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RELIABILITY OF BASEMENTS AND STRUCTURES IN CRYOLITHOZONE

GROUND TEMPERATURE DYNAMICS AROUND AND BENEATH THE YAKUTSK COMBINED HEAT AND POWER PLANT BUILDINGS

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Analysis of the long-term (from 2008 to 2011) research of the condition of permafrost on the territory of the Yakutsk Combined Heat and Power Plant is provided. Monthly ground temperature measurements in 36 boreholes 4–16 m deep under buildings and along the walls of adjacent buildings have been made. Currently there are talik zones found under all the buildings. The highest mean annual ground temperatures (up to 12–13 °C) and the talik thickness (23–25 m) have been found around the circulating pump station and near the water boiler facility. In most of the Yakutsk Combined Heat and Power Plant area, the ground is in perennially frozen state. Permafrost thawing under parts of the buildings results in differential settlement of some structural elements, while subsequent ground freezing leads to frost jacking. Foundation displacements lead to wall cracking, partial breakup of pile heads, chipping of bared reinforcement steel frames, and deflection of the foundation beams.

Mean annual temperatures, permafrost, taliks

INTRODUCTION

The Yakutsk Combined Heat and Power Plant (YCHPP) was put into operation on November 7, 1937 and has been supplying electricity to the city ever since, and since 1961, also heat [*Over the Lena River a Heat and Power Plant..., 2007*]. It is the first industrial structure of the USSR to have been built in accordance with the principle of using permafrost ground as the foundation.

Preservation of the permafrost condition of the foundation ground was ensured by placing the building on columns, which raised it above the ground surface. A ventilated open cellar was left between the ground surface and the building 1.2–1.8 m high, designed for protecting the foundation ground from deep thawing under the influence of the internal heat of the building, as well as for accumulating cold in the winter period (Fig. 1).

Foundations of the first YCHPP buildings are separately standing reinforced concrete footings 5–7 m away from each other. Depending on the assigned load, the columns' cross section varies from 30 × 30 to 80 × 80 cm, while the cross section of the footings varies from 130 × 130 to 317 × 317 cm. The foundations are placed on a foundation frame at the depth of 4.5 m from the site surface. The frame consists of two rows of square larch logs with the cross section of 20 × 20 cm, placed in a criss-cross manner. The foundations for turbine generators are made as solid concrete plates with the area of about 60 m^2 and 1 m thick, placed on the foundation frame and consisting of five rows of square larch logs. The brick walls of the building rest on strong reinforced concrete monolith foundation beams, which are firmly connected with the columns [*Tsytovich et al., 1947*].

All the works relating to preparation of the foundation pits, placing of foundation columns and plates, as well as their back filling with earth were conducted in the winter period. Simultaneously the opened layers were naturally frozen. The pits were back-filled with frozen ground from waste piles by layers of 20–25 cm. Gaps between the lumps of frozen soil were filled with dry sand, and the mass formed was later rammed. The immediate space around the columns was filled with sand-and-gravel mix.

Due to continuous growth of the city, its need for electricity increased, too; therefore the buildings of the heat and power grid were repeatedly extended and upgraded, meeting the current demands. During these works, the first construction principle was strictly observed – to preserve the permafrost condition of the foundation ground.

THE GEOCRYOLOGICAL AND ENGINEERING CHARACTERISTIC OF THE YCHPP AREA

The YCHPP is located in the north-eastern part of Yakutsk on the bank of a branch of the Lena River. It is erected on an alluvial terrace rising above the low-water level to 9–10 m (Fig. 2).

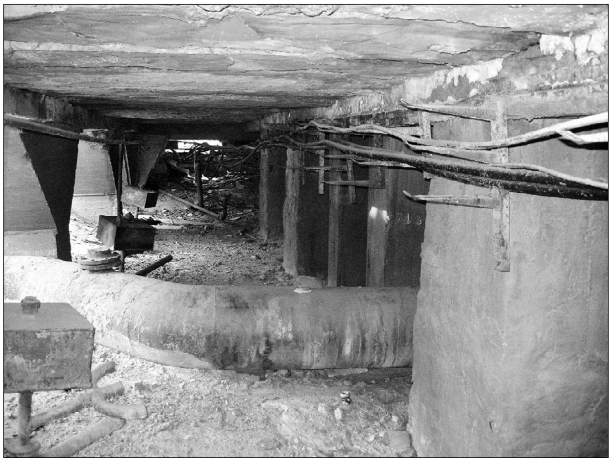

Fig. 1. Ventilated space under the main building of the Yakutsk Combined Heat and Power Plant. (A photo by S.I. Zabolotnik, 05.11.2009).

Fig. 2. A general view of the Yakutsk Combined Heat and Power Plant. (A photo by P.S. Zabolotnik, 05.09.2013).

The city of Yakutsk is located in the continuous permafrost zone, the thickness of which in the region varies from 100 to 300 m, while its mean annual temperatures at the depth of 20 m vary from –2 to –4 °C [*Balobayev, 1991*].

According to N.I. Saltykov, the thickness of the permafrost layer in the area of the YCHPP reached 180–200 m, while the mean annual temperatures of the ground at the depth of 15 m under the construction site before erection of the structures varied from –3 to –5 °C. According to the observations made by P.I. Melnikov, 10 years after the foundations were laid, the ground temperatures at the depth of 5 m varied from –3.2 to –3.6 °C, while the thickness of the seasonally thawing layers reduced by 0.8 m, not to exceed 1 m [*Tsytovich et al., 1947*].

The site around the main building of the YCHPP and a number of other facilities is partly paved with asphalt and filled with ground to the depth of 1–4 m consisting of fine to coarse sands, more rarely of loams with admixtures of gravel, pebbles, and slags. Below there are alluvial deposits, represented by fine sands, normally interlaid by medium and coarse sands. In the upper part of the cross section (down to 11–15 m), there are individual horizons of sandy loam, lenses and layers of loam, sandy loam and fine sand, as well as inclusions of plant detritus.

The moisture content of sandy soils varies primarily from 20 to 30 %, while their density varies from 1700 to 2040 kg/m^3. In the interbeds with large amounts of plant detritus, as well as in sandy loam and loam soils, the moisture content grows to 40 %, sometimes to 60–70 %, whereas their density drops to 1460–1500 kg/m^3. The density of the ground particles is rather stable: for sands and sandy loams, it is equal to 2640–2660 kg/m^3, for loams, it is 2690 kg/m^3.

The soils under the site of the YCHPP are not saline. The chemical analysis of the water extract of the samples taken from talik areas has shown the sum of minerals in them to be only 0.02–0.07 %. The composition of salts in the thawed and frozen ground is heterogeneous. The water extracts of thawed ground are primarily sodium chlorides hydrocarbonates, and alkalescent (pH 7.4–7.7), while the interstitial solutions of frozen soils contain hydrocarbonates; they are mixed for the composition of cations and more alkaline (pH 7.5–9.0). This is likely to be caused by cryogenic transformation of the water solutions [*Zabolotnik and Zabolotnik, 2009*].

Except for the areas of local taliks, the deposits in the territory of the YCHPP are in permafrost condition. Depending on the degree of thawing in the area, the thickness of the frozen layers varies from 1.5 to 4.0 m. the depth of seasonal thawing of the soils is 2.2–2.8 m near the northern sides of the buildings and grows to 2.5–4.6 m near the southern sides. Under the main building, it varies from 1.0 to 3.0–4.4 m.

FORMATION OF TALIKS, THEIR FREEZING AND IMPACT ON THE CARRYING CAPACITY OF THE FOUNDATIONS

During the first thirty years of the operation of the YCHPP, large talik zones were formed under the buildings and in the adjacent areas. The main causes of their formation were heat production from deeply located facilities and leaks of hot technical water directly into the foundation ground, as well as along the lines of defective drainage pipes, sewage pipes, and other communication pipes.

In 1967, to freeze the ground under the foundation of the main building, a set of six multi-tubular seasonal cooling facilities (SCF) designed by

S.I. Gapeyev, with the capacity of 500 L of kerosene each, was installed near the part of its wall, in the immediate proximity of which there is a circulating pumping station (CPS). In 1973, 17 more similar facilities were installed on three sides of the building. The SCFs were located at the distance of 1.7–3.5 m from the walls of the building in increments from 2.9–3.1 to 5–7 m (Fig. 3). In accordance with the opinion of Sibtekhenergo experts, the facilities installed for the YCHPP decreased the ground temperature at the depth of 6 m from positive values to –3 °C after two winter season's operation. The inventor himself noted: "Application ... of automated multitubular cooling facilities has allowed ... the frozen foundation to be restored and reinforced under the deformed buildings of the YCHPP" [*Gapeyev, 1983, p. 54*].

Launching the SCF decreased the ground temperature in the immediate proximity; however, the full expected effect of freezing of the foundation base has not been achieved. One of the main causes of that is that the SCFs were installed at a rather large distance from the building walls and between them. Based on the results of numerous tests provided by *L.N. Khrustalev, O.M. Yanchenko and L.A. Naumova* [*1983*], a conclusion was made that "depending on the climatic and permafrost conditions, it is possible to achieve freezing of the ground in the radius from 1 m (Krasnoyarsk) to 2.5 m (Vorkuta)" (*page 5*). Similar data regarding the radius of ground freezing with SCF during one winter season were provided by other researchers [*Alexandrov, 1983; Mirenburg and Fedoseyev, 1983*]. There was little chance to freeze the ground under the building, as most of the facilities were located outside the radius of their impact on the building foundations.

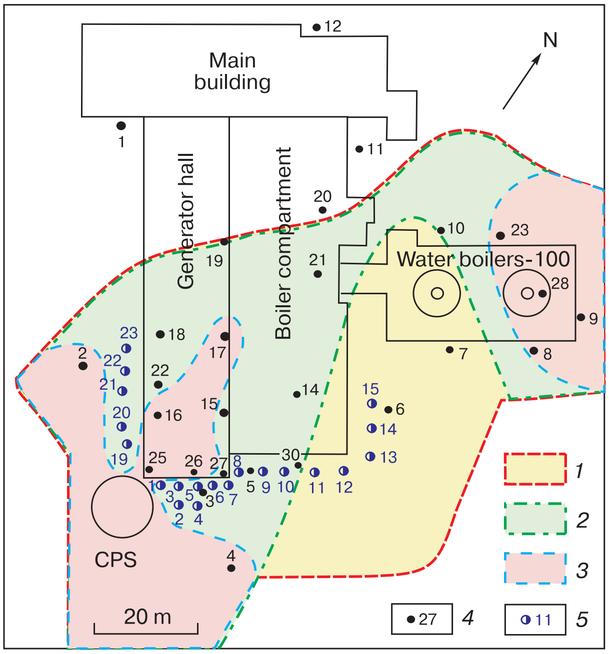

Fig. 3. Changes in the talik boundaries at the YCHPP site from 1976 to 1986 [*Zabolotnik and Novikov, 2002a*].

The talik boundaries according to the data provided by: *1* – the Yakutsk branch of the Krasnoyarsk Trust for Engineering and Construction Survey (KrasTISIZ), 1976; *2* – the Novosibirsk production association Sibtekhenergo, 1978; *3* – the Permafrost Institute, SB SAS, 1986; *4* – the borehole and its number; *5* – seasonal cooling facilities (SCF). CPS – the circulating pumping station.

S.I. Zabolotnik, who examined the soils at the YCHPP site, confirmed the conclusion that the thawed ground under the main building of the plant had not been fully refrozen. Measurements of the ground temperature in boreholes 3, 5 and 30, which were in the immediate proximity of the SCFs (about 1 m), showed that, from October 1982 to February 1986, the ground temperature in the range of depths from 5 to 14 m changed from –0.5 to –6.9 °C. Yet, under the southern corner of the main building, near which the SCFs were installed on the external side, a talik remained (Fig. 3), while the ground temperature at the depth of 4 m changed from –0.4 to +1.8 °C from May 1985 to April 1986.

In this place, the talik was not frozen due to regular heat emissions from the circulating pumping station submerged into the ground to the depth of 10 m and from the half-submerged piping and due to periodic leaks of hot water into the ground.

Hot water leaks from different systems and apparatuses exert rather significant impact on the permafrost both under foundations of buildings and structures and in the adjacent territories. They were observed by the first author from the extension of the main building designed for a boiler room during investigations conducted in 1982–1985. As a result of the leaks, permafrost in this place (Fig. 3, borehole 9) thawed to the depth of 24.5 m, while the talik expanded further to the depth under the building and around it. Periodic leaks of hot water into the ground under the building resulted in significant increase in the ground temperatures. Sometimes, they exceeded 20 °C at the depth of 9 m, varying from +20.4 to +50.7 °C [*Zabolotnik and Zabolotnik, 2012*]! As a result, the mean annual ground temperature (from October 1982 to September 1983) at the depth of 5–7 m reached 16–17 °C. After liquidating the continuous leaks, the temperature regime of the ground was gradually normalized. Yet, after three years of observations, it was far from complete recovery. In this interval, the mean annual temperature of the ground in the period from October 1984 to September 1985 decreased only to +7 °C (Fig. 4).

The warming effect of the water leaks under the buildings was manifested not only in summer but also in winter time, as the freezing water gradually filled the ventilated cellar space. As a result, the formed ice

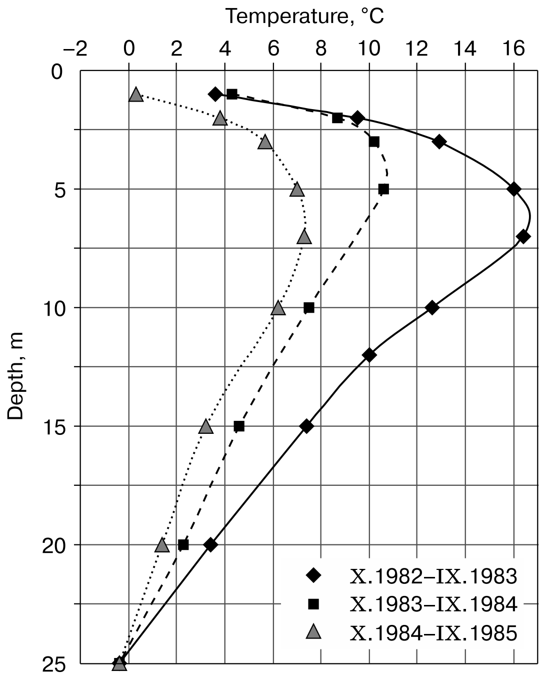

Fig. 4. Changes in the mean annual ground temperature in borehole 9 near the water heating boiler facility from October 1982 to September 1985.

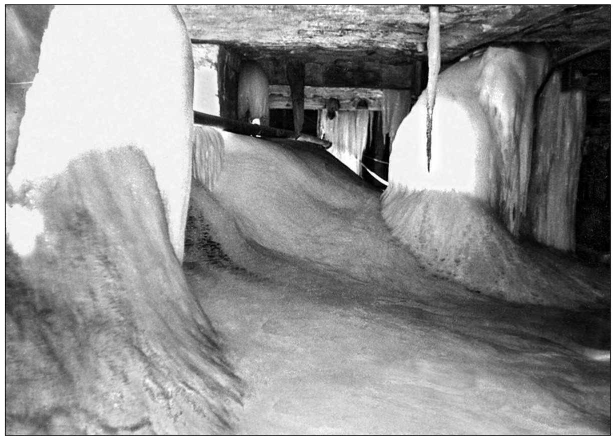

Fig. 5. Ice accumulations under the central part of the main building near borehole 19. (A photo by N.I. Novikov, 27.03.1986).

accumulations acted, on the one hand, as insulator, preventing the foundation from being cooled with external air, and, on the other hand, it partitioned the space and precluded air circulation under the building. In 1980s, the amount of ice accumulations was significant. At the end of March 1986, the ice accumulation under the main building formed a single field, with the total amount of ice exceeding 600 m^3, and it practically completely filled the ventilated space (Fig. 5) [*Zabolotnik and Novikov, 2002b*].

Increase in the permafrost temperature results in significant reduction of the building foundations' carrying capacity [*Streletsky et al., 2012*]. When permafrost thawed under parts of the facilities of the YCHPP, irregular settlement of certain elements of the structures occurred. On the contrary, during further freezing of the ground, their frost jacking took place. In the period from 1982 to 2002, a general trend was observed for vertical displacements of the foundations: the southern corner of the main building and the adjacent parts of the building under which there was a talik gradually settled, while in the freezing areas frost jacking of the structures occurred. Although in the annual cycle settlement did not exceed 3 mm and frost jacking did not exceed 1.1 mm, the foundation displacements resulted in various deformities, the most typical of which were wall cracking, partial breakup of pile heads, chipping of bared reinforcement steel frames, and deflection of the foundation beams [*Zabolotnik and Novikov, 2002b*].

STUDIES OF THE TEMPERATURE REGIME OF THE GROUND IN 2008–2011

The impact of many factors onto the territory of the YCHPP resulted in a rather complicated permafrost condition. To investigate the degree of impact for each structure and to examine the possibility of restoring the original condition of the ground under the building foundations, the Permafrost Institute, SB AS USSR started investigations there: monthly investigations from 1982 to 1986, investigations in certain periods from 2002 to 2006, and from November 2007 to December 2011, the investigations were again held on a monthly basis.

Over the recent years, ground temperatures were measured in 36 boreholes from 4 to 16 m deep, including 15 boreholes drilled directly under the buildings (Fig. 6). In 2008–2009, measurements were conducted with semiconductor thermal resistors embedded in dedicated thermal measurement facilities, in accordance with the manual developed in the Permafrost Institute, SB RAS [*Balobayev et al., 1977*], and in 2010–2011, the measurements were done with electronic gauges.

Over more than 70 years of operation of the entire complex of buildings and structures, significant changes occurred in the ground temperatures, both in the bases of the foundations and in the adjacent areas. The talik areas have also considerably expanded; at the same time, they remained where they were and formed under newly built structures.

The highest temperature of the thawed ground remained around the submerged building of the circulating pumping station. The heated building is a permanent source of significant heat. Prolonged heat radiation resulted in the fact that the ground around it thawed to a considerable depth. In July 2005, when

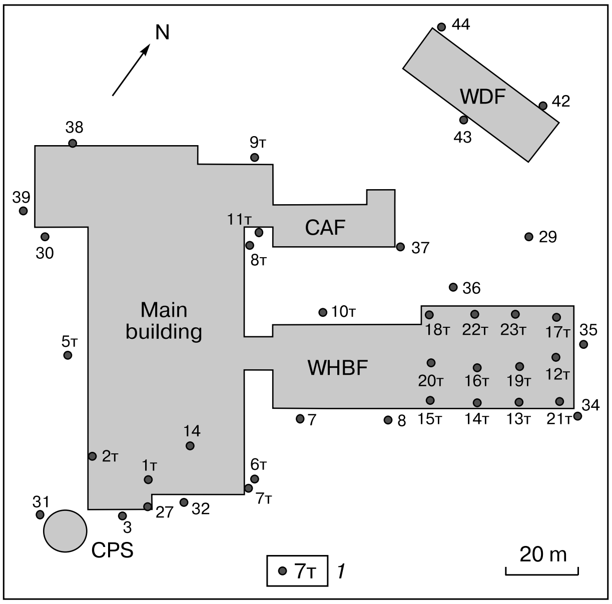

Fig. 6. Location of the boreholes in which ground temperature measurements were made in 2008–2011.

1 – the borehole and its number. WDF – the water demineralizing facility; WHBF – the water heating boiler facility; CPS – the circulating pumping station; CAF – the carbonic acid facility.

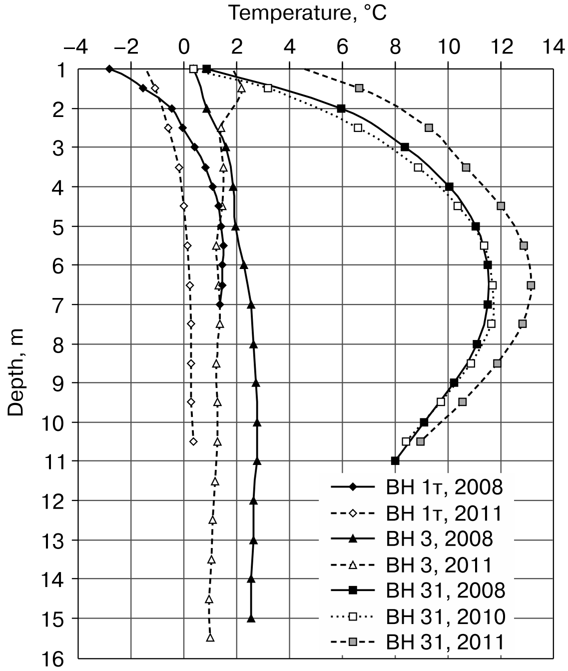

Fig. 7. Changes in the mean annual ground temperature in the talik around the circulating pumping station.

borehole 31, located in the immediate proximity of the station, was drilled, it was found that the ground had thawed to the depth of 23 m, while the talik zone around it had expanded to at least 25 m, to capture the southern corner of the building. In 2008, the mean annual temperature of the ground at the depth of 6–7 m reached +11.5 °C. By 2010, it reduced a little on the top; however, in 2011 it rose again along the entire depth of the borehole, having reached +13.2 °C at the depth of 6.5 m (Fig. 7, borehole 31).

Near the wall of the main building, the mean annual temperature of the ground was much lower, and in 2008 it varied from zero values near the surface to 2.8 °C within the range of 9.5–11.0 m. In the subsequent years, gradual cooling of the ground occurred in this place. In 2011, the mean annual temperature of the ground at the depth of the foundation base did not exceed 1.5–1.6 °C, while below 13.5 m it became equal to 1.0 °C (Fig. 7, borehole 3).

Under the main building, temperature measurements were conducted near the edge of the talik. While in 2008 below 4 m, the mean annual temperature of the ground was still rather high and varied from 1.3 to 1.5 °C, in 2011 it reduced to 0.1–0.3 °C (Fig. 7, borehole 1т).

A rather large talik was formed under the eastern part of the first unit of the building of the water heating boiler facility (WHBF-1). In 1986, the thickness of the talik in the immediate proximity of the eastern edge of the WHBF-1 (Fig. 3, borehole 9) was 24.5 m. In 1989, the building of the WHBF-1 was extended with the new building of the WHBF-2, which was much larger in its size. Unfortunately, in preparing the foundation pit, the 25-m-deep borehole 9 and borehole 28 were destroyed (Fig. 3). Instead, 12 new boreholes were drilled but their depth was only 4 meters (Fig. 6, boreholes 12т–23т). Although before the new building was erected, the foundation pit was exposed to freezing during the winter season, the talik has remained there until the present time. In 2008, it was located under the greater part of the WHBF-2 and expanded far beyond its boundaries. The mean annual ground temperature at the depth of 4 m under the WHBF-2 changed from 0.3 to 2.9 °C from 2008 to 2011 (Fig. 8). It was impossible to assess the thickness of the talik due to the small depth of the boreholes drilled.

In 2005, around the WHBF-2 the first author had three boreholes drilled: boreholes 34 and 36 10.5 m deep and borehole 35 16.0 m deep (Fig. 6). All of them revealed a talik the bottom of which was not reached. In the study period, the mean annual temperature of the ground was positive. From 2008 to 2011, gradual cooling of the ground took place. Near the north-western wall of the WHBF-2, the mean annual temperature of the ground decreased from 0.9–1.8 to 0.2–0.8 °C (Fig. 9, borehole 36), and near the eastern corner, it reduced from 2.1–2.6 to 1.3–1.6 °C

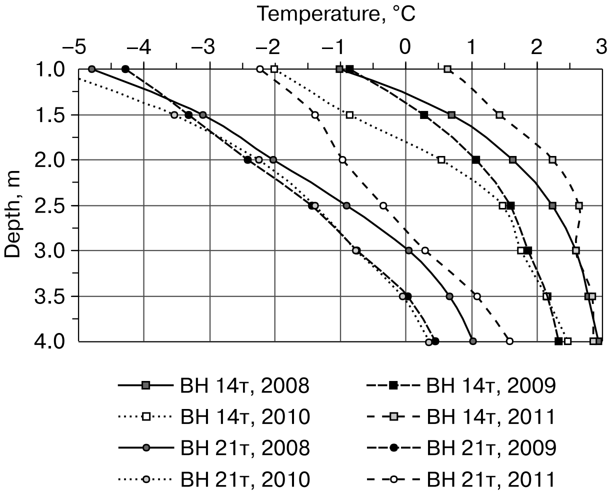

Fig. 8. Changes in the mean annual ground temperature under the water heating boiler facility (WHBF-2).

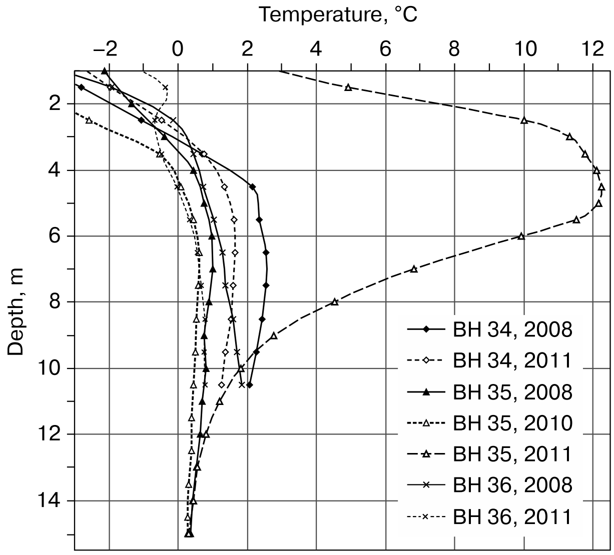

Fig. 9. Changes in the mean annual ground temperature in the talik zone near the WHBF-2.

(Fig. 9, borehole 34). In 2008–2010, near the northern corner of the WHBF-2 the process of ground cooling also took place, and the mean annual temperature of the ground reduced in the range of 4.5–15.9 m from 0.4–1.0 to 0.1–0.6 °C. However, on March 29, 2011, a sharp increase was recorded in the temperature of the ground in the range of 3.0–5.5 m: within 33 days after the preceding measurement, it increased from –0.6...+0.25 to 34.3...+35.8 °C. This can be explained only by a hot water leak, as the air temperature at that time was below –10 °C (Fig. 9–10, borehole 35). The talik thickness was not determined during borehole drilling: judging by the temperature measurements, it does not exceed 20 m.

A talik was also formed under the southern part of the carbonic acid facility (CAF). In 2008, its thickness was 11.5 m, and the mean annual temperature of the ground did not exceed 1.8 °C. In the subsequent two years, the ground thawed, and the highest value (up to 3.0–3.1 °C) was recorded in the range of 8–10 m. In 2011, the temperature regime of the ground began to be restored; however, their mean annual temperature remained rather high and changed from 1.7 to 2.6 °C (Fig. 11).

There is also a talik under the building of the water demineralizing facility (WDF). It is peculiar for being located at the depth of over 6.5 m. Its thickness was not established when the boreholes were drilled. It is not possible to determine it by the results of geothermal measurements, as the ground temperature only increases with depth (Fig. 12).

The talik is located only under the eastern part of the WDF building and near it. In 2008, the mean annual temperature of the ground varied in the range of 10–11 m from 0.9 to 1.5 °C. During three following years, gradual reduction of the ground temperatures took place, and in 2011 it did not exceed 0.5 °C, while the thawed ground got frozen from top to bottom to the depth of 8–9.5 m (Fig. 12, boreholes 42, 43).

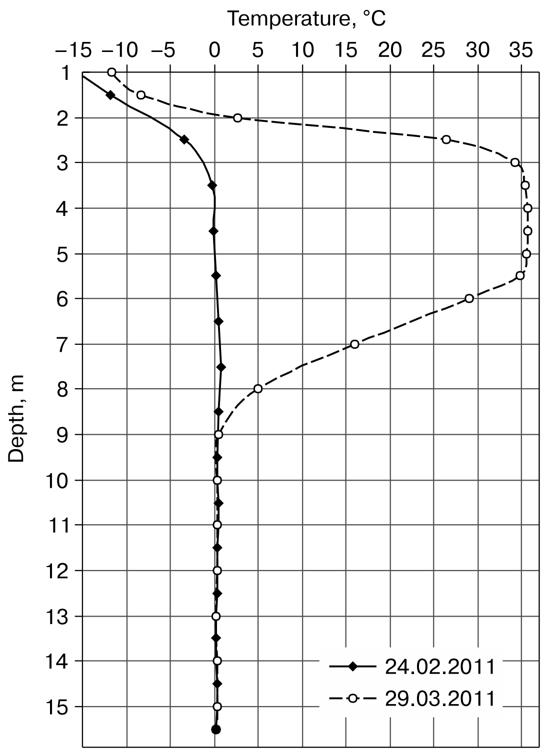

Fig. 10. Impact of hot water leakages in the winter of 2011 on the ground temperatures near the northern corner of the WHBF-2 (borehole 35).

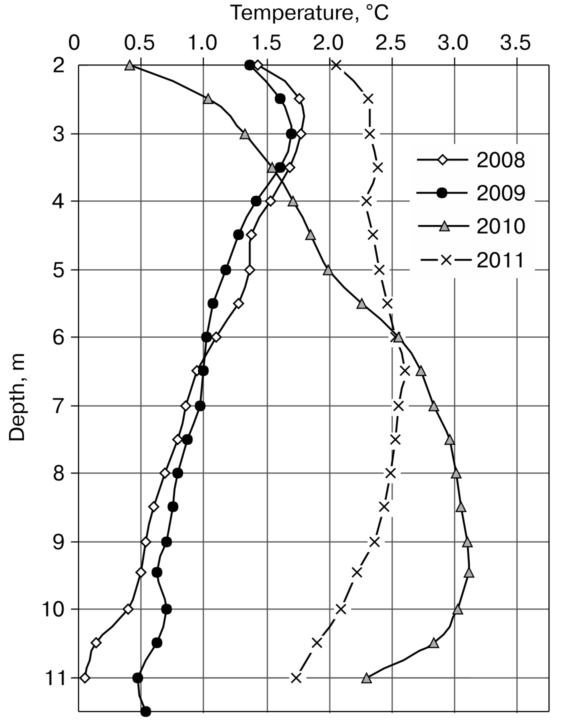

Fig. 11. Impact of hot water leakages in the winter of 2011 on the ground temperatures near the carbonic acid facility (borehole 11т).

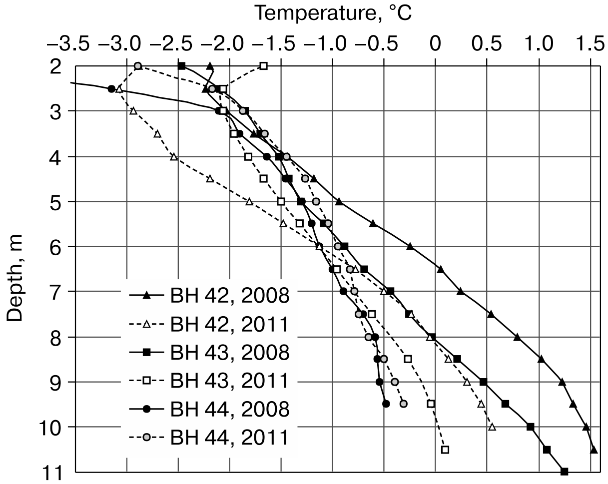

Fig. 12. Changes in the mean annual ground temperature around the water demineralizing facility.

Under the western part of the water demineralizing facility, the ground is fully frozen. From 2008 to 2011, the mean annual temperature of the ground here rose by 0.1–0.2 °C. The highest values were recorded at the depth of 9.5 m: from –0.5 to –0.3 °C (Fig. 12, borehole 44).

Despite the fact that in some places the ground has thawed to significant depths, *the foundations of the major part of the buildings have frozen bases.*

The lowest values of the mean annual temperature of the ground were recorded near the western corner of the main building. In 2008, at the depths lower than 4.5 m, they varied from –2.5 to –3.5 °C. During 2009–2010, the ground temperatures dropped to –2.8...–4.1 °C, while in 2011 they rose again nearly to the values of 2008 (Fig. 13, *a*, borehole 30, 39). This suggests that the pre-construction condition of the permafrost got nearly restored under this part of the building. Such low temperatures are accounted for by the fact that there are only administration offices in this part of the building and that there are no units with significant heat release there. It is natural then that the impact of the building on the underlying ground is minimal there.

Rather low temperatures of the permafrost ground were recorded along the northwestern wall and the northern part of the southwestern all of the main building. In the period from 2008 to 2011, near the northern corner of the main building, the mean annual temperature of the ground decreased from –1.6 to –2.6 °C at the depth of 7.5–8.0 m and from –2.6 to –3.4 °C at the depth of 4.5 m (Fig. 13, *b*, borehole 9т). Over the four years of observations, near the middle part of the southwestern all of the main building, the mean annual temperature of the ground also decreased from –1.0 to –1.2 °C at the depth of 15–16 m and from –1.7 to –2.3 °C at the depth of the foundation base (Fig. 13, *b*, borehole 5т).

The highest values of the permafrost temperatures were naturally observed near the talik zones. Near the eastern corner of the main building, the mean annual temperatures of the ground were rather low and varied from –1.5...–1.8 °C at the depth of 11–15 m to –1.8...–2.8 °C at the depth of 4.5 m (Fig. 14, *a*, borehole 7т).

In the direction of the talik which expanded around the circulating pumping station, the ground temperatures rose by nearly 2 °C. At the depths of 7.5–10.0 m, the mean annual temperature of the ground rose to –0.1...–0.2 °C, while at the depth of the foundation bases, they changed from –0.3 to –0.8 °C (Fig. 14, *a*, borehole 32).

Rather high ground temperatures were observed near the northeastern wall of the main building near the talik located under the carbonic acid facility (Fig. 6, borehole 8т), and in the zone between the buildings of the water heating boilers and the water demineralizing facility (Fig. 6, borehole 29).

Near the wall of the main building, the highest values of the mean annual temperatures of the ground (from –0.1 to –0.6 °C) were recorded at the depth of 9 m, while at the depth of 4.5 m they varied from –1.1 to –1.8 °C (Fig. 14, *b*, borehole 8т). In the territory where the impact of the buildings was minimal, variations of the mean annual temperature of the ground

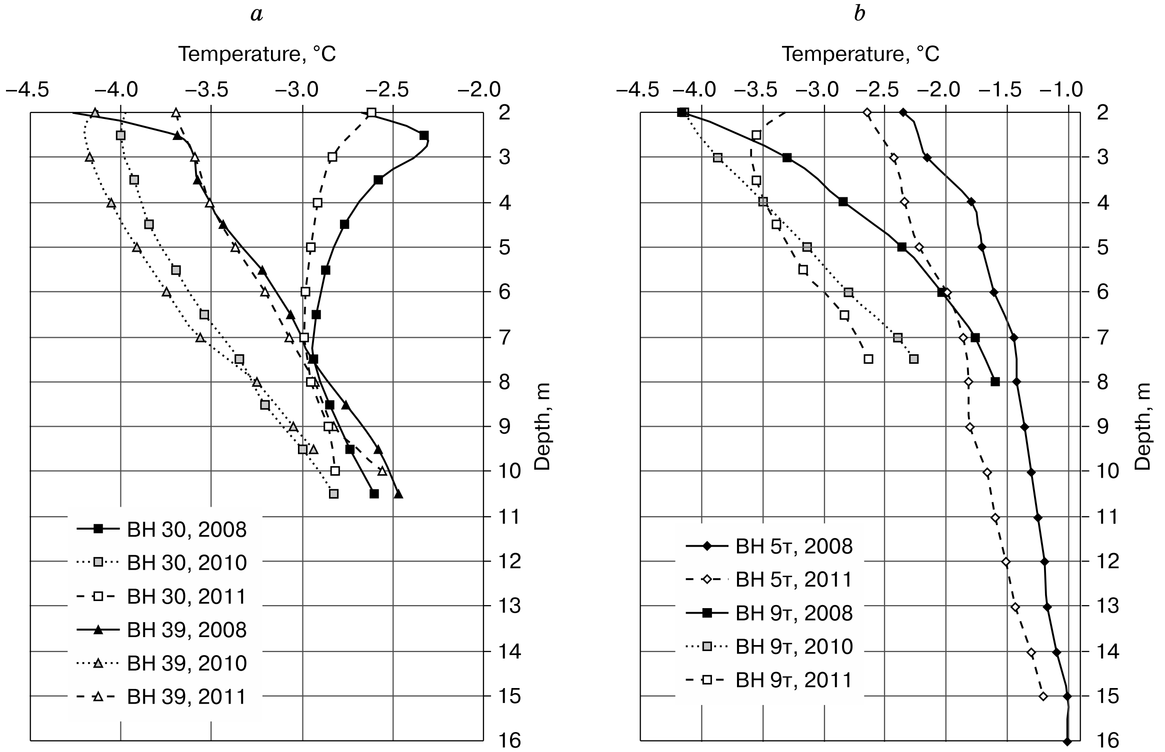

Fig. 13. The mean annual ground temperatures near the main building:
a – the western corner of the building; *b* – the northern corner and the southwestern wall.

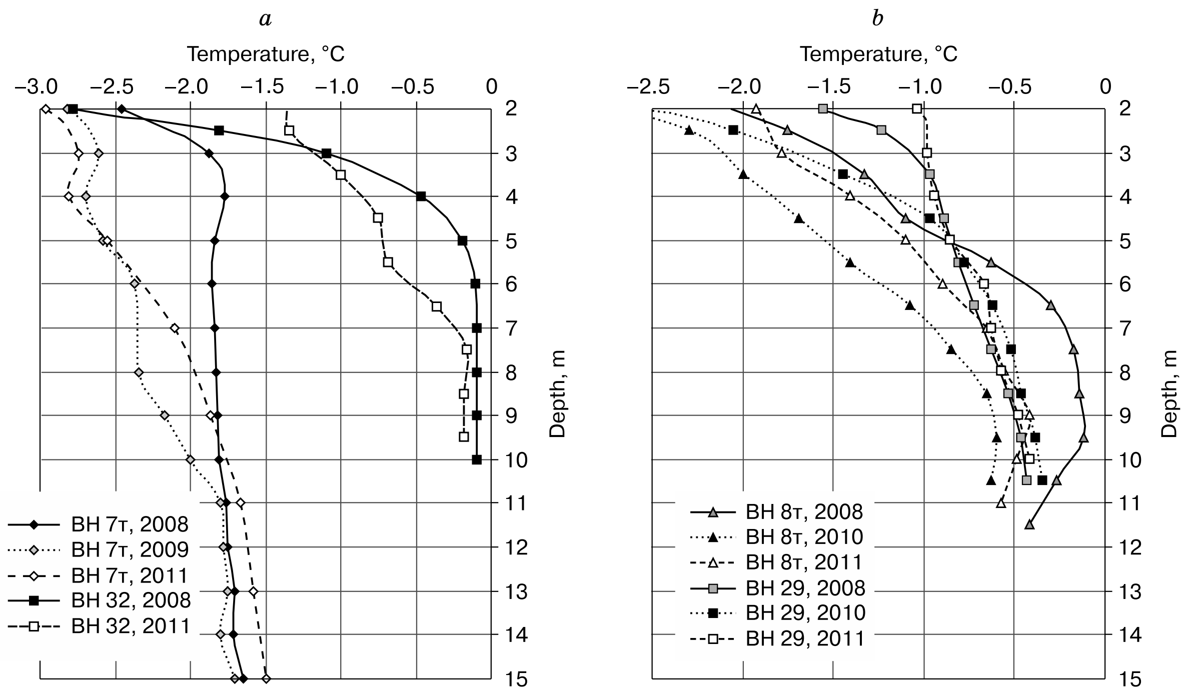

Fig. 14. The mean annual ground temperatures near the main building:
a – the eastern corner of the building; *b* – the northeastern wall (borehole 8т), between the water heating boiler facility and the water demineralizing facility (borehole 29).

were much less. At the depths of 6–11 m, they were only 0.1–0.3 °C, and at the depth of the foundation bases (4.5 m) they varied from –0.9 to –1.0 °C (Fig. 14, *b*, borehole 29).

To evaluate the condition of the ground at the bases of the foundations of the YCHPP and its changes over the entire period of the measurements, temperature fields were built, reflecting the mean annual temperatures of the ground at the depth of 4 m. This depth was chosen not accidentally: mainly because out of 15 boreholes preserved under the buildings, only one borehole was 10.5 m deep, while the others were 4 m deep. In addition, the foundation bases were only 0.5 m deeper.

In 2008, the foundations had frozen bases under the major part of the area under the main building, under the first-order building of the water heating boiler facility (WHBF-1) and partly under the adjacent WHBF-2, as well as under the northern half of the carbonic acid facility. Under the northwestern part of the main building, the ground temperatures were below –2 °C and below –3 °C in small areas. One talik spread around the circulating pumping station, capturing the southern corner of the main building; the second one penetrated under the major part of the WHBF-2, connecting with the talik under the carbonic acid facility (Fig. 15, *a*). All the foundations of the WDF had frozen bases, as the upper boundary

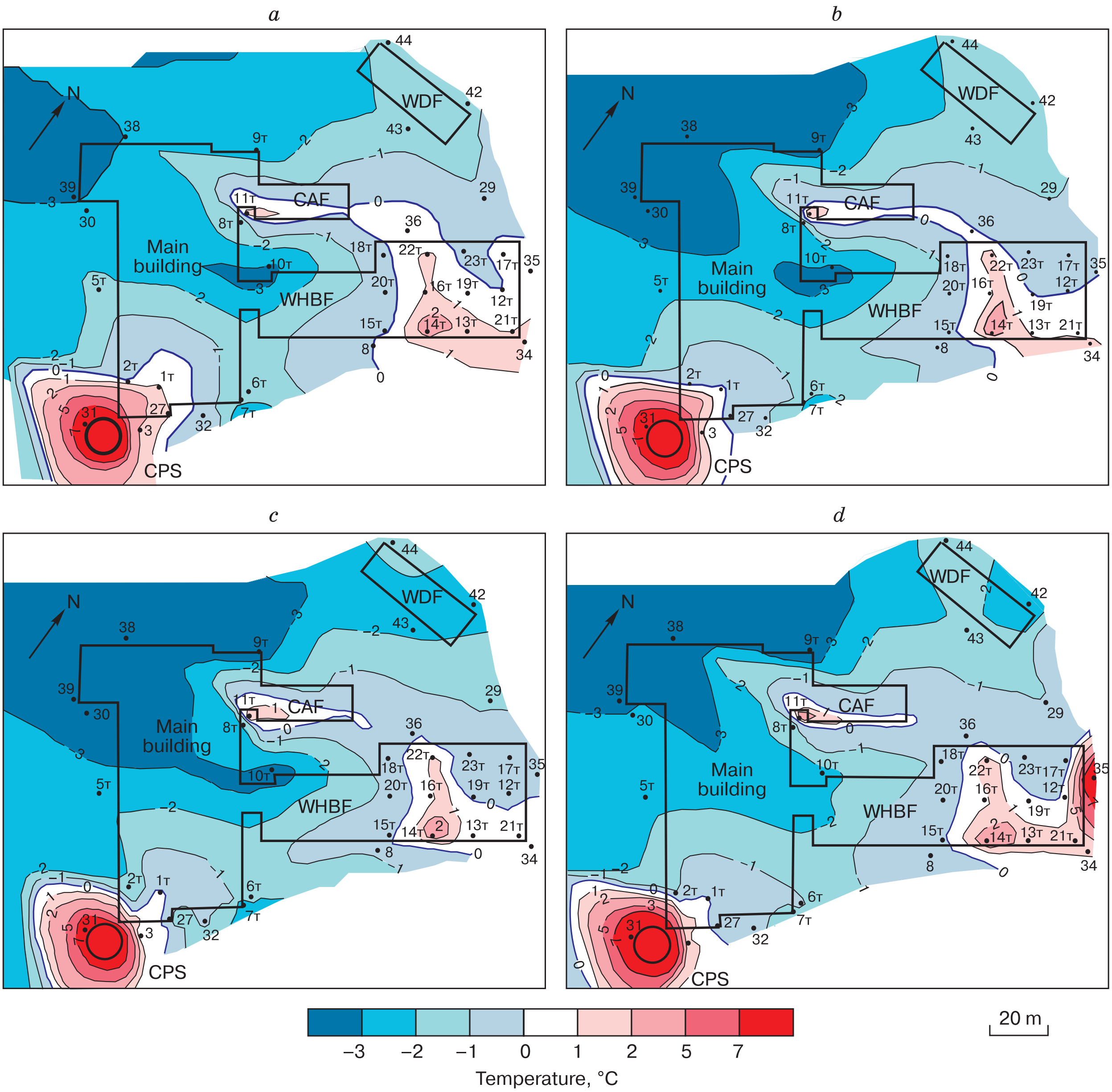

Fig. 15. The mean annual ground temperatures at the depth of 4 m:

a – 2008; *b* – 2009; *c* – 2010; *d* – 2011.

of the talik under part of the building was 2.0–3.5 m lower.

From 2007 to 2009, the mean annual air temperature in Yakutsk decreased every year by 0.2 °C [*Climate..., 2014*]. In addition, water leakages under the buildings were localized. This could not but influence the ground temperature fields under the buildings. The temperatures under the western part of the main building essentially decreased; the area of the talik under its southern corner and under the northern part of the WHBF-2 got contracted. The area of the talik under the carbonic acid facility remained practically the same (Fig. 15, *b*).

In 2010, the mean annual air temperature in Yakutsk further reduced by 0.3 °C, therefore slow recovery of the temperature regime of the ground in the foundation bases continued. The areas with the mean annual ground temperatures below –2.0 °C somewhat expanded, and the talik areas under the main building and WHBF-2 diminished; the talik between the WHBF-2 and the carbonic acid facility divided into two. At the same time, the talik area under the carbonic acid facility somewhat expanded due to the water leaks which continued (Fig. 15, *c*).

In 2011, the mean annual air temperature in Yakutsk remained to be the same as in 2010. In this regard, small changes occurred in the temperature field of the ground at the depth of 4 m, primarily caused by the thermal impact of the buildings and structures. Significant changes occurred only along the northeastern wall of the WHBF-2. Due to the water leaks into the base of this part of the building, in March 2011 the ground temperatures at the depths in the range of 3.0–5.5 m reached 34–36 °C (Fig. 10). As a result, the mean annual temperature of the ground in this place at the depths of 4–5 m exceeded 12 °C, whereas the talik advanced under the building (Fig. 15, *d*).

CONCLUSION

Many years' studies conducted in the territory of the YCHPP have shown that significant changes have occurred in the temperature regime of the ground. The mean annual temperature of the permafrost ground at the depth of the foundation bases rose from –5...–3 °C (directly in the area of construction before the buildings and structures were erected) to –4...0 °C in 2011.

In some places, taliks up to 25 m deep were formed, the mean annual temperature of which reached 12–13 °C. It has been found that taliks have remained to exist under all the buildings.

Under the buildings of the water boiler facility and of the carbonic acid facility, taliks occupy up to 30 % of the area, and their sizes almost do not change due to practically annual leakages of hot and aggressive technical water.

Under the main building, the size of the thawed part of the base got essentially reduced and does not exceed 5 % of its total area.

The foundation of the water demineralizing facility has a frozen base. The talik is deeper than 6.5 m and is located only under the eastern corner of the building. As no water leakages were observed, in 2011 the thawed ground got frozen to the depth of 8 m from the surface.

When permafrost thawed, irregular settlement of fragments of the structures occurred under certain parts of the YCHPP buildings. When the ground continued to freeze, on the contrary, their frost jacking occurred. The vertical displacements of the foundations observed from 1982 to 2002 resulted in different deformities, the most typical of them being wall cracking, partial breakup of pile heads, chipping of bared reinforcement steel frames, and deflection of the foundation beams.

Despite this, the condition of the entire complex of the buildings and structures remains quite stable. The cause of this is that, when the complex was designed, the margin of safety designed was sufficiently high. The loamy and sandy-loamy ground was replaced with sandy ground in their base as non-heaving. In addition, rather large sizes of the foundation columns' footings were designed, while the turbine generators and the boilers are supported by solid concrete slabs.

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