COMPARATIVE ANALYSIS BETWEEN EUROCODE 8 AND SNIP II-7-81*

Abstract

Report is based on the comparison of the Moldavian seismic design code (SNiP II-7-81*) and the European seismic design code EN 1998. It is focused on the main differences and similarities of this two codes and conduct reliability analysis between them.

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Table of contents

Introduction

Earthquake is one of the most dangerous natural phenomena that can easily destroy an entire city in few seconds. This is due to ground vibrations during such an event, which impose horizontal displacement in structures. Therefore, in order to reduce the seismic effect on structures, the design codes, normatives, standards are developed for improving the effects in building by giving to structural engineer a tool that could help him minimize damage and increase structure's dynamic proprieties.

In the early 20th century, each country, affected by earthquakes, started to develop its own design code for earthquake resistance buildings. The resulted codes vary depending on the developed region where they are applied, soil type, tradition in construction and other peculiar factor for each region.

The Eurasian continent consist of more than 100 countries, almost half of them are affected, partially or completely by earthquake. Every country has its own national design code, but it is necessary to emphasize 2 particular design codes due to the territory that they cover:

I. Eurocode 8 – Seismic code used in European Union and some countries affiliated to EU
II. SNIP II-7-81 – seismic code used in former Soviet Union. After collapse of Soviet Union codes are used by Commonwealth of Independent States (CIS) countries.

In Republic of Moldova the SNiP II-7-81* normative was adopted as national standard on 1 January 1982 and replaced the previous version – SNiP II-A-12-69*. During its existing science implementation, the normative suffered few changes (MEI, 2020):

- Change Nr.1, published in BOC (Bulletin of construction) Nr.9 from 1987
- Change Nr.2, published in BOC (Bulletin of construction) Nr. 11 from 1989

The Republic of Moldova is in the transition stage in with regards to implementation of the Eurocodes in the Republic of Moldova. The legal framework for the implementation and adoption of Eurocodes is:

- Law no. 112 of 02.07.2014 "*for the ratification of the Association Agreement between the Republic of Moldova, on the one hand, and the European Union and the European Atomic Energy Community and their Member States, on the other hand*"
- Government Decision no. 933 of 12.11.2014 "*on the harmonization of technical regulations and national standards in the field of construction with European legislation and standards*"
- Practical Code CP A.01.02 / L: 2014 "*Application and use of Eurocodes*"

The main scope of this paper is to provide a detailed comparison between the above mentioned two standards.

1. Brief history

1.1. Eurocode 8

The Eurocodes are European standards for the design of buildings and other civil engineering works and constructions products. These were developed by the European Committee for Standardization (CEN) upon the request of the European Commission.

The main purpose of Eurocodes is to harmonize technical specifications in European Union (EU) by creating a set of codes for structural design and remove obstacles that emerge from different national practices. There are ten structural Eurocodes that cover design principles. Eurocode 8 (EN 1998) applies to the design and construction of buildings and other civil engineering works in seismic regions. Its purpose it to ensure that in the event of earthquake, human lives are protected, the damage is a limited one; important structures for civil protection remain operational.

Table 1 Short history of EC

1971-1976	Public procurement Directive (1971) Appointment of a steering committee steering committee to examine the feasibility the feasibility of developing a common European common European set of technical documents covering the design of a design of a wide range of range of construction works.
1976-1990	Drafting the first set of technical documents under the Commission's authority: the Eurocodes – International inquiry (1980) – Unique Act and Act and New Approach (12/07/1986) (12/07/1986) – Construction product directive (CPD directive (CPD- 1989) – Transfer to CEN
1990-1998	Conversion, by CEN, of the first Eurocodes into provisional European standards (standards (ENVs)
1998-2006	Conversion of the provisional European standards ENV European standards EN
2007-present	Maintenance and evolution and evolution of the Eurocodes

In December 2012, through Mandate M/515, the European Commission asked CEN to develop new standards, or new parts of the existing standards. This was to include the incorporation of new performance requirements and design methods, the introduction of a more user-friendly approach in several existing standards, and a technical report on how to adapt the existing Eurocodes and the new Eurocode for structural glass such as to take into account the relevant impacts of future climate change.

1.2. SNiP II-7-81*

SNiP is the abbreviation that can be translated as “Construction norms and regulations”. The first SNiP were developed in 1929 in USSR and was called “Temporary norms and regulations for the design and erection of buildings and structures”.

For the first time, the documents called “Construction norms and regulations” (SNiP) ware published in 1954. All design and construction requirements were combined in 4 set of documents (Blinder, 2013):

- SNiP I – Construction materials, details and design
- SNiP II – Structural design
- SNiP III – Rules for production and reception
- SNiP IV – Price estimates indicators

Each part of SNiP is divided in separate sections, and each section in separated in chapters and paragraphs. While the academic institutions were in process of conducting scientific research in the field of construction, state organizations were increasing their experience in the design, construction and building management, separated chapters of SNiP were reviewed and new paragraphs were added.

Law of the USSR from 19991 “The Protection of Consumer Rights” classified building norms and rules as state standards (USSR, 1991). At the time of the collapse of the USSR in the construction industry, there were 140 building codes and 700 standards.

The SNiPs adopted in the USSR were not purely technical norms and rules, but also contained legal norms. So, SNiP 1.06.04-85 “Regulations on the chief engineer (chief architect) of the project”, approved by the resolution of the USSR Gosstroy of 06.06.1985 No. 103 and applied from July 15, 1985, determine the rights, duties and responsibilities of the chief engineer and chief architect of project.

The design norms applied on the territory of the Republic of Moldova are presented in the “Catalogul Documentelor Normative”(Catalogue of Normative Documents) The maintenance of the respective document is ensured annually by the Ministry of Economy and Infrastructure.

Currently, the system of normative documents in constructions (SNDC) of the Republic of Moldova consists of 2615 normative documents. Most normative documents in construction are adopted from the former U.R.S.S. and R.S.S.M., the application of which on the territory of the Republic of Moldova was allowed by letter of the former Ministry of Architecture and Constructions of the Republic of Moldova no. 03-05 / 340 of 01.04.1993 "Regarding the functioning of the construction norms on the territory of the Republic of Moldova". This letter authorized the application of the normative documents of the former U.R.S.S. and R.S.S.M., until their cancellation or other specification.

2. Structure of document

2.1. Eurocode 8

For the construction of a seismic resistant building, European Standards - Eurocode provide designers with a whole part dedicated to earthquake design which is Eurocode 8 also called EN 1998: “Design of structures for earthquake resistance”. The standard is applied for design and construction of buildings and civil engineering works in seismic regions.

Despite the fact that requirements presented in EN 1998 cover common structures; special structures such as nuclear power plants, dams, offshore structures are beyond of its scope. Seismic design presented in standard should satisfy additional requirements and be subject to complementary verifications. (Bisch, et al., 2012)

The objectives of seismic design in accordance with Eurocode 8 are explicitly stated. Its purpose is to ensure that in the event of earthquakes (EN 1998, clause 1.1.1):

- Human lives are protected
- Damage is limited
- Structures important for civil protection remain operational

These objectives are present throughout the code and condition the principles and application rules therein included.

Eurocode 8 is composed by 6 parts dealing with different types of constructions or subjects:

- EN 1998-1: General rules, seismic actions and rules for buildings
- EN 1998-2: Bridges
- EN 1998-3: Assessment and retrofitting of buildings
- EN 1998-4: Silos, tanks and pipelines
- EN 1998-5: Foundations, retaining structures and geotechnical aspects
- EN 1998-6: Towers, masts and chimneys

2.2. SNiP II-7-81*

As described in the previous chapter, for seismic design of buildings using SNiP normative one should use partition II “Structural Design”, chapter 7 “Construction in seismic regions”. Unlike EN 1998, SNiP II-7-81* regulations cover every aspect of seismic design in one document which includes 7 chapters with 1 annex.

Along with SNiP normative there are also official comments and guidance for most documents mentioned in every partition or chapter. This guidance named “Пособие к СНиП” contains generally adopted solutions with calculation examples that may serve as acceptable explanations for the designer’s choose.

3. Seismic hazard

In this chapter by “seismic hazard” will be considered how each code defines ground motion due to an earthquake.

3.1. Eurocode 8

In most of application given in EN 1998 seismic hazard is described in terms of a parameter, i.e. the value of the reference peak ground acceleration (PGA) , a_{gR}, on type A ground (Solomos, et al., 2008).

The PGA is strongly related with other two factors that should be described i.e. probability of exceedance in a certain period (annual rate of exceedance) and return period.

The annual rate of exceedance $w = w(a_g)$, is first defined as the number of exceedances per year of the ground motion level a_g at the site under consideration.

The mean or average return period, T_R, of this ground motion level ag at this site is next defined as simply the inverse of the above annual probability of exceedance, i.e.

$$T_R = \frac{1}{w} \tag{1}$$

One may seek to determine the probability of exceedance of the T_R return period ground motion (say the peak ground acceleration a_{gR}) in the next T_L years (in general $T_L \neq T_R$). This can be accomplished, based on the Poisson modeling.

In EN 1998 it is recommended that the reference peak ground acceleration on type A ground, a_{gR}, for the purpose of seismic zonation, corresponds to a reference probability of exceedance $P_{NCR} = 0.10$ in $T_L = 50$ years, or equivalently to a reference return period of $T_{NCR} \approx 475$ years.

The Poisson model for the occurrence of earthquakes, the mean return period T_R is given by following expression:

$$T_R = -\frac{T_L}{\ln(1-P)} \tag{1}$$

where P is the probability of exceedance of mean return period.

This information needs to be included in the National Annex. Thus, national territories are subdivided by the National Authorities into seismic zones, in the interior of which the hazard is assumed to be constant.

3.2. SNiP II-7-81*

In contrast with EN 1998, the SNiP normative is describing earthquake strength by using intensity MSK-64 scale. A differentiation of intensity zones according to the recurrence periods of earthquake for the general seismic zoning map of the territory of USSR was made, which had indexes 1,2,3 in list of settlements and on maps provided in SNiP II-7-81* annex. In addition to this for index 1 corresponds the average of earthquakes 0.01, index 2 – 0.001 and index 3 – 0.0001.

A new map of seismic zoning on the territory of Moldova Republic was implemented in April 2013. The new map reflects the seismic intensity of the territory more accurately in comparison with the old map developed in the earliest 1980s. Also, on the map the area 8 degrees of the MSK-64 scale was reduced (Alcaz, et al., 2011).

According to this map, the Republic of Moldova is divided into 3 zones with intensities between 6 to 8 degrees according to the MSK-64 scale, namely North-West with 6 degrees, in center of republic – 7 degrees and South-East – 8 degrees on MSK scale.

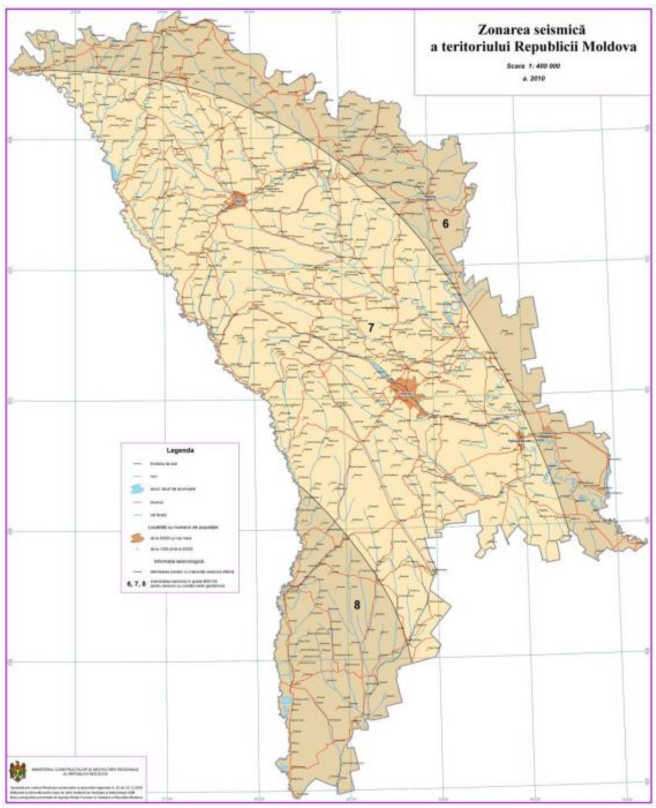

Figure 1 Seismic hazard map of Republic of Moldova in terms of MSK-64

The MSK-64 scale (see Annex 1) is based on earthquake results analysis and allows to predict intensity of seismic event using historical data. The table below (table 2), is generated from compiling the historical data with measurable results which provide an attempt of physical interpretation of MSK-64 scale.

Table 2 Seismic intensity based on recorded data. (Гордеев, et al., 2007)

Description	Design intensity according to MSK-64 scale			
	6	**7**	**8**	**9**
Maximum acceleration, $[m/s^2]$	0.5	1	2	4
Maximum soil speed frequency, $[m/s]$ for:				
Soft soils	0.06	0.12	0.24	0.48
Hard soils	0.045	0.09	0.16	0.36
Maximum soil displacement, $[m]$ for:				
Soft soils	0.045	0.09	0.17	0.35
Hard soils	0.025	0.05	0.1	0.19

In current code of Republic of Moldova, the only seismological parameter that describes construction site in design process is seismicity, measured in grades. For every grade of intensity in code is prescribed the maximum value of acceleration Ag, which is used for determination of inertial seismic loads that are introduced in seismic design of buildings as static loads.

Maximum design value of acceleration in terms of SNiP II-7-81* noted as Ag ($g = 9.81\ m/s^2$) is related to the factor A with design intensity I_p and computed in accordance with the following expression:

$$A = 0.1 \cdot 2^{I_p - 7} \tag{2}$$

Factor A, can take values 0.1, 0.2, 0.4 for site intensities 7,8,9.

3.3. Conclusion

As it can be summarized from the described above, seismicity of the site in both Europe and Republic of Moldova (new map) is evaluated in terms of return period and annual rate of exceedance. As it comes to evaluate the “strength” of seismic event the Eurocode uses more reliable parameter such as peak ground acceleration which is determined based on probabilistic seismic hazard analysis.

4. Ground condition and classification of soil profile at site

4.1. Eurocode 8

Seismic ground response proprieties depend on site soil conditions. In EN 1998 soil profile at site is classified according to the value of the average shear wave velocity, $v_{s,30}$, if this is available. Otherwise the value of N_{SPT} (Standard Penetration Test) should be used.

The average shear ware velocity $v_{s,30}$ is computed in accordance with the following expression:

$$v_{s,30} = \frac{30}{\sum_{i=1,N} \frac{h_i}{v_i}} \tag{3}$$

$$N_{SPT} = \frac{30}{\sum_{i=1,N} \frac{h_i}{N_{SPT}}} \tag{4}$$

where h_i and v_i denote the thickness (in meters) and shear-wave velocity (at a shear strain level of 10^{-5} or less) of the i-th formation level in a total of N, existing in the top 30 meters; N_{SPT} is standard penetration test blow number of the i-th formation level in a total of N.

The classification of soil conditions according to EN 1998 is described by following stratigraphic profiles:

Category of soil A

- Rock or other geological formation characterized by a shear wave velocity v_s of at least $800\ m/s$, including at most $5\ m$ of weaker material at the surface

Category of soil B

- Stiff deposits of sand, gravel or over consolidated clay, at least several tens of meters thick characterized by gradual increase of the mechanical proprieties with depth and by v_s values at least $360 - 400\ m/s$ at the depth 10 meters

Category of soil C

- Deep deposits of medium dense sand gravel or medium stiff clays with thickness from several tens to many hundreds of meters, characterized by v_s of at least $200\ m/s$ at depth of 10 meters, increasing to at least $350\ m/s$ at a depth of 50 meters

Category of soil D

- Loose cohesionless soil deposits with or without some soft cohesive layers, characterized by v_s values below $200\ m/s$ in the uppermost 20 meters
- Deposits with predominant soft – to – medium stiff cohesive soils, characterized by v_s values below $200\ m/s$ in the uppermost 20 meters

4.2. SNiP II-7-81*

SNiP normative defines 3 soil categories according to seismic properties. SNiP II-7-81* does not classify soils according to v_s – shear wave velocity and N_{SPT} – standard penetration test, it classifies soils according to consistency index, porosity ratios and other mechanical proprieties.

Category of soil I

- Rocks of all type (including permanently frozen and thawed out), non-eroded and slightly eroded: large fragmental soils, compact less humid magmatic rocks containing up to 30 %

of sandy-argillaceous filling: eroded and strongly eroded rocks and earth, permanently frozen soils at temperature minus 2 °C and below during construction and operation according to the Principle I(keeping the base soils frozen)

Category of soil II

- Eroded and strongly eroded rocks, including permanently frozen safe those related to the category I; large fragmental soils containing up to 30 % of sandy-argillaceous filling with prevalent contacts between the fragments; semi-gravel sands, coarse and medium, dense and medium, humid and less humid; fine and pulverescent sands, dense and medium, less humid; clay soils with consistency indices $I_L \leq 0.5$; at porosity coefficient $e < 0.9$ for clays and loams and $e < 0.7$ – for clay sands; permanently frozen earth, plastic-frozen and granular-frozen as well as hard-frozen at the temperature above minus 2°C during construction and operation according to the Principle I

Category of soil III

- Loose sands notwithstanding of humidity and coarsity; semi-gravel sands, coarse and medium, dense and medium, water-saturated; fine and pulverescent sands, dense and medium, humid and water-saturated; clay soils with consistency indices $I_L > 0.5$; clay soils with consistency indices $I_L \leq 0.5$ at porosity coefficient $e < 0.9$ for clays and loams and $e < 0.7$ – for clay sands; permanently frozen earth during construction and operation according to the Principle II (thawing of base soils is allowed).

Soil category is needed to define site seismicity which is chosen depending on region's seismicity.

Table 3 Site seismicity for region seismicity

Soil category	Site seismicity for region seismicity, grades MSK-64		
	7	8	9
I	6	7	8
II	7	8	9
III	8	9	>9

From table no 3 can be denoted that seismic intensity of any given site is in strongly dependence of soil category. For softer soil, the seismic intensity will increase and vice versa.

For example, if the site is situated in region with seismicity of 8 grade MSK-64, and soils of investigated site belongs to category I; then site seismicity is decreasing with 1 grade i.e. 7 grade MSK-64.

4.3. Conclusion

To conclude all above, one can say that both codes treat different soil classification. The main difference in classification is that the SNiP II-7-81* does not categorize by shear wave velocity of seismic waves, which is common parameter of soil classification in European, American, Japanese and other seismic codes of countries affected by earthquake. Moreover, other

CSI countries such asa (Russia, Ukraine, Azerbaijan, Armenia and others) which use modified version of SNiP II-7-81* made a clear transition from describing and grouping soils by their mechanical proprieties to applying share wave velocity in their seismic design codes. The attempt of this transition is shown in table below.

Table 4 Soil categories in SNiP II-7-81 and EN 1998*

V_s(m/s)	180		360	800 1600
SNiP	III		II	I
EC -8	D	C	B	A

5. Elastic response spectrum

Elastic spectrum graphs and soil amplifications coefficients defined in codes are the main parameters determining impacted seismic forces on structure. These factors are developed after a lot of research.

5.1. Eurocode 8

The response elastic spectrum given in EN 1998, part 1-1 is defined by following relation:

$$\frac{S_e}{g} = S \cdot S_e(T) \tag{2}$$

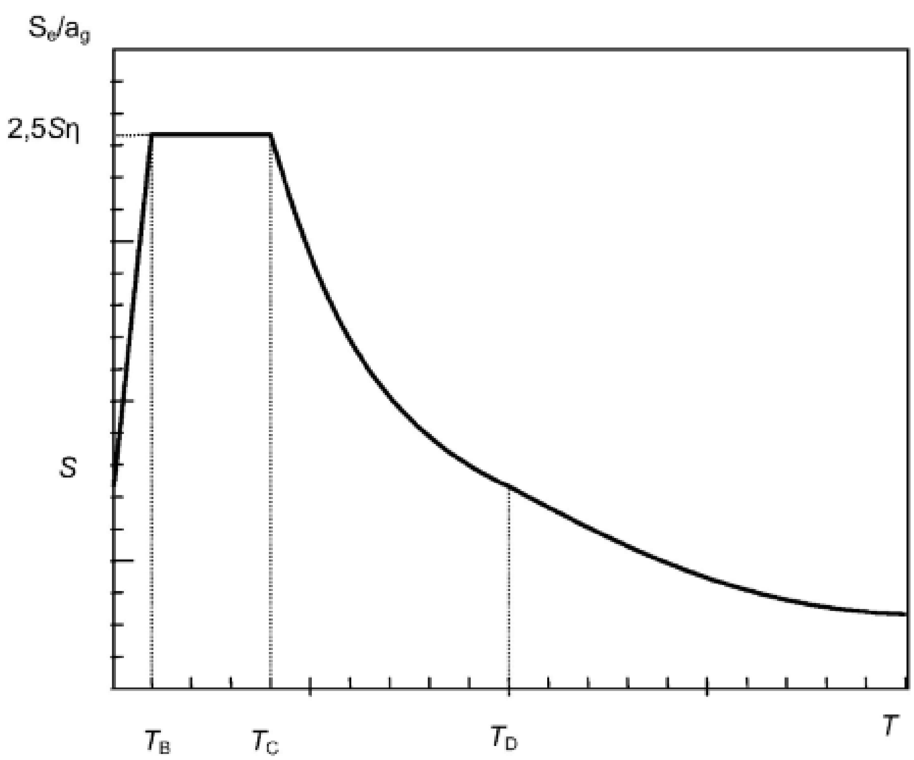

Figure 2

where function $S_e(T)$ is given by:

$$0 \le T \le T_B \qquad S_e(T) = a_g \cdot S \cdot \left[1 + \frac{T}{T_B} \cdot (\eta \cdot 2.5 - 1)\right]$$
$$T_B \le T \le T_C \qquad S_e(T) = a_g \cdot S \cdot \eta \cdot 2.5 \tag{3}$$
$$T_C \le T \le T_D \qquad S_e(T) = a_g \cdot S \cdot \eta \cdot 2.5 \left[\frac{T_C}{T}\right]$$
$$T_D \le T \le 4s \qquad S_e(T) = a_g \cdot S \cdot \eta \cdot 2.5 \left[\frac{T_C T_D}{T^2}\right]$$

where following notation is used:

$S_e(T)$ – elastic response spectrum

a_g – design ground acceleration on type A ground

T_B, T_C, T_D – corner periods in the spectrum

S – soil factor

η – damping correction factor ($\eta = 1$ for 5% damping)

Values T_B, T_C, T_D and S for each soil category and site proprieties could be found in national annex of Eurocode 8. The recommended values are shown in table below:

5.2. SNiP II-7-81*

The elastic response spectrum in SNiP II-7-81* is defined by following relation:

$$\frac{S_e}{g} = \beta \cdot k_{soil} \tag{4}$$

where β – is a dynamic coefficient with is equal to:

- For soil category I:

$$\beta = \frac{1}{T}\text{, but not greater then 3 and not less than 0.8}$$

- For soil category II and III:

$$\beta = 17 \cdot T + 1 \text{ for } T < 0.1\ (s)$$
$$\beta = 2.7 \text{ for } 0.1 \le T \le 0.5\ (s)$$
$$\beta = \frac{1.35}{T} \text{ for } T > 0.59\ (s)\text{, but not less than 0.8}$$

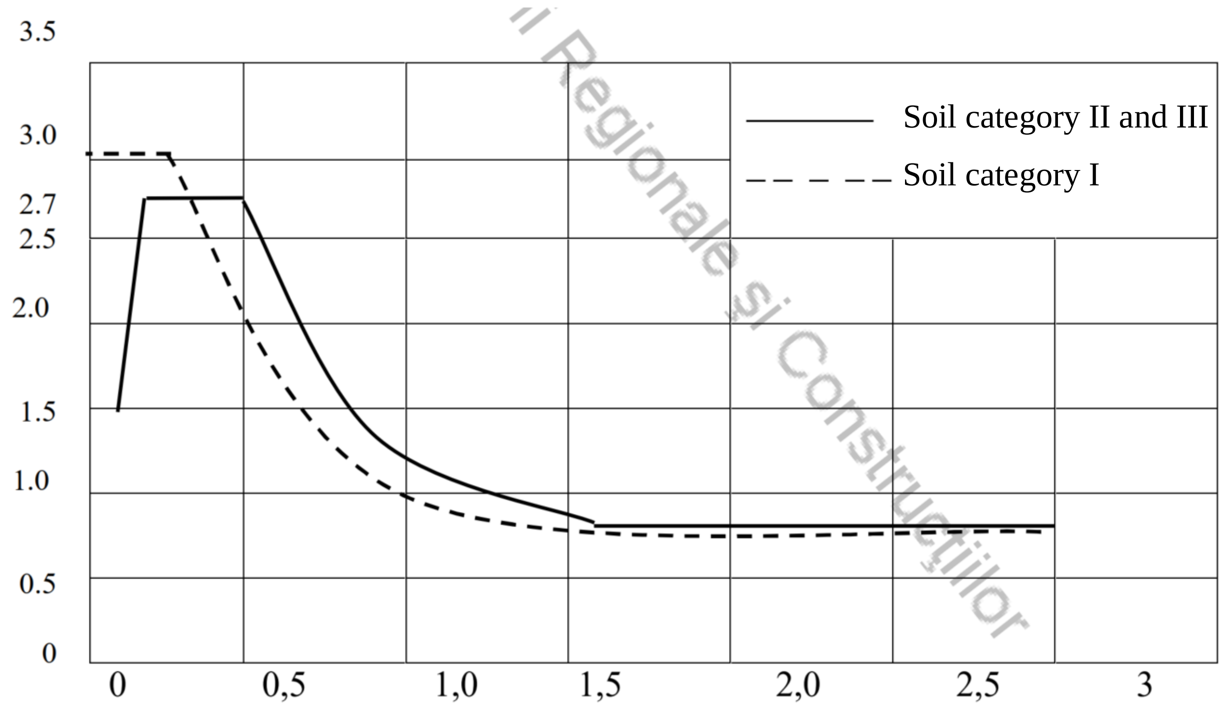

Figure 3

5.3. Conclusion

6. Building behavior factor

During the seismic design structural engineers are using the concept of the energy absorption, that leads to reducing the seismic forces in order to achieve economy. The behavior factor in design codes are taking important place in the design procedure by virtue of accounting implicitly for inelastic response, the presence of damping and other force reducing effects.

6.1. Eurocode 8

The European standards, EN 1998, specifies maximum allowable behavior factor q values for different structural configurations and forms of construction. For the design of the RC structures, three classes are defined: low (DCL), medium (DCM) and high (DCH).

Table 5

Structural type	DCM	DCH
Frame, dual and coupled wall systems	$3.0\alpha_u/\alpha_1$	$4.5\alpha_u/\alpha_1$
Uncoupled wall system	3.0	$4.0\alpha_u/\alpha_1$
Torsional flexible system	2.0	3.0
Inverted pendulum system	1.5	2.0

6.2. SNiP II-7-81*

In SNiP II-7-81* the behavior factor is described with coefficient k_1, which is the inverse of building behavior factor defined in EN 1998. Three values of coefficient k_1 are defined as follows:

- $k_1 = 1$ – Buildings and structures where damages and irreversible deformations are not allowed. The building behavior is completely elastic under seismic load.
- $k_1 = 0.25$ – Buildings and structures where residual deformations and damages complicating their normal operation are allowed, under conditions of human safety and equipment preservation. The buildings behave plastically under seismic load.
- $k_1 = 0.12$ – Buildings and structures where significant residual deformations, cracks, damage of separate elements temporarily suspending their normal operations are allowed in presence of measures ensuring human safety.

6.3. Conclusion

Both design codes treat the building behavior factor as an important coefficient that takes into account energy absorption during a seismic event. The behavior factor q is described more accurately in Eurocode 8, than in SNiP II-7-81* where it can be interpreted in two ways. (see general conclusion)

7. Comparative example

As example is considered a 3-story frame which design will be simplified as a cantilever with lumped masses at each story (see Figure 4)

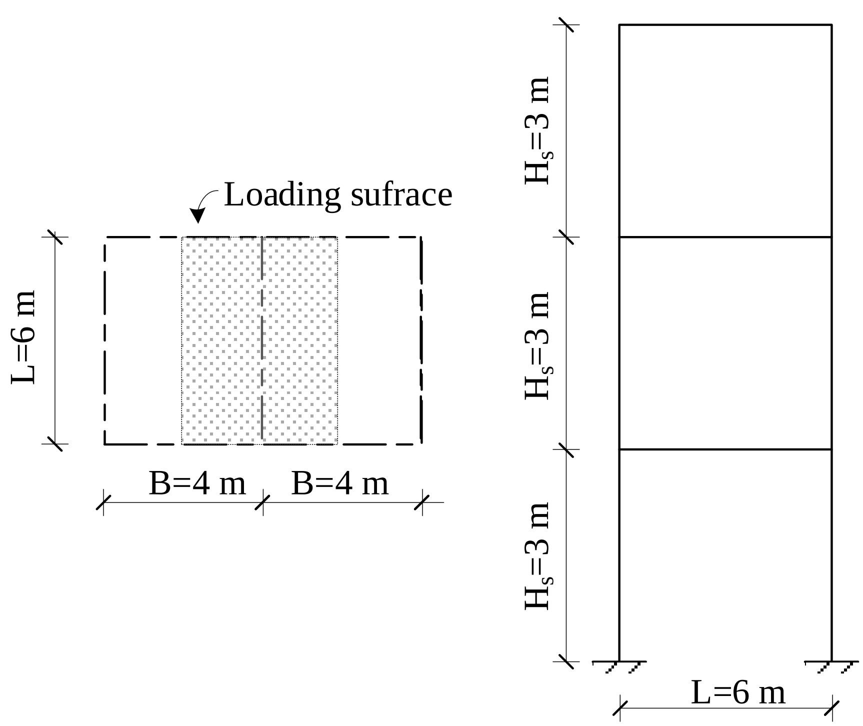

Figure 4

Table 6 Initial conditions for design

Description	U.M	Value
Frame span, L	m	6
Span length, B	m	4
Story height, H_s	m	3
Slab thickness, δ	cm	18
Material used	−	Concrete C15
Column section, bxh	cm	40x40
Beam section, bxh	cm	40x50
Live load according to SNiP II-7-81*, p	kPa	1.5
Live load according to Eurocode 1, p	kPa	2
Site intensity	MSK-64	8
Soil category according to SNiP II-7-81*	−	III
PGA	m/s^2	$0.16g$
Soil type according to EC-8	−	Type C

Table 7 Loads on structure

Description	Unit	Normative value	Safety coefficient γ_f	Design Value	Note
Permanent load on slab					
Laminate flooring	kN/m^2	0.118	1.3	0.153	СНиП 2.01.07-85, tab. 1
Acrylic adhesive for parquet based on solvent Thomsit P 618		0.110	1.3	0.143	СНиП 2.01.07-85, tab. 2
Screed from mortar M150		0.589	1.3	0.765	СНиП 2.01.07-85, tab. 1
Thermal and sound insulation		0.123	1.3	0.159	NCM F.03.02-2005
Concrete slab ($\delta = 18\ cm$, $\rho = 2400\ kg/m^3$)		4.32	1.1	4.75	СНиП 2.01.07-85, tab. 1
Total permanent load		5.26	-	5.97	
Permanent load on other elements					
Beam weight ($bxh = 40x50\ cm$)	kN/m	4.8	1.1	5.28	СНиП 2.01.07-85, tab. 1
Colum weight $bxh = 40x40\ cm$)		3.84	1.1	4.22	СНиП 2.01.07-85, tab. 1
Total permanent load on other structures		8.64	-	9.504	
Live load (P_t)					
Quasi-permanent (p_{qvc})					
Quasi-permanent on slab	kN/m^2	0.3	1.3	0.39	СНиП 2.01.07-85, tab. 1 and 3
Variable Load (p_{var})					
Variable load on slab	kN/m^2	1.2	1.2	1.56	СНиП 2.01.07-85, tab. 1 and 3
Total live load		1.5	-	1.95	
Snow load	kN/m^2	0.5	1.4	0.7	СНиП 2.01.07-85, p.5.7

$$Q_1 = Q_2 = 0.9 \cdot Q_{perm,1} + 0.8 \cdot Q_{qsp,1} + 0.5 \cdot Q_{var,1} = 206.46\ kN$$
$$Q_{perm,1} = q_{sl} \cdot B \cdot L + q_b \cdot L + 2 \cdot q_c \cdot H_s = 200.28\ kN$$
$$Q_{qsp,1} = q_{qsp} \cdot B \cdot L = 9.36\ kN$$
$$Q_{var,1} = q_{var} \cdot B \cdot L = 37.44\ kN$$

$$Q_3 = 0.9 \cdot Q_{perm,1} + 0.8 \cdot Q_{qsp,1} + 0.5 \cdot Q_{var,1} = 214.86$$
$$Q_{perm,1} = q_{sl} \cdot B \cdot L + q_b \cdot L + 2 \cdot q_c \cdot H_s = 200.28\ kN$$
$$Q_{qsp,1} = q_{qsp} \cdot B \cdot L = 9.36\ kN$$
$$Q_{var,1} = q_{var} \cdot B \cdot L + q_s \cdot B \cdot L = 52.24\ kN$$

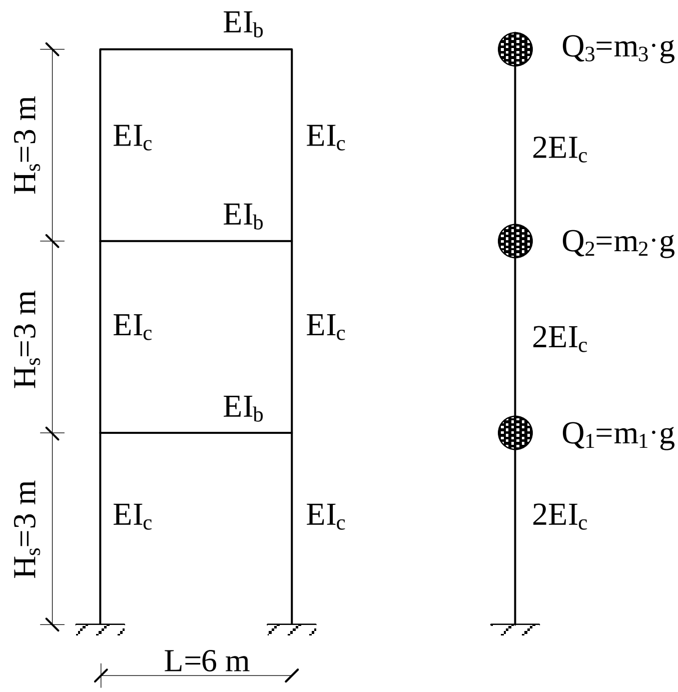

Figure 5

The stiffness matrix:

$$[K] = \begin{bmatrix} k_1 + k_2 & -k_2 & 0 \\ -k_2 & k_2 + k_3 & -k_3 \\ 0 & -k_3 & k_3 \end{bmatrix}$$

$$[K] = \begin{bmatrix} 7.585 & -3.793 & 0 \\ -3.793 & 7.585 & -3.793 \\ 0 & -3.793 & 3.793 \end{bmatrix} \left(\frac{N}{m}\right)$$

The mass matrix:

$$[M] = \begin{bmatrix} 2.105 \cdot 10^4 & 0 & 0 \\ 0 & 2.105 \cdot 10^4 & 0 \\ 0 & 0 & 2.191 \cdot 10^4 \end{bmatrix} (kg)$$

The motion equation is:

$$[M]\{\ddot{U}\} + [C]\{\dot{U}\} + [K]\{U\} = -[M]\{1\}\ddot{u_g}(t)$$

The eigenvalue problem can be solved using the following relationships:

$$([K] - \omega^2[M])[\Phi] = 0$$

$$|[K] - \omega^2[M]| = 0$$

Spectral matrix and mode shape matrix:

$$\Omega^2 = \begin{bmatrix} 5.826 \cdot 10^3 & 0 & 0 \\ 0 & 2.763 \cdot 10^3 & 0 \\ 0 & 0 & 349.086 \end{bmatrix} \left(\left(\frac{rad}{s}\right)^2\right)$$

$$\Phi = \begin{bmatrix} 2.263 & -0.782 & 0.521 \\ 1.806 & 0.466 & -1.233 \\ 1 & 1 & 1 \end{bmatrix}$$

Frequencies and natural periods of structures are:

$$\omega = \begin{bmatrix} 18.684 & 0 & 0 \\ 0 & 52.564 & 0 \\ 0 & 0 & 76.328 \end{bmatrix} \left(\frac{rad}{s}\right)$$

$$T = \begin{bmatrix} 0.336 & 0 & 0 \\ 0 & 0.119 & 0 \\ 0 & 0 & 0.082 \end{bmatrix}$$

In accordance with p.2.6 of SNiP II-7-81* for soil category III and vibration periods $0.1 < T_i < 0.5$, the dynamic coefficient is computed by following expression:

$$\beta_1 = \beta_2 = 2.7$$

In accordance with p.2.6 of SNiP II-7-81* for soil category III and vibration periods $T_i < 0.1$, the dynamic coefficient is computed by following expression:

$$\beta_3 = 17 \cdot T_i + 1 = 2.394$$

Relation for computing form coefficients can be found in SNiP II-7-81*, p.2.7.

- For I mode of vibration:

$$\eta_{11} = 0.583, \;\; \eta_{12} = 0.972, \;\; \eta_{13} = 1.218$$

- For II mode of vibration:

$$\eta_{21} = 0.352, \;\; \eta_{22} = 0.164, \;\; \eta_{23} = -0.275$$

- For III mode of vibration:

$$\eta_{31} = 0.11, \;\; \eta_{32} = -0.136, \;\; \eta_{33} = 0.057$$

Seismic force for each mode:

- For I mode of vibration:

$$S_{11} = 14.9\ (kN),\ \ S_{12} = 27.1\ (kN),\ \ S_{13} = 35.3\ (kN)$$

- For II mode of vibration:

$$S_{21} = 9.8\ (kN),\ \ S_{22} = 4.6\ (kN),\ \ S_{23} = -7.979\ (kN)$$

- For III mode of vibration:

$$S_{31} = 2.72\ (kN),\ \ S_{32} = -3.4\ (kN),\ \ S_{33} = 1.48\ (kN)$$

The resulted vector of forces on each story:

$$\{S\} = \sqrt{\{S\}_1^2 + \{S\}_2^2 + \{S\}_3^2} = \begin{Bmatrix} 18.12 \\ 27.67 \\ 36.24 \end{Bmatrix}\ (kN)$$

Eurocode

In Eurocode 8, clause 3.2.4 states that masses to be used in a seismic analysis should be those associated with the load combination:

$$G + \Psi_{E,i} Q$$

Table 8

Level	$G\ (kN)$	$Q\ (kN)$	$G + \Psi_{E,i}Q\ (kN)$	$Mass\ (kg)$
1, 2	$126.24 + 28.8 + 23.04$	48	201.84	$2.058 \cdot 10^4$
3		52	203.84	$2.079 \cdot 10^4$

The stiffness matrix:

$$[K] = \begin{bmatrix} k_1 + k_2 & -k_2 & 0 \\ -k_2 & k_2 + k_3 & -k_3 \\ 0 & -k_3 & k_3 \end{bmatrix}$$

$$[K] = \begin{bmatrix} 7.585 & -3.793 & 0 \\ -3.793 & 7.585 & -3.793 \\ 0 & -3.793 & 3.793 \end{bmatrix} \left(\frac{N}{m}\right)$$

The mass matrix:

$$[M] = \begin{bmatrix} 2.058 \cdot 10^4 & 0 & 0 \\ 0 & 2.058 \cdot 10^4 & 0 \\ 0 & 0 & 2.079 \cdot 10^4 \end{bmatrix}\ (kg)$$

Spectral matrix and mode shape matrix:

$$\Omega^2 = \begin{bmatrix} 5.977 \cdot 10^3 & 0 & 0 \\ 0 & 2.855 \cdot 10^3 & 0 \\ 0 & 0 & 362.987 \end{bmatrix} \left(\left(\frac{rad}{s}\right)^2\right)$$

$$\Phi = \begin{bmatrix} 2.251 & -0.797 & 0.546 \\ 1.803 & 0.451 & -1.243 \\ 1 & 1 & 1 \end{bmatrix}$$

Frequencies and natural periods of structures are:

$$\omega = \begin{bmatrix} 19.052 & 0 & 0 \\ 0 & 53.432 & 0 \\ 0 & 0 & 77.311 \end{bmatrix} \left(\frac{rad}{s}\right)$$

$$T = \begin{bmatrix} 0.33 & 0 & 0 \\ 0 & 0.118 & 0 \\ 0 & 0 & 0.081 \end{bmatrix}$$

Spectral parameters for design response spectrum for soil type C are:

$$S = 1.15,\ \ T_B = 0.2\ s,\ \ T_C = 0.6\ s,\ \ T_D = 2.0\ s$$

The reference peak ground acceleration is considered $a_{gR} = 0.16g = 1.57\ m/s^2$. The importance factor for the building is $\gamma_I = 1$, so the design ground acceleration $a_g = \gamma_I a_{gR} = 1.57\ m/s^2$. The resulting design spectrum is shown in Figure 4 for behavior factor $q = 1$ and $q = 4$

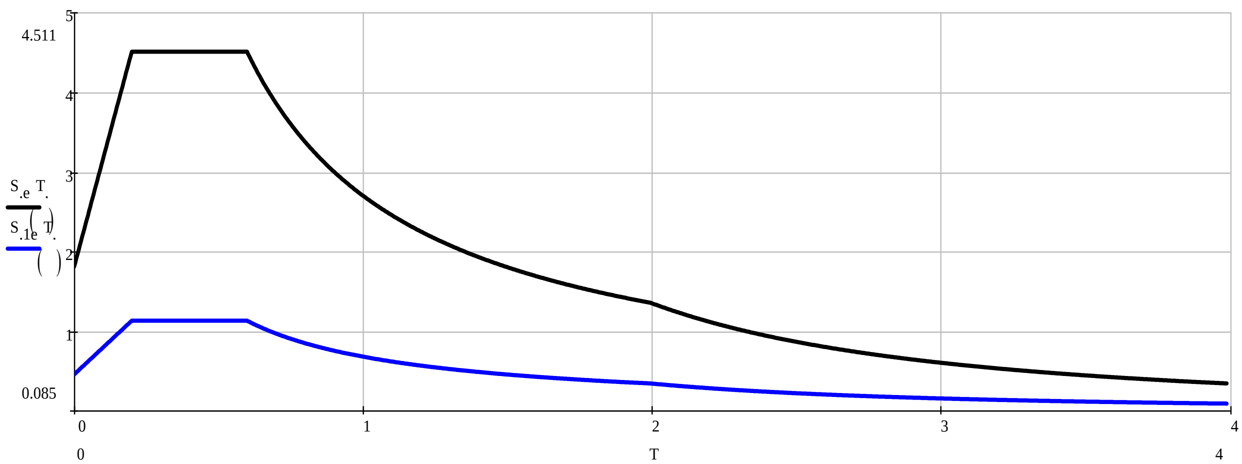

Figure 6

For the damping ratio $\xi = 0.05$ the following spectral data are extracted from graph:

$$S_{A1} = 1.128\ (m/s^2),\ \ S_{A2} = 0.85\ (m/s^2),\ \ S_{A3} = 0.725\ (m/s^2)$$

Modal participation factors:

$$\Gamma_1 = \frac{\{\Phi\}_1^T [M]\{1\}}{\{\Phi\}_1^T [M]\{\Phi\}_1} = 0.542$$

$$\Gamma_2 = \frac{\{\Phi\}_2^T [M]\{1\}}{\{\Phi\}_2^T [M]\{\Phi\}_2} = 0.35$$

$$\Gamma_2 = \frac{\{\Phi\}_3^T [M]\{1\}}{\{\Phi\}_3^T [M]\{\Phi\}_3} = 0.108$$

Seismic force for each mode:

- For I mode of vibration:

$$S_{11} = 12.579\ (kN),\ \ S_{12} = 22.681\ (kN),\ \ S_{13} = 28.603\ (kN)$$

- For II mode of vibration:

$$S_{21} = 6.12\ (kN),\ \ S_{22} = 2.757\ (kN),\ \ S_{23} = -4.928\ (kN)$$

- For III mode of vibration:

$$S_{31} = 1.615\ (kN),\ \ S_{32} = -2.009\ (kN),\ \ S_{33} = 0.891\ (kN)$$

The resulted vector of forces on each story:

$$\{S\} = \sqrt{\{S\}_1^2 + \{S\}_2^2 + \{S\}_3^2} = \begin{Bmatrix} 14.082 \\ 22.936 \\ 29.038 \end{Bmatrix}\ (kN)$$

Table 9 Final results

Level	Forces at story according to SNiP II-7-81*, kN	Forces at story according to EC 8, kN	Ratio, $\frac{EC-8}{SNiP\ II-7-81*}$
1 story	18.122	14.082	0.777
2 story	27.67	22.936	0.829
3 story	36.242	29.038	0.801

8. General conclusion

1. The SNiP II-7-81* elaborated in 1981 till present day did not suffer any significant change since for over 40 years, the information and prescription presented in SNiP is briefly described with further explanation in guidance. On other hand, Eurocode 8 that consists of 6 parts offers for engineers a detailed explanation on every step of design.

2. Not in any place of SNiP II-7-81* normative is explained how the seismic assessment of existing structures should to be made, that is different from Eurocode. European construction standards had dedicated a whole section for this – Eurocode 8, Part 3: Assessment and retrofitting of existing structures.

3. Regarding the seismic hazard, one can affirm that both normative have different approach of quantifying the seismic action i.e. ground motion. Nevertheless, the basis on which the hazard maps are made are the same – probabilistic seismic hazard analysis.

4. The soil classification varies in both codes. The main difference consists that in Eurocode the soils are classified in categories by physical proprieties - the shear wave velocities, unlike SNiP II-7-81* that divides 3 categories of soil that are categorized using mechanical proprieties of soil.

5. What concerns the elastic response spectrum, in chapter Nr.5 in clear shown that the shapes of spectrum are the same, i.e. for structures with lower natural period of structure have higher acceleration values, while structures with high natural period that will have smaller acceleration values, but higher displacement. Along with shape similarity, one can notice that this shape is formed in EC by using design acceleration of site, different corner periods and soil factor provided in EN 1998 or National Annex of EN 1998 for each soil category, in contrast with SNiP that uses only natural period of structure to plot the response sectrum.

6. Behavior factor are treated as important coefficient in both codes. Despite its importance; in SNiP II-7-81* one could find a double sense/interpretation for this coefficient. The first interpretation could be that design is made for a strong and rare earthquake; if we assume that during a strong earthquake in structure are allowed to be plastic deformation and local damage that does not cause harm to people then maximum efforts in structural elements could be raised. This explains multiplication with coefficient $k_1 \leq 1$, which is $k_1 = 0.25$ for most of structures. The second interpretation is that the design is made for weak and frequently earthquake; so, for a site intensity with 9 grade MSK-64 scale, it is diminished to 7 grade MSK-64 scale. This hypothesis suggests that during such events, the people safety is satisfied. Unlike SNiP, the behavior factor in EN 1998 is clearly described for every type of structure.

7. A comparative example had been performed for a simple 3 story structure. The result shown in table 9 denotes that final result using SNiP II-7-81* normative are higher then

the results using EN 1998. The main cause is in response spectrum. The dynamic coefficient values are higher in SNiP II-7-81* then the seismic acceleration from spectrum response of Eurocode 8. Other reason could be that in SNiP, before the special combination of force is generated, all actions and loads (permanent, quasi-permanent and variable) that affects structures are multiplied with a safety coefficient that is $\gamma_f \geq 1$, meanwhile the Eurocode does not prescribe this procedure for permanent loads.

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Annex 1

Table 10 The intensity MSK-64 scale

Intensity, grade	Building damage and earthquake description	
6 (Strong)	Perceive by people	Felt by most indoors and outdoors. Many people in buildings are frightened and run outdoor. A few people may lose their balance. Domestic animals run out of their stalls. In few instances dishes and glassware may break, books fall down. Heavy furniture possibly may move and small steeple bells may ring.
	Building damage	Damage of grade 1 is sustained in single buildings of type B and in many of type A. Damage in few buildings of type A is of grade 2.
	Damage on earth surface	In few cases cracks up to widths of 1 cm possible in wet ground; in mountains occasional land – slips; change in flow of springs and in level of well – water is observed.
7 (Very strong)	Perceive by people	Most people are frightened and try to run outdoors. Many find it difficult to stand. The vibration is noticed by persons driving in cars. Large bells ring.
	Building damage	In many buildings of type C damage of grade 1 is caused; in many buildings of type B damage is of grade 2; Many buildings of type A suffer damage of grade 3; few of grade 4. In single instances landslips of roadway on steep slopes; cracks in roads; seams of pipelines damaged; cracks in stone walls.
	Damage on earth surface	Waves are formed on water, and water is made turbid by mud stirred up. Water levels in wells change, and the flow of springs changes. In few cases dry springs have their flow restored and existing springs stop flowing. In isolated instances parts of sandy or gravelly banks slip off.
8 (Damaging)	Perceive by people	Fright and panic; also, persons driving motor cars are disturbed. Here and there branches of trees break off. Even heavy furniture moves and partly overturns. Hangings lamps are in part damaged.
	Building damage	Many buildings of type C suffer damage of grade 2, few of grade 3. Many buildings of type B suffer damage of grade 3 and few of grade 4, and many buildings of type A suffer damage of grade 4 and few of grade 5. Occasional breakage of pipe seams. Memorial and monuments move and twist. Tombstones overturn. Stone walls collapse.
	Damage on earth surface	Small land – slips in hollows and on banked roads on steep slopes; cracks in ground up to widths of several centimeters. Water in lakes becomes turbid. Dry wells refill and existing wells become dry. In many cases change of flow and level of water
9 (Destructive)	Perceive by people	General panic; Considerable damage to furniture. Animals run to and in confusion.
	Building damage	Many buildings of type C suffer damage of grade 3, a few of grade 4. Many buildings of type B show damage of grade 4, a few of grade 5. Many buildings of type A suffer damage of grade 5. Monuments and columns fall. Considerable damage to reservoirs; underground pipes partly broken. In individual cases railway lines are bent and roadways damaged.
	Damage on earth surface	On flat land overflow of water, sand and mud is often observed. Ground cracks to widths of up to 10 cm, on slopes and river banks more than 10 cm; a large number of slight cracks in ground; falls of rock, many landslides and earth flows; large waves on water. Dry wells renew their flow and existing wells dry