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Selected Bearing Problems of Old Railway Bridges Located On Mining Areas in Poland

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Selected Bearing Problems of Old Railway Bridges Located On Mining Areas in Poland

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Abstract. In this article are discussed bearing problems of old railway bridges located on mining areas in Poland. The problem is important because the old railway bridges in the areas of active mining exploitation are still in use, but often lack of money for their replacement or major reconstruction. Railway traffic is still underway after these objects, but the requirements for increasing the speed of rolling stock are bumped up. The article applies to bridge objects, which have the static scheme of the freely supported beam, which is universally used, and it is a structural solution. The article describes how mining exploitation affects bridge bearings and the conditions that bearings should fulfil on mining areas. A short review of Polish technical solutions and Polish literature information's on bearings of railway bridges in mining areas is made, it may be valuable for people dealing with similar problems in other countries. Attention is taken to the features that differ the bridge objects from cubature structures in the context of transferring mining influences, e.g. multi-solid of bridges and elevation of their main structural part (spans) above the ground. The general principles of ensuring kinematic freedom and selection of bearings are discussed. Typical damages and threats to the safety of the rail traffic (e.g. breaking the permanent bearing, blocking the bearing, cutting the head of the pillar) triggered by mining area deformations are pointed out. Author discusses the significant influence of bearings on the resistance of railway objects to mining deformations of the area. The article also draws attention to the necessity of frequent monitoring of bearing condition due to the possibility of sudden damage. Examples of Polish experiences are given, i.e. working SHM (Structural Health Monitoring) system is described. Safe maintenance of the object on the mining area requires a combination of knowledge from the bridge manager and mine and data from automatic monitoring systems, geodetic measurements, technical condition assessments - it indicates the need for proper organization of the process associated with acquisition, use and information flows, e.g. according to standards included in the BIM method (Building Information Modelling).

1. Introduction

The aim of this article is to show the state of science, researches and real technical problems in the field of bearings of old railway bridges with a static scheme of a freely supported beam, located on mining areas in Poland. This is the most popular static model of railway bridges in Poland in areas where exploitation of hard coal deposits is still conducted. Polish experiences, i.e. more than 150 years of intensive development of railways on large mining areas, provide a lot of practical information, valuable for both engineers and researchers. Theoretical considerations are complemented by practical examples of repair actions and actions associated with preventive protection and are illustrated with photos from real bridge objects.

In literature, there is lack of similar articles showing the state of technical knowledge, rules in Polish technical regulations and examples of failures, negligence and repairs in the field of old railway bridges located on mining areas in Poland. The examples come from the author's own practice. The author of the paper has dealt for over 25 years with this subject as a science worker, researcher, expert and active engineer. The article may be important for people dealing with similar topics in other countries as well as for people connected with the railways construction.

The problem of designing the kinematic freedom of bearings and spans is only one of the elements of maintenance of bridge structures on active mining areas. Mining predictions relate to points on the area and are not accurate in relation to squeeze/stretch of the soil-ground or terrain deflections. Much depends here on the method of foundation, geological structure of the ground surface or the direction of mining exploitation in relation to the bridge object. Therefore, special attention is paid to the difficulties in diagnostics of the bearings technical conditions and the possibilities of a sudden deterioration of bearing operating conditions as a result of mining deformation and the need of bearings monitoring. In the article, it is pointed out, when and how to monitor the "work" of bearings and attention is paid to the need to connect together (integration) SHM systems with rail traffic control systems. It is also described when traditional geodetic measurements do not ensure the safety of using a bridge object located in mining area. In such cases, the solution can be the system of permanent remote monitoring of displacements in which boundary values are determined. It is pointed out that in order to effectively use information from monitoring systems, it is necessary to have up-to-date bridge model with information about damages, up-to-date information on mining impacts and damage updates as they grow over time - relevant tools are provided by modern methods of building object information, known under common name as BIM.

2. Overview of literature and technical regulations in Poland, related to railway bridge bearings

Polish literature related to the bearing of railway bridges subjected to mining areas deformation is relatively poor. The technical basis is the guidelines from 1977 [1] containing information on the determination of "working" range of bearings (kinematic freedom). It is worth to add that there are no more recent guidelines for the design and construction of bridge objects on mining areas. The same formulas as in the guidelines [1], supplemented by an extensive theoretical foundation concerning the mechanics of rock mass disturbed by mining exploitation, are in the book written by professor Rosikoń [2] from 1979; this book is considered fundamental and still used in practice. The Salamak monograph (2013) [3] gives general information about the kinematics of the solids composing the bridge object. Only a small part of the monograph concerns typical damages to bridge bearings. Salamak [3] does not describe any repair and protection methods. In none of the publications mentioned above, the principles of conducting monitoring in relation to bridge bearings and free-supported spans are given. Examples of problems concerning bridge bearings and monitoring of railway bridges can be found in Poland only in individual articles, e.g. [4, 5, 6]. Bearings of railway bridges are described only in small chapters in bridges books, e.g. [7], [8]. The latest publication and practically the only Polish monograph about bridge bearings [9] (Niemierko, 2016) concerns modern bridge bearings and omits, for example, the problem of roller bearings (except for short information about their construction). This monograph [9] does not contain information on mining influences and bridges on mining areas.

In the instruction ID-16 [10] referring to the maintenance of railway engineering objects (bridges), there are no references to mining areas - the bearing schemes described there do not take into account the necessity of transferring mining terrain deformations. Bridge objects, starting from structural elements through equipment elements and the shape of the surroundings, had to comply with the technical conditions given in the manual ID-2 [11], and from 2015 in Technical Standards [12]. In ID-2 [11] mining impact contains only two single-sentence points, stating that technical documentation regarding new and rebuilt bridges should fulfil the requirements of the 1977 guidelines [1].

In Technical Standards [12] is written that the location of engineering objects in the areas of mining exploitation should take into account adverse effects that occur or may occur. In the areas of mining exploitation, appropriate protection should be applied, sufficient to the category of mining areas. There is, however, no indicated literature sources, from which this knowledge should be taken.

According to Technical Standards [12], the construction of engineering objects on the mining area should ensure freedom of displacements of structural elements and the possibility of rectifying the position of structural elements. Spans of bridges, viaducts or footbridges should have a static scheme of a free-supported beam [12]. It is allowed to use a bridge span with a static scheme of a continuous beam in the case of minor mining deformations carry by the structure of bridge, viaduct or footbridge.

According to ID-2 [11], in railway bridges and viaducts, the use of simple bearings made of steel sheets (tangent bearings) is allowed only in the spans of the theoretical length up to 20 m. Therefore, in old railway bridges with a span length of up to 20 m, tangent bearings were mostly used (i.e. two steel tangent sheets). Roller bearings were used in spans over 20 m long.

In current PKP regulations (Technical Standards [12]), elastomeric bearings are recommended to use in bridges with spans of up to 40 m. However, in elastomeric bearings in mining areas, permanent deflection (inclination) associated with mining deformation appears (Figure 1).

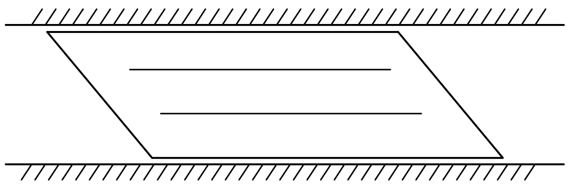

Figure 1. Elastomeric bearing inclination

The Technical Standards [12] include scheme of bearings for single free spans in railway bridges. According to this scheme, on one side of the span there are one fixed bearing and one multi-directional one, and on the other side of the span there are one single-directional bearing set in the bridge's axis direction and one multi-directional bearing. However, there is no information, whether this scheme also applies to the bearing of bridge structures on mining areas. According to [12], "floating" bearing [12] is unacceptable, i.e. such system where there is no permanent bearing.

In Poland, many old railway bridges have two permanent bearings on one of the supports and two one-way sliding bearings on the second support [2], [5], [6], [8]. This is related to the fact that the object is treated as linear, also in terms of mechanics. One of the dimensions dominates over the others and the construction is treated as a long bar supported on one side in a sliding manner and on the other side with a blockade of displacements. Such bearings (with simultaneous low stiffness of the spans in the horizontal plane) were successfully used also in bridge objects located on mining areas (eg [5], [6]) and were supposed to protect the continuity of the railway track, where linear compensators were in the track outside the bridge.

According to Technical Standards [12], the shape of bearing benches and the upper part of abutments and pillars should take into account the possibility of setting rams to rectify the level of bearing support or replace spans or bearings.

3. The influence of mining deformations on bridges

Mining exploitation under railway lines was carried out in most cases by the caving (breaking down) system. Such a mining system results in a visible revealing of the effects of exploitation on the surface in the form of mining area deformations (e.g. [2], [3]). Mining hollow of settlements is created above the excavation. According to the applied in practice the theory of Budryk-Knothe (which is Polish achievements) (the theory is described in e.g. [2]) mining hollow is described not only by settlements w, but also by creeping/spreading (extending/shortening) of area ε, radii of curvature R, slope of terrain T, horizontal displacements of points located on ground surface u.

Bridge objects show significant differences in the way, as they respond to mining impacts in relation to buildings. An important, fundamental difference with respect to cubature structures is the multi-solids of bridges. Typically, there are at least three such solids: two bridgeheads and the span. The resistance of such objects to mining influences depends on providing adequate kinematic freedom, e.g. by choosing the appropriate bearing scheme and bearings with appropriate displacement ranges.

As a result of mining deformation of the area, supports displace relative to the bridge spans. During the movement of the mining exploitation front in the region of the object, four different phases of displacements of the spans and supports may occur: rotation, inclination, span translation with respect to supports, displacement of supports, e.g. [1], [2], [3]. Railway bridges are usually narrow objects, and the dominant dimension is the length of the span. Such objects are particularly sensitive to the influence of surface deformations of the area, the abutments approaching/moving away and the widths of the expansion joints are changing and changing the position of the bottom plates relative to the upper ones in the bearings.

The calculations are simple geometrical formulas allowing to determine the displacements on bearings and the change in the width of expansion joints as a result of creeping/spreading and mining curvature of the area, the rotation of abutments against to spans [1], [2]. The example of calculations is given, for example, in the English-language open access publication of the author of the paper [13]. In multi-solid bridges, the character of the displacements of rigid solids is determined by the adopted bearing scheme, bearing technical conditions and the ranges of possible displacements on the bearings.

Mining shocks are the problem of separate analyzes (e.g. [14]). Bearings often determine the dynamic resistance of a bridge to mining shocks, e.g. by transferring additional mass forces caused by shocks. In the case of rigid, compact solids with regular shapes (spans, pillars and bridgeheads), the weakest link is the ability of bearings to carry horizontal mass forces (inertia) induced by mining shocks. Modal and spectral analysis due to the short period of impact of the shock and the natural adaptation of railway bridges to transfer vertical vibrations associated with the impact of rolling stock is generally not necessary.

The most frequent failures of railway bridges with free-support spans on mining areas are: inadequate range of bearings, bearing locks, displacement and/or rotation of the bearing axis relative to the axis of the bridge/track, insufficient expansion joints, scratching of bearing pads, insufficient width of the bearing benches.

Temporary (ad hoc) activities are generally the removal of displacement limiters and/or temporary support of the span. Repairs are replacement for longer or displacement of the bottom roller or sliding bearings plates, disassembly and reconstruction of the bearing pads, rectification of bearings.

Exhaustion of the bearing range is often accompanied with the narrowing of expansion joints. Re-enactment of the aperture widths can be done by disassembling the back walls and their reconstruction in a new position or in the case of thick massive walls forging recesses in them. In the case of steel spans, the ends of the spans can be cut off.

In the case of area stretching, the bearings may sometimes fall from the bearing benches, in this case it is necessary to disassemble and build new wider benches, often protruding from the frontal walls of the abutments. It is sometimes possible to change the bearing scheme (replacement permanent and directional bearings) when there is no space on the bearing bench under single-directional to transfer the predicted displacements, but there is place on the permanent bearing bench.

In railway objects, more often than in road objects, it is possible to observe serious pollution of bearings, blocking freedom of displacements, significant corrosion of sliding sheets in tangent bearings or damage to roller bearing constructions. Damage to bearings, pads and benches in such cases usually arises as a result of poor technical condition of bearings, this situation often occurs when the "working range" of bearings has not been exceeded - then, there is a limitation of kinematic freedom and the decisive influence is often the temperature changes, not mining deformations of the ground surface. Therefore, regular inspection of bridge structures located in mining areas is important, in particular with regard to ranges of bearing displacements and the width of expansion joints.

4. Examples of bearing damage and repairs - railway bridges in mining areas

4.1. Corrosion of tangent bearings and damages of bearing pads and benches

Tangent bearings made of steel sheets are susceptible to corrosion and, due to their low height, sensitive to contamination. As a result of corrosion and/or contamination, the coefficient of static friction on the surface of the contacting steel plates increases from $\mu s = 0.1 \div 0.15$ to approximate $\mu s = 0.5$. In this case, the span with respect to the support generates a horizontal force equal to half the vertical force on the bearing - steel plates can detach from the bearing pads/benches, which practically prevents control over the direction of displacement (Figure 2). Typical repair of such damages consists on cleaning and lubricating the bearings or forging and restoring the bearing pads or replacing the bearings with new ones (Figure 3). Popular nowadays on the railway are small-size pot bearings, which could replace tangent bearings, practically without interfering in the track's geometry and foundation (Figure 3).

The result of leaky covers of the dilatations (frequent case in railway bridges) leads to degradation of concrete on the surface of the bearing benches, corrosion of the reinforcement and detachment of the concrete jacket from the reinforcement (Figure 4). Permanent bearings are then unable to transfer vertical forces, and the spans work as if they were supported only on sliding bearings - railway regulations [11], [12] do not allow the so-called "floating" bearing schemes. The repair consists on cleaning the bearing and repairing the concrete on the benches (breaking of corroded concrete and reconstruction) - figure 5.

Figure 2. Corrosion of tangent bearing, cracks in ground beam

Figure 3. Pot bearing which replaced tangent bearing

Figure 4. Corrosion and incorrect support of tangent bearing

Figure 5. Repair of bridge bench and ground beams

4.2. Tangent linear bearings with insufficient range [13]

In this example, steel rails embedded in bridge benches (Figure 6) play the role of bearings.

Only the head of the rail protrudes from the bench. In the bridge slab, along the end edge, the C400 channel is embedded; the channel shelves are embedded in the bridge slab. Two narrow strips of steel sheets welded to the web of C-channel (parallel to its axis) work as displacement restraints.

Because of mining influences, the bridge span was jammed (Figure 7). Exhaustion of the possibility of displacements on "bearings" led to local damages of benches. The slab span of the bridge was slightly raised in the framework of ad hoc, temporary corrective actions; steel sheets that liquidated the "saddle" were put on the rail, which restored the freedom of displacements (Figure 6). The final repair consisted in shifting the back walls (disassembling the old ones and building new ones), widening the bearing benches and assembling new pot bearings with the displacement range adapted to the predicted mining influences (Figure 8, Figure 9).

Figure 6. Old tangent linear bearing: freedom of displacements was restored by additional sheets

Figure 7. Jammed span before rebuilding of the bridge object

Figure 8. Bridge object after rebuilding

Figure 9. New Multi-directional pot bearing

4.3. Cracking pads of roller bearings

The technical condition of pads under permanent bearings in bridge with two free-support spans is described below. Each span at one end has two permanent bearings (based on a pillar), on the other end of the span there are two single-directional roller bearings (based on abutments). This way of bearing provides theoretically freedom of displacements only in the axis of the bridge objects. In the context of the mining rotation of supports against the axis of the span, the bearings may wedge, a pair of horizontal forces is created on the weak pillar - there are two permanent bearings.

The twisting of the span in relation to the supports, led to cracking the pillar head (Figure 10). The bearing bench is narrow, the bearings are located at one of the edges of the pillar head - it threatens the cutting of the bench corner. In addition, in the case of significant horizontal deformations of the area and pillar deflections (T), when the horizontal displacement of the directional bearings has been exhausted, the span can slide out from the pillar. As part of remedial actions (mining prevention), permanent bearings of adjacent spans were placed on a common thick steel plate (Figure 11, Figure 12) to minimize the risk of rupture of the permanent bearing (with the fragment of the pillar head).


Figure 10. Permanent bearing, cracks in head of pillar (bearing bench)

Figure 11. Assembly of the steel plate under permanent bearings

Figure 12. The permanent bearings on common steel plate

4.4. Exhaustion of displacement range on roller bearings

The pictures (Figure 13, Figure 14) show a situation in which the displacement range of the single-directional roller bearing has been exhausted. In the situation displayed in figure 13, bearing structure was damaged due to the exhaustion of the bearing range. The span was provisionally, temporarily supported (Figure 13). In the object shown in Figure 14, the bottom plate of the roller bearing was detached from the bearing bench, a niche was made in the back wall (the back wall was massive, thick, with no visible reinforcement) and the bottom plate of the bearing was properly displaced.

Figure 13. Additional temporary support of bridge span

Figure 14. Niche in back wall and intentional displacement bottom plate of bearing

4.5. Change of the bearing scheme

Single-directional roller bearings on the pillar were temporarily blocked and permanent bearings on abutments were replaced by one-way for the implementation of horizontal displacements (in the direction of the span axis) (Figure 15). This prevented the span from sliding off due to mining deformation, because due to the high pillar inclination and deflection, one of the bearings was just next to the edge of the pillar - the pillar head was too narrow to take over predicted bearing displacements from the mining influences. The bearing blockade was made by welding to the bottom plate of the bearings, wedges blocking the displacements of the rollers (Figure 15). In addition, flat steel bars were welded so that the shafts do not overcome the wedges, e.g. during a mining shock or derailing the rolling stock on the bridge. Ultimately, replacement of bearings for steel rockers (fixed bearings) is planned. On the abutments, permanent bearings have been replaced by steel tangent bearings with displacement limiters on the sides (single-directional bearings).

Figure 15. Amendment to the bearing scheme: blockade of one-way-sliding bearings

5. Monitoring of railway bridge objects

On the bridge structures located on the areas of active mining exploitation, regular geodetic surveys are generally carried out. Settlement of control points and changing the distance of supports are mainly measured. Visually controlled are changes in bearing position. In the case of slowly occurring continuous mining area deformations, in objects with low supports, such actions are generally sufficient. However, in the case of objects with high supports/pillars or/and located in zones of discontinuous deformation, within a few months (typical measurement interval) can occur significant displacements of supports, torsion of spans with respect to abutments, deflection of supports, blockade of directional bearings, cutting/cracking of pads of permanent bearings. In bridges with narrow bearings benches on the head of the pillar, because of the detaching of the permanent bearing [3], the bridge span can slip off from the pillar.

The solution here is to perform continuous remote measurements of displacements performed near bearings using displacement sensors (extensometers). It is also possible to control the inclination of supports and spans using angle sensors (inclinometers). Examples of continuous remote monitoring systems in relation to bridge objects on mining areas are described, for example, in publications [3], [5], [6]. The monitoring system (SHM) should be configured to check the safety of the facility, so a critical threshold values should be set, which will cause automatic generation and sending of warnings. In addition to the monitoring function, SHM system provides information enabling verification of mining deformation prediction. SHM can be a helpful tool in settling disputes related to mining damages. Example of one railway monitoring system, operating in Poland on a mining area, was described in the English-language publications of the author [5], [6].

6. Information management according to BIM standards

In Poland methods of modelling information about building objects, know under common term BIM (Building Information Modelling) are widely popular, e.g. in modelling of building objects and construction processes, infrastructure management [17, 18]. In the next few years, BIM will be gradually introduced in all countries associated in the European Union, in accordance with the requirements of the European Directive 2014/24/EU announced in February 2014 on competitive tendering. In the first place, BIM will include public investments, and thus bridge objects. BIM technology can be implemented for mining damages, using available methods, algorithms and software [19]. BIM allows combining information from monitoring systems and other measurements, mining predictions and identified damages in one single model [19].

Static and dynamic resistance of bridge structures to mining influences is not constant, but it changes over time. Mining exploitation has a significant impact, e.g. by stretching/squeezing expansion joints, introducing significant displacements into bearings (e.g. Figure 13, Figure 14). The mining turning and tilting of abutments may lead to cracking on the abutments and spans. The change in the curvature of the area has a negative effect on the construction of abutments - significant cracks may be created that destroy the integrity of the solid of bridgehead (e.g. [15, 16]). Resistance of bridge structures to mining influences also changes as a result of normal using and impact of environmental (atmospheric) factors, e.g. bearings made of steel plates may be rusty and blocked (e.g. Figure 4, Figure 6).

Damage controls in traditional bridge maintenance systems are often ineffective, because such controls are usually performed too rarely and are not related to the occurrence of mining influences on the surface of the area.

Currently, damages are rarely included into models to assess the resistance of bridges to mining influences. Even in the case of such validation/verification/analysis, the damages come from a specific period of time and is not updated, neither the model is updated nor the calculation. In BIM technology, damages can be included into the model. The great advantage of BIM technology is the ability to use (in order to create, validate and update the model) many modern techniques that allow remote, automatic acquisition of information about the object, damages, displacements, e.g. by using electronic sensors, drones, satellites, cameras.

Bridge managers have access to measurements performed by SHM systems, but the lack of appropriate digital models of bridges forces manual data processing. Models are needed, that contain, for example, data about the "working" range of bearings. The necessary information is obtained by the geometrical inventory of the bearings (together with the appearing of mining influences the displacement of the upper and lower part of the bearing is progressing). Changes in measured quantities are manually calculated and referred to the range of bearing work at a certain point of time considered to be initial, then the displacement are calculated. The next step is to determine the displacements, which will be caused by another, subsequent mining exploitation and analyzes whether the bridge bearing will transfer these influences. The use of BIM technology enables the inclusion of measurement data into the model and the use of this data also automatically, e.g. after defining boundary conditions for emergency situation, system can automatically generate warnings, which facilitates supervision of the object and directly translates into improved safety.

7. Conclusions

The article reviews the technical conditions and literature information on the bearings of old railway bridges located on mining areas in Poland. In Poland there is a serious lack of coherent regulations on bridge bearings on mining areas and a shortage of technical literature.

The article discusses the impact of mining area deformations on railway bridges with freely supported spans. Examples of typical damages and corrective actions are given. It is pointed out that in the case of commonly used on the railway, objects with a static scheme of freely supported beams, bearings are most often the decisive elements for the static and dynamic resistance of the bridge objects to mining influences. The article also shows the problem of proper control of bridges located on mining areas, especially in the case of old railway bridges, where the technical conditions of structures and bearings are generally bad. Author proves how important is to acquire, collect and combine properly information from various sources.

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