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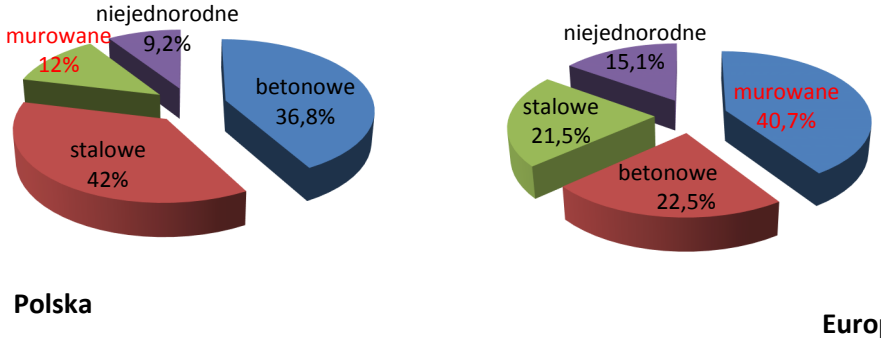
Strengthening the masonry bridges with use of corrugated steel plates

Abstract: The following work presents the problem of old arched bridges, built a long time ago as masonry constructions and their revitalization. Nowadays this kind of railway structures is very popular and extensively used in Europe. Moreover, in Poland there is a significant number of them. This work considers the possibility of strengthening these objects with using the corrugated steel plates as the material which is already being used in soil-steel structures. The usage of steel coatings is very convenient while providing any construction works as they are taking place underneath the arch. This is not causing any restrictions of movements on the bridge as only a small area under the bridge is occupied. According to different coatings geometry, this kind of technology is being presented based on already existing objects as the examples. The following study proves high efficiency of strengthening the masonry vaults with the usage of corrugated steel plates.

Keywords: masonry vaults; coatings of corrugated steel plates; strengthening technology

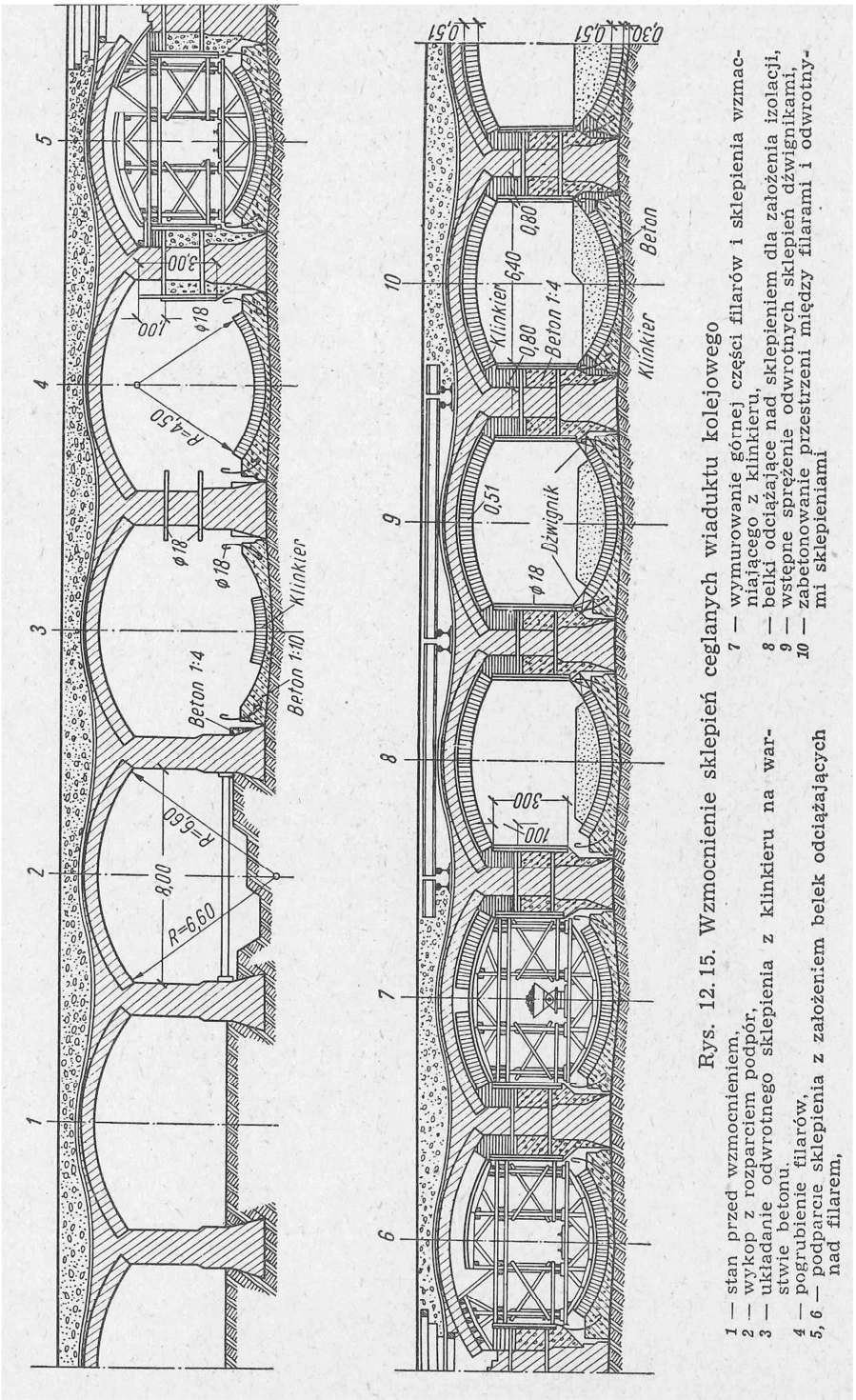
Arched masonry bridges are belong to the oldest objects currently operated. Summarized in Fig. 1 of bridges indicates that the brick buildings take on a European railway routes by far the highest position while in Poland, their share is much smaller - but significant. In the case of road bridges participation masonry is even smaller [2]. Determining the current capacity in use is difficult to determine because they are designed over a century ago to a completely different load moving than the present. It is important in assessing the current condition [2]. However, the characteristic feature of the static calculation vaulted is that they mostly carry their own weight and equipment in this substructure of the road surface. For this reason, even a slight strengthening of the structure results in significant improvements in capacity use, of course taking into account the degradation of the ceiling [2], which is the subject of the article.



1. Percentage share of construction material in railway bridges [2]

Strengthening facilities vaulted dealt with for a long time using the technology and material of that time [1]. The technological recommendations insistence on the need to connect the reinforcement of concrete with a vault. For this reason, it was very rare to strengthen concrete arches and in the case of reinforced concrete structures has not occurred [1]. So it was possible to combine concrete with brick vaults of brick and stone. At the recommended to strengthen the concepts

stated in [1] was preferred thickening the ceiling of the lower surface. It was connected with the expansion of the supports (pillars and abutments) and foundations. Fig. 2 shows one example of a brick strengthening property - in this case bold vaults made of clinker. The scope of works in such a concept of strengthening was huge!



2. Strengthening technology brick vaults of railway viaduct [1]

This elaboration presents used nowadays ways to strengthen masonry vaults using corrugated plates. In this group, depending on the shape of the coating, there are three geometries coating:

A. in the closed shape, used in *relining*;
B. in high profile, based on the foundation of object;
C. low-profile, mounted on a support under the vault.

The choice of one of these solutions affect the technical possibilities of reconstruction and costs. Important may be communication situation and thus the ability of exploitation (with limitations) facility during building works - as in the examples discussed in the technical work.

Relining as a way of strengthening culverts

A classic example of strengthening the culvert is relining. A similar technology is also used for the strengthening small arched bridges. In the implementation of this technology is used a coating from corrugated steel plates and concrete and composite prefabricates. Both amplification methods of bridges are mutually competitive as seen in application [5]. When it comes to culverts usually performed to strengthen them by incorporating into the interior of the existing building and a new construction of a sealed the space therebetween filled with concrete or other, suitable coupling material [3]. This method is called in the technical literature relining.

Relining is an effective way in case of expanding roadway and sidewalks and adding bike path. In such cases there may be different structure and the roadway in the area of broadening. The advantage of *relining* is the ability to carry out all the work without excluding the object from exploitation. It avoids also an alternative solution in the form of detour object used in the case of the demolition of the existing structure. Many examples of this technology are shown in [3].

To *relining* are used corrugated steel plates as objects of ground-coating [3, 4]. There are also used ferroconcrete prefabricated of tubular shape and a box shape and a tube of polyester or composites like GRP. Important meaning on decision, which type of strengthen should be used have: a geometry of the existing facility and the ability to change shape (reducing the useful cross-section) and the technical conditions of soil and water.

Examples of arched bridges strengthen

Figure 3 shows the strengthening of the object station in suburban of Philadelphia, Pennsylvania state, USA. The construction of the object consists of 7 stone vaulted arches. The bridge was opened 150 years ago and since then has undergone some minor repairs and reinforcements. Eventually it was decided that the 4 arches require strengthening steel casing corrugated profile SC 381×140×5 used in facilities with high load [5]. Span of arches 14,83 m and their width 7,39 m. Coating of strengthening construction was assembled at the workplace. Then merged sheets placed on steel rails and raised across the reinforced arches, as shown in figure 3. The space between the new design of sheet metal and arc vaulted in each case has been filled with pumped into the cement grout. After curing the mixture coating steel works with a vaulted ceiling. Renovation of this property was completed in February 2015.

3. Strengthening the stone vaults of brick railway bridge [5]

In the example of object on the river Zgłowiączka in Wloclawek, shown in figure 4 there were two different structures. One of them, treated as a basic was arched concrete bridge and the other object schema beam. In the converted facility used uniform way of strengthening. The choice of the concept of using corrugated steel plate with arch-shaped decided geometry of coating - adapted to the concrete vault. Span schema beam in this system subordinated to the main structure, vaulted. In the this way, was created a building of a common architecture, as in figure 4. Therefore, the use of such a uniform strengthening may be regarded as justified. In both cases shown in figures 3 and 4 applied the coating from corrugated plates were supported on the existing foundation bridge.

4. View of the road object under reconstruction and at the current state [5]

Shown in figure 5 the concept of strengthening also slightly interferes with the current system design. As in many cases, it is used herein support coating on the pillar or bridge abutment. It is also possible the realization during the use of the building, which may be an important advantage of such repair work. Figure 5 shows a bridge building with arched structure made of red sandstone, sprawled on the walls regulatory river Włodzica in the street Dworska in Nowa Ruda. A particular element of this amplification technology was the compression of the corrugated metal sheets with a brace prior to the filling space between the vault and the coating [6]. On the occasion of strengthening the construction also improved elevation of object.

Fig. 6 shows a schematic diagram of strengthening masonry arched bridge with the use of corrugated steel plates. Amplification technology consists in applying a coating of the corrugated structure and securing it to a support operated property. The next step is to fill the free area between the structure and the reinforced concrete coating. Filling layer has in this system several functions: a structure element and the role of the material that adapt to the geometry of the bottom surface of the ceiling to form the contact elements of the carrier (sheet and vaults). Due to the working principle of the transfer vault mainly axial force with a small eccentric coating and similarly operated switches are not required to force the cooperation of the structure elements. On the choice of the support coating has an impact the geometry of reinforced vaults.

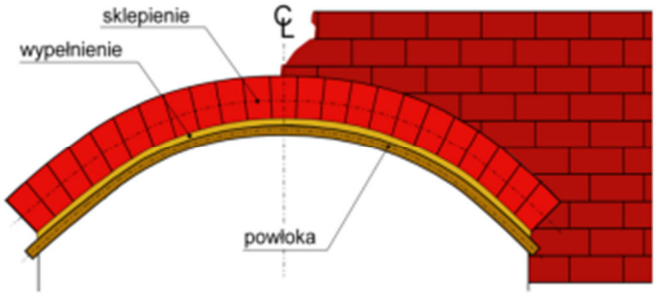
5. The facade of the stone brick building after renovation [6]

The effectiveness of the strengthening the masonry bridges

The design and layout shown in figure 6 before and after amplification does not change the rules of work - it is still arched vaulted structure. As a result of the strengthening is formed a layer system

made of three elements: the vault (*s*), coating (*p*) and filling (*w*). They transfer axial forces arising from the burden of performance in accordance with the principle of working vaults - in proportion to the rigidity of the layer system:

$$EA = (EA)_s + (EA)_w + (EA)_p \quad . \qquad (1)$$



6. Scheme of strengthening the brick vaults

Assuming, as in example of object shown in figure 5, that the reinforcement is made of corrugated steel plates with a low profile type MP 200×55×5,5 (the dimensions of wave: length, height, thickness [mm]), its rigidity is

$$(EA)_p = 205000 \cdot 6{,}512 \cdot 10^{-3} = 1335 \ MN/m \quad .$$

In case of filling the space between the plate and the concrete vault having an average thickness of 10 cm is obtained to the rigidity of the coating layer

$$(EA)_w = 30000 \cdot 0{,}10 = 3000 \ MN/m \quad .$$

Therefore, the rigidity of the system layer, as in figure 6, when h is the thickness of the brick vault is

$$EA = E_s h + 3000 + 1335 \ MN/m \quad .$$

The table summarizes the range of modules deformability of vault materials. In the values E_s it takes into account the current state of the material and therefore its degradation hence the values given in the table 1 are only indicative.

Table 1. The characteristics of vaults materials

Materiał sklepienia	E_s [MN/m^2]	α [%]
cegła	2000 - 5000	18,7 – 36,6
kamień	5000 - 10000	36,6 – 53,6
beton	10000 - 20000	53,6 – 69,8

From the formula (1) you can calculate the contribution of each element of the enhanced system. Taking an example of thickness vaults h = 0,5 m are obtained a percentage of the ceiling in the transmission of moving loads in reinforced structure in the form of a parameter

$$\alpha = \frac{E_s / 2}{3000 + 1335 + E_s / 2} \quad . \qquad (2)$$

With the value of α follows that the maximum efficiency of strengthening is obtained with a degraded ceiling brick and the lowest curves in concrete, the additive made of high strength concrete. In most cases, brick vaults gain (or corrugated steel plates with filling) thus becomes an essential element of the system.

Of course, the introduction of two additional elements in a strengthen layer changes the position of the original area of inertia, which differs to the line pressure vault formed from permanent loads. From the data presented in the table it shows that the shift surface of inertia may be high in the brick vaults. The use of corrugated steel plates on the one hand prevents the formation of a layer against possible tensile stresses. It is important for the safety of the layered structure thus becomes a ceiling top layer, in particular if it is made of brick and therefore very resistant to the formation of tensile stress.

In general, by strengthening the composite structure is formed consisting of many materials. The computational model of such a construction is complex and useful load capacity of such an object difficult to estimate [3]. In particular, the internal forces in the roof, formed as a result of its own weight construction and equipment as well as internal displacement resulting from the destruction of the structure [2].

Summary

Among the oldest of railway and road objects, is currently still in exploitation, a large group are brick buildings (arched). In view of their limited load capacity in use they require strengthening and when they are built on the major communication routes important is the possibility of overhaul without having to stop the traffic on the bridge, and in particular circumstances only its limitations. Strengthening vaults with corrugated steel plates can be an effective way of revitalizing the old masonry. The advantage of the proposed technology is a small intervention in the existing structural system. For strengthening arch it is sufficient to use corrugated steel plates with a low profile type MP 200×55×5,5 - even with large spans. Indeed, in the coating material the surface area transmitting an axial force, and no flexural stiffness. The advantage of strengthening the vaults of corrugated iron is a small reduction in the space under the object. In case of vaults with advanced degradation of the material it is convenient to expand the object and give it an aesthetic elevation.

Source materials

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