International Journal of GEOMATE, July, 2024 Vol.27, Issue 119, pp.92-99
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2024.119.4452
Geotechnique, Construction Materials and Environment

PRACTICAL EXPERIENCE OF TECHNICAL SURVEY RELIABILITY OF OVERHEAD TRANSMISSION LINE STRUCTURES

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*Corresponding Author, Received: 20 Feb. 2024, Revised: 22 May 2024, Accepted: 25 May 2024

ABSTRACT: Ensuring the reliability of the supporting structures of existing transmission lines is a key aspect of maintaining the stability and efficiency of the energy infrastructure. Various methods and technologies are used for this purpose. This study presents a methodology for comprehensively inspecting the load-bearing structures of overhead transmission lines located in the Aksu city of Pavlodar region of Kazakhstan. The survey included 2 main stages: visual and instrumental inspection up to the moment of line de-energization and inspection of all components of transmission line supports. During the design and construction, special reliability requirements were considered, such as the consideration of engineering-geological conditions when selecting a site for the construction of each support, considering the estimated climatic conditions of the region, wind speed, and the size of ice deposits. The results obtained from the inspection of all main and fastening elements of the supports' structures allowed us to assess the current state of the infrastructure and define a strategy for its maintenance and renewal. The results showed that deviations in metal profile thickness were minimal, averaging ±0.5 mm from design specifications, indicating minor structural failure. Grounding device resistance measurements varied within a narrow range of 5 to 7.45 Ohms, which met safety and operational standards, further confirming the reliability of the infrastructure. The strength of the concrete in the foundations, evaluated without failure, averaged 25 MPa, which meets Class B30 standards and indicates environmental resistance, which allowed us to conclude that further operation of transmission lines is possible.

Keywords: Transmission lines, Support structures, Steel structures, Technical survey

1. INTRODUCTION

The country's most important economic development task is creating favorable conditions for uninterrupted power supply to industrial and civil facilities. Today in developing countries there is wear and tear on power transmission line supporting structures, foundation structures, fasteners, main supporting above-ground structures, insulators, suspenders, and lightning protection ropes [1]. Numerous examples of collapse also result in the failure of power supply to industrial complexes and agricultural agglomerations [2-3].

Therefore, there is a need to clarify engineering and geological conditions, to identify the degree of change in natural and climatic conditions, which are reflected in the level of wind and snow loads and the level of icing [4-5]. It is also required to conduct a detailed engineering survey of reinforced concrete foundations, and ground steel bearing structures to clarify the degree of corrosion, damage, and reduction of bearing capacity of all structures of the considered transmission lines.

Engineering survey includes calculation and parametric analysis, considering the physical and mechanical characteristics of the material of structures according to the current normative documents on loads and impacts, steel structures [6-8]. Conventional power line inspection methods involve ground and airspace inspection [9].

Both methods typically identify the condition of power lines by using visual observation [10]. The ground inspection is conducted by a team traveling along the power line corridor on foot or by off-road vehicle [11]. This inspection has been widely used for decades because of its high accuracy, but problems including labor intensity, complicated geotechnical engineering, and weather conditions are sometimes impossible to apply.

A climbing system or an aerial system typically performs the airspace inspection. In recent years, the development of digital imaging technology has provided a new platform for power line inspection with drones [12]. The drone inspection method divides traditional inspection into two parts: data collection and data analysis.

However, both methods have their advantages and disadvantages, like as the drone method is safer, but the data obtained from both survey methods must be analyzed to determine the condition of the transmission line, and regardless of the survey method used, one of the responsible steps is to prescribe measures to eliminate faults. So, extensive investigations of eighty-two transmission lines that failed catastrophically, in the north-western part of Germany were observed [13]. It was revealed that some of the examined components were manufactured from Thomas steel which was partially in embrittled condition. The investigated lines fulfilled the design codes valid at the time of construction [13]. However, the present line loads of the wet snow rolls on the conductors exceeded by far the ones given in the design codes valid at that time.

Based on a field investigation of a damaged transmission line following Typhoon Mujigae a failure analysis was performed to estimate the load-bearing capacity of a transmission line [14]. Static nonlinear buckling and dynamic analyses were employed to assess the ultimate load capacity and the most vulnerable parts of the tower. In the dynamic analysis, a tower-line coupled model was established which accounts for members buckling capacity. Suggestions were given that the dynamic analysis should be adopted in integrally evaluating a transmission line, especially when locating the buckled member. More, emphasis should be given to the design of diagonal members.

In the work [15], a complementary method to the one prescribed by the International Standard (IEC 60826:2003) for estimating combined wind and ice loads on overhead transmission lines was proposed. The design approach in the standard is based on static loads only, which might be inadequate for certain atmospheric conditions causing significant dynamic loads. The study particularly focused on the potential development of aerodynamic instability conditions which may yield large amplitude and low-frequency cyclic motions, known as galloping.

The instability conditions were evaluated and compared based on Den Hartog’s and Nigol’s theories. The dynamic response of the system is restricted to the case of vertical galloping, and the amplitude of the vertical oscillation was computed by employing the linear theory of free vibrations of a suspended cable. Thus, assessing the technical condition of existing transmission lines remains an important issue and is an open question [16].

As Kazakhstan continues to develop its energy sector, maintaining a balanced and well-connected electrical grid will be crucial for meeting growing demand, ensuring energy security, and contributing to the country's sustainable development goals.

One of the key aspects of transmission line condition assessment is the monitoring of structural components, which is the study's focus. By demonstrating the effectiveness of comprehensive inspections and identifying correctable deviations, this study supports the introduction of detailed inspections as a standard [16].

2. RESEARCH SIGNIFICANCE

The paper surveys 601 bearing structures of overhead transmission line supports. The methodology presents a comprehensive approach including instrumental inspection and survey of all components of the supports. Important parameters such as the degree of wear and tear, detection of damage and corrosion, and assessment of the need for element replacement were determined. The methodology and results of this study have practical application, especially at the regional level with the development of specific recommendations and demonstrate the effectiveness of comprehensive inspections. The results showed the possibility of further operation and sufficient reliability of structures in case of implementation of the proposed recommendations.

3. MATERIALS AND METHODS

3.1 The Object Characterization

The Republic of Kazakhstan has backbone networks with voltages of 1150, 500, 330, 220, 110, 35, and 6-10 kV [17]. Transmission lines and distribution networks of Kazakhstan are divided into 3 parts: two in the north and one in the south, each of which is connected to the external energy system. The object of the study is the transmission line supports of Aksu city of Pavlodar region of Kazakhstan (Fig.1).

The survey was carried out over 601 transmission line supports of line No. 5537 with a length of 242 km, where 581 intermediate, 12 anchor-angle, 6 special, and 2 transposition transmission line supports are located (Figs.2,3).

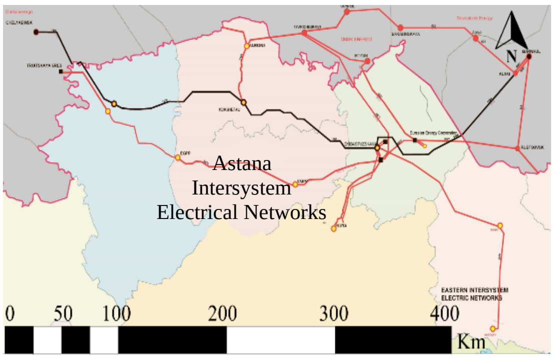

Fig.1 Map of the study is the transmission line supports

The object was started work in 1973. The climate of the Pavlodar region, where the transmission line is located, is sharply continental, characterized by a cold long winter (5.5 months) and, a hot and short summer (3 months).

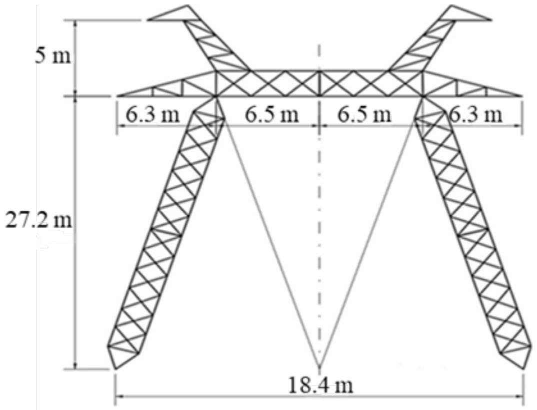

Fig. 2 Scheme of PB-3 support

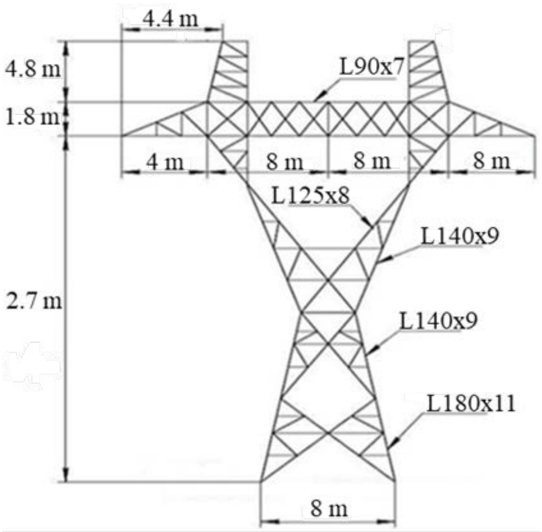

Fig.3 Diagram of supports R2+5

Physiographical and geographically, Pavlodar is located on the West Siberian Plain. In recent years, climatic conditions for the Pavlodar region have changed significantly. The air temperature fluctuates from +40°C in summer to -40°C in winter [18-19]. The maximum height of snow cover reaches 25-30 cm The diagram of wind loads in the Pavlodar region showed a difference of increase of wind load by 25% according to the data of old and new norms [20]. The engineering geological conditions of the site play an important role [21-22].

In general, engineering-geological, and climatic conditions for the long-term operation of transmission line construction facilities in the region under consideration are satisfactory due to the absence of aggressive components in the geological environment and the absence of multiple processes of freezing and thawing of moisture during the day, which affect the durability of building structures. Characterization of groundwater involves assessing its quantity, quality, flow patterns, and interactions with geological formations. The geological condition of the survey area is presented in Fig.4 [23].

Based on the field description of soils and results of laboratory tests
the assessment was made in the built-up area of the city and 4 engineering-geological elements were identified (Fig.4).

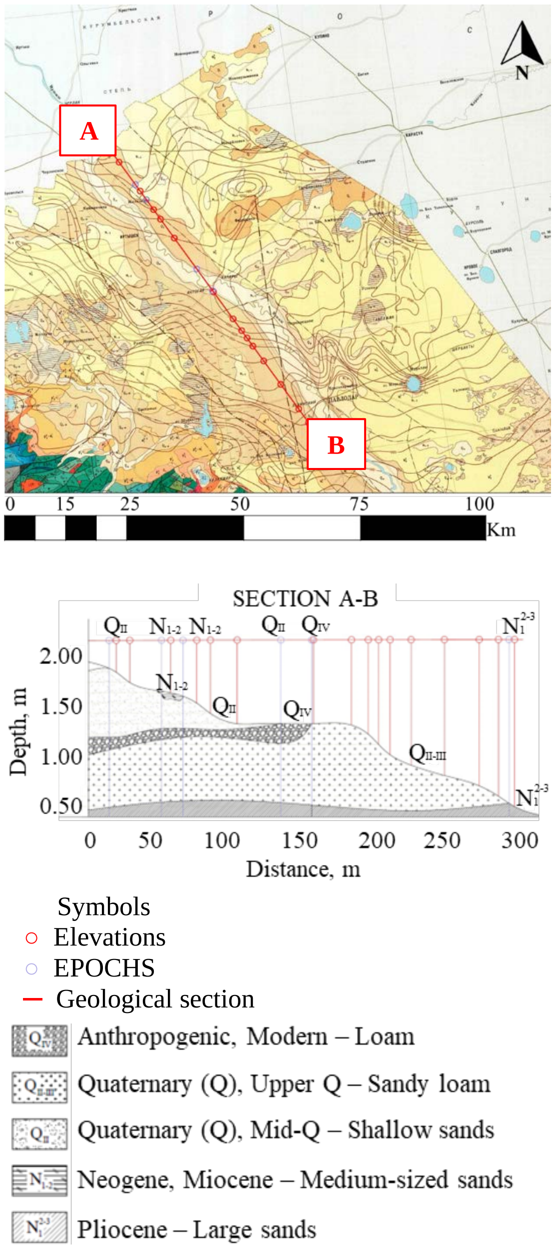

Fig.4 Engineering geological condition of investigation object

Groundwaters of over-flood terraces lie at a depth of 1 to 17 m (usually 2-5 m). In the last 25-30 years on the territory of Pavlodar region in the industrial zone of the city, there has been a systematic rise in groundwater levels. Contaminants infiltrate the subsurface, contaminating aquifers and compromising groundwater quality. Groundwater depth is 3-5 or more meters. The characteristics of the metal supports are presented in Table 1.

Table 1. Characteristics of overhead transmission line elements

The type of power transmission supports	Support type	Guy lines: Number of guy lines	Guy lines: Number of foundations	Amount of supports
Anchor-corner	U-2	—	12	6
Anchor-corner	U-2+5	—	12	4
Anchor-corner	US500-2+5	—	12	2
Transpositional	U2t+5	—	20	2
Intermediate	POUIM	4	2	142
Intermediate	PB1-3	4	2	205
Intermediate	PB-3	4	2	197
Intermediate corner	PUB-5	4	2	2
Specialized	R2+5	—	4	6
Intermediate	PS-3	4	2	34
Total				601

3.2 Technical Inspection of Overhead Line Structures

The technical survey flowchart is presented in Fig. 5. The survey was conducted in 2 stages [24]: before the moment of voltage cut-off in the line where the visual, instrumental survey of the 601 supports (2020 y.) and at the time of line de-energization where surveyed part of the foundations of line No. 5573 (2021 y.).

The technical survey of overhead transmission line facilities included: determining the actual technical state of serviceability of metal supports, foundations, and fastening units based on the results of visual inspection and instrumental measurements conducting geodetic measurements to determine the deviation values of the actual position of the support structures; fixation of defects for drawing up a statement of defects; testing the strength of concrete [25-26]; checking the quality of welds [27]; measurement of thicknesses of main profiles of supports including ultrasonic method; checking the condition of U-shaped anchor bolts.

The integration of visual inspections, instrumental measurements, geodetic assessments, defect documentation, and various testing methods collectively form a robust approach to ensuring the reliability and longevity of the overhead transmission line [28]. The geodetic measurements mentioned in the survey process play a crucial role in maintaining the structural integrity of the transmission line. Geodetic assessments provide precise information about the spatial positioning of support structures, helping identify any deviations from the intended design. These measurements contribute to the early detection of misalignments, settlements, or shifts in the supports, allowing for corrective measures to be implemented promptly.

Special vehicles KAMAZ were involved in the surveys for safety ties of the supports, where soil development was mechanized with the use of a tractor with a bucket. In addition, climbers were engaged to inspect the disconnected supports. During the inspection of the supports, a passenger car with a four-wheel drive Lada NIVA was used, as well as a set of equipment and devices for technical inspection**.**

In hard-to-reach places of access to support the inspection was carried out by a specialist on foot. This approach allowed to inspect all components. Special KAMAZ trucks and a tractor with a bucket were used to inspect the conditions of U-shaped anchor bolts.

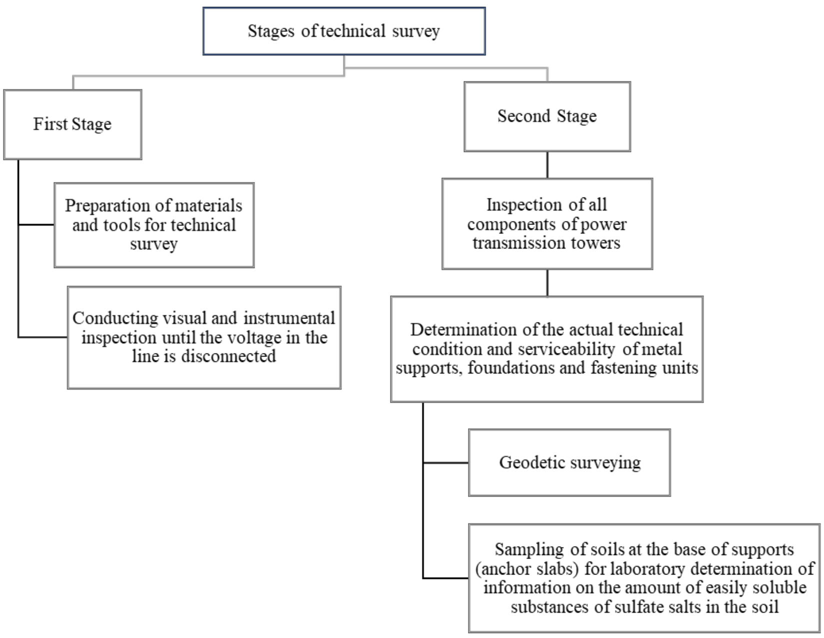

Fig.5 The technical survey flowchart

The strength of concrete in reinforced concrete foundations above the supports was checked by a non-destructive method using device IPS MG 4.03. The device operates on the principle of emitting signals, typically ultrasonic waves, into the concrete structure and measuring the velocity of these waves as they propagate through the material [29]. The density and homogeneity of the concrete directly influence the speed at which these waves travel. This non-destructive technique allows for evaluating the material's quality and strength without the need for invasive procedures, such as coring or drilling.

During the engineering inspection of metal structures, special attention was paid to geometric dimensions of the main profiles, corrosion of structures and elements, deviations of 500 kV overhead line support from vertical positions, determination of resistance of grounding elements of support structures, and quality control of welded and bolted connections.

Verification of verticality and determination of the roll of the supports were performed using a Leica TCR 407 Tacheometer in compliance with the current regulations. The Leica TCR 407 Tacheometer is a surveying instrument that combines the capabilities of a total station with those of a theodolite, enabling accurate measurements of angles, distances, and elevations. Its application in verifying the verticality and assessing the roll of supports suggests a meticulous approach to ensuring the structural integrity and safety of the constructed elements [30].

The resistance was measured with a UNI-T UT521 resistance meter. All insulating components on each support - insulating suspension, which includes insulators, pins, hooks, discharge and spark horns, and fittings (coupling supporting, tensioning, and protective) along the entire transmission line - were also checked.

4. RESULTS

The results of detected defects, deformation, damage, corrosion of concrete, and reinforcement of pylon foundations are given in Table 2. Evaluation of physical deterioration of reinforced concrete structures showed that in 60 supports on the foundations, there are insignificant weakly expressed surface shrinkage cracks with a width of opening to 1.5 mm, corrosion of reinforcement in the foundations is practically absent. In the foundations under 9 transmission line supports (less than 1.5% of all overhead transmission lines) with serial numbers of supports № 9,25,33,44,117,119,120,153,165, moderate concrete damage with a width of the opening to 2.5 mm with a depth of penetration up to 20-25 mm is observed [24]. Corrosion of the foundation reinforcement is up to 8% of the reinforcement thickness [24].

Table 2. Defects of 500 kV overhead line supports

№ support	Support foundation	Metal structure	Condition of anchor bolts and fastenings
3;4;83;91;92;93;94 100;106;144;145;150;152;154;155;157;162;167;168;170 ;177;182;215;240; 241;247; 263; 279;307;313;320;336;337;338;356	Minor defects at the foundation - weak deterioration of concrete on the ground surface.	Metal corrosion is medium, class - C3	Good condition
9;117;120;119;123 141;153;165;178	Significant foundation defects and moderate deterioration of concrete on the ground surface	Metal corrosion is medium, class C3, and there is a defective bent strut profile	Metal corrosion is high-class C4
5;281;355;357; 358;375;395;400; 406	Minor defects at the foundation - weak deterioration of concrete on the ground surface	Metal corrosion is very low, class - C1	
20;21; 27;51; 53; 201;202;209;216 217;218;219;220 221;223;225;228 265;266;267;268 269;270;271	Minor defects at the foundation - weak deterioration of concrete on the ground surface.	Metal corrosion is low, class - C2	Good condition
25	Significant defects at the foundation - moderate deterioration of the concrete at the ground surface.	Metal corrosion is high, class-C4	
33	Significant defects at the foundation - moderate deterioration of concrete on the ground surface. on one outermost support	Metal corrosion is low, class-C1	
44	Significant defects at the foundation - moderate deterioration of the concrete at the ground surface.	Metal corrosion is low, class-C2	
122;140; 156	Foundation defect - severe deterioration of concrete on the surface	Metal corrosion is medium class - C3	

Severe damage is observed in the foundation of transmission line support No. 140. Non-compliance with support deviations from the vertical position exceeding the normative indicators is given in Table 3.

Table 3. Verification results of verticality and roll of overhead transmission line structures

Support No.	Support coordinates	Support height in the Baltic Sea H, m	Linear vertical mapping		Side vertical mapping		Total vertical deviation ∑ δ, m
			Height of supports h, m	Deviation δ, m	Height of supports h, m	Deviation δ, m	
35	N 52°12.441' E 076°45.357'	119	29.197	0.081 to «E»	31.855	0.398 to «S»	0.240 to «SE»
61	N 52°17.161' E 076°42.646'	117	28.680	0.314 to «W»	32.048	0.272 to «S»	0.293 to «SW»
170	N 52°38.938' E 076°26.270'	113	29.262	0.068 to «E»	32.553	0.341 to «N»	0.201 to «NE»

Thus, supports No. 35, 61, and 170 showed non-compliance with the normative requirements of standard [31], while the remaining 601 supports comply with the requirements. Checking the strength of concrete by non-destructive method showed the average compressive strength of concrete in the foundations is 25 MPa, which corresponds to class B30 (Table 4).

Table 4. Results of concrete strength testing and measurement of U-shaped anchor bolts

Support №	Opening side	Strength of concrete, MPa	Loop size, mm		Size of U-shaped anchor bolts, mm	
			right	left	right	left
35	South	23.6	49	49	42	23.6
67		24.1	46	46	41	24.1
72		29.1	54	54	41	29.1
77		69.6	55	55	42	69.6
83		73.2	54	54	41	73.2
88		32.9	46	46	41	32.9
92		35.2	53	54	41	35.2
97		56.6	45	45	41	56.6
102		85.0	54	54	41	85.0
108		53.0	46	46	41	53.0
112		71.0	54	54	42	71.0
117		27.3	45	45	41	27.3
121		74.3	46	46	41	74.3

A survey of the transmission lines showed: that the geometric dimensions of the main and connecting elements corresponded to the design dimensions; 3 supports (№35,61 and №170) out of 601 transmission line supports had deviations insignificantly exceeding (up to 20%) the maximum permissible vertical, which can be eliminated in the working order; cross-sections of metal profiles had a deviation from the design on average ±0.5 mm [31] (Table 5); measured resistance values of grounding devices varied in the range from 5 Ohm (support No. 57) to 7.45 Ohm (supports No. 461 and No. 591) (Table 6).

Table 5. Measurement results of metal sections of support structures

Support type	Physical dimensions of the main load-bearing profiles of the belts	Profile thickness of metal foundation plates, mm	Physical dimensions of the main supporting profiles of the braces	Difference in profile measurements, mm	Amount
U-2	L160x160x10	14 – 18	L70x70x6	± 0.45	33;279, 307;329, 356;565
U-2+5	L180x180x11	19 - 20	L70x70x6	± 0.45	1;8;44;45
US500-2+5	L180x180x12	14 - 18	L60x60x5	± 0.45	12;13
U2t+5	L160x160x10	14 - 18	L70x70x6	± 0.45	221;451
POUIM	L90x90x8		L40x40x4	± 0.5	31;32; 34-43; 46-60;62-66; 230-261; 295-306;308-328; 330-338; 362-374; 457-479;
PB1 - 3	L90x90x8		L40x40x4	± 0.5	61;280-294; 339-355; 357-361; 375-421; 480-564;566-600
PB-3	L90x90x8		L40x40x4	± 0.5	2;3;11. 14-30;67-118; ПО- 169; 171-220; 222-229; 262- 278
PUB-5	L100x100x8	12	L40x40x4	± 1.25	119; 170
R2+5	L200x200x12		L140x140x9	± 0.35	4;5;6;7; 9;10
	L90x90x7		L40x40x4	± 0.35	422-450; 452-456

Table 6. Resistance results of grounding devices

Support №	Support type	Current resistance values in Ohms in 200Ω values
1	U2	23.4
3	R2+5	22.9
57	POUIM	20.4
395	PB1-3 bolted	29.3
461	POUIM	29.8
591	PB-3	29.8
601	PB-3	21.5

A diagram of the measurement results and identified deviations in percentages is presented in the following Fig. 6.

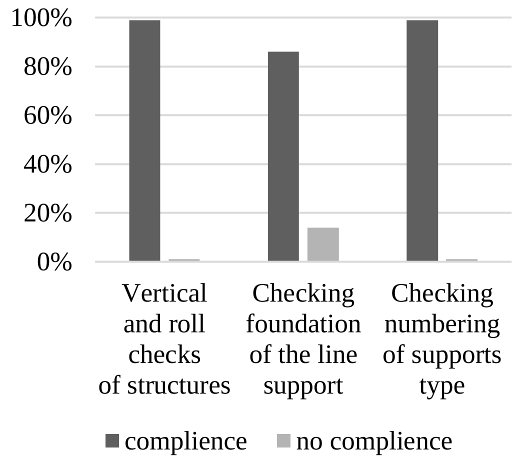

Fig.6 Results of measurement

5. CONCLUSION

To successfully upgrade the energy infrastructure, a set of engineering and technical measures must be carried out. This includes audit and diagnostics - conducting thorough inspections of existing high-voltage networks to identify areas with the greatest wear and tear. As a result of the comprehensive in-situ inspections of overhead transmission line facility structures, it was recommended to eliminate all defects, deformations, damages, and corrosion in the load-bearing elements of foundations and supports specified in the tables. The survey showed the deviations amounted to 1% in the verticality check and determination of the roll of the structures and checking the numbering of the support type, and 14% in checking the foundation of the line support. So, the results of the comprehensive survey of 601 supports showed the high quality of the initial design and construction considering the engineering-geological and climatic conditions of the region.

On metal structures, a solution has been proposed:

- supports that have been excessively deformed from the vertical position should be put back into the design position;
- bolts that have failed due to mechanical damage and excessive corrosion should be replaced, and bolts with minor damage and corrosion should be cleaned and coated with anticorrosion protection;
- corroded metal structures of bearing supports should be clean;
- replace grounding devices.

The conducted complex of multifactor inspections and calculations of overhead transmission line supports has shown that at the elimination of the noted defects, deformations, damages, and excessive corrosion, it is possible to replace the steel gas tether of TK-11 type with a gas tether with built-in fiber-optic cable.

In the future, during the operation of overhead power lines of 500 kV it is necessary to carry out:
annual technical inspection of the main supporting structures of the transmission line by the economic entity's forces and current repair of supports according to the schedule approved by the organization; at least every 5 years it is necessary to carry out a detailed comprehensive inspection of the entire line with the involvement of specialized organizations.

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