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Procedia Engineering 111 (2015) 550 – 555

Procedia Engineering

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XXIV R-S-P seminar, Theoretical Foundation of Civil Engineering (24RSP) (TFoCE 2015)

Assessing the reliability of a multi-storey monolithic concrete building with a base

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Abstract

In the article the reliability estimation of a multi-storey building under operating and seismic loads is considered, with base facilities interaction taking into account. To assess the reliability of structures under the action of a random seismic action, the basic quantitative characteristic of reliability - the probability of failure was defined. For statistical tests a computational model of a 5-storey building with a cross-wall design scheme was built. In the process of solving the problem on assessing the reliability, strength and stiffness characteristics of the construction and soil base were studied.

Peer-review under responsibility of organizing committee of the XXIV R-S-P seminar, Theoretical Foundation of Civil Engineering (24RSP)

Keywords: Reliability; Probability of refusal; Density function; Cumulative distribution function; Nonlinearity; Interaction with the base

1. Problem Statement

The estimation of the reliability of a 5-storey building under the action of a random seismic action is considered as a non-stationary random process, taking into account the interaction of structures with the ground base.

As a design scheme the following finite element model of the building was taken (Figure 1):

The study was conducted using direct dynamic method in LS-DYNA software package. In conducting each test to assess the failure probability by numerical solution of a direct dynamic method based on geometrical, physical and structural nonlinearities was made [1,2]. For the foundation soil the Mohr-Coulomb model was taken [3].

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Peer-review under responsibility of organizing committee of the XXIV R-S-P seminar, Theoretical Foundation of Civil Engineering (24RSP)
doi:10.1016/j.proeng.2015.07.041

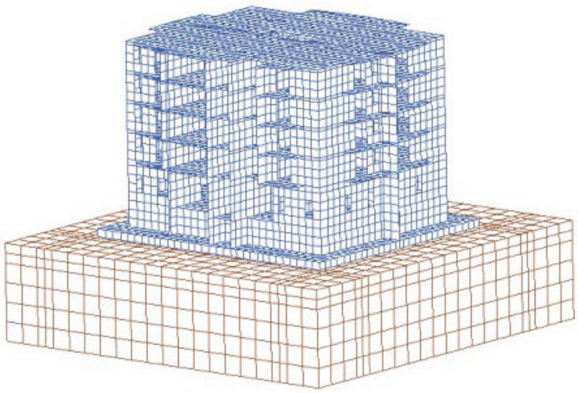


Fig.1. Finite element model of the building jointly with the soil base.

Uploading of a model structure with a base was produced by deterministic operational and random seismic loads.

With loads described by a stationary Gaussian process, the reliability function for any system is as follows:

$$P(t) = 1 - \frac{1}{2\pi}\frac{q'}{q}\int_{-\infty}^{\infty}...\int \exp\left[\frac{(g(x_1, x_2, ..., x_n) - m_q)^2}{2s^2}\right] f(x_1, x_2, ..., x_n) dx_1 dx_2 ... dx_n, \quad (1)$$

where m_q и q - the expectation and the standard loading process, q' - rate standard of a process change, $g(x_1, x_2, ..., x_n)$ - operability function.

However, for non-stationary random processes a decision obtaining involves considerable mathematical difficulties. In this case, it becomes the most appropriate application of the method of statistical tests.

Non-stationary random seismic action can be written as:

$$a(t) = A(t)y(t), \quad (2)$$

where $A(t)$ - a deterministic function called "envelope", $y(t)$ - stationary random process.

The stationary random process $y(t)$ was simulated by the method of canonical expansions using the action spectrum obtained by F.F. Aptikaev. The prevailing period of a stationary random process $y(t)$ can be determined from the formula:

$$\lg T - 0,15 M_s + 0,25 \lg R + C_1 + C_2 \pm 0,20, \quad (3)$$

here T - prevailing oscillation period, R - hypocentral distance, M_s - magnitude determined by surface waves, C_1 - parameter received -0,1 for reverse faults, 0 for shifts and 0,1 for discharges; parameter determining the influence of unrecorded factors that may be taken as $C_2 = 1,9$.

The resulting realization of the random seismic action are normalized to a maximum acceleration $a_{max} = 4$ m/s^2 which corresponds to 9 points earthquake intensity on the MSK-64 scale [5]. Figure 2 shows a realization of a random accelerogram (horizontal component X) of the original impact.

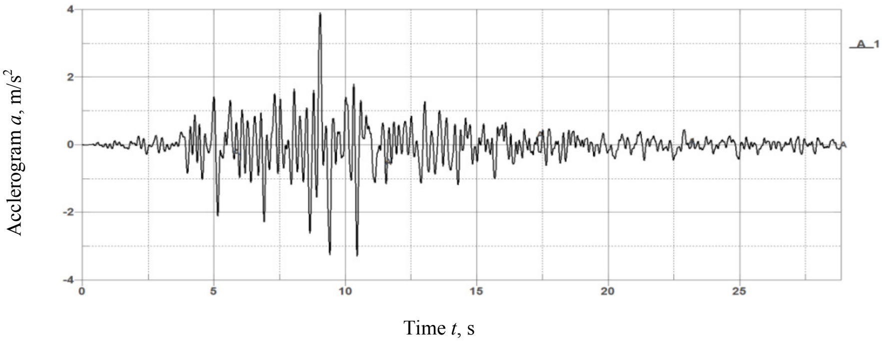


Fig.2 The horizontal component X of a 9 point impact intensity accelerograms.

Range of accelerograms (on Aptikaev F.F.) is shown in Figure 3.

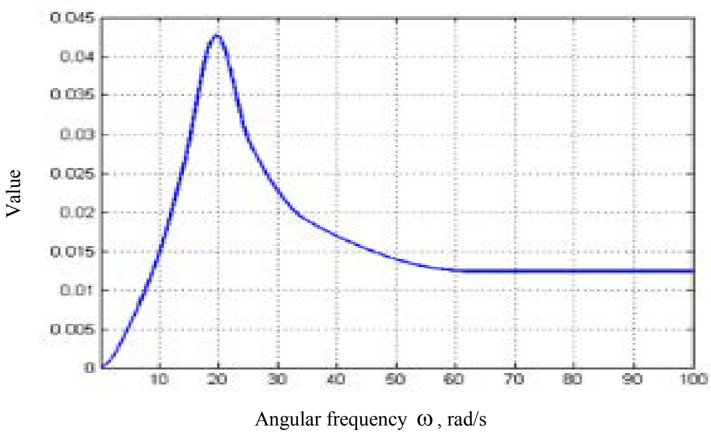


Figure 3. The spectrum of synthesized accelerograms (dominant frequency 3 Hz).

2. Estimation of reliability

To estimate the reliability of structures, 10 numerical tests have been conducted. During each test, its own load weight with temporal and vertical seismic loads was applied to the structure model.

The components of the synthesized ternary accelerograms are statistically independent.

Output parameters have the following values:

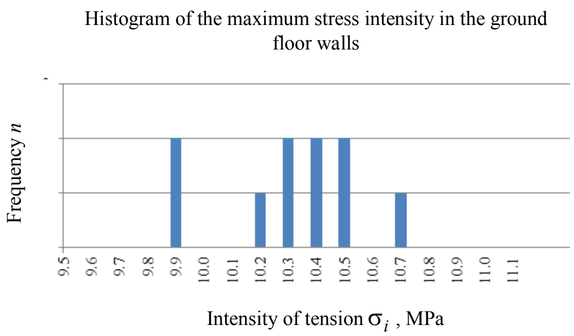
- the intensity of the stresses in the bearing walls of the ground floor σ_i;
- vertical stresses in the foundation soil σ_v;
- plastic deformation of soil base under foundation slab ε^{pl};
- foundation slab sediment s;
- relative horizontal displacement of the coating w_r;
- overlap relative displacements within the same floor w_1;
- horizontal acceleration of the coating a_r.

For all of the random parameters representing the response of the system to an external stimulus, numerical characteristics of distribution histograms were determined. The resulting empirical distributions were approximated by analytical distribution law, for which the corresponding distribution densities and the distribution functions were constructed. The probabilities of different failure modes were calculated [6].

For failures in this study the following events were taken:

- the emergence of plastic deformation in vertical structural elements of the ground floor ε_v^{pl} ;
- reaching building top total displacement to ultimate value w_r ;
- exceeding of the upper limit values by the absolute acceleration a_r ;
- exceeding stress in the foundation soil limits σ_v ;
- exceeding limit values by plastic deformations of soil base ε_s^{pl} ;
- precipitate exceeding foundation slab limits *s*;
- exceeding the limits by ultimate horizontal displacements of overlap within the same floor w_1 .

Picture 4,5 shows some of the results of evaluating the reliability of the building



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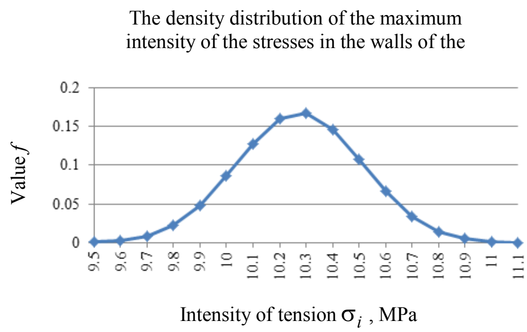

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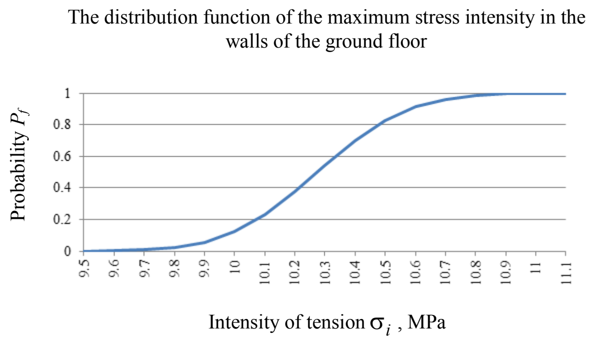

c

Fig. 4 (a) Histogram of the maximum stress intensity in the ground floor walls; (b) The density distribution of the maximum intensity of the stresses in the walls of the ground floor; (c) The distribution function of the maximum stress intensity in the walls of the ground floor.

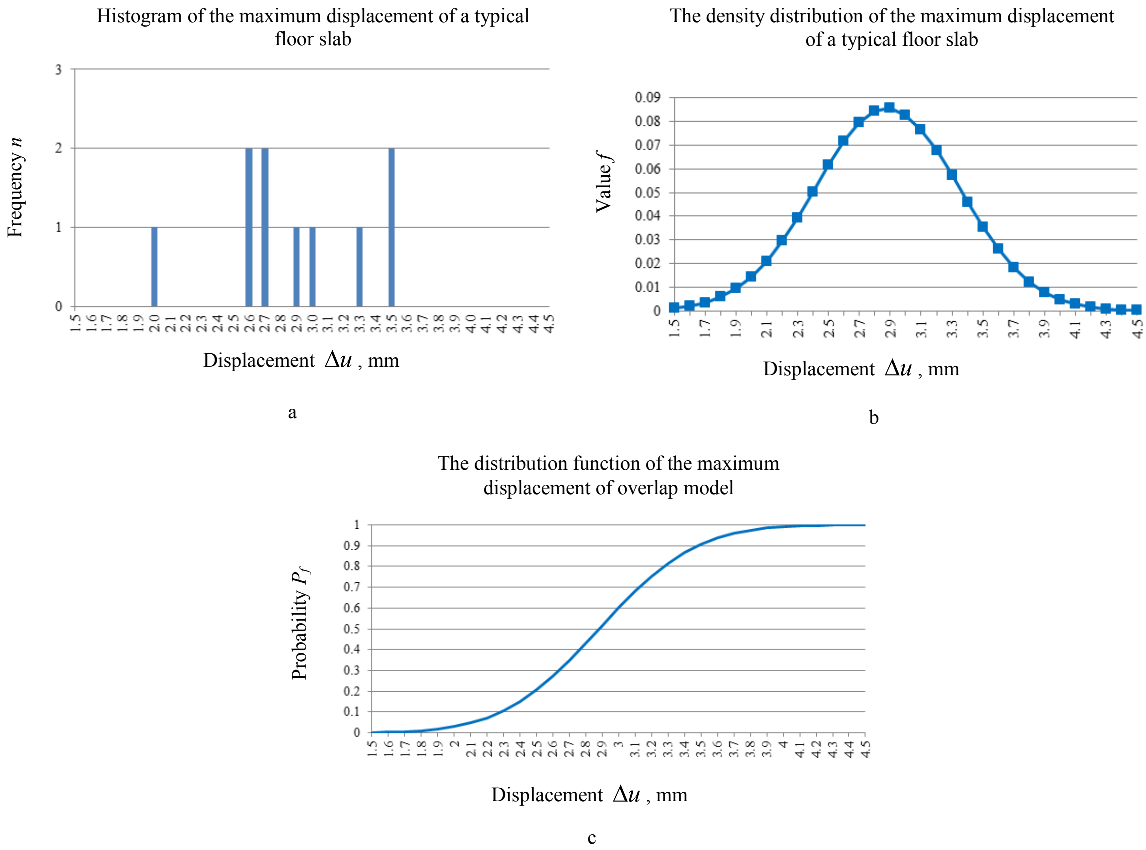

Fig 5 (a) Histogram of the maximum displacement of a typical floor slab; (b) The density distribution of the maximum displacement of a typical floor slab; (c) The distribution function of the maximum displacement of overlap model.

3. Analysis of the results

Table 1 shows the limiting values of output parameters and failure probability.

Table 1. Limit values and the probability of failure.

	Limit value	Probability of failure	Note
The maximum intensity of the stresses in the lower floor design σ_i , MPa	**18,50**	**$<10^{-12}$**	Limit value - normative strength of concrete B25
The maximum stress in the soil under the foundation slab σ_z , kPa	**300,00**	**$<10^{-12}$**	-
Maximum plastic deformation in the elements of the soil under the foundation slab of the building ε^{pl}	**0,05**	**0,9996**	-
Maximum foundation slab precipitate *w*, sm	**15,00**	**0,9150**	-
Maximum horizontal acceleration of the building top a , m/s²	**8,00**	**0,00017857**	-
The maximum displacement of the building top to the foundation slab *u*, sm	**3,80**	**0,00019135**	Limit value - 1/500 of the building height

The maximum relative displacement of overlap within the 1st floor *Δu*, mm	**14,00**	**<10^-12**	Limit value - 1/300 of the height of the floor
The maximum relative displacement of a typical floor slab *Δu*, mm	**10,00**	**<10^-12**	Limit value - 1/300 of the height of the floor

4. Conclusions

The developed probabilistic method of estimating reliability of buildings and structures, allows to design building structures with a given level of reliability, as well as a given seismic resistance of multiple systems when constructing in seismic areas. Used deterministic solutions allow taking into account geometric and constructive nonlinearity in the calculation, as well as working together with the construction of the foundation soil.

Acknowledgements

This work supported by the Ministry of education and science of Russia under grant number № 7.2122.2014/K.

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