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SELECTION, MAINTENANCE AND ACOUSTIC DIAGNOSTICS OF EXPANSION JOINTS IN BRIDGES LOCATED IN AREAS WITH GROUND DEFORMATIONS

Abstract

In the paper are presented general rules of the assortment of expansion joints in bridges located in areas being under the mining impacts. The maintenance problems associated with ground deformations are also mentioned. The special attention is given to the noise emitted by expansion joint devices. A legal status in the protection from noise and factors affecting this noise are discussed.

Keywords

Expansion joints, bridges, acoustic diagnostics, ground deformation.

1 INTRODUCTION

The construction of bridges in the Silesian urban agglomeration, in the operation area of a number of coal mines, is a specific task. This is mainly because of strong ground surface deformations. The reasons for such deformations can also result from shallow tunneling, groundwater withdrawal or post-seismic phenomena. Bridges with their heavy and rigid solid elements (abutments, piers, girders) are sensitive to the irregular subsidence, the horizontal strain in the subsoil and the inclination of the previously horizontal surface. The safety assessment of bridges located in areas with ground deformations should first start with the initial analysis of rigid solids kinematics. This is due to multi solid and freedom of mutual displacements of solids as well as much bigger bridge structures elements stiffness compared with flexible buildings. One of the protection methods recently used was providing a low sensitivity of the structure to deformation effects and, consequently, minimization of activities of restoring the proper condition.

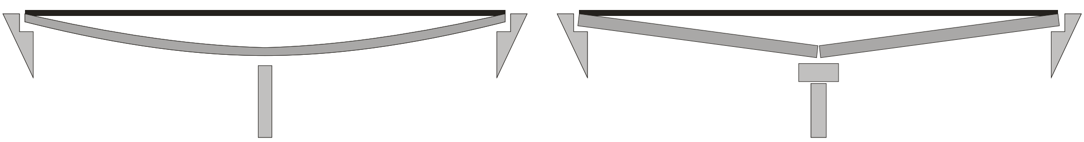

Fig. 1: Bending lines of continuous structure and freely supported structure due to irregular subsidence

For example, a double-span beam structure may be designed as a system of two freely supported spans (Fig. 1) or as a double-span continuous beam. The former is, at least in theory, totally insensitive to large differences in subsidence of supports, and therefore it does not require any repairs of the structure. However, the sharp deflection of the driving path over the middle support introduces discomfort to the fast-moving users or even poses a hazard. In order to eliminate this, the surface must be repaired (smoothed out). Moreover, gaps between every bridge solid must be formed

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into the expansion joint which, in this case, are usually very large and consist of rather complex accessories (Fig. 2). Uneven and considerable deformations together with dynamic impact from vehicles can cause expansion joints failures providing to a high-level noise generation. The modular expansion joint is advantageous for many reasons such as: water-tightness, cleaning requirements, geometric adaptability and, most importantly, translational and rotational motion capacity. It can accommodate the 3D movements without generating additional stresses or strains in the load-bearing members or in adjacent bridge or abutment structures. Apart from its advantages, it has been recognized that the noises generated by vehicle passage over the modular joints tend to be louder than those of ordinary expansion joints [12]. Although possible techniques have been reported [13] for solving the noise problem by welding or bolting sinusoidal and rhombus-shaped steel plates on top of the steel middle-beams of the modular joints, those techniques have not been successfully implemented in real applications [11].

Fig. 2: Examples of expansion joint in bridge along Silesian motorway A1 Gliwice - Ostrava

2 GROUND DEFORMATIONS IN AREAS WITH MINING IMPACTS

Deformation of terrain is usually connected with the presence of geodynamic phenomena which can include: impacts of mining, tunneling, crass processes, nontectonic movements, floods, flooding, and landslides. The most burdensome for road and bridge structures are phenomena connected with mining. They can cause changes in water levels, support conditions, displacements and deformations of soil and shocks of the rock mass. Due to the form of occurrence, deformations can be divided into continuous and discontinuous. More likely, continuous deformations of terrain can be found.

As a result of deformation of some sub-surfaces layers over the exploited coal seam on the ground surface, a depression called coal basin is formed. The size of continuous deformations is described by so-called deformation indices. Continuous deformations appear in specific periods of time and are usually directly related to the carried out exploitation. The process itself is long and not rapid and disappears after a few years. In post-mining areas, sometimes even several years after finishing mining activities continuous, delayed deformations can be noticed [5].

Bridge structures located in areas with ground deformation can suffer from additional loads which may cause different forms of risk [3]:

- safety of structure components,
- safety of usage,
- stability of supports and spans,
- reduction of aesthetic and utility functions,
- faster technical erosion.

Continuous terrain deformations can be described by the deformation indicators, namely lowering (*w*), inclination (*T*), horizontal displacement (*u*), strain of soil (ε) as well as the curvature radius of coal basin profile (*R*). Formulas for determining predicted values of these indicators can be found in some publications [1]. In the flat state of deformation, they are verified (actually interpreted) indirectly by measuring of lowering (*w*) and horizontal displacements (*u*) of steady terrain points.

3 SPECIFICITY OF BRIDGE STRUCTURES IN AREAS WITH GROUND DEFORMATIONS

Relatively simple kinematics of a single building solid can be described in an easy way by using not complicated trigonometric formulas based on earlier mentioned mining deformation indicators *T*, ε, *R*. Both designing and maintenance of buildings in areas with ground deformations tend almost routine ways of their protection and the basis of analyses is a categorization of the mining area due to the above indicators. In the case of compact structures, they can be taken as point models and therefore the impacts specified by the indicators are clearly estimated.

However, linear structures which include among others roads, railways, pipelines and bridges cannot be reduced to point models. In this class of structures, terrain lowering which is not used in the terrain categorization is very important). It influences directly on the most important function of the structure which is its profile line. Especially sensitive are all railways and drainage infrastructure. In those cases, the distribution of the *w* index along the structure is even more important than its value itself.

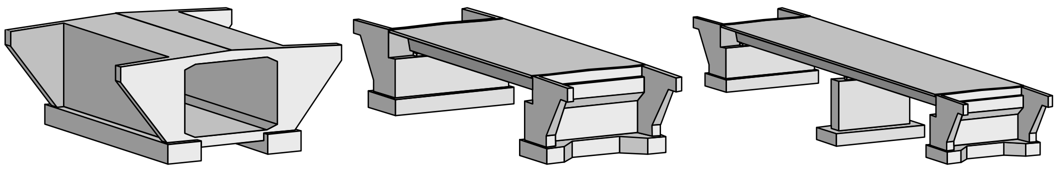

Fig. 3: Examples of bridges consisting of one, three, and four solids

Bridges have most characteristic features of linear structures. In the case of long overpasses, only one dimension dominates. Moreover, they are directly connected with transport routes which they carry or they pass over. However, the most distinguish–feature is a multi-body structure and often high elevation of the substantial structure parts over the terrain.

Multi-body structure results from the clear separation of independent stiff parts which to some extent are free to mutual displacements. Usually, there are at least three such solids: two abutments and superstructure (Fig. 3). But generally, the number of solids is substantial. Therefore, the analysis of structure behavior should start from the solution of the stiff solids kinematics problem only after which we can proceed to the analysis of the structure deformation [4].

The elevation above the terrain is connected directly with multi-body structure but creates peculiar consequences. No direct contact with the deforming terrain means there is no simple transference of terrain deformation index on superstructure strains or displacements. In this case, an additional influence of highly elevated and inclined solid support appears.

As mentioned before a typical bridge consists at least of three solid elements which are two edge supports usually in the form of massive abutments and the superstructure laying on them. Of course, there are many solutions that can be treated as a single solid bridge (frames, culverts, integral bridges). The description of their kinematics is then much easier. In case of larger objects, there can be even more solid components. This is the most often either internal supports in the form of pillars or dilatated parts of abutments.

As a result of terrain deformations, absolute displacements of each solid component and relative displacements of neighboring elements may happen. The description of this kinematics should help to identify the location of solid components with their mutual configuration and distance after deformation. It can be used to determine such parameters like changes in expansion joints, bearings parts displacements, supports declinations, changes of the road or track alignment on the bridge and lateral deck slopes changes.

In contrast to malleable buildings, both bridge support foundations and their stems are much more massive and stiff. The safety assessment of bridges located in areas with ground deformations should start first with the initial analysis of rigid solids kinematics. This is due to the multi-body structure and freedom of mutual displacements of solid components as well as much bigger bridge structures elements stiffness compared with flexible buildings.

5 MEASUREMENTS OF NOISE IN THE VICINITY OF THE EXPANSION JOINTS

Standard noise measurements in the vicinity of the roads consist of gathering a representative number of individual noise events used to determine the equivalent sound level characterizing measured source in the memory of the measuring device [2][10][11]. The logarithmic summation is done via dependence:

$$L_{AeqT} = 10\log\left[\frac{1}{T}\sum_{i=1}^{1} t_i 10^{0,1L_{Aeqi}}\right] \text{dB} \tag{1}$$

where:

L_{Aeqi} – the value of the equivalent sound level measured over a period of time [dB],

T – reference time (continuous measurement time), [s],

t_i – the observation period included in the reference time,[s],

n – the number of intervals over which the time of continuous measurement has been divided.

Typically, noise measurements are carried out in a representative cross-section of the measurement path with fixed and undisturbed characteristics. The resulting noise is dependent on the type of vehicle, volume and speed of traffic and the road surface. However, due to differences in the course of the road, there are places with abnormalities in the structure, and one of them is perpendicular intersection built over the expansion joints. They generate noises similar to pulse ones with the values of the peak sound pressure much higher than the average level of noise resulting from passing through a typical asphalt pavement. The assessment of expansion joint impact with an equivalent sound level seems not to be very useful. A short pulse sound formed by the tire on the expansion joint has little effect on the value of the equivalent sound level measured for a long time (Fig. 5).

One way to assess the acoustic properties of the expansion device is to measure the instantaneous value of PEAK sound pressure. In order to obtain the greatest number of measured pulses, a buffer register of the PEAK sound level recorded in steps of 10 ms, is carried out. This allows measuring the pulses of sound coming from the wheels of each axle, even of the fastest vehicles.

During the measurement, conducted by the authors, measuring microphone was arranged in the axis of the several measured expansion joints at a height 1.2 m over the plane of protective barriers. One of the test stands is shown in (Fig. 5). Analyzing the results it can be conducted that the noise caused by vehicles passing through expansion joints depends on the pavement characteristics, construction of the expansion joints, its technical condition and quality of maintenance.

Fig. 5: Location of the noise measuring point on the bridge expansion joint

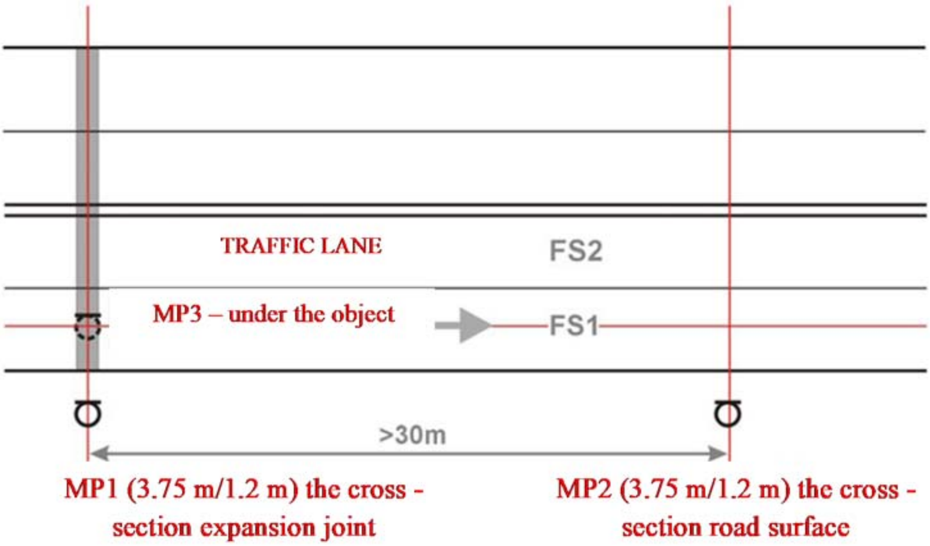

Fig. 6: Schematic cross-section and location of measuring points [8]

Another approach to the measurement and analysis of the acoustic behavior of expansion joints is the Austrian method [8], which can be used to evaluate both new and used types of expansion joints. This measuring procedure was developed in the framework of the research program "The increase in the noise level of road expansion joints on bridges ready". This method demonstrates that the acoustic assessment is best suited for observation of the movement of passenger cars. The aim of the method is the acoustic classification of expansion joints types referred to as standard or silent ones. Measurements are performed using digital recording method while passing through two measuring sections (Fig.6). The test vehicle must pass through each section of the measurement at least hundred times. To estimate the acoustic parameters of the expansion joint, the location of the measurement point in the cross-section of the expansion joint is required (MP1). Besides, the microphone should be set in a place of reference at a minimum distance of 30 m behind, or alternatively behind the expansion joint, just to obtain typical noise result from passing vehicles on the particular pavement (MP2). As a result, the measuring point can objectify the impact of the road surface. To measure any acoustic reflections under construction (MP3) another microphone should be placed in the cross-section expansion joint but under the bridge.

During the measurements, only single passing should be registered (no vehicles on other lanes). Only passings with maximum values 6 dB above the adjacent minimum sound level can be approved. This ensures that the moment of the maximum sound level of the other traffic and its effects on the measured levels will not be missed. Fig. 7 shows the locations of the measuring points in the vicinity of the A1 motorway bypass of Lodz city.

The method [8] recommends accepting the level of auditory event $L_{A,E}$ or SEL for the evaluation of the expansion joint, which is used to describe individual acoustic events and duration 1s it has the same energy content as the total noise event in the total time. In contrast to the equivalent sound levels $L_{A,eq}$, the exposition level $L_{A,E}$ is independent of time, so a better comparability of individual noise events can be achieved. The level of single auditory event $L_{A,E}$ gives the total acoustic energy away is radiated to the surrounding environment [8].

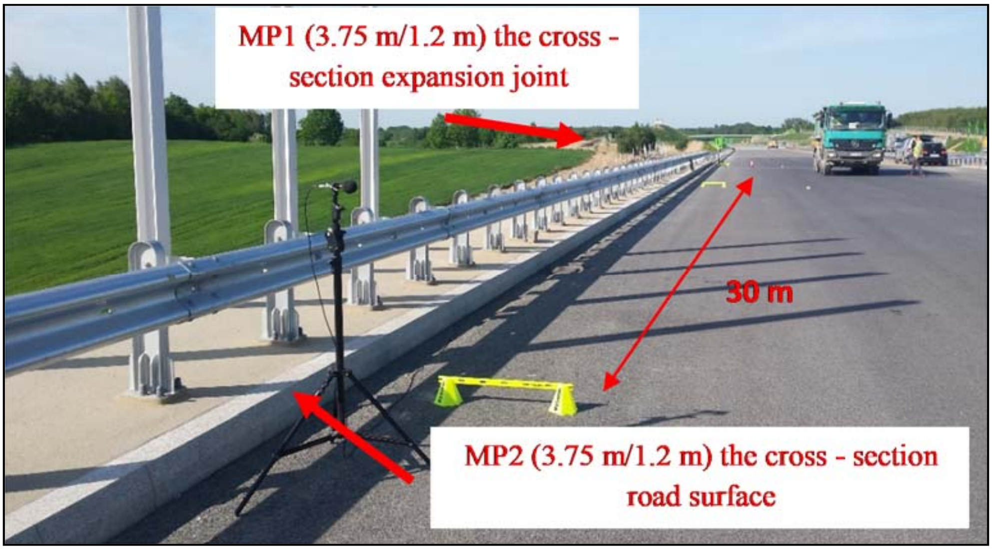

Fig. 7: Location of the measuring point on the A1 motorway bypass of Lodz city

Obtained results allow comparing MP1 and MP2 levels graphically locating them in one of two areas separated by a straight acoustic boundary (Fig. 8). Note that if the level of the expansion joint is lower than the measured reference points the evaluation of the expansion joints cannot be built because the road surface creates the acoustic climate. Therefore, alternative solutions to the road surface should be examined (eg. surface mounting silent).

6 MODELLING ACOUSTIC ROADS INCLUDING EXPANSION JOINTS

Currently, it is practiced to perform at the design stage of the theoretical model and perform on this basis computer simulations before the use of a particular technical solution. [10], [11] Assessment of the road impact on its neighboring environment needs acoustic analysis based on the results of interaction of acoustic conducted in specialized computer programs such as SoundPlan, Immi, Mithra, or Cadna A. These programs are adapted to the development of three-dimensional geometric and acoustic models, based on performed calculations, and the presentation of the acoustic field is realized in the form of planar and spatial noise maps. Among the various models of road noise sources in the Annex II Directive [7], for EU members not having a national calculation method, it is recommended to use the French method [14] and standard [15]. Fig. 9 presents the 2D and 3D noise maps showing the distribution of the noise in the vicinity of the road viaduct built on the A4 motorway at the height of city Ruda Slaska. Calculations were carried out based on the geometric and acoustic model. This model was created using digital terrain model, land cover, vector situational map, intensity and the structure of the movement, the speed of light and heavy vehicles, the frequency characteristic of the expansion joints obtained on the basis of measurement.

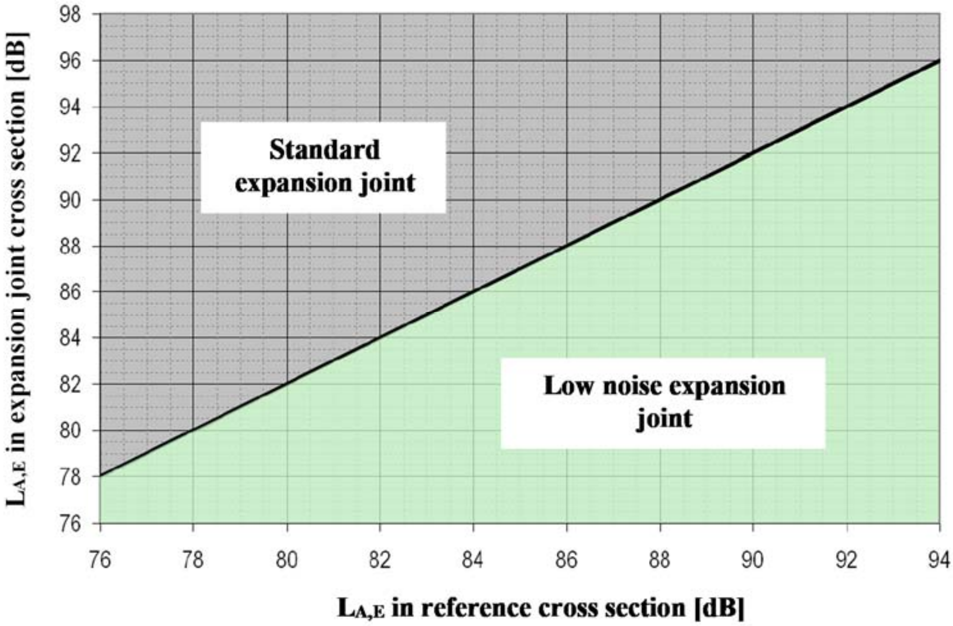

Fig. 8: Schematic cross-section and location of measuring points [8]

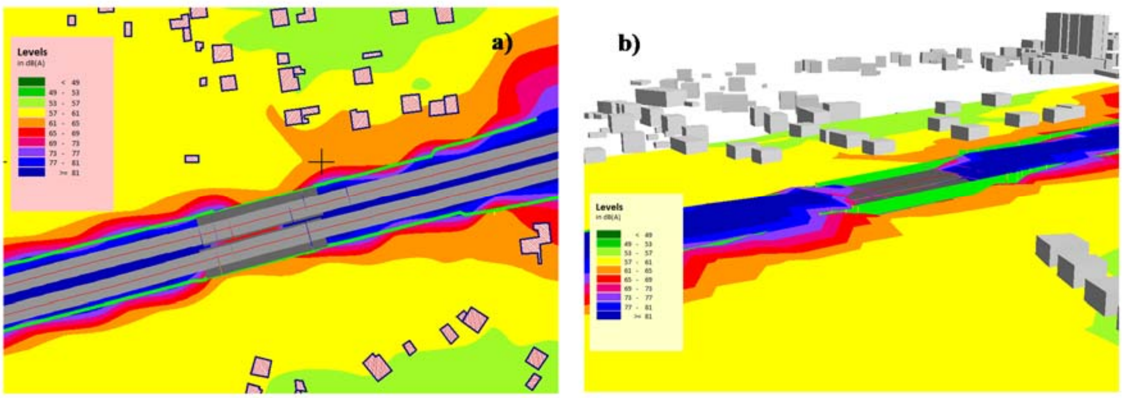

Fig. 9: The noise maps: a) map 2D, b) map 3D [6]

7 ACOUSTIC DIAGNOSIS OF EXPANSION JOINTS

Proper diagnosis of the expansion joints allows extending of the bridge structure service life. In addition to standard inspection the acoustic diagnostics of the expansion joints seems to be also very important. Therefore, some measurements were performed on the bridge constructed over the water reservoir located on the A1 motorway (section Gliwice – Ostrava) in the city of Knurów, measuring the values of noise L_A, L_{Lin} and PEAK using the sampling method. Measurements of noise expansion joints are made in close proximity of the same device under the motorway, for two measuring locations, as shown in Fig. 10:

- under traverse from No. 2 to 10 on a support No. II and No. III,
- under traverse No. 6 on a support No. II and No. III.

Fig. 10: Location of the measurement points under the bridge. Traverse No. 6.

The results of measurements are presented in following graphs: Fig. 11a – sound levels in various traverse on a support No. II, Fig.11b – sound levels under different mounts traverse No. 6 on a support No. II, Fig. 11c – sound levels in various traverse on a support No. III, Fig. 11d – sound levels under different mounts traverse No. 6 on a support No. III.

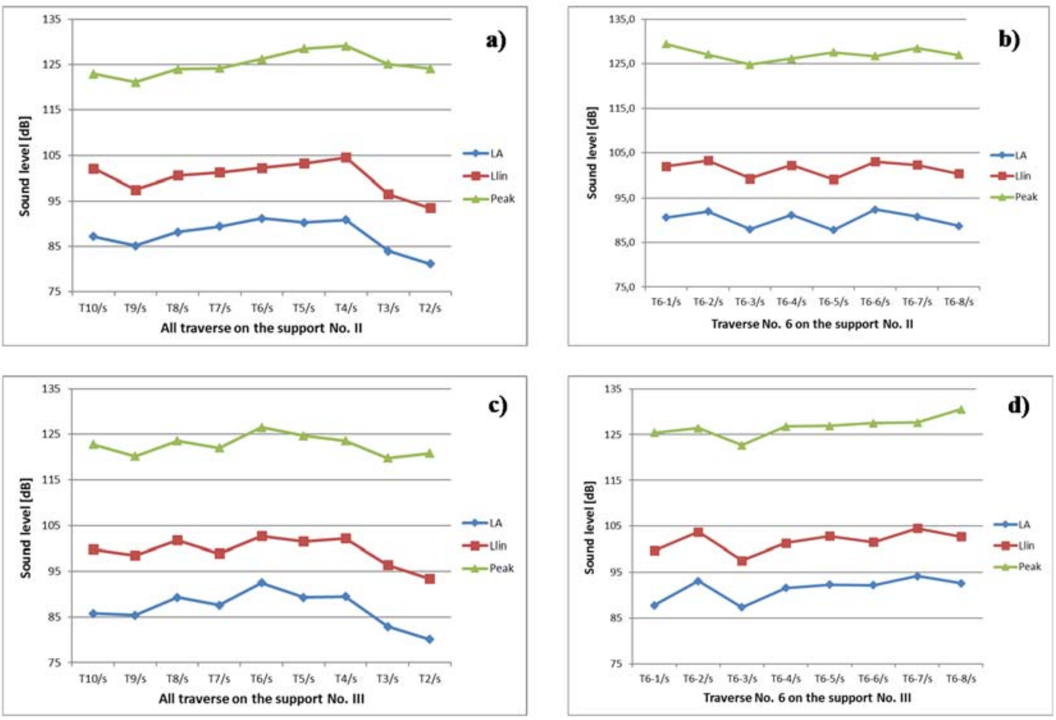

Fig. 11: Graphical presentation of the results of diagnostic tests of the bridge on the motorway A1

Presented research has a pilot character and can be used for the future diagnostics of the often used expansion joints. The results confirm diagnosed damage during the inspection depending on their degree of use. With the increasing failures of selected traverses and supports, the sound level increases as shown in Fig. 11. The measured sound levels are 87.4÷94.2 dB for measurements with curve A, from 97.6÷103.7 dB for measurements using a linear filter and the peak values is a range of 122.7÷130.5 dB. Performed research in the immediate vicinity of the expansion joint devices and the lack of methods for their implementation cannot be used in such form to evaluate the noise impact on the environment and human beings.

8 CONCLUSION

In the paper, the problem of noise generated by the expansion joints is discussed. Attention was paid to mining terrain deformation, as a factor that can have a significant impact on the increase of noise emitted by the expansion hole and reduce driving comfort. A collection of information on the measurements, acoustic diagnostics and acoustic modelling of the expansion joints is presented. The factors affecting the increase in noise, rules and methods of noise measurements, principles and objectives of acoustic analysis were collected and discussed. Attention was also paid to the shortcomings of technical knowledge in the field of noise generated by the expansion joints, the consequences of these gaps and possible directions for further research.

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