, *Y*-directions. Due to the fact that the number of analysis scenarios is considerably great, there have been selected only two earthquakes to be taken into account. The first earthquake was the one from 1986 recorded on IAS2 station, and the second one was from 1990, recorded on IAS1 station.

Table 6

Classification of the Case Studies Based on the Degradation Coefficient

Case study	δ_M	Degradation state
BP-30*D*	0.045	Minor degradations
BP-30*P*	0.114	Minor degradations
BP-30*T*	0.120	Minor degradations
BP-60*T*	0.335	Repairs of the structure are needed
BP-90*T*	0.616	Irreparable

Fig. 7 shows the maximum lateral displacement of the structure subjected to the seismic action 861IAS2, being part of the load combination presented in Table 4. There can be observed that the six graphs from Fig. 9 are correlated with the ones from Fig. 6. It can be observed a maximum lateral displacement at the attic level for the BP-30*D* case of 0.8 mm, similar with the one for the BP case. The value of the lateral displacement for the BP-30*D* case is still significantly smaller than the value in the BP-30*P* and BP-30*T* cases, 2.65 mm and of 2.86 mm, respectively. The maximum lateral displacements at the attic level are continuously increasing for the BP-60*T* and BP-90*T* cases, reaching maximum values for the BP-90*T* case, of 21 mm. Also, it can be observed that, at the superior level, the values of the lateral displacements on *X*-axis are higher than the ones on *Y*-axis. This behaviour is due to the fact that the plane geometrical shape of the building is not symmetric, the structure having the bigger moment of inertia with respect to *Y*-axis.

The same observations are also valid for the results presented in Fig. 8, taking into account the seismic action 902IAS1. Even if the structure remained the same, it can be observed that the maximum lateral displacements are bigger than in Fig. 7, because of the spectral component of the seismic action. Taking into consideration only the absolute values of the spectral accelerations, it can be seen that the values of the 902IAS1 seismic action are higher than the ones for the 861IAS2 seismic action.

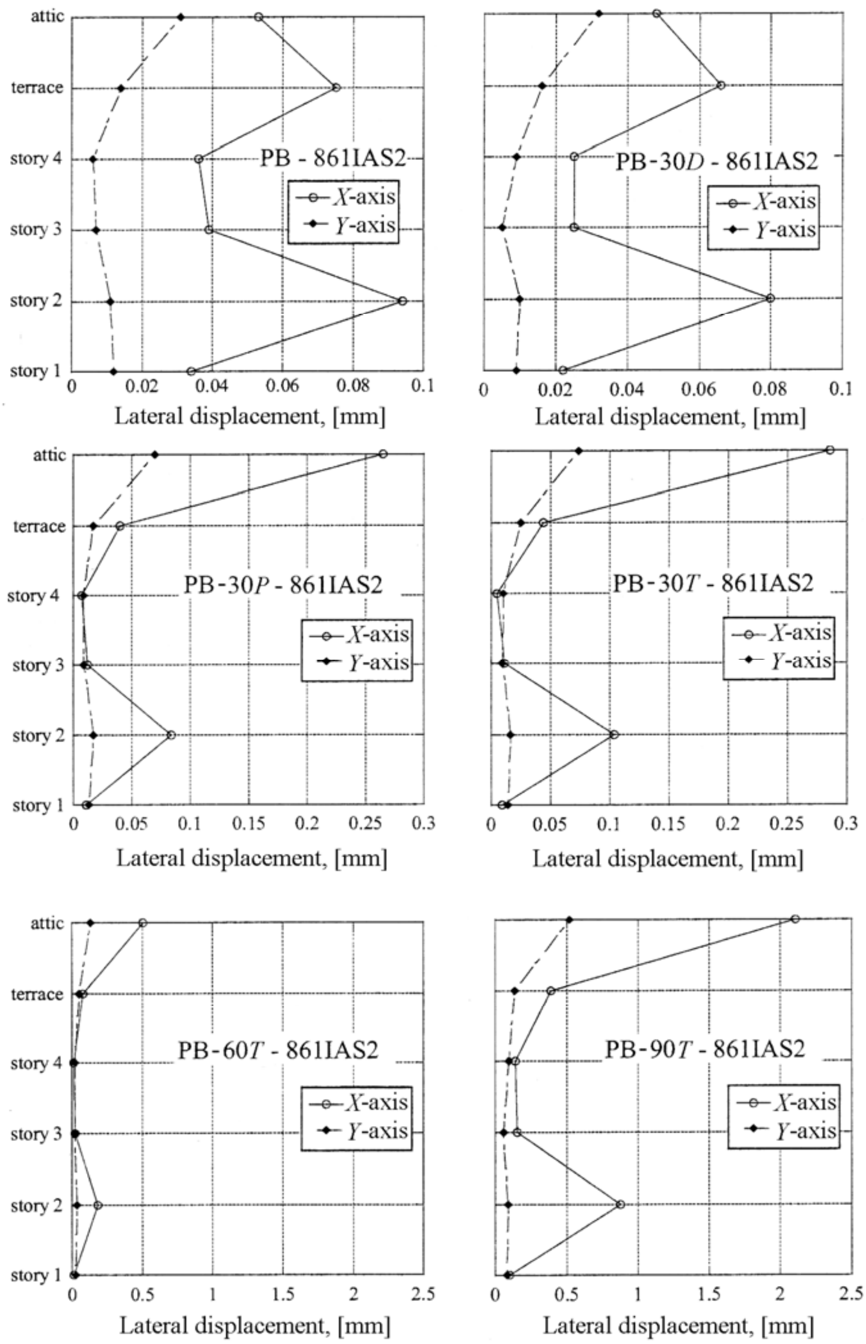

Fig 7 – The lateral displacements of the structure due to the 861IAS2 seismic action.

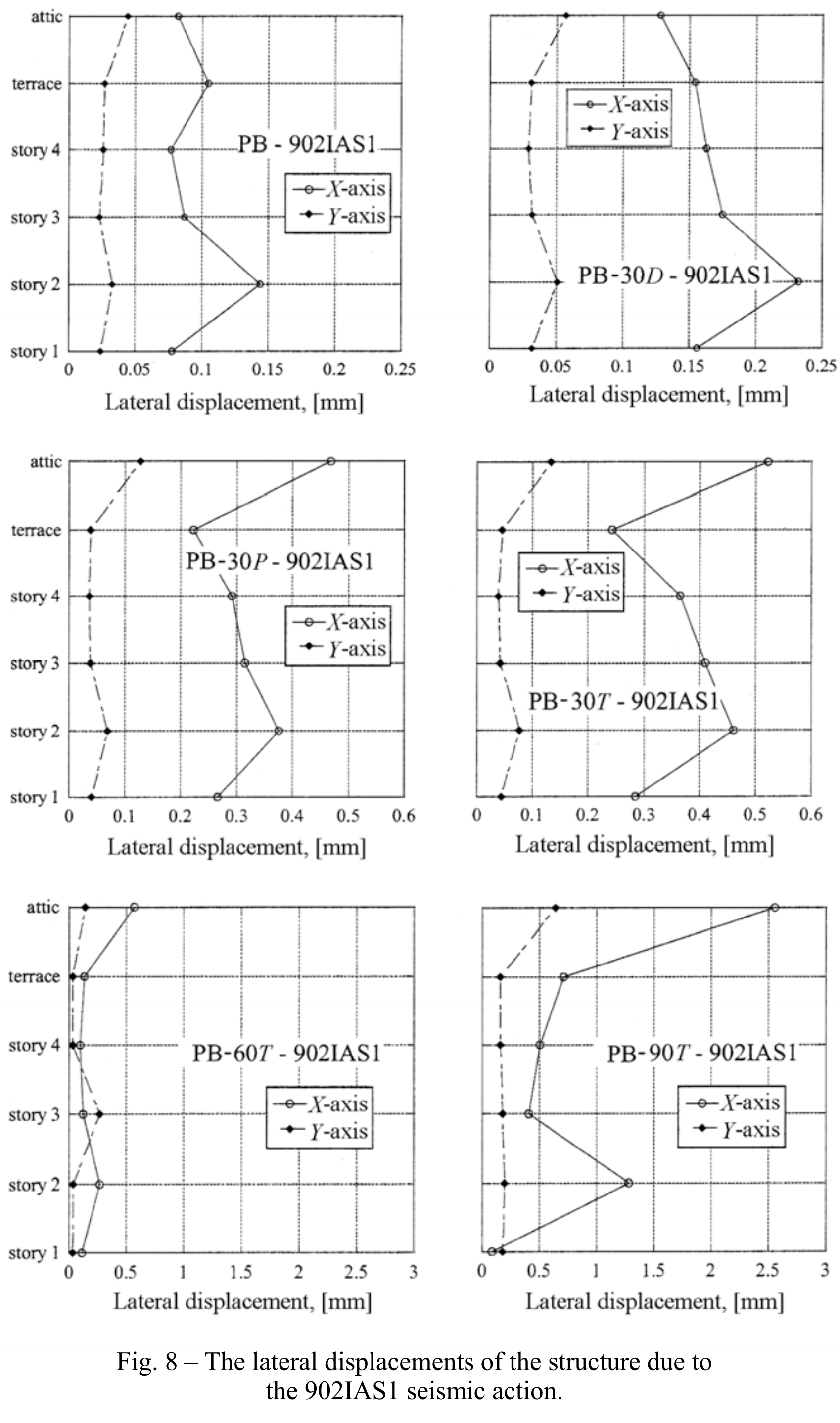

Fig. 8 – The lateral displacements of the structure due to the 902IAS1 seismic action.

4. Conclusions

The analysis of the vulnerability for a typical dwelling structure, of a developed urban area, subjected to repetitive seismic actions, is performed. This type of residential building can be met all over Romania, making more than 50% from the total number of buildings constructed in residential areas, built between 1965 and 1985. The structure chosen for analysis is a P+4 building, made of precast concrete panels, many districts in Iaşi being built using this type of project.

The deterministic approach of the evaluation is based on the modelling and numerical simulations using ETABS software. The methodology uses two types of numerical models. For the first model, the building is considered in its initial state and then in its degraded state, after the structure is subjected to more than two or three major earthquakes. The degradations of the elements are introduced taking into account nine scenarios, considering consecutively the structural elements and the walls with openings with different degrees of damage (30%, 60% and 90%).

Due to the fact that the degradations diminish the structural rigidity of the structure, the analysis results show that the presence of the degraded elements leads to an increase in the natural period of vibration. Also, the maximum lateral displacements of the models are increasing with the increase in the percentage of degradations. The degradation coefficient is a very fast and precise method of classifying the structures from the seismic vulnerability point of view.

It can be observed that the seismic risk factors of the structures are low for the buildings which withstood 30% degradations in any of their structural elements. These buildings need only minor reparations in case of an earthquake similar to the ones considered for the analysis. Increasing the percentage of degraded structural elements existing in the structure leads to the modification of the construction's seismic risk class. The buildings require substantial reparations for 60% degradation and become irreparable in case of a 90% degradation. In this last case of degradation, the buildings are considered being of very high seismic risk, close to collapse in case of a future earthquake.

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EVALUAREA VULNERABILITĂȚII SEISMICE ASISTATĂ DE METODA ELEMENTULUI FINIT A BLOCURILOR P+4 DIN PANOURI MARI DIN ZONA METROPOLITANĂ IAŞI

(Rezumat)

Se prezintă o analiză seismică structurală, bazată pe procedeul elementului finit, a unei clase de structuri solicitată la acțiuni seismice. Clasa de clădiri de locuit este prezentă în proporție de peste 50% în zonele urbane aglomerate din România: blocuri de locuit din panouri mari de beton armat, cu regim de înălțime de P+4 nivele. Studiul comportării la seism a acestei clase de structuri permite evaluarea vulnerabilității seismice a claselor de structuri de construcții din zonele urbane aglomerate.

Studiul s-a efectuat în baza unor experimentări numerice, deterministe, atât pe modelele structurilor în faza de proiectare, fără degradări, cât şi pe modelele clădirilor degradate, având diferite localizări la nivelul elementelor structurale, precum şi la cele nestructurale.

În final s-a urmărit analiza rezultatelor privind vulnerabilitatea seismică a tipului structural studiat şi clasificarea riscului seismic al structurilor în concept determinist.