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Steel crosspieces for medium voltage lines on spun concrete poles

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Abstract

The subject of the article is a natural-scale study of a steel crosspiece for a flat system of phase conductors in a sheath with a cross section of 120 mm^2 in a single-circuit medium voltage power line 15 and 20 kV with a span length of 90 m and the line bend angle of 1780. The crosspiece was mounted on a straight-line pole made of a prestressed concrete column E12/12. During the tests, the method of attaching the crosspiece to the power spun pole and its actual deformation and strength characteristics were checked. The test program was carried out by performing two different load tests (test 1 and 2 depending on the loads acting on the pole and the crosspiece), and then, after test 2, the load was incrementally added until failure.

1. Introduction

1.1. Crosspieces and cable systems on poles

As they are easy to manufacture, they are light and can be installed in a fairly straightforward manner on medium and high voltage overhead power lines, galvanized steel crosspieces are normally used in Poland, which made of rolled sections or bent sheets (Łodo and Michałek (2016)). They are attached to posts with the use of clamps and bolts.
The durability of this type of structure is 50 years in an environment with moderate corrosion load (Kim and Kim (2018)). In an industrial environment, the lifetime of galvanized steel structures is reduced. Additionally, the structures of power poles, being tall structures, are exposed to wind and dust (Souza et al. (2021)) as well as ultraviolet radiation. It entails the need for periodic inspections and maintenance of steel structures.
The use of concrete crosspieces is obviously not a panacea for all possible problems, but it can be a cheaper solution in the long run (mainly due to the fact that they do not need to be inspected or maintained). Reinforced concrete spun poles with reinforced concrete crosspieces observed (Michałek (2016)) in western and northern Poland from the beginning of the 20th century are still used in overhead power lines, thus confirming their durability for over 50 years. Positive features of concrete crosspieces have been noticed in many European countries (Kudzys (1975), Bascsa Kliukas et al. (2017)) and in the USA (Rodgers (1984), Fouad and Detwiler (2012)), in which concrete crosspieces are standard technical solutions. More and more frequently, due to the risks related to corrosion of reinforced concrete elements subjected to environmental influences (Lushnikova and Tamrazyan (2018), Tamrazyan et al. (2020)), resulting in the loss of reinforcement adhesion, glass or carbon fibre composites are applied in the production of crosspieces (Grzybowski and Disyadej (2008), Selvaraj et al. (2013)).
Depending on the rated voltage of the power line, the arrangement of wires on poles can be different. In the case of low voltage (LV) lines, an alternating system and a flat system (single and multi-level) of cables are used, with the protective (PE), protective-neutral (PEN), neutral (N) or street lighting cables at the lowest position. In medium voltage (MV) lines, the most common are the flat system (Fig.1) and the triangular system (in the form of an isosceles or even equilateral triangle, Fig.2); occasionally, the vertical or close to vertical system is applied.

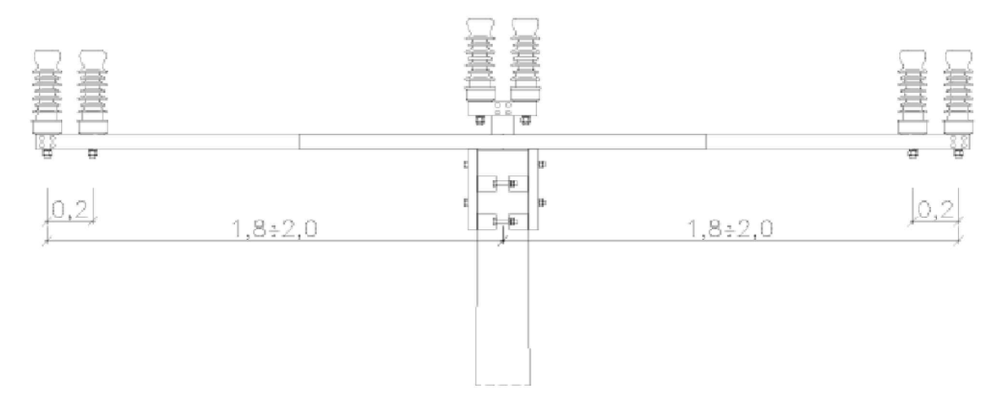

Fig. 1. Flat system of cables in single-circuit medium voltage lines

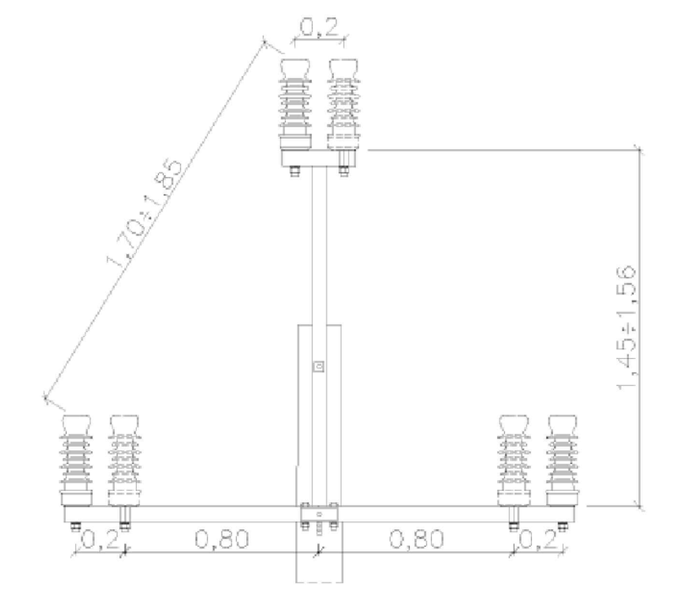

Fig. 2. Triangular systems of cables in single-circuit medium voltage lines

In the flat configuration, the central conductor is often placed asymmetrically in order to avoid the top of the column extending above the crosspiece. This results in electrical asymmetry, which is unfavourable for the line's operation. The arrangement based on an equilateral triangle provides favourable electrical symmetry. Flat systems are advantageous for two reasons: they require lower poles and provide access to each cable directly from the bottom, which is important for assembly, inspection and repair.

Cables are attached to crosspieces mounted on poles. There are two basic types of cable attachments: suspension clamps and tension clamps (Mendera et al. (2012)). In special cases, when a line crosses or approaches various objects, safe suspension clamps and safe tension clamps are applied as well, whose task is to prevent a conductor from falling down if it breaks near the insulator. Suspension clamps are used when the tension force does not act on an insulator or a chain of insulators, or when this force is negligibly small. This type of suspension is installed on poles in such a way that in the event of a significant longitudinal force (e.g. when a cable breaks and the line pole could damage as a result),the cable moves at the suspension point or slips out of the holder. The tension clamp is used to absorb the force along the lines caused by unbalanced tensions. It is also used to attach conductors on bends in the line. The tension clamp breaks the continuity of a line, and current bridges need to be made.
The geometry of the crosspieces for basic cable systems (flat and triangular) is shown as an example in Fig.1 and Fig.2; it depends upon:
– the rated line voltage (for LV lines: 400 and 230 V, for MV lines: 6÷20 kV),
– the type of pole in a line (suspension, corner, tension, end, branch),
– the material the pole is made of (wood, steel, reinforced concrete, prestressed concrete),
– the type of operating cable (in LV lines: bare Al aluminium cables with cross-sections: 16, 25, 35, 50, 70 and 95 mm^2 and insulated conductors in the form of a self-supporting bundle of insulated aluminium lines; in MV lines: steel-aluminium AFL lines with a ratio of aluminium cross-section to the steel core cross-section of 6:1 or 8:1, e.g. AFL-6-35 mm^2, AFL-6-50 mm^2, AFL-6-70 mm^2),
– the length of span (for LV lines: up to 55 m, for MV lines: 120÷200 m),
– insulation gaps (distances of cables from the ground and obstacles between cables and particular line elements on poles, Fig.1 and Fig.2),
– restrictions (additional requirements for cables, insulators, poles, suspension of cables and their fastening depending on the importance of the object which the power line crosses or approaches).

1.2. Prestressed concrete power poles made of spun concrete

In overhead power lines, various types of supporting structures (poles) and crosspieces are used, to which conductors with insulators are attached. In low voltage (LV) lines, concrete poles (reinforced concrete or prestressed concrete E poles made of spun concrete) are most often used with a vertical arrangement of conductors or, occasionally, with the flat arrangement of conductors on crosspieces. In single-circuit medium voltage (MV) lines, mainly E-type prestressed spun poles with a flat (Fig.1) or triangular (Fig.2) arrangement of conductors are used (Kubiak et al. (2001,2004)). Concrete spinning technology has been used in Europe for more than 110 years (Foerster (1912)). The spun reinforced concrete poles made in the early 20th century by the Dywidag company in Coswig near Dresden are still in use in medium-voltage lines in northern and western Poland.
In the case of prestressed spun concrete poles, the trade symbols E stands for its purpose (electric, power supply). The numerical part in front of the slash shows the length of the column L [m], and after the slash comes the value of the rated apical force Pk [kN] for the load factor $\gamma_f = 1.3$. The nominal peak force Pk is defined as the equivalent characteristic (utility) force applied at a distance of 0.20 m from the peak. The manufacture of spun rods in non longitudinally opened conical molds is carried out on semi-automatic production lines (Bascsa (1981), Rodgers Kubiak et al. (2015), Empelmann and Remitz (2018)). E-type poles with lengths of 9.0÷18.0 m (with 1.5 m gradation) and peak forces of 2.5÷35.0 kN are produced in non-dismountable forms (Fig.3). Power columns for the highest voltage lines with lengths of 12÷21 m (with 3.0 m gradation) and peak forces of 30÷50 kN (Michałek (2020)), as well as columns for the construction of advertising towers and mobile telephony are produced in longitudinally dismountable forms (Łodo et al. (2016); they are also produced for small wind farms (Michałek (2020)).
Type E prestressed-concrete spun poles are made of C40/50 class concrete. They are longitudinally reinforced with prestressing ties made of profiled wire ∅7.5 mm marked Y1670C (active reinforcement) and ribbed bars made of ordinary steel with a characteristic yield strength $f_{yk} \geq 500$ MPa (passive reinforcement in partly prestressed poles). Transverse reinforcement (helix) is made of smooth wire with a diameter of 3.5 mm and a $f_{yk} \geq 500$ MPa. Type E prestressed concrete power poles are manufactured in accordance with the EN12843:2008 standard and marked with the CE symbol.

Type E power poles are fixed in the ground in accordance with the general principles of geotechnical design (EN1997-1:2008), depending on the ground conditions in the place of foundation. Type E columns for small peak forces $P_k \leq 4.3$ kN (Kubiak et al. (2014)) can be embedded directly in the ground in a drilled hole (∅0.5÷0.8 m) or in a dug hole made using traditional methods to a depth of A = 0.2 L (L – total length of the pole). In the case of strong soil (non-watered gravel and sand), it is enough to fill the space between the column and the ground with non-cohesive native soil, compacted every 0.2÷0.3 m layer, or with sand. In the case of medium-strength soils, the trench should be covered with sand or gravel compacted as above. In weak soils, cement-stabilized sand should be applied (equivalent to sand concrete class C12/15), or stabilizing slabs according to a separate design should be used.
For columns with peak forces $P_k > 4.3$ kN, block concrete or reinforced concrete foundations (monolithic or prefabricated from stabilizing slabs (Kubiak et al. (2014))) can be used. The use of a specific type of foundation should be preceded by an appropriate static and strength analysis (EN1997-1:2008); also, by technological and economic analysis, and possibly by testing the lateral load capacity of poles in the foundation (Rybak (2017)).

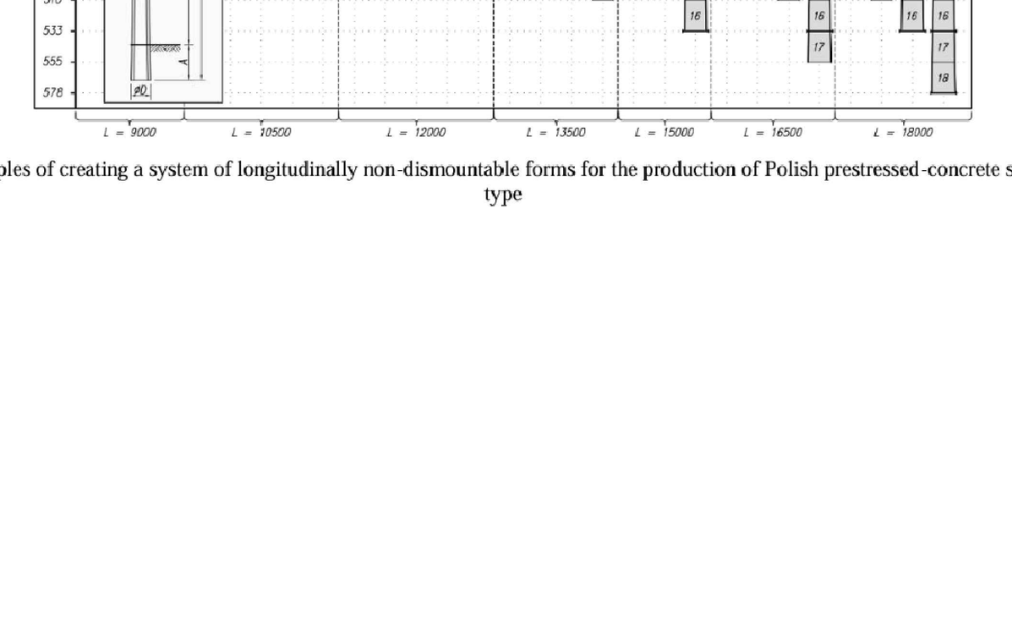

Fig. 3. Principles of creating a system of longitudinally non-dismountable forms for the production of Polish prestressed-concrete spun poles E-type

2. Materials and methods

2.1. Crosspiece of a suspension pole

The subject of the research is a suspension pole made of an E12/12 prestressed concrete column and a steel crosspiece for a flat system of phase conductors in a sheath with a cross-section of 120 mm^2 in a single-circuit power line of medium voltage 15 and 20 kV with a span length of 90 m and a bend angle of 178°. The line was designed for all climatic zones, i.e. W1÷W3 wind load, S1÷S3 icing load according to the standard (PN-EN 50341-2-22:2016-04) and in the pollution zone I÷III according to the standard (PN-E-06303:1998). The aim of the research was to check the method of mounting and the actual deformability and strength characteristics of the steel crosspiece for medium voltage lines attached to a E12/12 power spun pole.

The suspension pole crosspiece to be tested (Fig.4) consists of two independent parts: the mounting holder (1) to be attached to the spun concrete column (2) and the crosspiece (3). The main elements are made of hot-rolled steel sections. The holders (1) fastening the crosspiece (2) have flat steel bars with oval holes in them (4) welded to these holders for mounting the crosspiece. The holders are connected to the pole by means of two M20 bolts inserted through the top holes in the pole located 170 mm from the top of the pole, and again 600 mm below the first bolts. The crosspiece (3) is attached to the mounting holder with two M16 bolts. Standing insulators are fixed to the crosspiece (3) at its ends and in the middle, with the use of M20 bolts, which during the tests were replaced with pipes (5), 60 mm in diameter and 300 mm in height. The crosspiece between insulators is reinforced with ties (6). The crosspiece extends 600 mm on both sides of the pole.

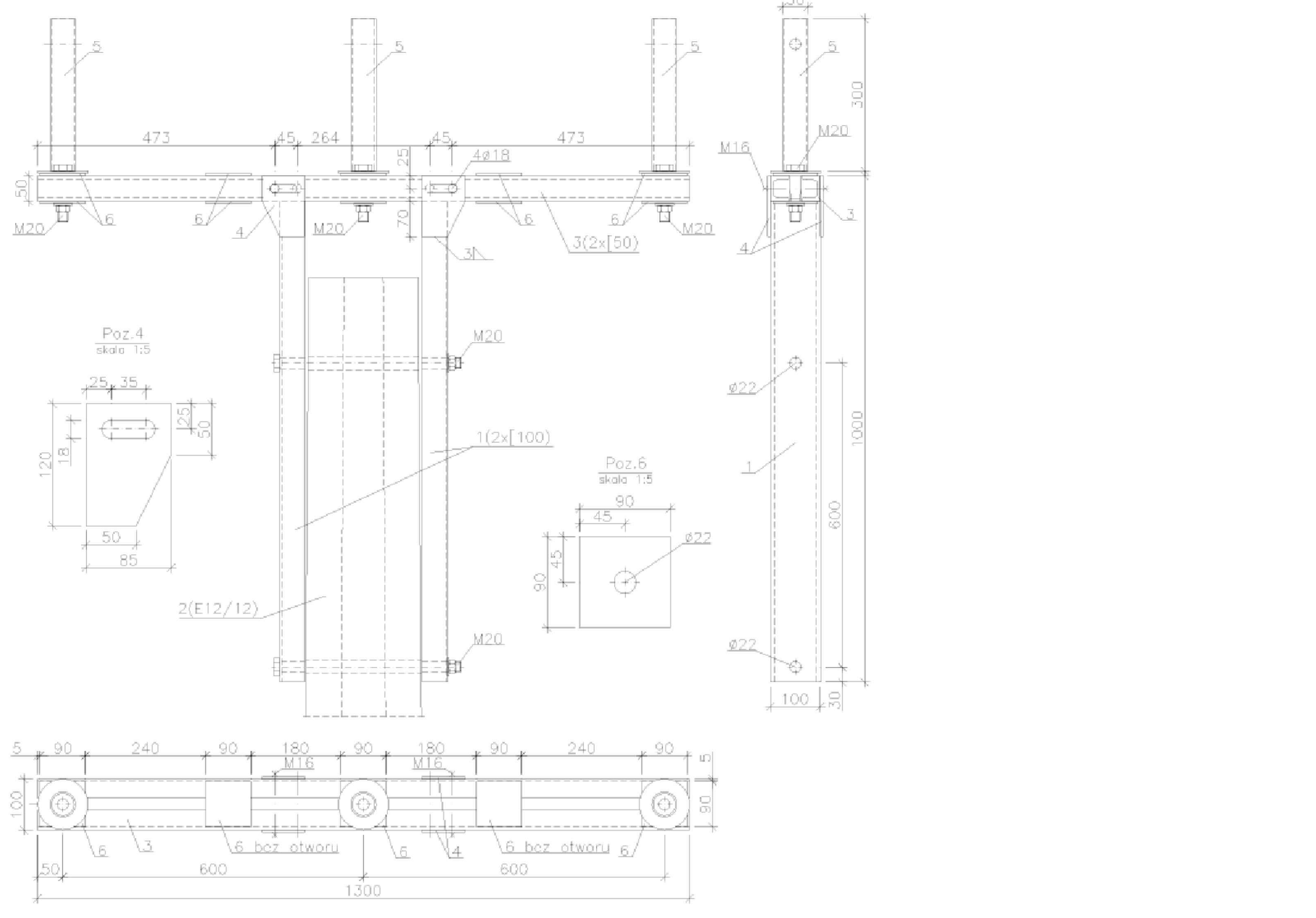

Fig. 4. Steel crosspiece of an extension pole

2.2. The test stand and the method of loading

The testing of the connection between a E12/12 pole and its crosspiece was carried out on a special test stand that allowed for loading poles in horizontal position. The test stand of a E12/12 suspension pole with a crosspiece mounted upon it consists of two steel supports (holders, Fig. 5a) anchored in the channels of the reinforced concrete floor in the laboratory hall. The holders are placed at a distance of b = 1.8 m. The third (sliding) support, which allows to reduce the influence of own weight on the test result, is a trolley supporting the pole in approximately one third of its length from the top (Fig. 5b).

The loading was carried out by means of steel tie-rod mounted at the top of the pipes imitating insulators, tied together in a steel T-bar ensuring the same load for each insulator and a rope pulled through a pulley and attached to the hook of the crane's electric tow (Fig. 6a and 6b). A strain gauge was mounted in the rope.
During the tests of the crosspiece mounted on the E12/12 spun pole, measurements were made of the displacements of the crosspiece's ends in the loading plane in relation to the pole, as well as the displacements of the pole itself at the bottom and at the top. Measurements were carried out with the use of inductive sensors. After completing the tests on the crosspiece, steel samples were taken in order to test the basic mechanical properties of the material.

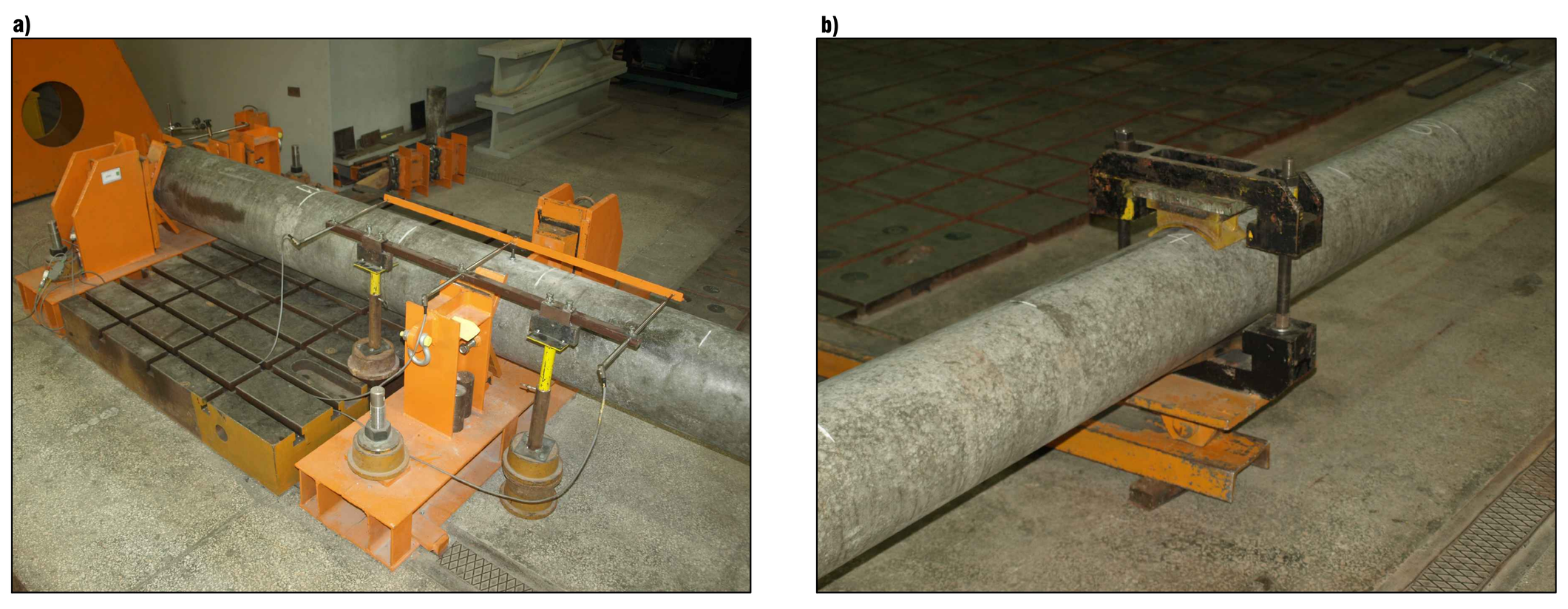

Fig.5. E12 /12 spun column on the test stand: a) view of the pole base mounting zone, b) sliding support reducing the impact of the pole's own weight on the test result

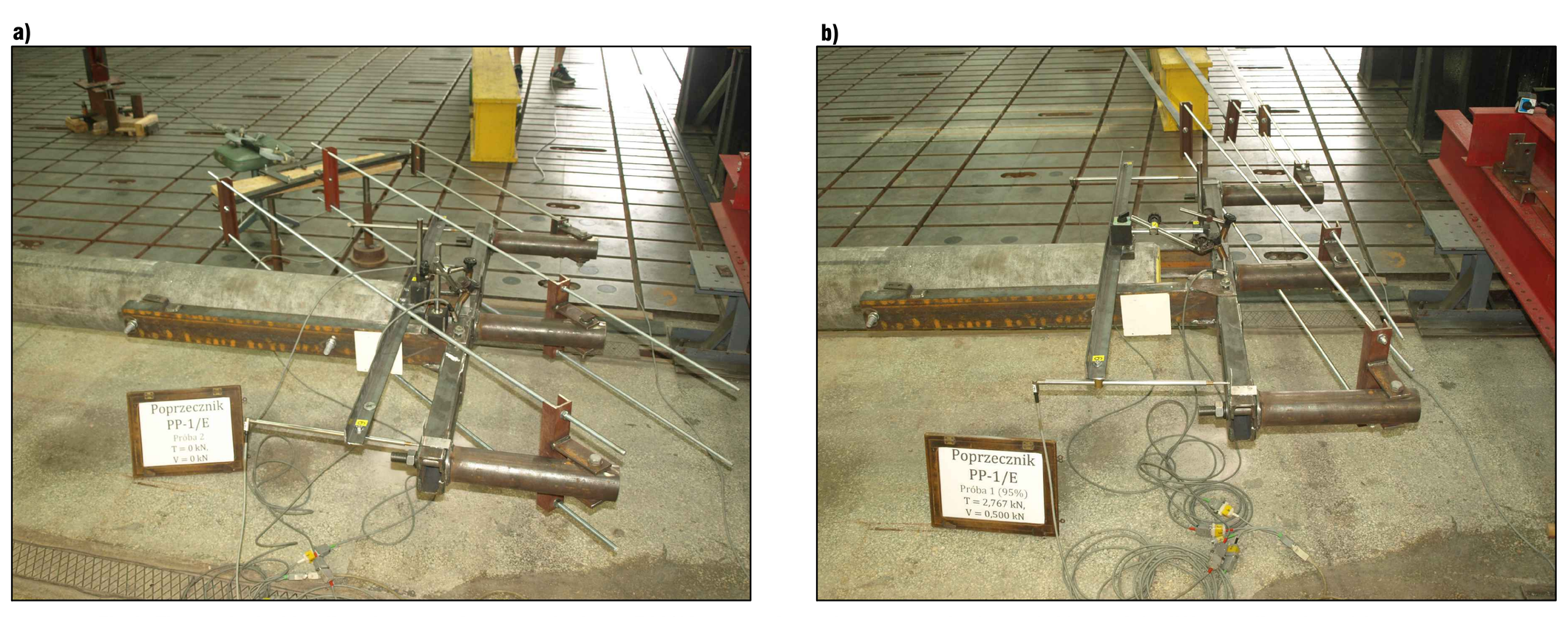

Fig.6. The method of loading the crosspiece attached to a E12/12 spun pole on the test stand: a) test 1, b) test 2 (a different direction of forces acting on insulators in this test compared to test 1 is visible)

The test program was carried out by performing two load tests (test 1 and 2), and then, after test 2, the load was added incrementally until failure. The load in test 1 (Fig. 6a) included the forces from resultant tensions at +100C and the load from the wind acting perpendicular to the power line, as well as the dead weight of the cables, insulation and structure. In test 1, the maximum calculated horizontal and vertical load (Fig.7) on each insulator on the crosspiece was respectively T = 2.913 kN and V = 0.526 kN (resultant P = 2.960 kN).
The load in test 2 (Fig. 6b) included the forces from the resultant tensions at -50C in conditions of extreme icing and the load from the wind acting perpendicular to the power line on the ice-covered conductors, as well as the dead weight of the conductors, insulation, structure and icing. The maximum calculated horizontal and vertical load (Fig.7) on each insulator on the crosspiece in this test was respectively T = 4.098 kN and V = 4.453 kN (resultant P = 6.05 kN).
The test results were considered positive if, during all tests, the crosspiece structure withstood the load of 100% of all the designed loads for at least 1 minute without being damaged.

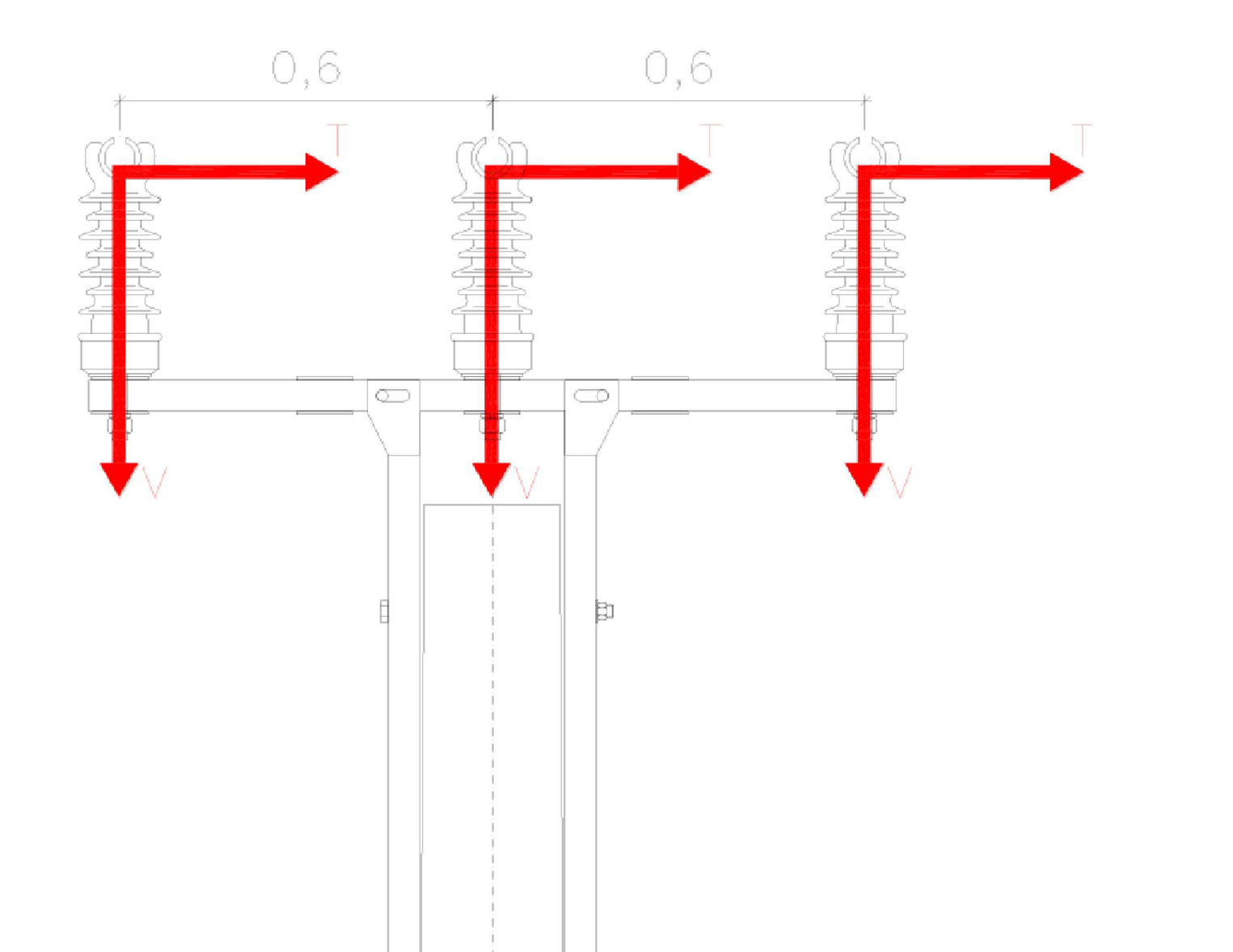

Fig. 7. Diagram depicting forces acting on each of the insulators attached to the crosspiece

3. Results and discussion

During tests 1 and 2, the load was applied to the top of the pipes (Fig. 6a, b) imitating standing insulators, fastened with M20 bolts in the middle and at the ends of the crosspiece. In test 1, after reaching the level of 100% of the calculated loads (P = 2.960 kN), the forces were maintained for 5 minutes, and then the maximum calculated loads were increased by 5%. After measuring the displacements, the crosspiece was completely unloaded. After test 1, permanent shifts of the crosspiece elements were found in the openings in the places of susceptible bolted joints (Fig.8), especially where the holders are attached to the pole and where the crossbar is attached to the above-mentioned mounting holders.

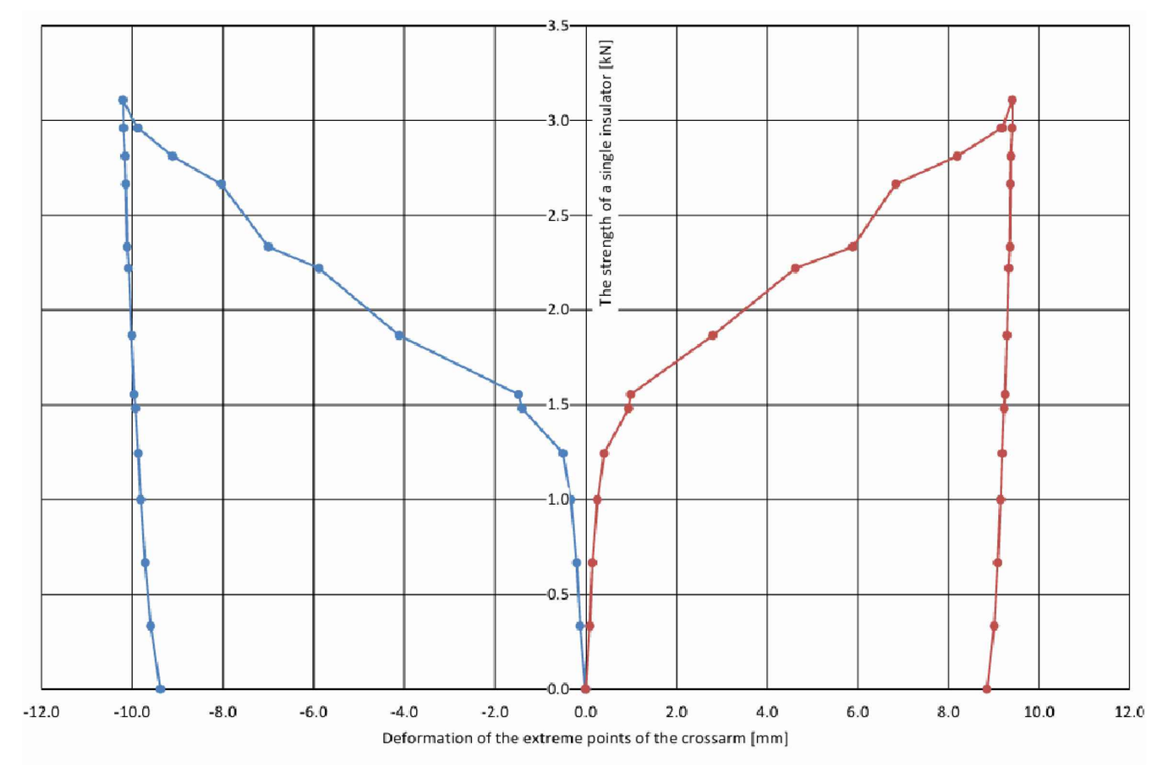

Fig. 8. Deformations of the extreme points of the crosspiece in relation to the column during test 1

The crosspiece in test 1 behaved correctly and transferred loads greater by 5% (T = 3.059 kN and V = 0.552 kN) than the maximum values of the design loads. There were no permanent deformations or damage to the crosspiece elements and its connectors. Therefore, the test result of the crosspiece in test 1 should be considered positive.
Loading in test 2 was carried out without disassembling the crosspiece after test 1. After the maximum values of the calculated loads were obtained (resultant P = 6.05 kN), the forces were maintained for 5 minutes, and then the load was incrementally increased, each time by 5% above the maximum calculated loads until destruction (Fig.9).
In test 2, the crosspiece burdened with the maximum load equal to 100% of the design loads (T = 4.098 kN, V = 4.453 kN) behaved correctly. No permanent deformations or damage to its elements or its connectors were observed. No further displacements (unlike in test 1) were observed in the holes in the places of bolted joints. Therefore, the result of test 2 on the crosspiece should be considered positive.

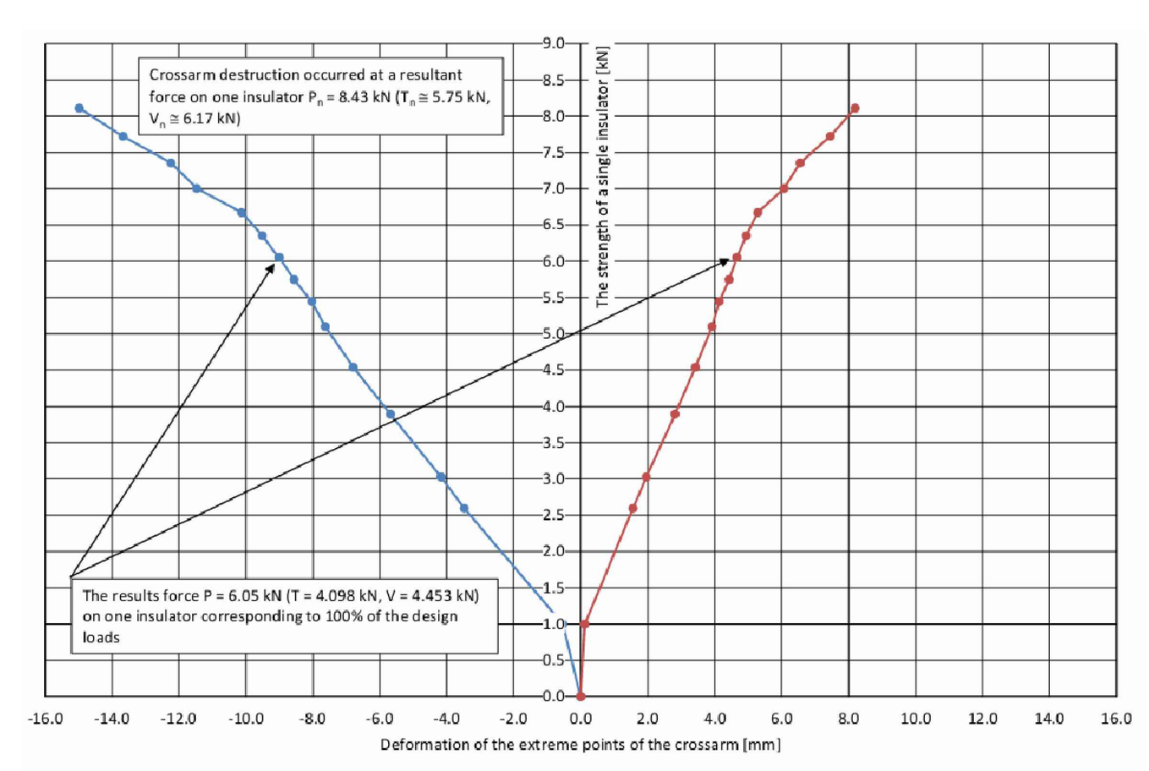

Fig. 9. Deformations of the extreme points of the crosspiece in relation to the pole during test 2

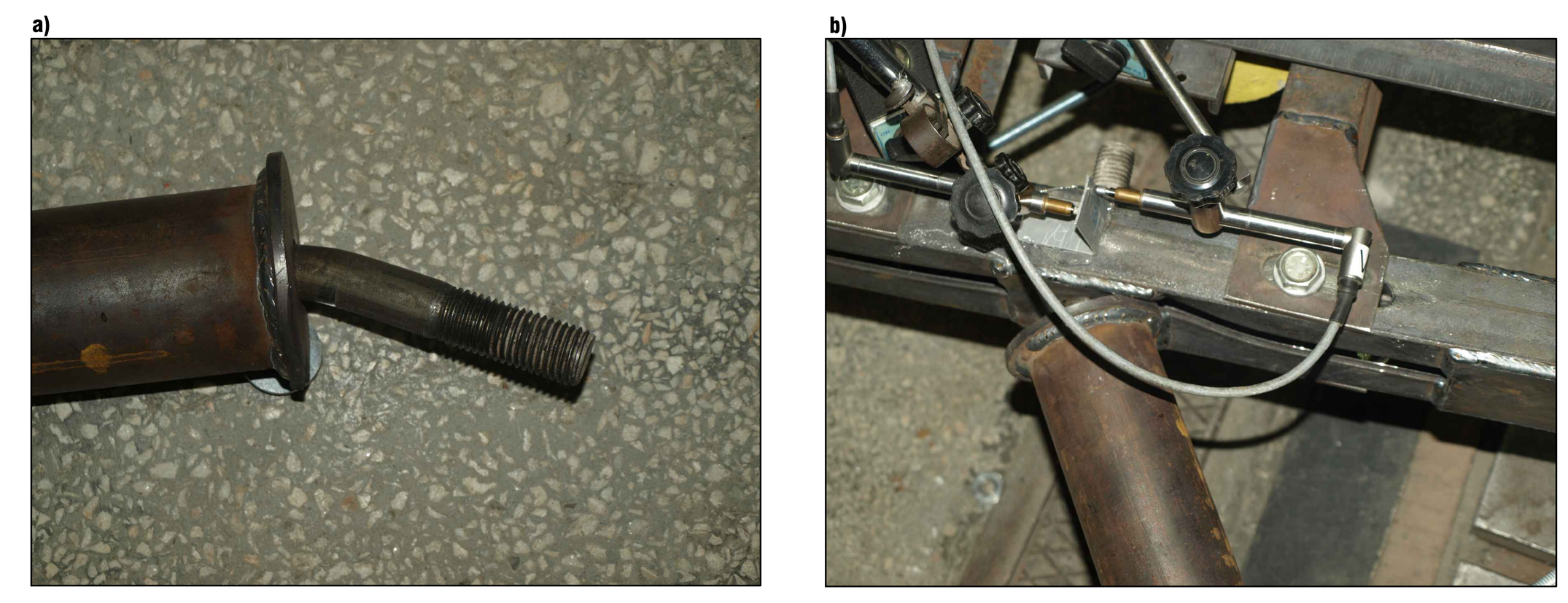

Fig.10. Destruction of the crosspiece in test 2: a) plasticization of channel bars of the crosspiece where the imitation central insulator is attached, b)plastically bent M20 bolt used to fasten the imitation insulator to the crosspiece

The crosspiece was destroyed with the resultant force per one insulator $P_n = 8.43$ kN ($T_n = 5.75$ kN, $V_n = 6.17$ kN) as a result of bolt M20 plasticization, the bolt being used to fasten the pipe imitating the central insulator (Fig.9, 10b). In the aftermath, elements of the crosspiece were permanently deformed in that place (Fig. 10a). The resultant destructive force per one insulator $P_n = 8.43$ kN ($T_n = 5.75$ kN, $V_n = 6.17$ kN) is 39.3% greater than the maximum calculated force P = 6.05 kN (T = 4.098 kN, V = 4.453 kN).

4. Conclusion

The crosspiece of the suspension pole was subjected to two load tests. The load in test 1 included the forces from the resultant tensions at +10°C in addition to the load from the wind acting perpendicular to the power line, as well as the dead weight of the wires, insulation and the structure. The load in test 2 included the forces from the resultant tensions at -5°C in conditions of extreme icing in addition to the load from the wind acting perpendicular to the power line on the icy wires, as well as the dead weight of the wires, insulation, structure and icing.
The crosspiece of the suspension pole with the maximum load equal to 100% of the design loads for the tests 1 and 2 behaved correctly. No permanent deformations or damage to the crosspiece elements and its connectors were observed. It is recommended that, in the future, crosspieces should be fastened to poles E12/12 with M24 bolts; alternatively, appropriate sleeves should be used for mounting holes ∅26 mm in the pole in order to stiffen the connection and limit possible permanent displacement of the crosspiece elements in the places of bolted connections.
MV insulators play a key role in power grids. They provide electrical insulation of conductors from support structures. In addition to their insulating properties, insulators must be able to withstand the tensile force of the conductor and the additional loads of rime, ice or wind. In the study in question, the actual standing insulators attached at the ends and in the middle of the crossbar were replaced by steel pipes with a diameter of 60 mm and a height of 300 mm (with a load capacity far greater than the actual insulator). The crosspiece (analyzed in the article) was destroyed with the resultant force per one insulator $P_n = 8.43$ kN, as a result of M20 bolt plasticization; the bolt was used to fasten the pipe imitating the central insulator; In the aftermath, elements of the crosspiece were permanently deformed in that place (Fig.10). The resultant destructive force obtained per one insulator $P_n = 8.43$ kN ($T_n = 5.75$ kN, $V_n = 6.17$ kN) is 39.3% greater than the maximum permissible, calculated force P = 6.05 kN (T = 4.098 kN, V = 4.453 kN) specified in the test programme. Based on the results of strength tests of the crosspieces of the suspension pole, it is stated that the crosspieces researched herein fully meet the requirements set for them, and can be safely used in overhead power lines of medium voltage.

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