CETRA^{2026} 27-30 May 2026, Bol, Island Brač, Croatia
9th International Conference on Road and Rail Infrastructure

STRENGTHENING OF EXISTING RAILWAY BRIDGES USING CORRUGATED STEEL PLATE SHELLS

Czesław Machelski[1], Adam Czerepak[2], Julia Nowak[1]
[1]*Wroclaw University of Environmental and Life Sciences, Poland,*
[2]*ViaCon Group, Product @ Solutions Director – Bridges @ Culverts, Wroclaw, Poland*

Abstract

Due to the rapid development of railway transportation at the turn of the nineteenth and twentieth centuries, many railway lines currently in service throughout Europe are more than one hundred years old. This also applies to railway bridge structures, which constitute an integral component of such routes. Railway bridges exhibit a wide range of structural forms, including steel, reinforced concrete, and masonry structures constructed of brick or stone. A different situation applies to masonry arch bridges. Despite their age, such structures generally demonstrate only a limited reduction in load-bearing capacity and may continue to serve their function following appropriate repair and rehabilitation works. Insufficient load capacity of masonry arch bridges can be enhanced through the application of strengthening techniques, such as relining using corrugated steel plate shells. The authors present examples of strengthening existing railway bridges using this method. The analyzed structures, due to the necessity of increasing train operating speeds along the railway line, were found to exhibit insufficient load-bearing capacity. The installation of corrugated steel plate shells on the intrados of the arch is an effective strengthening method, primarily due to the simplicity of execution and the ability to limit interruptions to railway traffic during construction works. Relining with corrugated steel plate shells has been successfully used on both railway and highway structures across Europe for several decades. Despite its widespread practical deployment, the volume of published academic research on performance and design optimization remains comparatively limited.

Keywords: strengthening, masonry bridges, corrugated steel sheets, numerical analyses, geodetic measurements

1 Relining as a method of strengthening culverts

Strengthening of a structure is a technical measure that enables an increase in the maximum service load that can be safely carried by the object. In the case of culverts, strengthening is most commonly performed by introducing a new structure into the interior of the existing object and tightly filling the space between them with concrete or another appropriately selected material [1]. This method is referred to in the technical literature as relining. The main advantage of relining is the possibility of carrying out all construction works without excluding the object from service. This also avoids the alternative solution of providing a detour structure, which is typically required when the existing construction is demolished and rebuilt. In the case of railway structures, such a solution is very difficult or even impossible to implement. Numerous examples of the application of this technology are presented in [1].

DOI: https://doi.org/10.5592/CO/CETRA.2026.2026

This technique has been in continuous use for several decades on railway and highway assets in Europe, with notable concentrations of projects in the Nordic countries, Germany, Poland, the Netherlands and the Baltic states. Nevertheless, despite extensive practice, comparatively few peerreviewed studies have documented its longterm structural performance. Corrugated steel sheets, commonly used in soil–steel structures, are applied for relining purposes [1, 2]. In addition, reinforced concrete prefabricated elements with circular or box-shaped cross-sections, as well as polyester and GRP composite pipes, are also used. The selection of the strengthening system is primarily influenced by the geometry of the existing structure and the possibility of modifying its shape (reduction of the effective cross-sectional area), as well as by geotechnical and groundwater conditions.

Figure 1 Examples of relining applied in a railway structure

2 Technology for strengthening arch bridges

In the example of strengthening the vaults of a multi-span railway structure shown in figure 2, the corrugated steel shell is supported on the foundation of the existing object. In many cases, the shell is also supported on the side walls, as in the example of the structure presented in figure 3. In this strengthening concept, the interference with the existing structural system is limited to a small extent. The implementation of the strengthening works during the operation of the object is also possible, which constitutes a significant advantage of this rehabilitation method. The use of protective enclosures enables construction works to be carried out at low temperatures. The technology of strengthening arch bridges, including masonry bridges, consists in introducing a corrugated steel shell into the free space beneath the structure. The next stage involves filling the space between the strengthened structure and the corrugated steel shell with concrete. Figure 2 presents a conceptual scheme of the analyzed method of strengthening an arch bridge using a corrugated steel shell anchored at the support of the exploited structure. The infill layer also serves as a material allowing for adjustment of the geometry of the intrados surface of the vault and for the formation of contact between the load-bearing system components (the steel shell and the vault). In the composite system, it acts as a contact layer within the structure. In the service stage, the vault together with the shell and the infill forms a three-layer system. Consequently, the geometry of the structure and its original static scheme remain unchanged. Due to the load-bearing principles of masonry vaults and corrugated steel shells, no mechanical connectors enforcing composite action are required [3, 4].

Figure 2 Strengthening of stone vaults

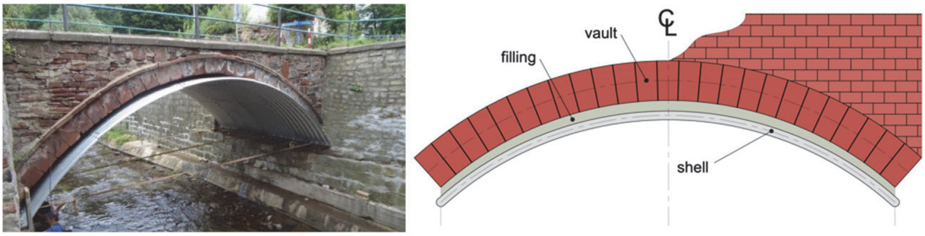

Figure 3 Scheme of vault strengthening

3 Effectiveness of strengthening

In the strengthened system, the infill performs the function of a significant structural component. After strengthening the vault with corrugated steel profiles and subsequent grouting, a three-layer system with differentiated material properties is formed. The Young's modulus of the steel shell is several times higher than that of the remaining components, which makes the shell an equivalent load-bearing element of the system, increasing the load-carrying capacity of the structure in comparison with its original state. Additionally, during the construction stage, the hydrostatic pressure of the infill induces a relieving effect on the vault. A considerable part of the previous permanent load acting on the vault is transferred to the corrugated steel shell, which allows the degraded vault to carry increased service loads [3]. The significant thickness of the strengthened vault and the distribution of loads in the soil cover above the structure [5, 6] result in a substantial reduction of bending effects in both the shell and the vault, while axial forces due to service loads remain small in comparison with forces caused by the permanent load of the structure and its equipment. The axial force in the arch, resulting from permanent loads and the technical condition of the vault, is therefore appropriately reduced. This configuration is natural for both types of structures: the arch bridge and the shell in a soil–steel structure. The structural system before and after strengthening does not change its static principle and remains an arch structure. As a result of strengthening, a layered system composed of three elements is formed: the vault (s), the shell (p), and the infill (w). These components transfer axial forces induced by service loads according to the load-bearing principle of the vault, proportionally to the stiffness of the layered system:

$$EA = (EA)_s + (EA)_w + (EA)_p \qquad [\mathrm{MN/m}] \tag{1}$$

Assuming, in the analyzed example, that the strengthening is performed using a low-profile corrugated steel sheet of type ViaPlate 200 × 55 × 5.5 (wave dimensions: length, height, sheet thickness [mm]), its stiffness is equal to:

$$(EA)_p = 205000\ \mathrm{MN/m^2} \cdot 6.515 \cdot 10^{-3}\ \mathrm{m^2/m} = 1335\ \mathrm{MN/m} \tag{2}$$

For the infill with an average layer thickness of 7 cm, the stiffness amounts to:

$$(EA)_w = 30000\ \mathrm{MN/m^2} \cdot 0.07\ \mathrm{m} = 2100\ \mathrm{MN/m} \tag{3}$$

Thus, the stiffness of the layered system, where h denotes the vault thickness, is expressed as:

$$EA = E_s h + 2100\ \mathrm{MN/m} + 1335\ \mathrm{MN/m} = E_s h + 3435\ \mathrm{MN/m} \tag{4}$$

The values of E_s account for the current condition of the material, including its degradation; therefore, the values presented in table 1 are only indicative. The equivalent contribution of the vault relative to the remaining components is described by the coefficient:

$$\eta = \frac{EA}{E_s h} = \frac{E_s h + 3435}{E_s h} = 1 + \frac{3435}{E_s h} = 1 + \frac{8587}{E_s} \quad [-] \tag{5}$$

assuming the vault thickness h=0.4 m. Table 1 presents the values of n calculated from equation (5). The results indicate that the highest strengthening efficiency is achieved in the case of brick vaults.

Table 1 Values of the strengthening efficiency coefficient n

Vault material	Es [MN/m²]	Coefficient n
brick	2,000 – 5,000	5.29 – 2.72
stone	5,000 – 10,000	2.72 – 1.86
concrete	10,000 – 20,000	1.86 – 1.43

Naturally, the introduction of two additional components into the layered system results in a shift of the original neutral axis, which initially was located close to the line of thrust of the vault generated by permanent loads. The data presented in table 1 indicate that this shift of the neutral axis may be significant. The application of corrugated steel sheets provides protection of this layer against possible tensile stresses. The upper layer becomes particularly important for the safety of the layered structure, especially when the vault is of masonry construction. In general, strengthening leads to the formation of a composite structure composed of multiple materials. The computational model of such a structure is complex, and the service load-bearing capacity of the object is difficult to estimate. This applies in particular to internal forces in the vault resulting from the self-weight of the structure and its equipment, as well as to internal displacements caused by progressive material degradation.

4 Filling stage

The main strength-related problem of the strengthened structure analyzed in this study concerns stresses resulting from deformations of the corrugated steel shell that arise during the filling of the space between the vault and the shell. The strength analysis of this problem made it possible to estimate the stress level of the corrugated steel shell during the construction stage. During the construction stage, as shown in figure 3, the system consists of the original part in the form of the vault together with the remaining equipment elements, and the corrugated steel shell.

Both parts of the system are subjected to the hydrostatic pressure of the infill p(s), as illustrated in figure 4. Its intensity and range along the length of the arch are determined by the ordinate z_p. With an increase in the ordinate $z–z_o$, the distributed load p(s) increases proportionally, in direct relation to the unit weight of the concrete mixture.

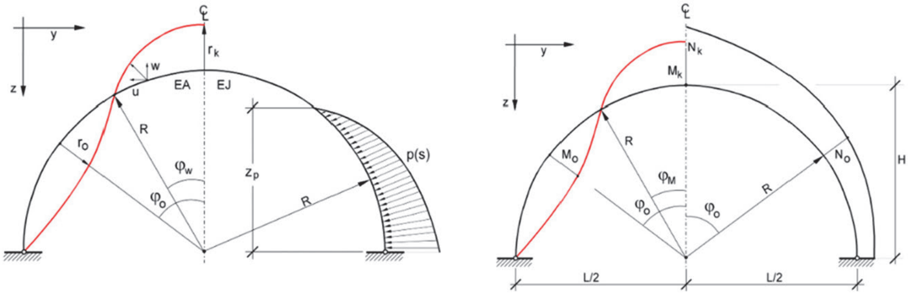

Figure 4 Scheme of infill action and deformation of circumferential shell strips

A circumferential segment of the shell was modelled as a circular arch with radius R, bending stiffness EI, and axial stiffness EA. The action of the load p(s)p(s) causes shell deformation, shown on the left-hand side of the scheme. This deformation is characterized by the maximum displacements: the vertical displacement w_k, corresponding to the uplift of the crown, and the horizontal displacement u_o, corresponding to the narrowing of the haunch. In the calculations presented in this study, the radial displacement component, denoted as r, was adopted. In the geometric model of the structure, two subsystems are distinguished, connected by the common hydrostatic action of the infill p(s). In general [7], this action is related to the distribution of the axial force N(s) and the bending moment M(s) along the circumferential strip of the shell, according to equation (6):

$$p(s)=\frac{N}{R}+\frac{d^2M}{ds^2}\ \text{[kN/m]} \tag{6}$$

Shell structures undergo deformations during concreting or backfilling works in classical soil–steel structures. Depending on the geometry and stiffness of the shell, these deformations may be significant and may affect the final shape of the structure. In the case described in this paper, where the shell is surrounded by concrete mixture in a liquid state, this effect can be reduced by applying staged filling of the concrete mix.

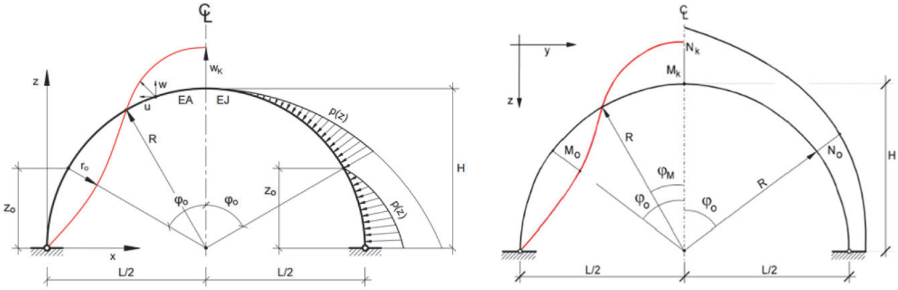

Figure 5 Scheme of infill action and deformation of circumferential shell strips during staged concreting

Staging consists in partial concreting of the structure followed by a pause in construction works until partial or complete setting of the concrete mixture occurs. This results in an increase in the stiffness of the shell structure, which begins to partially cooperate with the infill and the vault structure. Staged filling has a beneficial effect on shell deformations and, consequently, on the stress level of the shell during construction works. Staging also allows for a reduction of the final deformation of the shell after concreting. Control measurements of shell deformations during the execution of the infill can be carried out using modern geodetic measurement techniques, in particular terrestrial laser scanning, which enables non-contact assessment of displacements [8, 9].

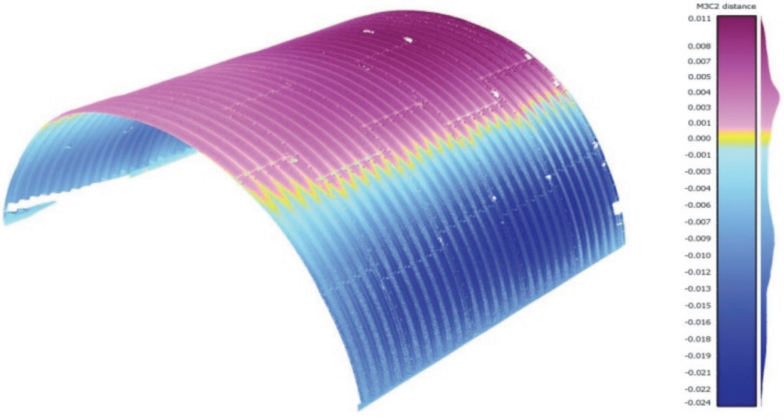

Figure 6 Radial displacement field of a shell segment

5 Conclusion

Many structures located on railway lines have been subjected to long-term service. Among them, masonry (arched) structures are also present [3]. The main advantage of the strengthening method presented in this paper is the possibility of rehabilitating such objects without the need to stop traffic on the bridge, and in special cases only requiring its limitation. The method has been deployed for several decades on both railway and highway bridges in many European countries, although the body of published research is still relatively limited. In many cases, due to the internal force distribution in the strengthened system, a lowprofile ViaPlate (200 x 55 mm) is sufficient. Where larger spans (›20 m) or lowrise arches increase the significance of bending moments, higher corrugation profiles may provide the necessary stiffness and strength to preserve safety margins. The industry also offers higher corrugation profiles (e.g. 380 x 140 and 500 x 237) with plate thicknesses up to 12 mm, manufactured in higherstrength steel grades (up to S420 and S500). These options extend the applicability of relining. The presented strengthening method is particularly advantageous in the case of widening existing structures. In such situations, it is also possible to modify the facade of the object, as shown in figure 7.

Figure 7 Example of the facade during strengthening of a masonry vault

This paper discusses changes in internal forces occurring during the injection process. During its execution, the hydrostatic pressure of the infill exerts pressure on the shell and induces a balanced relieving effect on the vault. Consequently, in the strengthened system, a significant part of the previous permanent load acting on the vault is transferred to the shell. As a result, the degraded vault is capable of carrying increased service loads. In the final part of the paper, an assessment of the strengthening efficiency is analyzed. The presentation includes examples of strengthening of arch bridges. A separate issue, not addressed in this paper, is the relining technology.

References

[1] Jasieńko, J., Bednarz, Ł.: Innovative Technologies for Strengthening Historical Arches and Brick Vaults, Building Materials, 2 (2009)

[2] Madryas, C., Wysocki, L.: Renovation of Brick Interceptor Sewers, Tunnelling and Underground Space Technology 23 (2008), pp. 718–726

[3] Machelski, C., Michalski, J. B., Szcześniak, K.: The Efficiency of Reinforcing Masonry Bridges Using Corrugated Steel Sheets, Advanced Models and New Concepts in Concrete and Masonry Structures Conference, Lublin, Poland, 21–23 October 2020.

[4] Nienartowicz, B.: Analysis of Selected Aspects of Pipeline Operation Renewed by Relining Method Based on Laboratory Testing Results, Underground Infrastructure of Urban Areas 3 Conference, Wrocław, 2015.

[5] Brencich, A., Cassini, G., Pera, D.: Load Bearing Structure of Masonry Bridges, 8th International Conference on Arch Bridges, pp. 418–425, Wrocław, Poland, October 5-7, 2016.

[6] Pytlos, M., Gilbert, M., Smith, C. C.: Use of a Physics Engine to Model Soil-Filled Masonry Arch Bridges, 8th International Conference on Arch Bridges, pp. 454–457, Wrocław, Poland, 5-7 October, 2016.

[7] Machelski, C.: Effects of Surrounding Earth on Shell during Construction of Flexible Bridge Structures, Studia Geotechnica et Mechanica, 2 (2019)

[8] Muszyński, Z., Rybak, J.: Evaluation of Terrestrial Laser Scanner Accuracy in the Control of Hydrotechnical Structures, Studia Geotechnica et Mechanica, 39 (2017) 4, pp. 45–57

[9] Muszyński, Z., Milczarek, W.: Application of Terrestrial Laser Scanning to Study the Geometry of Slender Objects, IOP Conference Series: Earth and Environmental Science, 95 (2017) 4