UDC 624

MODERN EFFECTIVE TYPES OF EARTHQUAKE-RESISTANT FOUNDATIONS

Kristev A.A., *student of gr. ICE-471,*
Apostol E.L., *student of gr. ICE-476,*
Scientific adviser – **Voitenko I.V.**, *PhD, Associate Professor (Department of Bases and Foundations, Odesa State Academy of Civil Engineering and Architecture)*

Abstract. The article is devoted to the analysis of modern earthquake-resistant foundations' types used in both domestic and international construction. Examples of modern effective foundations using seismic isolation structures and materials are discussed.

Due to the increased seismic activity, designers are faced with the challenge of developing earthquake-resistant foundation structures. Approximately 20% of Ukraine's territory is located in seismically dangerous areas, where earthquakes with intensities of 6 and above on the Richter scale may occur. Existing regulations unjustifiably limit the use of seismic isolation devices, recommending their application above the foundation structures, which does not correspond to historical and modern construction experience of effective foundations in conditions of heightened seismic activity.

Every year, over 300,000 earthquakes occur worldwide, resulting in the deaths of approximately 10,000 people. Seismic events (earthquakes) can be associated with tectonic, volcanic, or denudational processes. The most seismically dangerous regions in Ukraine are the Carpathian region, Odesa region and Autonomous Republic of Crimea.

The foundation part of a building absorbs seismic ground vibrations, transmitting them to the upper structures, after which the reverse impulse is transmitted back to the ground foundation through the foundation. This undoubtedly testifies the unique role of the foundation in the "base-foundation-superstructure" system and necessitates the design of seismic-resistant structural types for them.

1. Levitating buildings. Japan has pioneered this technology for seismic-resistant construction. In the event of underground tremors, the entire structure literally floats on an air cushion. Seismic-resistant buildings in Japan are capable of rising 3 cm above the ground to isolate themselves from ground vibrations. Sensors detect seismic activity signals and transmit a signal to the compressor to activate. Air is pumped between the foundation and the building's base using the compressor to create an air cushion. The air layer allows the building to levitate, avoiding destructive vibrations or reducing their impact. After the earthquake subsides, the compressor automatically turns off, and the building returns to its original position.

2. Rubber-metal supports. Such a support includes lower and upper parts, forming a closed chamber with an intermediate cushion made of balls and grease. The lower part consists of a threaded bushing (reduces friction, provides corrosion protection) and a bolt (creates initial tension in the intermediate cushion). The upper part consists of a support plate assembly, a guide sleeve, and a conical core (reduces specific pressure on the inner surface of the support). The stiffness of the upper part is provided by ribs and a cavity filled with concrete. The supports are fixed to the support plates using anchor bolts. The use of supports provides the protection of buildings and structures from seismic shocks.

3. Seismic protection systems with kinematic supports. Kinematic foundation supports (Fig. 1) create a sliding joint between the foundation supported on the ground and the above-ground part of the building, thus separating their movements in the event of seismic influences. The joint is created using supporting elements - bodies of rotation of a certain shape, or otherwise, kinematic supports, on which the above-ground part of the building rests.

During significant horizontal ground displacements, the supporting elements substantially reduce the displacement of the above-ground part of the building relative to the ground.

Fluoroplastic gaskets are used at the contact points of the rotating bodies with the concrete parts of the building to reduce friction forces.

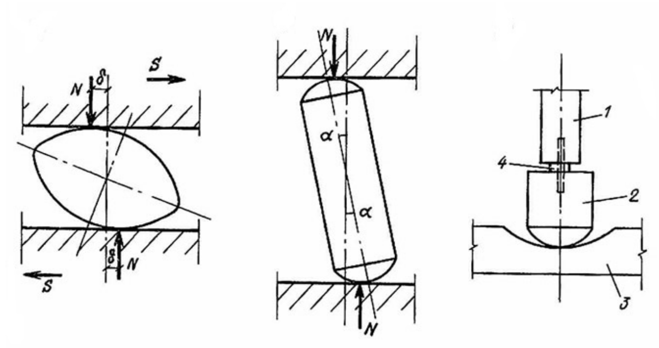

Fig. 1. Kinematic supports used for seismic isolation:
1 – Column, 2 – Armrest, 3 – Support plate, 4 – Centring washer

4. Foundation on bearings. The base isolation can be placed on composite rubber-metal cushions or components working on the principle of sliding. Flexible bearings or pads are often used for this purpose. For example, a building is constructed on top of flexible pads made of steel, rubber, and lead. During an earthquake, the building's foundation moves, but the structure itself remains stable. A heavy lead core is surrounded by layers of alternating rubber and steel. Steel plates are attached by bearings to the structure and foundation. When seismic waves occur, only the foundation moves, while the building itself remains immobility. Installing a large number of such isolators reduces seismic loading by 80%.

5. Seismic protection devices. Many skyscrapers around the world have a "secret" device that protects the building from strong movements caused by wind and earthquakes. Dampers are devices for damping vibrations that are installed directly into the structural frame of the building or structure.

There are many types to choose from depending on the specific project:

- inertial damper. It is usually made in the form of a concrete block that oscillates at the resonance frequency of the object. This is facilitated by a spring-like mechanism subjected to seismic loads;

hysteresis damper. Helps to improve seismic characteristics due to the dissipation of seismic load energy. Includes 4 groups of dampers;

- a a fluid viscous damper. It is installed in the structure of the building, being an additional damping system. It has an oval hysteresis loop and the damping is speed dependent. Although potentially requiring little maintenance, viscous dampers generally do not need to be replaced after an earthquake.

- friction dampers. As a rule, there are two main types: linear and rotary. They dissipate energy due to heat. The damper works on the principle of Coulomb friction. When used in seismically resistant conditions, wear is not a problem and maintenance is not required.

- metal elastic dampers. They have a margin of flexibility that allows them to absorb earthquake vibrations. This type of damper absorbs a lot of energy, but it needs to be replaced after an earthquake.

- viscoelastic dampers. Can be used for both wind and seismic applications. They are usually limited to small eliminations

6. Seismic foundation cushion. The principle of building foundations of a house on a heat-insulated foundation slab in earthquake-prone areas is used.

Taking into account the dynamic seismic forces affecting the increased edge loads of the foundation slab on the thermal insulation base, thermal insulation with a nominal compressive strength of at least 400 kPa is used; for taller and heavier buildings – 500 or 700 kPa.

FIBRANxps thermal insulation is laid on top of a well-stabilized gravel surface leveled with a layer of fine-porous concrete (concrete base). The waterproofing membrane is glued on top of the carefully laid first layer of FIBRANxps thermal insulation. Then the formwork of the foundation slab is installed on top of the glued layer of double-sided self-adhesive waterproofing membrane. Before installing the reinforcing rods, possible gaps at the joints of the slabs or along the formwork are provided with polyurethane foam or a suitable adhesive tape to prevent cement seepage during concrete placement. Then the reinforcement rods with spacers are installed on top of the seismic insulation and concreting.

7. Composite Foundation. Nanotechnology. Elastic metamaterials with appropriate locally resonant structures can filter the energy of propagating waves with frequencies in the stopping zone. The use of metamaterials to guide seismic waves characterized by bulk [primary (P) and secondary (S)] and surface (Rayleigh and Lava) waves has been demonstrated for Rayleigh-type waves through a series of full-scale experiments. Seismic metamaterials with subwavelength local resonators can be designed to have negative mass density and/or negative Young's modulus as a way to control elastic wave propagation in the seismic wave frequency range. (<50 Hz).

The proposed concept of a "composite foundation" combines the physics of seismic metamaterials based on the concept of mass-in-mass periodic systems directly with the building's foundation, creating on-site filters that reduce the energy transmitted from the seismic wave to the building at frequencies within the range of the building's primary vibration mode. The use of such systems represents a new paradigm for seismic protection development.

The composite foundation (Fig. 2) consists of four square-section reinforced concrete plates with a side length of 1 m and a thickness of 20 cm [Fig. 2 (a)]. Each plate is isolated from the others using a surface with ultra-low damping, created by a specific combination of steel and teflon layers.

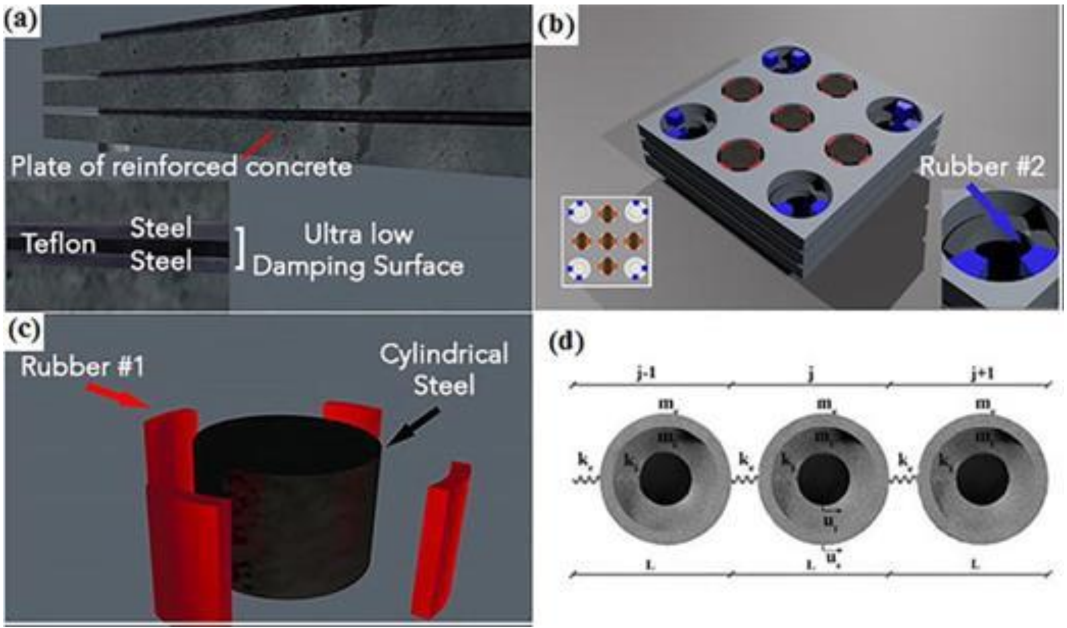

Fig. 2. Elements of the composite foundation

Mechanical connections, containing rubber with a low Young's modulus and a steel tube, are fixed at four corner inclusions (15 cm in diameter) to connect adjacent plates [Fig. 2 (b)]. Other inclusions are used to place steel cylinders and rubbers (rubber №1), as shown in Fig. 2 (c), to allow them to act as internal resonators. Along with damping through the rubber, the presence of spatially ordered local resonators with sizes smaller than the wavelength allows manipulation of sub-wavelength waves.

Figure 3 schematically illustrates an example of a composite foundation under a building for protection.

The plates with internal resonators are situated between the load distribution plate and the foundation plate to provide a more uniform distribution of loads on the foundation and, consequently, to improve its dynamic response.

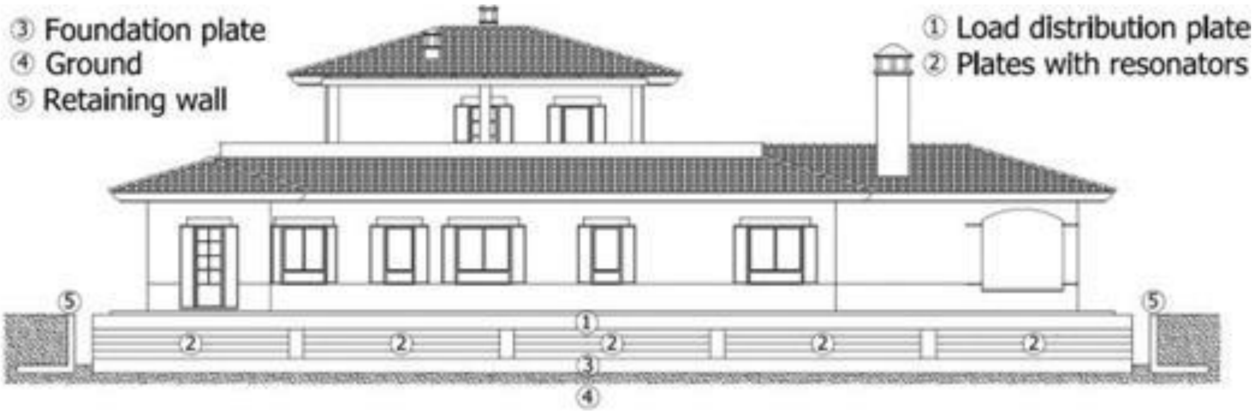

Figure 1. Scheme of the composite foundation:
1 - load distribution plate; 2 - plates with resonators;
3 - foundation plate; 4 - base; 5 - supporting wall.

Conclusions and Results. Design and construction of foundations taking into account seismic influences is carried out on the basis of current regulatory documents and has many years of positive experience. At the same time, the new building regulations unnecessarily limit the use of seismic isolation, recommending its use only above the foundation. But the international experience of building earthquake-resistant buildings shows the effectiveness of the use of seismic isolation devices and structures at the level and even under the sole of the foundations, which, by the way, happened in ancient times and is confirmed by thousands of years of experience.

Each of the structural schemes considered has its own advantages and disadvantages, therefore, for the effective protection of buildings against seismic influences, it is possible to recommend a combination of traditional schemes with modern effective structures of earthquake-resistant foundations.

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