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General Principles and Methods of Temporary Reconstruction of Railway Bridges

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Abstract
The purpose of this paper is to discuss the general principles and methods of temporary reconstruction of railway bridges. The essence of ad hoc and temporary reconstruction has been discussed. The principles of design of temporary bridges in terms of implementation of engineering design and static calculations in relation to the types of loads and permissible deformations of the span are given. Methods of temporary bridge reconstruction are also presented, and their technique and effectiveness are characterised.

Keywords: railway bridges, design, temporary reconstruction.

1. THE IDEA AND PRINCIPLES OF TEMPORARY BRIDGE RECONSTRUCTION

Partial damage or destruction of a bridge structure can occur for various reasons, e.g. (Białobrzeski, 1978; Bień, 2003, 2010; Cholewo & Sznurowski, 1970; Budka, Rabiega & Pękalski, 2006; Furtak & Radomski, 2006; Jarominiak, 1999; Maksymowicz, 2008):

- due to natural disasters such as ice jams, washed out piers, hurricanes,
- due to deliberate destruction with explosives
- due to faulty construction of the bridge, resulting in damage to its supports or superstructure and loss of serviceability.

In each of the above cases, it is necessary to quickly reopen the damaged or destroyed facility to rail traffic. Since permanent reconstruction would be time consuming, temporary reconstruction is used as it is much faster.

Provisional bridge reconstruction should generally be carried out in such a way that permanent reconstruction can be carried out in the next phase, without the need for a prolonged interruption of train traffic (Surowiecki & Zamiar, 2014, 2016).

Provisional bridge reconstruction is carried out in two variants (Cholewo & Sznurowski, 1970; Hydzik, 1986; Madaj & Wolowicki, 2013):
1. in the track centreline, directly above the damaged or destroyed object; or,
2. at a certain distance from this facility on a diversion.

Temporary bridges, built in the track centreline in such a way that damaged bridge or culvert components can be rebuilt underneath, are also referred to as relief bridges or relief structures. Such a temporary structure encloses the damaged structure and allows it to be rebuilt, thus ensuring the continuity of rail traffic.

When reconstructing or rebuilding small structures, e.g., culverts, or partially damaged certain bridge elements, e.g., abutments, it is possible to successfully limit oneself to the use of relief structures consisting of rail bundles in the active track.

The second variant of temporary bridge reconstruction is used when the local conditions, the size of the structure, and the extent of the damage do not allow the temporary bridge to be built along the track axis. In this case, a temporary bridge is built at some distance from the damaged structure, with the tracks being brought to the bridge on specially constructed (also temporary) embankments. Such bridges are called temporary diversion bridges.

When designing a temporary bridge reconstruction, attempts should be made to use (as much as possible) the salvaged fixed supports or parts of these supports.

A distinction is made between two types of temporary reconstruction of damaged bridges [miclin]: ad hoc reconstruction and temporary reconstruction. The type of bridge reconstruction adopted is determined by the type of damage, the timing of the reconstruction, the expected service life and the available materials of the collapsible bridge structure.

The ad hoc reconstruction is used to quickly activate the railway communication routes for a continuous efficient and rapid conduct of military operations, for example (Miklin & Sawicki, 1993; Miklin, 1980, 1984; Zamiar, 2011). Bridges of the ad hoc nature are designed without calculating the bridge lumen, and constructed without clearing the river bed of parts of the destroyed bridge and without considering flood and ice flow conditions. The ad hoc reconstruction uses all possible and foreseeable materials and construction techniques. Recycled materials such as wooden or concrete sleepers, rails and components from destroyed bridge spans can be used. Since the ad hoc reconstruction is the simplest method, the speed of trains over the reconstructed bridge is limited to 10 km/h. At the same time, the value of the moving loads of the rolling stock that will use the line is determined. The ad hoc reconstruction can be carried out according to simplified technical documentation. The service life of an ad-hoc-reconstructed bridge is limited by spring water and ice flows or further stages of its reconstruction (Miklin, 1984; Surowiecki, 2021).

The temporary bridge reconstruction aims to restore and maintain rail traffic on the bridge for at least 3 years (Miklin & Sawicki, 1993). This method of reconstruction is used when there is a lack of time, materials and equipment to construct a permanent bridge. In the process of temporary reconstruction, more favourable technical conditions may be applied and the materials used may have reduced technical characteristics. The rules for temporary bridge reconstruction apply (“PKP Polskie Linie”, 2005; Miklin & Sawicki, 1993; “Centralne Biuro”, 1991; Surowiecki & Zamiar, 2014):

- it is necessary to clear the riverbed of part of the collapsed bridge, but in order to speed up the opening of traffic on the bridge, this work can be carried out after the construction has been completed and the traffic has been reintroduced;
- the temporary bridge should be protected during floods and ice flows,
- the maximum speed of train traffic on the temporarily reconstructed bridge should not exceed 30 km/h,
- the horizontal dimension of the so-called “opening” of span bridges (on navigable rivers) should be at least 20 m, while the vertical opening should be agreed with the water authorities;
- in the case of other rivers, bridge spans and supports should be constructed so that the lower edge of the bridge span is at least 0.30m above the highest recorded water level and the elevations of the bearing niches are at least 0.25m above this level;
- a temporary bridge may be constructed along the axis of the damaged structures, possibly using damaged superstructures and supports, or adjacent to the damaged structure.

A temporary bridge built next to a damaged structure is called a temporary diversion bridge. A temporary diversion bridge constructed on a new alignment next to a collapsed permanent structure should meet the following conditions (Cholewo & Sznurowski, 1970; Rybak, 1982; Surowiecki & Zamiar, 2014):

- the distance between the diversion bridge and the destroyed bridge should be chosen so that there are no obstacles to the subsequent permanent reconstruction of the destroyed bridge,
- the diversion bridge should be located upstream of the destroyed bridge so that the downstream elements of the destroyed structure or scaffolding do not impede the reconstruction process;
- the aprons should be constructed in front of the diversion bridge supports (on the upstream side) (Cholewo & Sznurowski, 1970).

When constructing a temporary viaduct over a motorway, the opening span of the supports should be equal to the width of the carriageway plus 0.50 m on each side. The minimum clear height of these viaducts should be 4.50 m (Cholewo & Sznurowski, 1970).

2. GENERAL PRINCIPLES FOR THE DESIGN OF TEMPORARY RAILWAY BRIDGES

The bridges reconstructed on an ad hoc or temporary basis shall be designed on the basis of technical documentation. The documentation shall be prepared on the basis of the results of a technical survey of the damaged bridge. The reconnaissance should include (Bień, 2009; Cholewo & Sznurowski, 1970; Madaj & Wołowicki, 2013; Miklin & Sawicki, 1993):

1. name, type and location of the installation,
2. description of the damaged object, together with an inventory showing its condition after destruction,
3. characteristics of the railway line, number of tracks and gauge of the structure,
4. layout plan and longitudinal profile (scale 1:1000) of the section of the railway line in the area of the bridge,
5. cross-sections of any obstacle (water or terrain),
6. hydrological data (in case of water obstacle): normal, maximum and minimum water levels,
7. navigational requirements for the vertical dimension of the gauge under the bridge span.

In the case of emergency restoration, the reconnaissance may be lacking (4, 6, 7), but the possible highest water level should be determined (Cholewo & Sznurowski, 1970).

The documentation, i.e., the technical design of the temporary reconstruction, should include (Cholewo & Sznurowski, 1970; Miklin & Sawicki, 1993):

- a technical description and construction drawings of the facility,
- static calculations,
- material lists,
- organisation of the works,
- cost estimate (if necessary).

Railway authorities in many countries are equipped with collapsible bridges (Białobrzeski, 1978; Marszałek, Chmielewski & Wolniewicz, 2010). These bridges make it possible to quickly restore the operation of road and rail routes in the event of failure or damage to fixed bridges. Consequently, the design activity for the preparation of documentation for the ad hoc or temporary reconstruction of bridges has been limited to obtaining basic data on the destroyed structure and determining the appropriate type of bridge to be built into the interrupted traffic line.

Temporary bridges – ad hoc or temporary – are calculated for two types of loads: the first type, which is the main load (primary system), and the second type, which is the additional load (secondary system). The primary system includes: permanent load, moving load and centrifugal force acting in horizontal curves. The secondary system includes wind pressure and braking force.

Bridges that are rebuilt on an ad hoc basis should only be calculated for the first type of load and the stability of the bridge should be checked under the wind pressure loading.

The static calculation of temporary bridges with a more complex design – i.e. bridges with horizontal arches, lattice spans and piers over 4.0 m high – must take into account the first and second type loads. When designing these structures, it is essential to observe the principle of accepting loads in accordance with the assumptions of the relevant standard.

The design is also related to the control of the service condition, i.e., the control of the deflection of the bridge spans. The maximum allowable deflection of temporary bridges is (Miklin & Sawicki, 1993):

- for steel spans

$$y_{allowable} = f \leq l - (400)^{-1} \tag{1}$$

- for timber spans

$$y_{allowable} = f \leq l - (180)^{-1} \tag{2}$$

- for spans made of constant section beams, the maximum deflection is calculated from the formula:

$$y_{maximum} = 5/48 - M - l^{2} \, (E - J)^{-1} \tag{3}$$

In the above formulae:

M - maximum bending moment due to moving load [Nm],
l - theoretical span of the bridge span (beam) [m],
E - modulus of elasticity, e.g., for steel $E = 2.1 - 10^5$ MPa,
J - moment of inertia of the section at the centre of the beam (span) [m^4].

3. GENERAL METHODS OF TEMPORARY RECONSTRUCTION OF RAILWAY BRIDGES

3.1 Classification of methods used

The way in which temporary bridge reconstruction is carried out depends on (Cholewo & Sznurowski, 1970; Miklin & Sawicki, 1993; Surowiecki & Zamiar, 2014):

- the nature and extent of the damage,
- the conditions under which the reconstruction takes place (wartime or peacetime conditions),
- the deadline for completion of the works,
- the type of materials and equipment available,
- the qualifications and size of the installation teams.

The choice of method for the temporary reconstruction of bridges is determined by the principles of structural statics, strength of materials, safety of railway traffic, safety of assembly and economy of materials and labour. The most commonly used methods of temporary bridge reconstruction include:

- filling the openings of damaged bridges,
- covering with a temporary structure,

- use of damaged bridge spans,
- construction of bypass bridges.

In practice, temporary bridge reconstruction may be carried out by combining the above methods in the reconstruction of a single structure.

3.2 Filling in the holes in damaged bridges

This is a method used for the temporary reconstruction of damaged small bridges or culverts located in low embankments, under the conditions of low flow in watercourses (Miklin & Sawicki, 1993). The restoration of communication via such structures can be achieved by filling the opening with rock debris or rubble, after steel or concrete pipes have been laid to facilitate the flow of small volumes of water. If the hole is filled with earth material (soil with limited water permeability), a correspondingly larger number and diameter of water-conducting pipes must be provided.

In the case of high embankments, the stone surcharge is only built up to a certain embankment height, while the difference in height can be made up with temporary supports made of sleepers. Damaged culverts can be reconstructed using a triangular opening culvert structure made of timber or reinforced concrete sleepers (Fig. 1) (Cholewo & Sznurowski, 1970; Miklin & Sawicki, 1993).

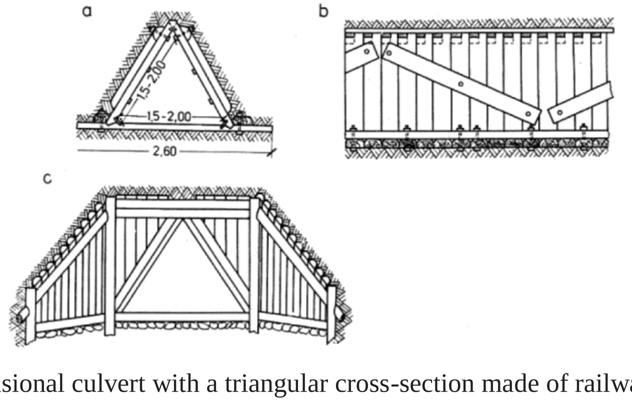

Fig. 1. Provisional culvert with a triangular cross-section made of railway sleepers (Cholewo & Sznurowski, 1970; Miklin & Sawicki, 1993): a – cross-section, b – side wall reinforcement, c – view from the inlet to the culvert

The opening of a collapsed small bridge can be filled with a structure in the form of a ‘cage’ made of railway sleepers (Fig. 2) (Cholewo & Sznurowski, 1970; Miklin & Sawicki, 1993). The cages are laid directly on the ground or on a layer of stone ballast, leaving an opening for water to flow through. To stiffen the overall structure, the individual cages must be tied together with longitudinal logs of a length equal to the length of both cages plus the width of the opening.

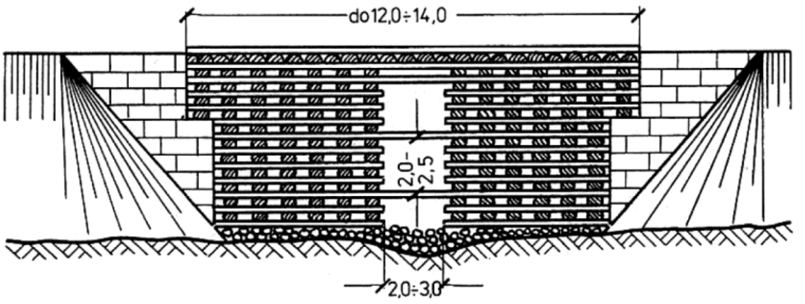

Fig. 2. Filling the opening of a damaged bridge using a structure in the form of ‘cages’ made of railway sleepers (Cholewo & Sznurowski, 1970; Miklin & Sawicki, 1993)

3.3 Covering the hole with a temporary structure

This method is one of the most commonly used for the reconstruction of damaged bridges. It involves the use of undamaged or partially destroyed elements of the bridge structure or supports for the construction of temporary bridges (Figs. 3÷10) (Cholewo & Sznurowski, 1970; Miklin & Sawicki, 1993). Provisional load-bearing structures are made on salvaged or temporary supports: from wooden beams, steel I-sections or lattice beams. Supports can be made as frame or caisson, with cages made of railway sleepers or on piles.

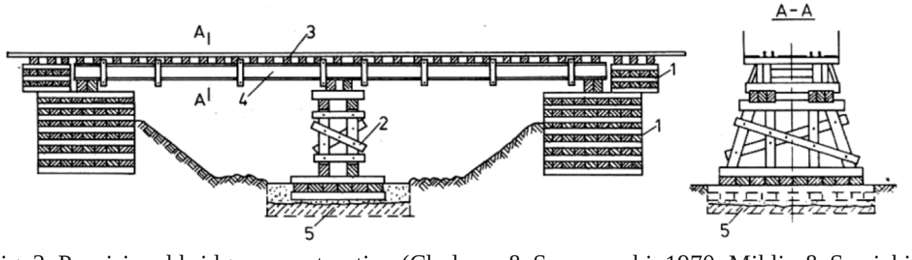

Fig. 3. Provisional bridge reconstruction (Cholewo & Sznurowski, 1970; Miklin & Sawicki, 1993): 1 – railway sleeper cages forming the bridge abutments, 2 – provisional support in the form of a wooden yoke, 3 – railway pavement, 4 – provisional span, 5 – substructure of the intermediate support in place of the destroyed pillar of the fixed bridge

Fig. 4 shows the covering of the opening with I-beams supported on sleeper cages as abutments. The cages were located on the deteriorated abutment walls.

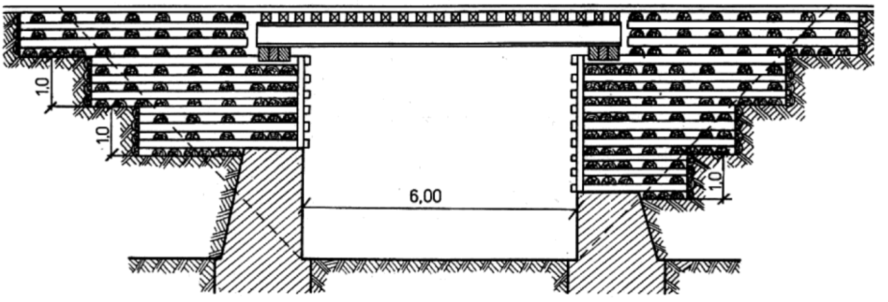

Fig. 4. Provisional reconstruction of a bridge with a span made of I-beams on supports (abutments) made of railway sleepers forming so-called cages (Cholewo & Sznurowski, 1970; Miklin & Sawicki, 1993)

Fig. 5 illustrates the reconstruction of the viaduct using frames placed on the foundations of the destroyed abutment and spans of steel I-beams and timber beams.

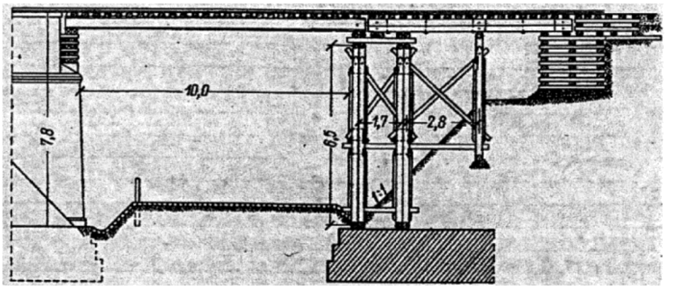

Fig. 5. Provisionally reconstructed viaduct (Cholewo & Sznurowski, 1970): left span made of steel I-sections; right span made of wooden beams; central pillar of frame construction set on the foundation of the destroyed abutment

A makeshift two-span bridge with two main girders in the span structure, founded on the outermost pile supports and the central pillar as a frame, is shown in Fig. 6 (Cholewo & Sznurowski, 1970). The main (load-bearing) girders consist of two NP 60 composite steel I-beams. Along each span, transverse stiffeners for the main girders were installed at appropriate intervals using 1.5 inch diameter bolts.

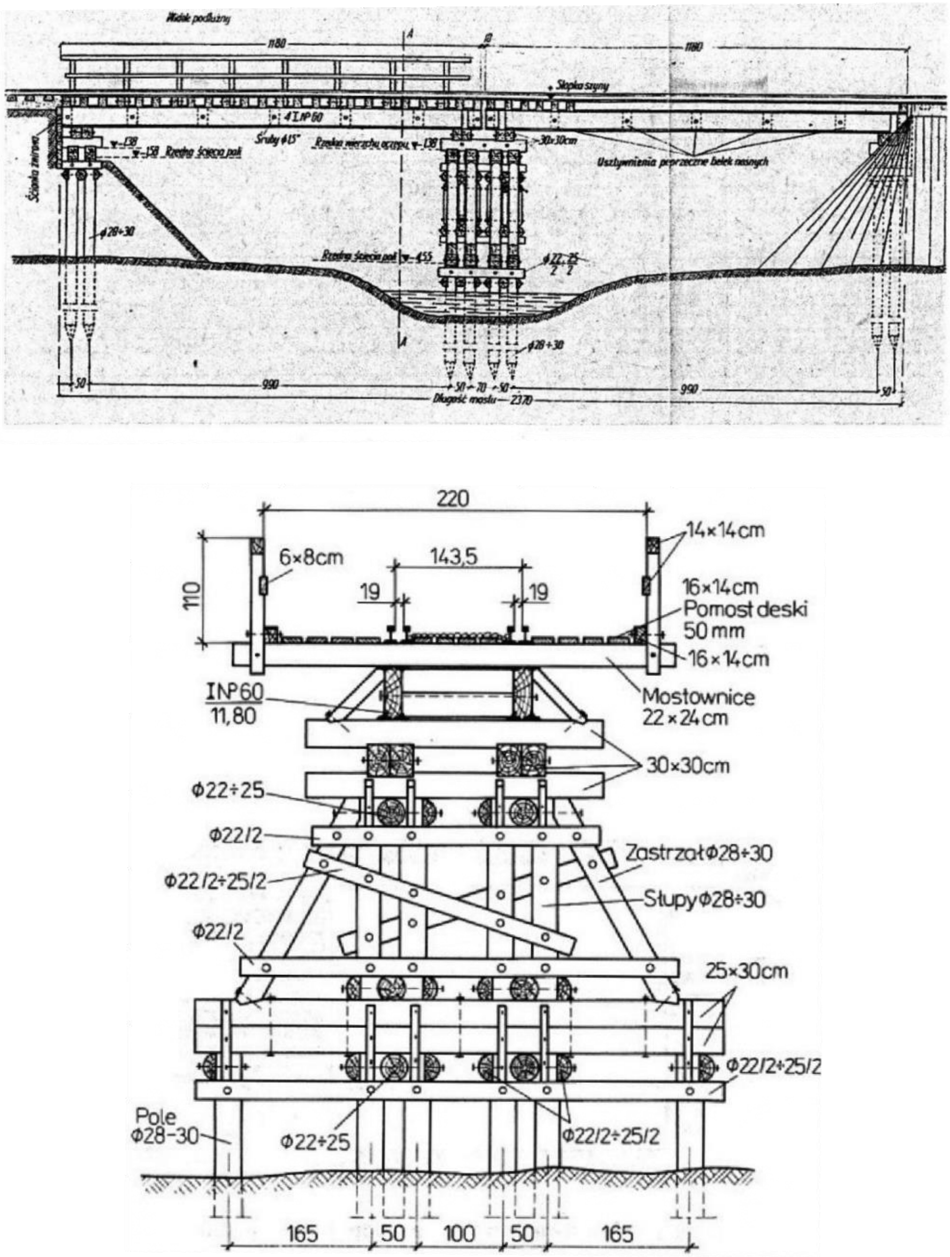

Fig. 6. Provisional bridge (Cholewo & Sznurowski, 1970): top – longitudinal view, bottom – AA cross-section through the bridge pillar

Fig. 7 shows a three-span bridge provisionally rebuilt with a central lattice span, end spans of steel I-beams and temporary timber pile frame supports.

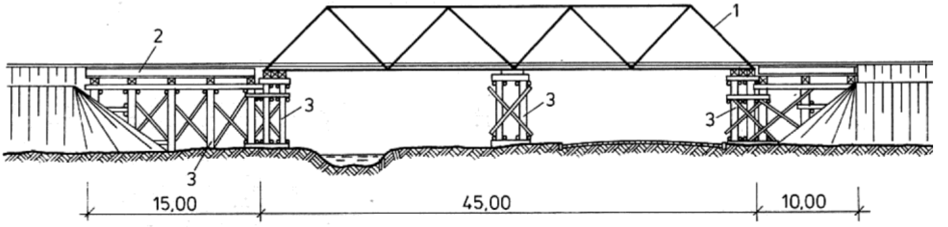

Fig. 7. Provisionally reconstructed bridge (Miklin & Sawicki, 1993):
1 – central lattice span, 2 – outermost spans made of steel I-beams,
3 – temporary wooden pile frame supports

In some cases, it is possible to use the damaged elements to rebuild the bridge on a temporary basis (Fig. 8) (Miklin & Sawicki, 1993). This Fig. shows a longitudinal view of a reconstructed two-span bridge consisting of two spans of plate girder construction. The left span rests on the existing abutment and a makeshift pillar, constructed as a cage of railway sleepers, adjacent to the existing pillar (stone or concrete), forming an integral whole with this structure. The right span was constructed using the damaged plate girders, with the damaged area supported by a temporary pillar of frame and pile construction.

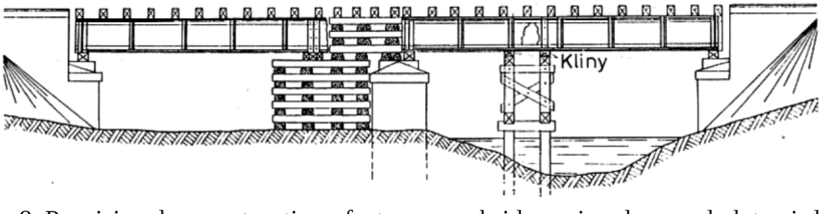

Fig. 8. Provisional reconstruction of a two-span bridge using damaged plate girders (right span) (Cholewo & Sznurowski, 1970; Miklin & Sawicki, 1993)

The method of reconstruction of a single-span bridge using additional pile support, due to the weakened span structure, is shown in Fig. 9 (Miklin & Sawicki, 1993). The span is made up of main girders constructed from existing plate girders, weakened by the disaster. The construction of an additional temporary support and the installation of timber packs, steel washers and steel tie rods on the bodies of the existing bridge abutments enabled the bridge span to be raised to its original position.

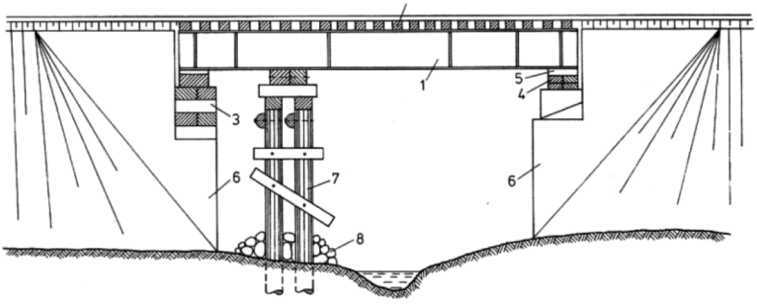

Fig. 9. Reconstruction of a single-span bridge (Miklin & Sawicki, 1993): 1 – bridge span raised to its original position, 2 – railway superstructure, 3 – hardwood packs, 4 – steel ties, 5 – steel washers, 6 – bridge abutment bodies, 7 – additional pile support due to weakening of the span structure, 8 – armour rock.

Fig. 10 shows a method of ad hoc reconstruction of a damaged truss, which is a span of a bridge with a downward traverse (Miklin & Sawicki, 1993). The reconstruction consists of leaving the damaged truss in place and supporting the damaged zone with temporary pillars of a cage-shaped structure made of railway sleepers. The cages are founded on a suitably prepared subsoil, i.e., levelled and, depending on local conditions, additionally underlain with applied armour rock (compacted).

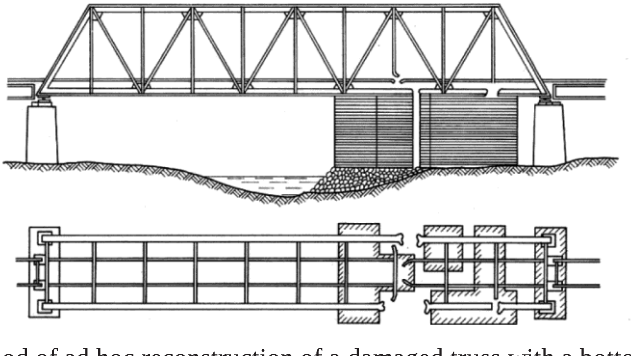

Fig. 10. Method of ad hoc reconstruction of a damaged truss with a bottom ride using additional supports constructed as cages from railway sleepers (Miklin & Sawicki, 1993)

3.4 Bypass bridges

If a temporary reconstruction along the axis of the destroyed structure is not possible, it is necessary to construct a bypass bridge at some distance from the axis of the existing destroyed bridge (Fig. 11) (Miklin & Sawicki, 1993). Bypass bridges are generally built when the reconstruction of a destroyed or damaged bridge is planned on a permanent basis in the future, or when there are significant technical and organisational difficulties. These difficulties can arise when:

- the dilapidated structure in the river bed makes it impossible to build the supports for the temporary bridge, and its removal is difficult and takes a long time;
- the damaged bridge had very high supports, which would have been complicated to reconstruct and would have taken too long with the resources available to the contractor;
- the nature of the river at the site of the destroyed bridge (stony and heterogeneous bottom, considerable water depth, etc.) is very unfriendly from the point of view of carrying out reconstruction works along the axis of the former bridge.

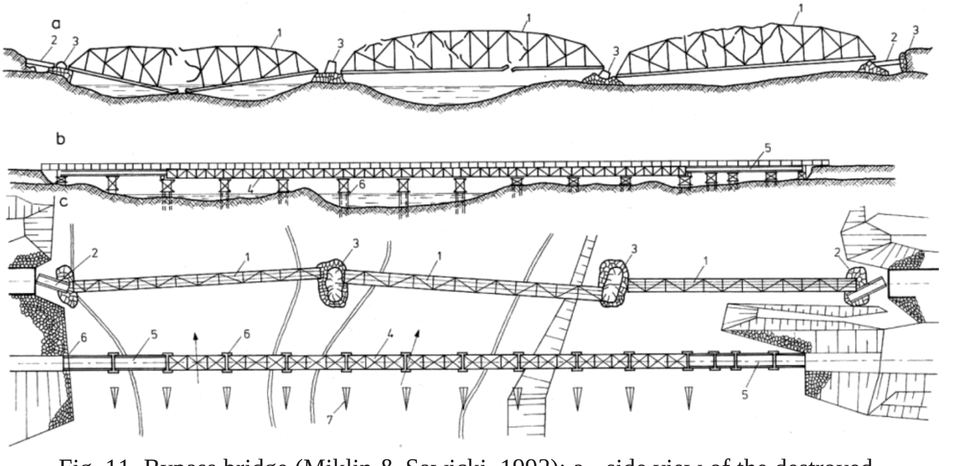

Fig. 11. Bypass bridge (Miklin & Sawicki, 1993): a - side view of the destroyed permanent bridge, b - side view of the temporary (bypass) bridge, c - top view of the destroyed bridge and location of the bypass bridge; 1 - destroyed lattice spans, 2 - sheet metal girders thrown off the supports, 3 - destroyed supports, 4 - lattice spans of the bypass bridge, 5 - sheet metal spans of the bypass bridge, 6 - pile supports of the bypass bridge, 7 – the aprons protecting the bypass bridge pillars from ice floes.

The bypass bridge should be constructed under the following conditions (Miklin & Sawicki, 1993):

- the distance between the damaged bridge and the bypass bridge should be such that there is no obstacle to the reconstruction of the damaged bridge;
- the bypass bridge should be located upstream of the damaged bridge so that the aprons of the temporary (bypass) bridge prevent the formation of ice blockages.

A bypass bridge is usually constructed in a line parallel to the axis of the existing damaged bridge and as close as possible to the existing embankment to allow access to the bypass bridge. In this way, the amount of earthworks during the construction of the diversion bridge can be reduced.

In terms of height, the bypass bridge can be lower than the existing damaged bridge. The amount of lowering depends on the length of the diversion, which must be equal to the maximum gradient provided for the railway line concerned or the maximum gradient permitted on lines of general interest, i.e., 12.5 ‰.

Bypass bridges shall be constructed on the same principles as temporary or timber bridges, usually on pile or pile-framed supports and spans of steel beams or trusses. The bypass route on the layout plan is designed by adapting its geometric layout to the position of the railway line – either on a straight line or in a horizontal curve.

The track on temporary spans should be laid on sleepers or pads with a clearance of 0.20 m, suitably fastened to the main girders by means of hook bolts and notches.

The aprons (in the form of a tent) should be filled with stone material up to the highest level of the ice flow and covered with a armour rock to protect them from being washed away. Within the limits of the ice flow level, the side walls of the aprons should be lined with logs at least 0.10 m thick and covered with sheet metal 2÷3 mm thick.

CONCLUSION

An important issue to summarise in this article is the maintenance of temporary bridges. The general principles of maintenance of temporary bridges are as follows (Surowiecki & Zamiar, 2014):

- the entire structure should be connected and bolted together;
- the wooden elements of the structure of the bridge pillars and aprons should be precisely fitted and connected via appropriate notches, felling bevels, locks and sockets, as well as claws (horisontal, transverse, longditudal) and braces;

- load-bearing structures and supports should be kept clean and of adequate stiffness (e.g., flexural stiffness EJ, where E [kN/m2] - longitudinal modulus of elasticity, J [m4] - moment of inertia of the section of the central axis perpendicular to the plane of external loading);
- the stiffness of the temporary bridge is ensured by constantly checking the tightness of the bolts connecting the individual elements and by checking the quality of the bolts that form the transverse bracing of the beams,
- the bolts connecting the individual timbers should have steel washers (round or square) with a minimum diameter of 60 mm and a minimum thickness of 6 mm, between the head of the bolt and the timber and between the nut and the timber,
- all steel parts of the temporary bridge structure shall be protected against corrosion by painting or bituminous coating,
- steel i-section girders, placed on wooden pillars (yoke caps or abutement caps), should be secured from side-shift via hooks or bolts or steel metal sheets, attached to the caps via screws:
- the wood in the supports should be protected against decay (by mechanical or chemical means),
- the entire temporary structure must be fireproofed.

In the opinion of the authors, the problem addressed in this paper is important because it could become topical in view of the uncertainties of the climate in the Polish and European regions. It is worth mentioning the enormous consequences of the 1997 floods in Lower Silesia and the dynamics of the course of the fight against this element.

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