

INTRODUCTION

More than 75% of engineering structures on permafrost in Russia are built according to the "First Construction Principle", which relies on the *freezing strength* (bearing capacity) of the frozen ground to support structures. Bearing capacity, defined as the maximum load (in kN/m²) for a standard foundation pile imbedded in permafrost, is used in Russia as a primary variable for engineering assessments in permafrost-affected territories. For given surface and subsurface conditions, the bearing capacity depends strongly on the active layer thickness (ALT) and the temperature at the top of the permafrost (TTOP), both of which are strongly affected by the atmospheric climate (Figure 1). Increases in TTOP and ALT resulting from climatic warming can significantly reduce the bearing capacity of the frozen soil and the stability of engineered structures.

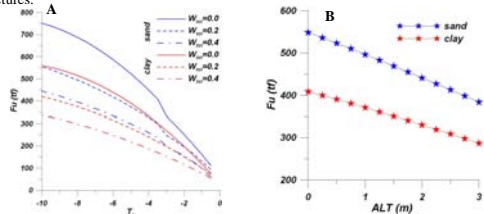


Figure 1. Bearing capacity of the frozen ground as function of TTOP and moisture content for soil composed of sand and clay (A) and the ALT with ground temperature of -5 °C.

Khrustalev (2000) used arbitrary values of air temperature increase to evaluate changes in bearing capacity for Yakutsk (Table 1). The safety standards for permafrost foundations outlined in the Russian *Construction Rules and Regulations 2.02.04-88* (CRR) state that a decrease in bearing capacity of more than 26% can result in significant deformation of foundations and possible collapse of structures (Figure 2). Here, we present preliminary results from a geographic assessment of changes in the bearing capacity of permafrost soils attributable to observed climatic change in the North of West Siberia.



Figure 2. Deformation of structure from possible loss in bearing capacity of the frozen ground

Table 1. Estimated decrease in bearing capacity of foundations in Yakutsk as a result of increase in air temperature

Air temperature increase, °C	0.0	0.5	1.0	1.5	2.0
Bearing capacity of foundations, %	100	93	85	73	50

GEOGRAPHIC ASSESSMENT OF PERMAFROST BEARING CAPACITY IN WEST SIBERIA UNDER WARMING CLIMATE



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GEOGRAPHICAL ASSESSMENT FOR WEST SIBERIA

To provide a spatial assessment of changes in bearing capacity the model was applied to the northwestern part of Siberia. We used the *Landscape Map of West Siberia* and empirical observations to construct a spatial characterization of surface and subsurface conditions in the region. Climate data were derived from the ERA40 gridded dataset. Calculations of bearing capacity were conducted for the 1960-1970 and 1990-2000 periods.

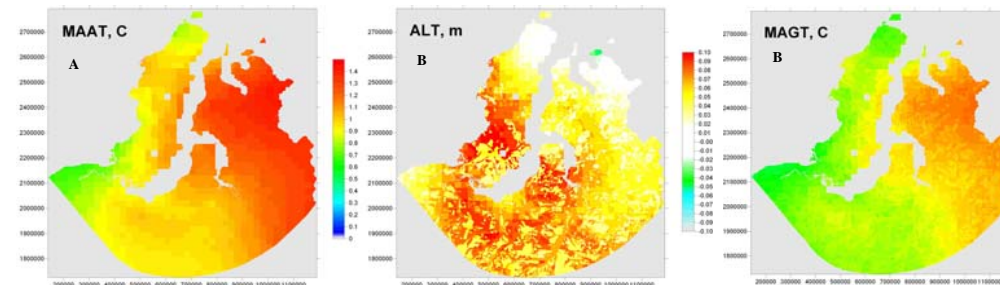
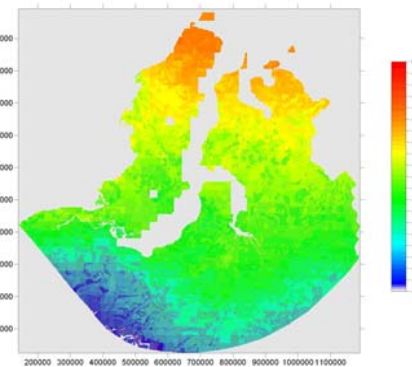


Figure 5. Difference in decadal 1960-1970 and 1990-2000 averages in (A) mean annual air temperature (MAAT), as estimated from ERA40 gridded data, (B) calculated Active-layer Thickness (ALT), and (C) Mean Annual Ground Temperature of top of permafrost (MAGT).

The difference in average decadal mean annual air temperatures (MAAT), TTOP, and ALT are shown in the maps presented in Figure 5. The difference field of MAAT shows more pronounced warming in the eastern part of northwestern Siberia. The increase in air temperature on the Yamal and Tazovskiy Peninsulas is 0.8 to 1.1°C, compared to 1.1 to 1.4°C on Gydan. The insulating effects of snow and vegetation are responsible for the less pronounced changes in TTOP: 0.7 to 0.9°C on Yamal and Tazovskiy and 1.0 to 1.2°C on Gydan. ALT has generally increased throughout the region, with the exception of small northern islands such as Oleniy and Sibiryakova. However, these increases are generally less than 0.1 m throughout the region.

The changes in climatic and permafrost parameters result in a decrease in permafrost bearing capacity in the study region (Figure 6). For the 1990-2000 period, bearing capacity has decreased by 5 to 20%, relative to the 1960-1970 period. Changes increase gradually toward the south, from 5% in the northern parts of the Yamal and Gydan Peninsulas to 10 to 20% in more continental parts of the North of West Siberia. Changes in bearing capacity exceed 20% in the southwestern part of the region. The spatial assessment of bearing capacity was conducted assuming natural, undisturbed conditions. Because construction is usually associated with the removal of topsoil and natural covers, our estimates can be considered as "potential" bearing capacity. The accounting for technogenic disturbances will result in more pronounced reductions in bearing capacity, as illustrated by the Nadyem example.

Figure 6. Percentage of change in bearing capacity of permafrost between 1960-1970 and 1990-2000 decades.



APPROACH

According to *Construction Rules and Regulations 2.02.04-88*, the bearing capacity of permafrost soils is estimated from the mean decadal values of air and ground temperature, with adjustment factors used to account for interannual climatic variability. Intensive industrial development of West Siberia began during the late 1960s and early 1970s. We assume that the engineering designs for infrastructure constructed during that period were developed based on 1960-1970 climatic conditions. Our research is driven by the hypothesis that by the year 2000 the bearing capacity had changed significantly as a result of observed climatic change. To evaluate this hypothesis we have developed a set of parameterizations to estimate the bearing capacity of frozen soils as function of TTOP and ALT, according to *Construction Rules and Regulations 2.02.04-88*. The effect of climate on TTOP and ALT was estimated by an equilibrium permafrost model (Shiklomanov and Nelson, 1999).

CASE STUDY FOR THE CITY OF NADYEM



Figure 3. The City of Nadyem

The city of Nadyem is the one of the largest cities in the North of West Siberia, with a population of about 50,000 people (Figure 3). The major phase of construction was conducted at the beginning of the 1970s, and was associated with the development of the Medvezhee gas field. Figure 4a shows the trend of mean annual air temperature between 1960 and 2000, as observed at the Nadyem climate station. The corresponding trend in active-layer thickness as measured at the Circumpolar Active Layer Monitoring (CALM) site located in the vicinity of Nadyem is shown in Figure 4b. Pronounced changes in air temperature and ALT are evident from Figure 4 a,b. We used observed values of air temperature to evaluate the interannual dynamics of permafrost bearing capacity for Nadyem. The following assumptions were made for calculations: (a) the soil profile is a homogeneous sandy loam with a gravimetric soil moisture content of 30%; (b) the vegetation and organic soils horizon was removed during construction; the (c) snow cover is absent under structures. Annual calculated values of bearing capacity, expressed as percentages of average bearing capacity for the 1960-1970 period, are shown in Figure 4c. Bearing capacity has decreased by 35% between the decades of the 1960s and the 2000s. These changes exceed the 26% threshold for safety of structures and may have contributed to the increase in structural damage of the buildings reported in Il'ichev 2003.

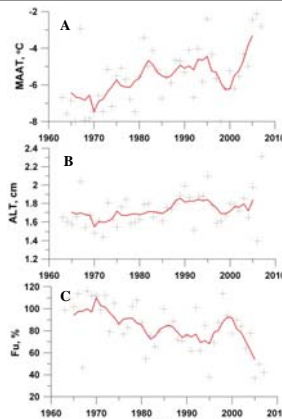


Figure 4. (A) Observed trends in Mean Annual Air Temperature (MAAT) for the city of Nadyem, (B) the trend of the Active Layer Thickness (ALT) observed in the vicinity of Nadyem, (C) calculated values of bearing capacity, (Fb) expressed as percentages of average bearing capacity for the 1960-1970 period.

CONCLUSIONS

Our analysis indicates that the observed climatic warming in the North of West Siberia has resulted in a substantial decrease in the bearing capacity of permafrost soils, which in turn undermines the stability of infrastructure built during the 1960s and 1970s. The map presented in Figure 6 outlines areas with the most significant changes in Potential Bearing Capacity (PBC) of permafrost soils. In areas with changes in PBC, values greater than 20% can be considered hazardous with respect to the stability of infrastructure.

This poster presents some preliminary results of our research on the stability of permafrost infrastructure. Future research will include the following components: a) analysis of infrastructure-specific stability factors that account for bearing capacity as well as ground heave and subsidence; b) analysis of uncertainty in spatial assessment of climatic, surface and subsurface conditions; c) development of procedures to assess infrastructure-specific safety factors accounting for random variations in air temperature, as well as climatic change. For future research, we will use remotely sensed imagery to assess critical changes in landcover/landuse associated with regional development and incorporate the results in our assessments of infrastructure stability.

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