BULETINUL INSTITUTULUI POLITEHNIC DIN IAȘI
Publicat de
Universitatea Tehnică „Gheorghe Asachi" din Iași
Volumul 65 (69), Numărul 3, 2019
Secția
CONSTRUCȚII. ARHITECTURĂ

OPTIMAL STRUCTURAL REHABILITATION STRATEGIES FOR RESIDENTIAL BUILDINGS

BY

BOGDAN CHIRILĂ* **and ION ŞERBĂNOIU**

Technical University "Gh. Asachi" of Iasi,
Faculty of Civil Engineering and Building Services,

Received: July 17, 2019
Accepted for publication: August 27, 2019

Abstract. The choice of a correct intervention strategy is conditioned by the complete understanding of the individual deficiencies of the structural and non-structural elements, their combined effect on the seismic behavior of the building, as well as the general deficiencies regarding strength, deformability, redundancy and structural regularity.

Intervention measures must be correlated with the degree of damage (degradation) of the materials as a result of earthquakes incurred by the construction, other specific exploitation actions, differential land-fill or environmental factors.

Intervention measures aim to eliminate or significantly reduce the deficiencies of the different nature of the structure and of the non-structural components.

The study examined the possibilities of implementing the proposed strategies for the structural rehabilitation of the D1 building, as well as only two strategies, namely the reduction of the exploitation period and the consolidation of the building.

Keywords: duration; exploitation; reduction; destination; sectioning; consolidation.

*Corresponding author: *e-mail:* chirila_bogdan2006@yahoo.com

1. Introduction

The process of choosing a correct intervention strategy is conditioned by the complete understanding of the individual deficiencies of the structural and non-structural elements, their combined effect on the seismic behaviour of the building, as well as the general deficiencies regarding strength, deformability, redundancy and structural regularity.

Intervention measures must be correlated with the degree of damage (degradation) of the materials as a result of earthquakes incurred by the construction, other specific exploitation actions, differential compaction or environmental factors.

Identification of resistance and deformability deficiencies, of deficiencies of individual and overall composition, of the degradation status are performed within the seismic assessment by checking the lists of construction conditions and setting the values of R_1, R_2 and R_3 of P 100-3.

Intervention measures aim to eliminate or significantly reduce the deficiencies of different nature of the structure and of the non-structural components and thus to obtain the safety condition: the seismic requirement ≤ the capacity of the construction.

The intervention strategy can be based on:

• reduction of seismic requirements;

• improving the mechanical features that the construction is endowed with;

• combined measures.

2. Optimal Structural Rehabilitation Strategies for Residential Buildings

Considering that the consolidation works imposed by the state of the building and the insufficient degree of insurance against seismic actions would require excessive material, human, financial resources and / or would involve the discontinuation of the construction function for a very long time, making an irrational intervention, there may be envisaged other options. Establishing the best strategy should be the result of a cost-benefit analysis of several possible solutions.

Analysis of all these requirements and material conditions can lead to other options in addition to the building consolidation as a whole.

Options for choosing intervention strategies for existing buildings can be:

A1 – reducing service time;
A2 – reducing the occupancy degree of the building;
A3 – reducing masses and demands;
A4 – destination change;
A5 – reducing the number of levels;
A6 – building sectioning;
A7 – leaving the building;
A8 – building consolidation;
A9 – total demolition and construction of a new building according to current standards.

The intervention strategies listed above can be applied individually or in combinations, depending on the requirements of the beneficiary, the economic impact and the results obtained.

2.1. Reducing Service Time

Reducing the service life of existing buildings requires the consideration of a lower average recurrence interval and, implicitly, the scaling of horizontal seismic acceleration. By applying a lower seismic strength to the building, intervention measures for building consolidation may be reduced, but the intervention measures required for repairs won't.

The average recurrence interval is determined, based on the probability of overtaking and the reference/exploitation duration, by the relationship:

$$\mathrm{IMR} = -\frac{T_e}{\ln\left(1 - p_d\right)}, \tag{1}$$

where: p_d is the probability of overtaking; T_e – the service life.

$$p_d = \left(\mathrm{e}^{\left(-\frac{T_e}{\mathrm{IMR}}\right)} - 1 \right) \cdot 100 . \tag{2}$$

Seismic Design Code - Part III - Provisions for seismic assessment of existing buildings, indicative P100-3 provides average recurrence intervals and overflow probabilities for a 50 year exploitation period indicated in Table 1.

Table 1

Average Recurrence Intervals and Probability of Overtaking for a 50-year Service Life According to P100-3

Average acceleration recurrence of the peak acceleration value IMR, [years]:	The probability of exceeding the peak of land acceleration in 50 years, [%]
30	80
40	70
100	40
225	20
475	10

For the recurrence averages provided in the code, horizontal scaling factors for the terrain are also provided according to Table 2.

Table 2

Average Recurrence Intervals and Probability of Overtaking for a 50-years Service Life According to P100-3

Type of seismic source	a_g^{30}/a_g^{225}	a_g^{40}/a_g^{225}	a_g^{100}/a_g^{225}	a_g^{225}/a_g^{225}	a_g^{475}/a_g^{225}
Vrancea, sub crustal	0.40	0.45	0.80	1.00	1.25
Banat, crustal	0.35	0.40	0.80	1.00	1.35

The current norms require a 50 year exploitation period, but for old and very old buildings located in central areas and not classified as a historical monument, this period is exaggerated. Therefore, we propose to take into account the lower exploitation periods (Table 3) for these types of buildings, keeping the probability of exceeding 20%. By this method, the seismic force applied to the building will be scaled by a sub-unit factor according to Table 6.4, and the intervention measures will be more reduced.

Table 3

Average Recurrence Intervals and Exceeding Probability for a 50-year Service Life under P100-3 and 40, 30, 25, 20 and 10 years of Service Life

T_e = 50 years		T_e = 40 years		T_e = 30 years		T_e = 25 years		T_e = 20 years		T_e = 10 years	
IMR years	p_d %	IMR years	p_d %	IMR years	p_d %	IMR years	p_d %	IMR years	p_d %	IMR years	p_d %
30	80	25	80	19	80	16	80	12	80	6	80
40	70	33	70	25	70	21	70	17	70	8	70
100	40	78	40	59	40	49	40	39	40	20	40
225	20	179	20	134	20	112	20	90	20	45	20
475	10	380	10	285	10	237	10	190	10	95	10

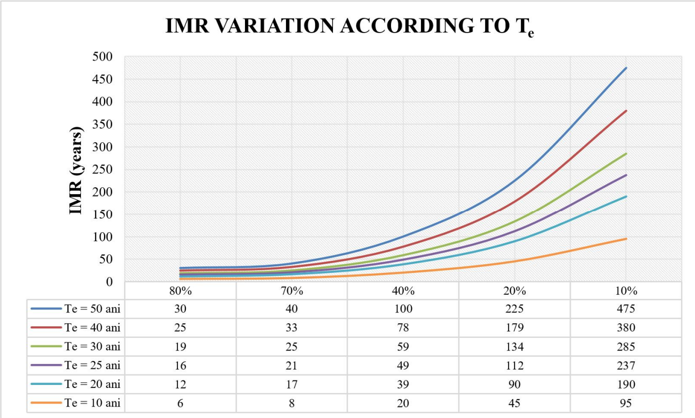


Fig. 1 – IMR Variation according to p_d for service periods T_e = 50/40/30/25/20/10 years.

Table 4

Scaling Factors to Determine the Peak Values of Horizontal Seismic Accelerations Reported to IMR = 225 years and p_d = 20% for T_e = 50/40/30/25/20/10 years

Type of seismic source	T_e = 50 years	T_e = 40 years	T_e = 30 years	T_e = 25 years	T_e = 20 years	T_e = 10 years
Vrancea, subcrustal	a_g^{225}/a_g^{225}	a_g^{179}/a_g^{225}	a_g^{134}/a_g^{225}	a_g^{112}/a_g^{225}	a_g^{90}/a_g^{225}	a_g^{45}/a_g^{225}
Banat, crustal	1,00	0,92	0,85	0,82	0,74	0,47

2.2. Reducing the Occupancy Degree of the Building

Reducing the occupancy degree of the building is a method by which a reduction in the building mass is achieved and implicitly the reduction of the seismic forces acting on the building. The method involves the total cancellation of floors resulting in a reduction of the useful surface, but it is difficult to apply it if the building has more owners.

2.3. Reducing Masses

The method consists of replacing heavy walls with light walls, replacing floors with other solutions with a lower weight per m^2, replacing the thermo-waterproofing layers over the floor of the last level with other layers with a lower weight per m^2, renouncing to the heavy framings and covers, moving heavy machines or equipment from the upper levels of the building to the basement or ground floor, etc.

2.4. Changing the Destination

By changing the destination, it is possible to reduce the useful load of some spaces in a building, thus resulting in lower efforts in the structural elements.

The scenario is plausible if the building is at the boundary between seismic risk classes, and by this discharge the building will fall into the upper seismic risk class immediately following.

2.5. Reducing the Number of Levels

Reducing the number of levels is a measure that greatly reduces efforts in structural elements. The solution may be particularly convenient when the building has substantial retractions at these levels with unfavourable eccentricities of the masses, strength characteristics and overall rigidity.

2.6. Building Sectioning

Building sectioning is a method that can be applied to buildings with larger width than height, to lamellar buildings, or L-, T or U-shaped buildings, dividing the structure into rectangular shapes. By this method a more favourable spatial behaviour is obtained, reducing the torsion effect.

Generally, the method works in combination with other methods, such as "reducing the number of levels."

2.7. Leaving the Building

Leaving the building is a measure that applies to buildings in the RsI seismic risk class and must be a temporary and binding solution.

The application of the measure generally depends on many factors, such as: number of owners, location, social impact, economic impact, etc.

The measure must be supplemented urgently with other measures to bring the building to the minimum degree of seismic structural insurance depending on the class of importance and exposure of the building or its demolition.

2.8. Consolidation of the Building

Consolidation of structural elements involves interventions of higher or lower magnitude depending on the degree of seismic structural damage of the building.

Intervention works may include the entire construction or may only be required for some structural elements with low resistance capacities compared to seismic stresses.

2.9. Total Demolition and Construction of a New Building According to Current Standards

The solution may be indicated for existing buildings located on high-value terrains where the cost of seismic rehabilitation would be unjustifiably high, without significant space remodelling being possible in order to improve the function.

3. Case Study. Residential Building

3.1. Description of the Building

As a result of the large number of buildings with resistance structure on unconfined load-bearing masonry (approximately 60 buildings in Mun. Suceava) built during the period when Suceava did not had the need to take into account the seismic action, the large number of inhabitants (about 6.000 people) living in these buildings, the degradations found at the visual inspections, the seismic structure conformance and the area in which they are located, we proposed to evaluate a building with a B + GF + 4F height regime with the structure on unconfined load-bearing masonry and sheets of prefabricated strips of F and FU types.

The building is located in the central area, on Ana Ipătescu Street, Suceava, County of Suceava (Fig. 2) and is part of the dwellings assembly comprising the Areni Neighbourhood, similar to 26 residential buildings in the Areni Neighbourhood.

Fig. 2 – Location – Block D1 located on Ipătescu Str., Mun. Suceava.

This type of structural system was used mainly in the 1960-1970 years for the construction of the buildings in the Areni neighbourhood and part of the central area, the number of buildings being approx. 30 just in the Areni neighbourhood. After the visual inspections of buildings with this type of structural system, similar damages have been identified, which leads us to the idea that these types of buildings have similar structural deterioration and deficiencies.

3.2. Determination of the Fulfilment Degree of Seismic Conditions – R_1

The fulfilment degree of the seismic composition conditions, R_1, is determined on the basis of the score attributed to each category of building conditions, depending on the type of structural material and the level of applied assessment methodology. Classification in seismic risk classes is done according to Table 5.

Table 5

Framing in Seismic Risk Classes Based on the Value of R1 Indicator

Framing in seismic risk classes - R_1 indicator			
I	II	III	IV
<30	30 – 60	61 – 90	91 – 100
	47		

The configuration of the structural system has been identified from the initial project plans and field investigations.

The table regarding the evaluation of the degree of fulfilment of the seismic composition conditions is summarized in Table 6.

Table 6

The Degree of Fulfilment of Seismic Conditions – Block D1 Using the Level 2 Methodology

Evaluation criteria	Score
1. Quality of the structural system	2
2. Quality of masonry	4
3. Type of flooring	4
4. Layout configuration	6
5. Elevation configuration	9
6. Distances between the walls	1
7. Elements that give side pushes	9
8.Type of foundation terrain and foundations	7
9. Possible interactions with adjacent buildings	2
10. Non-structural elements	3
Total R_1:	47

3.3. Determination of Degree of Structural Damage – R_2

The value of structural damage, R_2, is determined on the basis of the score assigned to each category of conditions for assessing the degradation status of the structural elements according to the materials and the evaluation methodology used. Seismic risk classes are classified according to Table 8.

A selection of degradations identified from field inspections are shown in Fig. 3.

Fig. 3 – Degradations block type D1.

The load-bearing capacity of these buildings built during the 1960s diminished with the passage of time due to the actions they were subjected to. As a result of the inspections, it is observed that block D1 presents moderate and severe cracks in load-bearing walls due in particular to non-uniform compactions and seismic action. Therefore, the fact that this building and the ones alike resisted the previous earthquakes does not conclude that they will resist the next earthquake(s), but on the contrary these buildings have become and become even more vulnerable after each earthquake.

The table on assessing the degree of structural damage is summarized in Table 7.

Table 7

Degree of Structural Damage to Block D1 Using the Level 2 Methodology

Evaluation criteria	Score
Vertical elements (Av)	25
Horizontal elements (Ah)	25
Total R_2:	60

Table 8

Classification in Seismic Risk Classes Based on R_2 Indicator Value

Classification in seismic risk classes – R_2 indicator			
I	II	III	IV
<40	40 – 70	71 – 90	91 – 100
	50		

3.4. Determination of Seismic Structural Assurance – R_3

As a result of the evaluation of the indicators R_1 (degree of fulfilment of the seismic conditions) and R_2 (degree of structural damage), the building is classified in the II seismic risk class, associated to buildings which, under the effect of the earthquake, may suffer major degradation, with reduced possibilities for the loss of stability.

For the studied building, the structural elements were not dimensioned to take over the seismic action for which the capacity of their structural elements was diminished by the previous earthquakes (1977, 1986 and 1990), as can be seen in Fig. 4. In the case of a major earthquake there is a risk that the already damaged elements will yield, fact what could produce the domino effect that results in the complete collapse of the building.

It is necessary to carry out the structural calculation of the buildings and to propose intervention strategies for the safety of the building in order to meet the conditions stipulated by the current seismic norms and codes.

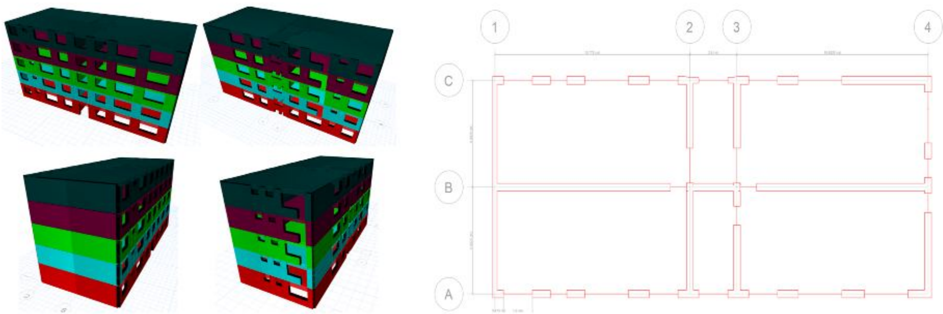


Fig. 4 – Modelling of the block D1 in the Etabs calculation program

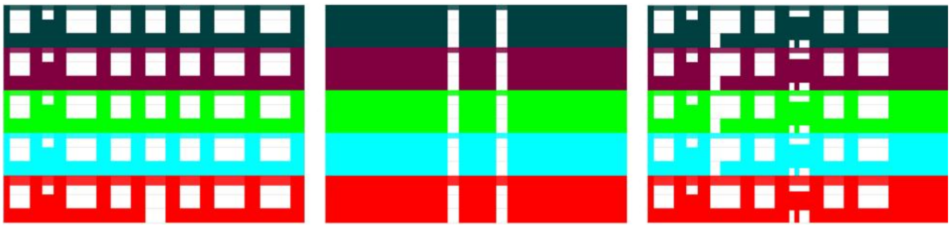


Fig. 5 – View from Etabs program Shaft A, B and C – Longitudinal Direction

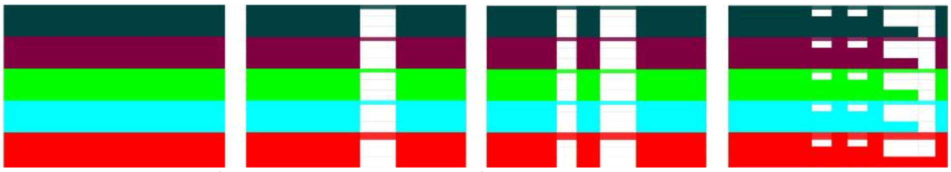


Fig. 6 – View from Etabs program Shaft 1, 2,3 and 4 – Transversee Direction.

The structural system of the building is composed of several similar sections in terms of structure, with a 3 cm joints. The structural calculation was performed on one of the sections using the Etabs finite element calculation program and the load bearing capacity verification of the elements was carried out in accordance with Annex D of the "Seismic Design Code for Existing Buildings, Indicative P 100-3".

The site parameters you consider are the following:

– terrain acceleration for design according to indicative P100-1 / 2013: $a_g = 0.20$ g;

– corner period according to P100-1/2013: $T_c = 0.7$s;

– characteristic snow load according to CR-1-1-3/2012: $s_k = 2.5$ kN/m^2;

– useful loads according to SR EN 1991-1-1.

Following the calculation, the vibration periods for the first 12 modes of vibration were determined (Fig. 7). The vibration period for the first vibration mode was compared to the fundamental period determined according to the Seismic Design Code. Part I – Design Checks for Buildings, indicative P100-1/2013 ", Annex B, resulting in an overrun of 20.2%.

The deformation resulted from the first two modes of vibration is shown in Fig. 8. The analysis shows that in the first vibration mode the building is deformed in the transverse direction and in the second vibration mode the building is deformed in the longitudinal direction.

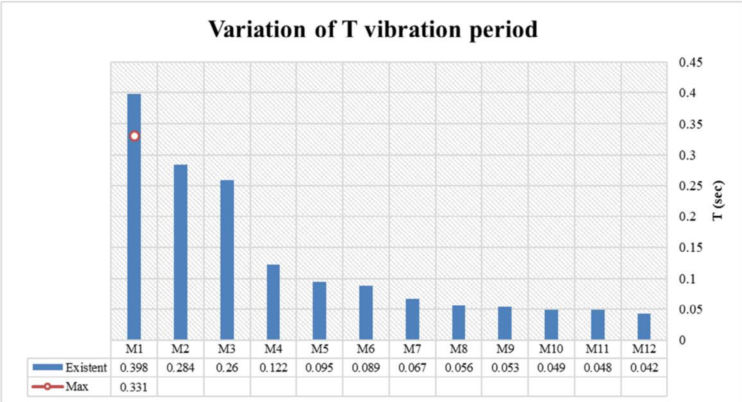


Fig.7 – Variation of vibration period T in the first 12 modes of vibration.

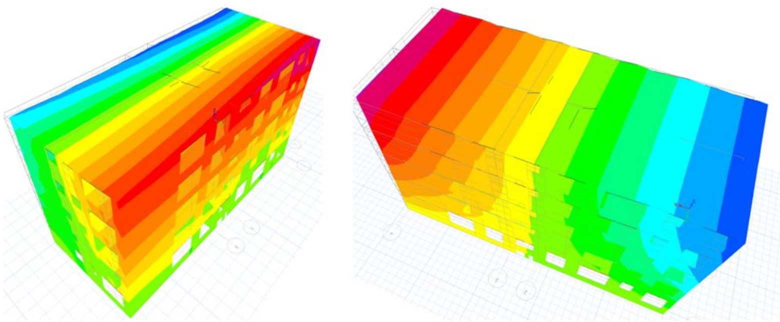


Fig.8 – Structure deformation in vibration mode 1 and 2.

The degree of seismic structural assurance was determined by checking the resistance properties of masonry pallets at failure by eccentric compression, ladder breaking and breaking through diagonal fissure by using relationships 3, 4 and 5.

The design value of the cut-off force associated with eccentric compression failure, Vf_1, of an unreinforced masonry wall required by the axial design force Nd was calculated with relation:

$$V_{f1} = \frac{N_d}{c_p \lambda_p} \cdot \left(1 - 1.1\upsilon_d\right), \qquad (3)$$

where: N_d is the axial design force; λ_p – the shape factor of the masonry wall; c_p – coefficient which depends on the wall-fixing at extremities conditions of the wall; υ_d – normal unitary compression effort.

The design value of the cut-off force by sliding in a horizontal joint, V_{f21}, was calculated with relation:

$$V_{f21} = \frac{1.33}{\mathrm{CF} \cdot \gamma_M} \cdot \left(f_{vk0} \cdot \frac{l_{ad}}{l_c} + 0.4\sigma_d \right), \tag{4}$$

where: CF is the confidence factor (equal to 1.35); y_M - partial safety factor (equal to 2.5); l_{ad} – the length on which the adherence is active; l_c – the length of the compressed area of the section that takes into account the alternating effect of the seismic force; f_{vk0} – the initial shear unitary characteristic resistance (equal to 0.045 N/mm^2).

The design value of the breaking force through a diagonal crack, V_{f22}, was calculated with relation:

$$V_{f22} = \frac{t l_w f_{td}}{b} \cdot \sqrt{1 + \frac{\sigma_0}{f_{td}}}, \tag{5}$$

where: t is the wall thickness; l_w – wall length; f_{td} – the main stretching effort; b – with values $1.0 \leq b = \lambda_p \leq 1.5$; σ_0 – the unitary compressive effort corresponding to the axial design force N_d.

The value of the R_3 indicator for each direction was calculated with relations:

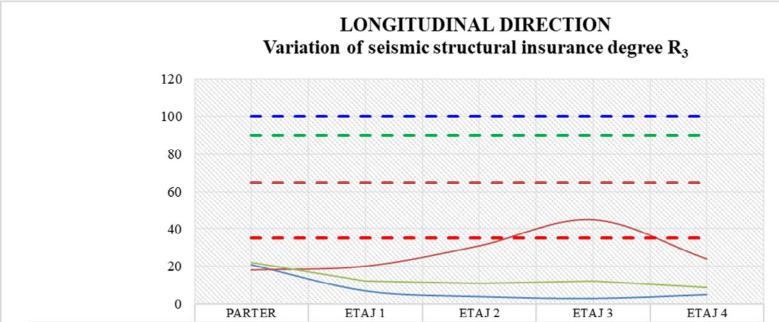
$$R_3 = \frac{\sum_{jd} V_{fd} + \sum_{kf} V_{ff}}{\sum F_{bi}} \tag{6}$$

where: $\sum_{jd} V_{fd}$ the sum of the strength capacities of the ductile fractured walls (j walls); $\sum_{kf} V_{ff}$ – the sum of the strength capacities of the ductile fractured walls (j walls).

The results obtained from the structural calculations according to the indicative P100-1/2013 and the verifications carried out according to the indicative P100-3 are presented in Figs. 9 and 10 in graphical form for each direction and level. The minimum value of the seismic structural insurance degree obtained in the longitudinal direction $R_{3\,\mathrm{long}}$ = 3%, and in the transverse direction $R_{3\,\mathrm{trans}}$ = 3%.

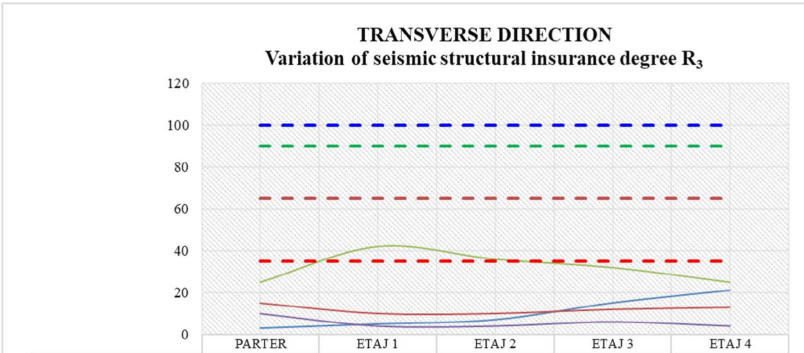
As a result of the evaluation of the indicators R_1 (degree of fulfilment of seismic composition conditions) and R_2 (degree of structural damage), the building is classified as seismic risk class II, but following the evaluation of the indicator R_3 (seismic insurance) the building is included in the seismic risk class I according to Table 9, which includes buildings with total or partial susceptibility to collapse at the design earthquake, corresponding to the ultimate limit state.

Intervention works are required to secure the construction.



	PARTER	ETAJ 1	ETAJ 2	ETAJ 3	ETAJ 4
AX A	21	7	4	3	5
AX B	18	20	31	45	24
AX C	22	12	11	12	9
Limita - RsI	35	35	35	35	35
Limita - RsII	65	65	65	65	65
Limita - RsIII (OPB)	90	90	90	90	90
Limita - RsIV (OPS)	100	100	100	100	100

Fig. 9 – Variation of seismic structural insurance degree R_3 – longitudinal direction.



	PARTER	ETAJ 1	ETAJ 2	ETAJ 3	ETAJ 4
AX 1	3	5	7	15	21
AX 2	15	10	10	12	13
AX 3	25	42	36	32	25
AX 4	10	4	4	6	4
Limita - RsI	35	35	35	35	35
Limita - RsII	65	65	65	65	65
Limita - RsIII (OPB)	90	90	90	90	90
Limita - RsIV (OPS)	100	100	100	100	100

Fig. 10 – Variation of seismic structural insurance degree R_3 – transverse direction.

Table 9
Classification in Seismic Risk Classes Based on R_3 Indicator Value

Classification in seismic risk classes – R_3 indicator value			
I	II	III	IV
<35	35 – 65	66 – 90	91 – 100
3			

4. Analysis of Structural Rehabilitation Strategies

4.1. Reducing the Service Life

Reducing the service life of existing buildings requires a lower average recurrence interval and, implicitly, the scaling of horizontal seismic acceleration. This, applying a lower seismic force to the building the intervention measures required to consolidate the buildings in order to increase seismic assurance are reduces, or in some cases completely removes these measures.

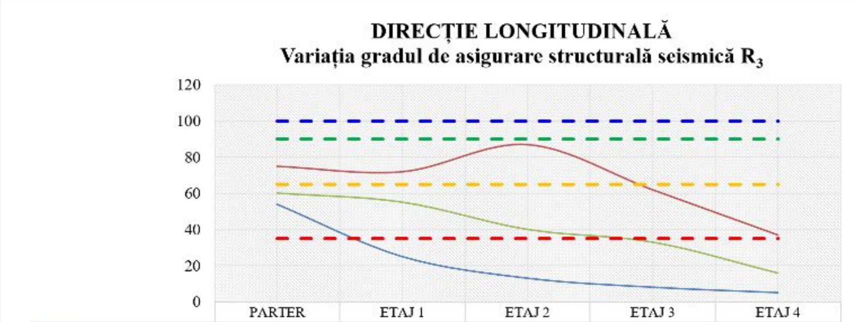
Repairs needed to bring the building to its original condition are mandatory in any situation or strategy applied by which the preservation of the building is wanted. These works are carried out before building consolidation works.

In the study, there was applied the reduction of the service life strategy for the building in question to the proposed 10-year minimum with a probability of exceeding 20%, resulting in a 45-year IMR and a horizontal scaling factor of 0.47 according to Table 4.

The variation in seismic structural insurance is shown in Figs. 11 and 12 for each direction and level. The minimum value of the seismic structural assurance degree obtained in the longitudinal direction $R_{3\ long}$ = 5%, and in the transverse direction $R_{3\ trans}$ = 13%.

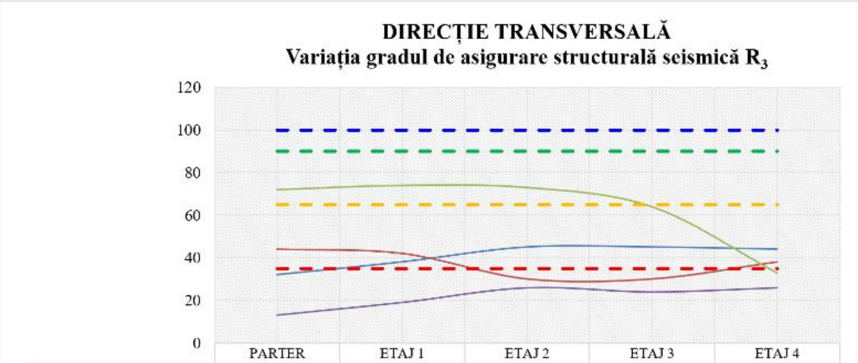
By reducing the exploitation period, significant increases in the degree of seismic structural insurance are achieved, but in the case of the analysed construction due to the fact that it falls within the seismic risk class RsI, by applying the strategy there is not achieved a degree of seismic assurance by which the construction could be classified in class III or IV of seismic risk. We therefore conclude that this strategy can be applied only in combination with other strategies or individually to the constructions in the seismic risk class RsII.

The values resulting from the application of the 10-year reduction strategy are presented in comparison with existent values in Tables 10 and 11.



	PARTER	ETAJ 1	ETAJ 2	ETAJ 3	ETAJ 4
AX A	54	25	13	8	5
AX B	75	72	87	62	37
AX C	60	55	40	33	16
Limita - RsI	35	35	35	35	35
Limita - RsII	65	65	65	65	65
Limita - RsIII (OPB)	90	90	90	90	90
Limita - RsIV (OPS)	100	100	100	100	100

Fig.11 – Variation of seismic structural insurance degree R_3 - longitudinal direction.



	PARTER	ETAJ 1	ETAJ 2	ETAJ 3	ETAJ 4
AX 1	32	38	45	45	44
AX 2	44	42	30	30	38
AX 3	72	74	73	64	33
AX 4	13	19	26	24	26
Limita - RsI	35	35	35	35	35
Limita - RsII	65	65	65	65	65
Limita - RsIII (OPB)	90	90	90	90	90
Limita - RsIV (OPS)	100	100	100	100	100

Fig.12 – Variation of seismic structural insurance degree R_3 - transverse direction

Table 10
R_3 Variation by Applying a 10-year Reduction of the Service Life Strategy – Longitudinal Direction

Level	Shaft A			Shaft B			Shaft C		
	proposed	existent	Variations [%]	proposed	existent	Variations [%]	proposed	existent	Variations [%]
Ground floor	54	21	**157**	75	18	**317**	60	22	**173**
1 floor	25	7	**257**	72	20	**260**	55	12	**358**
2 floor	13	4	**225**	87	31	**181**	40	11	**264**
3 floor	8	3	**167**	62	45	**38**	33	12	**175**
4 floor	5	5	**0**	37	24	**54**	16	9	**78**

Table 11
R_3 Variation by Applying a 10-year Reduction of the Service Life Strategy – Transversal Direction

LEVEL	Shaft 1			Shaft 2			Shaft 3			Shaft 4		
	proposed	existent	Variations [%]	proposed	existent	Variations [%]	proposed	existent	Variations [%]	proposed	existent	Variations [%]
Ground floor	32	3	**967**	44	15	**193**	72	25	**188**	13	10	**30**
1 floor	38	5	**660**	42	10	**320**	74	42	**76**	19	4	**375**
2 floor	45	7	**543**	30	10	**200**	73	36	**103**	26	4	**550**
3 floor	45	15	**200**	30	12	**150**	64	32	**100**	24	6	**300**
4 floor	44	21	**110**	38	13	**192**	33	25	**32**	26	4	**550**

4.2. Reducing the Occupancy Degree of the Building

The method of decreasing the occupancy of the building was applied to block D1, keeping only the useful spaces on the ground floor of the building. Thus, the existing structure was recalculated without any useful load from the upper floors, resulting in the following values in Tables 12 and 13.

As a result of the obtained results, it is found that the method is not advantageous for the buildings with resistance structure in the unreinforced load-bearing masonry due to the fact that the pallets yields to the cut-off force, and in a few cases at the compression or bending moment, and therefore the reduction of the useful loads has the effect of reducing the axial force, which also leads to the reduction of the cutting capacity of the pallets.

Table 12
Variation R_3 by Applying the Building Occupancy Reduction Strategy - Longitudinal Direction

LEVEL	Shaft A			Shaft B			Shaft C		
	proposed	existent	Variations [%]	proposed	existent	Variations [%]	proposed	existent	Variations [%]
Ground floor	21	21	**0%**	19	18	**6%**	10	22	**-55%**
1 floor	7	7	**0%**	24	20	**20%**	10	12	**-17%**
2 floor	5	4	**25%**	36	31	**16%**	10	11	**-9%**
3 floor	3	3	**0%**	25	45	**-44%**	12	12	**0%**
4 floor	4	5	**-20%**	22	24	**-8%**	14	9	**56%**

Table 13
Variation R_3 by Applying the Building Occupancy Reduction Strategy – Transversal Direction

Level	Shaft 1			Shaft 2			Shaft 3			Shaft 4		
	proposed	existent	Variations [%]	proposed	existent	Variations [%]	proposed	existent	Variations [%]	proposed	existent	Variations [%]
Ground floor	5	3	**67**	15	15	**0**	24	25	**-4**	6	10	**-40**
1 floor	7	5	**40**	9	10	**-10**	39	42	**-7**	4	4	**0**
2 floor	10	7	**43**	14	10	**40**	37	36	**3**	4	4	**0**
3 floor	21	15	**40**	15	12	**25**	40	32	**25**	7	6	**17**
4 floor	21	21	**0**	13	13	**0**	34	25	**36**	4	4	**0**

4.3. Reducing Masses and Demands

The method for reducing masses and demands for block D1 made with a structural load-bearing masonry system has the same result as the method of reducing the occupancy of the building. By replacing non-structural high mass elements with other similar but less massive elements, a reduction in useful and permanent loads is obtained. By reducing axial loads, the axial load force of the washers is reduced.

The method is not advantageous for buildings with the structure of resistance made from unreinforced load-bearing masonry.

4.4. Changing the Destination

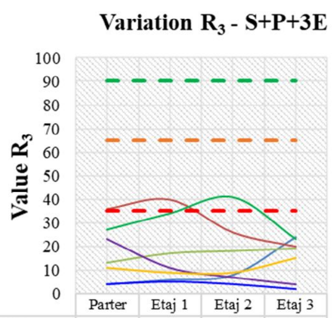
Useful charges have the minimum value for residential buildings, so these values can no longer be reduced. The change of destination in residential buildings would require the abolition of living spaces, which coincides with the method of reducing the occupancy of the building.

The method cannot be applied to residential buildings in order to obtain a higher degree of seismic structural insurance.

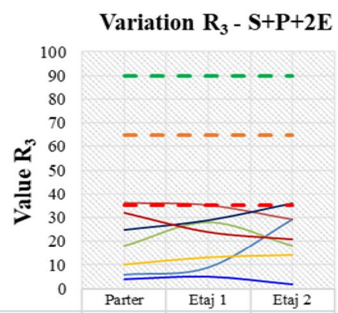
4.5. Reducing the Number of Floors/Levels

The method of reducing the number of levels has been progressively applied by gradually reducing the number of levels. Therefore, one floor was removed, the structure was recalculated and structural elements were checked. The results obtained are shown in Figs. 13 and 14.

The values of the results obtained from the point of view of the seismic structural insurance degree show no significant increases. Therefore, we consider that this method is not indicated in the case of residential buildings with the structure of resistance made from unreinforced load-bearing masonry.



	Parter	Etaj 1	Etaj 2	Etaj 3
AX A	4	6	8	24
AX B	36	40	26	20
AX C	13	17	18	19
AX 1	23	11	7	4
AX 2	11	9	9	15
AX 3	27	34	41	23
AX 4	4	5	4	2
Limita RsI	35	35	35	35
Limita RsII	65	65	65	65
Limita RsIII	90	90	90	90



	Parter	Etaj 1	Etaj 2
AX A	6	9	29
AX B	36	35	29
AX C	18	28	18
AX 1	25	29	36
AX 2	10	13	14
AX 3	32	24	21
AX 4	4	5	2
Limita RsI	35	35	35
Limita RsII	65	65	65
Limita RsIII	90	90	90

Fig.13 – Variation of Seismic Structural Insurance degree R_3 in variants B + GF + 3F and B + GF + 2F.

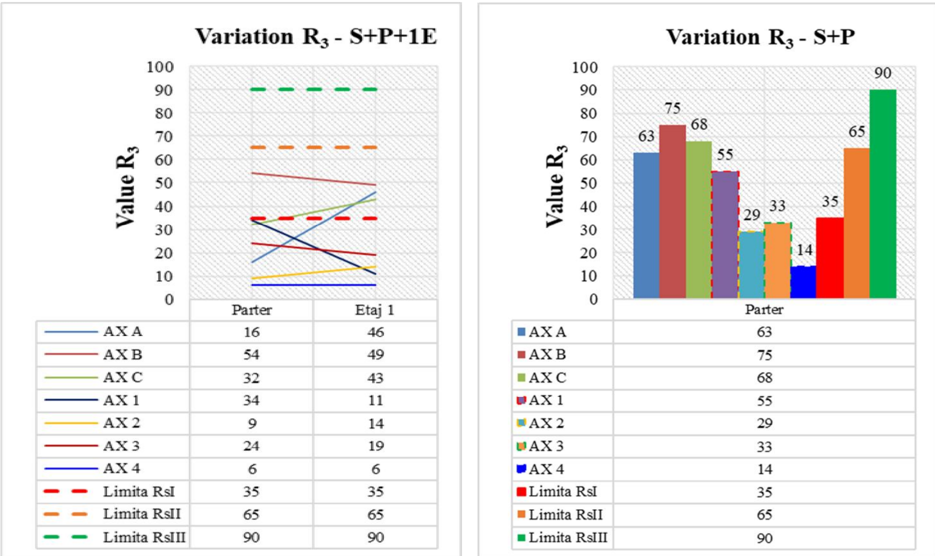


Fig.13 – The variation of the seismic structural insurance degree R3 in the variants B + GF + 13F and B + GF.

4.6. Building Sectioning

The structural system of the analysed building, Block D1, was realised in sections from the conception phase so the strategy does not apply to this building.

4.7. Leaving the Building

For the analysed building Block D1, this strategy may only be applied temporarily to avoid the risk of losing human lives, but the strategy must be combined with one or more of the proposed strategies to enhance the property and the land.

4.8. Building Consolidation

For the analysed building, Block D1, a consolidation strategy is the only solution for safe building operation.

The proposed consolidation method consists in covering the walls on both sides with a 6 cm thick mortar and reinforcing with steel nets.

Covering existing masonry with cement mortar or with concrete is a consolidation process widely used in Romania and in many other countries. This covering is applied on one or both sides after appropriate masonry preparation.

After the calculation, the vibration periods for the first 12 modes of vibration (Fig. 14) of the consolidated structure were determined. The vibration period for the first vibration mode was compared to the fundamental period determined according to the Seismic Design Code. Part I – Design Considerations for Buildings, Indicative P100-1/2013 ", Annex B, resulting in it falling within the permissible limit.

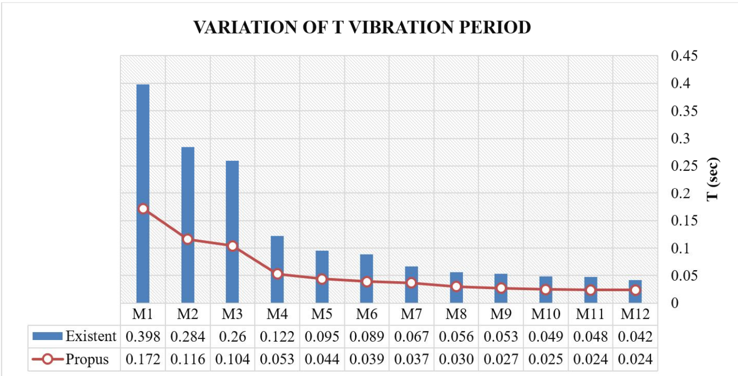


Fig.14 – Variation of the T-vibration period in the first 12 modes of vibration in the existing and proposed (enhanced).

From the calculations made on the block structure D1, a steel BST500C steel pipe consumption ranging between 4.5,...,10.7 kg/sq m on both sides of the wall resulted to be classified as consolidation in the seismic risk class RsIII and a consumption of about 15% higher for framing the building in the RsIV seismic risk class (Table 14). Due to the fact that the difference between the steel consumptions needed for the seismic risk class IV and III is low, for this type of buildings it is necessary that within the framework of the consolidation strategy it is chosen to fit the building into the RsIV seismic risk class.

Table 14

Consumption of Fixtures per Square Meter of Plated/Covered Wall

Seismic risk class	Consumption of fixtures per square meter of plated/ covered wall				
	Ground floor	1 floor	2 floor	3 floor	4 floor
RsIII	9.15	8.23	7.8	6.26	4.53
RsIV	10.7	9.95	8.95	7.47	5.09

Clearly, covering has a relatively greater effect on walls with masonry of poor quality (for example, for masonry with a cut-off strength of about 0.05 N/mm^2) for which the strength increase is very important, between 300,...,400% while for the walls with masonry of good quality the gain is only about 30%.

In order to secure the building and place it in the seismic risk class III or IV, the reinforcement method by plating/covering the walls on both sides with reinforced mortar with linked steel bars represents a solution to be verified after the structural calculation and the checks carried out.

The degree of seismic structural insurance results from the fixture area where the mortar layer is reinforces.

This method has the disadvantage that in some situations, depending on the bearing capacity of the foundation ground, it may be necessary to consolidate the foundations in order to take over the extra loads given by the weight of the mortar and reinforcements.

5. Conclusions

The study examined the possibilities of implementing the proposed strategies for the structural rehabilitation of block D1, being confirmed only two strategies, namely the reduction of the operational life and the consolidation of the building.

By reducing the service life, a reduction in terrain acceleration for design by scaling with a subunit factor is obtained, resulting in a lower seismic force applied to the building. For Block D1, the Long Term Reduction Strategy can be applied only in combination with the consolidation strategy. Applying only the strategy to reduce the service life, the building is kept in the RsI seismic risk class.

By reducing the operating lifetime, an increase in resistance is achieved, but not so high as to fit a building from the RsI seismic risk class into RsIII or RsIV. The strategy may apply to buildings where the value of the R_3 indicator is at the upper limit of the range, and by the resulting increase in strength, the building can fit the next seismic risk class.

Clearly, the consolidation of the structure by covering the walls with reinforced mortar has an important effect on walls with masonry of poor quality for which the strength increase is very important, in the case of the analysed structure the resistance increase reaching up to 550%.

For the structure under consideration and for similar structures, the only viable strategy for making it safe is the consolidation.

REFERENCES

Budescu M., Ciongradi I.P, Ţăranu N., Gravrilaş I, Ciupala M.A., Lungu I., *Reabilitarea construcţiilor*, Ed.Vesper, Iaşi, 2001.

Lungu D., *Protecţia antiseismică a clădirilor, o responsabilitate înţeleasă diferit de proprietari, autoritaţi şi specialişti*, Revista Ţara Bârsei, Anul **XIV** (**XXV**), 17-37 (2015).

* * * *Normativ condiţionat pentru proiectarea construcţiilor civile şi industriale din regiuni seismice*, P 13-63.

* * * *Normativ pentru proiectarea construcţiilor civile şi industriale din regiuni seismice*, P13-70.

* * * *Normativ pentru proiectare antiseismică a construcţiilor de locuinţe, social culturale, agrozootehnice şi industriale*, P100-78(81).

* * * *Normativ pentru proiectarea antiseismică a construcţiilor de locuinţe, social-culturale, agrozootehnice şi industriale*, P100-90.

* * * *Normativ pentru proiectarea antiseismică a construcţiilor de locuinţe, social-culturale, agrozootehnice şi industriale*, P100-92.

* * * *Cod de proiectare seismică.* Partea I: *Prevederi de proiectare pentru clădiri*, P100-1/2006.

* * * *Cod de proiectare seismică.* Partea I: *Prevederi de proiectare pentru clădiri*, P100-1/2013.

* * * *Cod de proiectare seismică.* Partea III: *Prevederi pentru evaluarea seismica a clădirilor existente*, P100-3/2008.

* * * *Legea 10/1995 privind calitatea in constructii*, republicată, cu modificările şi completările ulterioare, www.lege5.ro.

STRATEGII OPTIME DE REABILITARE STRUCTURALĂ PENTRU CLĂDIRILE REZIDENŢIALE DE LOCUIT

(Rezumat)

Alegerea unei strategii de intervenţie corecte este condiţionată de înţelegerea cât mai completă a deficienţelor individuale ale elementelor structurale şi nestructurale, a efectului combinat al acestora asupra mecanismului comportării seismice a clădirii, precum şi a deficienţelor de ansamblu privind rezistenţa, deformabilitatea, redundanţa şi regularitatea structurală.

Măsurile de intervenţie trebuie să fie corelate cu gradul de afectare (degradare) a materialelor, ca efect al unor cutremure pe care le-a suportat construcţia, al altor acţiuni de exploatare specifice, al unor tasări diferenţiale ale terenului sau al unor factori de mediu.

Măsurile de intervenţie urmăresc să elimine sau să reducă semnificativ deficienţele de diferite naturi ale structurii şi ale componentelor nestructurale.

În urma studiului efectuat s-a verificat posibilitatile aplicării strategiilor propuse pentru reabilitarea structurală a blocului D1, fiind confirmate ca şi aplicabile doar două strategii, şi anume, reducerea duratei de exploatare şi consolidarea clădirii.