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IMPORTANCE OF GEODETIC SURVEYS IN TERMS OF ASSEMBLY AND OPERATION SAFETY ON EXTERNAL TENDON – STRESSED TANKS

ZNACZENIE POMIARÓW GEODEZYJNYCH DLA BEZPIECZEŃSTWA MONTAŻU I EKSPLOATACJI ZBIORNIKÓW SPRĘŻANYCH ZEWNĘTRZNYMI CIĘGNAMI

Abstract

This article describes methods for control over geometry of tanks made of precast panels tensioned circumferentially with external tendons. Certain advantages and disadvantages of applied engineering methods for measurement, along with reasons for necessity to apply more accurate geodetic survey methods are discussed. An example of optimal, according to the author of this article, geodetic technology for control over panel assembly and monitoring of panels tensioning, including relevant study, have been detailed.

Keywords: *prestressed tanks*, *geodetic monitoring of structures*

Streszczenie

W artykule przedstawiono metody kontroli geometrii zbiorników z prefabrykowanych płyt sprężanych obwodowo kablami zewnętrznymi. Scharakteryzowano wady i zalety stosowanych metod inżynierskich pomiaru i przedstawiono argumenty przemawiające za koniecznością stosowania bardziej dokładnych metod geodezyjnych. Przedstawiono przykład optymalnej, według autora, geodezyjnej technologii kontroli montażu płyt oraz monitorowania procesu ich sprężania wraz z opracowaniem.

Słowa kluczowe: *zbiorniki sprężane*, *geodezyjny monitoring budowli*

The author is responsible for the language.

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1. Introduction

Recently, circular tanks made of precast ferroconcrete components and tensioned by external circumferential tendons have gained significant popularity. All systems of that type are noted for short-term construction, winter-time completion option, relatively low cost, as well as durability, and leak tightness of assembled structure (Fig. 1). These tanks have been widely used in waste-water treatment plants, farms, etc.

Individual systems for construction of precast tanks that are tensioned by external tendons are characterised not only by different structure of the panels, method of tightness or tension but by the procedures for ensuring appropriate structure geometry as well. Not always do these procedures require application of geodetic measurements. Tank erection and operation safety depends mainly on provision of accurate geometric parameters to the structures [1]. Insufficient erection accuracy may be one of the reasons for construction disaster [2].

Fig. 1. Circular tank made of precast components

Basing on professional experience [3] and bearing in mind the results of construction disaster reasons, the author proves that the technology for tank construction shall consider application of geodetic measurement methods in the course of assembly and tensioning.

Various recommendations related to geodetic projects, necessary to be carried out on site, along with accuracy requirements and technology for tension monitoring were developed.

2. Technology for tank construction

The foot of the tank constitutes a monolithic, reinforced ferroconcrete bottom plate. For assembly of tank walls, 1,295–2,295 mm wide and 3–7 m high precast panels are used (Fig. 2). Multiple capacity tanks are erected, both small, e.g. 260 m^3 volume consisting of 10 panels, and huge ones with volume of 6,460 m^3 consisting of 60 panels [4]. The structure is tensioned into circumferential direction through the application of external steel tends.

Fig. 2. Tank erection

Regardless of the system or the size of tanks, technology applied for construction remains almost unchanged. Bottom plate is reinforced and poured out on the site. On the plate circumference, approximate layout of wall components is set out through geodetic or engineering method and then some washers are arranged. These washers are placed at identical level with the application of levelling instrument. Precast wall panels are transported to the site in succession. Each time a couple of those panels are brought in by truck-tractor platforms. Directly from a vehicle, wall panels are moved to the bottom plate by a crane and then arranged onto the washers around its circumference. Consecutive panels are pushed close to each other. Every one plate is stabilised with a spacer fixed to the bottom of the tank.

This spacer holds the plate but still allows it to slide and incline within a limited range. Consequently, correction of the wall plate orientation against bottom plate and its verticality determination are ensured. Upon arrangement of all elements, control over tank geometry is carried out with application of various methods. One of those consists in controlling angle between panels with 1 meter staff. The staff is applied to the panels in a manner its endings are aligned within identical distances from their joints. Height of a triangle that is created by the staff and the panels is translated into the angle between those elements. In case of other systems, control over slits on joints between panels is not required. Panels are plumbed with the level line.

Upon pulling in and fabricating strands, initial tension is commenced and continued up to obtaining usually 20% of the final tension. A foundation ring is placed around new-built wall. Wall plate vertical joints are filled in with expansion concrete if in the course of arrangement adhesive sealing or mortars have not been applied. Then, final tension is commenced in double-stage process. Upon completion of each tension stage, control of tank geometry is carried out.

3. Tank geometry impact on failure hazard

The technology that is described above does not ensure implementation of tank geometry parameters with required accuracy. Plate inaccurate placement does present problems during erection, especially in the course of matching the last plate. The shape and size of the tank has a crucial impact onto stress pattern within the structure both throughout tensioning and, later, at some stage in operation as well [2].

Fig. 3. Construction disaster

Failure to maintain geometric conditions might have been one of the reasons for the construction disaster where some wall components of earlier tensioned finished tank collapsed (Fig. 3). Vertical plate joints were damaged since internal corners within concave parts of the joints were truncated. Component of force that causes truncation is all the bigger as the angle between the panels increases. In this case 3,990 m^3 tank, with R_w = 14.655 m internal radius, contained a wall consisting of 61 fabricated elements. Therefore the angle, 193.44^g, between those components was exaggerated from a basic premise (Fig. 4).

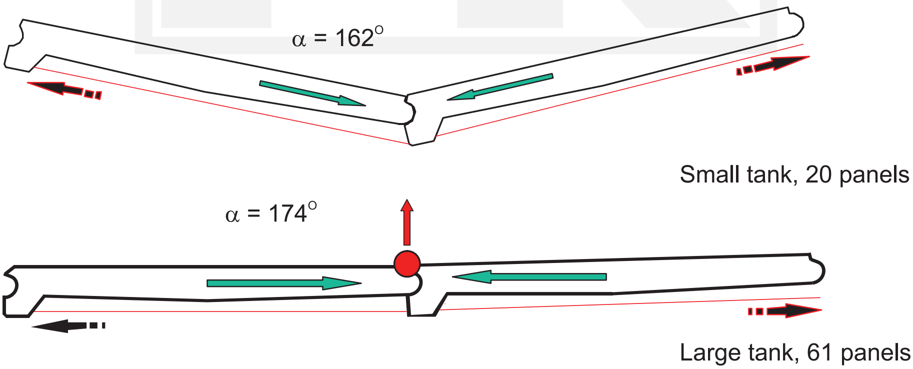

Fig. 4. Influence of tank size on angle between panels

Assembly manual for this tank allowed, among others, the following tolerances:

- provision of a tank radius R_a ±10 mm in comparison with design value,
- provision of an angle between panels ±1,5° in comparison with design value.

Recommended by the manual, geometry control methods that constitute a part of engineering methods included following measurements:

- measurement of radius with a tape from the centre of circle determined at the beginning of assembly works,
- measurement of angle between panels through measurement of distance (x) from panel joint to 1 meter staff applied symmetrically to tank walls (Fig. 6),
- it does not provide control of the size of the slit on panels joints.

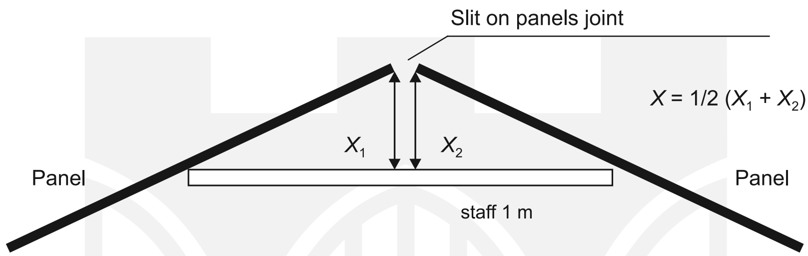

Fig. 5. Manner for determination of angle between panels through measurement of distance (X) from 1 m staff

It is hard to meet those requirements through the application of recommended measurement methods, as:

Measurement of radius is only theoretically easy to be carried out. In practice, accuracy of this measurement is limited on account of difficulties in identification of appropriate points on a plate. The second factor that deteriorates accuracy of measurements is the fact that in the course of tension panels relocate. For that reason the centre of the tank, which was determined at the beginning of erection, becomes outdated (the differences may achieve a few cm).

Angle measurement by recommended method is not accurate as well. The reason is too short staff and local irregularities of surface that may interfere the results of the measurements. Actual accuracy of the measurement was to be estimated only on the basis of records included in logbooks developed upon inspection that was carried out prior to disaster. On that basis, sum of internal angles for polygon created by the panels was determined. Angular deviation determined on the basis of polygon closure was fk = 7.7°. Assumption related to absence of mistakes brings following measure error for 61 angles:

$$m_\alpha = \sqrt{61} \cdot 7.7^\mathrm{o} = 0.9^\mathrm{o}$$

Similar analysis that was carried out for other tanks, proved that measure error for application of this method fluctuates from 0.3° up to 1.1°.

Obtained results prove that measuring methods applied for control over tank geometry are characterised by insufficient accuracy precluding verification of assembly tolerances that are required for that type of tanks.

4. Geodetic tasks to be carried out in the course of tank assembly

Recommendations related to geodetic observations that are to be carried out in the course of completion of tanks made of fabricated tension panels were developed. This method was confirmed in practice [3].

In the corners of each plate, 4 testing marks are installed. Optimally, these marks should be installed in the course of plate manufacture. In case it cannot be provided, this action may be carried out when panels are still placed on platform, prior to installation. These marks should be spaced within identical distances, e.g. 5 cm from plate edge with ±5 mm accuracy. The marks at the bottom of panels should be installed above foundation ring.

Control over geometry of spaced panels is carried out through geodetic observations of marks' placement. Topcon GPT-9003 scanning tachometer was applied for the observation. The measurement was completed through polarity method with application of the workstation placed nearby the centre of the tank. A distance to marks, measured with laser rangefinder, was carried out with 2 mm accuracy.

Differences between the distance to the lower mark and the distance to the mark placed above it constitute plate deflection from verticality. Distances between neighboring marks may indicate size of slits on panel joints.

Coordinates of the lower marks are determined. Basing on these coordinates, parameters of the circle approximating panel lower points are calculated. The difference between the distance of the point from the centre of the circle and the length of the circle radius constitutes radial stand-off distance of the panel from optimal location. These calculations may be carried out directly on the site. Duration of such measuring cycle depends on the number of the panels from which the tank wall is constructed of. Even in case of large tanks, the measurement duration including calculations does not exceed 1 hour. Typically, three observations are to be carried out. Firstly, upon panels' arrangement when on the basis of observation results the location of those panels is adjusted. On the strength of the results of the second observation, which is implemented upon initial tension, it is measured whether existing relocation of the entire structure does not impact geometric conditions and whether final tension may be carried out. Upon final tension, it is necessary to check the tank final geometric condition.

5. Example of measurements

Practical results of measurements and the manner for the data handling constitute an example of observations carried out in the course of the tank erection at waste water plant in Gdów [3]. It is 400 m^3 tank consisting of 2.275 m wide and 6 m high 12 wall components (Fig. 6).

Table 1 contains the results of tank measurements that were carried out prior to tension. Differences between measured distances to plate lower mark and to the mark placed above it (col. 10) constitute a degree of plate deflection from verticality. 'Plus' sign means deflection to outside, 'minus' sign means deflection to the centre. Maximum 40 mm difference means deflection from verticality by 0.4°. On account of obtained results, deflection of panels from verticality was corrected continuously.

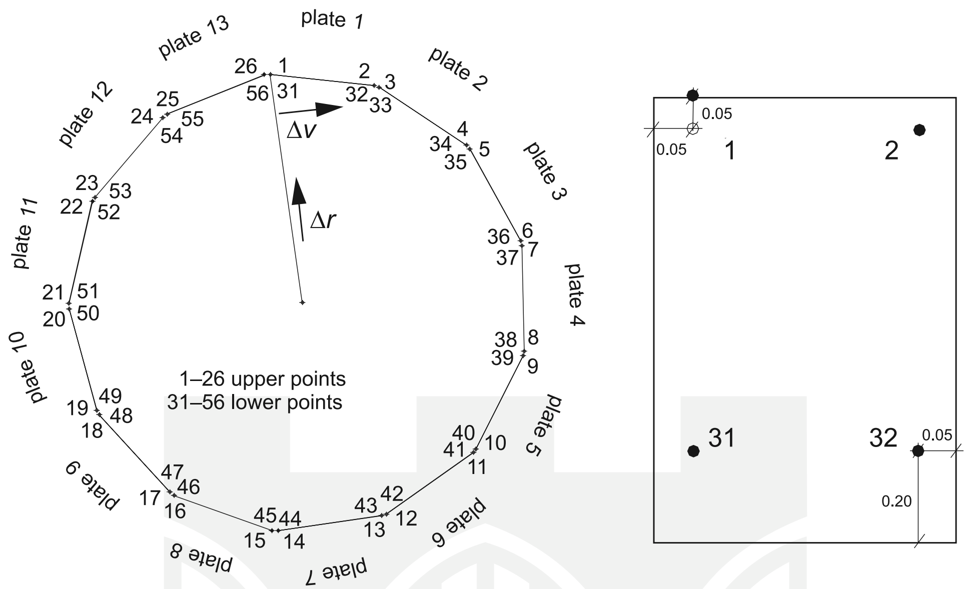

Fig. 6. Sketch of testing points arrangement

Table 1

Measurement results for control marks

Plate number	No. of upper point	*x*	*y*	R_g	No. of lower point	*x*	*y*	R_d	$\Delta R = R_g\text{-}R_d$ [mm]
1	2	3	4	5	6	7	8	9	10
1	1	4.685	–0.661	4.732	31	–0.661	0.239	4.733	–1
	2	4.461	1.492	4.704	32	1.496	0.239	4.703	1
2	3	4.424	1.594	4.703	33	1.597	0.240	4.704	–1
	4	3.235	3.401	4.694	34	3.407	0.239	4.694	0
3	5	3.148	3.477	4.691	35	3.478	0.240	4.695	–4
	6	1.253	4.530	4.696	36	4.528	0.240	4.698	–2
4	7	1.151	4.558	4.701	37	4.558	0.238	4.701	0
	8	–1.017	4.606	4.715	38	4.603	0.239	4.714	1
5	9	–1.126	4.576	4.712	39	4.577	0.239	4.713	–1
	10	–3.057	3.599	4.722	40	3.598	0.241	4.722	0
6	11	–3.142	3.522	4.720	41	3.527	0.243	4.727	–7
	12	–4.394	1.753	4.730	42	1.754	0.244	4.737	–7
7	13	-4.431	1.652	4.730	43	1.654	0.244	4.770	–40
	14	–4.745	–0.489	4.734	44	–0.493	0.244	4.773	–39

8	15	–4.732	–0.598	4.771	45	–0.603	0.243	4.804	–33
	16	–4.013	–2.641	4.777	46	–2.648	0.245	4.808	–31
9	17	–3.942	–2.732	4.798	47	–2.731	0.242	4.808	–10
	18	–2.345	-4.197	4.802	48	-4.198	0.244	4.811	–9
10	19	–2.248	-4.249	4.810	49	-4.247	0.244	4.825	–15
	20	–0.158	–4.823	4.807	50	-4.816	0.242	4.819	–12
11	21	–0.051	–4.823	4.825	51	-4.816	0.237	4.816	9
	22	2.064	-4.342	4.806	52	-4.330	0.240	4.795	11
12	23	2.164	-4.283	4.801	53	-4.279	0.243	4.779	22
	24	3.813	–2.881	4.791	54	–2.871	0.240	4.766	25
13	25	3.874	–2.790	4.774	55	–2.786	0.234	4.746	28
	26	4.682	–0.782	4.770	56	–0.770	0.240	4.740	30

In order to determine an optimum orientation of wall panels on the foundation plate, the points stabilised at the lower part of the plate were approximated with the circle. Basing on *x*, *y* coordinates (col. 7, 8), through parametric method, the elements of the circle equation were determined.

$$(x-A)^2+(y-B)^2=R^2$$

where:

A, B – coordinates of the circle centre,
R – the circle radius.

Determined equations for correction are as follows:

$$2(A_0-2x)\,dA+2(B_0-2y)\,dB-2R\,dR+x^2+y^2-R_0^2=0$$

Calculation results upon two iterations bring parameters for the circle equation:

$$A=-0.021;\quad B=-0.056;\quad R=4.752$$

It must be noted that A and B parameters represent displacement rate of the circle centre from its initial placement at the stage of panel assembly. In this case, measurement of the radius with application of traditional method would bring incorrect results.

Table 2 includes calculated distances of the points from the centre of the circle and radial deflection from the optimal placement $\Delta r = D - R$. ‘Plus’ sign means that the plate shall be slipped to the outside, whereas ‘minus’ sign means that the plate shall be slipped to the inside [3].

Graphic display of displacements is shown in Fig. 7. Basing on measurement results, correction of wall panels’ placement was carried out continuously. Measurement & calculation process, described above, was repeated twice, i.e. upon initial tension and upon final tension.

At the same time, testing on plate deformation during tension was carried out.

Table 2

Radial deflections for control points

Plate	Point	*D*	*R*	Δ*r* = *D* – *R*
1	31	4.746	4.752	–0.006
	32	4.740		–0.012
2	33	4.743		–0.009
	34	4.749		–0.003
3	35	4.750		–0.002
	36	4.758		0.006
4	37	4.761		0.009
	38	4.764		0.012
5	39	4.762		0.010
	40	4.751		–0.001
6	41	4.755		0.003
	42	4.739		–0.013
7	43	4.735		–0.017
	44	4.746		–0.006
8	45	4.750		–0.002
	46	4.760		0.008
9	47	4.753		0.001
	48	4.752		0.000
10	49	4.750		–0.002
	50	4.762		0.010
11	51	4.760		0.008
	52	4.754		0.002
12	53	4.750		–0.002
	54	4.750		–0.002
13	55	4.755		0.003
	56	4.752		0.000

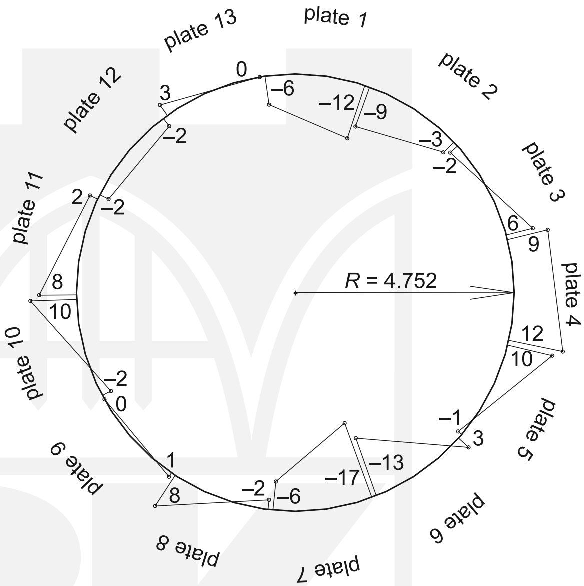

Fig. 7. Plate deflections from optimum location [3]

Fig. 8. Plate deformation isolines upon tensioning [4]

The panels were scanned prior to tension and upon final tension with Topcon GPT-9003A scanning tacheometer. Points network was obtained at approximately 60 cm distances, i.e., approximately 40 points in 10 rows meaning 4 points in each row. Comparison of the results of the scanning that was carried out prior to and upon tension enabled determining panel deformation. Deformation contour lines, which occur within panels as a result of tension (Fig. 8), were generated for individual panels. Within described example, panel deformations were minimal as these were not exceeding ±2 mm measurement accuracy [5].

6. Conclusion

The technology of construction of tanks made of fabricated panels tensioned circumferentially by tendons is unusually efficient. Numerous examples of failure indicate the necessity for distinctive care in the course of erection. Applied methods for control in some systems are limited to a certain degree, especially in case of large tank construction. In such cases, it seems to be necessary to apply geodetic methods of measurement.

The technology that has been applied by the author turned out to be efficient for two major parameters, i.e. in respect of the measurement duration and regarding obtained accuracy. This method enables current controlling over accuracy of plate assembly, as well as monitoring of plate tension. Monitoring refers to both displacement of individual fabricated components and determination of panel surface deformation under the influence of tensioning.

Major and crucial advantage of this technology is duration of measurements. Considering the fact that the panels are assembled directly from vehicles and it is necessary to carry out immediate control measurements on the site, it seems that this method may be optimal.

Significant acceleration of measurements including enhancement of accuracy might have taken place in case of assembly of control marks on panels in the course of their manufacture.

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