Evaluation of seismic stability of layered soil bases in areas that are composed of clays and water-saturated sandstones

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ABSTRACT

To study the dynamic stability of the layers of clay and water-saturated sandstones with the position estimate of their liquefaction at seismic impacts, relevant project (forecast) seismic activity area, in the laboratory of the Department of bases, foundations, structural dynamics and engineering geology tests of soils equivalent to a force against seismic action triaxial cyclic loading. The results obtained were used to develop recommendations for the construction of basements and foundations for the effects of seismic loads on the mechanical properties of the soil base and, as a consequence of vibration liquefaction soil.

Keywords: earthquake, water-saturated soil, vibration liquefaction, thixotropic properties

1. INTRODUCTION

As a result of construction Nizhnekamsk reservoir in the Republic of Tatarstan has been raising groundwater levels and flooding of some areas of the coast of the river Kama. This rise in groundwater levels and the presence of tectonic faults in the area Kamskie Polany provoked an increase in the level of seismic activity of the considered territories of the coast of the Kama river in the territory of the Republic of Tatarstan. In accordance with the new seismic zoning map OSR-97 on the territory of the Republic of predicted earthquake with an intensity of 6.5 points on the middle ground, and as a result, the need to evaluate dynamic properties of soils of the grounds for the research and application of seismic reinforcement in the design and construction of buildings.

Taking the above into account, when designing the foundations of responsible structures it is necessary to consider the effects of seismic loads from potential earthquakes on the change of physical-mechanical properties of soils.

2 GENERAL INFORMATION ABOUT THE CONSTRUCTION SITE

The study area is located on the left bank of the Kama River, in the northeast of the Republic of Tatarstan. The results of the seismic zoning of the construction site show that seismic activity at the site soils data base is estimated as 6.5 points on a scale MSK64 acceleration 112 cm²/sec for short and medium term fluctuations. The estimated accelerogram scenario earthquakes and the corresponding spectra of the reaction is presented in figures 1 and 2.

This area is composed of layers of alternating layers of clay and water-saturated sandstone at a depth of 28 m.

Geomorphologicaly survey area related to watershed plateau of the Kama River and the river Steppe Zai, complicated by Tunghuch brodevalley (Inysh), right tributary of the river Avlashka (basin of the river Steppe Zai).

Technologically generated area’s relief is relatively plain and has a gentle slope in the north-west direction, within the absolute marks 205,32-202,97 m.

Geological structure of the survey site consist of srednepermsk eluvial interbedded clays, sandstones, siltstones and limestones. In some areas srednepermsk alluvial sediments overlayed by a thin Quaternary eluvial-diluvial loam. From the top of the surface Quaternary eluvial-talus and srednepermek eluvial sediments overlayed by made ground with thickness from 0.2 to 4.0 m.

These soils located in the groundwater level’s fluctuating zone.
LABORATORY TESTING OF SOIL

To study the dynamic stability of the layers of clay and water-saturated sandstones with the position estimate of their liquefaction at seismic impacts, relevant project (forecast) seismic activity area, conducted laboratory tests equivalent to the power relation to seismic impact triaxial cyclic loading.

In modeling the deformation conditions in which soil is under seismic impacts in real field conditions, before cyclic loading is carried predictive modeling seismic load based on the methodology proposed by Seed (1996) and Idris (Ishihara, K. (2006)).

In accordance with this method may be characterized by a seismic load value above cyclic shear stress (CSR) at a predetermined frequency and earthquake intensity.

\[ CRS = \frac{\tau_{av}}{\sigma_v}, \]

where \( \tau_{av} \) – the mean value of the expected cyclic shear stress at a given magnitude;

\( \sigma_v \) – vertical compressive stress.

It is assumed that before the earthquake ground element located below the horizontal surface, is exposed for a long time in a state of consolidation \( K_0 \) (\( K_0 \) - the ratio of the horizontal and vertical stresses during consolidation under natural conditions). During an earthquake on this element in the soil undrained conditions operates a series of consecutive cyclic shear stresses. These voltages are applied in the absence of lateral deformation because it is believed that the flat earth surface extends infinitely in the horizontal direction.

In practical calculations to assess the potential dilution of clay and sandy soils with varying water saturation average values of shear stress \( \tau_{av} \) caused by the earthquake at a depth \( h \) can be determined from the following expression:

\[ \tau_{av} = \left(0.65 \cdot \frac{\gamma \cdot h}{g}\right) \cdot a_{max} \cdot r_d. \]

The value of \( a_{max} \) is adopted by earthquakes accelerograms peak horizontal acceleration for the horizontal components of the oscillation.

The number of loading cycles \( N \) in a laboratory experiment, simulating the seismic action depends on the duration of the earthquake, and consequently the magnitude of the earthquake.

The above calculation (approach) gives the maximum value of the expected cyclic shear stress during an earthquake \( (\tau_{av}) \), which during triaxial dynamic tests corresponds to half the axial dynamic loading (Fig. 3).

Based on the one discussed above methodology developed computational model of the stress-strain state of a layered base, folded sandy and clay soils with varying degrees of water saturation of scenario earthquakes with the possibility of an array of ground acceleration in three directions, as well as the interference layers of different stiffness.
To quantify dilution layers of saturated sands and clays with a random multidirectional irregular seismic action introduced correction function to correct the cyclic strength obtained in stationary cyclic loading to take into account the above-mentioned characteristics of the real seismic loading $C_2$ and $C_3$. The coefficient $C_2$ considers the impact of non-periodicity of the load acting in one direction only, coefficient $C_3$ considers the impact of multi-directional seismic loading. Multiplication of these coefficients reflects the combined influence of nonperiodicity and multi-directionality of the load (Ishihara, K. (2006)).

Based on the developed computational model, equivalent parameters defined regular cyclic loading for laboratory research resistance to liquefaction of sandy and clay soils reason of the construction site at the following design characteristics of the scenario earthquake: 6.5 points, the acceleration of $A = 112 \text{ cm}^2/\text{sec}$, the fundamental frequency $\approx 2 \text{ Hz}$ main oscillation period of 0.56 seconds.

To evaluate the resistance to vibration liquefaction, the following failure criteria (Mirsayapov & Koroleva 2012):
1. The occurrence of axial strain under triaxial cyclic loading of less than 5%;
2. The rate of pore pressure $\beta = p_u/\sigma_{vp}$ should be $\beta \leq 0.6$;
3. The width of the hysteresis loop at the 30th cycle, the loading must be less than the width of the loop 29 on the loading cycle, i.e. $\Delta \varepsilon_{x0} \leq \Delta \varepsilon_{x9}$.

Experimental studies of resistance to vibration liquefaction 143 series undisturbed soil samples (134 series) and impaired (9 series) structure (three specimen - twins in each series) in the triaxial apparatus (triaxial) under cyclic loading with option equivalent scenario earthquake with an intensity of 6.5 points established for the construction site of the facility "deep conversion of heavy residues" in Nizhnekamsk. Results of the study are given in Table 1 partially.

During experimental studies established the basic parameters characterizing the state of sandy and clay soils under cyclic loading: longitudinal and radial deformation, pore pressure, and mean effective stress.

The experimental studies revealed patterns of deformation at an equivalent cyclic loading.

Analyzing the results, we can conclude that under cyclic triaxial compression of soil samples varying degrees of saturation with the parameters of equivalent seismic loading with an intensity of 6.5 points, is the development of strains with different intensity (Fig. 4).

At the initial stage of development of deformations more intense due to additional sealing sample, then strain stabilized. In all the samples tested at a cyclic loading, the calculated equivalent screenwriting earthquake with an intensity of 6.5 points, the amount of axial strain does not exceed 3.0 %, the ratio of the pore pressure of less than 0.6, the ratio $\Delta \varepsilon_{x0}/\Delta \varepsilon_{x9}$ less than 1. In the process of testing is not installed outward signs of the ultimate resistance (education barrels and an inclined plane shear).

Table 1. Fragment a PivotTable risk assessment liquefaction of sandy and clay soils under equivalent cyclic loading.

| Ground     | Depth, m | $\beta$ | $\Delta \varepsilon_{x0}/\Delta \varepsilon_{x9}$ | $\varepsilon_{p},\%$ |
|------------|----------|---------|-----------------------------------------------|----------------------|
| Sandstone  | 2.00     | 0.20    | 0.81                                          | 1.81                 |
| Sandstone  | 4.00     | 0.15    | 0.84                                          | 1.71                 |
| Clay       | 6.00     | 0.09    | 0.91                                          | 1.30                 |
| Clay       | 8.00     | 0.07    | 0.98                                          | 1.09                 |
| Sandstone  | 10.00    | 0.13    | 0.97                                          | 1.91                 |
| Clay       | 12.00    | 0.21    | 0.95                                          | 0.70                 |
| Clay       | 14.50    | 0.26    | 0.92                                          | 1.90                 |
| Clay       | 16.50    | 0.41    | 0.82                                          | 1.54                 |
| Clay       | 18.00    | 0.13    | 0.97                                          | 2.21                 |
| Sandstone  | 20.00    | 0.15    | 0.92                                          | 1.83                 |
| Sandstone  | 22.00    | 0.18    | 0.93                                          | 1.98                 |
| Clay       | 24.00    | 0.10    | 0.98                                          | 1.12                 |
| Clay       | 17.00    | 0.14    | 0.82                                          | 1.11                 |
| Clay       | 19.00    | 0.23    | 0.69                                          | 1.54                 |
| Sandstone  | 21.00    | 0.21    | 0.71                                          | 1.81                 |
| Clay       | 23.00    | 0.245   | 0.78                                          | 1.28                 |
| Clay       | 24.77    | 0.28    | 0.84                                          | 1.34                 |
| Clay       | 4.00     | 0.28    | 0.91                                          | 1.51                 |
| Clay       | 6.00     | 0.31    | 0.67                                          | 1.45                 |
| Clay       | 8.00     | 0.24    | 0.89                                          | 1.84                 |
| Clay       | 10.00    | 0.18    | 0.75                                          | 1.51                 |
| Sandstone  | 12.50    | 0.14    | 0.84                                          | 1.79                 |
| Clay       | 14.00    | 0.22    | 0.80                                          | 2.10                 |
| Clay       | 16.00    | 0.20    | 0.91                                          | 1.93                 |
| Clay       | 18.00    | 0.15    | 0.81                                          | 2.52                 |
| Sandstone  | 20.00    | 0.16    | 0.77                                          | 2.33                 |
| Clay       | 22.00    | 0.25    | 0.69                                          | 2.62                 |
| Clay       | 24.00    | 0.19    | 0.78                                          | 1.97                 |

After the test of cyclic loading with parameters estimated screenwriting equivalent seismic impact, soil samples were brought to the destruction of the deviator static load on a "crush" (Fig. 5). It was found that most seismic influence on soils did not reduce the limiting deviatoric stress compared with the results of static load.

In the character of static destruction along the path "crush" sandy and clay soils was unlike that samples of clayey soils were destroyed on the descending branch of the deformation diagram $< \sigma_1 - \sigma_3 > - \varepsilon_p$, and sandy
soils samples were destroyed on the ascending branch of the deformation diagram. This is due to different initial soil density.

Fig. 4. Deformation diagram \( \varepsilon = (\sigma_1 - \sigma_3) - \varepsilon_1 \) at the stage of triaxial cyclic loading.

Fig. 5. Deformation diagram \( \varepsilon = (\sigma_1 - \sigma_3) - \varepsilon_1 \) at the stage of the deviator static load on a "crush".

4 CONCLUSIONS

Based on laboratory tests the following can be concluded:

1. Estimation model of stress-strained condition of sand and clay grounds with different saturation rate under the scenario earthquakes was developed in view of acceleration of ground array in 3 directions.

Based on developed estimation model equivalent parameters of regular cyclic loading for laboratory investigations of sand and clay grounds resistance to dilution at the following characteristics of the earthquake: intensity 6.5, acceleration \( a=112 \text{ sm}^2/\text{sec} \), main frequency \( \approx 2 \text{ Hz} \), the main period of oscillation is 0.56 sec.

2. During the experimental investigation main parameters which characterize state of sand and clay grounds under the cyclic loads determined: longitudinal and radial deformations, pore pressure, effective and main stress.

3. Experimental investigation's results showed that sand and clay grounds resistance to dilution at the parameters equivalent to the main characteristics of the scenario earthquake with intensity 6.5 points was provided according all accepted criterions.

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