1. INTRODUCTION

Symmetry as such is a commonly known aspect not only in architecture, arts, mathematics or technology. Symmetry is an important factor used to understand some complex technical issues. It is used very often to evaluate the safety of road structures or their elements. Basically symmetry has a positive dimension. A unique example are soil steel bridges in which keeping the symmetry of shape is of fundamental importance. These structures are flexible and can undergo changes of geometry of their shape during backfilling. As they are easy to deform during backfilling and subject to some deformations during service these structures should be monitored during those stages. Observation of symmetry is easy during construction and can help in the evaluation of service safety of the structure during the service stage. Loss of symmetry is a signal for corrective action during construction. Corrective action allows to eliminate further negative consequences during service. This paper deals with issues of changes of geometry during construction of soil-steel structures. These changes are not necessarily the consequence of bad practices. As the basic assumption it is said that the axis of symmetry is considered to be taken as a straight line coming down from the top of the structure including any possible shape tolerances that are relevant to the structure as per manufacturer’s recommendation. This assumption will release us from a purely theoretical approach.

2. SOIL STRUCTURE INTERACTION

Appropriate soil-structure interaction causing tensioning effect is based on soil equilibrium in the vicinity of the steel structure. Tensioning caused by backfilling leads to changes in geometry of the steel structure and generates stresses in the steel. The structure tends to release the stress and the backfill surrounding prevents it. Obviously the amount of soil restricting changes of stress in the steel must be sufficient. It is easy to observe that the more tensioning there is, the more backfill soil is needed. The idea is to incorporate as much soil as possible to interact with the steel structure. The steel structure on the other hand will pre-
vent loosening of soil particles which can lead to a reduction of friction. This interaction determines the load bearing capacity of soil-steel bridges. It is described as total friction forces in the soil or the amount of tensioning caused by the backfill.

3. CHANGES OF GEOMETRY CASUED BY THE BACKFILL

Properly chosen and placed backfill soil leads to controlled deformations of the structure. With the increase of backfill height one can observe an increase of the structure height with immediate narrowing of its span. The increase of height continues until the backfill soil reaches the crown. Lateral dimensions change depending on considered height of the structure and the shape of the profile. Therefore a peaking effect (increase of height) is practical in measuring the amount of deformation. Deformation can be recorded with total station and a measuring accuracy of 1.0 mm is sufficient. After the backfill crosses the crown the peaking decreases and, depending on the amount of overburden soil, it may completely disappear. The reduction is also a function of stress level in the steel structure (tensioning effect). In some cases it can lead to a drop of initial height of the structure prior to backfilling. It means that there was a redistribution of stresses in the steel wall. Normal stresses have either changed their sign or moved aside. Figures below present various cases of changes in structure geometry during backfilling and service stage.

PHASES OF BACKFILLING PROCESS
The best practice is to tension the steel structure in the crown area as high as possible. Figures presented below show the history of deformation of a structure during backfilling and service stage. As one can observe the reduction of peaking at the moment of completion of the construction impacts the future behavior of the structure during service. Therefore excessive deformations cause a loss of symmetry of the structure. Monitoring of the axis of symmetry during construction is an important control element showing the accuracy of construction process.
4. RELOCATION OF THE AXIS OF SYMMETRY DURING CONSTRUCTION

It is not easy to keep symmetry during construction. Due to mechanization of backfilling works the process should be as continuous as possible. Estimation of expected deformations is important for the safety of works. The orthotrophy of corrugated steel structure impacts the change of the geometry also in the longitudinal direction. Observation of coordinates „x” and „y” selected on the periphery of the steel structure show their movements alongside axes during backfilling and service stage. Based on the analysis of coordinates („x” ; „y” ; „z”) in observed points one can notice that during peaking there is a rotation vs. vertical axis of the corrugated steel structure. The magnitude of the rotation angle depends from the degree of tensioning of the corrugated steel structure. The increase of the angle continues until backfill reaches the crown when the tensioning of the structure has the highest value. When placing the overburden soil and during service stage the angle changes adversely. The figure presented below illustrates this phenomenon.

DEFORMATION OF OBSERVED POINTS IN THE STEEL STRUCTURE ON HORIZONTAL LEVEL "X-Y"

LEGEND:
- angle of rotation of the cross-section during tensioning
- negative angle of the cross-section due to decrease of tensioning level (due to overburden soil)
- final angle of cross-section = |φ + φs |
In the figure one can see that the more tensioning is applied the higher the rotation angle value is. On higher levels of the structure the rotation angle increases. Points above of the structure support level undergo more rotation. The axis of symmetry rotates slightly during backfilling. Therefore it means that deformation of a soil-steel structure must be considered in the three-dimensional analysis.

5. MAJOR CAUSES OF SYMMETRY LOSS IN A CROSS-SECTION

As the backfill soil determines the geometrical changes it is important to place it around the structure in the way which will not cause asymmetrical changes of the geometry. In practice it is impossible to keep the symmetrical axis of the cross-section. Nevertheless one should control that changes are not exceeding a certain level that may jeopardize to the safety of the structure. Besides during service stage one should limit the expected reduction of the height of the structure related to height of cover and applied live loads. Stops in placing the backfilling, especially when backfill soil is above the crown have negative effects on the tensioning. The part of the soil placed after break in the backfilling procedure is not interacting in soil-structure interaction process but acts as a ballast to the structure. The cause of a reduction in tensioning during technological breaks in backfilling is the change of geotechnical parameters of the backfill soil (moisture content, density, cohesion). A scheme below presents a limited soil-structure interaction referred to a/m comments:

SOIL - STRUCTURE INTERACTION SCHEME

in practice: ΔH = 0.60 - 1.20 m in depending on road category.
The first structure was built with a technological break in backfilling caused by the need of allowing a temporary access to the next structure and the second structure was built without having this break.

The view of a jobsite with the temporary access road over the structure (in the embankment next to jobsite backup office):

Deformation of the profile during backfilling (when technological break was applied):
Deformation of the profile during backfilling (when no technological break was applied):

View of the structure with technological break (final stage of construction):
View of the structure without a technological break:

An object is built with a break over the corrugated steel structure i.e. when it is tensioned to the maximum extent causing maximum peaking of the profile:
From presented cases one can conclude that additional deformations of structures can be caused by their insufficient tensioning. As mentioned above the break in backfilling when the tensioning of the structure is reaching its’ maximum value causes a tendency to reduce the tensioning. Due to the lack of soil over the tensioned structure a reduction of tensioning will follow and the further overburden soil would not be needed any longer to counterbalance the peaking and tensioning and will act purely as a ballast simply overburdening the structure. A static analysis of the theoretical deflection of the crown caused by the cover shows much higher values than those measured in reality on the jobsite. It means that a part of the overburden soil interacts with the steel structure in taking the loads which do not cause its deflection. Geometrical changes in the shape of the soil-steel structure shows asymmetry. The inclination of road grade can contribute to the increase of asymmetry.

6. CONTROL OF THE SYMMETRY OF A SHAPE

This requirement is one of six requirements of safety for soil-steel bridges. The estimation of safety in the view of change of geometry must be supported with on-site observation. It is important to verify the final shape vs. the initial one. The flexibility of a corrugated steel structure is a challenge for a contractor and inspecting engineers. Lack of control during construction makes it impossible to check whether the structure had been built properly. Based on many years of experience the author concludes that in some cases deformations exceeded allowed levels. One of the causes of failing to tension the structure properly is the lack of sufficient amount of soil around it, especially when it occurs on one side of a structure. Even if we apply special geometrical measures on this part it may turn out to be insufficient. Below one can find details of a project when proper control of symmetry allowed for correcting a deformed shape.
As one can see in order to correct the symmetry of shape the contractor had to move with excavator over the structure to upgrade parameters of soil and compaction on one side:

Observed asymmetry was corrected with a special compacting tool presented in the figure below:
DEFORMATION OF OBSERVED POINTS in the steel structures on horozontal level "Y"

coordinates "Y"

- day when assembly is completed (16-12-2008)
- deformation on the day of completion of construction (16-04-2009)
7. SUMMARY

To build soil-steel structures in a correct way one must understand soil-steel structure interaction and control deformations during construction. Thanks to data obtained one can perform remedial actions “on the fly” to keep the shape within limits. Based on measured final shape it is easy to estimate the safety factor of the finished bridge and verify it against required safety in service stage.

REFERENCES

2. Machelski Cz. ; Michalski J.B. ; Michalski B. ; Efektywny most objazdowy gruntowo-powłokowy. Inżynieria i Budownictwo. Nr 1/2006 s. 11 ÷ 13
3. Machelski Cz. ; Michalski J.B.; Obiekty gruntowo-powłokowe w obwodnicy Nowej Rudy. Drogi lądowe, powietrzne i wodne. Nr 10/2008 s. 66 ÷ 71

Streszczenie