Concrete prestressed poles in the high voltage lines

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Abstract: In the paper the structure of Polish post-tensioned concrete poles used in 1950s and 60s for construction of overhead power lines of 110 kV voltage was described. Short description of precast concrete columns and their foundations are given with respect to technical solutions and durability. The conclusions drawn from long-term exploitation and maintenance were given on the basis of actual and contemporary Codes of Practice. On the background of these solutions modern post-tensioned spun concrete poles were presented as attractive alternative in terms of their economical efficiency.

1. Introduction – electrical power cable concrete poles

In high voltage lines 110 kV and higher, steel poles in the form of spatial trusses are mainly used as support structures. An alternative to these constructions are currently steel tubular and prestressed concrete columns made of spun concrete [1-5]. A common feature of these constructions is their annular cross-section.

In Poland, the first constructions of prestressed power columns with an annular cross-section appeared in the mid-1950s [6]. On the initiative of prof. T. Kluza then developed a design for a three-segment cable concrete pole with a length of L=18 m. Column segments with a length of 6.0 m were made in demountable forms. Cable ducts were formed with the help of bars pulled out of concrete.

The elliptical annular cross-section of the cable concrete column in the lower part had dimensions in the ellipse axes 0.70 m and 0.40 m, respectively. The wall thickness of the column cross-section on the small axis of the ellipse was only 45 mm. Perimeter reinforcement of the column was a spiral of Ø4.5 mm plain wire compacted at the ends of the segments. Normal longitudinal reinforcement was intended only for assembly loads. The segments were prestressed at the construction site with six cables consisting of 8Ø5 mm wire bundles (2 cables along the length of the two bottom segments) and 6Ø5 mm (4 cables along the entire length of the pole). The cable was tensioned using a TK-6 press, using Freyssinet type steel conical anchorages. Cable ducts were injected with cement paste.

The first MV (medium voltage) power lines on the cable concrete poles designed in this way were put into operation in the years 1955-56 (in total about 600 poles were built [6]). After several years of column operation, vertical scratches were noted in the middle and buttress segments along the wall with a thickness of 45 mm. Studies have shown [6] that the direct cause of the cracks were thermal and technological stresses when pulling steel cores forming an annular cross-section. The scratches increased over time due to the uneven heating of the concrete surface and over the years turned into cracks in which corrosion of the transverse reinforcement occurred.

The first solutions of L=18.0 m cable concrete poles used in MV lines became an impetus for the development and implementation of two types of cable concrete poles L=21.80 m and 21.45 m at the
beginning of the 1960s at the Institute of Building Technology in Warsaw (figure 1) for 110 kV high voltage monorail lines with AFL 120 or 185 mm\(^2\) working cables and 50 mm\(^2\) FL lightning conductor. These columns are designed for spans with a length of 250÷275 m [6]. Columns were designed comprehensively, including girders and crossbars (figure 1).

**Figure 1.** Polish cable concrete poles from the 1960s:

a) through, b) strong (resistant and corner-proof)

Cable-through concrete posts (figure 1a) for 110 kV lines had a structure similar to columns in medium voltage lines L=18 m. Due to higher horizontal loads in 110 kV lines and greater height of the pole shaft, 4 cables 8Ø5 mm were used for prestressing mm along the entire pole height and 2 cables of 10Ø5 mm grade II or 8Ø5 mm grade I along the length of the two lower segments. The cross-members of the through columns were designed from prestressed concrete boards with a cross-section of 4×23 and 4×28 cm, which were prestressed with Ø2.5 mm wires with \( f_{pk} = 2100 \text{ MPa} \). The segments of the pole shaft and plank boards are made of concrete brand R\(_w\) 500 (current class C35/45).

The reinforced concrete shaft of the strong pole had an annular cross-section with variable diameter of the circle (figure 1b) and a constant wall thickness of 8 cm. Three pole segments with a length of 7.0 m (bottom and middle) and 7.45 m (top) were prestressed on the site 6 m with 10Ø5 mm steel cables of grade I (4 cables ran through the entire length of the pole, and 2 cables only through middle and bottom segment). Due to the fear of destruction of the strong column with a torsional moment, individual column segments were reinforced with a bidirectional spiral.

Strong pole crossbars (figure 1b) were made of four elements with an inverted channel section. Each branch of the cross member was prestressed with two 12Ø5 mm cables passing through the pole shaft. In this way, the crossbars formed a rigid structure with a pole shaft capable of transmitting torsional moments caused by unsymmetrical tension of the wires.

About 100 km of high voltage lines have been made on the cable concrete poles described above. These poles were operated without any maintenance for about 40 years. Due to the small cover of
transversal reinforcement (it was smaller than 20 mm) and the low yield strength of the steel winding, numerous damage occurred in the form of longitudinal cracks, whose genesis was similar to that of L=18 m columns. Damaged cable concrete columns are replaced with new ones - including prestressed concrete from spun concrete.

2. Precast concrete columns

Precast concrete poles made of spun concrete began to be used in high-voltage power lines as early as the 1960s. Precursors in their use were the countries of the former Soviet Union [7] as well as West Germany and the USA [1,8]. The Russians started the production of spun prestressed poles with cylindrical and conical cross-section over the length of the elements. The smallest element length was 20.0 m for cylindrical columns and 22.6 m for conical columns. The maximum lengths of these columns were 26.4 and 26.0 m, respectively [7]. The columns were designed as one-piece for implementation in longitudinally dismantled forms.

For the construction of new and reconstruction of existing 110 kV high voltage lines, national pre-tensioned concrete columns (one- and two-segment) made of spun concrete, designed for embedding in socket foundations or for connection with block foundations by means of a steel head and anchors protruding from the foundation [3,4]. The outer diameter of the columns increases from a minimum dimension of 488 mm with a constant convergence of 15 mm/m (table 1).

Table 1. Pre-tensioned concrete poles for the line 110 kV

| Pole type | Single track line | Double track line |
|-----------|-------------------|-------------------|
| Pole height h [m a.s.l.] | P1 | P2 | M3 | M6 | M9 | K | P1 | P2 | M3 | M6 | M9 | K |
| +0 | 21 | 15 | 18 | 18 | 18 | 18 | 24 | 18 | 21 | 21 | 21 | 21 | 30 | 24 | 27 | 27 | 27 | 27 |
| +3 | 24 | 18 | 21 | 21 | 21 | 21 | 27 | 21 | 24 | 24 | 24 | 24 | 30 | 24 | 27 | 27 | 27 | 27 |
| +6 | 27 | 21 | 24 | 24 | 24 | 24 | 30 | 24 | 27 | 27 | 27 | 27 | 30 | 24 | 27 | 27 | 27 | 27 |
| +9 | 30 | 24 | 27 | 27 | 27 | 27 | 30 | 24 | 27 | 27 | 27 | 27 | 30 | 24 | 27 | 27 | 27 | 27 |
| Diameter Dw [mm] | +0 | 488 | 488 | 713 | 938 | 1118 | 938 | 803 | 713 | 983 | 1208 | 1388 | 1208 | 848 | 758 | 1028 | 1253 | 1433 | 1253 |
| +3 | 488 | 488 | 713 | 938 | 1118 | 938 | 803 | 713 | 983 | 1208 | 1388 | 1208 | 848 | 758 | 1028 | 1253 | 1433 | 1253 |
| +6 | 488 | 488 | 713 | 938 | 1118 | 938 | 803 | 713 | 983 | 1208 | 1388 | 1208 | 848 | 758 | 1028 | 1253 | 1433 | 1253 |
| +9 | 488 | 488 | 713 | 938 | 1118 | 938 | 803 | 713 | 983 | 1208 | 1388 | 1208 | 848 | 758 | 1028 | 1253 | 1433 | 1253 |
| Diameter Dp [mm] | +0 | 623 | 623 | 713 | 893 | 983 | 893 | 983 | 893 | 983 | 893 | 983 | 983 | 983 | 983 | 983 | 983 | 983 |
| +3 | 623 | 623 | 713 | 893 | 983 | 893 | 983 | 983 | 983 | 983 | 983 | 983 | 983 | 983 | 983 | 983 | 983 | 983 |
| +6 | 623 | 623 | 713 | 893 | 983 | 893 | 983 | 983 | 983 | 983 | 983 | 983 | 983 | 983 | 983 | 983 | 983 | 983 |
| +9 | 623 | 623 | 713 | 893 | 983 | 893 | 983 | 983 | 983 | 983 | 983 | 983 | 983 | 983 | 983 | 983 | 983 | 983 |

The columns were designed based on the standard [9]. They are designed for single and double track 110 kV lines with phase conductors AFL-6 240 mm² and lightning conductors AFL-1.7 70 mm². P1 and P2 pass columns (for basic spans 440 m and reduced 300 m) and strong columns M3, M6 and M9 and end column K (for basic spans 440 m) of standard height with +3, +6 and +9 m elevations (table 1). All types of columns in single-track lines as well as P1 and P2 columns in two-track lines are...
designed as one-element, and the remaining columns M3, M6, M9 and K in two-track lines as two-element (figure 2). Columns up to a height of 21 m can be made as one-piece, and above 21 m as two-segment. Column segments at the contact with each other are terminated with galvanized steel heads used to anchor the longitudinal reinforcement and connect the segments with each other using prestressing screws [10]. The columns are designed from C50/60 class centrifuged concrete and reinforced longitudinally with $\varnothing 12.5$ mm (top segment) or $\varnothing 15.5$ mm (bottom segment) with Y1860S7 symbol.

Cross-member crossbars transfer relatively small vertical loads from the weight of wires and insulators (increasing significantly in the event of icing of the network) and horizontal forces from wind pressure to the network. In the crossbars of strong columns (end, resistance and resistance-corner), high horizontal forces arise from the tension of the cables, causing bending with torsion of the pole shaft. Crossmembers can be made as reinforced concrete and prestressed concrete [11] or more often as steel. The permanent connection of the steel cross member with the pre-stressed concrete column shaft in 110 kV lines requires special structural solutions [4,12].

In the high-voltage 110 kV line, forces from the steel cross member are transferred to a column made of spun concrete, most often by means of a two-part steel clamp with rough steel-concrete contact surfaces. After connecting the two parts of the clamp with screws, the space between the pole and the clamp is filled with a hardening mass based on epoxy resin. This operation is carried out after the pole has been placed vertically and in favorable weather conditions (the contact surfaces must be dry). An alternative way of connecting a steel cross member with a column made of spun concrete consists of screwing the cross member with screws to threaded sleeves placed inside the column concrete [4,12]. This solution significantly reduces the installation time of WN line columns by fully equipping the columns with ground level crossbars before they are fixed in foundations.

The designed durability of spun concrete spun columns is 50 years. This durability is ensured by the appropriate thickness of the reinforcement cover and hot-dip galvanizing of steel heads as well as epoxy resin protection with a mineral filler of the ends of the tie rods anchored in the steel heads.

3. Foundations for concrete power poles
3.1. Chalice foundations

The foundations of high-voltage poles must safely transfer loads from the structure to the ground, ensure the stability of the structure and protect the structure against excessive deformations resulting from ground displacements. The choice of foundation type is determined on the one hand by soil conditions (layering, load-bearing capacity and deformability of the subsoil, groundwater level, etc.), and on the other by data related to above-ground structure (type and dimensions of the structure as well as the size and nature of the loads transferred).

The most commonly used types of massive socket foundations (pole and block) for supporting high voltage columns in the ground are shown in figure 3. According to the standard [13], column foundations should have a base area $A \leq 0.25 \text{ m}^2$ and a relative width $\beta = b/D \leq 0.5$ (figure 3a). Foundations that do not meet these relationships are treated as blocks (figure 3a,b,c). Light pole foundations made in holes drilled in the ground are mainly used to set up LV and MV power poles and lighting poles.

The simplest variety of massive socket foundations are column (for $b/D \leq 0.5$ – figure 3a) or block ($b/D > 0.5$ – figure 3b) foundations with a circular or square section. To reduce concrete consumption, monolithic or prefabricated alloy foundations ($b/D > 0.5$ – figure 3c) can be used.
In the event of heavy loads or high groundwater levels, plate foundations with a square or circular base (b/D>0.5 – figure 3d) are used, in which the height D depends on the diameter of the base of the rotated element (D≥1.2·\(\varnothing\)+0.5 m). Alloy and slab foundations can be placed possibly on piles that transfer loads to the deeper layers of the bearing soil.

3.2. Geotechnical categories of constructions

In order to determine the requirements for geotechnical documentation and projects, as well as the scope and accuracy of field and laboratory tests of soil, the standard [14] distinguishes three geotechnical categories. Category 1 relates to small and relatively simple structures set up in soils, for which basic requirements can be guaranteed based on experience and qualitative soil testing, and when the bottom of the excavation is above groundwater level or the planned excavation will be easy to perform. Category 2 concerns simple and complex soil conditions requiring quantitative assessment of geotechnical data; typical structures and foundations which do not pose a particular risk, and easy ground and load conditions. Category 3 includes structures that cannot be classified in geotechnical categories 1 and 2. In particular, category 3 covers cases of very large or atypical structures, structures exposed to extraordinary risk in atypical or extremely difficult ground or load conditions, as well as structures located in seismic and paraseismic areas.

The foundations of concrete high voltage power poles should generally be classified in the second or third geotechnical category. In the event that part of the line will be located in areas subject to ground deformations, the foundations should be absolutely qualified to the third geotechnical category. For the second geotechnical category, standard field and laboratory soil tests can be used, while for the third category, specialist tests are required. Standard [13] for lines with a voltage of 400 kV and higher recommends using method A of the subsoil testing. For 110 kV and 200 kV lines, the B or C method should be used (determination of geotechnical parameters based on practical experience of power line construction in other similar areas). For lines with a voltage of 60 kV and lower, the C method should be used. Method A standard [13] also recommends when foundations are laid in areas with poor soils (peat, silt, cohesive soils in soft plastic, loose sands, etc.) or in areas with weathered, swelling or sinking soils, karst, landslide or erosion processes, mining damage. A cautious geotechnical design and supervision is mandatory anyway [15].

3.3. Ultimate limit states and serviceability

The basic ultimate limit states requiring verification in the case of foundations of supporting structures are: loss of structure or ground stability (EQU) and the limit state of destruction or deformation of a structural element (STR) or ground (GEO). Within the serviceability limit states, check the rotation and settlement of the foundation and the deflection arrow of the structure, taking into account the susceptibility of the foundation.

In the case of column, block and alloy foundations, the overturning moment M and the accompanying horizontal forces V and vertical N (figure 3) are the dominant impact. Their lateral
resistance of the soil (on the side surfaces of the foundation) oppose along with additional shear and vertical forces resulting from the upward soil resistance. The methodology for calculating column and block foundations used for foundation of supporting structures is given in the standard [12] and literature [16,17].

The depth of anchoring (embedding) \( l_k \) of the concrete tower structure or power pole in the socket foundation (figure 3) depends on the length of the anchoring of the reinforcement \( l_{bd} \) [18]. The standard [18] also requires that the depth \( l_k \geq 1.2 \cdot d_s \), where \( d_s \) is the outer diameter of the column in the base.

3.4. Implementation of foundations

In most cases, the installation of prestressed telecommunication towers in the ground is carried out by means of plate foundations (figure 3d) made directly at the construction site. For prestressed concrete columns of spun high-voltage single- and double-track lines, foundations are most often implemented as monolithic well constructions (figure 4) of the pillar or block type [19]. These solutions (figure 4) have undeniable advantages in the form of intact soil structure adjacent to the foundation side and a small construction site.

![Figure 4. Well-type post and block foundations: a) pole shaft anchored in the foundation body, b) screw fastening of the pole with foundation.](image)

The direct connection of the tower shaft or the spun column to the well foundation (figure 4a) is troublesome due to the lack of a typical cup as in figure 3, which is used to set the pole vertically. In the case of a well foundation as in figure 4a, concreting in coils must be carried out in two stages. First, the bottom part of the foundation is concreted to the level of the base of the column, and then, after partial setting of the concrete, the column is set up and the vertebrae are filled with concrete to a minimum level of 0.15 m a.s.l. (figure 4). Installation of high-voltage lines can only take place after the concrete has set (theoretically after 28 days).

The solution given in figure 4b does not have these defects, but requires very precise arrangement of anchor bolts on the pitch diameter identical as in the steel head of a spun column. This solution enables fast assembly of columns on previously prepared foundations and their rectification with nuts under and above the steel head of the column. This solution is used to make column foundations within the four legs of the lattice column of an active 110 kV power line intended for reconstruction.
4. Discussion and conclusions
Currently, the use of cable concrete poles in high voltage lines should be considered inefficient due to their cumbersome assembly at the construction site. The best results are obtained by using one-part prestressed concrete columns made of spun concrete up to 21 m long or two-segmented connected on site with galvanized steel heads and prestressing screws.

Pre-tensioned poles of high-voltage lines can be reinforced in block or well-pitched foundations, as well as in plate pit foundations (figure 3d). The foundation cup is usually made with the base. Prefabricated sockets with joining reinforcement made at the foundation site may be used.

The most convenient and at the same time fast way is screw connection of columns with well foundations. For connecting high-voltage line poles with well foundations, screw anchors (figure 4b) with a diameter of up to 30 mm are most often used. For the construction of the foundation, rigid reinforcement baskets with installed anchors enabling connection with a steel head of a rotated column should be provided. In addition, such fixing enables rectification of columns to bring it to a vertical position (which is of practical importance in areas of mining damage).

Due to the anticipated 50-year durability and virtually no need for maintenance [20], pre-stressed concrete spun concrete columns should be used more often in the construction and modernization of 110 kV overhead power lines in the coming years.

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