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ON THE ISSUE OF «SOIL – FOUNDATION – STRUCTURE» SYSTEM INTERACTION FOR THE NPP CONSTRUCTIONS UNDER SEISMIC IMPACT

One of the important issues of environmental security is the possibility of natural or man-caused accidents on the objects of increased responsibility, which include buildings and constructions of nuclear power plants (NPP). It is an extremely important task, to guarantee a safe work of nuclear power plants, as well as a safety of staff and environment. According to the regulated international and industry standards, the construction of buildings and nuclear power plants are to be relied on seismic effects is required in order to establish the boundary seismic resistance, and also finding the kinematic parameters of the building. The calculation of buildings and structures on the seismic effects should be carried out taking into account the interaction between the foundation and ground base. The problem of interaction between the foundation and soil base occupies a central place in the general theory of seismic stability.

Keywords: *interaction system «soil – foundation – structure», a dynamic model, nuclear power plants, seismic action, evaluation of seismic area.*

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ПРО ПИТАННЯ ВЗАЄМОДІЇ СИСТЕМИ «ҐРУНТ – ФУНДАМЕНТ – СПОРУДА» ДЛЯ КОНСТРУКЦІЙ АЕС ПРИ СЕЙСМІЧНОМУ ВПЛИВІ

Одним із важливих питань екологічної безпеки є можливість виникнення аварій природного або техногенного характеру на об'єктах підвищеної категорії відповідальності, до яких відносять будівлі та споруди атомних електростанцій. Гарантування безпечної експлуатації атомних електростанцій, а також безпека персоналу і навколишнього середовища є надзвичайно важливим завданням Згідно з регламентованими міжнародними та галузевими нормами, конструкції будівель і споруд АЕС необхідно розраховувати на сейсмічні впливи з метою встановлення граничної сейсмостійкості, а також знаходження кінематичних параметрів будівлі, при цьому розрахунок необхідно виконувати з урахуванням взаємодії фундаменту з ґрунтовою основою, тому що проблема взаємодії фундаменту з ґрунтовою основою займає одне з центральних місць у загальній теорії сейсмостійкості.

Ключові слова: *взаємодія системи «ґрунт – фундамент – споруда», динамічна модель, АЕС, сейсмічна дія, оцінка сейсмічності майданчика.*

Introduction. One of the important issues of environmental security is the possibility of natural or man-caused accidents on the objects of increased responsibility, which include buildings and constructions of nuclear power plants (NPP). In particular, these threats include seismic events that can lead to environmental disasters with considerable human casualties.

According to the regulated international and industry standards [1 – 9], the construction of buildings and nuclear power plants are to be relied on special effects, in particular the calculation of seismic effects is required in order to establish the boundary seismic resistance, and also finding the kinematic parameters of the building. The calculation of buildings and structures on the seismic effects should be carried out taking into account the interaction between the foundation and ground base.

The problem of interaction between the foundation and soil base occupies a central place in the general theory of seismic stability. The intensity of seismic effects in the construction area is the most significant factor affecting the seismic resistance of structures. An equally important factor is the calculation of the buildings in the «foundation – structure» system as subgrade accounting helps to ensure a more correct results, which is essential for buildings and nuclear power plants.

Analysis of recent research sources and publications. In recent years, the general trend of increasing areas' seismicity is recorded, so the problem of taking into account the interaction between the soil and buildings under seismic impacts is being given considerable attention [10 – 13]. This topic is the subject of numerous publications, scientific works and the literature [14, 15]. In particular analysis of the interaction of the system «soil – foundation – structure» in the calculation of boundary seismic resistance, as well as finding the kinematic characteristics of the NPP buildings, is presented in the works of A. N. Birbrayer [16], Shablinskiy G. E. [17], J. Wolf [18]. Many researchers, both in our country and abroad, deal with the seismic analysis of structures of increased liability category, and the study of influence of subgrade is considered in works of T. K. Datta [19], A. M. Uzdin [20], A. G. Tyapkin [21].

Identification of general problem parts unsolved before. In order to prevent incidents on the NPP objects under seismic impact it is necessary to estimate the intensity of the actual seismic impact within the territory of the object, as well as to perform a detailed analysis aimed at the structural design and verification of the reliability of the structures. Lately, an overall trend of the seismic rating increase has been noted on the territory of Ukraine. Under these circumstances the issue of consideration of «soil – foundation – structure» interaction when designing or performing structural analysis of the NPP objects persists to be a topic of interest. Therefore, it is essential to analyze the available in the literature approaches and methodologies of consideration of soil in the «soil – foundation – structure» system, and to assess the investigations of the contemporary scientists within the field.

Formulation of the problem. The analysis of regulatory documents on «soil – foundation – structure» system interaction problem for NPP buildings and structures under seismic impacts. Consideration of the methodology for assessing the seismicity of the site and obtaining baseline data on the free surface of the soil. Consideration of base simulation methods in interaction with a structure.

The main material and results. According to regulatory documents, namely [7, 22] in the assessment of seismic resistance of NPP buildings, the building itself and its foundation must be considered in unity, i.e. the interaction with the base construction should be taken into account. In accordance with [22] the purpose of the analysis of dynamic soil – structure interaction is to determine the dynamic response of structures taking into account the effects of the interaction between the building and the environment base, when an integrated system is subjected to external impact or dynamic loads associated with the earthquake ground motion.

As a result of the dynamic interaction «soil – foundation – structure» the seismic response of structures will differ in some respects from the response of the same design, designed for hard ground (fixed base) and subjected to an identical disturbance, for the following reasons [8]:

1) motion of the construction foundation on an elastic baseline is different from the free-field motion and may comprise a significant component of the construction of swing with a fixed base;

2) the fundamental period of structure vibration on elastic baseline will be longer than the period of the structure vibration on a fixed base;

3) periods of natural oscillations, vibrations and modal formula coefficients of the construction on an elastic baseline will be different from the same design parameters with a fixed baseline;

According to [8] «soil – foundation – structure» dynamic interaction effects should be considered in:

1) the structure with massive or deep-laid foundations;

2) thin tall structures such as towers and chimneys, covered by [9];

3) constructions based on very soft soils.

For most conventional building constructions «soil – foundation – structure» interaction effects are rather favorable, because they reduce the bending moments and shear forces in the various elements of the superstructure, but in previously listed constructions, in particular structures with massive or deep-laid foundations, which include buildings and facilities of nuclear power plants, the effects of the interaction of «soil - foundation – structure» can be devastating [8]

According to [3] for the calculation of the joint facilities and baseline the analytical, numerical and other methods can be used (including the finite element method, finite difference method, boundary element method, etc.).

When calculating the system «soil - foundation – structure» evaluation of seismic site and obtaining baseline data on the free surface are of a great importance.

*Assessment of seismic site and receiving the response spectra on the free surface***.** In accordance with the recommendations of the IAEA SSG-9 [6] geological and geophysical studies should be carried out at four levels: regional, subregional, areas near the site location and site area itself, which provides a gradual and more detailed study of the object.

Geological and geophysical works on assessment of site seismicity include: seismic, geophysical, engineering-geological, tectonic, non-tectonic and geomorphic studies of various scales to assess seismicity of the NPP constructions location area of SLE level (repetition period of 1 per 1000 years) and SSE (return period 1 every 10,000 years), taking into account local conditions.

In the course of activities carried out a comprehensive assessment of seismic hazard of the site for SLE and SSE in points of EMS-98 scale and peak accelerations was performed.

The procedure for obtaining spectra of accelerograms and response to industrial site soil surface is reduced to the following points:

1) analysis and comparison of the standard response spectra given in the regulations for the event level of the SLE and SSE;

2) records of local resonance conditions due to the peculiarities of the geological structure and physical properties of the section of the industrial site for the various response spectra;

3) construction of a generalized response spectrum;

4) generation of three-component synthetic accelerograms.

The obtained response spectras and accelerograms are the initial data for further calculations of NPP buildings and structures on the seismic action.

System «foundation – structure» analysis methods under seismic loads. In the literature [14, 16, 18, 19, 20, 21] different base models are described, used in the analysis of the system «ground – foundation – structure» of the simplified:

– model with multiple degrees of freedom with lumped mass;

– model with springs and dampers;

to complex, such as three-dimensional finite element model.

According to [8] for the submission of base in the analysis of the interaction of the system «ground – structure» four main methods are used:

1) method of model with equivalent dynamic characteristics of the foundation (springs and dampers) and concentrated ground parameters;

2) the method of three-dimensional model with an infinite half-space and the substructures;

3) the method of three-dimensional finite element model and substructures;

4) direct (one-step) finite element method with a two-dimensional axisymmetric model.

Approach to soil simulation with equivalent dynamic characteristics of the foundation is widely used by engineers in practice.

Method of equivalent dynamic characteristics of the baseline is a set of springs and dampers connected to the base plate, which characterize stiffness and energy dissipation in the ground with a frequency-dependent or frequency-independent coefficients of stiffness and damping (Pic. 1).

Calculation of generalized characteristics of the base is made taking into account the features of the array of soil (depth of laying the foundation and the physical and mechanical properties of the soil under the foundation base).

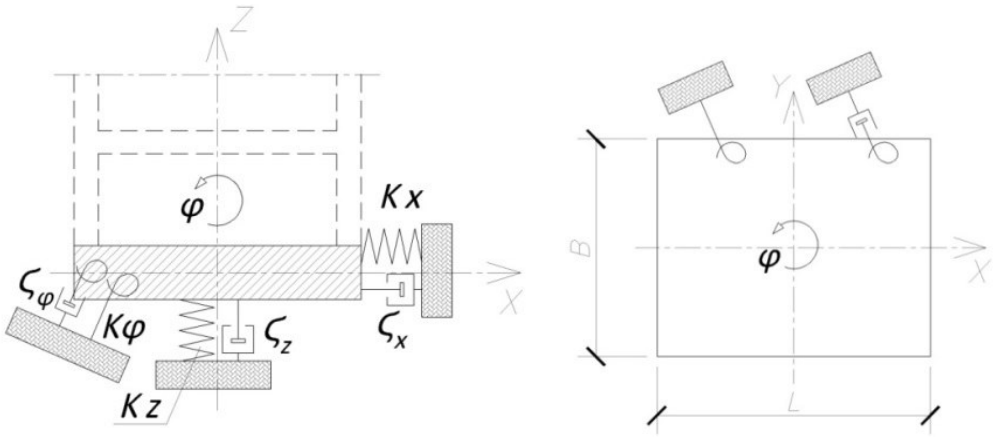

Figure 1 – The springs and dampers to simulate the effect of the base

Method for determining the equivalent dynamic characteristics of the foundation in the majority of cases is presented in the form of simple algebraic formulas and dimensionless charts, covering a wide range of possible characteristics of the foundation geometry.

In the simulation, the base equivalent to the dynamic characteristics of the calculation procedure in the construction of the system «ground – foundation – structure» boils down to the following points:

1) Development of the finite element model of structure (Pic. 2);

2) The calculation of the equivalent dynamic characteristics of the baseline to record the interactions in the system «construction – baseline»;

3) Development of a dynamic model of the building in order to obtain the estimated impact on the level of the sole construction of the foundation (Pic. 2);

4) The calculation of the finite element model structures on the seismic action.

a) b)

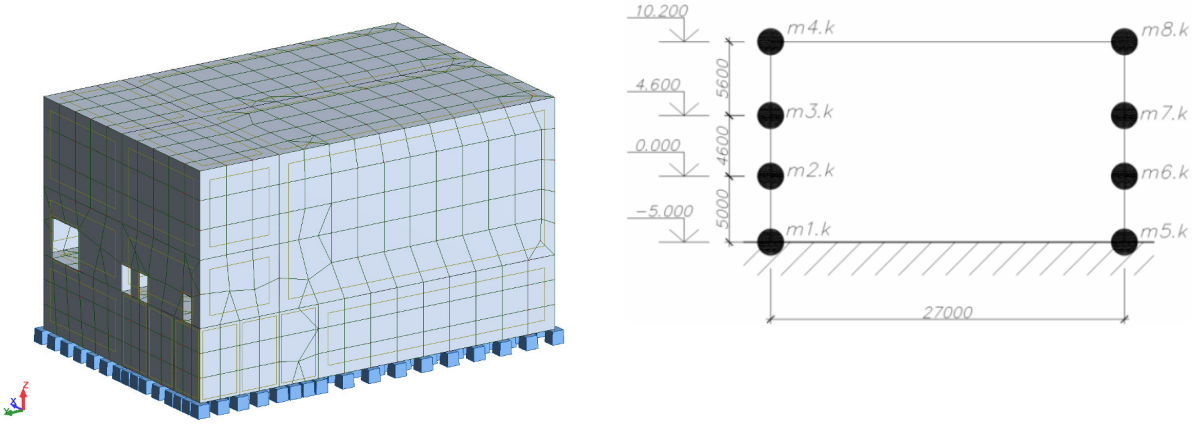

Figure 2 – Example of a finite element model of the structure (a) and the corresponding dynamic model (b)

In the simulation of the baseline in the form of three-dimensional finite element model, the soil is represented as a continuous medium together with the foundation and building elements (Pic. 3). It is necessary to take into account the fundamental difference in the requirements for the base model for static and seismic calculations.

In the first case it is sufficient to select such a size of the soil area, so that edge effects at its external boundaries did not affect the tensions under the construction. Typically, this boundary is removed by 3 – 4 maximum size of the foundation. If such a limited area at the base of seismic calculations is set, the waves reflected from the foundation, which in a real earthquake freely go for a half-base, will be reflected from the boundaries of the area and, returning to the construction, distort its oscillation («box effect»). To avoid this, it is necessary to remove the boundaries of soil area so that the waves of the earthquake did not have time to reach back. But in fact, this task is difficult in the performance, as a model of this size is hardly subjected to calculations. Therefore another is done: on the edges of a soil area special boundary conditions are set that mimic the smooth passage of seismic waves.

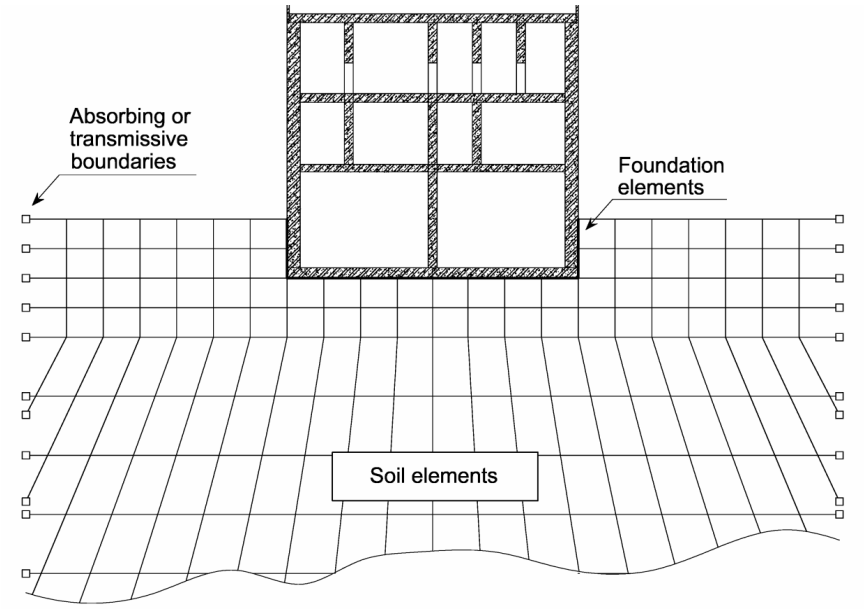

Figure 3 – Three-dimensional finite element model of the interaction of the foundation and constructions

The lower limit may be drawn across the surface of the underlying layer of rock or soil, the module of elasticity of which is not less than 10 times higher than the module of the soil directly beneath the foundation. If such layers on a fairly shallow depth are not present, the depth of this boundary shall be three times the maximum size of the foundation slab. This limit can be regarded as absolutely rigid.

Ultimately, the three-dimensional finite element model of the interaction of the soil and buildings is ground together with the foundation and building elements, absorbing boundaries on the faces of KE mesh and plate elements on the edges of the foundation (Pic. 3).

Conclusions. According to regulatory documents calculation of NPP buildings and structures on the seismic effects must be carried out taking into account the interaction of the system «soil – foundation – structure», while for baseline data obtaining it is necessary to assess the seismic site activity and get the response spectras of the free surface of the soil. For simultaneous calculation of buildings and foundation analytical, numerical and other methods can be used (including the finite element method, finite difference method, boundary element method, etc.).

In practice, when modeling interaction system «soil – foundation – structure» a method of equivalent dynamic base characteristics is widely used, which is a set of springs and dampers connected to the base plate and characterize stiffness and energy dissipation in the ground. A direct method of interaction can also be used, where the oscillations of buildings and grounds are considered together, in a single step, for which a compiled computational model is set, including the structure itself and some areas of foundation, but at the same time at the edge of ground area special boundary conditions are to be set, which mimic the full absorption or the smooth passage of seismic waves. The regulatory documentation on «soil – structure» system interaction issues for buildings and seismic impact nuclear facilities is analyzed. The method of evaluation of seismic site and obtaining the baseline data on the free surface of the soil is examined. The methods of modeling the interaction of the base with the construction are examined.

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