SPORTS HALL – WARRANTY DEFECT OF FLOOR

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DOI: 10.31490/tces-2019-0007

Abstract. *The paper examines the issue of managing complaints after buildings have been put into operation. The problem is documented through the case study example "Sports Hall Reconstruction", in which a fault appearing in part of a large concrete slab is described. The construction of large concrete slabs to form the base floor layers in sports and industrial buildings is often accompanied by numerous problems. Achieving an even structure in the final surface is one of the main problems on account of the large amounts of processed concrete used. Construction of the base layers beneath concrete floors using the materials prescribed by project documentation therefore demands considerable attention. Technological discipline in processing concrete mixtures in relation to potential shrinkage cracking or cracks caused by improperly installed expansion joints is an equally important part of industrial flooring construction.*

Keywords

Construction, complaints, faults, survey, floor, concrete, non-stationary temperature field.

1. Introduction

During and after a construction project, several problems requiring solutions are often encountered. After contracting services have been completed, the situation in new constructions and reconstructions is frequently similar. Contractual relationships in the construction industry are governed by the Civil Code, under which a construction is seen as a product [15], and the Act on Public Procurement [16]. The contractual nature of a construction project creates obligations for all participants involved in the construction process (i.e. the investor, designer, contractor and subcontractors) [5], [11], [17]. Professional experience shows that after buildings are put into operation, faults preventing the proper use of the buildings are detected and the complaint process is initiated. In order to eliminate detected faults or other defects properly and definitively, a technical survey must be performed and draft expert opinions or analyses given. As reported in the scientific literature [18], a technical survey is not uniformly prescribed or otherwise specified, and each expert group chooses its own methodology.

2. Documentation of the problem in the case study

The problem of warranty complaints concerning faults and defects after buildings have been put into operation is mentioned in the case study "Sports Hall Reconstruction", which describes surface roughness and cracks in the concrete flooring of a section of an ice-skating rink and a section of its spectator stands at ± 0.00 m. In order to properly identify the problems, it is important to first become familiar with the structural and material solution of the reconstructed sports hall given in the project's implementation stage documentation. The design and material characteristics and technological stages of reconstructing the sports hall were given in the project documentation as follows:

- Demolition of the floor in the indoor area of the sports hall up to a thickness of 150–570 mm; demolition of the ice surface in the first stage down to the level of the base plate.
- Demolition of flooring structures beneath the ice section of the hall and dismantling of existing structures in the ice section to the top of the base plate.
- Demolition of concrete floors outside the ice rink and floors up to a thickness of 150–500 mm (floors were dismantled to a greater depth because of

subsoil tempering, the new floor layers with utilities and the poor quality of the base layer for the new cement layers).

- Demolition of 250-mm-thick reinforced concrete walls. Openings as large as the existing shafts and the technological channel were knocked into the reinforced concrete walls at the connection of the existing ammonia channel with the existing rewinding equipment channel.
- Dismantling of the concrete rib of the gallery and part of the ceiling at the resurfaced entrance; the metal ceiling was also dismantled [5].
- Earthmoving work in class 3 soil according to ČSN 73 3050 and excavation at the site of the new channel, the bottom of the pit being at -3.15 m and the width of the trench at 3.4 m (deformation modulus Edef2 achieved by compacting equals 45 MPa, and a ratio of Edef2/Edef1 < 2.5).
- Implementation of the new 150-mm-thick sub-base using a well compacting material, processed by compacting to $Edef_2$ = 45 MPa, with compacting verified by in situ tests.
- After completion of the construction works, the pit was filled with recycled concrete and compacted in layers up to 250 mm thick to $Edef_2$= 45 MPa [5].
- Foundation structures such as the base feet or strips were not present in the sports hall, as the base plate below the ice and the concrete slabs outside were considered the foundations [5, 6].
- The concrete floor slabs outside the ice rink were made of C25/30 concrete and reinforced with dispersed wire reinforcement, at a quantity of 25 kg/m3
- The floor slabs were made 115–272 mm thick, with reduced thickness over the channels at a thickness of 120 mm and reinforced with KARI netting.
- The floor slabs laid on the ground were constructed over a 200-mm-thick compacted layer with a value of = 45 MPa; a waterproofing layer and concrete underlay were placed beneath the slab.
- The slabs were insulated from surrounding structures with a 10-mm-thick vertical insulation polystyrene-based strip, and the joints were cut and bonded in a 6/6 m grid (where electrical channels were installed in the floor, shrink joints were placed 500 mm from the edges of the chan- nels).
- The new part of the utility channel, called the “connecting channel”, was designed as a monolithic block with a rectangular cross-section and external dimensions of 1.9 * 2.69 m, with a 250-mm-thick slab made of C25/30 concrete reinforced with steel bars forming its base; vertical support structures in the utility channel were constructed with 250-mm-thick monolithic concrete wall panels with rectangular cross-sections and made of C25/30 concrete reinforced with steel bars.
- The roofing of the new section of the utility channel was constructed with a 150-mm-thick reinforced concrete monolithic slab made of C25/30 concrete reinforced with steel bars; the ceiling structure over the rewinding channel was constructed using a combination of a monolithic slab and a bent steel beam with an HEB profile.
- The project documentation described different solutions for the floor structure beneath and outside the ice rink.
- The wear layer of the floor outside the ice rink consisted of thin poured layers of epoxy-based material, called the “Quartz color” system, with added colored sands, and sealed with a transparent epoxy resin (waterproof profile for 10 mm thickness complies with all requirements for laying floors).
- The floor in the ice rink was constructed with a walk-on cover consisting of a 120-mm-thick reinforced concrete slab, reinforced with polypropylene fiber netting and KARI netting with conventional reinforcement; the surface was mechanically smoothed with poured hydraulic-based binder (in the ice section, the floor’s composition was characterized by floor heating distribution located in the 70-mm-thick concrete screed).
- The lower part of the structure was protected against ground moisture using SBS modified waterproofing asphalt sheets reinforced with polyester mat, and the expansion joints and all areas with tensile stress were reinforced with a thickened band.
- Waterproofing of the existing and new waterproofing slurry consisted of a cement-based design with modified polymers and condensed silica fume; bonding of the sewer line passages through the reinforced concrete wall using an expanding polyurethane-based tape and the joint surface was then closed with a polyurethane sealer, similar to the insulation on the newly built sumps.
- Dilation of the floor structures was constructed over the walls of the underground utility channel with a 10-mm-thick profile, and the gap was filled with a polystyrene-based inlay.
- Sealing of the dilation between the skating rink and the drainage channel was constructed with Combiflex sealing tape, which was fixed with Sikadur 31 CF glue; according to the project documentation, the tape was to be mounted after one year of use of the skating rink; a permanently elastic insert of nonabsorbent 30-mm-thick Mirelon was placed between the side plate of the steel channel and the ice-skating rink slab; a polystyrene slab was placed between the channel and the

floor in the hall (see A1-26).

- The new connecting channel route was thermally insulated with 40-mm-thick extruded polystyrene along its perimeter; the slab resists compressive strength up to 250 kPa at 2% compression; additional insulation on the inside of the channel necessary due to the temperature differences between the interior of the hall and the environment of the underground channel was constructed with a 60-mm-thick Fasrock insulating mineral slab; the slabs were bonded to the inner surface of walls and ceilings, which were repaired and filled with putty; all joints were jammed and fixed with plugs according to the technological process; 50-mm-thick Foamglas T4 insulation was used in the area under the in-goal section 4.0 m from the outlet of the cooling distribution and glued with PC 56 emulsion anchored mechanically to the walls and ceiling with four anchors.
- After performing geophysical measurements, placing probes into the bedrock under the slab and visually inspecting the foundation slab, it was decided that the foundation slab would be retained.

2.1. Unevenness of the floor, technical survey and in-situ diagnostics

The complaints process was initiated almost immediately after the sports hall had been put into service. The investor pointed out the uneven ice surface as a result of the concrete floor lifting two months after commencing the process of freezing the ice surface. Surveys and inspections were immediately launched under the complaints process to determine the cause of the fault. The most significant height difference on the surface of the ice was observed near the contact between the newly integrated concrete floor with the ammonia duct outside the ice rink. The following technical surveys and in-situ diagnostics were performed:

- Measurement of temperature using S1 to S6 sensors at selected surface locations to detect temperature differences between the time when the freezing the ice surface commenced and the time when cooling ended [1].
- Continuous measurement of moisture [1].
- Destructive test of concrete strength, which determined the minimum value corresponding to cylindrical concrete strength (C) 23/28 [4].
- Measurement of seismic effects to show that the measured frequency during, for example, a music band concert, reached 25% of the limit value for structural damage (however, as this was an atypical and irregular structure, it cannot be ruled out that certain elements of the structure may be stressed by intense vibrations, and it can be concluded that the results of the seismic measurements correspond to the limit values according to ČSN 73 0040, and excessive stress or damage to the structure therefore does not occur [2]).

The building investor and contractor also attempted to verify the quality of the backfill material used, which, according to the original project documentation, was replaced with recycled concrete instead of the crushed gravel-sand backfill with the prescribed fraction initially proposed in the project documentation. Tests were therefore performed to assess the quality of the backfill material under the floor in the spectator stands section, and samples of the backfill material under the floor across the sports hall were analyzed. Diagnostics and analysis showed that the recycled concrete used had different mechanical and physical properties compared to the backfill material proposed in the project. It was concluded that the backfill material was rather heterogeneous, containing a relatively large amount of binder (40–60%); however, the internal, recycled fragments demonstrated changes in volume. This volatility in the backfill material's volume was therefore identified as the main cause of the concrete surface lifting its edges [3]. The effect of difference in temperature and internal moisture was also studied in relation to water leakage and lack of water tightness, which was detected during the structural and technical survey. It was therefore concluded that leakage and lack of tightness could have affected the evenness of the concrete surfaces.

3. Evaluation of the tests and determination of the causes of the fault

To determine the causes of the concrete floor structures lifting, several diagnostic tests and in-situ measurements were performed, as mentioned in chapter 1. Measurement of temperature, moisture, and vibrations and evaluation of backfill material quality were the main tests performed.

3.1. Measurements of temperature and moisture, destructive and non-destructive testing of concrete

Sensors were installed at locations designated S1 to S6 along the channel supplying cold (i.e. the ammonia duct) in holes prepared using a core drill with a diameter of 150 mm. Moisture sensors with an integrated SNS THE 3m, thermometer were fitted at the bottom of the holes at the required depths and connected to THT2 electronics for discrete output readings at the floor's surface. The holes with probes were subsequently re-filled with the drilled material, and a cover for the electrical equipment was fitted at floor level to make sure traffic was not impeded. The cover was then encased in a waterproof material with multiple terminals for connecting sensing equipment. This device showed that the temperature difference between the time when freezing the ice surface commenced and the time when cooling ended was up to 5 °C.

Moisture measurement detected a constant moisture level of 100%. It should be noted that in 4/2013, approximately 90 m^3 of water had previously penetrated the subsoil and reached the space beneath the foundations. Based on these measurements, the average moisture level of the backfill materials according to ČSN EN ISO 17892-1 was 26.4% in 2015 [1]. Destructive and non-destructive tests on concrete were also performed. Sampling for the destructive tests was performed with a cup diamond crown drill bit with a diameter of 160 mm. Samples from probes S2, S3 and S6 were used in the non-destructive tests. The results of the concrete strength tests fell in the pressure range 24.5–29.7 MPa. The volumetric weight of the concrete was also established in the range 2180–3150 kg/m^3. The strength of the concrete floor structure can be classified as the nearest strength class of the detected cylindrical concrete strength. In this case, the lowest cylindrical concrete strength was found at the location of probe S6; this corresponded to the strength of concrete class C23/28 (B28), which fully complied with the requirements of the project documentation [1], [3].

3.2. Vibration measurement test

Measurement of seismic effects was performed using GAIA type solitary seismic stations with three-component ViGeo2 sensors. The sensors were installed on solid surfaces, and throughout the duration of the test (i.e., during the concert), the four stations were positioned as proposed by the investor - Station 1 ammonia channel; Station 2 – fall; Station 3 – grandstand B 8; Station 4 – stand B 6. The maximum measured velocity of vibrations were around 20% of the value of the effective movement speed that would introduce the need to calculate dynamic stresses in the tested structure.

Furthermore, the limit value for damage to the building was not reached, only achieving 25% of this value. To summarize, it can be stated that the seismological measurements at the monitored locations did not document the maximum velocities of vibrations that would, according to ČSN 73 0040, lead to increased stresses in or damage to the building [2].

3.3. Evaluation of the quality of the backfill ing material beneath the concrete floor

A macro-petrographic analysis of fragments of the material was performed. The analysis concentrated on the material's grain size and fragment shapes and a relative qualitative comparison of individual fragment types present in the representative sample material. The important data is presented in both the summary tables and descriptions of individual documented samples in the documentation. A test of the linear expansion of the backfill according to 6 ČSN EN ISO 13286-47:2012 was also performed. A moisture level value of 20% was determined from the natural moisture content results. The initial expansion reading was determined before saturating the sample and monitored until stabilization. The standard length of the test was 96 h. The largest change in volume was observed in the first few days for all selected samples, which were initially dried and then absorbed water until they reached a humidity value of 20% (Fig. 1).

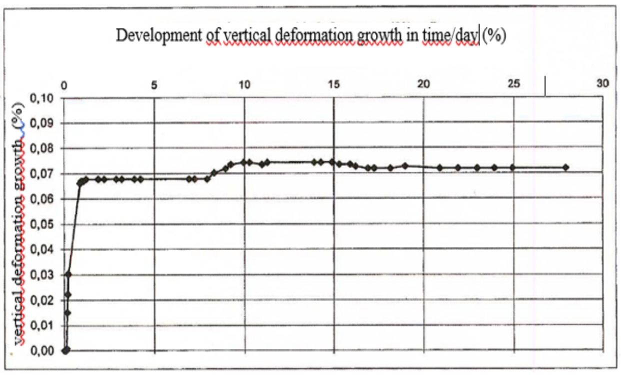

Figure 1. Measurements of the progress of vertical deformation in the backfill sample[4]

It was concluded that the backfilling material specified in the project documentation, (i.e., natural aggregate) would not have demonstrated these changes in volume. The evaluation also measured temperature changes in the backfill and identified the binder type present in the recycled concrete. Just as in the previous test, a dried sample was mixed with water and the resulting heat of hydration values were compared to various binder types, such as cement and plaster. In order to precisely identify the material in the backfill, more tests were needed, including elemental analysis of the sample using x-ray fluorescence spectrometry on an XRF spectrometer and analysis of the powder using X-RAY diffraction. From these tests, several conclusions were made.

The backfill material consisting of pieces of concrete, ceramics, wire reinforced concrete and rock (greywacke, quartz) was stable. Changes in volume were exhibited in the backfill material that contained binder in the recycled concrete, especially in white or shell-like layers, crystals and phenocryst that made up 40–60% of the backfill material. These parts consisted of calcite containing vaterite, gypsum and basanite. Calcium silicate hydrate (C-S-H), ettringite and portlandite was also identified. Changes in volume are associated with rehydration and carbonatation. The occurrence of these materials was also corroborated by the thermal reaction of the dried sample with water and the initial increases in volume [3].

Further analyses were performed for the comprehensive sample analysis. The conclusions of all analyses were more or less identical. The cause of the increase in volume was seen in the mineral change in the binding system associated with hydration and carbonatation. For Ca(OH)2, which is transformed into Ca(CO3) through carbonatation, anhydrite hydrating to bassanite and emerging ettringite is accompanied by a change in volume of the newly created minerals. Their emergence and intensity of formation, however, was not the same in all samples. Carbonatation requires a permanent supply of CO_2, which in this case was considerably restricted, and can affect the progress of the process significantly. Estimation of the degree of change in volume is impor- tant but was not possible since the original porosity or density of the filling material was unknown. Additional relevant information identified in the laboratory analyses included a height deformation of approx. 2.1 mm/m caused by expansion of the backfill, meaning an increase of 5.2 mm for backfill 2.5 metres thick. The concrete floor along the ammonia channel was lifted by approx. 20 mm, however, which is a value four times higher. It can be observed though, that an improper technical solution for the floor heating could affect the structural engineering of the entire construction, as noted in the implementation project for constructing the ice rink's cooling technology [3][4].

4. Corrective actions

The following must be considered when determining corrective actions:

- The discrepancy between the height deformation value of the backfill based on laboratory tests and the real unevenness caused by lifting of the con- crete floor.

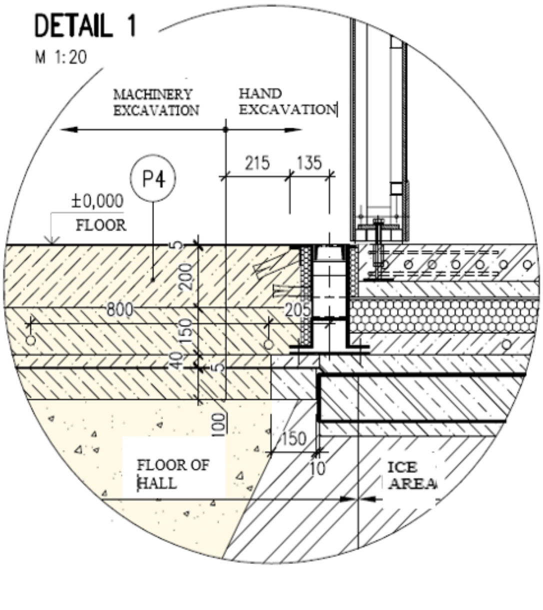

Figure 2. Detail of the contact between the concrete floor and the ammonia channel from reconstruction in 2012.[11]

- For the volumetric strain of the backfill, which was initially thought to be the cause of the lifting concrete floor, corresponding faults in the adjacent ammonia channel would have occurred
- Lifting of the concrete floor only affected one side of the ammonia channel, although the same mate- rial was used on the other side.
- Lifting of the floor always occurred around two months after commencement of freezing the ice surface, indicating a direct correlation to change in temperature. However, measurement of the deve- lopment of temperature where the ice surface and bedrock contact within the effective range of the floor's cooling and heating solution (see chapter 3.1) cannot be considered as relevant in view of the thermo-technical characteristics of the concrete and backfill, because probes S1 and S2 located along the faulty ammonia channel were about 900 mm away from the last heating pipe installed during reconstruction in 2012.
- Substantial leakage of around 90 m^3 of water in the spring of 2013 through an unsealed dilation along the perimeter between the ice rink section and the lip (according to the project documentation, this should have been sealed within one year before thawing) did not affect lifting of the floors in any following period. Figure 1 shows the increase in volume of the backfilling material occurring in the first few days, with the first lifting of floors occurring immediately after commence- ment of operation.

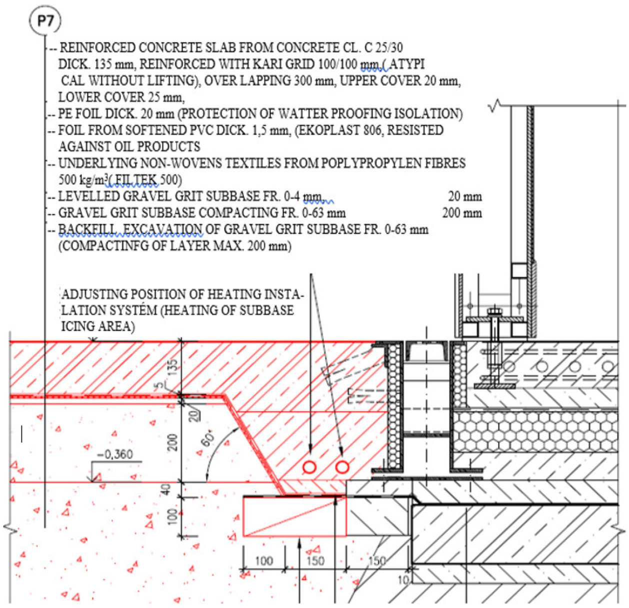

Figure 3. Detail of the contact between the concrete floor and the ammonia channel from reconstruction in 2016. [11]

The backfill material was probably activated by the penetration of water from the remaining old infrastructure or by a change in the level of ground water. The problem is illustrated in Figures 2 and 3. The redesigned project documentation already addressed the two problems, i.e. exchange of the backfill material, which did not comply with the project documentation in terms of its technical properties, but also a change in the floor heating system and floor composition. Figures 3, 4 and 5 show that the lower concrete part of the floor was exchanged with backfill and the side pipe of the heating grid was moved closer to the longer side of the ice section, with the original spacing of the two outer pipes of the heating system being 800 mm according to the solution from 2012 [5] (Fig. 2).

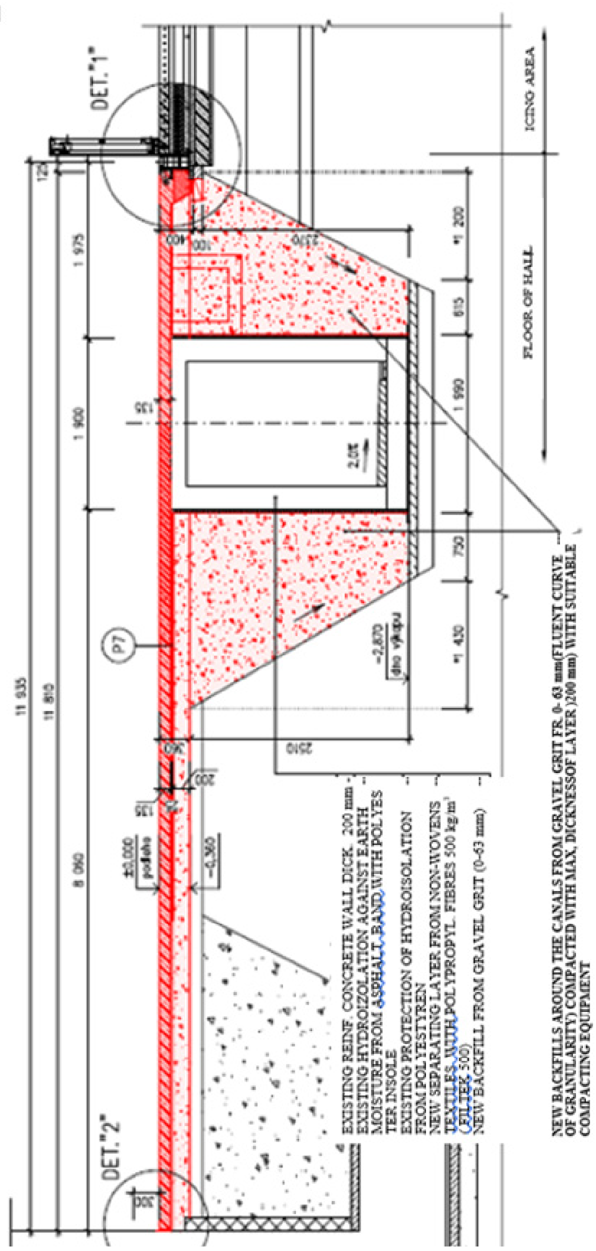

Figure 4. Cross section of sewerage pit [11]

The current spacing of the heating pipes is only 80 mm according to the project documentation for concrete floor repairs in 2016 [11]. This change significantly strengthened the heating effect of the pipe located on the outer side of the drainage channel and also significantly reduced the thermal bridge by thinning the connecting part of the concrete slabs of the floor to practically half of the original thickness (Fig. 5).

Figure 5. Ground plan of the new solution [11]

5. Conclusion

The presented case study suggests that the change of backfill material to recycled concrete, which is detailed in the project documentation, did not have a major influence in lifting the concrete floor. The development of temperatures in the subsoil layers and temperature gradient in the thickness of concrete slabs contributed a far more important effect. Laboratory tests show [1], [3] that the backfill consisting of recycled concrete had a moisture level of up to 100% at the beginning of 2014 [1] and that the average moisture level a year later was 26% [3] Reactions in the binding material producing calcite with vaterite, gypsum, bassanite, C-S-H, ettringite and portlandite, caused changes in volume associated with rehydration and carbonatation. The occurrence of these materials was corroborated by the thermal reaction of the dried sample with water and the initial increases in volume. However, the greatest change in volume, according to [3], [4], occurred in the first few days when dried samples were mixed with water, which is not consistent with the emergence of unevenness in 2013, 2014 and 2015. It is therefore highly probable that subsequent temperature differences or even freezing bedrock could cause additional increases in volume, given that temperature measurement was not relevant in view of the locations of probes S1 and S3 (see chapter 4).

In the case of volumetric strain in the backfill material caused either by the bedrock freezing or by carbonatation or rehydration, deformation changes in the side walls of the ammonia channel must have subsequently occurred, and this was not noted. It is therefore very likely that lifting of the concrete slab edges was caused by a combination of all the known factors, namely expansion of the underlay due to rehydration and carbonatation, freezing of the subsoil due to temperature differences and the temperature gradient in the concrete floor, which may have been the main cause of the fault. The temperature gradient in the thickness of the slab, lower temperature being on the upper side of the slab and higher temperature on the lower side, caused the edges to lift and created tensions on the upper side. For the base layers with large horizontal dimensions, maximum tensile stress was caused by bending on the upper surface during the cooling phase [14]. The issue of fluctuating temperature fields has been studied in a number of professional publications [12], [13], [14]. This problem cannot be assessed precisely, as calculating the development of temperature in the concrete floor was not a part of the project documentation for the floor heating. The temperature calculation principle is based on the generally accepted Fourier differential equation describing a fluctuating temperature field in a general orthotropic body [12]:

$$\frac{d}{dx}\left(\lambda_x \frac{dT}{dx}\right) + \frac{d}{dy}\left(\lambda_y \frac{dT}{dy}\right) + \frac{d}{dz}\left(\lambda_z \frac{dT}{dz}\right) + q = \rho c \frac{dT}{dt} \qquad (1)$$

where t is time (s), $T(x, t)$ is the temperature depending on the coordinate and time (K), ρ is density ($kg.m^{-3}$), λ thermal conductivity ($W.\ m^{-1}.\ K^{-1}$), c is specific heat capacity at constant pressure ($J\ .kg^{-1}.K^{-1}$), q is heat flow due to hydration ($W.m^{-2}$)

Corrective actions in the form of replacing the backfill material, thinning the concrete floor to half its thickness and changes to the floor heating system by reducing the spacing between heating pipes led to a different temperature gradient and therefore tension in the concrete floor structure, which was the reason for the edges of the structure lifting initially. After these modifications were implemented in 2016, no further height irregularities caused by the floor lifting near the ammonia duct have been observed.

Document is published with agreement of the investor.

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