Repair and Protection of Small Railway Viaduct with Jammed Span at the Mining Influence

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Abstract. This paper is about the maintenance of bridge objects on mining areas. Based on several years of observation is shown as functional parameters and technical conditions were deteriorated. As a result of the mining area deformations appeared among others following damages: block of bearings, jam of span, cracks on the abutments. The article describes series of clever maintenance repairs (such as the restoration of displacement freedom on non-standard tangent bearings) which enabled the exploitation of the viaduct without interruptions of railway communication. The region of the bridge is planned to further mining activities, which prejudged, that a repair of the viaduct was necessary to realization. The article discusses the predicted mining area deformation and analyses their influence on the bridge structure. Repair of the viaduct is a comprehensive example of the mining facility protection with the restoration of the expansion joints, bearings replacement, widening benches under bearings, stitching cracks and strengthening abutments, recreating the isolation and the drainage system damaged by mining influences, performance strut in the foundation level. An important element in determining the durability of repair is the selection of appropriate materials and repair technology, which is analysed in the article. All of these tasks completed in less than four months. Article illustrates the photo documentation made before and after repairs and technical drawings that show the range of the repairs.

1. Introduction

In the article is shown the impact of mining deformation on a small railway viaduct with a static scheme of the span in the form of a freely supported beam. The viaduct was subjected to the influences of long-term mining. Several hard coal walls were exploited in the vicinity of the viaduct and directly below it. In the substrate in different periods, alternating compression and stretching dominated.

The viaduct was not adapted to take over the influence of mining exploration. During the construction of the viaduct, i.e. in 1960, there was no mining exploitation in its area. Mining exploitation appeared in the area of this bridge only in the early 1980's.

In the article, the technical history of the viaduct is described. This viaduct is a representative example of the impact of mining influence on bridge objects with spans freely supported.

All most frequent failures of railway bridges with freely-supported spans located in mining areas were revealed: insufficient bearing range, blocking bearings, displacement and/or rotation of bearing with respect to axe of bridge/railway track, insufficient width of expansion joints, scratches of bearing pads, cracks on the concrete abutments.
In the article are described some interesting, non-standard technological processes that enable continuous, uninterrupted use of the viaduct (e.g. temporary unblocking of bridge bearings).

Ultimately, it was necessary to renovate the viaduct and apply it to predicted further significant mining impacts.

Finally, after technical and economic analysis, the owner of the viaduct decided to renovate this object, due to the shorter closing time of the railway line than the replacement (rebuilding) of the viaduct to the new bridge. There is very intensive railway traffic on the railway line running through the viaduct. At the time of renovation, the railway traffic was conducted on an adjacent viaduct. It is important that all the repair works took less than 4 months.

In the article is described how to protect the structure for predicted mining influences: reconstruction of expansion joints, replacement of bridge bearings, "sewing" cracks up and strengthening of concrete abutments, restoration of waterproof insulation and damages of the drainage system caused by mining area deformations. Proper methods of repair of damaged abutments (proper injection of cracks, surface repair of concrete) are described. Choosing the appropriate materials and technology are here important.

The article is supplemented with analyses on the determination of kinematic freedom of bridge spans. The viaduct is located in Poland, the country where for over 200 years mining has been conducted under active railway lines. Poland has significant scientific and practical achievements in the maintenance of bridges in mining areas, e.g. [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11]. Knowledge important in bridge engineering also brings a lot of experience in maintenance of other large buildings in the mining areas, e.g. [1, 2, 3, 12].

2. Description of the viaduct
The railway viaduct consists of two parts which are separate constructions. These structures are assigned to individual tracks:

- under the track No. 1 is a reinforced concrete structure, with static scheme of span as beam freely supported (figure 1).
- under the track No. 2 is a reinforced concrete frame construction, a frame with foundation bottom slab.

The railway line is electrified.

The viaduct under track No. 1 was built in 1960. That is a one-span object consisting of two reinforced concrete abutments and a reinforced concrete span with static scheme of beam freely supported. The span is structurally separated by dilatations from the abutments - the bridge slab span is supported on the abutments via the steel sheets, acting the role of bearings. Reinforced concrete wing-walls are parallel to the axis of the track. Horizontal beam: 5,00 m; vertical beam: 4,27 m; width of the abutments (parallel measurement to the car road): 5,10 m; total length of the viaduct with the wing-walls (measured parallel to the railway track): 16,70 m. The older viaduct located under track No. 1 was described in the article, that older viaduct has numerous damages caused by mining.

Viaduct under the railway track No. 2 was built in 1973. It is a single-span frame construction - closed frame with rectangular cross-section. From the outside (exit/entry) are made parallel to the axis of the railway track reinforced concrete wing-walls - connected monolithically with the span. Dimensions of the viaduct are similar to the object under track No. 1. The viaduct under track No. 2 did not require additional important repairs during several decades of the use. Concrete surfaces were mainly repaired. That was necessary to fit loose, deaf concrete fragments and local injection of deep cracks. In the article, the viaduct under track No. 2 is not further described.

3. Technical condition of the viaduct before renovation
The mining exploitation had negative impact on the technical conditions of the bridge object described in this article. The slab span of the viaduct under the track No. 1 (Figure 1) is jammed. The consequences of "jamming of the span" are: cracks and horizontal features on the frontal walls of the abutment and a sharp crack (fracture) on the northern wing-wall (Figure 2).
Scratching of the abutment wall and the squeezing and stretching of the ground could have contributed to damage to the insulation if the insulation was made in the form of bituminous layers applied directly to the concrete - hence the damp patches are visible.

Figure 1. View of the viaduct under track No. 1 before renovation

The span is jammed. In the case of a free supported span, the abutments work (and are therefore designed) as pillar (wall) fixed in the ground. The jam changes the static scheme of the work of the span to the frame and introduces significant additional internal forces (mainly bending moments and cutting forces) into the abutment structure.

Figure 2. Crack on the north wing-wall of abutment

4. Impact of mining on the viaduct

4.1. Mining exploration done in the past
The official start of the mine exploiting hard coal deposits in the area of the viaduct was made in 1974. In 1982 the viaduct was the first time in a range of mining influences (subsidence of about 5 cm, deck 346/1, wall W-3, distance of the end of the wall from the viaduct about 177 m).

To December 2016, nine decks were exploited (at depth 451 – 919 m). The exploitation was conducted both under the viaduct and in its vicinity, practically in all directions with relative to the viaduct. The dominant there was the north direction - to the north of the viaduct was formed the local hollow of the settling, the viaduct is located on her hillside (Figure 3).

The majority of the mining exploitation period was a gentle stretching in the ground (the mining was at least a few hundred meters from the object). The squeezing (compression) appeared in the ground only from 2007.
As a result of the mining exploitation, the viaduct settled about 2.8 m, the complete shortening of area in the direction of the viaduct axis (railway track axis) was about $\varepsilon_\parallel = -4.0$ mm/m, and on the direction perpendicular to the axis of the viaduct (railway track) $\varepsilon_\perp = -1.0$ mm/m.

Below is concerned information about the impact of mining exploitation in the point in the geometric centre of the viaduct:

- $w=2.79$ m (settlement),
- $T = 6.6$ mm/m (inclination to the north),
- $\varepsilon_d= -3.8$ mm/m (shortening of area without reducing with passage of time),
- $\varepsilon = -2.4$ mm/m (area shortening decreases with passage of time, relaxation of ground is included),
- $R_d=46.3$ km (radius of curvature without reducing with the passage of time),
- $R_d=65.5$ km (radius of curvature increases with the passage of time).

4.2. Mining exploration predicts in the future
The purpose of planed work was to repair and protect this viaduct for a period about 10 years. After 10 years, analysis of the technical condition of the object and the estimation of influences of the further mining will be necessary.

In the period 2017.01.01 to 2026.12.31, five decks are planned in the area of the viaduct at a depth of 815 ÷ 990 m. Exploitation will be carried out in 14 mining walls. Exploitation will be carried out both under the viaduct and in its vicinity, practically in all directions relative to the viaduct.

The dominating effects of the mining exploitation will be revealed to the north-east of the viaduct - on the north-east side of the viaduct will raise the settlement hollow, the viaduct will be on its slope (Figure 4). The north-east corner settlement will be higher about 10 cm until 2026, than the south-west object corner. The viaduct will be turned regard to the axis of the track - the direction of the dominant influences is deviated from the axis of the railway track for an angle about $\alpha = 45^\circ$.

The area around of the bridge object will be subjected, depending on the period, to compression and stretching in different directions to the viaduct.
By the end of 2026, the viaduct will settle about 1.7 m, the stretching of area in the direction of the viaduct axis (railway track axis) is about $\varepsilon_{II} = 2.0$ mm/m, and on the direction perpendicular to the axis of the viaduct (railway track) is about $\varepsilon_{\perp} = 1.0$ mm/m.

Below you will find information about the planned mining exploitation in the period from 2017.01.01 to 2026.12.31.

- $w = 1.70$ m (settlement),
- $T = 4.5$ mm/m (inclination to the north),
- $\varepsilon_d = 1.9$ mm/m (extension of area without reducing with passage of time),
- $\varepsilon = 0.9$ mm/m (area extension with passage of time, relaxation of ground is included),
- $R_d = 73.4$ km (radius of curvature without reducing with the passage of time),
- $R_d = 163.7$ km (radius of curvature with the passage of time).

4.3. Determination of working ranges of bridge bearings

Computational values of area deformation indicators are determined according to [1].

- $T_0 = 1.2* T_{II} = 5.4$ mm/m
- $\varepsilon_{o,+} = 1.1* \varepsilon_{II,+} = 2.4$ mm/m
- $\varepsilon_{o,-} = 1.1* \varepsilon_{II,-} = -2.2$ mm/m
- $R_0 = R / 1.3 = 54.4$ km

During approaching mining deck to the bridge may appear stretching and then after the finish of the exploitation in the coal wall, in the ground should dominate compression or stretching of the area appropriate for the mining wall.

In order to analyse the displacements of structures induced by mining deformation of the ground substrate was assumed, that the western viaduct (under track No. 1) consists of three rigid chunks: two abutments and the slab span.

It has been assumed that mining exploitation is slowly approaching the object; mining influences (hollow) include the object from one of the corners. First one of the abutments is rotated, then with some delay the other abutment.
Total length of the span is \( L = 6.2 \) m. Changing the distance of the support points of the span (change of the distance of the abutments) due to the mining deformation of the area:

\[
\Delta l = \varepsilon_{o,+} \cdot L = 2.4 \times 6.2 = 14.9 \text{ mm (stretching)},
\]

\[
\Delta l = \varepsilon_{o,-} \cdot L = -2.2 \times 6.2 = -13.7 \text{ mm (compression)}.
\]

The height of the front wall of the abutments is about 5 m, \( h = 5 \) m. Additional inclination of one abutment relative to the second from abutments (each of the abutments inclines in the opposite direction respectively for shape of mining settlement hollow) in the viaduct axis the inclination of the abutment is: \( \Delta h = 2 \times T_{o} \times h = 2 \times 5.4 \times 5 = 54 \text{ mm} \).

The width of the abutment is approximately 5.0 m, \( b = 5.0 \) m. Additional displacements in the viaduct axis associated with the abutments rotation:

\[
\Delta s = (\varepsilon_{o,+}) \times b/2 = 2.4 \times 2.5 = 6 \text{ mm (stretching)},
\]

\[
\Delta s = (\varepsilon_{o,-}) \times b/2 = -2.2 \times 2.5 = -5.5 \text{ mm (compression)}.
\]

The permissible span deflection for freely supported reinforced concrete railway bridges is \( L/800 \), where total length of the span: \( L = 6.2 \text{ m} = 6200 \text{ mm} \):

\[
f = L/800 = 6200/800 = \pm 8 \text{ mm},
\]

It was assumed that the deflection of the span changes its length measured at the upper and lower edges.

Thermal influences:

\[
\alpha_t = 1.0 \times 10^{-5} \quad \text{– coefficient of thermal expansion for concrete},
\]

\[
\Delta t = 35^\circ \quad \text{– maximum temperature change relative to reference temperature},
\]

\[
\gamma_f = 1.3 \quad \text{– safety factor to temperature}.
\]

Length of the span: \( L = 6.2 \text{ m} \),

\[
\Delta l = L \times \Delta t \times \alpha_t \times \gamma_f = 6200 \times 0.00001 \times 35 \times 1.3 \approx \pm 2.8 \text{ mm}.
\]

Sum of maximum displacements in the axis of the viaduct:

\[
\Sigma \Delta l = 14.9 + 54 + 6 + 8 + 2.8 = +85.8 \text{ mm} \approx 90 \text{ mm (stretching)},
\]

\[
\Sigma \Delta l = -13.7 - 54 - 5.5 - 8 - 2.8 = -84 \text{ mm} \approx -90 \text{ mm (compression)}.
\]

The calculated width of the expansion joints is \( \pm 90 \text{ mm} \).

This width should be increased by 10 mm (1 cm) due to the permissible and inevitable unevenness on the contact surfaces of the backwall and wing-walls. Expansion joints between the slab span and the abutment should have a range of min. 100 mm, and the adopted bearing system should have a suitable displacement range \( \pm 100 \text{ mm} \).

5. Repair of damages and protecting to projected mining influences

5.1. Scope of repair work

The scope of repairs with the protection of the viaduct for predicted mining influences consisted in: reconstruction of expansion joints, replacement of bridge bearings, expansion of bearing benches to accommodate new larger bearings, "sewing" cracks up and strengthening of concrete abutments by shotcreting, restoration of waterproof insulation and damages of the drainage system caused by mining area deformations, construction of reinforced concrete strut at foundation level.

Scope of works is shown in drawings - Figure 5, Figure 6.

Major repair tasks are described below in the sections: 5.2÷5.5.

Renovation works were done between September and November 2016.
5.2. Bridge bearings and bearing benches

Until the bridge was repaired, the role of bridge bearings performed steel rail embedded (in concrete) in the bearing benches. Only the head of the rail was above the bench and the rail was raised by means of steel sheet pads, which acted as tangential bearings. These steel pads were strongly corroded (Figure 7, 8). U-sections C400 is embedded along the edge of the end of span slab (Figure 7). Two narrow strips of steel sheet welded to the channel, parallel to its axis, form a saddle for the rail and perform the role of stopper of displacements. Rigid steel components were embedded directly in concrete, led to the creation of numerous cracks in connection rail-bench of abutments (the cause of the damage mainly was area deformation).

Damage to the benches has caused by exhaustion of the ability to move (freedom of movement) on the "bearings". Span was raised as part of short-term temporary, provisional, corrective actions and metal pads were placed to eliminate the "saddle", which restored freedom of displacements (Figure 8).
Some of the steel pads have moved towards the road, which looks unaesthetic and threatens to fall out in the situation of an appearance of mining stretching area. Such technical condition of the bridge bearing is insufficient, especially in the perspective of predicted mining deformation in the future.

Damage repair consisted in replacement of old tangent linear bearings on pot bearings. It was necessary to raise the span during corrective measures, and builds new bearing benches. Due to the larger dimensions of the new bearings, it was necessary to widen the benches. Enlargement accomplished by dismantling the old back-walls and building new ones that have shifted towards the side of the old embankment.

At this way the dilatation aperture of width 100 mm was obtained (before repair span was jammed, there were not any dilatations.

![Figure 7. Tangent linear bearing: restoring the freedom of displacements by additional metal pads](image1)

![Figure 8. Bearing: a) correct condition, b) additional metal pad in the destination of displacements' freedom](image2)

5.3. Strut in the level of foundation

Abutments of the viaduct can approach along with the ground as the result of mining area compression. In the past, the asphalt pavement of the road under the bridge was scratched and deformed when approaching the bridgeheads were approached.

As part of the bridge rebuilding, a reinforced concrete slab was made under road in the level of the foundation. This slab acts as a strut, preventing the approach of the abutments.

The depth of excavation under the slab is 1.3 m below ground level.

At the bottom of the excavation make a coarse-grained sand layer of thickness 10 cm thickened to degree of consolidation $I_d = 0.9$ (to provide a sliding layer in order to weaken mining influence).

To place the PEHD foil on sand. The foil was also laid on the foundation foot of the abutments in order not to connect the foundations of the abutment with the strut.

5.4. Front wall superstructure (in order to raise the track's level in the future)

Track tamping technology is used to remove irregularity of the track and to correct its level.

Front wall (cornice) of the viaduct on the inlet side was too low compared to the present thickness of the layers of chipping substructure (track foundation) - this wall was pre-built (elevated) with steel sheets. These steel sheets are bent, a strong surface corrosion is visible, hence the further lifting of the rail level by the track tamping is difficult.
During the renovation a new taller front walls of reinforced concrete was build, anchored in the span slab. After repairing the front walls are possible to raise the track level by approx. 0.5 m.

5.5. **Reinforcement of abutments and surface repairs of concrete elements**

Due to the poor conditions of the concrete elements of the abutments, serious repair work was required.

Repair work includes: hacking off "loose, deaf" concrete; cleaning of the reinforcement steel bars (sandblasting); injection cracks important for structure; jointing the wing-walls with steel bars anchored in concrete and connecting both edges of the cracks; application of the anti-corrosion preparation on the exposed steel bars and making bond layer on the concrete surfaces of the abutments; performance of the shotcreting on the front walls of abutments minimum 4 cm and on the remaining elements of viaduct layer min. 2 cm (except the bottom of the span, where a layer of PCC mortar was made) (shotcrete additionally filled up blank earlier scratches and reinforced the structure).

The scope of work includes hydrophobising concrete surfaces and making a paint coating (increases the durability of the structure and enhances the aesthetics) (Figure 10).

Concrete tests (Schmidt hammer, pull-out, pull-off) and chemical parameters of concrete (presence of chlorides, carbonization CO, PH of concrete i.e. acidity/alkalinity) were performed. It has become necessary to remove the concrete coating of steel bars.

Cracks in order to eliminate the water leaks were fulfilled elastic gelling (expansive) mass and not jointed with epoxy resin as the load carrying capacity of concrete was poor (concrete class C12/15) and it was not possible to obtain durability of the "glued" connections.

![Figure 9. View of the viaduct under track No. 1 after renovation](image)

6. **Conclusions**

As a result of mining deformations of the area on object viaduct appeared numerous damages, however in spite of the damages, in the result of clever maintenance repairs (e.g. rebuilding of bridge bearings) managed to keep the uninterrupted railway traffic on the object for over 30 years.

As a consequence of the development of damages in 2016 it was necessary to repair the viaduct. The repair works were preceded by detailed analyses of the impact of mining on the viaduct, taking into account the rise over time and the development of mining deformation. As a result of these analyses, repair works were done along with prevention for mining influences. These works are briefly described in this paper.

It was assumed that as a result of the overhaul, the damages caused by the mining area displacements would be removed and the necessary work related to the adaptation of the facilities to the transfer impact of planned mining exploitation would be done. The durability of repairs (trouble-free maintenance) can be guaranteed only by the correct technology of renovation work adjusted to the
technical conditions and material parameters of the bridge. This article discusses also the most interesting elements of mining protection.

The purpose of the renovation work was also to ensure adequate durability of the object, increase the resistance to the influence of atmospheric factors, which should guarantee the durability of made mining protections.

In addition, the superstructure of wing-walls and front walls on the span (building new taller walls) is provided (on the occasion repair of cornices, damaged by atmospheric), which will allow to raise the railway track level by approx. 0.5 m in the future and to correct the track gradeline by track tamping.

This viaduct is an example of successful co-operation between the railway line manager and the local mine, and this cooperation enables the intensive exploitation of the rich coal deposits located in the area of the railway line on which intensive rail traffic is conducted.

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