BURIED STEEL-SOIL ARCH STRUCTURES IN EUROPE

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SUMMARY

Paper will present steel-soil arch constructions built in Europe in the last 20 years. Span dimensions of structures of this type usually fluctuate in the range of values lower than 8 m, whereas in this paper authors will focus on review of long span structures. For such, constructions with spans over 17 m long have been recognized. The reader will get acquainted with the upper limits of applicability of flexible constructions. Authors will describe structures with record span lengths, achieved by results of the latest analysis of manufacturers R&D departments. Various aspects of creation of this type structures will be shown, starting from dimensioning questions, through assembly technics to construction behaviour. Paper will introduce results of static analysis in every phase of construction performance, taking into account steps of the backfilling process, phase of test loads and also phase of service. Paper will include in its scope not only road and railway structures, but also ecological overpasses. Aesthetic and economic aspects related to the execution of long span steel-soil arch construction will also be presented.

Keywords: *Arch, steel-soil structures, buried structures, backfill, bearing capacity, large-span, design, culverts, bridges, design.*

1. INTRODUCTION

Corrugated steel structures are successfully used in Europe for over 30 years. Initially soil-steel structures were principally used for small span culverts. Such kind of objects are excellent alternative to reinforced concrete structures, mainly due to faster assembly time as well as cost effectiveness.

The increasing popularity of soil-steel structures has contributed to the growth of challenges – rising spans. At the beginning there were used only shallow types of corrugation. For helically corrugated culverts utilized 68x13, 100x20 and 125x 26 mm. These parameters allowed to design pipes up to 4.0 m span. At first for the structures made of corrugated steel plates used a 150x50 corrugation than 200x55. This allowed to build soil-steel bridges up to approximately 12.0 m span. In the 1980s developed a new type of corrugation 381x140 mm which allowed while appropriate configuration of steel plates to achieve a span of 25.5 m. The need of larger spans continue to grow. The high strength steel appeared on market. All this replenished by an economic factor had an impact on the need for a new corrugation which could make it possible to achieve spans up to 40.0 m. The first implementations of superstructures with 500x237 mm wave dimensions were in Canada, however they were only testing structures with small spans.

The first structure of this type in Europe with span equal to 25.74 m is currently under construction in Poland.

2. CASE STUDIES

Paper presents large span arch structures located in Europe. Due to the large number of already built structures the authors recognize structures with spans over 18m as these which fulfil the criteria of „large span". Just a position in order of the time of embedded are introduced in the Table 1.

Table 1. *List of structures with span > 18 m.*

No.	SuperCor Type	Span B [m]	Rise H [m]	Bottom length [m]	Place of built	Country of built
1	SCA-35	20.00	7.42	63.32	E20 Railway Line Warsaw-Rzepin (LK3) m. Kunowice	Poland
2	SCA-35	20.00	7.42	63.32	E20 Railway Line Warsaw-Rzepin (LK3) m. Kunowice	Poland
3	SCA-33	19.50	5.97	67.89	A-4 Zgorzelec - Krzyżowa, PZ-51 km 24+900	Poland
4	SCA-33	19.50	5.97	67.89	A-4 Zgorzelec - Krzyżowa, PZ-51 km 24+900	Poland
5	SCA-33	19.50	5.97	67.89	A-4 Zgorzelec - Krzyżowa, PZ-52 km 31+000	Poland
6	SCA-33	19.50	5.97	67.89	A-4 Zgorzelec - Krzyżowa, PZ-52 km 31+000	Poland
7	SCA-31	19.00	5.89	64.70	A4 Szarów - Brzesko, PZ - 49A km 477+775 - K1	Poland
8	SCA-31	19.00	5.89	64.70	A4 węzeł Szarów - Brzesko, PZ - 49A km 477+775 - K2	Poland
9	SCA-28	18.00	5.55	87.92	S5 Poznań - Wrocław section. Kaczkowo - Korzeńsko, Construction WZ-50c – K1	Poland
10	SCA-28	18.00	5.55	87.92	S5 Poznań - Wrocław section Kaczkowo - Korzeńsko, WZ-50c - K2	Poland
11	SCA-28	18.00	5.55	87.92	S5 Poznań - Wrocław section Kaczkowo - Korzeńsko, WZ-55 – K1	Poland
12	SCA-28	18.00	5.55	87.92	S5 Poznań - Wrocław section Kaczkowo - Korzeńsko, WZ-55 – K2	Poland
13	SCA-28	18.00	5.55	87.92	S5 Poznań - Wrocław section Kaczkowo - Korzeńsko, WZ-61c - K1	Poland

14	SCA-28	18.00	5.55	87.92	S5 Poznań - Wrocław section Kaczkowo - Korzeńsko, WZ-61c - K2	Poland
15	SCA-28	18.00	5.55	15.32	Rebuiding of DW753 section Huta Nowa - Wólka Milanowska km 13+796,16 do km 14+847,75 Mała Pętla Świętokrzyska	Poland
16	SCA-28	18.00	5.55	75.12	A4 Rzeszów-Korczowa section Radymno-Korczowa PZ-48 w km 662+425 K-2	Poland
17	SCA-28	18.00	5.55	75.12	A4 Rzeszów-Korczowa section Radymno-Korczowa PZ-48 w km 662+425 K-3	Poland
18	SC-29NA	18.00	7.00	30.56	A4 Jarosław-Radymno woj. Podkarpackie m. Chłopice	Poland
19	SCA-28	18.00	5.55	66.37	S8 Syców-Sieradz section III: Wieruszów - Walichnowy PZ-3 w km 89+364,49 - K1	Poland
20	SCA-28	18.00	5.55	66.37	S8 Syców- Sieradz section III: Wieruszów - Walichnowy PZ-3 km 89+364,49 - K2	Poland
21	SCA-28	18.00	5.55	66.37	S8 Syców-Sieradz PZ-6 km 93+110,9 - K3	Poland
22	SCA-28	18.00	5.55	66.37	S8 Syców-Sieradz section III: Wieruszów - Walichnowy PZ-6 w km 93+110,9 - K4	Poland
23	SC-63S Special	18.46	7.16	26.06	Zgłowiączka river bridge repairing in Włocławek city	Poland
24	SC-86SA	22.26	11.13	40.46	S8 Wrocław –Białystok, km 561+043,28 to km 575+955,00 (DES8)	Poland
25	SC-80S	20.67	10.35	13.38	Nova Bystrica-Oravska Lesna, 2005	Slovakia
26	SC-80S	20.67	10.35	15.32	Nova Bystrica-Oravska Lesna, 2005	Slovakia
27	SCA-39	21.50	6.93	31.54	Mankovice, 2007	Czech Republic
28	SCA-39	21.50	5.46	23.81	Butovice, 2009	Czech Republic
29	SCA-39	21.50	5.46	27.22	Butovice, 2009	Czech Republic
30	SC-40NA	22.00	5.92	63.32	Northern Marmara Bypass of Istambul City	Turkey

In the next part some of the interesting bridges will be shortly described.

2.1. Structures in Slovakia

In 2005 and 2006 the new road No 520 was built in Slovakia from Nova Bystrica to Oravska Lesna two steel arches were built. Due to hilly topography road was design to minimize numbers of climbs and descends. Two very deep valleys were crossed with use of corrugated steel arch buried structures. It were the regular arches with 20.670m Span and 10.335 m Rise dimensions. Both were built under ca 3.5 m cover with the MSE headwalls. Both structure were built with use of 7 mm corrugated steel plates. They were also square cut at inlets and outlets. Due to very high normal force in a steel the EC (Encased Concrete) Ribs (t = 7 mm spaced 762 mm c/c – i.e 100%) were used.

Fig. 1. *Structure assembly Nova Bystrica.*

2.2. Structures in Czech Republic

In period of 2007/2009 the new section of D1 Motorway was built in Czech Republic between towns Butovice and Mankovice. On this very short section three steel arches were built. Structures pass through the local traffic under the D1 Motorway. There were used a low profile Arches with Span 21.5 m and Rise 6.93 m dimensions. To minimize the quantity of Earth works only 1.0 m of cover was designed. To carry the heaviest traffic structures were built with 7 mm steel plate reinforced with 7mm EC Ribs spaced 1524 mm c/c (i.e. 50%)

Fig. 2. *Inlet view Mankovice.*

2.3. Structures in Poland

In years 2004 and 2005 international electrified railway line E20 Berlin-Warsaw has been partially modernized. Line was not protect against the migration of wild animals. Due to that in 2007 Polish Railway Authority has commissioned a "design and build" project of two animal crossings located over double track railway to allow the migration of animals on the territory divided by this line.

To cross double track line the 20.0 m Span and 7.424 m Rise low profiles arches were built. Location of animal overpasses was fixed with Board of Forestry. Structures was designed for Class "C" Acc. To PN-85/S-10030 Bridge Structures. Loads (4 x 100 kN/axle). Advantage of this project was as short as possible erection time and no traffic stops.

Fig. 3. *Inlet view Kunowice/Gajec.*

3. RESEARCH AND DEVELOPMENT

Due to rapid development of road network corrugated steel plate business must follow the market and continuously improve their products. Thanks to this we can see how the technology evaluate. Corrugations became more stiff, plates are even thicker, steel used for manufacturing is much stronger.

Limits of spans are everyday overtaken. This, what was not possible to do a few years ago, now can be reached easily. Corrugations increases their stiffness a few times. First helically corrugated pipes were made in 68x13 mm, now we are able to corrugate 500x237 mm.

In cooperation with the Scientist from Technical Universities all over the world we still improve the calculation methods. We can check the calculation method with use of FEM software. We are able to calculate internal forces based one the structure deformation. Finally, even the most advanced computer calculations can be verified by in-situ tests.

One of the in-situ test of large span structure was performed in Rydzyna (Poland) in 2009/2010. Tested was a low profile arch of 17.67 m span and 5.55 m Rise dimensions. Structure was made of 7.00 mm steel plate barrel without any additional rib plates. It was backfilled with use of well graded Cu=d60/d10=6.63 medium sands compacted to min 98% of Standard Proctor Density.

Fig. 4. Test structure during backfilling.

With use of Plaxis FE Software we tried to adjust the soil model to obtain crown point deformation similar to test value.

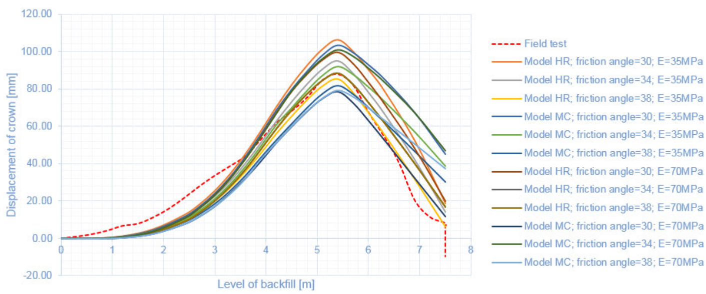

***Fig. 5.** Relative displacement of the crown point.*

As shown on the Fig. 5 if the soil model is scaled well the difference between calculated and measured value of the stresses should not exceed 25%.

Where is the limit ? The biggest in Europe, probably the biggest in the World corrugated steel structure is during construction now in northern part of Poland. The 25.74 m span structure has been assembled and it became to be backfilled soon.

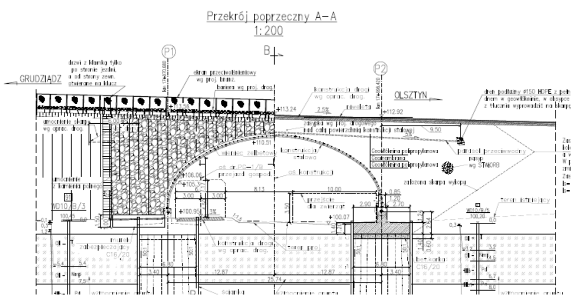

***Fig. 6**. UltraCor in Ostróda (Poland) cross section.*

Structure was designed to carry the heaviest load of Class “A” (4x 200 kN/axle) Acc. to polish standard PN-85/S-10030 Bridge structures. Loads. To confirm the static analysis results ViaCon Poland (steel structure supplier) with cooperation with Budimex S.A. (General Contractor) will perform the strain gauges and steel shell deflection monitoring during backfilling and for final stage of construction including the Live Load test. A long term observation will be also performed.

Fig. *7. UltraCor in Ostróda assembly - birdeye view.*

Structure was instrumented with set of 48 strain gauges and additionally in five different cross sections with nine geodetic measurement points each what gives total 45 measurement locations.

Fig. 8*. Strain gauges installation.*

4. CONCLUSION

Corrugated steel buried structures are commonly used in a civil engineering projects. For small spans (up to 7-8 m) closed profile are use much often then Arches. When the span increase up to min 10-11 m arches became much more cost effective. For a years of seventy of 20-th century corrugated steel arches were used in road and railway infrastructure in Europe Since late years of ninety 20-th century became very popular in Central and Eastern Europe. In growing Markets this technology was strongly developed especially to carry the heavy loads and to cross even larger spans. The question is: Where is the limit?

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