The main causes of accidents of space lattice Kislovodsk-type structures

Emil Kodysh¹, Nikolay Trekin¹,², Aleksej Chaganov³, Vladimir Bobrov²,³, Sergej Shmakov¹

¹ JSC TNIIPromzdaniy, building 2, 46, Dmitrov highway, Moscow, Russia
² Moscow State University of Civil Engineering, Yaroslavskoe shosse, 26, Moscow, 129337, Russia
³ Vyatka State University, 36, Moskovskaya street, Kirov city, Kirov region, Russia

E-mail: kodyshem@yandex.ru, otks@yandex.ru, chabpilot@yandex.ru, vbobrov1985@bk.ru, sergey3456789@gmail.com

Abstract. The article deals with the operation problems of space lattice constructions (SLC) of the Kislovodsk-type, revealed as the results of a survey of more than ten structures within the period from 2000 to 2020. The main causes of accidents of the SLC system was revealed and presented. The disadvantages of production mounting of the Kislovodsk-type system with a hidden capital are considered; the recommendations for preventing the displacement of the SLC support connectors of the Kislovodsk-type system with a hidden capital are presented. As an example, the collapse causes of the Kislovodsk structure made with a hidden capital according to a rare scheme operated in Syktyvkar were analysed in the work. The results of numerical study of the load-bearing capacity of constructions made in CAD SCAD 21.1.1.1 were presented. The most common structural defect of this type – the elements overload of the SLC system is considered in this work. The calculation showed that the structural plate has a three times overload of 35% of the elements (compressive stability, strength). The overload is connected with the normative load increase of snow cover in 2003 and in 2016, and the weighting of the roof structure (twice as compared to the production solution) during its repair work. The load calculation was based on the survey of the SLC constructions. Based on analysis of constructions of this type, the authors give the recommendations on the list of works required for additional inclusion in the survey program of the technical condition of constructions.

1. General information about space lattice constructions of the Kislovodsk-type
For many decades, space lattice constructions (SLC) of the Kislovodsk-type and their improved constructions are used to cover industrial and agricultural buildings. According to the information [1] since 1975 the annual building commissioning with this coating was up to 1.5 million m². The coating is a structural construction in the form of a space-rod lattice and is composed of repeated rod and node elements [2]. Producers made a number of improvements during the theoretical and practical operational time for optimizing this construction and improving calculation methods [3-6]. Initially, being a solid structure it received a rare (redesigned structure with a number of rods removal) frame; it allowed to reduce costs while maintaining the necessary load-bearing capacity. Later, a column capital hidden in the structure was added to the Kislovodsk-type construction; it allowed to reduce the overall height of the building and, accordingly, the amount of air necessary for the room heating.
Emergency situations of this type structures have been occurred since 1983 [1]. The most typical accident causes are gross violations of the operation requirements of the capital construction object: irregular survey of constructions; untimely and incomplete repair and maintenance of constructions; poor quality of performed works; inaccurate calculation of snow and wind loads, as well as the impact of beyond-design loads of various origins [7]. The typical collapse time of the coating structures is the end of winter and the beginning of spring, when the snow load is heavy [8].

The survey results of more than ten coating structures of this type [9-11] showed that in all cases a significant eccentricity was recorded; it was created by support connectors placed on the columns of buildings. The eccentricity was about 50-80 mm. The connectors made of high-strength steel have low weldability. Often it is not possible to make a high-quality installation weld in building conditions. The structure supports with declination from the designed installation places (due to the poor quality of construction and installation work [7, 12] while the SLC construction) also did not allow the design to support the structure and roof elements where the coating adjoins the walls. The building columns with a high bearing capacity help to operate building without strengthening works; it is possible since the start of the building of the even when the increased snow loads and the availability of eccentricities in the bearing structure of the coating.

Kislovodsk structures made in the "capital" version (Fig. 1) have a design solution for fixing the support connectors in the horizontal plane additionally welded to the support platform of the column with the metal corners (Fig. 2) [2]. The production with a hidden capital makes it impossible to use this fixing method (the production solution is welding the connector to the support platform of the column). This production solution, due to the use of high-strength steel in connectors of the Kislovodsk-type structure, is usually made with low quality of the weld or it is completely ignored during installation. The load change, for example, during the repair work, this defect may cause the deformations in the horizontal plane [13, 14].

![Figure 1. SLC of Kislovodsk-type. Cut. Production 1.466-2 [2]](image-url)
2. Accident in Syktvykar

In 2017 a part of the building covering structures collapsed in Syktvykar (Fig. 3). The main supporting structures of the building are three independent structures of the Kislovodsk-type. The structures are made in accordance with a rare scheme with hidden capitals in a plan of 27x27 m and 2.12 m height from rod-shaped tubular elements of various cross-sections of 3 m length. The intracountour plate is supported on four columns (pipe diameter - 530 mm, a wall thickness - 9 mm), space is 18x18 m. The building roof is made with girders located transversely and joints are placed on the structural units. The girders are bent channel of GN120x60x5-type. Wall fencing is brick walls of 510 mm thickness. The structure girders are set up in the brickwork of the wall along the building contour. The material of the supporting structures is steel 20.

The survey determined the type of structural plate – SP27-350A (code 351/02. 0,3; code 167.02.00.00.00) [15, 16]; its permissible design load (in accordance with the documentation) is no more than 350 kg/m². Subject to Building Acts 20.13330.2016 "Loads and impacts", the roof structures weight is not exceed 50 kg/m². The collapse of the coating structure occurred during the partial replacement of the roof covering, made with gross violations of the technology and construction materials storage. During the dismantling of the old roof covering, there was a local overload of roof sections and partial removal of the roof covering; together with the wind load it led to the SLC sliding from the supports and to the collapse of the middle structural part of the coating.

The results of the survey showed the following:

- the support depth of the coating rods on the wall was made with violation of the rules of construction and installation works and was about 50 mm;
- the corrosion of structural elements (thickness of corrosion products up to 1 mm), girders and profiled flooring was detected;
- the connectors of the structural plate are supported with an eccentricity (Fig. 4); there is no connectors fixing to the support plates in accordance with the production requirements;
- deformations in and out of the cross-section plane of the girders, including deformations of the support pillars of the girders (the defect is connected with an overload of the roof structure);
- indirect signs of horizontal shift of the structure in the longitudinal direction (cracks of the internal longitudinal walls, cracks of the paint coating of the structural elements connecting at the units);
- the connectors remained after the structural plate collapse have the damage of the threaded part of the rod elements occurred during the structure operation long before the collapse (Fig. 5); it led to the removal of these elements from the design scheme when the stress-strain state changes (when the loading scheme of the structural plate changes);
- mechanical damage of the structural elements as a result of impact action on the area directly connected to the collapse area.

![Figure 3. The collapse of the Kislovodsk-type structure](image)

**Figure 3.** The collapse of the Kislovodsk-type structure

![Figure 4. SLC support unit with 8 cm eccentricity, fixing the support connectors according to the production requirements is not performed.](image)

**Figure 4.** SLC support unit with 8 cm eccentricity, fixing the support connectors according to the production requirements is not performed.

![Figure 5. Damaged connector with defects received long before the collapse.](image)

**Figure 5.** Damaged connector with defects received long before the collapse.
3. The results of numerical study of the constructions bearing capacity

Based on the survey results, the building model was made using CAD SCAD 21.1.1.1; the elements were designed according to working design standards. The loads were designed based on the opening of the coating structures made during the survey. The structure was designed for the most dangerous load combination - from the weight of load-bearing structures and roofs, snow and wind load. The results are presented as an effort and movement diagram.

The coating runs made in the form of continuous multi-span beams with support through the posts to the units of the upper part of the structure are used in the design scheme of the structure.

The layout of the structural elements is shown in figure 6, the calculation results are shown in figures 7-10.

![Figure 6. The layout of the structural elements](image)

![Figure 7. Movements of control units (vertical, Z axis) standard load component.](image)

The maximum displacement of units 91.4 mm > normalized SP-1/250 = 72 mm
**Figure 8.** Forces in the structural elements, the calculated load component, T.

**Figure 9.** The test results of the load bearing capacity of the covering runs (Kmax factor), the overload is up to 70 %
Figure 10. The test results of the load bearing capacity of structural elements (Kmax factor) for four elements, the overload is up to 300%.

The results analysis showed that the structural plate has a three times overload of 35 % of the elements (compressive stability, strength). Overloading is connected with the normative increase of the snow load in 2003 and 2016 and with the weighting of the roof structure (twice as compared to the production solution) during its repair work.

4. Conclusions
To prevent emergency situations of slipping the coating of Kislovodsk structural unit from the supports produced with hidden capital together with the weld quality provided for the production solution and also the large and widely detected movement at the column areas from the centre of the project fixing of the supporting connectors, it is recommended to perform checking calculation of connectors for current structures [17-20] and its fixing to the supporting areas stands by drilling the upper (empty) technological hole of the connector, according to the checking calculation and fixing it to the support area with a stud made of high-strength steel (Fig. 11).
a) general view; b) the option of fixing the connectors of the Kislovodsk structure to the support platform of the column using a high-strength stud; 1 – column; 2 – rod of the CLS structure; 3 – high-strength bolt (stud); 4 – washer; 5 – connector; 6 – support platform of the column.

Figure 11. Connectors of the Kislovodsk structure

For structural coating plates of various designs we recommend to:
- calculate the wind load during repairs with partially dismantled roofs for buildings with open and permanently open aperture;
- perform unscheduled survey of the Kislovodsk-type SLC runs in the months with the highest snow load (in case of a large amount of precipitation, it is necessary to perform timely mechanical cleaning of the roof from snow);

During a technical survey of the Kislovodsk-type SLC, it is recommended to include the following works in the survey program:
- the use of structural elements to the work (the lack of damage in the units);
- the control of corrosion depth of the coating structural runs;
- the control of geometric characteristics of the coating structure;
- the control of tightening special bolts of connectors.

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