Pile Foundations for Areas With a Joint Manifestation of Permafrost and High Seismic Activity

T A Belash[1], M N Mitrofanova[2]

[1]Head of Department "Buildings", Department "Buildings", Federal State-Funded Educational Institution of Higher Professional Education Emperor Alexander I St. Petersburg State Transport University, 9, Moskovsky pr., St. Petersburg 190031, Russian Federation

[2] Master's Degree, Department "Buildings", Federal State-Funded Educational Institution of Higher Professional Education Emperor Alexander I St. Petersburg State Transport University, 9, Moskovsky pr., St. Petersburg 190031, Russian Federation

E-mail: belashta@mail.ru, kobrik.mary@yandex.ru

Abstract. One of the top focus areas of the country's development is development of natural resources of the Far East and Eastern Siberia. When developing these territories, builders have to face many severe conditions of construction, i.e. permafrost and high seismic activity. In such circumstances reliability of buildings can be provided in different ways and one of them is seismic isolation ensured by special foundation structures. For areas of permafrost, pile foundations are the main foundation structures which allow ensuring the building safety under conditions of permafrost persistence and these pile foundations under certain conditions can be considered as elements of flexible ties between buildings and soils. In this case a high pile grid will act as an aseismic foundation. The present research provided in the report is dedicated to specific features of structural solutions of high-grid pile foundations in areas of permafrost which act as aseismic structures during seismic activity.

1. Introduction

One of the top focus areas of the country's development is development of natural resources of the Far East and Eastern Siberia. It is intended to further develop existing cities and towns, as well as to build new enterprises, railway stations, bus terminals, roads, etc. However builders have to face many severe conditions of construction and these are permafrost and high seismic activity. In this regard issues of how to ensure seismic resistance of buildings for various applications are becoming quite urgent and important.

In order to improve reliability of buildings under such severe conditions of construction, during the last years, in addition to conventional ways, some special means are used and among them is seismic isolation. Among these special means the aseismic foundations are the most commonly used. For areas of permafrost, pile foundations are the main foundation structures which allow ensuring the building operation safety under conditions of permafrost persistence. Under certain conditions these structures can be considered as elements of flexible ties between buildings and soils. Such solutions were studied and considered in works by A T Aubakirov, S I Grib, A V Kharitonov, D I Fedorov, T A Belash, D A Sergeev and others [1-19]. Meanwhile the issue of how to improve seismic resistance and safety of

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buildings supported by aseismic foundation structures in the form of high-grid pile foundation is not fully studied. In this regard it is necessary to carry out further studies on specific features of structural solutions of pile foundations acting as seismic isolation.

2. Main part

In order to study this issue it was necessary to set the initial data. Novaya Chara station of Baikal-Amur Mainline was chosen as the place of supposed constructions. This area is characterized by high seismic activity (9 points) [20]. A five-storied block of flats was taken as the subject of the present research. The space and layout design was developed based on Series 122 blocks of flats designed in the 20th century for the BAM areas and showed good results under these conditions. The space and layout design of the block of flats is given in Figure 1.

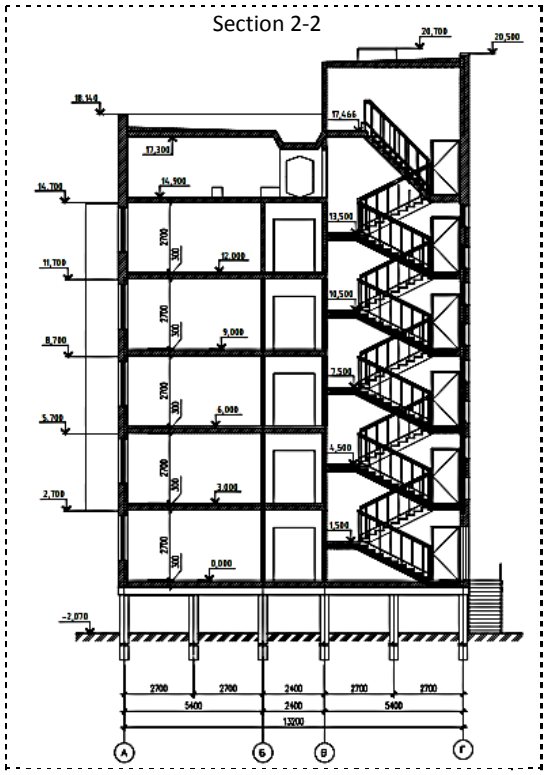


Figure 1. Section of building.

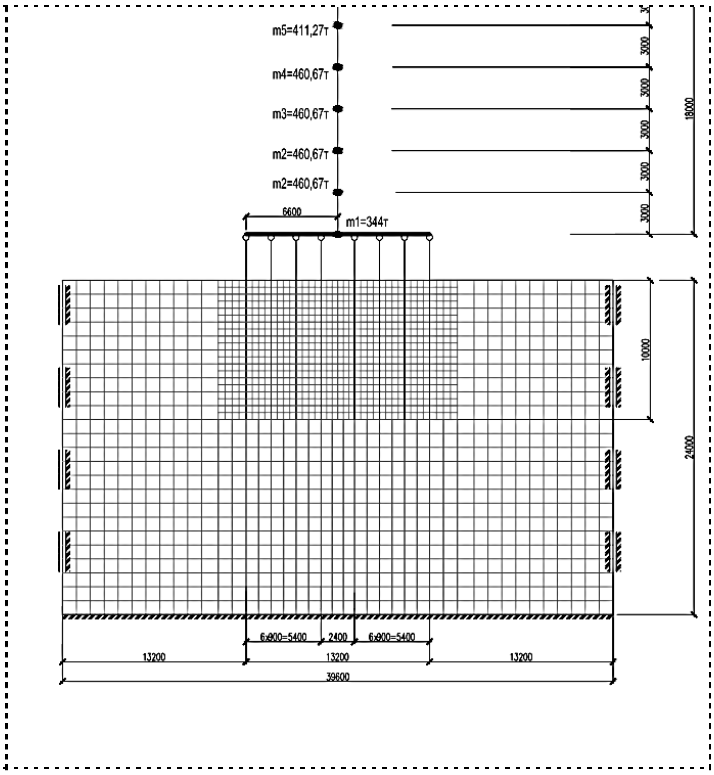


Figure 2. Calculation model.

The calculations were made on 3D model using SCAD software package and the linear and spectral method. The building was replaced with a rod fixed in the infinite rigid plate which in its turn was supported by rods serving as piles. Pile bottom parts are fixed in the soil. Masses are concentrated on floor structure levels. The calculation model is given in Figure 2. Besides it should be noted that according to the existing standards it is usual to estimate inertia seismic loads of a building using the following acceleration response spectrum:

$$A \cdot g \cdot \beta_i \tag{1}$$

where A is a coefficient of the site seismic activity, g is gravity acceleration, and β_i is a dynamic response factor depending on a structural period. When the period increases, the β_i factor decreases considerably. Efficient performance of high-grid pile foundation was estimated based on this very indicator.

The results of the calculations showed that the higher is the pile rigidity, which is achieved by increase of pile thickness, the shorter is the structural period. The structural period is also influenced by the way of fixing piles to the grid: hinging extends the structural period, whereas anchoring, on the

contrary, shortens it. Moreover, when anchoring piles to the grid, changes in rigidity of piles have smaller effect on changes of the structural period. These dependences are shown in Figure 3.

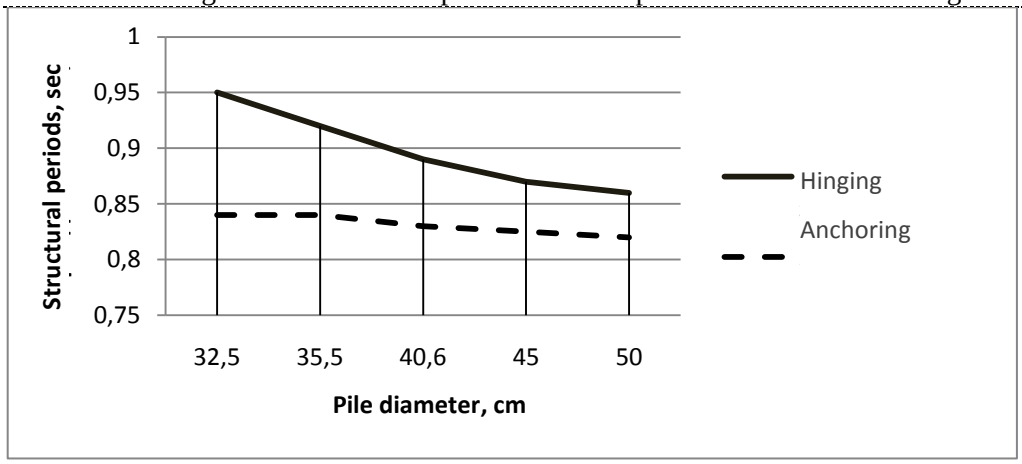


Figure 3. Diagram of dependency of structural period on pile rigidity. Pile grid height is 2.5m above the ground level. Piles are made of steel. Depth of pile toes is 10m below the ground level.

The structural period is also influenced by the length of the pile part not fixed in the soil. The higher above the ground level is the grid, the longer is the structural period. This dependency is illustrated on the diagram in Figure 4.



Figure 4. Diagram of dependency of structural period on pile grid height. Piles are made of steel. Depth of pile toes is 10 m below the ground level. Pile diameter is 32.5 cm. Way of fixing piles is hinging.

These results are also given in Table 1. The results analysis shows that when the structural period becomes longer, the absolute displacements of a building increase, however relative displacements appearing inside of a building get smaller which indicates the positive effect of seismic isolation.

The next considered factor is influence of pile embedment depth. The research showed that increase of pile embedment depth makes the structural period shorter, but this factor has a slight impact.

The structural period influences the forces appearing in a building and specifically bending moment and shear force. In this case the study considered aggregate forces appeared in the bottom part of the building. The results showed that the maximum values of bending moment and shear force were reached when the structural period equaled to 0.92 seconds. Larger latter values give smaller values of forces: the longer is the structural period, the smaller are the forces appearing in a building. Axial force remains relatively constant when the structural period changes.

Table 1. Dependency of structural period and displacements on pile height.

Height	Displacements, δ, m			Structural period, Tc, sec
	Top of building	Bottom of building	Top vs. Bottom	
2	0.22	0.13	0.09	0.887
2.5	0.25	0.16	0.09	0.95
3	0.28	0.2	0.08	1.03
3.5	0.3	0.23	0.07	1.14
4	0.33	0.27	0.06	1.26
4.5	0.36	0.3	0.06	1.39
5	0.4	0.35	0.05	1.54

During the research it was found that in order to ensure the pile integrity and sufficient structural period during seismic impacts it is necessary to use large number of small-diameter piles. Thus, use of annular cross-section piles made of C690 steel having diameter of 20 cm, placed in line and spaced at 750-900 mm enables to decrease seismic loads on a building by 25-30%. The height of the pile part not fixed in the soil is to be about 4 m.

3. Summary

- When arranging the high-grid pile foundation as a seismic isolation system under conditions of permafrost, the use of metal piles with annular cross section is the most reasonable.
- The structural period is mostly influenced by the pile rigidity, the height of the pile part not fixed in the soil and the way of fixing piles to the grid – hinging is more preferable.
- In order to ensure a sufficient structural period and pile integrity it is recommended to place smaller piles closer to each other.

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