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THE PROBLEM OF SCAFFOLDS FAILURES DURING THE CONSTRUCTION OF NEW VIADUCT OVER HIGHWAY

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1. Introduction

Formerly in Poland, a little attention was paid to the bridge-specific design and erection of scaffolds, which was the cause of many serious failures [4, 5, 6, 15, 16, 21, 22, 24]. Today, bridge scaffolds are classified as engineering structures and require the detailed design including all aspects, which may occur from their erection, through the full loading of the spans during casting and to their dismantling, in accordance with the current guidelines [18, 19, 20]. In the case of the construction of new bridges over transport obstacles, continuity of traffic should be ensured, in particular on national roads where traffic must continue throughout the period of construction of the bridge [7, 8, 9].

Unfortunately, the heavy trucks (e.g. TIR lorries) and tractor-trailer units, carrying various machines and equipment drive through the clearance gates shaped in the scaffolds used during building highway bridge structures, most often strike at the new scaffold components already built. It refers these both as well as the trucks of permissible and over normative dimensions, which mainly conducting to serious damage of scaffolds or their structural elements.

Using as example highway viaducts WD-14 and WD-12 built over national road A-18 being upgraded, the failures of the scaffolds erected to build on site the concrete objects are described and their causes are explained. The cases considered here and the ones presented previously [1, 3, 4, 5, 8, 9, 22] clearly show the need to modify and update the guidelines for erecting scaffolds for the building of road bridge structures. This applies particularly to the minimum headroom as vertical clearance since the current standard one is inadequate. The above considerations should be taken into account in the designs of bridge structures.

2. Description of old and new viaduct WD-14

The old reinforced concrete viaduct built in 1934 consisted of two spans having an effective length l_e = 14.00 + 14.00 = 28.00 m. The span overall width was 7.70 m, load class D (200 kN) [17], and the vertical clearance 4.53 m. The viaduct was situated at a skew of 45° to the road's longitudinal axis.

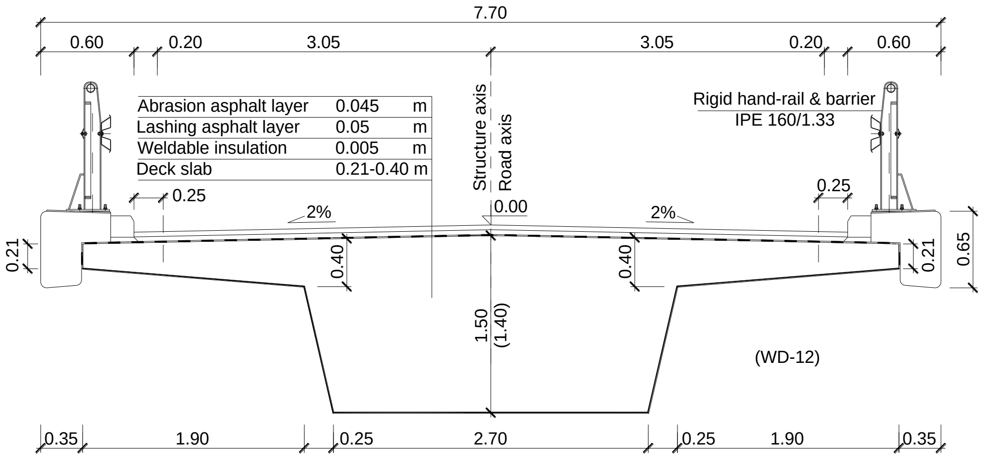

Fig. 1. Cross-sections of viaduct WD-14 and WD-12 (dimensions for the latter are given in brackets).

Because of the viaduct's bad technical condition, it was not worthwhile to upgrade it, so it was demolished.

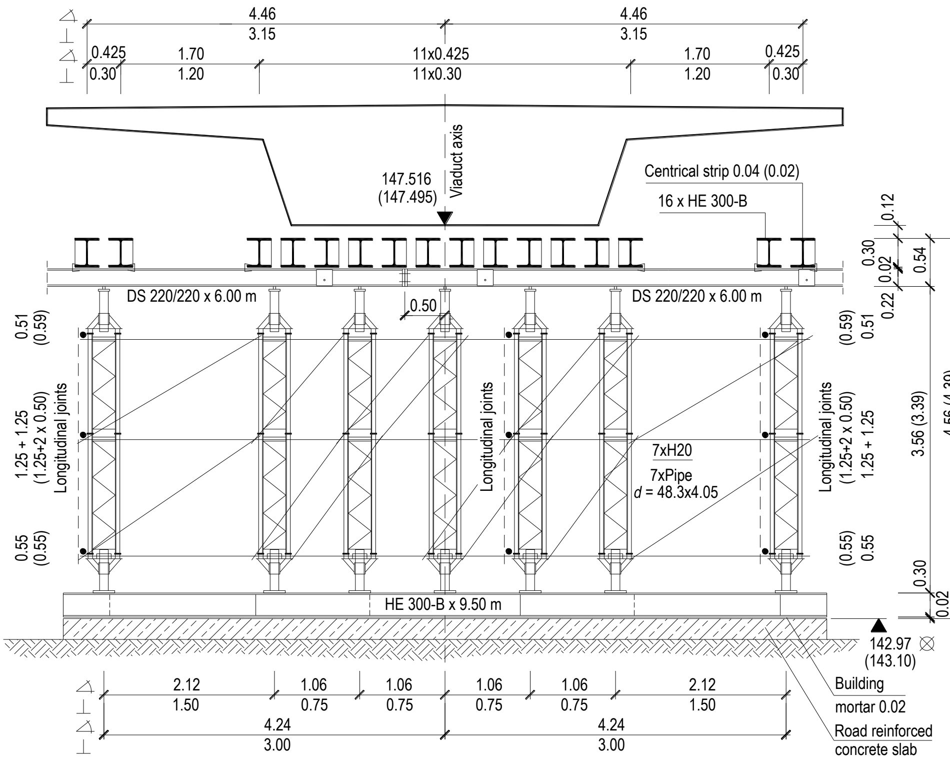

Fig. 2. Cross-section of viaduct WD-14 with structure of scaffold put up above road clearance.

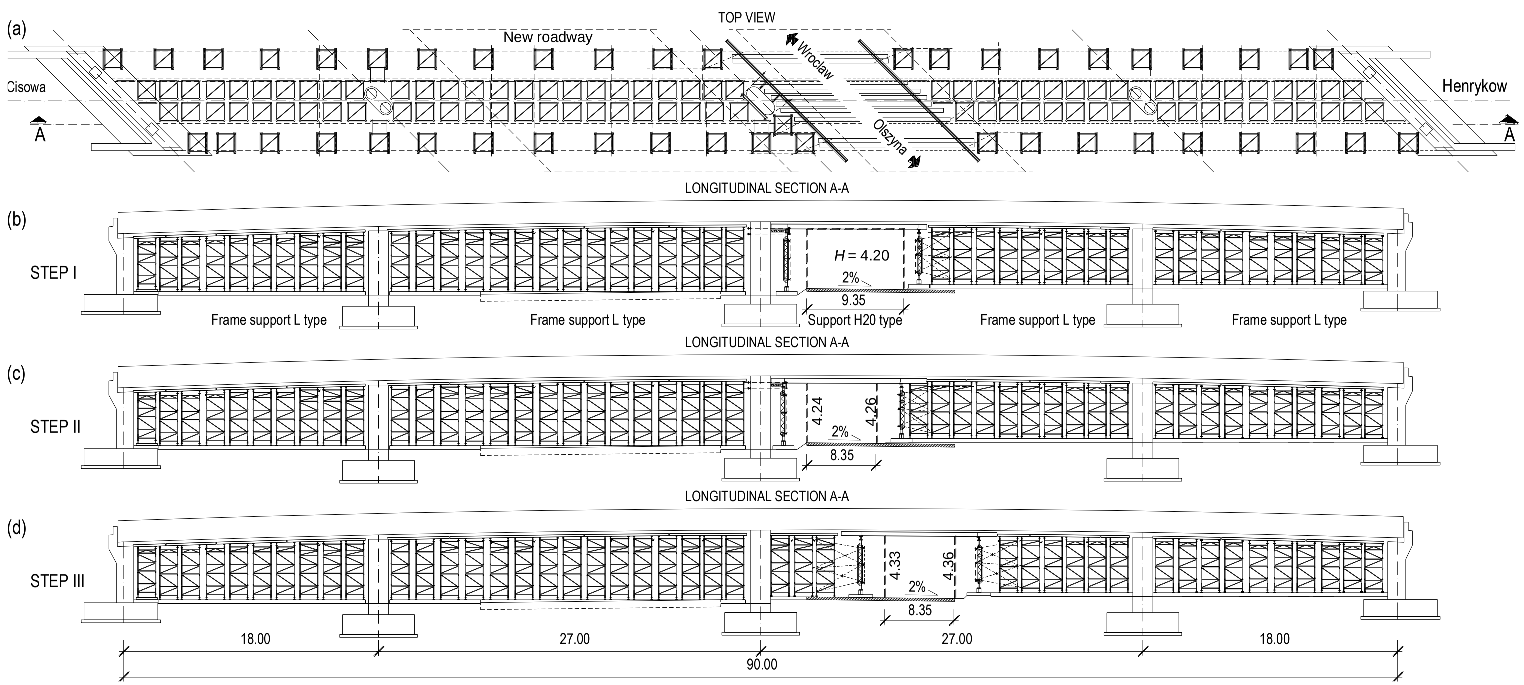

Fig. 3. Arrangement of EngelhardRöRo scaffolds for viaduct WD-14: (a) top view, (b) longitudinal section A–A (vertical clearance 4.20 m), (c) longitudinal section A–A (vertical clearance 4.24 m), and (d) longitudinal section A–A (vertical clearance 4.33 m).

The new viaduct is located at the 179.79 km of Cisowa-Jędrzychowiczki (Henryków) local road No. 4918009 being upgraded. The viaduct makes possible the safe crossing of national road No. 18 at its 13+634.37 km. The rebuilt viaduct WD-14 is located in the place of the old demolished one (Fig. 1).

The new reinforced concrete viaduct with a trapezoidal single-girder cross-section and a continuous-beam static scheme has four spans with an effective length l_e = 18.00 + 27.00 + + 27.00 + 18.00 = 90.00 m. The axes of the supports are parallel to the national road and with the viaduct's longitudinal axis form an angle of 44.99°. The middle spans cross the two carriageways of the national road. There are technological strips and the local road embankment slopes under the extreme spans. The main girder is 1.50 m high and 2.70 m and 3.20 m wide respectively at the bottom and top of the cross-section. The cantilevers' width varies from 0.21 to 0.40 m and their outreach is 1.90 m. The overall width of the superstructure is 7.00 m. The overall width of the viaduct is 7.70 m, including the roadway between the curbs (6.10 m) and sidewalks with the rigid barriers (2×0.80 m). The viaduct's total surface area bounded by the deck edges is 7.70 m × 92.10 m = 709.17 m^2. The local road's technical class is L. The target traffic clearance under the viaduct is 4.70 m. The viaduct traffic loading is as for class B (400 kN) according to the Polish Bridge Load Standard [17].

The viaduct superstructure was made of reinforced concrete, and it reposes on intermediate supports and abutments via elastomer bearings (the middle support and the span structures are joined together monolithically). The grade of the superstructure concrete is B35 [17] (currently C30/37) and the steel grade – 18G2-b (currently S235).

The intermediate piers have the form of oval columns 2.40 m wide and 1.00 m thick, and they are founded directly on a continuous footing 3.60 m × 7.20 m in plan and 1.40 m thick. There is B35 and B30 (currently C30/37 and C25/30) concrete [17] in the columns and the footing respectively. The massive abutments are sunk in the embankment and founded directly on a continuous footing 4.50 × 1.20 m in the cross-section. The wing walls are suspended from the abutment body and joined with the continuous footing.

3. The application of scaffolds for construction of viaduct on A-18 highway

Proper working designs of the span scaffolds for the WD-14 – WD-19 viaducts were created. For the already built supports [25], the necessary scaffold and formwork to be used under viaduct spans was designed [2, 10, 11, 12, 13, 14, 23]. The grade lines for the new viaducts were taken from their design documentation [25]. The elevation of the pavement reinforced concrete slabs under the scaffolds was determined based on the levels obtained from geodetic surveys carried out by the building contractor (Fig. 2).

The RöRo scaffolds of type L erected outside the road clearance (on each side two towers in the axis of the load-carrying structure and, in addition, more widely spaced scaffolds under the spans' cantilevers) were to be used for casting the spans of the viaduct (Fig. 3).

The spans situated directly above the road clearance were supported by heavy scaffolds H20 type on which double-T steel girders were put up (Fig. 2).

The following scaffold components were used:

- steel beams – HE-B 160, HE-B 360, HE-B 300, 220M HE;
- frame supports – RöRo L supports;
- grillage supports – HUNNEBECK H20;
- pipe bracings – Ø48.3×4.05/S 235;
- various connections, i.e. steel couplers and clamps, etc., conforming to the EngelhardRöRo standard [2, 3].

(a) (b)

Fig. 4. View on the damaged scaffold supports in viaduct WD-14 after vehicle struck to the main girders located above drive-through clearance: (a) view from roadway, (b) side view.

Moreover, a template of constant-cross-section formwork (Fig. 2) with a single girder trapezoidal in the cross-section was designed and made [10, 11].

4. Scaffolds damage during its erection

4.1. General remarks

During the construction of viaduct WD-14, the structural components of the scaffold near the drive-through clearance were damaged twice due to the too small standard headroom (insufficient for the proper location of scaffolds for the construction of bridge spans). The standard clearance is 4.20 m, and, in many cases, it no longer meets the current service conditions.

Therefore, after the first vehicle struck at the girders of the scaffold situated immediately above the road clearance (conforming to the technical documentation approved by the highway supervision authority), the headroom was increased by the available reserve (by redesigning and rebuilding the load-bearing structure of the scaffold). This, however, did not help much since soon another vehicle hit the lower part of the scaffold located directly above the drive-through. After the second vehicle strike, the designers of the scaffold together with the viaduct builder had to increase the vertical clearance. They decided that the minimum safe vertical clearance in this case should be 4.30 m. At this clearance no more vehicle strikes occurred. The scaffolds and the new vertical clearance were tried out on another viaduct, i.e. WD-19. The vehicle, which previously damaged the scaffold of WD-14 this time, drove through.

(a) (b)

Fig. 5. View of viaduct WD-12 scaffold after vehicle strike: (a) damaged and turned steel girders of scaffold (two girders on Wrocław side were turned), (b) collapsed reinforcement of span load-bearing structure before planned casting.

4.2. Description of accidents involving vehicles striking scaffold components

The first collision occurred on 29 September 2005. A TIR lorry (semi trailer height over 4.20 m) from Ukraine struck the scaffold, and, as a result, got stuck under the span seriously damaging the structural components of the scaffold. A few days later, on 3 October 2005 in the morning hours, a tractor-trailer unit transporting an excavator struck the scaffold components situated immediately above the clearance of viaduct WD-14. As a result, all the girders were knocked off and fell down onto the roadway (Fig. 4). Another strike of this vehicle into the scaffold of viaduct WD-12 caused two girders to turn (Fig. 5). The transported excavator, as the police findings showed, probably was stolen from another building site, which explains the driver's unusual determination to ram all the obstacles on his way. Luckily at this time, the vehicle traffic on the road was relatively light, there were no construction workers on the scaffolds, no casting work was being conducted, and so there were no casualties.

(a) (b)

Fig. 6. Side view of encased scaffold of viaduct WD-14 prior to superstructure casting after two vehicle strikes into girders located above clearance: a) H20 scaffolds erected under formwork, b) drive-through clearance outline shifted to edge of roadway.

Fig. 7. View of beam marking height of clearance (3.70 m) before entry into the road section where scaffolds were being erected and reinforcement installed prior to casting spans (vertical clearance for all viaduct being built was 4.20 m and was larger than clearance height on warning gate where there was exit leading to another road).

4.3. Change of vertical clearance in viaduct WD-14

Because of the relatively low elevation of the spans of viaduct WD-14 over the A-18 highway, nobody expected that the standard vertical clearance of 4.20 m could be insufficient. In the case of the other viaduct over the same road, there were substantial reserves in height owing to the grade line adopted in the design. Therefore, quite simply and naturally, the actual vertical clearances under the scaffolds were much larger than the required minimum of 4.20 m.

In the case of viaduct WD-14, two vehicle strikes into steel girders located above the drive-through clearance occurred whereby the contractor and the designers had to redesign the scaffold structure several times.

The first alteration in the height of the drive-through clearance under the load-bearing girders of the scaffold was made by replacing the HE 360-B girders (10 units) with 16 girders of the HE 300-B type because of which the spacing of the main H200 girders decreased from 9.35 m to 8.35 m. In this way, a vertical clearance of 4.26 m was obtained. It was thought that there would be no more collisions (Fig. 3c).

After the second vehicle had stricken into the increased from 4.20 m to 4.26 m vertical clearance, it became necessary for safety reasons to redesign the height of the drive-through gate. A detailed analysis of the causes of the damage to the scaffold showed that replacing the HE-B 300 girders with shorter ones was out of the question because of the insufficient load-capacity of any shorter girders. It was found, however, that it was possible to reduce the height of the formwork trusses situated immediately above the clearance from 0.10 m to 0.06 m. In addition, because of the roadway cross fall of 2%, the whole drive-through gate was moved to the edge of the roadway towards the lowest road grade line whereby a few more reserve centimetres were obtained (Fig. 6). In this way, a vertical clearance of 4.33 m was obtained at the lowest point of the road 4.36 m at the edge of the clearance, i.e. by 0.13 m larger than the standard clearance of 4.20 m and by 0.07 m larger than the other clearance of 4.26 m (Fig. 3d). The new drive-through height of 4.33 m ensured safe work on the viaduct until its completion.

5. Conclusions

Considering both cases of scaffold failures on the viaducts built on the upgraded A-18 highway, caused by the vehicle strikes into scaffold girders situated above the clearance, the much out-of-date guidelines on the minimum vertical road clearance of 4.20 m required during the construction of bridge structures should be amended in the nearest future. Based on the authors' experience in the design, site supervision and use of scaffolds, it can be stated that the vertical clearance should not be smaller than 4.30 m instead of 4.20 m.

Until the proper amendments are adopted, half-measures must be used, and, in the cases where the height of the drive-through clearance cannot be increased above 4.20 m, unbreachable solid drive-through gates and warning systems should be erected – such as audible and visual signalling devices warning drivers early that their vehicles exceed the height of the drive-through gate located in front of the road structure. It should be added that, if all the above possibilities have been exhausted, one should contact the road services which must screen vehicles and direct the ones with excessive height to previously prepared diversions.

Regardless of the increased road height clearance and additional protections (Fig. 7), it should always take into account the fact that, because of some irresponsible road users, there is a real possibility that the scaffold will be damaged.

Bibliography

[1] Barzykowski, W., Derecki, J., Feder, A., Jaczewski, L., Jarominiak, A., Pierożyński, M.: Bridge Construction Mechanization, Wydawnictwa Komunikacji i Łączności (WKiL), Warsaw, Poland, 1971 (in Polish).

[2] Catalogue, EngelhardRöRo L and H20 Types Scaffolds, 1998-2008 (in Polish).

[3] Construction Equipment, Bridge Formworks, Magazyn Autostrady, Special edition, 37 (2006) (in Polish).

[4] Flaga, K.: Technical-Construction Expert Opinion on Causes of Collapse of Viaduct on Skoczów-Cieszyn National Road S-1 in Ogrodzona, Typescript, Cracow, Poland, 2003 Aug. (in Polish).

[5] Flaga, K.: Reflections on Collapse of Viaduct in Ogrodzona, 22nd Scientific-Technical Conference on Structural Failures, Prevention-Diagnostics-Repairs-Reconstruction, Szczecin-Międzyzdroje, Poland, 2005, May 17-20, 53-66 (in Polish).

[6] Furtak, K., Wołowicki, W.: Bridge Scaffolds, Wydawnictwa Komunikacji i Łączności (WKiL), Warsaw, Poland, 2005 (in Polish).

[7] Głomb, J.: Technology of Building Concrete Bridges, Wydawnictwa Komunikacji i Łączności (WKiL), Warsaw, Poland, 1982 (in Polish).

[8] Hołowaty, J.: Case of Damage to Bridge Scaffold Support Caused by Vehicle Strike during Concreting of Spans, 21st Scientific-Technical Conference on Structural Failures, Prevention-Diagnostics-Repairs-Reconstruction, Szczecin-Międzyzdroje, Poland, 2003, May 20-23, 567-572 (in Polish).

[9] Hołowaty, J.: Scaffold Structures for Building Overpasses Providing Access to Bridge Crossing Over Regalica River in Szczecin, IV All-Polish Bridge Engineers Conference on Bridge Structure and Accessories, Wisła, Poland, 2005, Oct. 12-14, 63-70 (in Polish).

[10] Kałuziński, D., Mańko, Z.: Designs of Viaducts WD-14 – WD-19, MOSTAR Scientific-Research Centre for Bridge Construction Development, Wrocław, Poland 2005 (in Polish).
[11] Kałuzinski, D., Mańko, Z.: Designs of Formwork for Viaducts WD-14, WD-15, WD-16, WD-17, WD-18, WD-19., MOSTAR Scientific-Research Centre for Bridge Construction Development, Wrocław, Poland, 2005 (in Polish).
[12] Kałuzinski, D., Mańko, Z.: EngelhardRöRo Scaffolds, Magazyn Autostrady, Special Edition, Part I, 10 (2006), 40-48, and Part II, 12 (2006), 84-89 (in Polish).
[13] Kałuziński, D., Mańko, Z.: Damage to Scaffolds during Construction of New Viaduct over A-18 Highway, 23rd Scientific-Technical Conference on Structural Failures, Prevention-Diagnostics-Repairs-Reconstruction, Szczecin-Międzyzdroje, Poland, 2007, May 23-26, 895-902 (in Polish).
[14] Kałuziński, D., Mańko, Z.: Damage to Scaffolds during Construction of New Viaduct over A-18 Highway, Magazyn Aurostrady, (2018) (in Polish) (in print).
[15] Ministry Technical Requirements. Minister of Transport and Marine Economy Order of 2 March 1999 concerning "Technical Requirements which Public Roads and their Location Should Meet"., Law Gazette (Dz.U.), 43, 430 (1999) (in Polish).
[16] Ministry Technical Requirements. Minister of Transport and Marine Economy Order of 30 May 2000 concerning "Technical Requirements which Road Structures and their Location Should Meet"., Law Gazette (Dz.U.), 63, 735 (2000) (in Polish).
[17] PN-85/S-10030 (1985), Bridge Structures. Loads., the Polish Bridge Load Standard (in Polish).
[18] PN-M-47900-3 (1996), Standing Working Metal Scaffold. Frame Scaffolds (in Polish).
[19] PN-M-48090 (1996), Steel Scaffolds Made From Folding Components for Bridge Construction (in Polish).
[20] PN-M-47900-1 (1996), Standing Working Metal Scaffold. Definition. Division and Main Parameters (in Polish).
[21] Rowiński, L.: Working and Load-Bearing Scaffolds, Polskie Centrum Budownictwa (PCB), Warsaw, Poland, 2001 (in Polish).
[22] Rymsza, J.: On Causes of Collapse during Construction of Viaduct over Dual Carriageway S-1 on Skoczów-Cieszyn Section, Inżynieria i Budownictwo, LX, 3 (2004), 140-143 (in Polish).
[23] Technical Guide, Scaffolds. Formworks., 2005 (in Polish).
[24] Wolf, M.:, "Bridge Scaffolds and Formworks," Wydawnictwa Komunikacji i Lacznosci (WKiL), Warsaw, Poland, 1964 (in Polish).
[25] Working Designs, Modernization of National Road No. 18 along Section: Olszyna Interchange-Golnice Interchange, Section 3. Road Structures WD-14, WD-15, WD-16, WD-17, WD-18, WD-19., TRANSPROJEKT – WARSZAWA Roads & Bridges Design-Research Office, Warsaw, Poland, 2003 (in Polish).

Summary

The paper presents cases of failures of steel scaffoldings damaged by vehicle strikes during the construction of new viaducts over the upgraded A-18 Highway in Poland. After several vehicle strikes into the scaffold structures, their damaged components were no longer serviceable (considering the safety of the construction works being carried out). This put the contractor to additional expenses connected with the replacement of the damaged scaffolding. The causes and consequences of the failures are given, and the necessary solutions adopted

in the considered cases (whereby the traffic situation significantly improved) are described. Moreover, it is proposed to increase the minimum vertical clearance required during the building or repairs of bridge structures.