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RETROSPECTIVE ANALYSIS OF THE REQUIREMENTS OF REGULATORY DOCUMENTS FOR SEISMIC RESISTANT CONSTRUCTION OF MASONRY BUILDINGS

[1]**Murashko O.V.**, Doctor of Engineering Science, Associate Professor,
alexeymurashko@gmail.com, ORCID: 0000-0002-2812-5951
[1]**Voloshchuk V.V.**, graduate student,
vadims9292@gmail.com, ORCID: 0000-0001-6259-7090
[1]*Odesa State Academy of Civil Engineering and Architecture*
4, street Didrichson, Odesa, 65029, Ukraine

Abstract. The article presents the results of a retrospective analysis of the building codes for the design of masonry buildings in seismic areas. The main attention is paid to the regulatory documents that were developed from the 1930s. The main regulatory documents that were introduced in Soviet times and their improvement are considered. The approval of regulatory requirements for seismic resistance in Ukraine, the introduction of seismic zoning maps depending on the place of construction. The main part of the paper contains a table comparing the main parameters, criteria and requirements of regulatory documents for the design of masonry buildings in seismic areas. The table can be used to track trends in the increase of requirements for seismic-resistant construction both by certain criteria (checking the strength of off-center compression, opening width, the ratio of the width of the partition to the width of the opening, etc. Based on the results of the assessment, the paper describes the possible use of retrospective analysis in the visual assessment of the seismic resistance of masonry buildings.

The systematisation of building codes performed in the paper makes it possible to: first, to trace trends in the development of regulatory documents; second, to identify elements that are obviously deficient in seismic resistance; third, to emphasise the list of issues that should be given priority attention during certification.

Thus, the year of construction, when compared with the regulatory documents which were valid at the time of construction, makes it possible to make a conclusion about the degree of initial prerequisites and solutions made in the project. The practical interest of this table is that when collecting information as part of the assessment process, based on the date of construction of the building, it is possible to conclude which clauses of the applicable regulatory documents the facility potentially does not comply with.

Keywords: seismic resistance, assessment system, retrospective analysis, regulatory framework.

Introduction. Today, in seismic areas of many countries, an important task is to assess the seismic resistance of buildings. The seismic resistance of buildings is assessed by applying a comprehensive seismic resistance assessment system. The first stage of this system is visual assessment, which includes a set of procedures for certification, visual assessment and seismic monitoring. To date, such a system has already been developed for buildings with a monolithic reinforced concrete frame, and development is ongoing using the existing methodology for other structural schemes of buildings. [1-3]. For this purpose, a comprehensive analysis of the regulatory framework for construction in seismic areas was conducted.

Analysis of recent research and publications. During the twentieth and twenty-first centuries, requirements for the seismic resistance of masonry buildings in the territory of modern Ukraine were developed. The development of the regulatory framework for ensuring earthquake resistance in Ukraine dates back to Soviet times, when the territory of modern Ukraine was part of

the USSR. During this period, the basis for regulating earthquake-resistant construction was the all-Union norms that took into account the experience of construction in various seismically active regions of the USSR, such as the Caucasus, Central Asia and the Far East. The development of the regulatory framework for earthquake-resistant construction was aimed at addressing the challenges of earthquake protection in various regions, including those that are now part of Ukraine. In the 1930s, the Soviet Union began to formulate the first rules for anti-seismic construction, according to which the intensity was 5-8 points, attention was paid to the symmetry of buildings to avoid uneven distribution of loads, and the use of rigid horizontal and vertical elms in structures was mandatory, but the first recommendations included simplified approaches to calculating seismic impacts due to the lack of advanced computing technology. In the 1950s, regulatory documents appeared, namely PSP-101-51 "Regulations for Construction in Seismic Areas" and design guidelines SN 8-57. "Norms and Rules for Construction in Seismic Areas" of earthquake-resistant structures. Their creation was caused by significant earthquakes in the USSR, in particular in Turkmenistan (Ashgabat, 1948), which had catastrophic consequences. These documents focused on the choice of materials, design schemes and construction technology. Requirements were developed for the rigidity of buildings and their ability to withstand horizontal loads during earthquakes [4-8].

The adoption of SNiP II-7-81 "Construction in Seismic Areas" [9] not only improved the methodology of calculations for seismic impacts, but this document also took into account international experience and research results in Soviet research institutes.

After gaining independence in 1991, Ukraine began to adapt the Soviet regulatory framework to national conditions, taking into account local geological features. In the current DBN B 1.1-12:2006 [10] and DBN B1.1-12 2014 [11], the intensity of seismic impacts, in terms of microseismic scale points, for the construction area should be taken on the basis of the General Seismic Zoning Maps (GZM-2004) of the territory of Ukraine.

In addition to the introduction of seismic zoning maps, the requirements for materials, structures and construction technology have become more stringent. This document has significantly changed the situation with seismic risk assessment, as the intensity has been increased by at least 1 point for a significant part of the territory of our country. Changing requirements for buildings and increased seismic hazard have led to the fact that a large number of buildings need to have their seismic resistance assessed.

Table 1 provides a comparative analysis of the requirements of regulatory documents for the design of masonry buildings. Presentation in the form of a table makes it possible to follow the trends in the change and development of regulatory documents, identify the most vulnerable parts and elements that have insufficient seismic resistance, and indicate issues that should be given more attention.

The purpose of the study. To perform a generalized retrospective analysis of the requirements of regulatory documents regarding the seismic resistance of masonry buildings.

Materials and methods of the study. In this paper, we analyzed the project documentation on the start of implementation and changes in the requirements for ensuring the seismic resistance of masonry buildings. In particular, a retrospective analysis was performed for buildings with a frame structural scheme [12-14]. Also, the American FEMA 154 indicates the year that shows changes in the regulatory framework of requirements and norms, so it is possible to track the trend of improving these norms and introducing more stringent requirements for the seismic resistance of buildings [15].

Table 1 – Comparative table of requirements for the design of masonry buildings

Criterion		SNiP II-12-62	SNiP II-12-69	SNiP II-7-81	DBN 2006	DBN 2014
1. Brick grade for masonry is not lower than		M75	M75	M75	M75	M75
2. The grade of mortar for masonry is not lower than		M25	M25/50	M25/50	M50	M50
3. Concrete stones, solid and hollow, with a total density of not less than		---		1200 kg/m^3	1200 kg/m^3	800 kg/m^3
4. Axial stretching Rp	1 category	Rp≥1.8 kg/cm^2	Rp≥1.8 kg/cm^2	Rp≥1.8 kg/cm^2	Rp≥1.2 kg/cm^2	---
	2 category	1.8 kg/cm^2>Rp>1.2 kg/cm^2	1.8 kg/cm^2>Rp>1.2 kg/cm^2	1.8 kg/cm^2>Rp>1.2 kg/cm^2		
	3rd category	1.2 kg/cm^2>Rp>0.6 kg/cm^2	1.2 kg/cm^2>Rp>0.6 kg/cm^2	---		
	4th category	0.6 kg/cm^2>Rp>0.3 kg/cm^2	---			
5. Emptiness		---			up to 20%	up to 35%
6. Off-center compression strength test		---			+	+
7. An anti-seismic belt (with a supporting section of the floor) should be arranged, as a rule, for the entire width of the wall; in external walls with a thickness of 500 mm or more, the width of the belt may be 100-150 mm less. The height of the belt should be at least 150 mm, and the concrete grade1 should be at least 150. Anti-seismic belts should have longitudinal reinforcement of 4dl0 for a design seismicity of 7-8 points and not less than 4 d12 for 9 points.		+				
8. Stairwells on two sides of the building for 9 points		---	+			
9. The value of vertical seismic load for the calculated seismicity should be taken as	7-8 points	---	15%		---	
	9 points		30%			
10. Beam lintels shall be embedded in the masonry walls by 30-35 cm. Lintels with a span of up to 1.5 m are allowed to be embedded by 25 cm.		+				
11. The removal of balconies at the calculated seismicity should not exceed	7 points	1.5 m			1.5 m	
	8 points	1.25 m				
	9 points	1.0 m	1.25 m			

Continuation of Table 1

Criterion			SNiP II-12-62	SNiP II-12-69	SNiP II-7-81	DBN 2006	DBN 2014
12. The height of the floor of buildings with load-bearing stone walls should not exceed in areas with seismicity (in case of reinforcement of masonry with reinforced concrete inclusions, another height is allowed)	7 points	1 category	8 m	6 m		5 m (6 m)	
		2 category	7 m				
		3rd category	6 m				
		4th category	5 m				
	8 points	1 category	7 m	5 m		4 m (5 m)	
		2 category	6 m				
		3rd category	5 m				
		4th category	---				
	9 points	1 category	6 m	4 m		3.5 m (4.5 m)	3.2 m (4.2 m)
		2 category	5 m				
		3rd category	---				
		4th category					
13. The distance between the axes of transverse walls or frames that replace them is not more than	6 points		---				20 m
	7 points	1 category	25 m	18 m			15 m
		2 category	20 m	15 m			
		3rd category	16 m	12 m		---	
		4th category	10 m	---		---	
	8 points	1 category	20 m	15 m			12 m
		2 category	16 m	12 m			
		3rd category	12 m	9 m		---	
		4th category	---	---		---	
	9 points	1 category	16 m	12 m			9 m
		2 category	12 m	9 m			
		3rd category	---				
		4th category					
14. The length of the sections should not exceed the standard seismicity	7 points	1 category	As for non-seismic areas	---		80 m	80 м
		2 category					
		3-4 categories				---	
	8 points	1 category	As for non-seismic areas	80 m		80 m	
		2 category		70 m			
		3rd category		60 m		---	
		4th category		---			
	9 points	1 category	No more than 60m	60 m		60 m	60 m
		2 category	No more than 40m	40 m			
		3rd category	-//-	---			
		4th category	-//-				

Continuation of Table 1

<table>
<tr><th colspan="3">Criterion</th><th>SNiP II-12-62</th><th>SNiP II-12-69</th><th>SNiP II-7-81</th><th>DBN 2006</th><th>DBN 2014</th></tr>
<tr><td colspan="3">15. Connecting walls in masonry</td><td>The masonry infill should be connected to the frame by reinforcement laid in horizontal joints in each direction from the post at least 70 cm.</td><td>In the wall joints, reinforcing mesh 1.5-2 m long should be laid in the masonry every 70 cm in height at a design seismicity of 7-8 points and every 50 cm at 9 points.</td><td colspan="3">Reinforcing mesh with a total cross-sectional area of longitudinal reinforcement of at least 1 cm^2, at least 120 cm long in each direction, should be placed in the masonry at wall joints every 70 cm in height at seismicity of 7 and 8 points and every 50 cm at 9 points.</td></tr>
<tr><td rowspan="14">16. The width of the walls should be not less than</td><td>6 points</td><td></td><td colspan="4">---</td><td>0.64 m</td></tr>
<tr><td rowspan="4">7 points</td><td>1 category</td><td colspan="4">0.64 m</td><td rowspan="2">0.77 m</td></tr>
<tr><td>2 category</td><td colspan="4">0.77 m</td></tr>
<tr><td>3rd category</td><td colspan="3">0.9 m</td><td colspan="2">---</td><td></td></tr>
<tr><td>4th category</td><td>0.9 m</td><td colspan="2">---</td><td colspan="2"></td><td></td></tr>
<tr><td rowspan="4">8 points</td><td>1 category</td><td colspan="4">0.9 m</td><td colspan="2" rowspan="2">1.16 m</td></tr>
<tr><td>2 category</td><td colspan="4">1.16 m</td></tr>
<tr><td>3rd category</td><td colspan="3">1.55 m</td><td>---</td><td colspan="2"></td></tr>
<tr><td>4th category</td><td>1.55 m</td><td colspan="2">---</td><td></td><td colspan="2"></td></tr>
<tr><td rowspan="4">9 points</td><td>1 category</td><td colspan="4">1.16 m</td><td colspan="2" rowspan="4">1.55 m</td></tr>
<tr><td>2 category</td><td colspan="4">1.55 m</td></tr>
<tr><td>3rd category</td><td colspan="4" rowspan="2">---</td></tr>
<tr><td>4th category</td></tr>
<tr><td rowspan="14">17. The width of the openings should be not less than</td><td>6 points</td><td></td><td colspan="4">---</td><td colspan="2">3.5 m</td></tr>
<tr><td rowspan="4">7 points</td><td>1 category</td><td colspan="4" rowspan="2">3.5 m</td><td colspan="2" rowspan="2">3 m</td></tr>
<tr><td>2 category</td></tr>
<tr><td>3rd category</td><td rowspan="2">2.5 m</td><td>2.5 m</td><td rowspan="2">---</td><td colspan="2" rowspan="2"></td></tr>
<tr><td>4th category</td><td>---</td></tr>
<tr><td rowspan="4">8 points</td><td>1 category</td><td colspan="4" rowspan="2">3 m</td><td colspan="2" rowspan="2">2.5 m</td></tr>
<tr><td>2 category</td></tr>
<tr><td>3rd category</td><td rowspan="2">2 m</td><td>2 m</td><td rowspan="2">---</td><td colspan="2" rowspan="2"></td></tr>
<tr><td>4th category</td><td>---</td></tr>
<tr><td rowspan="4">9 points</td><td>1 category</td><td colspan="4" rowspan="2">2.5 m</td><td colspan="2" rowspan="2">2 m</td></tr>
<tr><td>2 category</td></tr>
<tr><td>3rd category</td><td colspan="3" rowspan="2">---</td><td rowspan="2">---</td><td colspan="2" rowspan="2"></td></tr>
<tr><td>4th category</td></tr>
</table>

Continuation of Table 1

Criterion		SNiP II-12-62	SNiP II-12-69	SNiP II-7-81	DBN 2006	DBN 2014
18. The ratio of the width of the partition to the width of the opening should be not less than	6 points	---	---		0.3	
	7 points		0.33		0.35	
	8 points		0.5		0.5	
	9 points		0.75		0.8	
19. Wall projections in the plan are not more than	6 points	---			3.5 m	
	7 points	4 m	2 m			
	8 points	2 m	1 m			
	9 points	1 m	---			
20. The length of the section of resting of floor slabs and coatings on load-bearing structures shall be not less than:		120 mm	120 mm	120 mm	120 mm	120 mm
21. Partitions shall be attached to the vertical structures of buildings, and for lengths over 3 m – to the ceilings.		+	+	+	+	+

Results of the research. Based on this study, before a visual assessment of seismic resistance, based on the date of construction of the facility, it is possible to conclude which clauses of the current regulatory documents the facility does not comply with. In particular, the DBN V.2006 and V.2014, unlike the soviet standards, require that the strength of structures be tested for off-center compression when calculating them. The requirements for supporting beam lintels remain common to all documents. The requirements for the maximum floor height at different intensities are clearly visible, and the same trend is observed in the permissible distance between the axes of transverse walls or frames.

The requirements for the installation of anti-seismic belts, slab abutment areas, beam lintels, requirements for fixing partitions to vertical structures and for floors with a length of more than 3 m remained unchanged.

The systematization of the requirements of the regulatory documents presented in the table makes it possible to:

– first, to trace trends in the development of regulatory documents;

– second, to identify elements that obviously have a deficit in seismic resistance;

– third, to emphasize the list of issues that should be given priority attention during certification.

Thus, the year of construction, when compared with the regulatory documents in force at the time of construction, makes it possible to draw a conclusion about the degree of initial prerequisites and decisions made in the project. The practical interest of this table lies in the fact that when collecting information as part of the certification process, based on the date of construction of the facility, it is possible to conclude which clauses of the applicable regulatory documents the facility potentially does not comply with.

Conclusions.

1. A retrospective review and systematization of regulatory documents on the seismic resistance of masonry buildings has been carried out.

2. The tendency of development and detailing of the required parameters depending on the category, score and dimensions of the structure was noted, the unchanged requirements and the

requirements that were improved were identified.

3. According to the results of this study, when conducting a visual assessment of the seismic resistance of a building, based on the year of construction, it is possible to determine the main criteria to be paid attention to.

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РЕТРОСПЕКТИВНИЙ АНАЛІЗ ВИМОГ НОРМАТИВНИХ ДОКУМЕНТІВ З СЕЙСМОСТІЙКОГО БУДІВНИЦТВА ДО БУДИНКІВ З КАМ'ЯНОГО МУРУВАННЯ

[1]**Мурашко О.В.,** д.т.н., доцент,
alexeymurashko@gmail.com, ORCID: 0000-0002-2812-5951
[1]**Волощук В.В.,** аспірант,
vadims9292@gmail.com, ORCID: 0000-0001-6259-7090
[1]*Одеська державна академія будівництва та архітектури*
вул. Дідріхсона,4, м. Одеса, 65029, Україна

Анотація. У статті представлено результати ретроспективного аналізу будівельних норм щодо проєктування будівель з кам'яної кладки у сейсмічних районах. Основну увагу приділено нормативним документам, які розроблялися з 1930-х років. Розглянуто основні нормативні документи, які були введені за радянських часів та їх удосконалення. Затвердження нормативних вимог до сейсмостійкості в Україні, введення карт сейсмічного районування в залежності від місця будівництва. Основна частина статті містить таблицю порівняння основних параметрів, критеріїв та вимог нормативних документів до проєктування будівель з кам'яного мурування у сейсмічних районах. За допомогою таблиці можна відстежити тенденції підвищення вимог до сейсмостійкого будівництва, як за окремими критеріями (перевірка несучої здатності на позацентровий стиск, ширина прорізу, відношення ширини перегородки до ширини прорізу тощо), так і за всіма іншими (перевірка на несучу здатність на позацентровий стиск, ширина прорізу тощо). За результатами оцінювання в роботі описано можливість використання ретроспективного аналізу при візуальному оціюванні сейсмостійкості кам'яних будівель.

Проведена в роботі систематизація будівельних норм дає можливість: по-перше, простежити тенденції розвитку нормативних документів; по-друге, виявити елементи, які явно не мають достатнього рівня сейсмостійкості; по-третє, виокремити перелік питань, на які слід звернути першочергову увагу під час сертифікації.

Таким чином, рік будівництва, порівняно з нормативними документами, що діяли на момент будівництва, дає можливість зробити висновок про ступінь вихідних передумов і рішень, закладених у проекті. Практичний інтерес цієї таблиці полягає в тому, що при зборі інформації в рамках процесу оцінювання, виходячи з дати будівництва будівлі, можна зробити висновок про те, яким пунктам чинних нормативних документів об'єкт потенційно не відповідає.

Ключові слова: сейсмостійкість, система оцінювання, ретроспективний аналіз, нормативна база.

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