BEHAVIOUR ANALYSIS OF STEEL-SHELL-AND-SOIL CORRUGATED STRUCTURE IN THE CONSTRUCTION PHASE ILLUSTRATED WITH SUPERCOR SC-57S

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Abstract

The paper below presents the results of studies of the flexible SuperCor SC-57S structure built by Polish manufacturer 'ViaCon Polska Sp. z o.o.' at their test site in Rydzyna. The tests aimed to examine the behaviour of the steel shell and soil structure in the construction phase. The measured quantities included the displacement, determined through geodetic surveys, and stress, recorded with a set of strain gauges. Values of internal forces that occur in the structure were determined. The conclusions based on these results may be helpful in understanding the behaviour of flexible steel shell and soil structures in the construction phase.

Keywords: Steel-shell-and-soil structure, corrugated steel plate, flexible structures, the SuperCor structures

1. INTRODUCTION

Analysis of structure response in the construction phase provides a lot of information about behaviour of bridges. This is particularly important during long-term operation of objects, when structural failures are observed as a result of static as well as fatigue loads. [1] [2]

This paper presents the results of the studies carried out on the SuperCor SC-57S structure by 'ViaCon Polska Sp. z o.o.' at their test site in Rydzyna. The conducted research aimed to examine the behaviour of the steel-shell-and-soil structure in the construction phase. The displacement was determined through geodetic surveys. The values of stress were recorded with a set of strain gauges. The numerical model of the structure was developed in the CandeCad computer program implementing the finite element method. Computations were performed for comparison with the results of the measurements. This paper presents the values of displacement and internal forces that occurred in the structure.

The study involved the SuperCor SC-57S flexible corrugated steel structure with a design span of lt=17.59 m and the curvature radii of 13.74 m and 3.43 m. The structure, fixed to a concrete footing, consists of the 7 mm thick plates made from S315MC steel. The corrugation profile has a depth of 140 mm and a pitch of 381 mm. The plates are bolted using M20 compression bolts with nuts tightened up to the required torque of minimum 360 Nm. The backfill consists of 25 layers, 30 cm in thickness each. The soil density index was ID=0.95 in the direct vicinity of the steel structure and ID=0.98 in the remaining part of the backfill. It is important that backfill be properly constructed, as this component interacts with the steel shell and carries significant part of the load. The effect of positive arching is particularly important here. [3] [4]

2. CONDUCTING THE RESEARCH

During the construction process, the displacements were measured through geodetic surveys. The values of stress were determined with a set of strain gauges. The gauges were placed at the valleys and crests of the corrugation. Geodetic surveys were carried out after the construction of each layer of backfill and at 7, 25, 53, 84, 132, 211, and 403 days from the backfill completion date. Vertical and horizontal deflections of the structure measurement points were taken into account in the surveys. The first geodetic survey, zero reading, was performed after assembling the steel structure, therefore the deflections due to the dead load were not accounted for. Strain gauge readings were taken after the placement of each layer of the backfill. The additional readings were taken after 12 hours for layers marked as V, VII, X, XII, XIV and XVII. The output for layer denoted as XXV was read after 12 hours and at 3 weeks. Basic dimensions of the structure, location of the strain gauges and geodetic measurement points are shown in **Fig. 1** and **Fig. 2**.

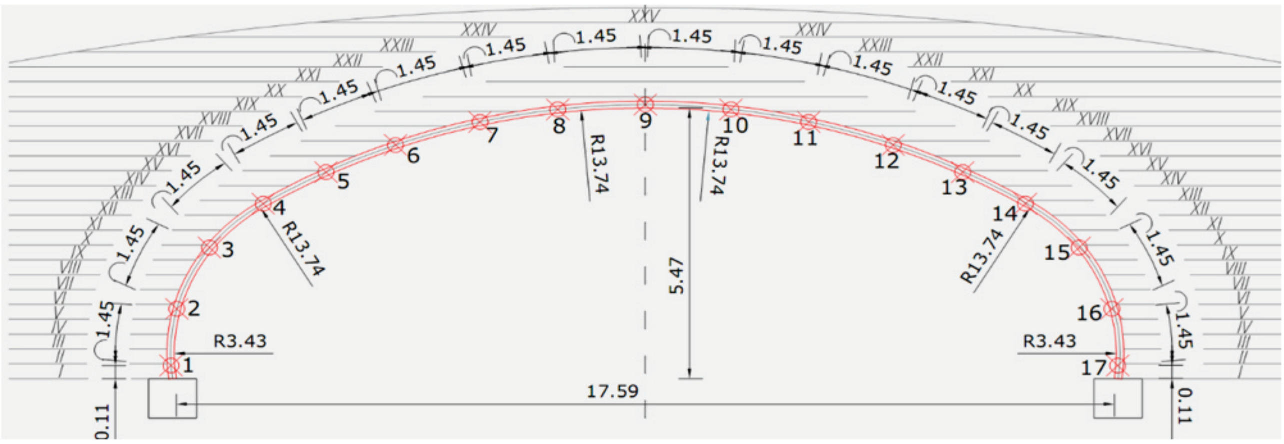

Fig. 1 Basic dimensions of the structure and location of geodetic measurement points.

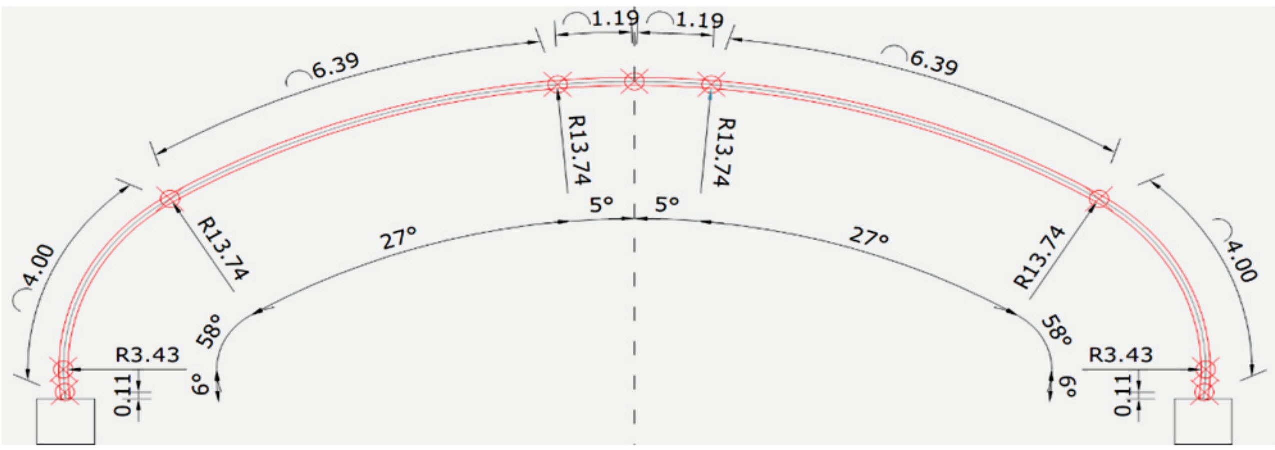

Fig. 2 Basic dimensions and location of strain gauges on the structure

3. ANALYSIS OF THE STRUCTURE BEHAVIOUR

In soil-steel structures, the steel shell shares the load with the soil backfill. During the construction process, the weight of the backfill and its pressure on the steel shell cause the deformation of the structure. The structure arches upwards and its width narrows. Following the placement of consecutive layers of backfill the deformation decreases [5]. The diagram below shows the vertical displacements in the crown and U value of the narrowing at points 1 and 17. It indicates that the buckling and the narrowing reduced after placing layers XIX-XXV. Successive measurements conducted from 02.04.2009 to 03.05.2010 showed that the structure underwent further deformation. The measurement points 1 and 17 moved away for nearly 20 mm; the point at the left corner moved more than 22 mm and the point at the right corner moved approximately 3 mm to the left. The displacement in the crown reached the value of 43 mm.

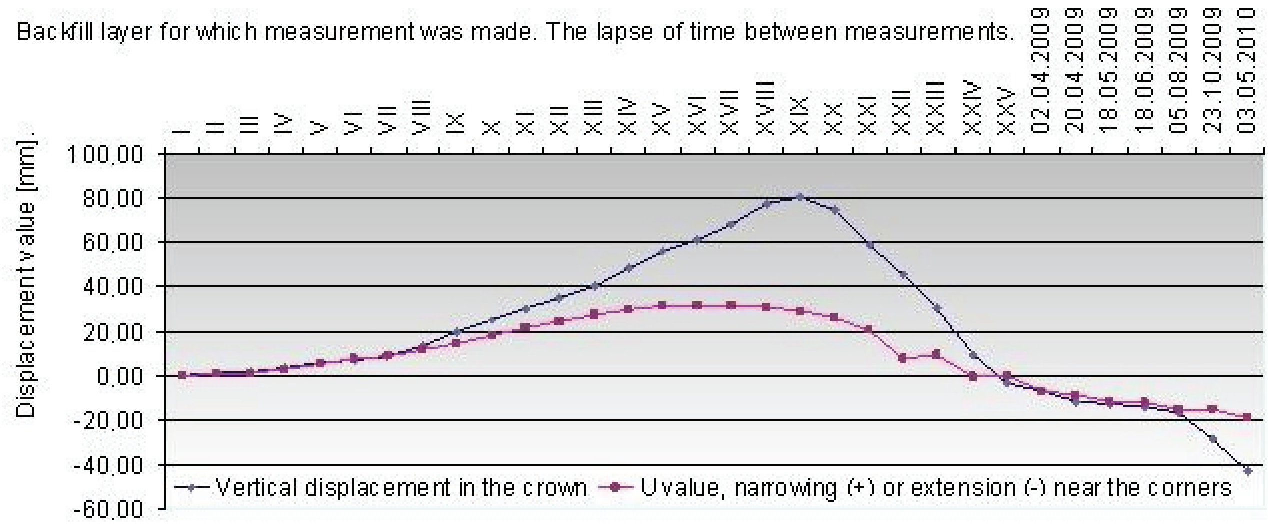

Fig. 3 Measured displacements in SuperCor SC-57S structure

The diagram presented below confirms the measured displacements. The reduction in bending moment in the crown appeared after placing layers XIX- XXV and at the corners of the structure, after placing XVIII and successive layers. After the placement of layer XXV, the bending moment for all three points was negative.

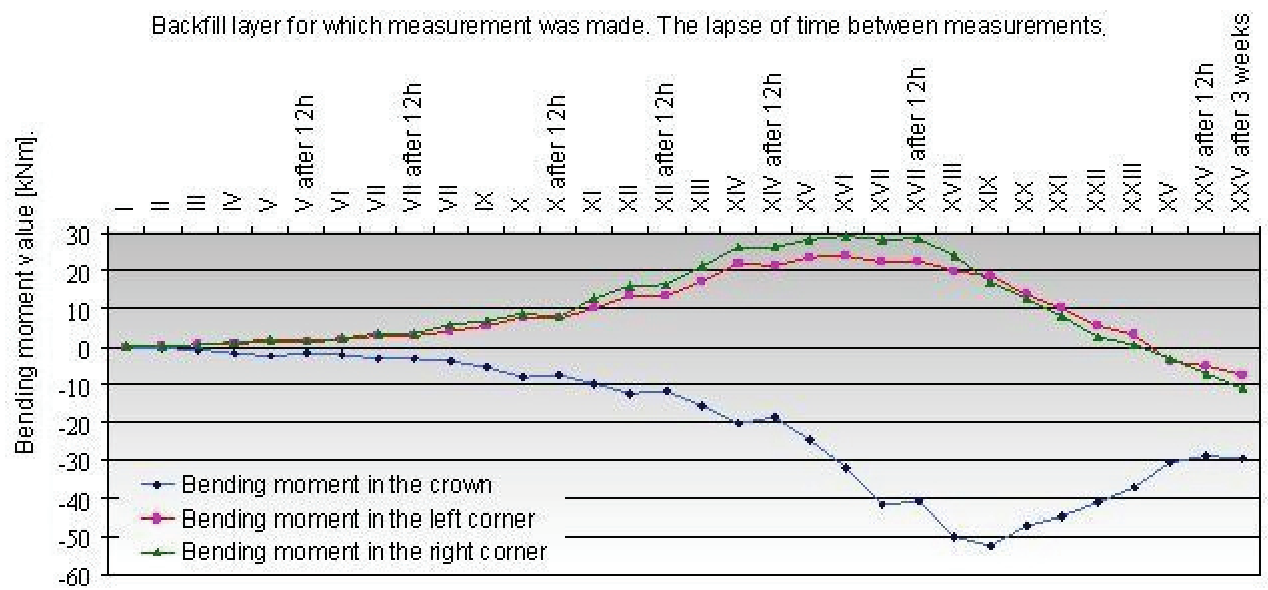

Fig. 4 Bending moments occurring in the crown and corners of the structure

A constant rise in normal forces was recorded in the corners of the structure along with the placement of successive backfill layers. The rise was uniform up to layer XVII. Axial forces increased considerably faster after the placement of the layers XVIII-XXV. Normal forces in the crown of the structure increased non-uniformly. Significant compressive force gains were recorded after 12 hours and three weeks from the completion of backfill layers. This might be a result of the compacted backfill relaxation and soil pressure on the sidewalls of the structure. The compressive forces decreased with placing of successive backfill layers. It may be assigned to the effect of vibrations and the disruption of adhesion on the steel-soil interface. [5] [6]

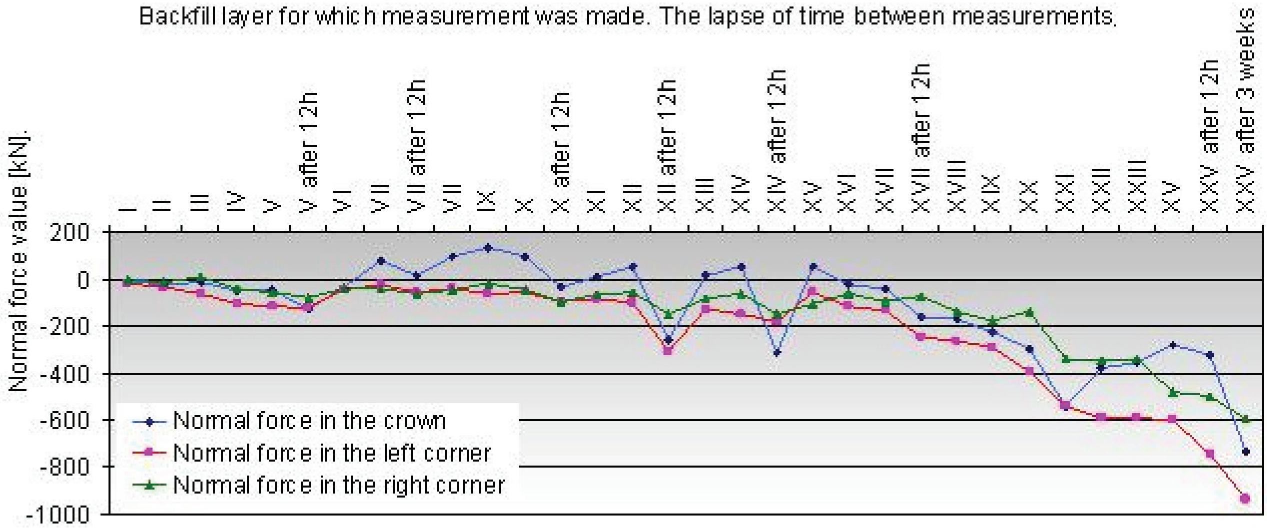

Fig. 5 Normal forces in the crown and corners of the structure

At the end of the backfilling process, a reduction in the valley tensile stresses was recorded. These stresses nearly disappeared after three weeks from the completion date. This confirms the redistribution of stress over time. Maximum value of normal stress in the crown for the lower wave was reached after layer XIX was laid (133.5 MPa), and for the upper wave, after layer XXI was laid (-210.9 MPa). The diagram below shows determined stresses, normal forces and the bending moment in the crown of the structure.

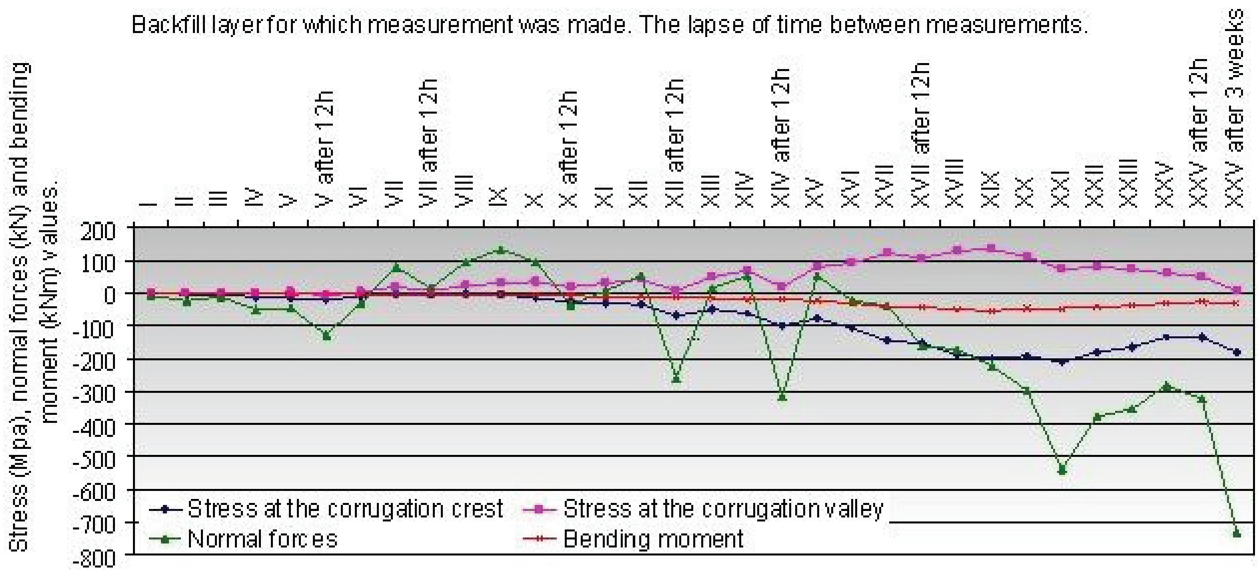

Fig. 6 Values of stress, normal forces and bending moment in the crown of the structure

The values of stress, normal forces and bending moment in the left and right corners of the structure are presented in the diagrams below.

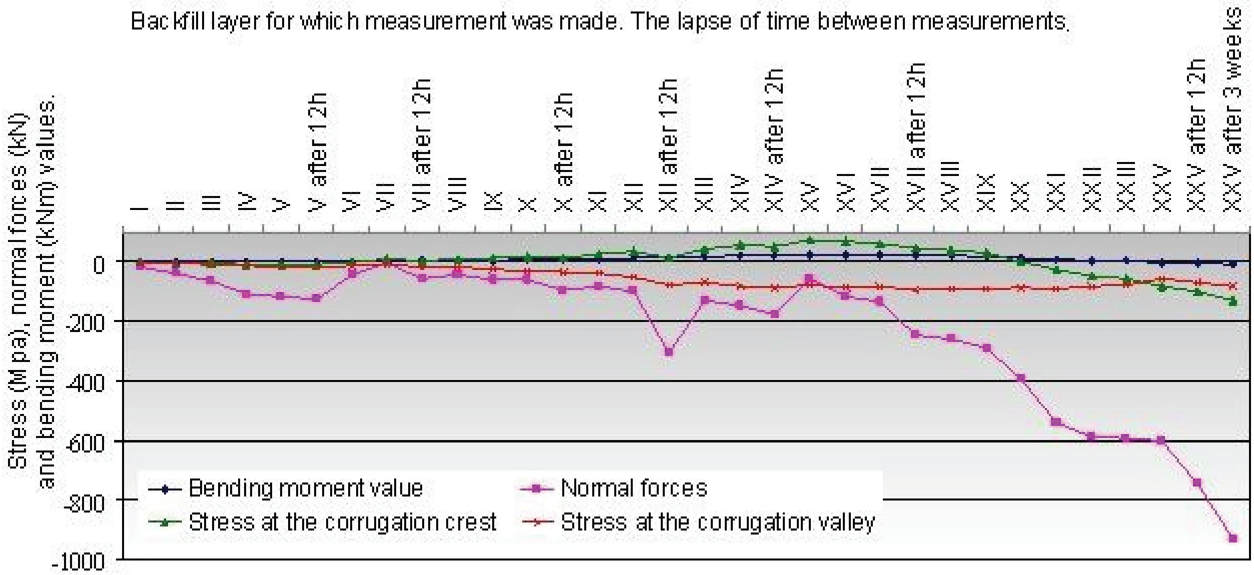

Fig. 7 Values of stress, normal forces and bending moment in the left corner of the structure

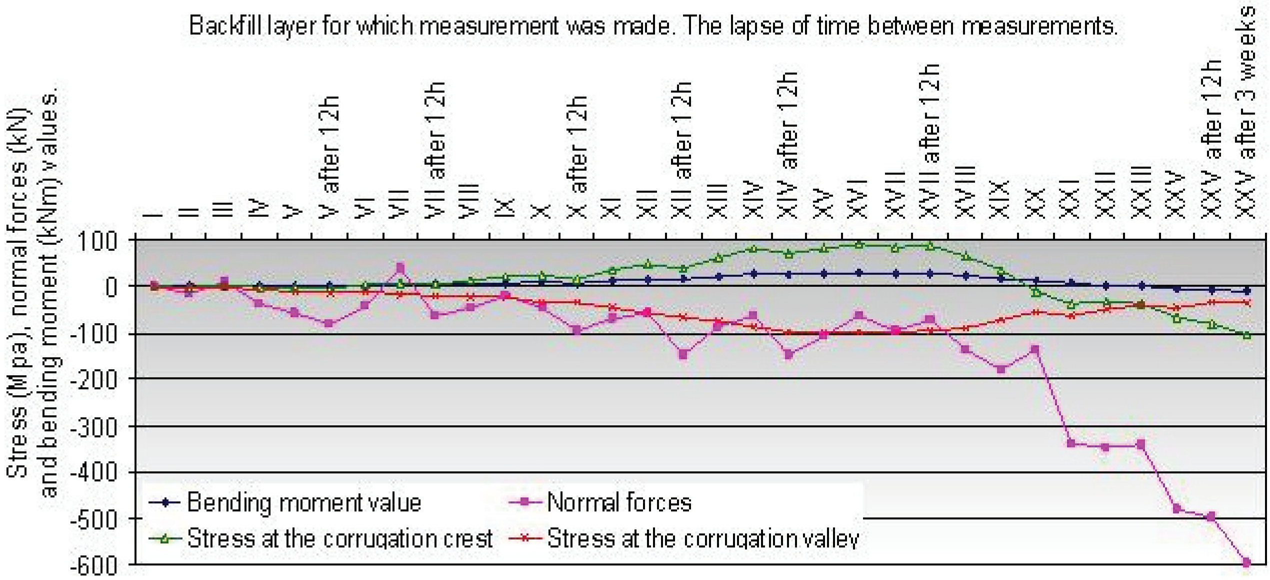

Fig. 8 Values of stress, normal forces and bending moment in the right corner of the structure

In both corners, the compressive stress at the corrugation valley was present during the whole construction process. Maximum compressive stress in the lower wave was recorded after 12 hours following the placement of layer XVII (-96.3 MPa, left corner) and layer XV (-98.2 MPa, right corner). Maximum tensile stress in the upper wave was recorded after the placement of layer XV (73.2 MPa, left corner) and layer XVI (91.7 MPa, right corner). Then tensile stress was decreasing until the change of sign. The compressive stress occurred in the left corner after placing layer XXI and in the right corner after placing layer XX. It confirms that the structure was (pre)stressed. The maximum values of compressive stress for the left corner (129.5 MPa) and the right corner (104.6 MPa) were reached three weeks after the placement of layer XXV.

The measuring points marked as 7, 8, 9, 10 and 11 were considered in the analysis of the vertical deflections that appeared near the crown of the structure. Point 9, placed in the centre of the crown is where the largest displacements are expected. Smaller deflections should occur at points 8 and 10. The smallest should be recorded for points 7 and 11. [7] **Fig. 9** shows the results of geodetic survey of vertical displacement obtained after placing consecutive layers and at 7, 25, 53, 84, 132, 211 and 403 days from the completion date.

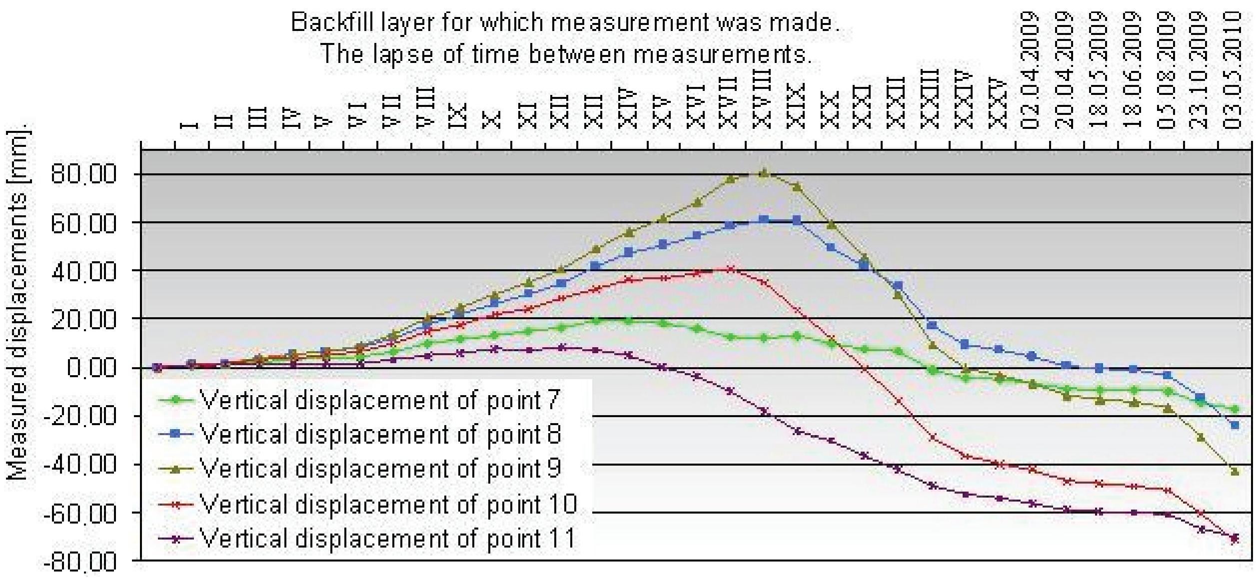

Fig. 9 Geodetic measurement results: displacements of points 7-11

Table one presents the values of the measured vertical displacements at points 7-11 after placement of layer XXV and 403 days from the completion date.

Table 1 Values of vertical displacements at points 7-11

Measurement point	7	8	9	10	11
Vertical displacement after completion of backfill (mm)	-5.09	-6.82	-3.67	-39.75	-54.29
Vertical displacement after 403 days form the completion date (mm)	-17.23	-24.35	-43.06	-71.48	-70.17

The geodetic surveys indicate that the vertical displacements were also caused by settlement of the foundations. This is confirmed by the displacements of points 1 and 17 located at a small distance (approximately 10 cm) from the supports. **Fig. 10** shows that these values are increasing with time.

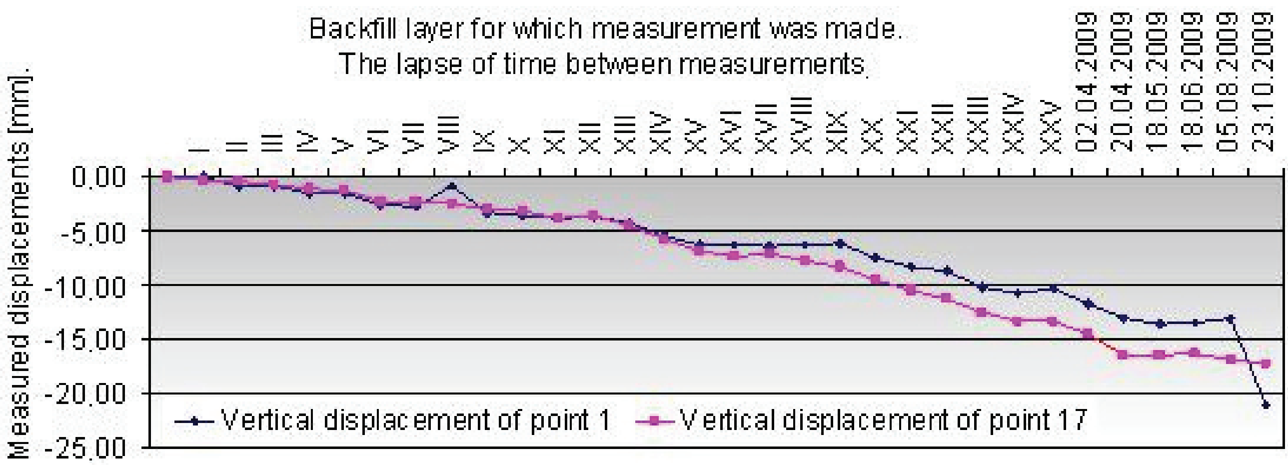

Fig. 10 Geodetic measurement of displacement of points 1 and 17

CONCLUSIONS

Based on the studies, the following conclusions can be drawn. The largest deflections and bending moments occurred in the construction phase. They rose with the backfill height until the level of crown was reached. Subsequently, the values decreased with backfilling continued above the crown. The tensile stresses in the structure also decreased significantly, hence the structure was (pre)stressed. The upward deflection of the steel structure during the construction of backfill is a positive phenomenon. [5] The studies have confirmed that the construction process is the most critical phase of the work of flexible shell and soil structures. Significant regularity observed relates to the change of shape of the examined structure. It is confirmed by the displacements recorded at points 7-11. The largest were expected at point 9 in the centre of the crown. After completion of backfill, the vertical displacement at point 7 was -5.09 mm. The upward deflection of 6.82 mm was recorded at point 8. Displacements that occurred at point 9 reached -3.67 mm and -39.75 mm at point 10. The largest was at point 11: -54.29 mm. The structure did not behave in the manner anticipated. This may be the evidence for the imperfection of construction procedure. Survey conducted 403 days later revealed displacements: -17.23 mm at point 7, -24.35 mm at point 8 and -43.06 mm at point 9. The largest deflection: -71.48 mm, occurred at point 10, located closer to the centre of the crown. The structure changed its shape to one closer to the anticipated. It confirms the redistribution of stresses with time.

More full scale tests should be conducted to identify the behaviour of soil steel structures under long term service conditions and their load-carrying capacity determined by using the damage mechanics methods. [8] The global monitoring system based on the measurement of acoustic emission (AE) may be helpful in locating and identifing the type and the dynamics of the deterioration processes. The resulting data may be used for determining and locating the damage zones that are dangerous for the structure. [9]

ACKNOWLEDGEMENTS

Data concerning the studied structure were provided by courtesy of The Management Board of 'ViaCon Polska Sp. z o.o.'.

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