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# Prestressed concrete railway traction poles mounted on prefabricated piles


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## Abstract

The main railway lines in Poland are being modernized in order to reach European standards and ensure the interoperability of the Polish railway network in the trans-European conventional rail system. Modernization is also subject to electric traction, which are part of traction poles. The article presents prestressed ETG traction poles (from abbr. PL Elektroenergetyczny słup Trakcyjny z Głowicą stalową = Electric power traction pole with steel head) for the construction of individual railway and tram support structures on pile foundations. Historical background of implementation of prestressed concrete traction poles in Poland, design assumptions and selected results of experimental research are discussed. The stages of production of prestressed concrete ETG traction poles are also presented.


## 1. Introduction

### 1.1. Parameters of prestressed concrete railroad traction poles

Currently in Poland the traction network for train speeds up to 200 km/h is suspended on individual support structures made of reinforced concrete or steel. From the point of view of their functions, anchor, cross and through poles are distinguished on the route. Among the reinforced concrete traction poles (Table 1 – Kubiak et al. (2010)) there are STŻ I-beams (used since the mid-1960s as STŻ through poles) and rectangular ŻK (used since the 1970s as through, cross and anchor poles with the possibility of running non-traction lines on them). The technical condition of the reinforced concrete and steel supporting structures of the traction network is mostly unsatisfactory (Kubiak et al. (2013)). In 1996, pre-stressed spun concrete poles of the ET and ETG types appeared on the railway market for the first time. Currently, the main railway lines in Poland are being modernised in order to achieve European standards and ensure the interoperability of the Polish rail network in the trans-European high-speed and conventional rail system (Żurkowski (2018)).

Table 1. Characteristics of reinforced concrete ŻK and STŻ traction poles (Kubiak et al. (2010))

| Type of data | | | Pole type: rectangular ŻK 1 | rectangular ŻK 2 | rectangular ŻK 3 | I-section STŻ |
|---|---|---|---|---|---|---|
| Application | | | through-pole | cross-pole | anchor-pole | through-pole |
| Pole dimensions | length | mm | | 9500 | | 8750 |
| | cross-section at the base a × b | | | 450 × 210 | | 385 × 210 |
| | cross-section at the top c × d | | | 180 × 210 | | 175 × 210 |
| Steel wear | longitudinal steel | kg | 80.3 | 128.2 | 166.0 | 91.0 |
| | transverse steel | | 5.7 | 10.0 | 8.8 | 11.0 |
| Pole mass | | | | 1570 | | 965 |
| $M_{Rd}$ moments | fixing in the foundation | kNm | 69.08 | 106.16 | 139.95 | 70.54 |
| | at the boom attachment point | | 35.12 | 53.97 | 47.74 | 22.33 |

These pre-stressed concrete ETG railway traction poles, with a standard length of 8.2 m, manufactured using the concrete centrifugation method. Among the ETG type poles, there are three basic varieties: ETG-1, ETG-2 and ETG-3, and an additional reinforced type ETG-4, resulting from the different function of the pole in the tension section. ETG traction poles are designed to be fixed on driven reinforced concrete pile foundations using typical bolted connections used in railroads for steel poles (Fig.1).


Fig.1. Detail of the connection of the head of the ETG prestressed concrete pole with the foundation pile

In the trade symbols of traction poles, the letter part ETG indicates the type of pole (from abbr. PL Elektroenergetyczny słup Trakcyjny z Głowicą stalową = Electric power traction pole with steel head), and the digital part after the dash – the load-bearing function of the pole in the tension section (1 – through pole, 2 – cross and central anchoring pole, 3 and 4 – anchor pole). The rated apex force Pk (Table 2) is defined as the equivalent characteristic force applied at a distance of 0.2 m from the top of the pole.

Table 2. Dimensions and load capacity of ETG-1; ETG-2; ETG 3 and ETG-4 spun poles

| Type of data | | | | ETG-1 | ETG-2 | ETG-3 | ETG-4 |
|---|---|---|---|---|---|---|---|
| Length of the concrete part of the pole L | | | | 8200 | | | |
| Pole dimensions [mm] | top | diameter | $d_w$ | 177 | 233 | | |
| | | wall thickness | $t_w$ | 60 | 65 | | |
| | base | diameter | $d_p$ | 300 | 356 | | |
| | | wall thickness | $t_p$ | 75 | 80 | 85 | |
| Head dimensions [mm] | head size $A_1 \times B_1 \times g$ | | | 440 × 320 × 35 | 505× 365× 35 | 555 × 375× 35 | 555 × 375× 40 |
| | spacing of mounting holes $A_2 \times B_2$ | | | 320 × 190 | 385× 225 | 435 × 255 | 435 × 255 |
| | diameter of the mounting holes in the head | | | ∅43 | ∅49 | ∅55 | ∅55 |
| | thread of mounting screws | | | M30 | M36 | M42 | M42 |
| head weight $G_g$ [kg] | | | | 35.0 | 44.6 | 49.2 | 55.6 |
| Equivalent vertex force | nominal $P_k$ [kN] | | | 7.0 | 11.0 | 12.5 | 15.0 |
| | real $P_{k,rz}$ [kN] | | | 7.0 | 11.2 | 12.6 | 15.2 |
| | destructive (theoretical) $P_{n,t}$ [kN] | | | 12.6 | 20.2 | 22.7 | 27.4 |
| Load capacity $M_{Rd}$ [kNm] at the attachment point | | | | 73.735 | 116.973 | 131.923 | 158.099 |

The external conical shape of the poles increases in the direction of the root with a constant taper of 15 mm/1 m. The hole inside the pole was used to pass the 120 $mm^2$ AFL stiffening wire, which was connected to the head in the lower part. There are ∅13 mm holes in the head for connecting an external ground wire. ETG poles are equipped with M8 threaded sleeves for mounting track axis adjustment marks. The 50-year durability of ETG poles is ensured by a concrete class of at least C40/50 and a 25 mm cover of prestressing wires and rods of longitudinal ordinary reinforcement (Michałek and Łodo (2017)).

ETG traction poles are longitudinally reinforced with prestressing tendons (active reinforcement) and ribbed bars made of ordinary steel (passive reinforcement) evenly distributed around the circumference. The poles are provided with prestressing reinforcement in the form of ∅7.5 mm profiled wires made of Y1670C steel and reduced relaxation to 2%. The initial prestressing force in the tendon was assumed to be equal to $P_0$ = 51.67 kN. In the prestressed concrete traction poles in question, the concept of passive anchoring in the steel head of cold-upset prestressing wires (at the base of the pole) was combined with traditional adhesion anchoring (at the top of the pole), using technological Gifford jaw clamps (Dolan and Hamilton (2019), Tagowski et al. (2017), Bujňáková, P., (2020)). Upset tie rod heads are hidden in the head in ∅7.7 / ∅12 mm holes and must be permanently protected against corrosion (the holes after tensioning the strings should be plugged with epoxy resin and plastic, brass or lead plugs). The connection of the prestressed concrete part of the pole with the steel head is reinforced with ordinary steel rods screwed into the blind holes in the steel head with a characteristic yield strength of $f_{yk}$ = 500 MPa. The transverse reinforcement of the columns is made of ∅3.5 mm smooth wire with $f_{yk}$ = 500 MPa.

### 1.2. Fabrication of prestressed concrete railway traction poles

IETG prestressed concrete poles are manufactured on semi-automatic production lines in the technology of concrete spinning in self-supporting forms that do not open longitudinally (Kubiak et al. (2015)). The production process begins with the preparation of steel heads (Fig. 2), upsetting of prestressing wires and construction of a reinforcing cage on reinforcement needles (Fig. 3).

Then the finished reinforcement cage is placed in a steel form (Fig. 4). A bundle of prestressing wires is stretched on one side from the top side of the column. The wires upset at the ends are anchored in the steel head of the column (passive side) and at the top in the technological head of the mould using Gifford jaw clamps (Fig. 5). The concrete mixture is fed into the mould by a pneumatic pump (Fig. 6). As a result of the process of spinning the concrete mixture on a roller centrifuge (Fig. 7), the concrete mass is evenly distributed and vented, and then drained.

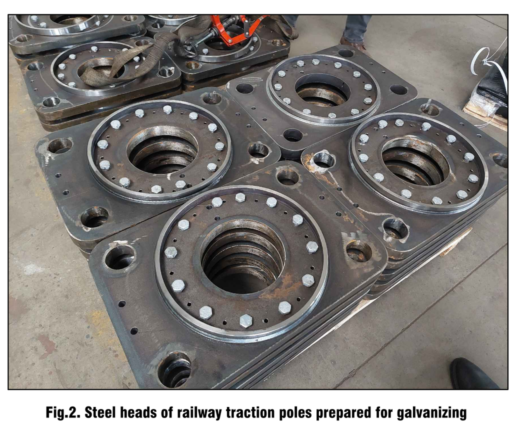

Fig.2. Steel heads of railway traction poles prepared for galvanizing

Fig.3. Construction of a reinforcement cage; phase 1 - moving the upset tendons through the head

After pouring the lime laitance from the spun concrete, the mould is moved by an overhead crane directly to the brewing chamber (Fig. 8). Steam is fed into the chambers gradually after about 4 hours from the concrete swirl (the temperature increase should not be greater than 10°C / 1 h). The temperature in the chambers ranges from 60 ÷ 70°C. The time of thermal treatment of concrete is 6 ÷ 8 h; then the steam supply to the chamber is turned off in order to naturally cool the molds to a temperature below 40°C.

Fig.4. Placement of the reinforcement cage inside the steel mold

Fig.5. Technological jaw anchorages at the top of a pole

Fig.6. Introduction of the concrete mixture into the mold

Fig.7. A concrete mould filled with a concrete mixture in a roller centrifuge

Fig.8. Mould with a column in the brewing chamber


Fig.9. ETG poles in the landfill

Releasing the technological tension of the tendons and prestressing the pole (partial pushing out) and then pulling it out of the mould takes place after the concrete has reached about 70% of its 28-day strength. Partial pushing of the pole out of the mold is one of the most difficult activities in the production of spun pole in molds that are not opened longitudinally, because when cutting the tendons and pushing out the poles, damage to the concrete at the top of the element may occur (Trapko and Michałek (2012), Kliukas et al. (2017)). Marking, export and storage of finished products (Fig. 9) completes the production cycle.

## 2. Materials and methods

The bending test of prestressed concrete traction poles was carried out at the Wrocław University of Science and Technology on a special test stand allowing for the execution of pole loads in a horizontal position (Fig. 10). The pole test stand consists of two steel supports (handles) anchored in the channels of the reinforced concrete floor of the laboratory hall. These handles are located at a distance of 1.0 m from the head of the pile foundation and 0.2 m from its base. A prestressed concrete ETG traction pole of the type consistent with the type of pile is attached to the foundation. The third (sliding) support, which allows to reduce the impact of the ETG poles own weight on the test result, is a support trolley at a distance of about L/3 from the top. The horizontal vertex force P is realized by means of a rope pulled through a pulley and hooked to the hook of the crane electric hoist. A strain gauge force gauge is installed in the rope.

Fig.10. ETG traction pole on the test stand

Fig.11. Fastening of the ETG-3 pole to the pile foundation with measuring instrumentation

During the tests, the deflection of the pole was controlled with a rangefinder, the structure of cracks at subsequent load levels was observed and the width of their opening was measured. Measurements were made on an ongoing basis with inductive sensors of the deformations of the pile foundation at the supports and the connection of the pole head with the foundation (Fig. 11). The pole loads (elastic test and bending test) were carried out in accordance with the guidelines of the standards (PN-B-03265:1987 and EN 12843:2008) and shown in Fig.12 for ETG-2 and ETG-3 poles.

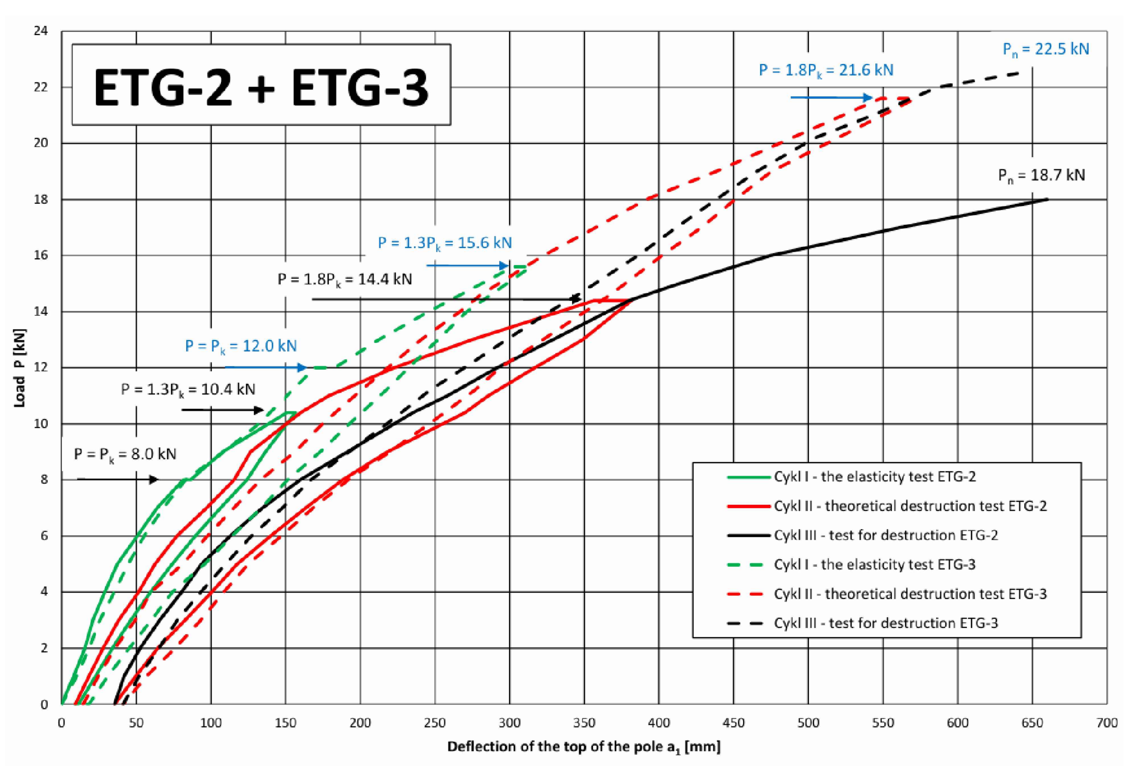


Fig.12. Deflection: $a_1$ [mm] of the top of the ETG-2 and ETG-3 poles depending on the value of force P [kN]

## 3. Results and discussion

The basic results of the tests of the deformability and strength characteristics of the tested poles and comparative indices are presented in Table 3. Strength tests of ETG traction poles in the so-called elasticity test (load up to the active force $P_k$ and overload by 30% in relation to this force) showed (Table 3) very good elastic properties of the poles (atrw / a(1,3$P_k$) < 0,1) and appropriate bending stiffness (Fig.12) of ETG-1 through poles ($a_1(P_k) < a_{lim}$ = 248 mm) and strong ETG-2 and ETG-3 poles ($a_1(P_k) < a_{lim}$ = 164 mm).

In Table 3, on the basis of a special opinion (Michałek and Łodo (2019), the equivalent apex forces Pkz calculated for the maximum characteristic moments from short-term loads in restraint were determined, for which, according to the standard (ZN-89/MTZiŁ-CBP-11), the deflection condition $a_2 < a_{2lim}$ = 60 mm measured at the contact wire level (level +5.60 m above the rail head, i.e. at a distance of about 6.14 m from the base) should be met. The deflections a2 of the tested ETG poles caused by the forces of $P_{kz}$ (Table 2) do not exceed the value of $a_{2lim}$ = 60 mm recognized in accordance with the standard (ZN-89/MTZiŁ-CBP-11) as acceptable.

In the tested ETG traction poles, it was found that the condition of the limit state of opening of perpendicular cracks $w(P_k) < w_{lim}$ = 0.1 mm under the payload $P_k$ was met (the condition $w_{lim}$ = 0.1 mm according to the PN B 03265:1987 standard is sharper than $w_{lim}$ = 0.2 mm according to the EN 1992-1-1:2008 standard). Condition $w_{lim}$ = 0.2 mm is permitted for the exposure environment class of rods XC4 and XF2 assuming no scratches within the tendons.

Table 3. Results of bending tests of ETG-1, ETG-2 and ETG-3 traction poles

| L.p. | Pole type | $P_k$ [kN] | $P_{cr}$ [kN] | $P_n$ [kN] | $a(P_k)$ [mm] | $a(1,3P_k)$ [mm] | $a_{trw}$ [mm] | $a_n$ [mm] | $w(P_k)$ [mm] | $s=P_n/P_k$ | $a_{trw}/a(1,3P_k)$ | $P_{kz}$ [kN] | → $a_2$ [mm] | Place and description of the destruction |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | ETG-1 | 6,4 | 6,4* | 14,4 | 181,9 | 301,7 | 18,4 | 947,7 | < 0,1 | **2,25** | 0,061 | 2,4 | 27 | Crushing of concrete in the compression zone at the steel head |
| 2 | ETG-2 | 8,0 | 9,0* | 18,7 | 81,6 | 150,9 | 9,1 | 659,9 | - | **2,34** | 0,060 | 3,6 | 19 | Crushing of concrete in the compression zone at a distance of approx. 6 m from the top** |
| 3 | ETG-3 | 12,0 | 8,0* | 22,5 | 159,9 | 264,3 | 14,4 | 586,4 | < 0,1 | **1,88** | 0,054 | 5,9 | 38 | Crushing of concrete in the compression zone at the steel head |

$P_k$, $P_{cr}$, $P_n$ – appropriately usable, drawing and destructive vertex force;
$a(P_k)$, $a(1,3P_k)$ – deflection of the top of a pole rigidly fixed in the foundation due to the vertex force respectively $P_k$ i 1,3 $P_k$,
$a_{trw}$ – permanent deflection of the pole after the elasticity test, $a_n$ – maximum deflection of the pole loaded with a destructive force $P_n$,
$w(P_k)$ – width of crack opening when pole is loaded with force $P_k$,
$P_{kz} \to a_2$ – vertex force $P_{kz}$ and the corresponding deflection $a_2$ at contact wire level (according to the standard ZN-89/MTZiŁ-CBP-11: $a_2 \le a_{2lim}$ = 60 mm)
Requirements according to the standard PN-B-03265:1987: $a(P_k) \le a_{lim}$, for poles: throughs $a_{lim}$ = 8200 / 33 = 248 mm, strengths $a_{lim}$ = 8200 / 50 = 164 mm,
$s = P_n/P_k \ge s_{min}$ = 1,8 – certainty coefficient for destruction,
$a_{trw}/a(1,3P_k) < 0,1$ – permanent deflection $a_{trw}$ should not exceed 0.1 total deflection $a(1,3P_k)$ in the elasticity test according to the standard PN-B-03265:1987,
$w(P_k) \le 0,1$ mm – crack opening width in a partially prestressed rod loaded with a usable (vertex) force $P_k$.
Requirements according to the standard EN-1992-1-1:2008: $w(P_k) \le 0,2$ mm – permissible crack opening width for elements in the XC4 and XF2 environment
* the value of the $P_{cr}$ force was determined on the basis of the first crack noticed by the naked eye,
** the ETG-2 pole was destroyed at the point where some of the bars of the ordinary reinforcement ended.

To assess the resistance of the ETG poles to failure while bending, the global certainty coefficient for destruction $s_n = P_n / P_k \ge s_{min}$ = 1.8 was used, expressing the ratio of the apex failure force $P_n$ to the vertex force $P_k$. The tested poles were characterized by the global certainty coefficient for destruction while bending sn above the minimum value (Table 3). Thus, the condition of the limit state of the bending resistance has been fulfilled.

The reason for the failure of the tested ETG poles while bending was the achievement of the compressive strength fcm by the concrete. Fig.13a shows the damaged ETG-3 pole with the force $P_n$ = 22.5 kN from the tensile side. Ordinary steel in this zone has plasticized, as evidenced by the observed scratches in the concrete. With further loading, the bars of ordinary steel broke (Fig.13b). The prestressing wires did not break along the length of the failure zone or in the area of upsetting (head).

Due to the required high level of safety of ETG traction pole structures, the tests described in the article should be repeated periodically. More extensive control of the behavior of foundation piles in terms of durability after driving into the ground and work under load is also needed (work is being carried out). It also seems necessary to analyze the pole-foundation pile connection itself (especially in terms of fatigue).

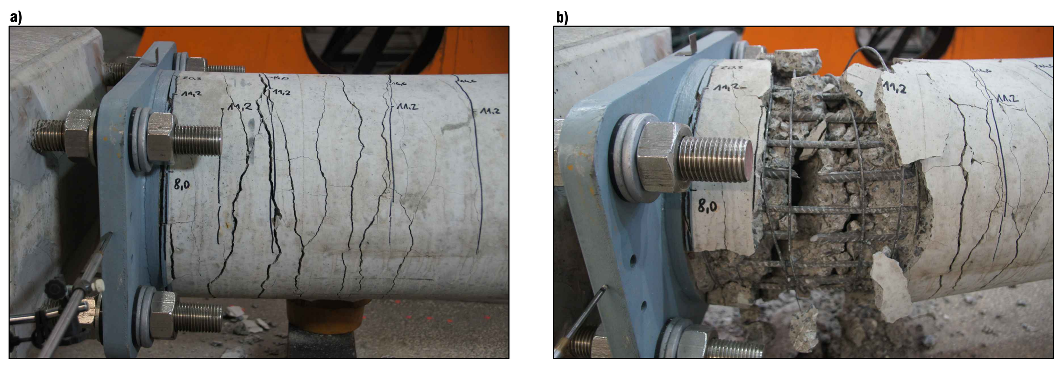


Fig.13. ETG-3 pole destroyed while bending: a) view of the tensioned concrete zone of the pole, b) broken bars of ordinary reinforcement on the tension side when the pole is further loaded

## 4. Conclusion

ETG poles are an interesting example of a prestressed concrete structure, in which mechanical, passive anchoring of prestressing wires in the steel head is used at the same time by heading (upsetting) and on the top side of the pole classic adhesion anchoring of wires with the use of technological jaw anchorages. In addition, it is interesting to use the concrete spinning technology to compact the concrete mix in self-supporting forms that are not opened longitudinally.

As a result, a prestressed concrete precast element is obtained in the form of a truncated cone with an annular cross section with a top outer diameter increasing in the direction of the base with a constant taper of 15 mm/1 m. The ETG poles obtained in production are characterized by easy and quick assembly on typical reinforced concrete piles used on Polish railways, long service life without maintenance, streamlined shape reducing noise caused by air turbulence during the passage of the train, easy assembly of equipment with clamps and the possibility of suspending non-traction lines.

The experimental tests confirmed the positive behavior of ETG poles in the so-called elasticity test (load up to the active force Pk and overload by 30% in relation to this force) and showed good elastic properties of the poles and their appropriate bending stiffness. The serviceability limit state requirements for cracking and deflection at contact wire level have also been met. The condition of the limit state of the bending resistance has also been met. ETG poles were deteriorating as a result of crushing the concrete in the compression zone. During the destruction, the bars made of ordinary steel were plasticized and then broken. The prestressing wires did not break along the length of the failure zone, nor in the area of upsetting (head) in the steel head. Thus, it was confirmed that the use of a headed anchorage of prestressing wires in the steel head in ETG poles is a good solution.

The pre-tensioned, spun traction poles, used for the first time in Poland over 25 years ago, have confirmed their very good functional and operational characteristics. Currently, they can be successfully used in modernized railway and tram lines as maintenance-free elements during the 30- or 50-year service life (depending on the thickness of the reinforcement cover used).

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