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SEISMIC RESPONSE HYDRAULIC HAMMER ON THE SECUNDARY LINING TUNNEL

SEIZMICKÁ ODEZVA HYDRAULICKÉHO BOURACÍHO KLADIVA NA DEFINITIVNÍ OSTĚNÍ TUNELU

Abstract

Construction and subsequent tunnels collapse of the Jablunkovsk's pass are already among well known of the professional public. After the collapse left part of the tunnel already standing with secondary lining. The second part was temporarilied concrete secured stopper and heavy bridge formwork. During the progress of work was already reached that stage when plug must be removed. The stopper was removed by combination of blasting operations and hydraulic hammer. This article deals with seismic effect hydraulic hammer. It is therefore a unique measuring effect of vibration on the final tunnel lining. A vibration downturn was monitored in the first meters of the lining and the records were evaluated in the amplitude and frequency resort. This assessment was made on the basis CSN 73 0040.

Keywords

Hydraulic Hammers, seismic measurement, secondary lining.

Abstrakt

Výstavba a následná havárie tunelů v Jablunkovském průsmyku jsou již mezi širokou odbornou veřejností dobře známy. Po havárii zůstala část tunelu stát s již vybudovaným definitivním ostěním. Druhá část byla provizorně zajištěna betonovou zátkou a těžkým mostním bedněním. Při postupu prací se již dosáhlo etapy, kdy musí být zátka odstraněna. K odstranění se používá kombinace trhacích prací a hydraulického bouracího kladiva. Tento článek se zabývá seizmickým vlivem hydraulického bouracího kladiva. Jedná se tedy o unikátní měření vlivu vibrací přímo na definitivní ostění tunelu. Byl sledován útlum vibrací v prvních metrech ostění a získané záznamy byly vyhodnoceny v amplitudové i frekvenční oblasti. Vyhodnocení bylo provedeno na základě ČSN 73 0040.

Klíčová slova

Hydraulické bourací kladivo, seizmické měření, definitivní ostění.

1 INTRODUCTION

The tunnels in the Jablunkov mountain-pass lying on the strategic Bohumín - Žilina railway communications. Due to the extent of their utilization as a transport corridor, their reconstruction was

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approached in 2007. The older tunnel built in 1871 is currently used for traffic and the latter one built in 1917 is being reconstructed. After the extraordinary event in November 2009, when part of the tunnel collapsed, up to now dissolution in the reconstructed tunnel takes place whereas the tunnel heading is divided into six partial stopes [1].

In order to protect the tunnel against subsequent collapsing, partial fill-up of the tunnel with a concrete fill mix was implemented as one of the precautions. The so-called "Pižmo" support was built onto the plug that came into being in that way. It is a special supporting structure used when a bridge is constructed. However, the work flow in the tunnel construction has entered the stage in which the "Pižmo" support and its concrete base has been begun. This sort of work is under way near to the final lining built prior to the accident. Owing to the strength of the concrete that significantly exceeds the strength of the surrounding rock, blasting operations and/or a hydraulic demolition hammer on the frame of a heavy shovel excavator are the only methods that come into question for the removal. The proximity of the final lining does not allow using the blasting operations without risk of damaging. The only way how to solve this problem remained the use of the hydraulic demolition hammer.

Most of vibration measurements on tunnel structures are carried out by means of blasting operations [2, 3, 4, and 5]. The uniqueness of the measurement presented consists not only in a different rock disintegration technology but also in placing the sensors on the final lining that has been built. This resulted in the possibility of direct evaluation of the effect of vibration on the lining structure. The evaluation itself consists of processing the relevant attenuation curves and of evaluation of records both in amplitude and frequency areas. The main objective was to find out if the lining damage might have occurred.

2 EXPERIMENTAL MEASUREMENTS

Experimental measurements carried out during the Jablunkov tunnel construction was implemented using the GAIA 2T seismic apparatus by Vistec with the ViGeo 2 (Vistec) velocity sensor. These are the same sensors and apparatus that were used during the implementation of experimental measurements on the Stend structure [6].

The measurement was carried out when removing the concrete plug. To remove the concrete, the TEREX TC 240 heavy caterpillar shovel excavator equipped with the TEREX THX4400S hydraulic demolition hammer was used (Fig. 1).

Fig. 1: Heavy crawler excavator TEREX TC 240

Fig. 2: Situation measurement

The measurement took its course during the removal of the concrete plug (in Fig. 2, numbered 3). The objective was to find out the influence on the final lining of poured concrete (numbered 1) between the place of work executed and the final lining there was a 13 m long portion of primary lining of shotcrete (numbered 2). The distance between the primary lining and the place of work was

3 m. The minimum distance beyond which the demolition hammer can get during its operation to the final lining is 16 m. Therefore, the first sensor was put at a distance of 16.5 m, while the others were put at distances of 21 and 27 m respectively.

In terms of geology, the reconstructed tunnel is found in complicated conditions. In terms of geology, the wider surroundings are found in the Outer Western Carpathians, consisting mostly of flysch sediments (alteration of claystone, siltstone, sandstone and agglomerates), which are represented by the Silesian and Račany Units. Both units form independent sheets, which are thrust over one another, forming the so-called Magura Overthrust. The Magura Overthrust line runs along the eastern slope of the Jablunkov Pass (alongside the new E 75 road between Jablunkov and Čadca). The complex overthrust structure is accompanied by fault tectonics. In terms of engineering geology, the flysch complex is a typical slide area.

The tunnel route itself is found in the upper part of the Palaeogene Silesian Unit, consisting mostly of claystone with hornblende and sandstone layers (menilite series of measures). The tunnels are driven through the least favourable geology, consisting of micro-cyclic flysch series of strata with prevailing calcareous, very low to extremely low strength claystone (with corresponding strengths in simple compression within the range of 1.5 – 0.5 MPa). The excavation has encountered first of all folded, partially schistose to sheared, laminated dark-grey claystone, which is often faulted. The claystone contains thin and irregular interbeds of siltstone and sandstone (up to 5 cm in thickness). The stratification with medium inclination to the south-east prevails; the schistosity is of steep inclination with the prevalent East - West direction.

The Quarternary overburden is predominantly built up with diluvial sediments with the thickness reaching approx. 0.8 - 3.2 m (sporadically up to 6.1 m). The diluvia have mostly the nature of sandy clay up to medium plasticity clay, mostly solid, locally of plastic or solid consistency.

Due to configuration of the terrain, several minor streams flow down from the adjacent hills into the pass area irrigating the area of the tunnel overlaying rock. The water table is at the depths of 0.25-6 m beneath the terrain. No more significant inflows have been encountered during the excavation; the excavation has been dry to moist [as per 7, 8, 9, and 10].

The lining of the mined tunnel consists of two shells and a 3mm thick intermediate waterproofing membrane. The primary lining consists of a C 16/20 shotcrete layer, lattice girders and two layers of mesh. The top heading stability during excavation is secured by a spilling umbrella. The final lining is in C 30/37 grade, in-situ concrete, which is reinforced by lattice girders and horizontal steel bars [11].

3 EVALUATION OF MEASURED DATA

The wave images of the registered operation of the hydraulic demolition hammer are the output of the seismic measurement. The measurement was carried out on the final reinforced concrete tunnel lining, namely at the distances of 16.5 m, 21 m and 27 m; the measurement took its course continually for approx. 6 minutes so it was possible to process more operation cycles. 13 operation cycles were processed in the aggregate. The division of the measurement into single cycles is shown in Fig. 3. An example of a fragment of the cycle 2 wave image is shown in Figure 4. Vertical /SHZ/, horizontal radial /SHN/ and transversal /SHE/ components are indicated in above figures, the horizontal axis represents the time. In Fig. 3, the time on the horizontal axis is given in minutes and seconds; in Fig. 4, the time scale is extended to single seconds for illustration. The oscillation velocity values in mm/s on vertical axes are shown in both figures.

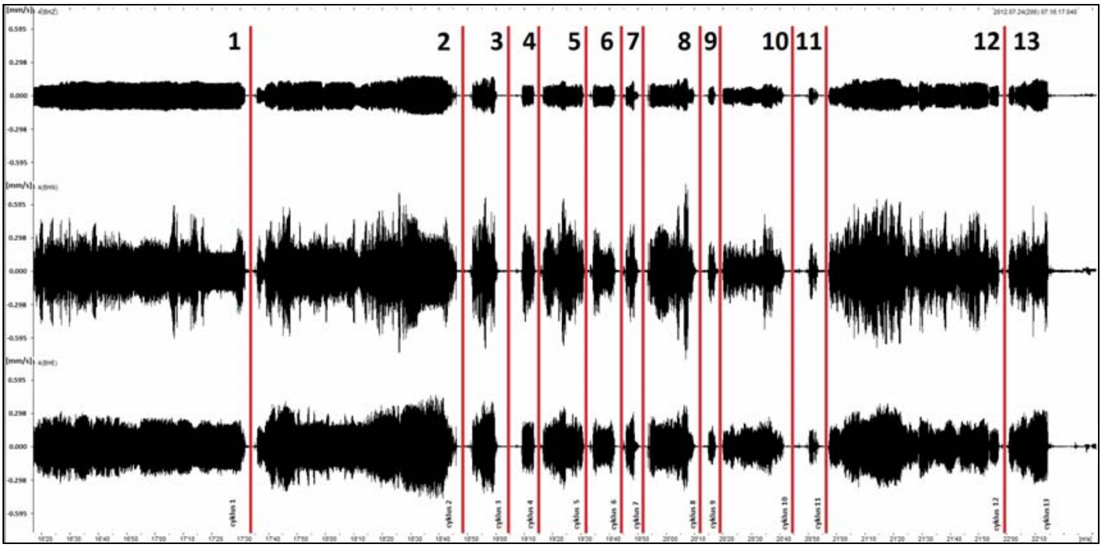


Fig. 3: Distribution of total wave image of hydraulic demolition hammer record

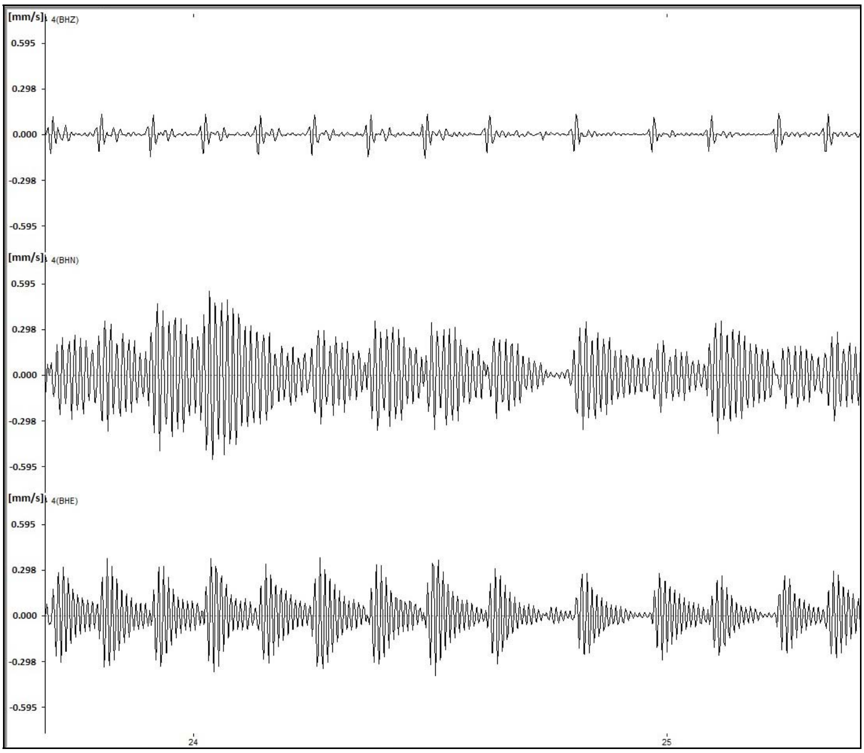


Fig. 4: Example of operation cycle 2 wave image segment at a distance of 16.5 m

The frequency spectrum of the vibration record is another output (Figs. 5, 6 and 7). As shown from the spectra acquired from the wave images of hydraulic hammer vibrations, the frequency in individual measuring locations varies. At the distance of 16.5 m (Fig. 5), the frequency is 80Hz, at the distance of 21 m, and it corresponds to 75 Hz (Fig. 6). The prevailing frequency range (Fig. 7) from 60 to 90 Hz with two peaks at 65 and 74 Hz corresponds to the location at the distance of 27 m. This phenomenon can be explained by a different frequency response of the tunnel, lining and total attenuation longitudinally.

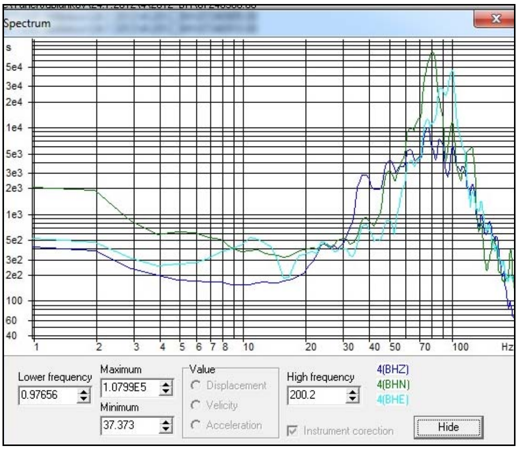


Fig. 5: Example of frequency spectrum at the distance of 16.5 m

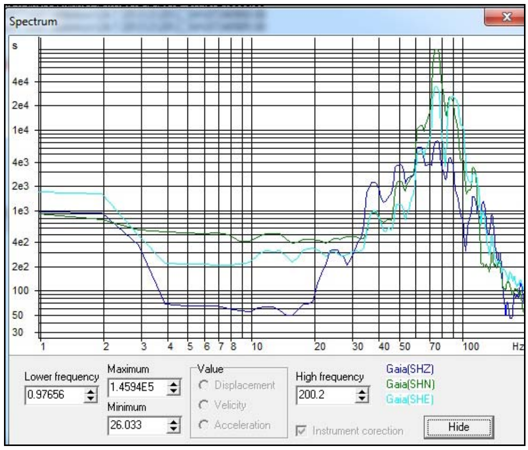


Fig. 6: Example of frequency spectrum at the distance of 21 m

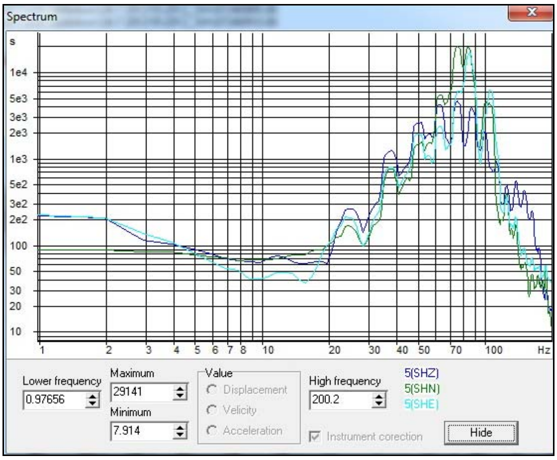


Fig. 7: Example of frequency spectrum at the distance of 27 m

Maximum values of vibration speed amplitudes were read from wave images for individual cycles and also for distances of individual sensors (Tab. 1). The values acquired in this way were processed using the statistical median function and put in Table 2. Apart from other statistical methods, the median function was selected for its advantage consisting in the lowest affection by extreme values.

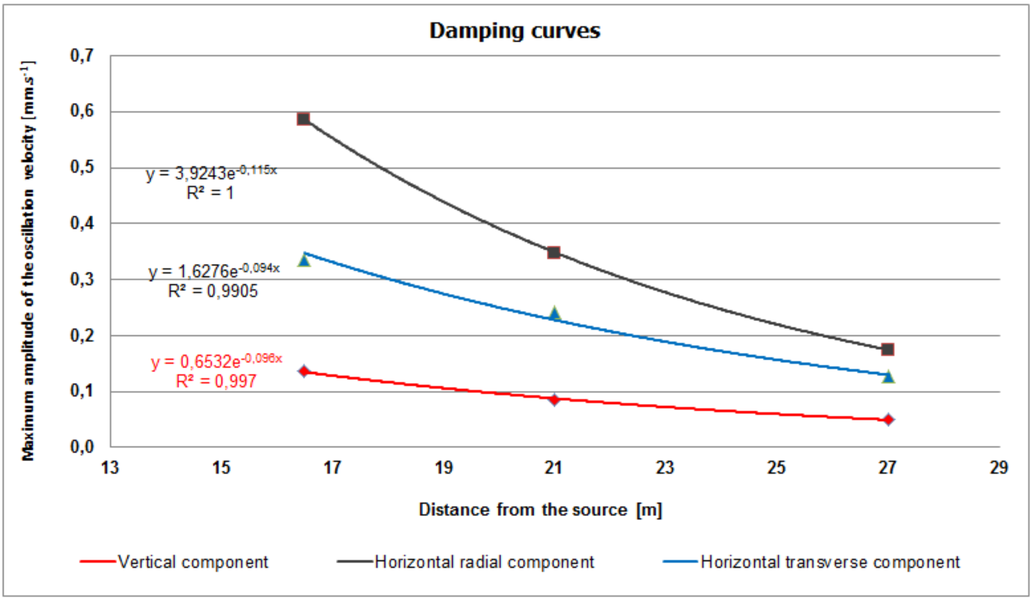
Tab. 1: Maximum component amplitudes of oscillation velocity

Distance from the source [m] /Cycles	Maximum amplitude of the oscillation velocity [mm.s^{-1}]		
	Vertical component	Horizontal radial component	Horizontal transverse component
16,5m/ 1.cycle	0,137	0,604	0,336
16,5m/ 2.cycle	0,174	0,729	0,461
16,5m/ 3.cycle	0,167	0,693	0,422
16,5m/ 4.cycle	0,108	0,443	0,249
16,5m/ 5.cycle	0,134	0,675	0,372
16,5m/ 6.cycle	0,108	0,408	0,261
16,5m/ 7.cycle	0,137	0,452	0,312
16,5m/ 8.cycle	0,156	0,779	0,399
16,5m/ 9.cycle	0,085	0,284	0,187
16,5m/ 10.cycle	0,119	0,515	0,261
16,5m/ 11.cycle	0,089	0,257	0,166
16,5m/ 12.cycle	0,159	0,684	0,372
16,5m/ 13.cycle	0,152	0,586	0,336
21m/ 1.cycle	0,094	0,348	0,241
21m/ 2.cycle	0,098	0,592	0,330
21m/ 3.cycle	0,098	0,419	0,396
21m/ 4,.cycle	0,062	0,276	0,178
21m/ 5.cycle	0,085	0,387	0,393
21m/ 6.cycle	0,067	0,298	0,205
21m/ 7.cycle	0,076	0,342	0,218
21m/ 8.cycle	0,089	0,476	0,290
21m/ 9.cycle	0,058	0,214	0,134
21m/ 10.cycle	0,080	0,209	0,178
21m/ 11.cycle	0,058	0,165	0,125
21m/ 12.cycle	0,089	0,500	0,321
21m/ 13.cycle	0,089	0,414	0,263
27m/ 1.cycle	0,060	0,175	0,127
27m/ 2.cycle	0,071	0,253	0,206
27m/ 3.cycle	0,063	0,215	0,182
27m/ 4.cycle	0,038	0,121	0,073
27m/ 5.cycle	0,044	0,169	0,123
27m/ 6.cycle	0,044	0,131	0,102
27m/ 7.cycle	0,046	0,188	0,161
27m/ 8.cycle	0,054	0,288	0,209
27m/ 9.cycle	0,040	0,090	0,058
27m/ 10.cycle	0,050	0,098	0,088
27m/ 11.cycle	0,033	0,073	0,046
27m/ 12.cycle	0,063	0,277	0,207
27m/ 13.cycle	0,062	0,221	0,142

Tab. 2: Maximum component amplitudes of oscillation velocity

Distance from the source [m]	Maximum amplitude of the oscillation velocity [mm.s^{-1}]		
	Vertical component	Horizontal radial component	Horizontal transverse component
16,5	0,137	0,586	0,336
21	0,085	0,348	0,241
27	0,050	0,175	0,127

Based on the values in Table 2, three mutually perpendicular directions were put together and three amplitude attenuation curves for final lining at the distance of first few metres from the source of dynamic loading (Graph 1).



Graph 1: Attenuation curves for the given environment acquired pursuant to in-situ measurement

4 ANALYSIS OF MEASURED DATA IN LIGHT OF INFLUENCE OF VIBRATION ON TECHNICAL FACILITIES

CSN 73 0040 "Loads of technical structures by technical seismicity and their response" was used for evaluation [12]. Except for the response of the blasting operations, the evaluation of technical seismicity is carried out according to Table 3. It is a transcription of Table 8 – Limit values of effective velocity v_{ef} v mm.s^{-1} and it is found on page 20 of the standard.

Tab. 3: Limit values of effective oscillation velocity

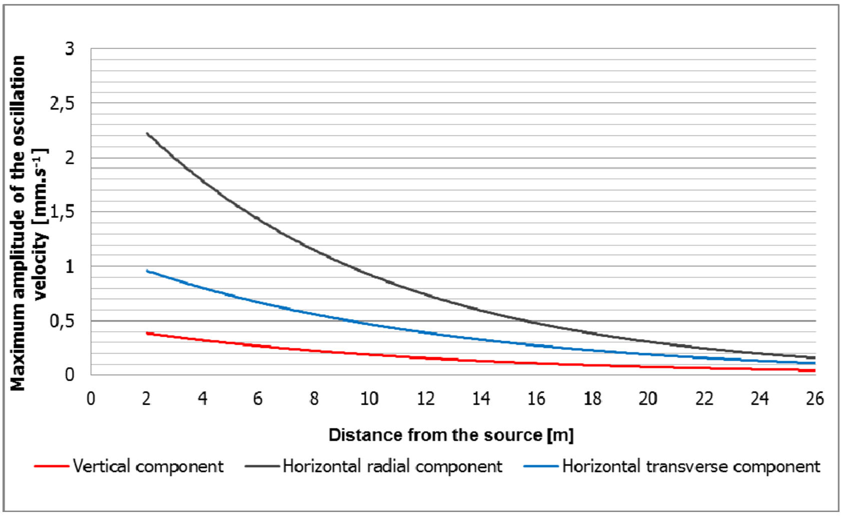
Resistance class Object	v_{ef} [mm.s^{-1}]			
	Significance of the object class			
	U	I	II	III
A	0,2	0,4	0,7	1,1
B	0,4	0,6	1	1,8
C	0,7	1,5	2	2,8
D	0,9	2	2,5	3,5
E	1,1	2,5	3	4
F	1,5	3	4	5

The response to loads by technical seismicity is generally evaluated by the value of effective oscillation velocity at the reference location, i.e. on the lowest floor of the facility or on its foundation. That is why the sensors were located on the final lining of the floor. If values lower than those given in Table are measured at the reference location, it is not necessary to further evaluate the structure against damaging in light of the bearing capacity limit state. Assessment on the basis of the given standard requires the classification of a technical structure under the significance class and the resistance class. Structures are divided into four classes by the significance class (ČSN73 0031 [12]), namely U, I, II, and III. Structures with extraordinary and/or social significance are designated as Class U, Class I has great significance, Class II medium one and Class III designates structures of limited significance.

Structures are divided into 6 classes by the resistance class (A – structures which are most susceptible to damage, not complying today's building regulations, e.g. historical monuments; B – ordinary brick buildings; C – large buildings made of bricks and blocks, stone bridges, the stone facing of underground structures, and stoneware piping; E – reinforced concrete and steel structures, reinforced concrete engineering communications and service pipelines, concrete monolithic constructions of underground structures, core and coaxial communication cables; F – the most resistant structures, reinforced concrete and steel tunnel lining, civil defence shelters, and steel piping) and further into four subgroups (residential, civil, industrial and agricultural structures; engineering structures; underground structures; and underground services and cables).

Based on the above given summary, the final lining of the reconstructed tunnel can be included in resistance class F. The final lining had been built before the accident. It has reached its full design strength. Due to the strategic importance of the railway route, the class of significance is U.

The Czech standard CSN 73 0040 assesses vibrations of the nature of a longer lasting shock load or a steady periodic load by means of their effective values. The processing of the measured records took place as the reading of the maximum oscillation velocities and that is why the maximum values were converted into effective ones for assessment. Attenuation curve equations determined on the basis of Graph 1 (exponential dependence) were chosen for the analysis of the measured values. A graph (Graph 2) was plotted on the basis of these equations, which considers the values in all the three measured directions to determine clearly in which of the directions the decisive maximum values are. In addition to determining the amounts of the effective values which are decisive of assessment, the graphs can be used to obtain, for information, the minimum distance at which the value of the limit effective oscillation velocity will not be exceeded for the structure being assessed. A value of 3 mm.s^{-1} was chosen as the maximum oscillation velocity value on the graph vertical axis, which corresponds to significance class II and structure resistance class E. This value was selected as a limiting one because higher values of effective oscillation velocity were not obtained with the given source of dynamic load. The calculated values begin with the value of 2 m because the development of oscillation velocity at this distance follows other regularities and these must be determined by measurement.



Graph 2: Graphic representation of the assessment according to standard

After determining the direction with the maximum effective values, the horizontal radial direction in our case, the calculation of the distances at which the oscillation velocity values according to Tab. 3 were reached was carried out. The calculated values of safe distances also for different facility classes and their significance other than FU class when threatened by the effects of the demolition hammer used and in given geological conditions are given in Table 4. If a structure was assessed according to the standard in locations of a similar geological profile and if compaction work was performed by a similar device, you would only need to find out the calculated distance at which the structure does not have to be assessed using a dynamic calculation after the classification of the structure was carried out.

Tab. 4: Calculated distances of structures when the limit oscillation velocities were reached for the measurements taken

Resistance class Object	Distance when reaching the limit oscillation velocity			
	Significance of the object class			
	U	I	II	III
A	23,95	17,60	12,50	8,40
B	17,60	13,90	9,25	3,95
C	12,50	5,60	2,95	-
D	10,25	2,95	0,95	-
E	8,40	0,95	-	-
F	5,60	-	-	-

5 CONCLUSION

In geotechnics and tunnel building it is always necessary to struggle with unpredictable effects of the surrounding rock environment. In some cases, the combination of several such effects may result in an industrial accident on site as in the case of reconstruction of Jablunkov tunnels [14, 15]. However, these measures must be overcome during the sequence of development on site to make way for successful completion of the construction work. This relatively exceptional measurement was implemented during the removal of the concrete plug. The uniqueness consisted in proximity of work processes generating vibrations and the already completed final lining. In this way, the influence of vibrations could be measured and investigated right on the structure. The measured values of vibration effect on the structure were presented in the form of attenuation curves. Furthermore, the measurement was assessed according to the relevant standard and a table was prepared with distances within which, in similar geology, analogous material composition of the lining and similar work the facility should not get damaged.

It was found out during evaluation that for the structure significance class U and structure resistance class F this boundary for structure damage is at the distance of 5.6 m. As it was not necessary to get demolition work closer to the final lining than 13 m, the use of demolition hammer was fully competent.

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