Safety level assessment of frame buildings by example of NPP unit engine compartment

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Abstract. The paper considers the parameters determining issue during the frame building inspection and its safety level assessment. It was proposed to use the “synthesized” tolerance for the transverse frame of the workshop frame as an estimated value. The dimension chains well-known theory is used to determine this tolerance value. As a final characteristic of the framework technical state the safety factor is proposed to use which is determined by the limiting and current value of the "synthesized" tolerance.

Introduction
The development of any state is associated with the advanced development of its energy industry. At the present time Russia has approved the “Territorial Planning Scheme of the Russian Federation in the Field of Energy” by decree of the Government of the Russian Federation of August 1, 2016 No. 1634-p. A list of nuclear power stations planned to be placed on the territory of the Russian Federation is a part of this document (refer with Table 1).

These facilities construction is scheduled to begin in 2020, and it is expected to be completed in 2030. In addition, stations with WWER-1000 reactor which have proven to be safe during operation, but have developed a design life, are taken to extend their use by 20-30 years. Thus, the immediate prospects for the energy complex development are formulated in terms of nuclear energy, while all the previously developed safety conditions for nuclear power stations are inconspicuously observed. This complex includes monitoring works and comprehensive inspection of NPS facilities at both the construction stage, commissioning, and when they are used in the billing period. It also includes the industrial safety expertise works with the industrial safety declaration formulation for their use extension. These works are obligatory for implementation at the indicated stages of the NPS existence, on their basis, firstly, conclusions on the facilities conditions are made, secondly, measures that restore the operational suitability are being designed, and, thirdly, the safe operation conclusion is drawn for the next calculated period [1-9]. There are their general characteristics, special features and evaluation criteria for these works complexes.

The complex of monitoring works is the parameters dynamics determination of the object technical state or its individual characteristics. At the same time, depending on the determined characteristics volume (quantity), monitoring can be complex when the object technical condition...
dynamics is estimated as a whole and the certain characteristics monitoring, such as the object precipitation (uniform, uneven, etc.), object cracks, their distribution on the surfaces and their dynamic properties (development, deployment, etc.). In the general case monitoring is carried out starting from the moment of facility foundations building and it is completed as a result of the facility disposal program implementation. At all stages of existence monitoring is carried out according to the program and in accordance with the requirements of the current regulatory documentation.

Table 1. Planned nuclear power stations

| List of nuclear power stations planned for placement | Name                        | Location                                      | Station number, equipment type | Installed capacity (MWth) |
|-----------------------------------------------------|-----------------------------|-----------------------------------------------|--------------------------------|---------------------------|
| NPS -1                                              | Kola NPS -2                 | Polyarny Zori, Murmansk region               | 1 WWER -600                    | 600                       |
| NPS -2                                              | Central NPS                 | Bui, Buisky district, Kostroma region        | 1 WWER-TOI 2 WWER-TOI total    | 1250, 1250, 2500          |
| NPS -3                                              | Smolensk NPS -2             | Desnogorsk, Roslavl district, Smolensk region | 1 WWER-TOI 2 WWER-TOI total    | 1250, 1250, 2500          |
| NPS -4                                              | Nizhny Novgorod NPS         | Navashinsky municipal district, Nizhny Novgorod region | 1 WWER-TOI 2 WWER-TOI total    | 1255, 1255, 2510          |
| NPS -5                                              | Tatar NPS                   | Kamskie Polyany, Nizhnekamsk District, Republic of Tatarstan | 1 WWER-TOI                    | 1250                      |
| NPS -6                                              | Beloyarsk NPS               | Zarechny, Sverdlovsk region                  | 5 BN-1200                      | 1200                      |
| NPS -7                                              | South Ural NPS              | Chelyabinsk region                           | 1 BN-1200                      | 1200                      |
| NPS -8                                              | Seversk NPS                 | Seversk, closed territorial entity of Seversk, Tomsk region | 1 BREST-300                   | 300                       |

Inspection is a technical condition determination of the facility by comparing its actual characteristics with the permissible parameters. Depending on the scope the inspection can be complex when diagnosing the maximum achievable amount of characteristics for a given object under investigation, and technical inspection when diagnosing a limited or specific type of characteristics. The inspection is carried out starting from the construction moment and it is completed before its disposal. The inspection is implemented in the order, scope and in accordance with the methodology set out in the current regulatory documentation.

Expert examination of industrial safety is a technical condition determination of the facility with the current level assessment of safe operation, the residual life determination of its operational
properties and the decision on the possibility of using this facility for the estimated next post period.

Expert examination of industrial safety is carried out after man-made or natural events (impacts on the object) to reduce its operational suitability, or when the object reaches the standard operating life. Examination is carried out in the order, scope and in accordance with the methodology set out in the current regulatory documentation. In cases established by law according to the results of work for this facility, a declaration of industrial safety is issued.

**Justification of Proposals**

For all groups of works it is common that all information on the facility state is obtained from the results analysis of visual or instrumental inspections of buildings and structures. At the same time today in general the geometrical characteristics determined during the inspection of engineering projects are:

- $s$ - total base settlement;
- $\bar{s}$ - average base settlement;
- $s_d$ - subsidence;
- $h_{sw}$ - vertical movement of the base during the swelling (drying) of the soil;
- $s_{sf}$ - suffusion subsidence;
- $\Delta s$ - subsidence difference;
- $\Delta s/L$ - subsidence relative unevenness of the two foundations;
- $i$ - columns, buildings inclination;
- $\vartheta$ - relative twist angle;
- $f/L$ - relative deflection or bend;
- $p$ - curvature of the facility bended part;
- $u$ - horizontal displacement.

When developing programs for the buildings and structures inspection, their most informant geometric characteristics for assessing the technical condition are appointed based on the characteristics of their construction solutions. So, when examining frame-type buildings, for example, the machine rooms of nuclear power stations whose building structures are diagnosed every four years upon the demand of regulatory documents, they determine:

1. The axes offset of the column base with the building axes – $u = \pm 10$ mm;
2. Girder, with span $l$, relative vertical deflection - $f/L = l/300$;
3. Steel column inclination, with the column height - $l - Q = l/500$;
4. The difference in elevations of the upper end of adjacent steel columns in a row or in the span - $\Delta s = \pm 10$ mm.

When building NPS units, the fulfillment of the above requirements is a prerequisite for providing the construction quality. When performing controlling filming, these characteristics of building structures are determined, compared with the normatively acceptable. The information is applied to the drawn up schemes and provided for inspection and delivery of this stage of work to the customer.

It should be noted that the described characteristics are provided at the installation stage and for each building structure individually. At the stage of operation the compartment frame, its building structures work in an interconnected system. Moreover, the number of hard links in the longitudinal and transverse direction of the shop is not the same. In the longitudinal direction of the compartment, the columns of the frame are interconnected by frames with inclined links at the beginning and end of each row. In addition, crane runway beams are installed along each row for a 15-ton crane at checkpoint of 23 meters and for 125 and 200-ton cranes at checkpoint of 28 meters. In the transverse direction the columns are connected only by girder floors in each frame, see figure. Analyzing the possible deformations accumulation in this frame, we note that in the longitudinal direction the change in geometric characteristics of the frame due to the above, rigid links is unlikely. The accumulation of deformations of the geometric parameters is possible in the transverse frame. When diagnosing, it is necessary to carry out the control and measurement work in this section.
It should be noted that the regulatory requirements imposed at the stage of its construction do not characterize its technical condition at the stage of operation of the framework. Due to the fact that the transverse frame structures work as a single system, the characteristic that evaluates the technical justification should be unified and unambiguous.

**Authors’ Submitted Proposals**

We propose to use the "synthesized" tolerances to assess the frame technical condition. They can be calculated using the well-known theory of dimensional chains. At the same time, it is necessary to formulate the rule of signs, the positive direction characterizes the increase in the size of the object, the negative direction characterizes the decrease in size. For the transverse frame we have

\[
\Delta_i = B_{12} + H_1 \sin(J_1) + H_2 \sin(J_2) - b_{12}
\]  

where: \(\Delta_i\) - closing link value;  
\(B_{12}\) - transverse center distance between columns;  
\(H_1, H_2\) - column heights;  
\(J_1, J_2\) - columns inclination;  
\(b_{12}\) - longitudinal size of the frame truss.

Applying the "min-max" calculation rules of dimensional chains, using the standard permissible parameters, we obtain that the "synthesized" tolerance for the truss stable position in the transverse structure frame is equal to \(\Delta_{add}\). The maximum value of the same tolerance will be:

\[
\Delta_{limit} = \gamma \cdot \Delta_{add}
\]  

where \(\Delta_{limit}\) - limit value of the "synthesized" tolerance;  
\(\gamma\) - safety factor.  
\(\gamma = 1.5\) is adopted according to regulatory requirements for the frame building. At the same time \(K\) safety factor, which assesses the technical condition of the building frame, for example, the NPS block building is calculated [8]
\[ K = \frac{\Delta_{\text{limit}} - \Delta_i}{\Delta_{\text{limit}}}. \]  

Let us make the formula (3) analysis based on the requirements set out in [6]. So when \( \Delta_i = 0 \) then \( K_i = 1 \) which fully complies with the safety condition or the regulatory technical condition. And if \( \Delta_i = \Delta_{\text{add}} \), for example, for \( \gamma = 1.5 \) then \( K_{\text{add}} = 0.33 \), therefore with a given reliability coefficient \( 0.33 \leq K_i < 1 \), i.e. the compliance condition of the object with a functional condition is provided. In the case of \( \Delta_{\text{limit}} > \Delta_i > \Delta_{\text{add}} \) then \( 0 < K_i < 0.33 \), i.e. the condition of the object compliance with the limited-working technical condition is provided, and when \( \Delta_i \geq \Delta_{\text{limit}} \) then \( K_i \leq 0 \) is the condition of the emergency state of the object.

**Summary**

Thus, if it is necessary to assess the safety level of a frame building, the proposed method can be implemented. Besides, the implementation of this technique allows to determine the safety level at all stages of the object existence, including the stages of the work completion to restore the operational suitability of the building structures. That is, the planned safety level assessment should be achieved by implementing the projected repair and rehabilitation works. Therefore, the safety level of the operated construction facility, for example, the frame building of the NPS unit compartment should be controlled.

**References**

[1] OS SRO-C 60542960 00043 -2015 *Organization Standard. Nuclear Energy Use Facilities. Geodetic Monitoring of Buildings and Structures During Construction and Operation*, Moscow, 2015.

[2] DDD FO 1.1.2.99.0624-2011. *Guiding Document of Operating Organization (OJSC Rosenergoatom Concern), Building Structures Monitoring of Nuclear Power Stations*, Moscow, 2011.

[3] DDD FO 1.1.2.99-0007-2011. *Guiding Document of Operating Organization (OJSC Rosenergoatom Concern). Typical Operating Instructions for Industrial Buildings and Structures of Nuclear Power Stations*, Moscow, 2011.

[4] GOST P53778-2010, *Buildings and Constructions. Technical Condition Inspection and Monitoring Rules*, Moscow, Standardinform, 2010.

[5] Federal Law of July 21, 1997 No. 116-FL "Industrial Safety of Hazardous Production Facilities" (as amended, effective from July 24, 2015)

[6] Federal Law of December 30, 2009 N 384-FL “Technical Regulations on the Buildings and Structures Safety”. Adopted by the State Duma on December 23, 2009. Approved by the Federation Council on December 25, 2009.

[7] CR 52-102-2004, *CR for Design and Construction. Pre-Stressed Reinforced Concrete Structures. Approved and Recommended for Use by Letter of Gosstroy of the Russian Federation* 24.05.2004, Moscow, LB-473/9 2004.

[8] Pimshin Yu I, Zotov V D, Klyushin E B, Zayarov Yu V 2016 *On the Assessment Coefficients for the Buildings Safety*, News of Higher Educational Institutions (Geodesy and aerophotosurveying) 6 32.

[9] GOST P53778-2010, *Buildings and Constructions. Technical Condition Inspection Rules and Monitoring*, Standardinform, Moscow, 2010.