Flexible Engineering Structures from the Corrugated Metal Sheets - Comparison of Costs of Solutions used in the Road Building

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Abstract. The flexible structures from the corrugated metal sheets are used in particular in the road building, especially as passages for animals. Easy and quick assembly, as well as lower realization costs when compared to the traditional solutions increase interest in such structures. Availability and variety of systems allows for searching for solutions which are the best and optimal in the economical range. The article presents the comparison of costs of the basic materials used in various systems of flexible structures from the corrugated metal sheets. In order to determine the costs of the material solutions the data for two systems used in Poland (for construction of the upper passages for animals) since 2008 have been used. The cost estimation for the basic materials required for realization of 1 m² of the flexible structure from the corrugated steel sheets have been prepared with use of prices obtained directly from the Polish contractors and manufacturers, as well as process included in the quarterly information (Sekocenbud). The difference of prices of materials available on the market allows the investor for selecting the structure depending on the needs and financial possibilities, as well as for achieving some savings. The savings in case of purchasing sheets of identical parameters (thickness, profile characteristics) are from approx. 4% to 8% per 1 m² of sheet. The connectors in form of bolts M20 cl. 8.8 of various lengths are an expense from 3.00 PLN to 3.50 PLN. Those values may seem low, but taking into consideration amounts connected with construction of many square meters of structure they may become very important factor in the total investment costs.

1. Introduction
The first applications of the flexible structures reach the end of the 19th century [1]. Currently the flexible structures from the corrugated metal sheets are commonly used in the road building as passages, bridges, tunnels, pedestrian subways, agricultural passages, passages for animals. In particular the last use is especially desired due to the harmful influence of the communication investments on free migrations of animals, as there are many important environmental areas in Poland inhabited by rare species, like elks, bison, lynxes, or wolves. On one hand we have barrier influence of roads, fragmentation of animal habitats and crossing of ecological corridors [2, 3], as well as necessity of building the passages for animals as minimization of unfavourable influence of roads. On the other, we have structures from the corrugated metal sheets which are easy in designing due to lower number of details, readily available portfolio of profile drawings, and prepared base of strength calculations for the typical applications, quick in assembly, and less expensive in realization when compared to the traditional solutions. The corrugated metal sheets are used in construction of structures of either lower and upper passages [4]. The passages for animals are divided into the following types [5]:

a) in respect of dimensions and fulfilled functions:
- small passages - mainly for amphibia and reptiles,
- medium passages - mainly for small and medium mammals,
- large passages - mainly for big mammals.

b) in respect of position of road grade line:
- upper passages - located above the road on the footbridges, overpasses, or tunnels in which the road is located,
- lower passages - located below the road in the tunnels or culverts across the road embankment, or under the overpasses.

c) in respect of connection with other functions:
- independent passages,
- combined passages (with the dirt roads or water course).

Classification including size, fulfilled functions, and position in respect of the road grade line divides the passages into the following types:
- small lower passages,
- medium lower passages,
- large lower passages,
- medium upper passages,
- large upper passages.

2. Materials used for flexible engineering structures from the corrugated metal sheets

The engineering objects are made from flexible structures consisting of spiral-coiled sheets and sheets connected with bolts [6]. The spiral pipes are manufactured in a continuous way from the galvanized steel sheet, which is then subjected to crimping in the bending machine and connected with use of machine seam depending on designed diameter. In order to protect it from corrosion the sheet is covered with special protective foil [7]. The separate sheets are obtained in the cold rolling process. In the prepared elements the holes are drilled for the bolt connections. The corrugated form of sheet increases the element rigidity and the wave dimensions are strictly connected with desired and required rigidity. The most common waves are: 150 x 50 mm, 200 x 55 mm, 381 x 140 mm, where the values are the wave length and height. The sheet dimensions as well as bolt holes number and spacing depend on the wave profile, structure dimensions, and sheet location in the structure cross section. The sheet length is the multiple of axial distance between the bolt holes located along the longer edge.

The individual elements from the corrugated steel sheets are connected with use of galvanized bolts, and the connection method is designed by the structure manufacturer. The connectors (bolts, nuts, washers) are selected according to the structure type and should fulfil the requirements specified in appropriate standards. The most commonly used bolts are M20 of class 8.8 and of length from 32 to 75 mm. The bolt length depends on the sheet thickness. The common shapes of bolt heads include hexagons, cones, and cylinders. All bolts must be tightened to the specified torque. The tightening torque must be in range of 240 - 450 Nm depending on sheet thickness and structure span. Exceeding the torque limit value may cause incorrect operation of the structure.

The structures made from corrugated steel sheets are placed on the reinforced concrete foundations, and fixing consists in placing the structure with welded flat bar in the hole made in the foundation, and then placing the concrete or fixing with use of bolts to the anchored channel bar.

The structures are protected with dip zinc coating, alu-zinc coating, paint coating, or polymer coating. While selecting the coating thickness for a given structure it is required to assess the environmental conditions, technological possibilities, and required durability. An important element influencing safety during the structure operation is the backfill. It must fulfil the specified requirements during the object construction and during many years of operation.

In case of some objects from the corrugated sheets it is required to use the additional elements, like unloading slab (from corrugated sheets or reinforced concrete), transverse bracing, longitudinal bracing, reinforcing of the object inlet and outlet. They are aimed for increasing the load capacity and reducing the structure deformations.

The article presents the comparison of costs of the basic materials used in various systems of flexible structures from the corrugated metal sheets.
3. Prices of the basic materials used in the flexible structures from the corrugated metal sheets

In order to determine the costs of the material solutions the data for two systems (A and B) used in Poland (for construction of the upper passages for animals) since 2008 have been used. The cost estimation for the basic materials required for realization of 1 m² of the flexible structure from the corrugated steel sheets have been prepared with use of prices obtained directly from the Polish contractors and manufacturers, as well as process included in the quarterly information (Sekocenbud - issue no. 2/2017 [8]).

Table 1 presents prices (1 PLN = 0.26 USD) of 1 m² of the corrugated steel sheet of various thicknesses but comparable profile characteristics (wave), and table 2 presents the summary of prices of the basic connectors for the corrugated steel sheet used in the flexible engineering structures.

**Table 1.** Prices of 1 m² of the corrugated steel sheet used in the flexible engineering structures.

| No. | Specification                           | Net price in PLN per 1 m² |
|-----|----------------------------------------|--------------------------|
| 1   | Corrugated sheet 7 mm thick - system A | 509.48                   |
| 2   | Corrugated sheet 5.5 mm thick - system A | 440.52                 |
| 3   | Corrugated sheet 4 mm thick - system A  | 335.91                   |
| 4   | Corrugated sheet 3 mm thick - system A  | 272.90                   |
| 5   | Corrugated sheet 7 mm thick - system B  | 490.00                   |
| 6   | Corrugated sheet 5.5 mm thick - system B | 402.27                 |
| 7   | Corrugated sheet 4 mm thick - system B  | 315.90                   |
| 8   | Corrugated sheet 3 mm thick - system B  | 256.65                   |

**Table 2.** Prices of the basic connectors for the corrugated steel sheet used in the flexible engineering structures.

| No. | Specification                        | Net price in PLN per 1 piece |
|-----|--------------------------------------|-----------------------------|
| 1   | Bolt M20 cl. 8.8 70 mm long          | 3.50                        |
| 2   | Bolt M20 cl. 8.8 63 mm long          | 3.37                        |
| 3   | Bolt M20 cl. 8.8 50 mm long          | 3.20                        |
| 4   | Bolt M20 cl. 8.8 37 mm long          | 3.00                        |
| 5   | Anchor ø 20 365 mm long              | 9.75                        |
| 6   | Anchor ø 20 225 mm long              | 7.30                        |
The sheet thickness and the wave characteristics are determined with use of calculations and they depend on the external loads, structure form, structure span, and environment aggressiveness. However, while analysing data from table 1 and comparing sheets of identical parameters (thickness, profile characteristics) but used in different systems the difference in the purchase cost of those sheets is seen. The net price of 1 m$^2$ of 7 mm thick sheet in system A is higher by 19.48 PLN from the price of 1 m$^2$ of 7 mm thick sheet in system B. That difference is almost 4%. The analysis of prices of 5.5 mm thick sheets reveals that the purchase cot of 1 m$^2$ of sheet in system A is440.52 PLN, while in system B it is 402.27 PLN (difference of over 8%). In case of 4 mm thick sheets system A has value higher by almost 6%. Very similar price relation is seen in case of 3 mm thick sheets - 1 m$^2$ of the corrugated sheet (used in the flexible engineering structures) of system A is more expensive by almost 6% from 1 m$^2$ of sheet of system B.

A required element for connecting the corrugated steel sheets is bolts. Their length depends on thickness and number of connected sheets. Comparing the prices of those basic connectors (with nut and washer) in table 2 one may see that the price increase is directly proportional to their length. The difference in the purchase price for bolt M20 cl. 8.8 of length of 70 mm and bolt M20 of the same class and length of 63 mm is approximately 4%, for bolt M20 cl. 8.8 of length of 63 mm and bolt M20 cl. 8.8 of length of 50 mm - 5%, while for bolts (cl. 8.8) 50 mm and 37 mm it is 6%.

An important element of correct fixing of the structure from the corrugated sheets are the anchors, channel bars and flat bars, which prices depend on their basic dimensions. Analysing data in table 2 and data included in the quarterly information of “Sekocenbud” one may see that the increase of the geometric parameters is correlated with the increase of prices.

The difference of prices of materials available on the market allows the investor for selecting the structure depending on the needs and financial possibilities, as well as for achieving some savings.

4. Summary
Construction of roads poses a threat for the natural environment. It is necessary to use the passages for animals. They allow the animals to use terrain located on both sides of the road and for moving to distant locations (the basic function of passages for animals, particularly important for protection of rare species having significant spatial requirements), influencing the maintaining of genetic variety of many species of animals. Currently used material and design solutions allow for very large possibilities of technical realization of such objects. The passages for animals are constructed from steel, concrete, and plastics. For over twenty years there are more and more small bridges and culverts from the corrugated steel sheets designed and constructed in Poland. They are easy in designing due to lower number of details, readily available portfolio of profile drawings, and prepared base of strength calculations for the typical applications, quick in assembly, and less expensive in realization when compared to the traditional solutions.

The comparison of costs of the basic materials used in the engineering structures from the corrugated steel sheets allows for determination of some more or less “economical” solutions. However, while selecting the system and materials it is also required to take into consideration the realization potential, experience, and know-how.

The savings in case of purchasing sheets of identical parameters (thickness, profile characteristics) are from approx. 4% to 8% per 1 m$^2$ of sheet. The connectors in form of bolts M20 cl. 8.8 of various lengths are an expense from 3.00 PLN to 3.50 PLN. Those values may seem low, but taking into consideration amounts connected with construction of many square metres of structure they may become very important factor in the total investment costs.

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