NEW GENERATION BUILDING CODE DBN V.1. - 1-12:2014 "CONSTRUCTION IN SEISMIC REGIONS OF UKRAINE"

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Abstract

Provisions of new release of state Norms of Ukraine are presented: "Building in the seismic areas of Ukraine", that take into account modern achievements of the earthquake resistance theories, used for planning of building and facility in seismic areas by intensity from 6 to 10 points on DSTU V.1.1-28: "Scale of seismic intensity" taking into account the requirements of the National Standard of DSTU-N V.1.2-16:2013 "Estimation of class of consequences and categories of complication of construction objects" and recommendations of European Standard EN 1998-1 (Eurocode 8): 2004 "Design of structures for earthquake-resistance".

Keywords: Seismic hazard, Building codes, Ukraine

1. Historical data on the development of seismic-resistant construction standards in Ukraine

The state standards for the design of buildings in seismic regions of Ukraine were first developed and introduced in 2006 [1]. DBN V.1.1-12:2006 [1] were designed to meet the Soviet SNIP II-7-81* "Construction in seismic areas" [2] and the main provisions of the rules of the CIS countries (Armenia, Georgia, Kazakhstan, Uzbekistan) [5, 6, 7], the rules of the European Union and US standards UBC- 97 [8].

A scale MSK-64 (GOST 6249-52) was previously used for determining the strength of the earthquake. By the order of the Ministry of Regional Development of Ukraine dated on 23.12.2010 the National Standard of Ukraine DSTU-B-V.1.1-28:2010 "The scale of seismic intensity" was introduced [9], which reflects the requirements for the assessment of the earthquake consequences, taking into account the recommendations of the "European macro seismic scale EMS-98" [10].

The new edition of the State standards DBN V.1.1-12:2014 [11] was developed in 2013-2014 and introduced with the Order of the Ministry of Regional Development of Ukraine № 143 dated on 16.05.2014 for using since the October 1, 2014. This map of seismic intensity refers to the soils of the second category on seismic behavior.

2. Seismic hazard in Ukraine

Design seismicity of the construction site in accordance with DBN V.1.1-12:2014 is recommended to determine on the basis of seismic micro-zoning (SZ) of the construction site. Normative intensity of seismicity (in points) for the construction area is recommended to be determined based on the list of settlements of Ukraine and a set of maps of general seismic zoning (GSZ-2004) in Ukraine. Set of maps GSZ-2004 includes four maps:

- GSZ-2004 "A" map corresponds to a 10% probability of exceeding the estimated seismic intensity for 50 years and the average return period of these intensities of one time every 500 years. Map is used for the design and construction of facilities and structures of mass civil and industrial use, various residential projects in urban and rural areas which belong to the consequences class (importance) CC1 and the consequences class (importance) CC2 [12] for buildings up to 73.5 m*;*

- GSZ-2004 "B" map (Fig. 1) corresponds to a 5% probability of exceeding the estimated seismic intensity during 50 years and the average return period of such intensities once in 1000 years. The map should be used for the design and construction of facilities and high level of responsibility, consequences class (importance) CC2 for buildings in height from 73.5 to 100 m, damage or destruction of which at earthquakes can lead to an emergency situation on the regional level;

- GSZ-2004 "C" map corresponds to 1% probability of exceeding the estimated rate for 50 years and the average return period of such intensities once in 5,000 years. The map should be used for the design and construction of particularly important objects and structures of consequences class (importance) CC3 in accordance with DBN V.1.2-14, damage or destruction that the earthquake can lead to an emergency on the state level;

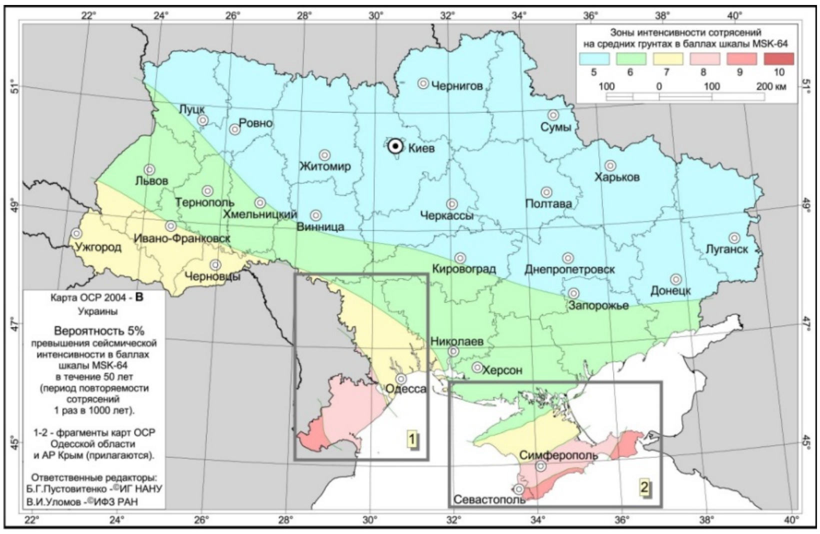

Fig.1 - Map of general seismic zoning of Ukraine: Type "B"

- detailed GSZ-2004 "A0" maps correspond to 39 % probability of exceeding the estimated seismic intensity earthquake during 50 years and the average return period once in 100 years. Maps should be applied to the design and construction in the Crimea and Odessa region for not responsible buildings consequences class (importance) CC1 and complexity in accordance with DSTU-N B V.1.2-16 [13].

Maps of General seismic zoning in Ukraine are presented in DBN V.1.1-12:2014 [11]. When selecting the GSZ-2004 map for the design of objects in seismic areas should be guided by the instructions of DBN V.1.2-14-2009 [12] in terms of the destination consequences class (importance) of buildings and structures:

- map A or A0 is used for consequences class CC1 the GSZ-2004;
- map A or B is used for consequences class CC1 the GSZ-2004;
- map C is used for consequences class CC1 the GSZ-2004.

The following scheme for accounting consequences class (importance) is recommended:

- objects of I and II category of complexity correspond to CC-1 class consequences;
- objects of III and IV category of complexity correspond to CC-2 class consequence;
- objects of V category of complexity correspond to CC-3 class consequences.

Resolution of the Cabinet of Ukraine No 368 dated on 24 March 2003 determined that the "possible violations of normal living conditions lasting more than three days are danger for life of people". In accordance with it the objects of IV and V category of complexity are subjected to mandatory state examination.

The main feature of earthquake resistance assessment is that the category of complexity of construction projects is established on the basis of consequences class (importance) of facilities.

Another important feature of the method lies in the fact that the consequences class (importance) can be determined for the separated parts of an object with appropriate justification.

Changing №1 to DSTU-N B V.1.2-16 [13] enables to consider not only entire building as a whole to determine the consequences class (importance) but a separate part (section) when design of earthquake-resistant buildings. In the absence of seismic zoning maps the definition of seismicity of the construction site on the basis of geological engineering survey can be simplified. To clarify regulatory a site state the micro-seismic zoning should be carried out on the site taking into account the results of geotechnical surveys.

3. General principles of buildings and structures seismic resistance

The general conditions for providing of structural safety of buildings are following:

1. For buildings and structures with a height 73.5 m or more and for objects of consequences class (importance) SS3 the requirements of these standards should be applied for the construction site with seismicity at 6 points and more.

2. The new design scheme of buildings and structures are subjected to mandatory expert examination by specialists of basic organizations in the design process in accordance with DBN V.1.2-5 [15].

3. At the design of earthquake-resistant buildings and structures it is necessary:

- to accept the space-planning and design solutions providing symmetry and regularity of distribution in building plane and height of the mass, stiffness and loads on floors;
- to use materials and structures to ensure the lowest values of seismic loads (lightweight materials, seismic insulation and other dynamic systems for control of seismic load);
- to create the possibility for development in the structural elements of permissible non-elastic deformations and to perform calculations based on nonlinear deformation structures;
- to ensure rational distribution of engineering equipment, taking into account its impact on the level of seismic load.

4. In the case of seismic isolation system selection the calculation and design must be carried out with the participation of specialized organizations

5. It is necessary to monitor the sites during construction and after its completion.

Standards of Ukraine in earthquake engineering have some features:

1. The acceleration levels corresponding to the "Weak Earthquakes" (WE), "Design-basis Earthquakes" (DE) or "Maximal Design Earthquakes" (MDE) or a combination of earthquakes are corresponding to seismic intensity (in points of seismic scale) on the maps "A0" , "A" , "B" and "C".
2. The correspondence between consequences class (importance) and the applicable seismic zoning map GSZ – 2004 is determined.
3. For areas of the construction site with seismicity in 6 points it is necessary to perform structural measures to ensure a seismic stability of buildings.
4. To reduce the seismic loads the use of seismic isolation is provided.
5. Installation of the stations of Engineering Seismometric Service (ESS) and the dynamic certification is provided on the buildings and structures with height more than 70m and at the facilities of the experimental construction.

6. Differentiated values of inter-storey alignment errors of the floors depending on the level of seismic effects corresponding weak (WE), design-basis (DE) and maximal design earthquakes (MDE) are proposed.
7. The section DBN "Hydrotechnical facility" is significantly redesigned. The rules regulate the use of the direct dynamic method (DDM) and linear-spectral method (LSM) for calculation when action of the Project (PE) and the maximum design earthquakes (MDE) depending on the prescribed class or subclass of consequences (importance) of Hydrotechnical facility.
8. The method of seismic loads determination corresponding to the recommendations of Eurocode 8 is worked out in DBN. Its main provisions are listed in Annex G of DBN which refers to the recommended methods and it is presented in detail in the monograph [17, 18].

4. The rules for determining seismic loads on buildings and structures taking into account the recommendations of the Eurocode 8 and the requirements of DBN B.1.1 - 12 : 2014

4.1. Basic information about the building standards Euro code

Construction Eurocodes are combined into 10 functional groups. Each group includes some parts. Designing in seismic regions should meet the requirements of EN 1998 Eurocode 8: “Design of structures for earthquake resistance” [19].

National Annex can contain only information on those parameters which are free in the Eurocode for national choice, and are known as Nationally Determined Parameters (NDPs).

National choice in Standard EN 1998-1 is defined in a special table with reference to the provisions/requirements including 55 points.

The gotten results are focused on the pre-emptive usage of spectrum method of bearing capacity (SMBC) which is recommended by Eurocode 8 and international standards. Practical implementation of seismic loads calculations of buildings leads to necessary to use the different calculation methods:

• **Linear static analysis** (usually referred to as a static method of transverse forces);

• **Modal response spectrum analysis** (method is recommended as the reference method for linear dynamic analysis which uses a linear- elastic model of the structure and design response spectrum). In the regulations of Ukraine and the CIS countries this method is called "**spectral method**"**;**

• **Non-linear static analysis** (known as “Pushover Analysis”). The method is based on the analysis of the sequence of destruction of structural elements under the action of external loads on the structure;

• **Non-linear time history (dynamic) analysis** (stepwise analysis of accelerograms of earthquakes in time taking into account the consideration of all the known nonlinearities.

4.2 Non-linear static (Pushover) analysis. The method of ATC-40

Estimation of target movement is carried out using a calculation based on a sequential analysis of the destruction of structures under the action of an external load (ultimate strength analysis of the building) which in the European literature got the name Pushover Analysis [20, 21].

Dynamic system with many degrees of freedom is reducing to a system with one equivalent weight of M_{eq} and generalized horizontal stiffness K_{eq} for practical usage. This transformation scheme is shown in Fig. 2.

If we denote the value of the equivalent weight as $M_{eq} = M^*$ and horizontal rigidity as $K_{eq} = K^*$ of single-mass system and assume that the main form of movement will correspond to fluctuations of the first form of multi-mass console system (as shown in Fig. 2) then period of oscillation T of the system can be written as:

$$T_{экв} = 2\pi\sqrt{\frac{M^*}{K^*}}, \quad (1)$$

where

$$K_{экв} = K^* = \frac{F_y^*}{u_y^*}. \quad (2)$$

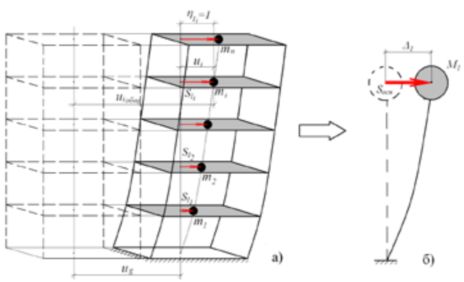

Fig.2. – Conversion scheme of multi-mass system to an equivalent system with one degree of freedom

The accepted procedure comprises the following consecutive stages, and solutions:

1. Running the calculation of bearing capacity of structures (Pushover Analysis) and the roof displacement Δ_1 is calculating, also the base share $\boldsymbol{V}_o$ is determining (Fig. 3).
2. Conversion procedure of bearing capacity curve into bearing capacity spectrum in the format **"Acceleration-Displacement Response Spectrum" (ADRS)** is carrying out. Its shape is a graph of the seismic accelerations change S_a depending on seismic movements S_d [22]. It is allowed the presentation of non-linear curve of bearing capacity as a bilinear diagram (Fig. 4).

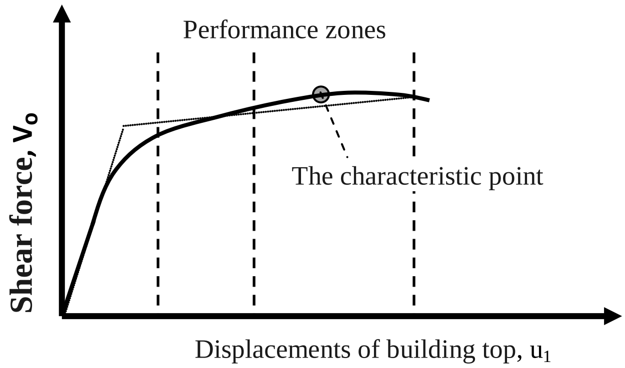

Fig.3 - Curve of the bearing capacity of the building, $V_o - u_1$

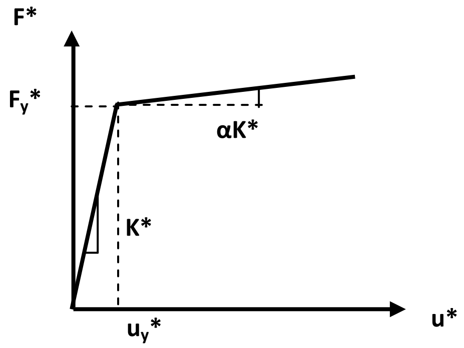

Fig.4 – Approximation of bearing capacity curve **V_o - u_1**
in two lines in a linear system with equivalent stiffness **K***

3. The required conversion of relations have the following form (in the notations of ATC-40).

Spectral acceleration

$$S_a = \frac{V_o}{\alpha_1 W} = \frac{M^* \ddot{u}_o(t)}{\alpha_1 M^* g} = \frac{\ddot{u}_o(t)}{\alpha_1 g} = \frac{a_o}{\alpha_1} \quad (3)$$

Spectral displacement

$$S_d = \frac{\Delta_r}{k_{\phi 1}\phi_{r1}}. \quad (4)$$

Where : W – the overall weight of the building (kN);
V_o – shear force at the base (kN);
$\Delta_r = \Delta_1$ – displacement to the upper level of the building (at roof level);
α_1 – modal mass coefficient for the basic (the first) waveform of the oscillations;
$k_{\phi 1}$ – parameter of contribution (modal participation) of basic waveform of the oscillations;
ϕ_{r1} – amplitude of the first waveform of the oscillations at the roof level (top of the building);
S_a - spectral acceleration (m/sec^2 or cm/sec^2);
S_d - spectral displacement (m or cm);
$V_o = M^* \ddot{u}_o(t)$, where $\ddot{u}_o(t)$ - maximum amplitude of the acceleration in the base;

$a_o = \ddot{u}_o(t)/g$ – seismicity coefficient (in shares of g) corresponding to DBN [13].

Modal mass coefficient α_1 and coefficient of contribution rate of the first form of natural oscillations of the structure are defined as

$$\alpha_1 = \frac{\left[\sum_{i=1}^{n}(m_i\phi_{i1})\right]^2}{\left[\sum_{i=1}^{n} m_i\right]\left[\sum_{i=1}^{n}(m_i\phi_{i1}^2)\right]} \quad ; \qquad k_{\phi 1} = \frac{\left[\sum_{i=1}^{n}(m_i\phi_{i1})\right]}{\left[\sum_{i=1}^{n}(m_i\phi_{i1}^2)\right]}, \qquad (5)$$

where m_i – mass at the level of i multi mass system equal to weight w_i/g (in shares of g); i = 1,2 …n; n – general number of masses (see Fig. 4).

The relationship between the acceleration S_a of the dynamic system and the range of displacement spectrum S_d is determined by the following formula

$$S_a = \omega^2 S_d\,, \qquad (6)$$

where ω^2 - the square of the angular frequency of natural oscillations.

From (6) we can obtain the relation between S_d and S_a for each i -th point on the curve of the spectrum:

$$S_{di} = \frac{T_i^2}{4\pi^2} S_{ai}\, g\,, \qquad (7)$$

which is represented as a share of the of free fall acceleration g .

From the standard spectrum we obtain the desired values for spectrum $S_a - S_d$. A general view of such transformation is shown in Fig. 5. The periods of T_i in this format meet with straight lines radiating from the origin (0; 0).

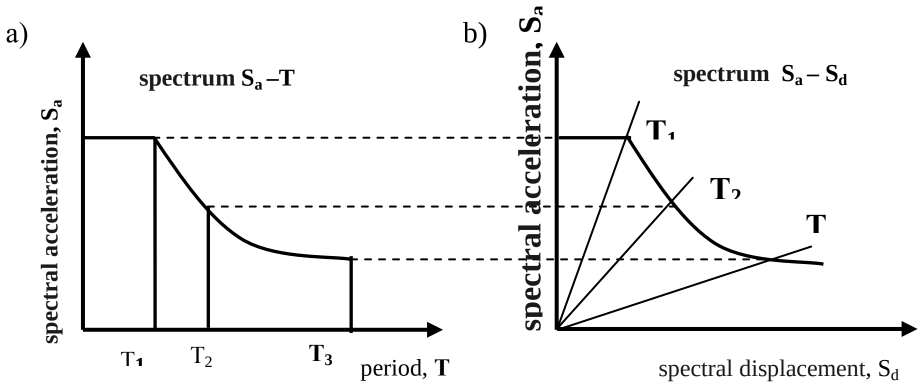

Fig.5 - Conversion of the standard response spectrum "acceleration - the period of oscillation" [S_a – T] (a) in response spectrum "acceleration - displacement" [S_a – S_d] (b)

4. Any point V_i, Δ_{roof} on the curve of the bearing capacity is converted to the corresponding point S_{ai} - S_{di}, in the spectrum using formulas (3) and (4), Fig.5.

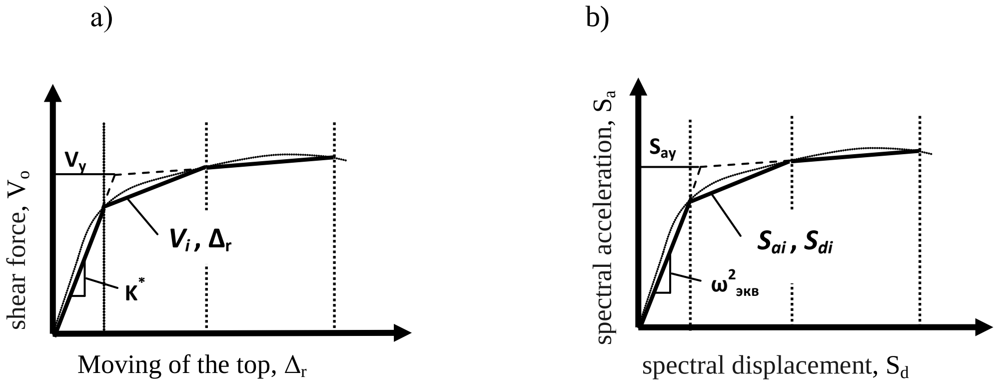

Fig.6 - The conversion range of bearing capacity from format "transverse force - displacement" [V_o– Δ_r] (a) in the format of "spectral acceleration - spectral displacement" [S_a – S_d] (b)

5. The correlations of parameters for the equivalent system with one degree of freedom corresponding to notation in Fig.4 we obtain as:

$$M^* = \alpha_1 M; \quad (8)$$

$$K^* = \omega_{экв}^2 M^*; \quad (9)$$

$$F_y = V_y = S_{ay} W^*. \quad (10)$$

M – the mass of the building (t);
M^* – equivalent (effective) mass of the system with one degree of freedom [SDF] (t);
K^* – equivalent (effective) horizontal stiffness of the system SDOF (kN/m);
ω_{eq} – equivalent (effective) natural frequency of the system oscillation SDOF (rad/sec);
$W^* = M^* g$ – equivalent (effective) weight of the building (t·cm/sec^2);
S_{ay} – spectral acceleration corresponding to the strength limit (conditional yielding) of the structures (m/sec^2);
F_y – force corresponding to the conditions of yielding formation (kN);
V_y – shear force (load) at the base of the building (kN).

6. Further using of the bearing capacity spectrum method according to ATC- 40 is reducing to the analysis of the two spectra evaluation (*Sa -T standard spectrum and the spectrum Sa - Sd*). On each of them the diagram "of the bearing capacity spectrum" is applied (Fig.7) presented in the appropriate format. As an outcome spectrum "*standard spectrum*" with 5% damping is used. General view of the resulting spectrums is shown in Fig.9.

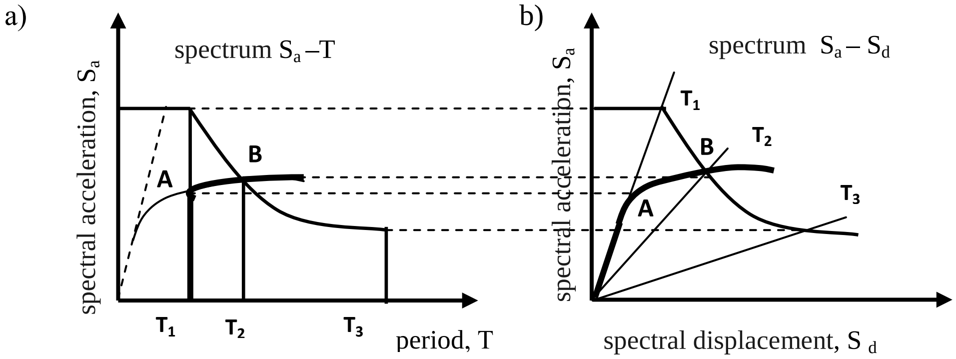

Fig.7 - The "bearing capacity" (ultimate load) spectrum, combined with a spectrum of reactions in a standardized format (a) and in the format of "acceleration - displacement" [ADRS] (b)

7. The further transformations of bearing capacity spectrum method come to the construction of a slightly decreased response spectrum due to the development of inelastic deformations in the structure. Detailed conversion of attenuation characteristics and required illustrations can be found in a number of publications [20, 23]. The elastic response spectra (when 5% damping) is converting in a spectrum of reactions in which the damping values exceed 5% of the critical damping. Reduced response spectrum is calculated by multiplying each point of the spectrum by the appropriate reduction coefficients R_A or R_V

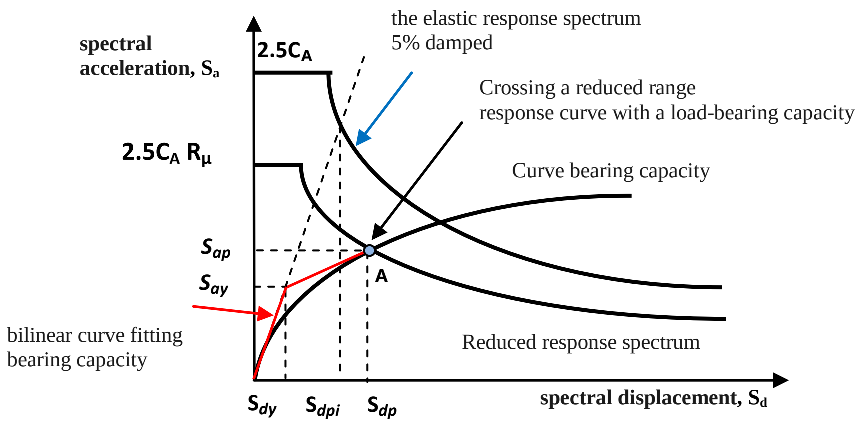

Fig.8 - Drawing of a decreased response spectrum with using reduction coefficients R_μ
(on the example of the US Code UBC-1997)

Point **A** applied to the intersection of the spectrum is the desired characteristic point that defines the reserve of structure carrying capacity. Limit lateral misalignment of the floors should not exceed the prescribed misalignments for buildings of different structural systems. In the National Annex the permissible alignment errors of various building structural schemes should be taken from Table 6.8 of DBN V.1.1-12: 2014 (see a Table below).

Table - Permissible limit alignment errors of building stories [11]

Bearing structure of the building	**Inter-storey alignment error for operational level**		
	IO	**LS**	**CP**
Steel frame building	0.0067	0.012	0.02
Buildings with reinforced concrete frame without vertical diaphragms or stiffening cores	0.0067	0.012	0.03
Buildings with reinforced concrete frame with vertical diaphragm or stiffening cores	0.004	0.017	0.025
Buildings with solid reinforced concrete walls and large reinforced concrete panels and blocks	0.0028	0.01	0.02
Buildings with walls of stone and brick masonry	0.0025	0.004	0.008
Frame and stone buildings	0.0025	0.004	0.008

IO – Absence of damages (weak earthquake – WE); **LS** – Life support (design earthquake - DE); **CP** – Ensuring of the sustainability of the building, saving of the people life, valuable equipment and infrastructure needed to eliminate the consequences of the earthquake (maximal design earthquake - MDE).

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