

**TOPIC 7. DESIGN FEATURES OF
EARTHQUAKE-RESISTANT FOUNDATIONS
AND STRUCTURES.**

Content

1. Seismic phenomena
2. Types of earthquakes, their causes and mechanism of occurrence
3. Types of seismic waves
4. The classification of earthquakes by the depth of their hypocenters
5. Tsunami

SEISMIC PHENOMENA

Seismic phenomena (from the Greek seismos – earthquake) are endogenous, much less anthropogenic processes and phenomena associated with earthquakes and their consequences. Earthquakes threaten many vast, often densely populated territories and even entire countries, such as Japan, Nepal and Haiti. The greatest danger of earthquakes lies in the poor predictability of the time of their occurrence, intensity and possible consequences. Earthquakes are multidirectional oscillations of the earth's crust, which are also manifested on the earth's surface caused by the action of seismic waves.



Fig. 1. The Great Lisbon Earthquake of 1755 (old picture)



Fig. 2 Terrain after the Great Alaskan earthquake, 1964



Fig. 3. The consequences of the 1976 earthquake in the city of Tangshan, China: a – the destroyed bridge

a



б



в



г



Fig. 4. Consequences of earthquakes: a – San Francisco, USA, 1906, б – Neftegorsk, Sakhalin, 1995., в – Izmit, Turkey, 1999., г – Hindu Kush, Pakistan, 2015



Fig.5. Destruction during the Crimean earthquakes of 1927: a – the Swallow's Nest castle, Alupka; b – residential building in Balaklava



Fig. 6 Consequences of the earthquake in Hatay, Turkey. February 2023



TYPES OF EARTHQUAKES, THEIR CAUSES AND MECHANISM OF OCCURRENCE

Classification of earthquakes by causes of occurrence

Earthquake type	Percentage of total	Maximum magnitudes
Tectonic	almost 95 %	up to 9.5
Volcanic	up to 5 %	up to 8
Landslide (denudation)	<1 %	< 5
Technogenic (anthropogenic)	<0.1 %	up to 7

Preliminary Determination of Epicenters
358,214 Events, 1963 - 1998

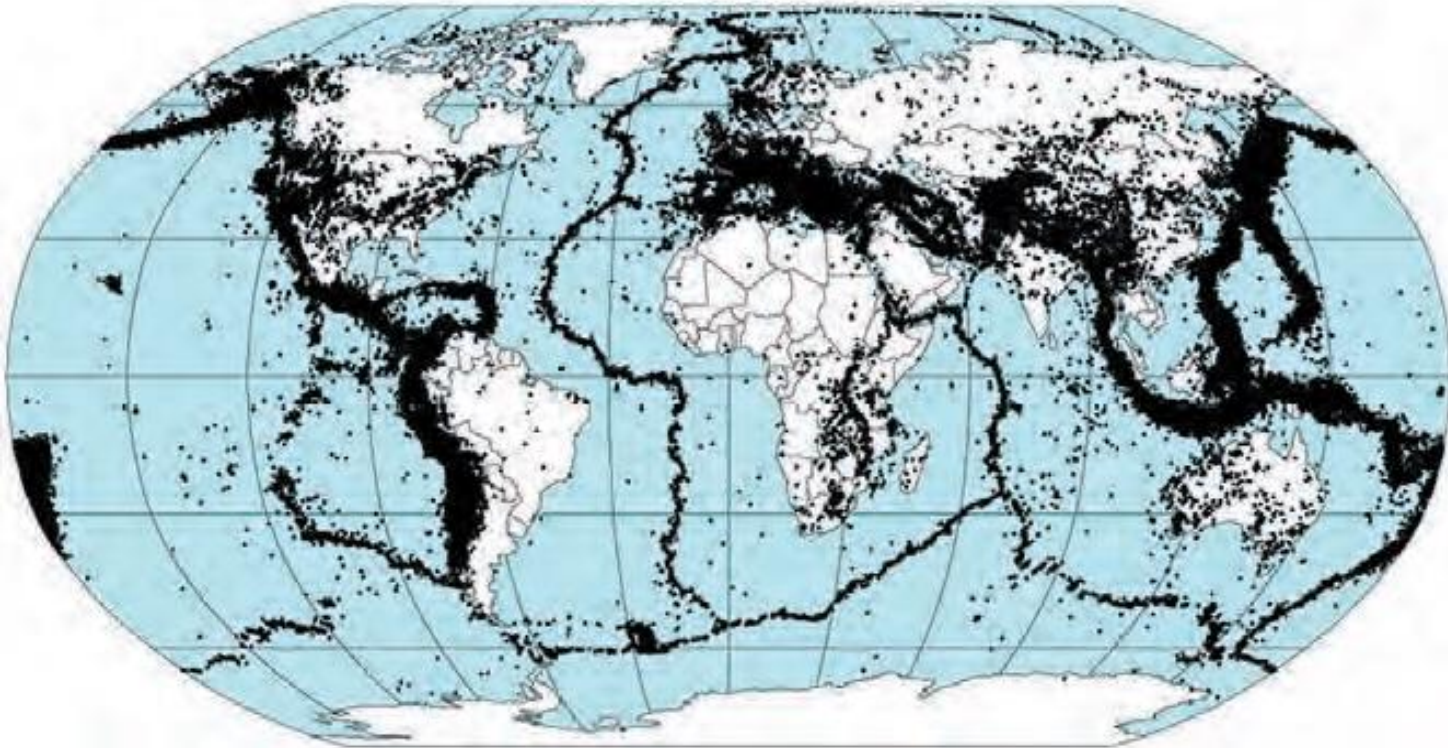


Fig. 7. Epicenters of earthquakes (indicated by black dots) that occurred during 1963–1998, a total of 358,214 events

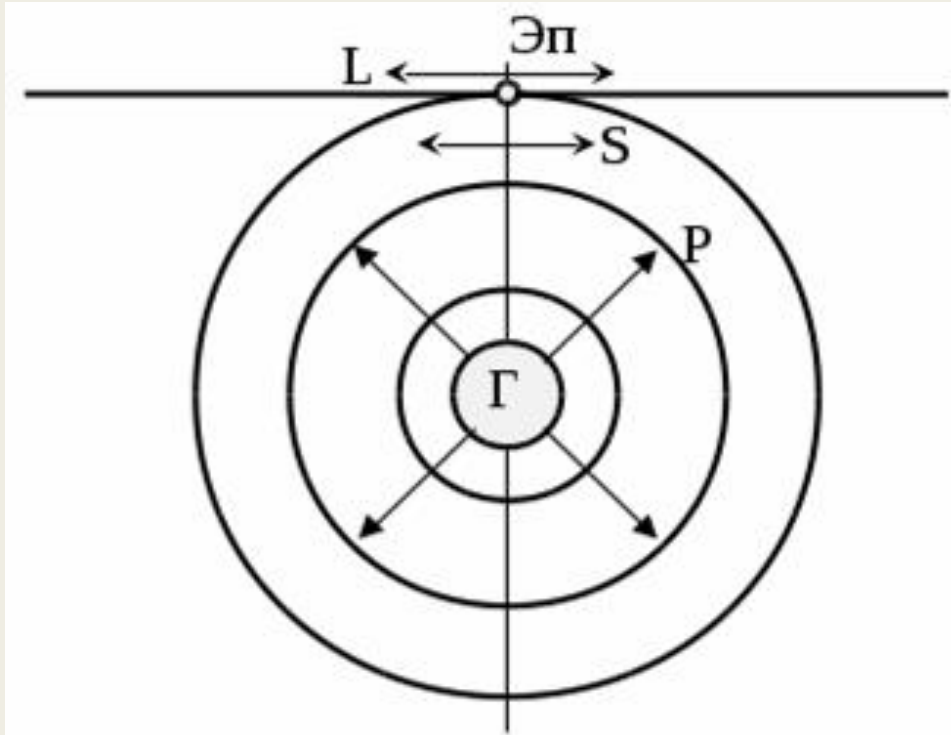


Fig. 8. Seismic wave propagation: Γ – earthquake hypocenter; $\Xi\pi$ – epicenter of the earthquake; P – longitudinal waves; S – transverse waves; L – surface waves

DBN V.1.1-12:2014 Construction in seismic areas of Ukraine

TYPES OF SEISMIC WAVES

Longitudinal or primary waves – P-waves (from Latin prima – first) propagate in all directions from the hypocenter and reach the earth's surface first. The propagation velocity of P-waves at great depths reaches 13.6 km/s (at the boundary of the mantle and the Earth's core), near the Earth's surface it decreases to 5–6 km/s, so they have a speed one and a half to two times greater than the transverse waves.

Transverse or secondary waves – S-waves arise as a result of the reaction of an elastic medium to a change in shape under bending forces. With the passage of transverse waves, each particle of the rock oscillates perpendicular to the line of direction of wave propagation. S-waves propagate only in a solid medium. The speed of their movement in the earth's crust is 3–4.5 km/s, and near the mantle/core border reaches 7.3 km/s.

Surface or long waves – L-wave is the third type of waves that arise at the interface between a solid and air medium, i.e. on the earth's surface and spread in all directions from the epicenter. Their amplitude is greater than the above-mentioned waves and their speed is in the range of 3–3.5 km/s.

THE CLASSIFICATION OF EARTHQUAKES BY THE DEPTH OF THEIR HYPOCENTERS

Name	Depth range	Percentage of total
Surface	<100 km	51 %
Intermediate	100–300 km	36 %
Deep focus	300–720 km	13 %

TSUNAMI

Earthquakes (or powerful volcanic eruptions) occurring at the bottom of oceans, often generate gigantic sea waves which reach the coast and can rise to a very high altitude. Waves, generated during a tsunami often bring disastrous consequences to coastal areas. The height of the waves at the epicenter reaches 5 m, off the coast – up to 10 m and in coastal areas (depending on the ground relief) may rise up to 50 m (Fig. 9). The speed of tsunami reaches 900–1000 km/h and they mostly (up to 80%) occur on the Pacific coast.

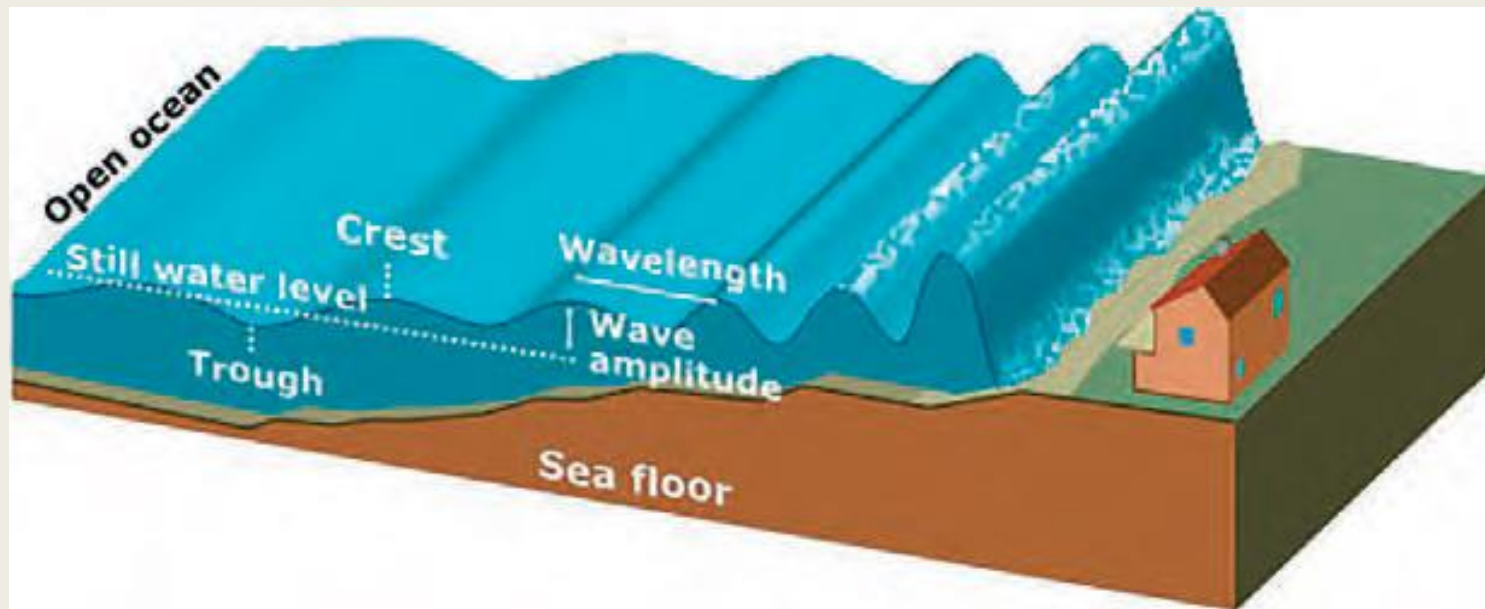


Fig. 9. Tsunami occurrence pattern

a



b



^c Fig. 10 a –beginning of the tsunami on the coast of Honshu, Japan, 11. 03.2011; b, c – Tsunami



Fig. 11 Consequences of an earthquake and tsunamia



Fig. 12. Fire extinguishing at the Fukushima-1 nuclear power plant, Japan

Earthquake strength assessment

To assess the magnitude of earthquakes, the Richter scale is most commonly used, but there are also other intensity scales like the MSK-64 among others.

The magnitude of an earthquake (from lat. magnitudo – greatness, importance, significance) is an indicator that characterizes the energy that was released during an earthquake in the form of seismic waves. The magnitude of an earthquake is a dimensionless quantity which is proportional to the logarithm of the ratio of the maximum amplitude of waves generated in a particular earthquake and the amplitude of a standard earthquake. There are a number of differences in the methods for determining magnitudes of nearby, remote, shallow and deep focus earthquakes. Magnitudes of different types of waves differ in magnitude.

The magnitude scale was first developed in the United States by the seismologist Charles Richter in 1935. The modern improved Richter scale contains arbitrary units ranging from 1 to 9.5, which are calculated by vibrations recorded by seismographs during an earthquake. The Richter scale uses a logarithmic scale, and every integer value on the scale indicates an earthquake ten times larger in power than the previous one. The magnitude scale should not be confused with the earthquake intensity scale in points (according to the 12-point system), which is based on the external manifestations of tremors – the effects on people, objects, buildings and structures and natural objects.

Earthquake Intensity Scale (EMS 98)

Point	Earthquake strength	A brief description
I	Imperceptible	Not felt by people. It is noted only by seismic instruments.
II	Barely tangible	It is felt only by individuals who are in a state of complete rest on the upper floors of buildings, and very sensitive pets.
III	Weak	It is felt in the rooms by some people. People at rest indoors feel a swing or a slight trembling.
IV	Widely observed	Recognized by the slight rattling and vibration of objects, dishes and windowpanes, creaking doors and walls. Inside the building, most people feel the concussion.
V	Strong	Feeling of an earthquake inside the building, but not by everybody who are outside the building. Many sleepers wake up and some run out into the street. Buildings experience a slight concussion. Suspended objects swing significantly. The dishes are ringing. The vibrations are strong. Objects with a high center of gravity, may fall. Doors and windows swing.
VI	Light damage	The vast majority of people feel an earthquake inside buildings. People are scared and run out of building. Small objects are falling. Slight damage to most ordinary buildings; for example, thin cracks in the plaster.
VII	Damage	The vast majority of people run out of buildings. Furniture moves, most items fall from shelves. Many buildings are moderately damaged: small cracks in the walls; partial collapse of chimneys.
VIII	Severe damage	Inverted furniture. Most buildings suffer significant damage: chimneys fall; large cracks in the walls; some buildings may partially collapse.
IX	Destructive	Monuments and columns fall. Many buildings are partially destroyed, some completely.
X	Very destructive	Most buildings are completely destroyed.
XI	Devastating	Almost all buildings are completely destroyed.
XII	Completely destructive	All ground and underground structures are very badly damaged or destroyed.

Volcanic earthquakes

Volcanic activity is accompanied by explosive emissions of huge volumes of steam and gases into the atmosphere, which causes seismic and acoustic vibrations. The rise of high-temperature magma from the bowels of the volcano to the surface is accompanied by cracking of overlying rocks, which in turn also causes seismic and acoustic effects.

Collapse (denudation) earthquakes

These are relatively weak earthquakes that occur in areas where underground voids or mining works are common. Their magnitude usually does not exceed 5.0, and they do not occur often – the proportion of landslide earthquakes does not exceed 1 % of the total number of earthquakes.

Man-made (anthropogenic) earthquakes

These earthquakes are associated with civil engineering and military activities, as well as mining. Carrying out underground nuclear explosions, extracting large amounts of water, oil or gas, coal and other minerals from the bowels of the earth can cause seismic shocks.



Fig. 12. Lake Mead Reservoir and Hoover Dam (221 m high) on the Colorado River, the border of Arizona and Nevada, USA. The creation of a reservoir led to the transformation of the surrounding area into an area of increased seismicity

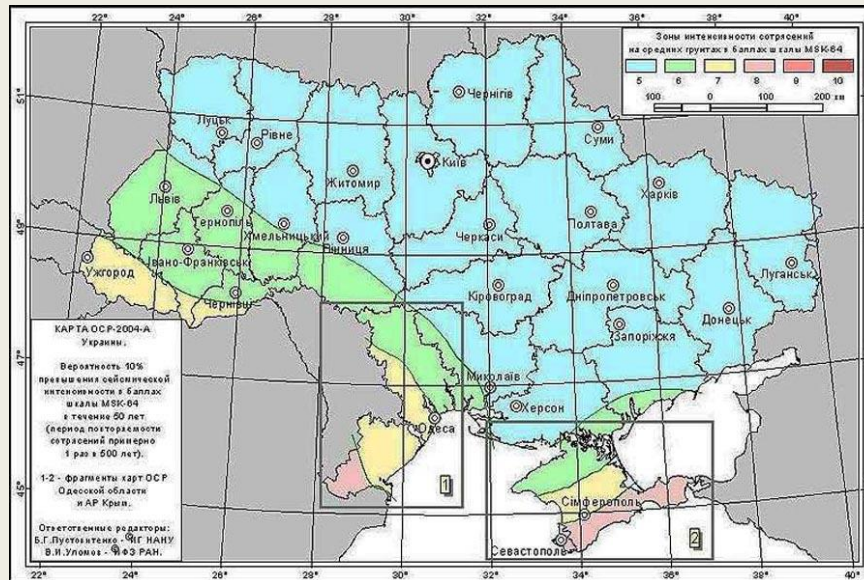


Fig. 13. A funnel at the site of an underground nuclear explosion of a 104-kiloton charge on July 6, 1962.

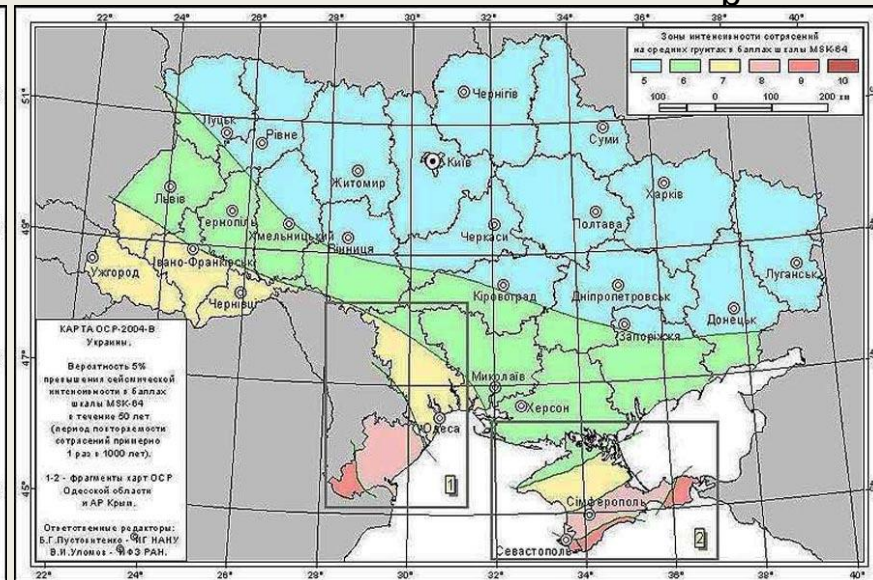


Fig. 14— Consequences of the earthquake of December 7, 1988 in the north of Armenia

a



b



c

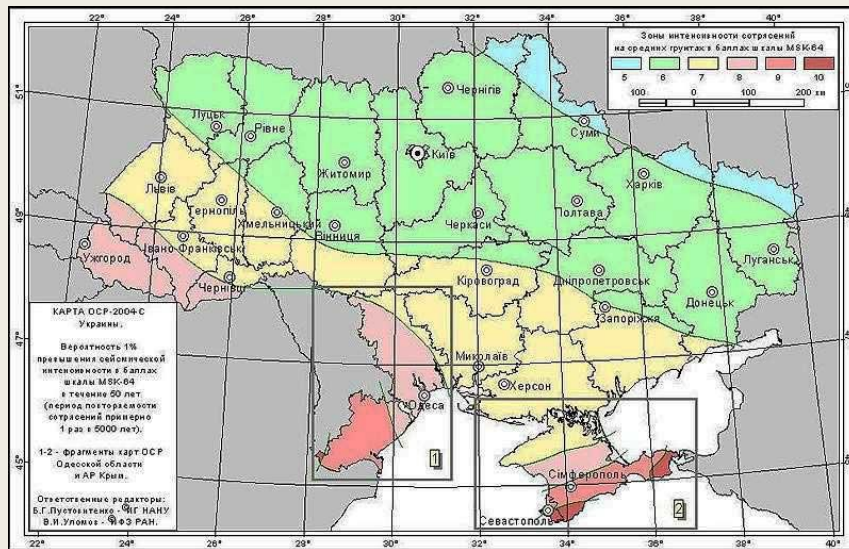


Fig. 15. Maps of the general seismic zoning of Ukraine, ZSR-2004. Recurrence period of earthquakes:
 a - 1 time in 500 years;
 b - 1 time in 1000 years;
 c - 1 time in 5000 years

The main requirements for construction in seismic areas are reduced to the following measures:

1. Selection of a site for construction.
2. The choice of a constructive decision and volume-planning decision.
3. Ensuring high quality construction.
4. Separation of buildings and structures with anti-seismic seams.

Construction sites for settlements and structures are selected taking into account geological data, as far as possible from possible or obvious discontinuities, far from steep slopes that threaten collapses and landslides.

Loose soils and cracked rocks are considered unfavorable for construction.

When choosing a plot for construction, such concepts as seismic resistance of construction objects and seismicity of the construction site are taken into account.

The ability of soils, buildings and structures to withstand seismic impacts is called seismic resistance. Measures to increase seismic resistance of buildings are applied in areas with seismicity of 7 points and above. Regulatory substantiation of these measures is carried out according to DBN V.1.1-12:2014 "Construction in seismic areas of Ukraine". For seismicity of more than 9 points, the construction of capital buildings is prohibited.

TAKING INTO ACCOUNT THE INFLUENCE OF SOIL CONDITIONS

Soil category according to seismic properties	Soils	Seismicity of the construction site at the seismicity of the area, points				The speed of propagation of seismic waves in the ground, V_s , m / s
		6	7	8	9	
I	Rocky soils of all types are unweathered and slightly weathered; high-debris soils, dense, low-moisture, from igneous rocks, containing up to 30% of sand-clay aggregate	5	6	7	8	$V_s > 800$
II	Rocky soils are weathered and heavily weathered; large-clastic soils with the exception of those assigned to category I; sands are gravelly, coarse and medium-grained dense, and medium-density low-moist and wet sands; sands are fine and dusty, dense and of medium density, moist; dusty-clay soils with a Liquidity index $IL \leq 0.5$ with a void ratio $e < 0.9$ for clays and loams and $e < 0.7$ - for sandy loams	6	7	8	9	$500 < V_s < 800$
III IV	Sands are loose, regardless of the degree of humidity and coarseness; gravelly, coarse and medium-grained sands are dense and medium-density sands are water-saturated; sands are fine and dusty, dense and of medium density, moist and water-saturated; dusty-clay soils with a Liquidity index $IL > 0.5$; dusty-clay soils with a Liquidity index $IL \leq 0.5$ with a void ratio $e \geq 0.9$ - for clays and loams and $e \geq 0.7$ - for sandy loams	7	8	9	10	$200 < V_s < 500$
	Loose sands are saturated with water, prone to liquefaction; bulk soils; sediments, biogenic soils and silts	According to the results of special studies				$V_s < 200$

When designing earthquake-resistant structures, the following principles are followed:

1. *The principle of symmetry*: the mass and stiffness of the structure must be distributed evenly and symmetrically relative to the planes of symmetry passing through the center of gravity of the structure. That is, the buildings are designed to be simple in plan and symmetrical (circle, square, rectangle). Buildings of complex shape in plan divided into compartments of a simple shape by anti-seismic seams (Fig.) in the form of paired walls (in wall buildings) or paired frames (in frame buildings).

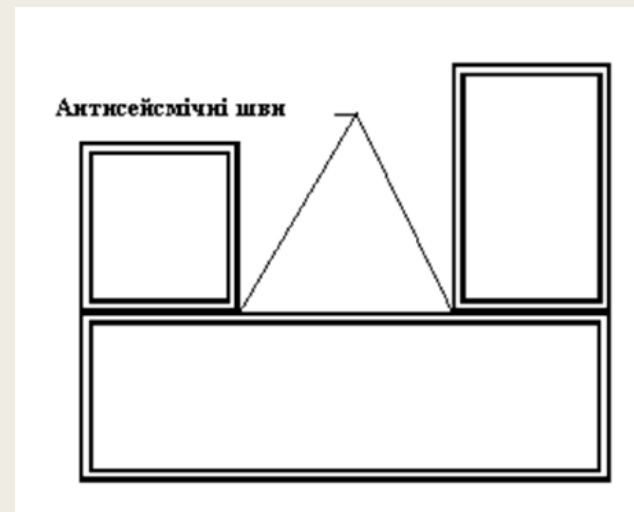


Figure 16 – An example of designing buildings of a complex shape in seismic areas

2. *The principle of harmony*: it is necessary to observe proportionality in the dimensions of the building, while its length or height should not be extremely large. Boundary dimensions, number of floors, height of floors of buildings are accepted in accordance with the requirements of DBN V.1.1-12:2014.

3. *Principle of anti-gravity*: it is necessary to design the building as light as possible, with the center of gravity located as low as possible.

4. *The principle of elasticity*: it is desirable to use materials in the construction that are strong, light, and have elastic properties; constructions from them should have uniform properties.

5. *Ensuring a closed circuit*: the load-bearing elements of the structure must be connected to each other, forming closed circuits both in the vertical direction and in the horizontal direction.

6. *Ensuring the reliability of the foundations:* for earthquake-resistant structures, the foundations must be strong, laid deep enough, preferably on pliable layers or special substructures that replace weak soils, to ensure the uniformity and strength of the soil base. Strip prefabricated foundations are laid on one mark and made continuous.

The pile cap of the pile foundation is made low, buried in the soil.

It is recommended to use a solid slab foundation. The basement is located under the entire compartment. In frame buildings, foundations for columns are connected to each other by continuous reinforced concrete foundation beams in the form of cross bands.

7. *Application of seismic isolation:* it is advisable to use devices that reduce the intensity of oscillatory processes that are transmitted from the ground to the building.

Buildings and structures should be separated by anti-seismic joints in cases where:

- the building or structure has a complex shape in plan;
- adjacent areas of the building or structure have height differences of 5 m or more.

In one-story buildings up to 10 m high, anti-seismic seams may not be installed with an estimated seismicity of 7 points.

Anti-seismic seams must separate buildings and structures along the entire height.

It is allowed not to arrange a seam in the foundation, except for cases when the anti-seismic seam coincides with the sedimentary one.

Staircases should be closed, with window openings in the outer walls. The location and number of stairwells should be determined based on the results of the calculation performed in accordance with the requirements of DBN B.1.1-7-2002 "Fire Protection. Fire safety of buildings and structures", but to accept at least one stairwell between anti-seismic joints in buildings more than three stories high.

Anti-seismic seams should be performed by erecting paired walls or frames, as well as erecting a frame and a wall.