Design of Base and Foundation for the Earthquake-Resistant Building

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Abstract. The article presents the design of base and foundation for the earthquake-resistant 5-9-storey building of rigid structural system. The main technical idea is to exclude the most destructive components of seismic effects, which are transmitted to the lateral vertical walls of basements and foundations, and to reduce the interaction forces of the foundation soils on the foundation. The design of earthquake-resistant base and foundation includes a solid reinforced concrete foundation slab with criss-cross strips, freely supported on an intermediate sandy cushion, which separates the soils from the foundation slab, and the channels around the foundation.

1. Introduction
Every year 100000 or more earthquakes that can be felt by people occur worldwide. These earthquakes range from very small events felt by only a few individuals to great earthquakes that destroy entire cities. The number of lives lost and the amount of economic losses that result from an earthquake depend on the size, depth and location of the earthquake, the intensity of the ground shaking and related effects of damage of building [1].

Today’s design professionals know how to design and construct buildings and other structures that can resist even the most intense earthquake effects with little damage.

Earthquake engineering has been one of the most rapidly evolving areas of structural engineering practice during the past 40 years. Extensive research and development has occurred at major universities and new technologies have been adopted into engineering practice.

In modern construction it's important to ensure the reliability of buildings and structures and their foundations in earthquake prone areas. The following works [1-12] are devoted to solving various problems of the theory of seismic stability. This paper reviews the design of base and foundation for the earthquake-resistant building of rigid structural system.

2. About foundation of earthquake-resistant building
Consider the basic recommendations for earthquake-resistant buildings [2]:

• it is necessary to reduce the connections of foundations with the soil – the source of seismic effects;
• side faces of the foundations in contact with the soils accumulate (contribute to an increase the value) horizontal seismic effects on the foundation, leading to its
displacement. In this connection, it is advisable leave an air gap to reduce these effects;
  - reducing friction between the base of the foundation and the soils reduces the transmission of horizontal seismic effects on the foundation and at exceeding of the friction resistance contributes to the slippage of the seismic wave under the foundation;
  - protection of the foundation by a trench is effective and depends on the depth, size and location of the trench closer to the building, from wave length, type of foundation.

It is known, a foundation is the supporting part of a structure that transmits the loads from the structure to the foundation soils.

Due to seismic loading, foundations can experience a reduction in bearing capacity and increase in settlement. Two sources of loading must be taken into consideration: inertial loading caused by the lateral forces imposed on the structure, and kinematic loading caused by the ground movements developed during the earthquake.

Generally, a properly designed and performing foundation system should [3]:
  - support the mass of the structure without excessive settlement;
  - transfer large lateral earthquake loads between the structure and the ground;
  - resist earthquake - induced overturning forces;
  - resist both transient and permanent ground deformations without inducing excessive displacements in the structure or in-plane distortions in elements supported by the structure.

A design earthquake is a theoretical earthquake event that modern building designers use to check the resilience of a new structure. It is impossible to create a completely earthquake-proof structure. However, a building may be engineered to withstand a design earthquake or at least behave in a predictable way if a design earthquake should occur.

The above discussion suggests that there are many aspects which require research and development efforts, especially in order to achieve optimal designs.

A degree of seismic resilience can be achieved by applying a sound understanding of structural engineering and construction principles to the structural elements and system that make up the building.

3. Design of base and foundation for earthquake-resistant building

It was noted, in major earthquake the building of rigid structural system with clamped foundations in dense soils received more severe damage compared to the similar buildings located on weak soils [8].

According to the experimental results of sandy soils at the base of a rigid stamp with dynamic (seismic) load, it has been determined that the friction force in the base of a rigid stamp is decreased by 3-4 times [13].

It is known, in strong earthquakes, including the existence of major seismic tremors, decrease of the friction force in the base of rigid buildings to a value less than the inertia force of the mass of rigid buildings is obvious.

Taking into account the test results, it should be considered that with the decrease of friction force in the base of the foundations to values

$$F_{fr} \leq F_{in},$$

(1)

the seismic impact on the clamped foundations are transferred to the structure of rigid buildings by not through the foundations but through the vertical walls of foundation of the backfill soil [5].
The impulse shifts of the foundations from the effects of more dense backfill soils on the vertical walls of the foundations at maximum acceleration of the foundation soils cause seismic tremors of great force and serve as the main reason of more severe damage of rigid buildings with clamped foundations in more dense soils.

In connection with the above, the foundations of earthquake-resistant 5-9-storey building of rigid structural system are proposed to design in the form of a solid reinforced concrete foundation slab with criss-cross strips freely supported on an intermediate sandy cushion (without clamping) at the base of the foundation slab with channels around the foundations used for laying various communications (heating, plumbing, etc.). Figure 1 illustrates the design of base and foundations for earthquake-resistant building.

![Figure 1. The design of base and foundations for earthquake-resistant building.](image)

1 - wall panel, 2 - transverse and longitudinal beams of foundation, 3 - solid reinforced concrete foundation slab, 4 - intermediate sandy cushion.

Freely supported slab on the intermediate sandy cushion of river rounded sand without impurities of clay, clay particles will reduce the friction force in the base of the foundation slab due to the dynamic effects on foundation soils during strong earthquakes.

An inelastic shift of the foundation soils relative to the base of the foundation slab will occur.

Displacement of the foundation slab with slippage during strong earthquakes cause seismic loadings on rigid buildings that do not exceed the friction forces in the base of the foundation slab. And due to the absence of clamping of the foundation slab, it will be no horizontal seismic tremors.

Only elastic displacements of the foundation slab save together with the base (without slippage) during periods when the friction force in the base of the foundation slab is greater than the friction inertia force of the building mass \(F_{fr} > F_{in}\) in case of earthquakes of lower intensity, at lower accelerations of the foundation soils [8].

In this connection, the seismic impact on the structures of the foundation slab and, especially, on the structures of the above ground part of the rigid buildings are sharply reduced.

A similar example of seismic protection of building structures is the installation of narrow channels around buildings to exclude the frontal pressure of backfill soils on vertical surfaces of foundations from surface seismic waves.

For the purpose to simulate soils in the backfill of the foundations and a sharp decrease in the impact force in case of horizontal seismic tremors during strong earthquakes, it is also advisable to replace the channels around the foundations by an elastic, flexible, low strength layer, and it will be increase the seismic resistance of rigid buildings.

4. Results and discussions

The proposed constructive solution of the foundations of seismic resistant buildings is confirmed by the results of tests of sandy soils at the base of a rigid stamp with dynamic (seismic) load, by construction experience, and the results of a survey of the load-bearing structures of rigid buildings after strong earthquakes.

The construction of rigid buildings with foundations, in according with the proposed design scheme, will allow to exclude horizontal seismic impact on the vertical walls of the foundations (due to the absence of clamping), and therefore horizontal seismic tremors on the buildings are also excluded.
At the same time, seismic impact on the structures of rigid buildings are significantly reduced due to the smaller displacements of the foundation slab during the slippage of the foundation soils, thereby increasing the seismic resistance of rigid buildings and structures.

The main technical idea is to exclude the most destructive components of seismic impact transmitted to the lateral vertical walls of basements and foundations, and to reduce the forces of interaction of the foundation soils on the base of the foundations, due to set intermediate sandy cushion between foundation and soil ground of fine or medium-sized sand with channels around the foundations.

The analytical and numerical analyses of the design will be carry out for modelling the behaviour of the scheme. So, model tests will be undertaken with following objectives:

- to validate the theoretical predictions of the ultimate bearing capacity of the foundation under increasing shear force and overturning moment,
- to identify the failure mechanism of the foundation under these loads.

Theoretical bases of calculation of dynamic stiffness and seismic loads on foundations are presented for the case of soil cushion in [11]. The article [12] is given an example of practical calculation of these values, the author shows the specific problems arising at the calculation of structures on the soil cushions.

It is necessary to carry out the calculation of the real building object by using the design scheme of considered foundation for the purpose of justification, the quantitative and qualitative description of the design scheme. In calculations it must be to take into account the interaction of all parts of the system «foundation soils – foundation – structure», instead of its separate part. It should be a single multi-connected system [14].

5. Conclusions
The design scheme of the earthquake-resistant base and foundation presented in the article includes a solid reinforced concrete foundation slab with criss-cross strips, freely supported on an intermediate sandy cushion, which separates the soils from the foundation slab, and the channels around the foundation. For the scientific justification of the work and its implementation in the future will be to conduct a set of experimental and theoretical studies for the purpose the reactions of buildings (models) and to identify the mechanism of interaction of soils and foundations of the building for the considered design scheme.

So the implementation of the aims of the work will significantly clarify the design scheme adopted for the selected base and foundation for the earthquake-resistant building of rigid structural system, and to identify the mechanisms of interaction of foundations (buildings) with the foundation soils, taking into account the impulse and wave nature of seismic impact.

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