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Impact of Mining Exploitation on the Road Viaduct Situated in the Immediate Vicinity of the Edge of a Mined Wall**

1. Introduction

Prediction of mining impacts on the surface allows a reasonable protection of the objects located thereon (e.g. [3, 4]). In the case of bridge structures, a key indicator for the risk assessment are horizontal strains ε and a radius of curvature *R*, and in particular their component occurring on the direction of the object length. These indicators make a decisive impact on the dimensioning of bearings and expansion joints (e.g. [1, 2]). The situation becomes more complicated when we are dealing with a statically undetermined span system. Additional stresses associated with bending of the spans in the vertical and horizontal planes may occur.

The article discusses the test results, which allowed a comparison of the predicted indices of area deformations with those measured during the occurrence of mining impacts, which have an effect on such a structure, located directly on the edge of a mined wall.

2. Description of Viaduct Construction

The described road viaduct (Fig. 1) was erected in 1994 in a traffic route over a motorway. On the northern side of the motorway the viaduct additionally intersects with a trestle of a coaling belt conveyor. It is a triple-span viaduct with a steel load-bearing structure of the spans and reinforced concrete construction of the piers.

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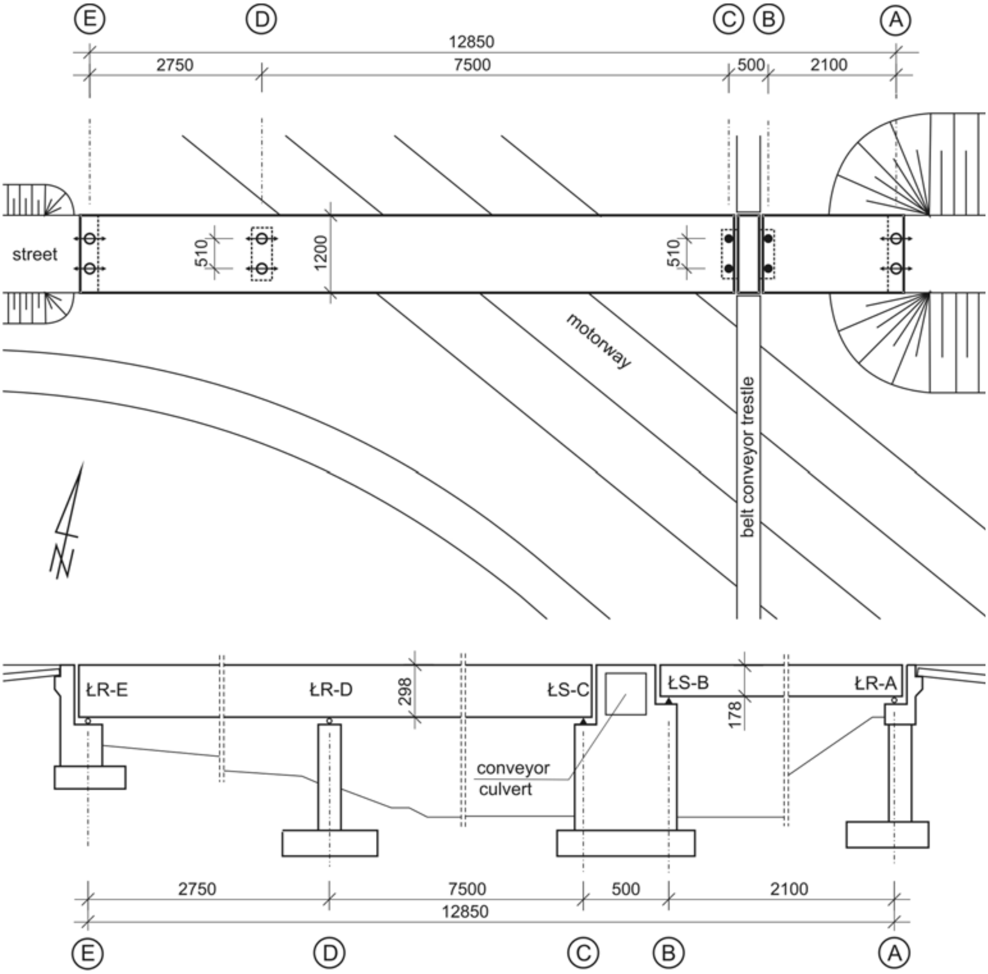

Fig. 1. Horizontal projection, longitudinal section and bearing scheme of the viaduct spans

The total length of the structure, including the wings, amounts to of approximately 141 m. A plate girder double-span continuous beam with a box--section constitutes the load-carrying structure of the two western spans (CD and DE). The theoretical span length amounts to 75.0 + 27.5 m. The eastern span (AB) with the static scheme of a free-ends beam was constructed as plate girder double--beam with orthotropic platform plate. The theoretical span length amounts to 21.0 m. The total width of all the spans is 12.0 m.

The spans were supported on piers with the use of spherical bearings. Fixed bearings were installed on both sides of the BC pier. The remaining bearings are movable in the longitudinal direction. The structure was equipped with tight steel-rubber segment expansion devices of the Maurer type: in the A, B, C, D axes – single-insert with the movement capacity of ±40 mm, and in the E axis – triple-insert with the movement capacity of ±120 mm.

According to the project documentation, the viaduct was adapted to absorb mining effects with the following values of deformation indexes:

- horizontal specific strains $\varepsilon = 1.0$ mm/m,
- area inclination $T = 1.0$ mm/m,
- curvature radius $R = 20$ km.

In order to prevent mining effects, expansion joints and bearings of proper movement capacities were applied along the viaduct axis. In static and resistance calculations, the possibility of change in the radius of the western span summit due to convex curvature, was taken into account. Additionally, the possibility of raising the spans was predicted.

3. Anticipated Mining Impacts in the Vicinity of the Structure

3.1. Mining Exploitation in the Area of the Viaduct

The history of coal mining in the analysed region dates back to the eighteenth century. From the 50's of the nineteenth century, the seams of the group 300, which were deposited at a shallow depth under the ground surface, were exploited. In the 60's of the twentieth century, the exploitation of the seams of the group 400 started. This exploitation was carried out with the fall of the roof at the depths from 290 to 560 m at the height from 1.5 to 3.1 m. The seams of the group 500 were exploited from the 70's of the twentieth century, at the depths from 520 to 630 m, both with the fall of the roof and with the use of hydraulic filling.

In recent years, the exploitation was carried out at the seams 510 and 620. Seam 510, exploited with hydraulic filling, has seam thickness of about 10 m and it is deposited at the average depth of about 580 m. In turn, the seam 620, with the seam thickness of about 1.5 m – at depths of up to 700 m.

The article discusses the impact of mining effects on the viaduct, which are associated with the mining of the wall 308 of the seam 620. The wall was mined from October 2003 to June 2005, at depths from 670 to 700 m in the direction from the south-east to the north-west, with the fall of the roof. The seam thickness of the selected seam ranged from 1.4 to 1.5 m and the operating speed was about 2.4 m per day. In February 2004, the south-west edge of the wall passed under the eastern bridgehead of the viaduct, and continued its course for another 1200 m (Fig. 2).

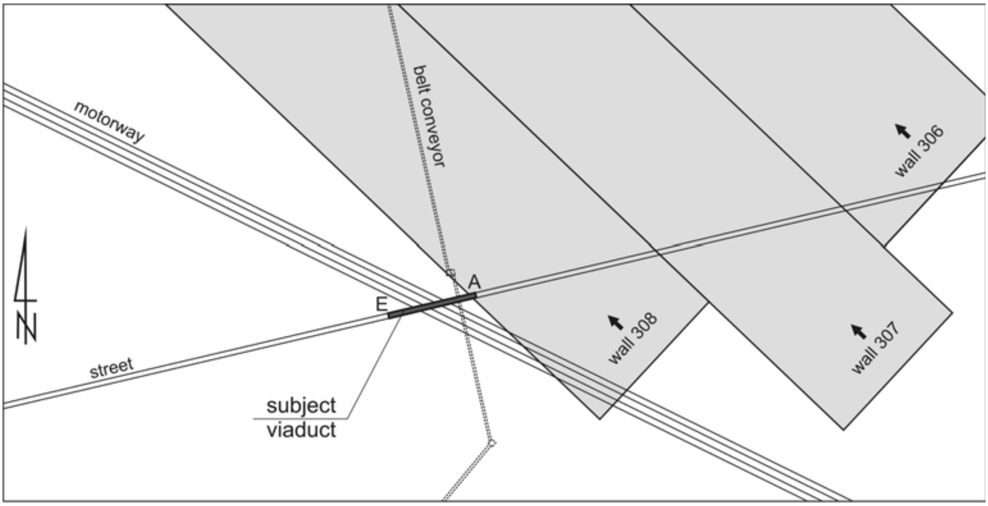

Fig. 2. The location of the viaduct against the mined walls

3.2. Estimated Surface Deformation Indices

The exploitation of the wall 308 of the seam 620 was preceded by the forecast, in which the values of subsidence, extreme horizontal strains and the radii of curvatures were specified. The estimated deformation indices were calculated at five points located in the axes of successive piers (A, B, C, D and E). The values of these indices which are the most relevant to the viaduct were presented in table 1.

Table 1. Area deformation indices in a parallel and perpendicular direction to the longitudinal axis of the viaduct and on the direction of mining effects

Pier	Subsidence w [mm]	Horizontal specific strains ε and the radius of curvature R					
		parallelly to the axis of the viaduct		perpendicularly to the axis of the viaduct		ε_{extr} [mm/m]	$R_{\min}$ [km]
		ε_1 [mm/m]	R_1 [km]	ε_2 [mm/m]	R_2 [km]		
A	497	–1.9	63	–1.6	77	+0.3 –2.2	–500 +59
B	478	–1.7	71	–1.5	83	+0.3 –2.0	–333 +67
C	470	+0.1 –1.6	1000 71	–1.5	83	+0.3 –1.9	–333 +67
D	358	+0.4 –0.5	500 333	–1.1	125	+0.5 –1.1	–250 +111
E	310	+0.5 –0.1	77 1000	–0.9	167	+0.6 –1,0	–200 +167

In the places where the A and B piers were located, on the direction parallel to the axis of the viaduct, only compressive strains were expected. In the cases of other piers, compressive strains were to be preceded by slight tensile strains.

4. Observation of the Viaduct During the Occurrence of Impacts of Mining Exploitation

Due to mining exploitation, the structure became a subject of a program of geodetic surveys and observations, which also included the surveying of subsidence of height bench-marks fixed on the viaduct, as well as surveying of horizontal dislocations of the spans.

4.1. Subsidence of the spans

Two bench-marks were fixed on each of the piers, one on the southern side, one on the northern side. As a reference point, the survey made on 2 December 2003 was adopted. Since the exploitation front of the wall 308 was then distant by about 200 m away from the viaduct, this survey may be considered as made prior to the initial occurrence of the impacts of mining. The next two surveys were made at monthly intervals and then the surveying cycle was extended. The last series of surveying was performed in June 2009, i.e. nearly 5 and a half years later than the exploitation front had gone past the viaduct. All surveys were conducted using precise levelling method. Table 2 presents the survey results of subsidence of individual piers. For each of them, the readings from the northern and the southern side were presented, as well as the mean subsidence (Fig. 3).

Table 2. Surveying results of the viaduct pier subsidence

Date of surveying	Subsidence of the pier [mm]														
	A from the side:			B from the side:			C from the side:			D from the side:			E from the side:		
	S	N	mean	S	N	mean	S	N	mean	S	N	mean	S	N	mean
02.12.2003	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29.12.2003	10	9	9	9	8	9	8	9	8	3	4	4	3	3	3
28.01.2004	18	12	15	26	26	26	24	24	24	6	7	6	4	4	4
31.03.2004	179	185	182	127	133	130	121	124	122	28	28	28	17	16	16
29.05.2004	295	306	301	214	228	221	206	214	210	53	53	53	34	32	33
29.07.2004	353	368	360	265	283	274	258	268	263	83	84	84	64	61	62
21.12.2004	391	408	400	300	322	311	296	306	301	113	116	115	93	91	92
30.06.2009	438	455	446	343	364	353	339	349	344	151	155	153	129	129	129

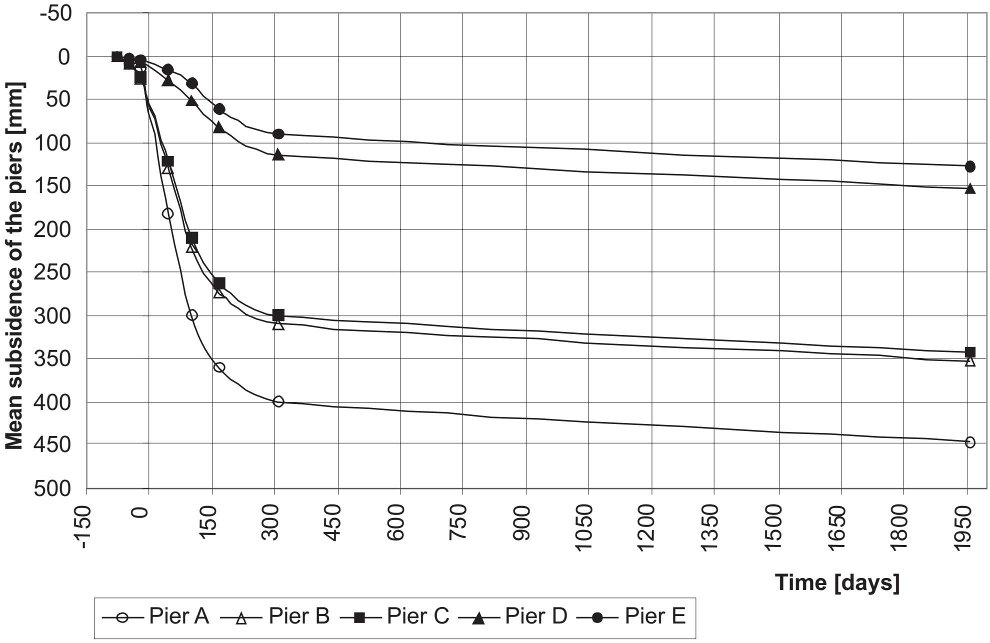

Fig. 3. The diagram of pier subsidence in time

The survey results of the viaduct pier subsidence allowed to make the following observations:

- from the beginning of the mining exploitation, the overall mean subsidence of the eastern bridgehead (A) was about 450 mm and of the western bridgehead (E) about 130 mm;
- the largest increase in subsidence was recorded in March 2004; in case of the eastern bridgehead it exceeded 2.5 mm per day, and in the case of the western bridgehead 0.5 mm per day;
- the result of uneven subsidence of the piers is the viaduct lateral inclination in the southern direction, approximately 2.5 mm/m for the eastern bridgehead, and decreasing and then disappearing in the western direction;
- viaduct longitudinal inclination in the eastern direction, resulting from the same causes, is about 4 mm/m for the eastern span, and about 1 mm/m for the western spans;
- the survey conducted in June 2009 revealed just a slight increase in subsidence (26–48 mm) compared to the previous survey, most of which probably took place even back in 2005.

4.2. Bearings Position Surveying

Precise surveying of dislocations at the bearings, made possible by the marks installed in December 2003, were performed simultaneously with the carried out surveys of subsidence. Due to the renovation works conducted on the viaduct, the last reading (30 June 2009) proved to be impossible.

The survey results have been presented in table 3. Corrections resulting from the temperature differences during conducting particular surveys were taken into account. The sign "–" indicates dislocations corresponding to compressive strains, whereas the "+" sign indicates dislocations corresponding to tensile strains. Figure 4 shows the dislocation in the length of the individual spans as a function of distance of the exploitation front from the longitudinal axis of the viaduct.

Table 3. The overall measured dislocation values on the length of the spans

Date of surveying	Measurement date, overall measured dislocations on the length of the spans											
	eastern (AB)				western (CD)				western (DE)			
	from the side:		mean value:		from the side:		mean value:		from the side:		mean value:	
	S	N	[mm]	[mm/m]	S	N	[mm]	[mm/m]	S	N	[mm]	[mm/m]
02.12.2003	0	0	0	0.0	0	0	0	0.0	0	0	0	0.0
29.12.2003	+2	+2	+2	+0.1	+3	+2	+3	0.0	+4	+4	+4	+0.1
28.01.2004	+9	+8	+9	+0.4	+14	+13	+13	+0.2	+4	+3	+3	+0.1
31.03.2004	+13	+8	+11	+0.5	+87	+86	+86	+1.1	+17	+15	+16	+0.6
29.05.2004	+14	+19	+17	+0.7	+111	+116	+113	+1.5	+18	+12	+15	+0.5
29.07.2004	–35	–32	–34	–1.4	+114	+117	+116	+1.5	+17	+14	+15	+0.6
21.12.2004	–39	–32	–36	–1.5	+118	+122	+120	+1.5	+20	+18	+19	+0.7
30.06.2009	–	–	–	–	–	–	–	–	–	–	–	–

The presented data allow to form the following conclusions:

– The increased rate of occurrence of the horizontal strains was observed in March 2004, that is when the exploitation front was located at 100–200 m behind the axis of the viaduct.

- For both of the western spans, tensile strains have been determined exclusively. The corresponding largest overall dislocations which were measured did not exceed +140 mm, which converted, corresponds to horizontal strains of +1.3 mm/m.
- In the case of the eastern span, tensile strains were observed until mid-June. The corresponding largest dislocations which were measured did not exceed +17 mm, which converted, corresponds to strains of +0.7 mm/m. At the time when the exploitation front was about 300 m behind the viaduct axis, the tensile strains started to decrease, and after passing through the front of the further ca. 100 m, they changed their character to compressive strains. At the end of July, dislocations of –34 mm corresponding to the compression were measured, which converted, corresponds to compressive strains of –1.4 mm/m. This trend continued till the end of the surveying, when the observed values increased slightly, reaching an average of –36 mm (–1.5 mm/m) respectively.
- Dislocation values measured on the southern side only slightly differed from these measured on the northern side, which meant that there was practically no bend of the viaduct in the horizontal plane. This is particularly important due to its statically undetermined static scheme.

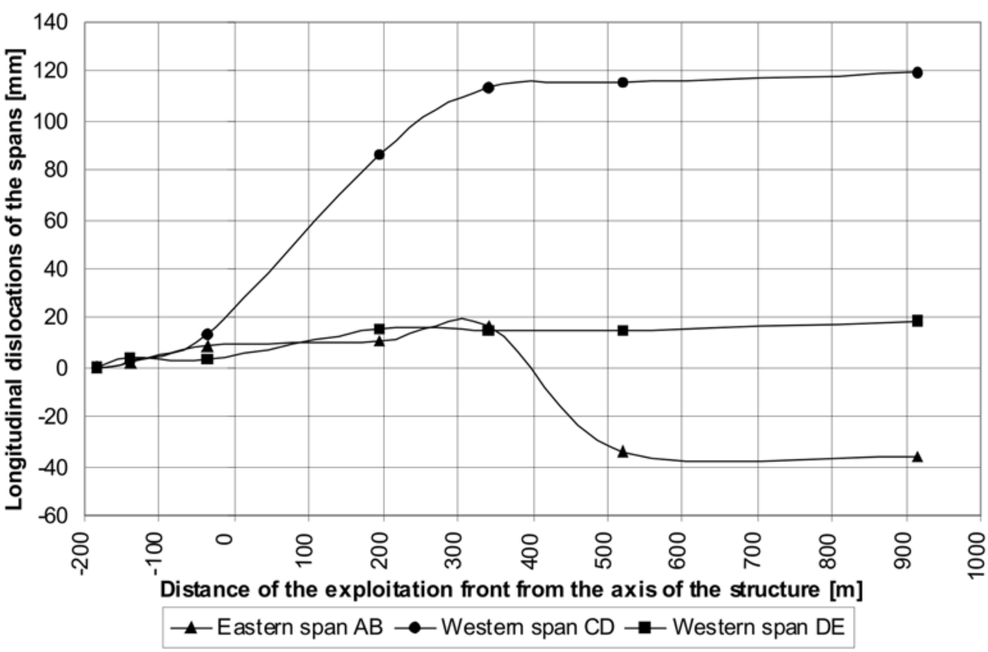

Fig. 4. Longitudinal dislocations on the length of the spans as a function of the exploitation front distance

5. Comparison of Measured Dislocations and Subsidence of the Viaduct Elements with the Projected Ones

Table 1 presents indices of area deformation, as predicted in the location of individual viaduct spans. On the basis of widely used patterns [3, 4], the following maximum predicted differences of the piers movements in the longitudinal direction were obtained for individual spans:

- on the length of the eastern span (AB) = d_{AB} = –45 mm,
- on the length of the western middle span (CD): = d_{CD} = –84 mm,
- on the length of the western terminal span (DE): = d_{DE} = –9 mm,

Table 4 compares the predicted differences of span movements with the measured dislocations on the length of the spans, as shown in table 3. The summary of the results of subsidence predictions and surveys have been contained in table 5.

Table 4. Summary of predicted and measured values of dislocations

Dislocations [mm]	Spans				The whole viaduct (AE)
	eastern (AB)	western (CD)	western (DE)	both of the western spans (CE)	
measured d^m	–36	+120	+19	+139	+103
predicted d^p	–45	–84	–9	–93	–138
the difference Δd	+9 (20%)	+204 (243%)	+28 (311%)	+232 (249%)	+241 (175%)

Table 5. Summary of predicted and measured values of piers subsidence

Piers subsidence [mm]	Piers				
	A	B	C	D	E
measured w^m	446	353	344	153	129
predicted w^p	497	478	470	358	310
the difference Δw	–51 (–10%)	–125 (–26%)	–126 (–27%)	–205 (–57%)	–181 (–58%)

Table 4 point out discrepancies between the predicted and measured differences of piers dislocations of the western spans. According to the forecast, the horizontal tensile strains were to occur only at the beginning, to finally give way to compressive ones. However, in the course of time, tensile strains in the western part of the viaduct were steadily increasing, exceeding the predicted values by 200%. In the case of the eastern span, located in the immediate vicinity of the mined wall, the forecasts proved to be much more accurate. Here, after initial tensions, compressive strains occurred. The measured differences of piers dislocations were smaller than predicted by only 9 mm, which, due to the small-scale predicted values, corresponds to the relative difference of 20%. The occurrence of the dislocations in the direction opposite to the expected, resulted in a need for urgent adjustment of the bearings.

In the case of piers subsidence, the maximum compliance was achieved on the eastern side of the viaduct, i.e. for the pier A, for which actual subsidence turned out to be lower than the predicted by a little over 50 mm (10%). At the opposite end of the viaduct, the actual subsidence turned out to be smaller than the predicted one by 58%.

6. Summary

The paper discusses the results of tests that allowed to verify the values of the predicted area deformations in the vicinity of a road viaduct, situated adjacent to the edge of a mined wall. The analysis showed a relative compliance of the forecasts related to the eastern part of the viaduct situated in the immediate vicinity of the mined wall, both in terms of subsidence and horizontal strains. For the western part of the structure, which was more distant from the edge of the wall, the values of actual subsidence turned out to be more than twice lower than expected, and the horizontal strains also differed as to their character – compressive strains were anticipated and tensile strains occurred.

The reasons for discrepancies between the measured and the predicted values should be sought in the adoption of the parameters needed to prepare the forecasts, which were too different from the actual ones, and also in the methodology adopted to compare the predicted and observed values of the deformation indices.

Despite such a large discrepancy between the predicted and the measured values, there was no threat to the security of the structure, which could become the cause of the failure and closure to traffic. This was mostly due to the low index values of the occurring mining effects.

References

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