Advances in Applied Science Research
ISSN: 0976-8610

Open Access Research Article

Using Micro Seismic Waves to Investigate the Influence of Thermal Conditions on Stability of Piles

Ngwu Tochukwu Ambrose[1*], Konstantin V Fedin[2], Lucky more Ngomayezwe[2], Ekolle Ndinde Eya[2]

[1]*Department of Geology and Geophysics, Novosibirsk State University, Novosibirsk, Russia*

[2]*Department of Geology and Geophysics, Trofimuk Institute of Petroleum Geology and Geophysics, Novosibirsk, Russia*

ABSTRACT

Studies show that in the Norilsk region, about 250 buildings were damaged due to the deterioration of permafrost conditions over the last decade due to warming temperature regimes, which significantly effects the natural vibration characteristics of structures found in this area. The investigation of the influence of thermal conditions on pile stability was carried out between 21st August to 25th October 2021, using peak frequencies of seismo-acoustic noises to evaluate proper oscillations of building piles and comparing the compiled peak frequencies with average temperature of the corresponding time windows. The results from graphical illustration shows that temperature fluctuations result in little to significant adjustments in peak frequency values. The period between 11th to 14th October illustrated the most intriguing outcomes as the highest peak frequencies of 9.4 Hz, 8.3 Hz (first floor) and 3.55 Hz, 3.53 Hz (roof) during a negative temperature regime of -6.5°C, which indicates drastic decrease in temperature as winter period approaches. This finding proposes that temperature changes have an influence on the stability piles of the building and this method is able to detect slight changes and fluctuations in temperature, by recording micro seismic waves on piles of the building and indicating varying peak frequency responses (viewed using SPECTRUM), against temperature changes throughout the period of monitoring and this illustrates that temperature fluctuations has an influence on stability of piles. Hence, there is high possibility that the relationship between these two parameters will be more significant over extensive course of monitoring (through summer and winter) as it can provide broader information about the behavior of the piles as temperature changes occur.

Keywords: Standing waves; Peak-frequency; Temperature; Stability; Building piles

INTRODUCTION

According to geostatistical analyses, Norilsk and Susuman are identified as hot spots zones for permafrost degradation. Thus suggested that the soil bearing capacity in permafrost regions is an important issue related to climate change, mainly as a result of its temperature dependency and frozen soil, which significantly experience strength loss when the temperature becomes warmer. Climate factors, such as temperature, humidity, wind speed and extreme harsh environments, may also have a significant effect on the natural vibration characteristics of structures and these changes may even be

Received: 23-September-2022; Manuscript No: AASRFC-22-14427; **Editor assigned:** 26-September-2022; PreQC No: AASRFC-22-14427(PQ); **Reviewed:** 10-October-2022; QC No: AASRFC-22-14427; **Revised:** 23-November-2022; Manuscript No: AASRFC-22-14427(R); **Published:** 30-November-2022; DOI: 10.36648/0976-8610.13.7.76

Corresponding author: Ngwu Tochukwu Ambrose, Department of Geology and Geophysics, Novosibirsk State University, Novosibirsk, Russia; E-mail: tochukwuambrose@gmail.com

Citation: Ambrose NT, Fedin KV, Ngomayezwe LM, Eya EN (2023) Using Micro Seismic Waves to Investigate the Influence of Thermal Conditions on Stability of Piles. Adv Appl Sci Res.13:76

greater than those caused by actual damage, hence complicating the identification of structural damage, observed that the effects of atmospheric processes on thermal conditions of the soil is controlled by climatic changes, local hydrology and processes occurring in the boundary layer of snow, vegetation and surface organic matter. However, recent studies by shows that the continuous variation in climatic conditions partly explain the increased rate of structural deformation of buildings constructed on permafrost and that the main cause of infrastructural accidents in these permafrost areas can be due to changes in the soil temperature regime, as a result of natural or anthropogenic factors. In the Norilsk industrial region, more than 250 buildings have suffered significant deformations due to the deterioration of permafrost conditions over the last decade and about 40 residential houses have been demolished or are scheduled for demolition due to temperature changes and permafrost warming, which affects the stability of foundation piles and buildings, causing structural deformation and collapse. Generally, the distribution of temperature and its variations in bridges and buildings are generally non-uniform and time-dependent, which means that physical parameters change asynchronously among the structural parts, hence, changes in temperature affect the structure in a complicated way. It can be suggested that temperature changes not only affect constraint conditions, mechanical properties, it also the boundary conditions and geometrical features. Since a few researchers have studied the relationship between temperature and vibrational characteristics of structures, assumed that mass and boundary conditions of structures are constant and only the mechanical and geometry properties of the system are affected by temperature. A similar work by estimated that the natural frequency of the surface soil layer may differ from that of the layer directly beneath the investigated building. Therefore, the results of the measurements shows that changes in seasonal resonant properties of the sub-surface soils may negatively affect the seismic characteristics of the structure built on them. Standing waves, also referred to as micro seismic waves, are a combination of 2 waves taking possession opposite directions, with both having identical amplitude and frequency. Micro seismic waves have proven to detect minute disturbance and micro noises emanating from the environment. One of the most recent concerns of standing waves is in the aspect of structural stability of geotechnical constructions such as bridges, dams, buildings etc. The impact of standing waves on structures has become of great disturbance because such structures have a natural period or resonance, which refers to the number of seconds it takes for the structure to naturally vibrate back and forth. In other words, as the period of ground motion coincides with the natural resonance of the structure, it will experience the largest possible oscillations and undergo the greatest damage. In a study conducted by these waves were extracted using numerous noise recordings to accumulate numerous amplitude spectra, which lead to the regular appearance of peaks on the averaged SPECTRUM and this corresponds to the standing wave used this method to separate standing waves from seismo acoustic noises, which was used to study the proper oscillations of piles of buildings. Introduced a passive seismic method that relies upon standing wave isolation from the signal field, to form microseismical movements in the cavity or low-velocity zone (ZMS) from the day surface. However, this study will focus on the investigation of stability and behavior of natural frequency of piles with respect to temperature changes by recording micro seismic wave particles on piles of the building and comparing the peak frequencies of the wave particles to the corresponding temperature values, within same time window. The manifestation of thermal energy is found in all matters and constitutes an energy flow, which occurs when a body comes in contact with a warmer or colder body, causing the molecules of the body to exhibit vibrational kinetic energy, also known as translational kinetic energy which has a long-term influence on the stability of the body. The building under investigation has suffered diagonal cracks, which instigated the urgency for studies, in order to investigate the possible cause of the damage on the first floor of the building. Thus, this paper presents the possibility of using micro seismic waves to investigate the influence of thermal conditions on stability of piles [1-5].

Climate

For the purposes of this study, the geographical coordinates of Norilsk are 69°20' 42.468'' N and 88°12' 17.892'' E and an elevation of 192 ft above sea level. In Norilsk, the temperature typically varies from -17°F to 65°F. From June 14 to September 4 is usually the warm season, while July is the hottest month. The cold season starts from November 10 to March 24, lasting for 4.5 months, while the coldest month is January, with an average low temperature of -16°F and high of -5°F. The period of Snow fall lasts from October 12 to May 12, while the most snow days occur in November, which makes Norilsk a region of continuous permafrost **(Figure 1)**.

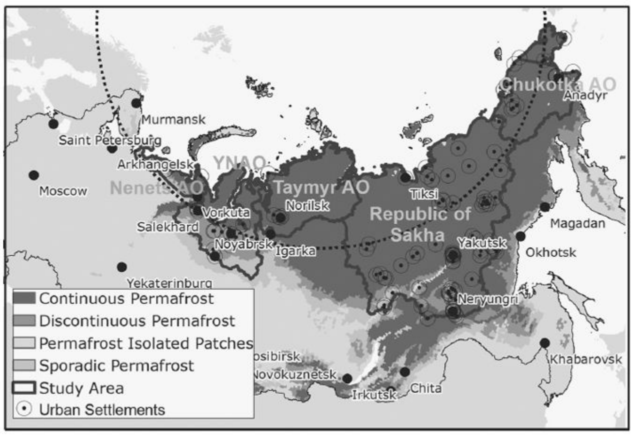

Figure 1: Map showing pattern of permafrost distribution in russia, adapted from streletskiy and shiklomanov.

MATERIALS AND METHODS

Object of Study and Observation Methodology

The palace of culture of PJSC "Norilsk nickel" was considered as the object of the study and the geographic coordinates are 69°20' 42.468'' N and 88° 12' 17.892'' E **(Figures 2 and 3)**.

Figure 2: The palace of culture of PJSC "Norilsk nickel".

Figure 3: Shows cracks on the 1st floor.

Method

The method of investigation is based on partitioning of standing waves from seismo-acoustic noises to evaluate proper oscillations of piles of buildings. The basis of the method is to accumulate a large amount of amplitude spectra of sound recordings, resulting in average (or accumulated) spectra having peak sequences corresponding to packets of standing waves of different types. This method has been used several times in our previous physical simulations of micro seismic waves in various objects and has also been successfully tested on the results of field experiments. In the explained series of investigation, Seismo-acoustic noise was recorded on the building from 21st August to 24th October, 2021. Horizontal and vertical geophones GS20DX and single-channel autonomous digital recorders Texan (Reftek-125a) with a sampling rate of 5 kHz were used for registration. The noise recording was carried out on the external pile walls with horizontal and vertical geophones GS20DX and single-channel autonomous digital recorders Texan (RefTek-125A), for the best contact in some cases the sensor was fixed with a rigid clamp. The duration of continuous recording at each observation point was 15 minutes and a total of 133 piles were studied [6-9]. The standing vertical compression-stretching waves above the free upper boundary of the cavity and the speed of longitudinal waves V_p, is given by the equation:

$$f_n = \frac{nV_p}{2h}, \qquad (1)$$

where n is the number of modes of standing waves, V_p is the speed of longitudinal waves and h, the distance from the upper boundary of the cavity to the daytime surface. Thus, if the distribution of the regular peaks of the average amplitude spectra on the frequency axis at any location corresponds to the formula (1), this indicates the presence of an underground cavity or other activation at a substantially reduced speed relative to the medium of containment. The second stage of the work consisted of constructing the spatial partitioning of amplitudes of own oscillations of the building by own modes of oscillations. To accomplish this task, sets of «Baikal-7» recorders and 3-component sensors «GD-10» were used. This shows the data registration process based on the first floor of the palace of culture **(Figures 4 and 5)** [10-12].

Figure 4: Example of installation of horizontal and vertical geophones gs20dx and single-channel digital recorders Texan (RefTek-125A) on piles.

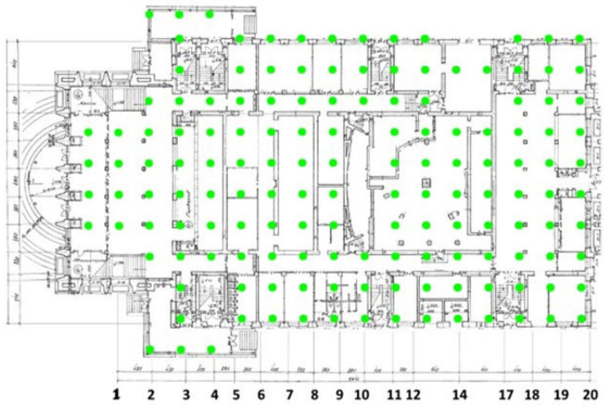

Figure 5: Showing the positions of the sensors on each of the piles, during the investigation.

A summary of procedures adopted for this investigation are as follows:

- Registration of coherent «micro seismic» noise, from piles of the building was carried out on the first floor and roof part, which comprises of 133 piles, studied using horizontal and vertical geophones GS20DX and single-channel digital recorders Texan (RefTek-125A).
- Recording of sound on the piles are examined by separating the micro seismic waves in them using two sensors, which must be static at one point while the other sensor is being moved at chosen intervals.
- Using SPECTRUM to visualize the amplitude distribution and peak frequencies of the various components (X, Y and Z) and classify these peak frequencies based on daily records and windows of observation for the months of August, September and October.

SPECTRUM is a software system, equipped with a package that performs express data analysis in real time, which draws the SPECTRUM and spectrogram in time of the recorded signal in the specified windows. Based on the criteria for the level of values of natural frequencies and the amplitudes of their oscillations, a notification of dangerous processes (SMS notification) is issued or a warning for the operator with the following values:

- Green colour-safe level of vibrations of the structure,
- **Yellow colour-attention:** There is a slight deviation in the value of the natural frequencies of the structure/increased oscillations occur,
- **Red colour-danger:** The shift of the value of natural frequencies of the building/the level of fluctuations has reached critical values.

The comparison and evaluation of the relationship between the two parameters was performed using graphical simulations and illustrations to provide a solution to understand the relationship between peak frequency (Hz) and average temperature data (°C) *via* a temperature-peak frequency curve, which matches the equal observation window of data for both peak frequencies and temperature for the chosen days **(Figures 6 and 7)**. The data for average daily temperature used for this investigation was obtained from © 2021 AccuWeather, Inc. "AccuWeather Professional" dating from 21st August to 25th October 2021 [13,14].

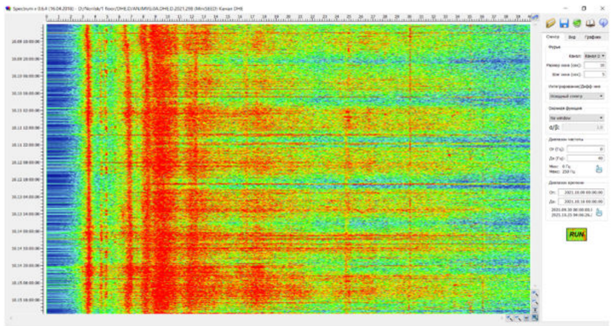

Figure 6: Showing the SPECTRUM display of standing waves between 9th and 16th October, the green, yellow and red colors described earlier are also shown.

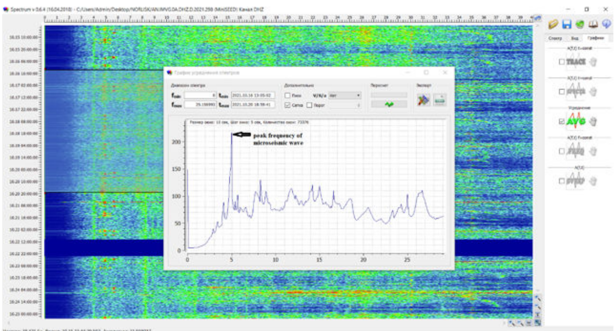

Figure 7: Showing the SPECTRUM display of amplitude frequencies while the arrow indicates peak frequency between 16th and 20th October.

RESULTS

The following tables shows the peak frequencies in Hz, obtained during the experiments. It demonstrates the days, peak frequencies (Hz) and average temperature ˚C of the corresponding time windows **(Tables 1-6)**.

Table 1: l

Days	Peak-Freq (Hz)	Temp (°C)
21	3.5	15
22	3.38	17
23	3.44	17

24	3.56	16
25	3.56	16
26	3.39	15
27	3.47	14
28	3.39	14
29	3.47	12
30	3.55	12
31	3.45	17

Table 2: August roof.

Days	Peak-Freq(Hz)	Temp (˚C)
21	3.47	15
22	3.53	17
23	3.51	17
24	3.51	16
25	3.5	16
26	3.53	15
27	3.52	14
28	3.5	14
29	3.5	12
30	3.5	12
31	3.51	17

Table 3: September first floor.

Days	Peak-Freq(Hz)	Temp (°C)
01-Mar	3.39	9.8
04-Jun	3.5	9
07-Sep	3.53	11
10-Dec	3.57	11.3
13-15	3.54	9.1
16-18	3.5	11.1
19-21	3.6	7.1
22-24	9.2	3.6
25-27	3.43	5.5
28-30	3.37	2.8

Table 4: September roof.

Days	Peak-Freq (Hz)	Temp(°C)
01-Mar	3.46	9.8
04-Jun	3.56	9
07-Sep	3.51	11
10-Dec	3.51	11.3
13-15	3.57	9.1
16-18	3.39	11.1
19-21	3.41	7.1
22-24	3.44	3.6
25-27	3.33	5.5
28-30	3.42	2.8

Table 5: October first floor.

Days	Peak-Freq (Hz)	Temp(°C)
01-Feb	3.43	6
03-Apr	3.57	3
05-Jun	3.43	2
07-Aug	3.4	5
09-Oct	3.47	6.2
11-Dec	9.4	-6.5
13-14	8.3	-6.5
15-16	3.37	4.5
17-18	3.5	6.5
19-20	3.5	6
21-22	3.4	6
23-25	9.61	7

Table 6: October roof.

Days	Peak-Freq (Hz)	Temp(°C)
01-Feb	3.33	6
03-Apr	3.33	3
05-Jun	3.51	2
07-Aug	3.43	5
09-Oct	3.46	6.2

11-Dec	3.55	-6.5
13-14	3.53	-6.5
15-16	3.46	4.5
17-18	3.46	6.5
19-20	3.31	6
21-22	3.46	6
23-25	3.46	7

The following graphs illustrate the various graphs of temperature *vs.* peak frequency for the period of 21st August to October 25th 2021 **(Figures 8-13)**.

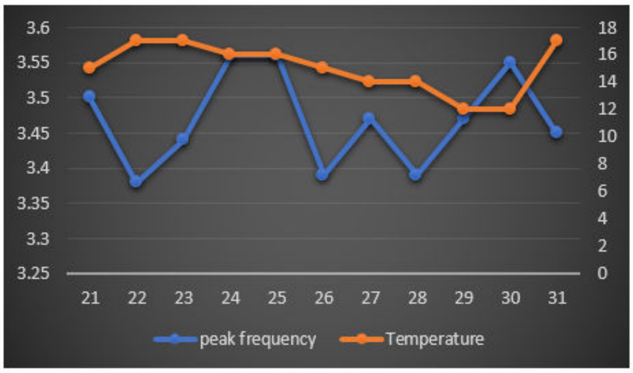

Figure 8: First floor august.

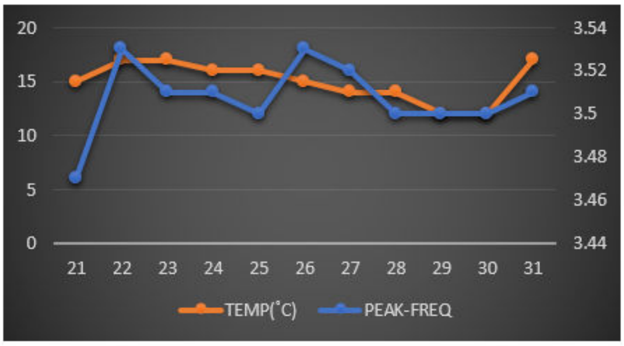

Figure 9: Roof august.

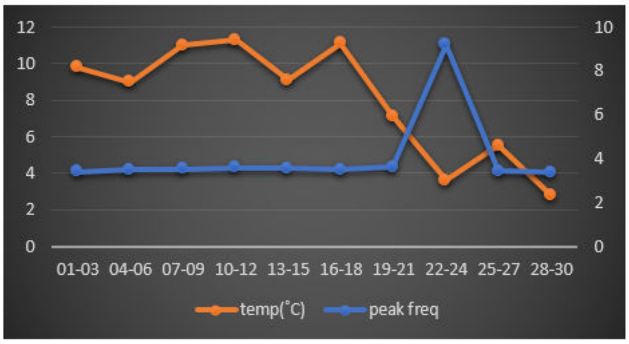

Figure 10: First floor september.

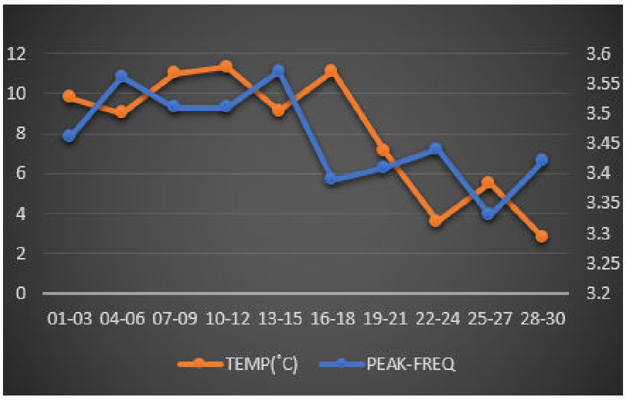

Figure 11: Roof september.

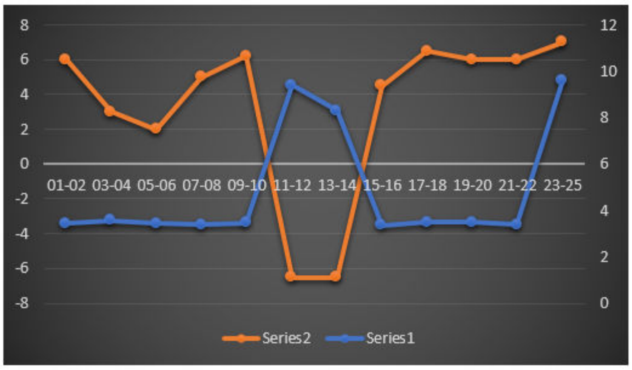

Figure 12: First floor October.

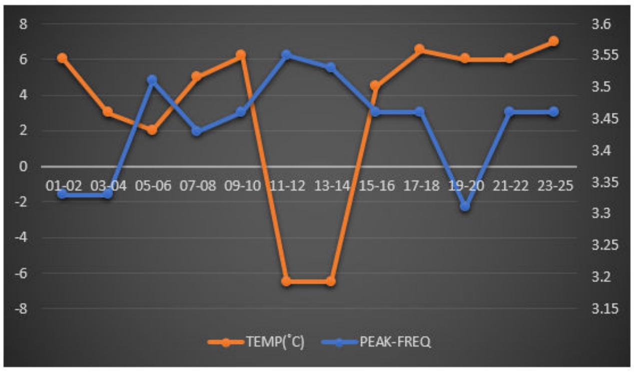

Figure 13: Roof October.

Interpretation

The illustration of influence of temperature on the stability of piles by observing changes in the peak frequency of the micro seismic waves on the piles was carried out using graphical models. A total of 133 piles were studied and 51 piles were found to be unstable. This study considers the peak frequencies of X components of the chosen window of days of the months with the corresponding temperature. The results of August (first floor) show a high peak frequency on the 30th, which corresponds to the lowest temperature within the month and a low peak frequency around 22nd at a high temperature of 17°C. The roof part of the building, during August showed no significant interaction as the lowest peak frequency occurred either at a low or high temperature. The observation for September was done considering a 3 days time window for both peak frequencies and temperature. During September the peak frequencies were almost uniform but took a high rise of 9.2 Hz between 22nd and 24th as there was low temperature on this day compared to other days and for the roof, the peak frequency varies as much as temperature, which produced continuous interception across the month, showing that the variation in temperature interacts very much with peak frequency as there were low peak frequency high temperature correspondence between 16th-18th. The month of October was studied considering a 2 days time window and it exhibited the most interesting interaction between both parameters. Firstly, the period of October had the most days with low temperature as the lowest was -6.5°C. The highest peak frequencies of 9.4 Hz and 8.3 Hz in October occurred between 11th-12th and 13th-14th for the first floor and during these days, the temperature was as low as -6.5°C and similar conditions occurred on the roof during the same days, but in addition was days 5th-6th which also had high peak frequency and low temperature. These interactions in October are responsible for the observable particular decline in temperature curve between 11th-12th and 13th-14th and a counter incline in peak frequency during same days. However, the values of peak frequencies were static between 1st-8th and from 17th-20th of October on the first floor, whereas, the highest peak frequency was observed between 23rd-25th and this corresponds to high temperature.

DISCUSSION

The major observations from the results show that in most of the cases, a slight increase or decrease in temperature, there is a consequent fluctuation in peak frequency across all components of the building. The results from graphical illustration shows that, at every change in temperature value, there is little to significant adjustment in peak frequency, as most of these changes occurred due to observable increase or decrease in temperature. The period of 11th to 14th October illustrated the most interesting results as the highest peak frequencies of 9.4 Hz, 8.3 Hz (first floor) and 3.55 Hz, 3.53 Hz (roof) were observed, during a negative temperature regime of -6.5°C, which can be attributed to the mild decrease in temperature as winter closes by and hence, there is a high possibility that at large scale, the interaction between these two parameters will be more significant over a long course of monitoring (through summer and winter) as it can provide broader information about the behavior of the permafrost, which bears the piles of the building. Monitoring the stability of piles in this context entails measuring the peak frequency (Hz) of micro seismic waves, occurring due to natural and external forces acting on the piles of a building and comparing the results to average temperature is an approach to investigate the combined effects of these two parameters on the stability of piles of buildings. Hence, this method is able to detect slight changes and fluctuations in temperature using the piles as an object, by demonstrating varying peak frequency responses across the period of monitoring. It is also worth mentioning that few months after investigation, the building was mapped out of commission as result of the continued cracking in some parts of the building.

CONCLUSION

Climate change conditions are responsible for temperature fluctuations, which can affect the natural frequency of piles and may result to destabilization of geotechnical environments such as buildings and bridges. In order to effectively monitor or investigate the dependency or relationship between temperature and stability of piles of buildings, this study considered the peak frequency of micro seismic waves obtained from measurement carried out between 21st August to 25th October 2021 and the corresponding average temperature for the following days. The results from graphical illustration shows that, at every change in temperature value, there is little to significant adjustment in peak frequency, as most of these changes occurred due to observable increase or decrease in temperature. The period of 11th to 14th October illustrated the most interesting results as the highest peak frequencies of 9.4 Hz, 8.3 Hz (first floor) and 3.55 Hz, 3.53 Hz (roof) were observed, during a negative temperature regime of -6.5°C, which indicates drastic decrease in temperature as winter period approaches. The possibility of establishing long-term system for monitory the impact of temperature on stability of geotechnical structures is limited to certain requirements such as accuracy, sustainability and effectiveness due to lack of advanced technology for this observation. However, this method is able to detect slight changes and fluctuations in temperature using the building piles as an object of study, by indicating varying peak frequency responses throughout the period of monitoring. Hence, slight temperature fluctuations have an influence on stability of piles.

ACKNOWLEDGMENTS

Data micro-seismic waves for this project was obtained by Konstantin V. Fedin and his colleagues between 21st August to 25th October 2021 and Temperature data was obtained from © 2021 AccuWeather, Inc. "AccuWeather Professional".

AUTHOR CONTRIBUTIONS

Author1 completed part of the experiment, literature and graphs and wrote the manuscript, Author 2, Author 3 and 4 contributed to revision of the manuscript.

CODE/DATA AVAILABILITY

The data for peak frequencies of standing waves on the building was obtained by Konstantin Fedin and his colleagues and was studied and evaluated by all authors. The temperature data of Norilsk was obtained from © 2021 AccuWeather, Inc. "AccuWeather Professional" dating from 21st August to 25th October 2021.

COMPETING INTERESTS

The authors have no competing interest in the work.

REFERENCES

1. Fedin KV, Kolesnikov YI, Ngomayezwe L (2021) Mapping of underground cavities by the passive seismic standing waves method: The case study of Barsukovskaya cave (Novosibirsk region, Russia). Geophys Prospect. 69(1): 167-179.
2. Guang Dong Z, Ting-Hua YA (2014) Summary review of correlations between temperatures and vibration properties of long-span bridges. Math Probl Eng. 3(14): 1-19.
3. Kolesnikov YI, Fedin KV (2018) Detecting underground cavities using micro tremor data: physical modelling and field experiment. Geophys Prospect. 66(2):342-353.
4. Kolesnikov YI, Fedin KV, Ngomayezwe L (2021) On the influence of seasonal changes in the resonant properties of surface soils on seismic safety of structures. J Appl Geophy. 193(21):104-412.
5. Ngomayezwe L, Kolesnikov YI, Fedin V (2022) Diagnostics of asphalt pavement using elastic standing waves. Near Surf Geophys. 20(1):82-93.
6. Pavel IK, Vanda ZK (2021) Building stability on permafrost in Vorkuta, Russia. Geography, Environment, Sustainability. 14(4):67-77.
7. Shiklomanov NI, Streletskiy DA, Swales T, Kokorev VA (2017) Climate change and stability of urban infrastructure in Russian permafrost regions: prognostic assessment based on GCM climate projections. Geogr Rev. 107(1):125-142.
8. Shiklomanov NI, Nelson FE (2013) Thermokarst and civil infrastructure. In John F. Shroder (ed), treatise on geomorphology. San Diego, CA: Academic Press. Treatise Geomorphology. 8(13):354-373.
9. Streletskiy DA, Sherstiukov AB, Frauenfeld OW, Nelson FE (2015) Changes in the 1963-2013 shallow ground thermal regime in Russian permafrost regions. Environ Res Lett. 10(12):25005.
10. Streletskiy DA, Suter LJ, Shiklomanov NI, Porfiriev BN, Eliseev DO (2019) Assessment of climate change impacts on buildings, structures and infrastructure in the Russian regions on permafrost. Environ Res Lett. 14(2):02500.
11. Streletskiy DA, Shiklomanov NI, Nelson FE (2012) Spatial variability of permafrost active-layer thickness under contemporary and projected climate in Northern Alaska. Polar Geogr. 35(2):95-116.
12. Wang F, Li G, Ma W, Mu Y, Zhou Z, et al. (2018) Permafrost thawing along the China-Russia crude oil pipeline and countermeasures: A case study in Jiagedaqi, Northeast China. Cold Reg Sci Technol. 155(18):308-313.
13. Xia Y, Hao H, Zanardo G, Deeks A (2006) Long term vibration monitoring of an RC slab: temperature and humidity effect. Eng Struct. 28(3):441-452.
14. Yanxia C, Kai Z, Zhoujing Y, Chang L, Kaiji L, et al. (2021) Influence of temperature on the natural vibration characteristics of simply supported reinforced concrete beam. Sensors. 21(12):42.