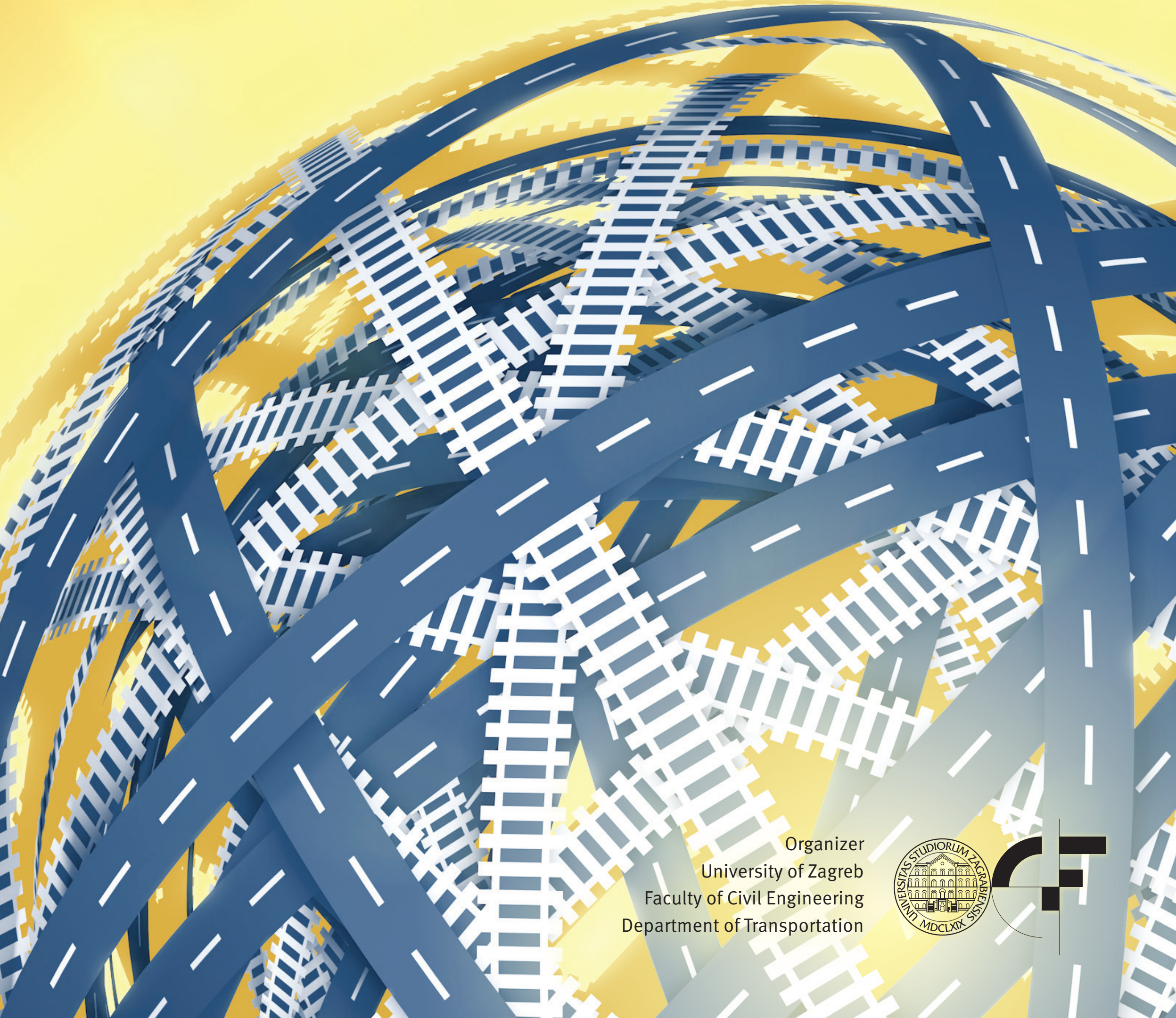
CETRA^{2016}

4^{th} International Conference on Road and Rail Infrastructure

23–25 May 2016, Šibenik, Croatia

Road and Rail Infrastructure IV

Stjepan Lakušić – EDITOR



Organizer
University of Zagreb
Faculty of Civil Engineering
Department of Transportation

CETRA^{2016}
4th International Conference on Road and Rail Infrastructure
23–25 May 2016, Šibenik, Croatia

TITLE
Road and Rail Infrastructure IV, Proceedings of the Conference CETRA 2016

EDITED BY
Stjepan Lakušić

ISSN
1848-9850

PUBLISHED BY
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Kačićeva 26, 10000 Zagreb, Croatia

DESIGN, LAYOUT & COVER PAGE
minimum d.o.o.
Marko Uremović · Matej Korlaet

PRINTED IN ZAGREB, CROATIA BY
“Tiskara Zelina”, May 2016

COPIES
400

Zagreb, May 2016.

Proceedings of the
4th International Conference on Road and Rail Infrastructures – CETRA 2016
23–25 May 2016, Šibenik, Croatia

Road and Rail Infrastructure IV

EDITOR
Stjepan Lakušić
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Zagreb, Croatia

CETRA^{2016}
4th International Conference on Road and Rail Infrastructure
23–25 May 2016, Šibenik, Croatia

ORGANISATION

CHAIRMEN

Prof. **Stjepan Lakušić**, University of Zagreb, Faculty of Civil Engineering
Prof. emer. **Željko Korlaet**, University of Zagreb, Faculty of Civil Engineering

ORGANIZING COMMITTEE

Prof. **Stjepan Lakušić**
Prof. emer. **Željko Korlaet**
Prof. **Vesna Dragčević**
Prof. **Tatjana Rukavina**
Assist. Prof. **Ivica Stančerić**
Assist. Prof. **Saša Ahac**

Assist. Prof. **Maja Ahac**
Ivo Haladin, PhD
Josipa Domitrović, PhD
Tamara Džambas
Viktorija Grgić
Šime Bezina

All members of CETRA 2016 Conference Organizing Committee are professors and assistants of the Department of Transportation, Faculty of Civil Engineering at University of Zagreb.

INTERNATIONAL ACADEMIC SCIENTIFIC COMMITTEE

Davor Brčić, University of Zagreb
Dražen Cvitanić, University of Split
Sanja Dimter, Josip Juraj Strossmayer University of Osijek
Aleksandra Deluka Tibljaš, University of Rijeka
Vesna Dragčević, University of Zagreb
Rudolf Eger, RheinMain University
Makoto Fujiu, Kanazawa University
Laszlo Gaspar, Institute for Transport Sciences (KTI)
Kenneth Gavin, University College Dublin
Nenad Gucunski, Rutgers University
Libor Izvolt, University of Zilina
Lajos Kisgyörgy, Budapest University of Technology and Economics
Stasa Jovanovic, University of Novi Sad
Željko Korlaet, University of Zagreb
Meho Saša Kovačević, University of Zagreb
Zoran Krakutovski, Ss. Cyril and Methodius University in Skopje
Stjepan Lakušić, University of Zagreb
Dirk Lauwers, Ghent University
Dragana Macura, University of Belgrade
Janusz Madejski, Silesian University of Technology
Goran Mladenović, University of Belgrade
Tomislav Josip Mlinarić, University of Zagreb
Nencho Nenov, University of Transport in Sofia
Mladen Nikšić, University of Zagreb
Dunja Perić, Kansas State University
Otto Plašek, Brno University of Technology
Carmen Racanel, Technological University of Civil Engineering Bucharest
Tatjana Rukavina, University of Zagreb
Andreas Schoebel, Vienna University of Technology
Adam Szeląg, Warsaw University of Technology
Francesca La Torre, University of Florence
Audrius Vaitkus, Vilnius Gediminas Technical University

CETRA2016 23–25 May 2016, Šibenik, Croatia
4th International Conference on Road and Rail Infrastructure

EXAMPLES OF FLEXIBLE FOUNDATIONS OF SOIL-STEEL STRUCTURES MADE OF CORRUGATED SHEETS

Czesław Machelski[1], Adam Czerepak[2], Mario Bogdan[3]
[1] *University of Technology Wrocław, Poland*
[2] *ViaCon Sp. z o.o., Poland*
[3] *Protekta. d.o.o., Zagreb, Croatia*

Abstract

Soil-steel structures are the engineering structures that also fulfil the functions of bridges, flyovers, pedestrian bridges, culverts, tunnels, subways, farm accommodation bridges or wildlife crossings. A large group of these structures serves as municipal facilities, normally shaped as closed pipes or intended for transport purposes, e.g. for the housing of the conveyor belts. They are constructed in the form of a corrugated steel structures (steel shell) and the surrounding, specially concentrated soil. They are designed in a manner ensuring a long-lasting, beneficial interaction between essential elements of the bearing system in a classic design, that is, the shell, founded on the foundation, and the soil backfill.

Keywords: soil-steel structures, corrugated sheets, tunnels, culverts

1 Introduction

The effect of interaction of the shell with the soil is observed as an apparent relief of a vulnerable shell (called bridging in reference [1]). The intensity of impact exerted by the soil on the bearing structure depends on the stiffness of the shell in relation to the backfill that surrounds it. For this reason, the soil-steel structures are divided into two principal groups: stiff and vulnerable. When designing vulnerable soil-steel structures the backfill and the surface of the road are treated as essential elements of the bearing structure [1]. In a stiff structure, they perform very different roles [1]. The steel shell in the soil-steel structure fulfils two different technical functions. During backfill laying, the shell acts as a formwork that secures the space under the structure, and during the use of the finished structure, it interacts with the soil and the surface in the transfer of constant and variable loads. The construction phase is important for the safety of the steel shell, which is exposed to the greatest displacements and internal forces. Hence, this situation is considered mainly when selecting the geometric parameters of a sheet.

Figure 1 Central support of a twin soil-steel structure

2 Classification of soil-steel structures foundations

Monographs [1, 2] present typical (currently produced) corrugated steel structures cross-section profiles. According to the foundation, shapes of steel shell cross-section profiles are divided into two groups: closed-bottom shapes (founded on a soil sub-base) and open-bottom shapes (mounted on the foundation). Shells with a closed-bottom circular shape form circular, elliptical, vertical and horizontal, as well as drop-shaped and pear-shaped cross-sections. Shells with an open-bottom shape constitute a group of arch-shaped, low-profile and high-profile cross-sections, and box-shaped cross-sections [1, 2]. According to the shape of the steel shell in a soil-steel structure, the steel shell supports, listed in Table 1, are constructed.

Table 1 Measuring results

No.	Shape of the corrugated steel structures	Type of corrugated soil-steel structure foundation	
1	closed-bottom	non-piled	on a soil sub-base
2			in a watercourse
3	open-bottom	on corrugated sheet	horizontal
4			vertical
5		on piles	non-piled
6			with a retaining wall
7			topped with a strip footing
8		on a concrete foundation	on a precast foundation
9			in the form of a beam grid
10			in the form of a solid footing

3 Closed-bottom foundations of soil-steel structures

3.1 Placement of soil bedding sub-base for the corrugated steel structures

Sand bedding is used for the construction of foundations for closed-bottom shells made from corrugated steel sheets. For structures with greater spans, an aggregate sub-base is used, on which an appropriate backfill and shell contact layer is placed. Fig. 2 shows the initial phases of the construction of the structure. The contact layer is profiled with the use of a template shaped to conform with the curvature of the shell. On such a sub-base, the lower bowl of the shell is mounted, and then the side walls are constructed from corrugated sheets. Methods of corrugates steel structures erection, sheet manufacturing technology and selection of materials are discussed in [2]. This type of foundation is used as a standard solution for closed-bottom steel shells. It cannot be used in the case of active watercourses.

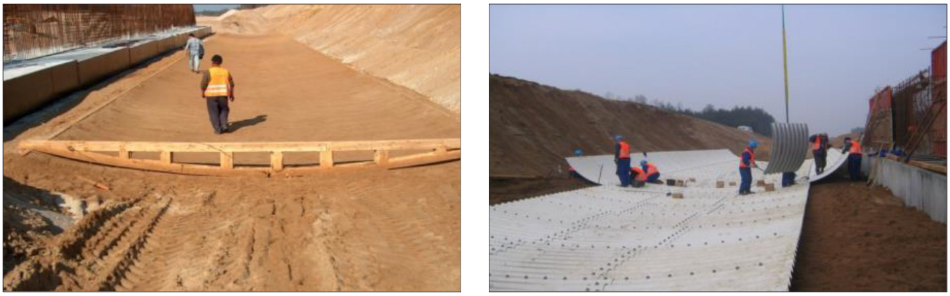


Figure 2 Classic closed-bottom foundation of soil-steel structures

3.2 Soil-steel structures placed in a watercourse

Cases when a pipe-shaped corrugated steel structure is being placed in a watercourse, without connection with the construction period, constitute a difficult task for the engineers. In such a specific situation, an inadequate shaping of a sub-base from waterlogged native soil occurs. Thus, it is important to place the soil backfill layer under the shell while maintaining the design geometry of the shell, both in cross-sections and in the axis of the tube. In [2], a description of the construction process and results of tests on the culvert was provided, as in Fig. 3.

The structure that is discussed here was built along the road from Niemodlin to Lewin Brzeski. An obstacle was a channel characterised by a constant, high water level (of 1 m), with a width of 3 m and a very low hydraulic gradient of 0.4%. The culvert was made from MP 150·50·5 corrugated steel sheet, and in its construction, 150 GL–6-type shell geometry was applied. The tube was formed from corrugated sheets in the vicinity of the point where it was placed, on a shelf with a width of 5 m, formed above the water level (approximately 15 cm).

Figure 3 Initial phases of the construction of the structure in a watercourse

Sheets were folded according to a sequential method; that is, one coat after another. After the entire steel structure was erected (the example of erection with full prefabrication), it was inserted into the channel with an excavator, which fulfilled the function of a crane. A total reconstruction period (dismantling the former structure and construction involving the placement of the asphalt surface) of the culvert was two weeks, including all downtime. The bottom of the watercourse under the shell was protected with the backfill through an appropriate process of compaction and loading process of the soil placed on both sides of the corrugated steel structure. As a result of the compaction of the soil backfill around the steel culvert, the raising of the shell occurred. In the crown of the structure, the ordinates from the inside and on the outside of the shell, as well as the height of the vertical clearance of the culvert were measured. In this way, changes in the corrugated-steel structure cross-section deformation were controlled. After obtaining an appropriate longitudinal gradient and a sufficient level of backfill above the watercourse, the road embankment could be formed in accordance with a classic formation method. The subsequent layers of backfill were compacted by repeated passing of a loader with a weight of 24 tons (roller compacting), with a simultaneous compactive effort applied by a vibratory plate attached to the compactor. Thanks to a simultaneous use of the three methods that were applied in the construction of these structures, it was possible to increase thickness of the layers that were being formed.

4 Founding the soil-steel structures on a corrugated sheet

Thanks to the soil whose compaction constantly increases, vulnerable soil-steel structures increase their stiffness [3, 4, 5], which has an impact on an increase in the ability to carry greater and greater useful loads while using such structures. This is a feature, different than in the classic bridges, characteristic of those structures in which the load-carrying capacity reduces in the course of structure deterioration process. Results of tests and numerical analyses of the constructed structures suggest that the reduction in stiffness of the shell causes the reduction in the internal forces in the shell. This means that the moving loads that are exerted on the road of the bridge are to a lesser extent transferred on a delicate shell, while there is an increase in the strain in the internal vault, formed in the soil backfill. The above conclusion suggests that one should tend to design shells with lesser sheet thickness and lower wave heights (and to resign from overlays). In an extreme case, experiments also indicate the possibility of using a flat sheet [4].
A comparison of the flow of forces in the classic arched bridge and the structure formed from a vulnerable shell immersed in the soil shows that there is a significant, visible difference in their trend [4]. In the soil-steel structure, an internal vault is formed in the backfill, which carries the loads of the soil surcharge, formed above the shell up to the native soil layers. In the literature, this phenomenon is called bridging [1, 2]. Therefore, in the soil-steel structure, the construction of a stiff foundation is not necessary, as the solid foundations restrict the flow of forces in the backfill. Thus, it can be concluded that a vulnerable support is also adapted to a vulnerable steel sheet, as shown in the examples of structures discussed below. A vulnerable support of a steel shell facilitates the formation of a natural vault in the soil backfill and in the native soil base [4]. In this case, it is important to design the shape of the shell similar to the parabolic arch shape. Another issue that comes to mind in connection with the above specific features of the bridges discussed here, is the idea of searching for benefits that result also from the manner of the foundation of such bridges. Selected examples of structures constructed with the use of vulnerable supports for the open-bottom shells are provided below.

4.1 Supporting the soil-steel structures on a horizontal corrugated sheet Support on a wall made from corrugated sheet

Open-bottom corrugated steel structure (Fig. 4) together with a component of the foundation made from corrugated sheet during the process of erection on the previously prepared subbase. The whole steel structure of this built feature is being placed on gravel bedding with the use of a crane. This type of foundation is often used in the engineering structures when time is of the essence. In this case, there is full prefabrication of the corrugated steel structures, including the support. The effectiveness of this method is confirmed by experiments performed as part of numerous tests on the structures constructed in this manner.

Figure 4 Erection of the corrugated steel structure with an attached support in the form of a flat sheet

4.2 Supporting the soil-steel structures on a horizontal corrugated sheet Support on a wall made from corrugated sheet

The example of a prototype support of a corrugated steel structure on a delicate wall (vertical corrugated sheet) was designed on the structure located along a local road with little traffic, but intended for heavy weight vehicles. In fact, the main load exerted on this structure is the lorries transporting spoils excavated material from quarries to the Bartnica train station near Nowa Ruda [2]. The corrugated steel structure has been designed from low-profile MP 150·50·5 sheet with a half-circular shape and a span of L = 5.00 m. The width of the structure was B = 15.0 m. The wall is immersed in the native soil down to the depth of approx. 1.00 m. In this case, the essential element of the support structure is a groin made from a circular corrugated sheet sector that was used to construct the wall and the shell. The soil backfill laid behind the corrugated steel structure is protected from the watercourse side with a corrugated sheet wall, as in Fig. 5. The first built-in component of the support is a corrugated sheet, placed vertically in a watercourse, as in Fig. 3. Its stabilisation in the support line is achieved with the use of the soil material obtained from the place of construction. This wall is used for fixing the groin, as in Fig. 5. The groin, made from circular-sector-shaped sheets, is attached to vertical sheets with the use of screws. The groin rests on low-strength concrete bedding. In the use phase, it is supposed to protect the structure of the shell against settlement. Corrugated sheets of the shell with the supporting part are joined in a classic (for these shells) overlap fashion.

Figure 5 Corrugated sheet wall with a groin supported on the native soil

5 Supports on piles

Fig. 4 presents the examples of prototype soil-steel structures constructed using the support on piles, which were arranged along a single line. This case is completely different from the spatial arrangement of piles topped with a cap beam, used for classical foundations. The greatest success was the foundation of the shell made of flat sheet on piles made of steel sections. It was constructed in the ring road region of Niemcza with the use of a specific foundation for a soil-steel structure, as shown in Fig. 6 and discussed in paper [3].

5.1 Supporting the corrugated soil-steel structures directly on piles

A pile support made of steel pipes and used for the structure made of corrugated sheets with an MP 200·55·7 profile was designed and constructed in Świdnica [3]. The structure was created in the location of a formerly used flyover with a steel structure. The inlet and the outlet were finished with reinforced concrete portals with wings situated parallel to the axis of the track. The span of the shell in the support line is Lo = 9.49 m, and its maximum horizontal clearance is L = 10.31 m. The height of the shell measured from the support level up to the crown is h = 5.50 m. The shell was mounted from the sheets attached to corrugated sheet of the shell from the obstacle side. The space between the supporting sheets, as in Fig. 6, was filled with concrete.

Figure 6 Supporting the soil-steel structures on piles

5.2 Retaining wall founded on reinforced concrete piles

The support on reinforced concrete piles was designed in a tunnel with a length of 67.30 m in Biernacice. The span of the steel shell in the support line is Lo = 9.50 m, and its maximum horizontal clearance is L = 10.36 m. The height of the shell measured from the support level up to the crown is h = 5.90 m. The shell was made from a corrugated sheet with a low MP 150·50·7 profile. The sheet of the shell was directly supported by a reinforced concrete wall with a height of 1.40 m and a thickness of 0.3 m. The structure of the retaining wall was founded on reinforced concrete piles with a diameter of 60 cm and pile spacing of 3 m, drilled in the soil down to a depth of 6 m, as in Fig. 7. Thus, the thickness of the wall was half the diameter of the pile, which allowed for extending the half of the pile longitudinal reinforcement from the pile. The inlet and the outlet of the tunnel were finished with reinforced concrete portals with wings situated parallel to the axis of the track, with a length of 10 m each.

Figure 7 Supporting the soil-steel structure on a wall topping the piles

6 Concrete foundations

6.1 Precast concrete footings

The construction of concrete strip footings can also be accomplished with the use of prefabrication. In the example shown in Fig. 8. the used foundation was a shallow foundation on the level of the soil, though with the anchoring of precast components, with piles made in the monolithic technology. The reinforcement made of these two components was joined in the crowns drawing the precast components in the strip footing. The method of the erection of the foundation and the shell is presented in Fig. 8.

Figure 8 Supporting the soil-steel structures on piles

6.2 Supporting the soil-steel structures on a beam grid

The method of support that is analysed here was designed in a soil-steel structure constructed as a road tunnel under a ski trail in Karpacz, Lower Silesia Province [13]. It was made in an open-cut excavation, with walls protected with the use of prestressed soil anchors. A steel shell made of corrugated sheet type MP 200·55·7, with a typical VBH19 shape, was used for tunnel lining. Essential catalogue dimensions of the cross-section of the tunnel are as follows: a span of L = 11.15 m, a height of h = 6.48 m, and an upper radius of R = 7.07 m. The steel shell is founded on a concrete foundation, and the distance between the shell support points is Lo = 10.23 m. In a top view, the axis of the tunnel is geometrically complex, resembling the C letter, and the road gradeline slope is variable. The length of the tunnel is approx. 100 m. A specific method consisting in supporting the shell on a beam grid was applied for the structure. Classically constructed concrete footings were joined with transverse, reinforced concrete components.

6.3 Solid foundations

The foundation applied for the open-bottom, arched-shaped steel shells is most frequently (as a general rule) the reinforced concrete foundation, as in Fig. 9. This applies to both concrete layers and the ones made of corrugated sheets. The concrete foundation of the largest dimensions was designed and constructed in a structure to be used under the shell made of corrugated sheets, with a base width of 4.0 m and a height of 3.1 m; and a length of the structure was nearly 60 m. On such a foundation, it is possible to successfully construct even a classic concrete bridge.

Figure 9 Soil-steel tunnel foundation on a beam grid / Solid foundation of a soil-steel structure

7 Conclusions

Observably, in vulnerable soil-steel structures, the impact exerted by the backfill on the steel shell immersed in the soil is lower than in the case of stiff structures. This is due to the fact that, in these structures, a natural vault is formed in the soil backfill. Such a vault is limited from the top by the road surface, and from the bottom by the curve of the steel shell. In the literature, this phenomenon is called bridging [2], although in a natural situation, it occurs as a result of the formation of an opening inside stable rock mass, and not in an embankment of the constructed soil-steel structure. In such a situation, a constant weight of the soil surcharge (the soil backfill and the road base) and the moving loads cause much smaller reactions of the shell towards the foundation than in the case of a stiff (classic) arched structure. The conclusion of this discussion is that vulnerable shells should be constructed on vulnerable supports, rather than solid foundations. Thus, the examples of vulnerable foundations of the soil-steel structures presented in the paper are also adapted to lightweight structures of shells made of corrugated sheets. Another relevant feature of the supports presented here lies in the technological qualities of their construction in difficult terrain conditions. The results of the studies conducted so far suggest that a support has a significant impact on the internal forces and deformation of soil-steel structures.

References

[1] Machelski, C.: Budowa konstrukcji gruntowo-powłokowych. Dolnośląskie Wydawnictwo Edukacyjne, Wrocław 2013.

[2] Machelski, C., Antoniszyn, G., Michalski, B.: Influence of Live load on the Soil-steel shell Bridge Founded on Elastic Supports. Studia Geotechnica et Mechanica. 2-4/2006, pp. 65-82

[3] Machelski, C., Michalski, J.B., Michalski, B.: Case study of steel shell structure supported on piles. Archives of Institute of Civil Engineering. I European Symp. Rydzyna 23-24 April 2007.

[4] Machelski, C., Michalski, J.B., Janusz, L.: Application of Flexible Foundations under Soil-steel Bridges. 89th Annual Meeting Transportation Research Board, Washington, January 11-15, 2010, pp. 10-0950 (CD).

[5] Machelski, C., Mońka, M.: Prognosis of deformation of a soil-steel structure on steel, corrugated, flexible supports. Archives of Institute of Civil Engineering No. 12/2012, pp. 147-156.