

## ENVIRONMENTAL PROTECTION AND THE NECESSITY OF MEASURING BLAST INDUCED VIBRATIONS IN TUNNEL CONSTRUCTION

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### SUMMARY

*Blast induced ground vibrations generated by explosives in tunnel construction may cause structural damages. Therefore, the aim in blasting must be to suppress the vibration effects and mitigate the possible hazards on structures. Commonly used criteria for vibration – induced building damage is summarized in DIN 4150. It is generally assumed to be in terms of peak particle velocity. But the psychological character of human response to vibration involves highly subjective attitudes about what kind of environment is allowed even if no structural damage is occurred.*

**Keywords:** Blast induced vibrations; Ground vibrations; Tunnel blasting, Vibrations monitoring

### 1. INTRODUCTION

There are several sources of ground vibrations which may cause structural damage, particularly in urban areas. Focusing on the life-cycle of motorways, the most threatening sources of vibrations are tunnel blasts during construction including drilling, vibrations caused by construction machines during road construction and pavement maintenance and vibrations caused by heavy road traffic. The effects of these vibrations on historic heritage buildings, including their occupants, is complex subject and has been studied a lot in the past. The fact, that human body senses and responds to vibrations in a different way as sophisticated scientific measurement equipment, makes the task of reducing the negative impact even more difficult [1]. The impact of railway traffic has been studied the most [2]. There is also a lot of evidence on damage caused by road traffic [3] and the measurement and prediction of (airborne and ground-borne) vibrations [4],[5]. Some recommendations and evidence can also be found on countermeasures against road traffic vibrations [6],[7]. Suppressing the ground vibration effects generated by blasts of commercial explosives in tunnel construction on buildings in the surrounding area is important. The same problem, to have as much as possible effect of the vibrations nearby and as little as possible mitigations, is to be solved also during the implementation of (compressing, vibrating) construction

machinery. The intensity of ground vibration is influenced by numerous factors, studied on a lot of specific sites ([8], for example).

## **2. PHYSICAL CHARACTERISTIC OF MINING**

Seismic waves resulting from blasting cause movement of the soil, which is manifested by non-stationary periodic fluctuations. When seismic waves reach the facility, part of the energy fluctuations in soil transfers to the foundations of the building. The dynamic forces in these structural assemblies appears stress. High intensity of seismic waves can cause stresses which can cause a permanent deformation and local destruction of the building. The intensity of the earthquake as a result of blasting and the impact on the surrounding buildings is mainly dependent on:

- physical and mechanical properties of the soil,
- geological composition of the soil,
- the quantity and type of explosive,
- type of blasting and
- distance from the blastfields to facilities.

Protection of buildings from the effects of earthquakes caused by blasting is a problem that can be solved through the application of research. This research consists mainly of defining the mathematical relationship between intensity fluctuations in the soil, the explosive charge quantity and the distance from the blastfields. Known solutions are more theoretical and empirical equations, based primarily on a large number of measurements and the use of statistical methods. Through intensity fluctuations can appear in different physical quantities, such as the oscillation velocity, acceleration, frequency, ground motion intensity (degree), displacement and energy. Slovenia in the field of measurement of vibration in the construction industry doesn't have its own standards. By joining the European Union, we have the opportunity to take over the standards in this area that are already established in Europe. As standards are certainly possible standards:

- DIN 4150 Vibrations in buildings, which have three parts, Part 1: Prediction of vibration parameters, Part 2: Effects on persons in buildings and Part 3: Effects on structures,
- ÖNORM S 9020 Building vibrations; blasting vibrations and comparable immissions of impulse shape and
- SN 640 312a Swiss Standard on vibration effects on buildings.

In Slovenia in the field of measuring and assessing the impact of vibrations on buildings the most commonly used standard is DIN 4150.

The oscillation velocity is given as the limit value as a function of frequency. Among the other standards, DIN 4150 is the most restrictive one, which actually intends to minimize perceptions and complaints [8],[9].

Blasting is part of the technological process in the construction industry, which is very demanding and precise science. As part of this process is essential to proper planning, which includes:

- determining the holed depth, geometry and spacing of blastholes,
- determining the type of explosives and the optimal amount of selected explosives and
- determining the maximum charge quantity per initiation interval.

In the vicinity of settlements and facilities that are historically protected, it is necessary to determine blasting with small charges, which means more often through blasting, but this way we ensure that the effect of vibration on the environment is minimal. When blasting is properly selected and the technology is optimal we can achieve significant effects. This means that almost all energy is consumed in the blasting area, which represents the blastfield. Technological process of blasting in the vicinity of old residential buildings and historically protected buildings must be wisely chosen so that the vibration will be the lowest. This means

that blasting should be carried as a series of small chain explosions. In practice this is achieved by the field provided for the blasting with more blastholes to a certain depth, which are filled with explosive and clogged. Filling with explosive associated with time-delay explosive initiators. Blasting in this way reliably achieves successive initiation of individual blasthole within a specified time and sequence. The impact of such blasting on the surrounding area is thus very similar to blasting effect with only one small charge. The reasons for such impacts are primarily in the fact that the effects of vibration are divided into several intervals. The immediate effect of blasting is not only to cause ground vibrations and throws, but also an air shock wave.

### 3. MEASUREMENTS ON SITE

Residential old building, which was to be monitored is located almost directly above the tunnel tube Leščevje of new highway Pluska – Ponikve in Slovenia. The building has a basement with two floors. Load-bearing walls of this building were constructed of natural stone with irregular shape and the binder is lime mortar, with an estimated strength about 0,5 MPa. Ceiling constructions of basement and first floor were designed as reinforcement concrete slabs, without built-in anti-seismic ties. The facility also has no fundaments. On load-bearing walls of the building before the first blasting we noticed several cracks which were recorded.

Measurements of the vibration caused by blasting in tunnel tubes was performed by measuring equipment InstanTel Minimate Plus with triaxial geophone which is mounted on the basic wall of building 0,6 m above the ground. Blasting in the two tunnel tubes was conducted from March to July 2008. During that period there were 551 measurements of the blasting effects.



Figure 1. Tunnel tube map – highway Pluska – Ponikve

At the facility were measured:

- displacements on the geodetic benchmarks and retro targets,
- displacements of cracks,
- ground vibration velocity in transversal, vertical and longitudinal direction.

With the Blastware InstanTel software has been designated:

- resultant vector of ground vibratin velocity (Peak Vector Sum – PVS),
- vibration frequency analysis and
- typical spectrum of the measured vibrations considering the criteria for DIN 4150.

Results of monitoring are summarized in the accompanying table and chart.



Figure 2 and 3. Facility where monitoring was performed before and after the completion of the tunnel

Table 1. Measurements results on site

	March	April	May	June	July
BP	20	19	36	116	85
SP	37	58	112	52	17
MU	-	3	-	-	-
TN-DIN	14	9	3	-	-
Total number of blasting	53	80	148	168	102

Abbreviations in table 1 represent:

- BP; Barely to distinctly perceptible vibration
- SP; Distinctly perceptible to strongly perceptible vibration
- MU; Strongly perceptible to mildly unpleasant vibration
- TN-DIN; Total number of excess ground vibration velocity (DIN 4150)

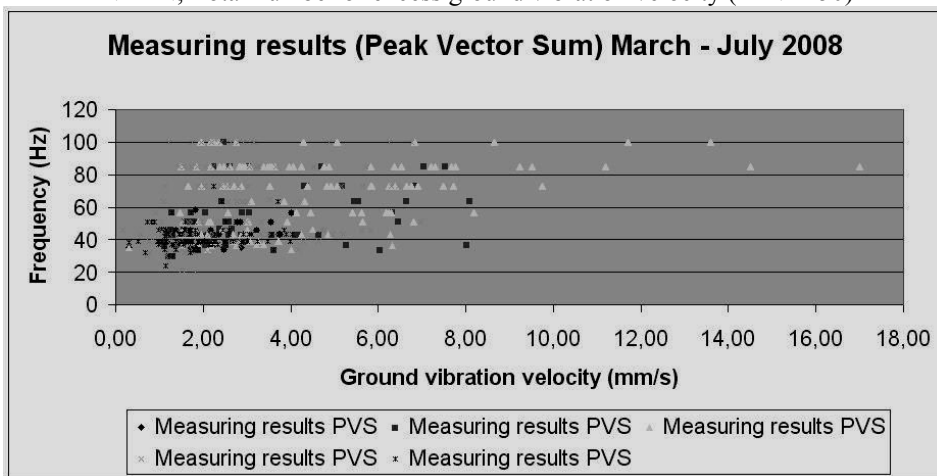


Figure 4. Monitoring results – total number of results PVS (551 measuring)

#### 4. ANALYSIS OF MEASUREMENTS RESULTS

Human response to blast vibration and airblast is difficult to quantify. Vibrations and airblast can be felt or heard well below the levels that produce any damage to structures. The duration of the event has an effect on human response, as does blast frequency. Blast events are relatively short, on the order of several seconds for sequentially delayed blasts. Generally, as blast duration and vibration frequency increase, the potential for adverse human response increases. Studies have shown that a few blasts of longer duration will produce a less adverse human response than short blasts that occur more often. Table 2 summarizes the average human response to vibration that may be anticipated when a person is at rest in quiet surroundings. If the person is engaged in any type of physical activity, the level required for the responses indicated is increased considerably[10].

Table 2. Human response to Ground Vibration for Blasting

Response	Ground Vibration Range (mm/s)
Barely to distinctly perceptible (BP)	0,5 – 2,54
Discinctly perceptible to strongly perceptible (SP)	2,54 – 12,69
Strongly perceptible to mildly unpleasant (MU)	12,69 – 25,38
Mildly unpleasant to discinctly unpleasant	25,38 – 50,76
Distinctly unpleasant to intolerable	50,76 – 253,8

Results of analysis of the measured ground vibration velocity and the human response, taking into account criteria by U.S. Department of the Interior, Bureau of Reclamation, State Water Resources Control Board are presented in graphs on figures 5 to 9.

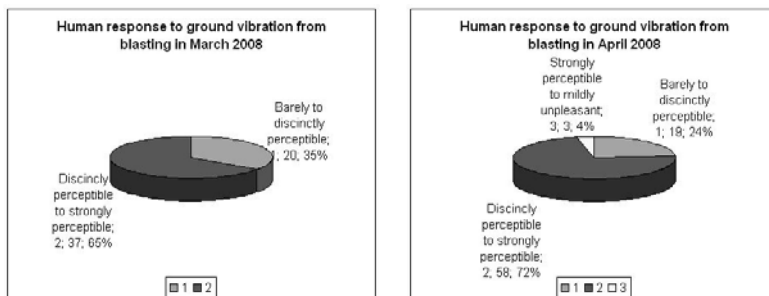


Figure 5 and 6. Monitoring results – total number of results PVS (March 53, April 80 measurements)

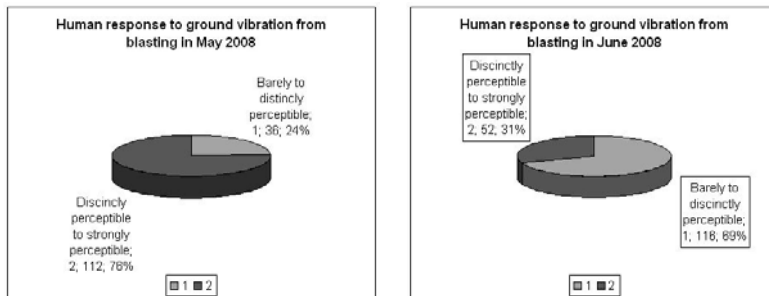


Figure 7 and 8. Monitoring results – total number of results PVS (May 148, June 168 measurements)

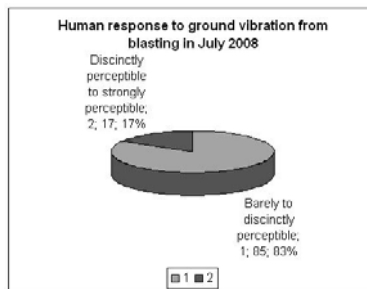


Figure 9. Monitoring results – total number of results PVS (July 102 measurements)

From analysis of the results follows that the 55 blasting induced:

- 26 times excess of the maximum permissible ground vibration velocity according to DIN 4150 and
- 3 times strongly perceptible to mildly unpleasant level of vibration.

## 5. CODE OF GOOD PRACTISE

### 5.1. Practical measurements to reduce vibration

Tunneling techniques vary considerably but known sources of groundborne vibration include tunnel boring machines, hydraulic drilling and drill-and-blast operations. Effects of these sources can be relatively short-lived but might expose a sensitive receiver to high magnitudes of vibrations. Bristish standard BS 5228-2:2009 Code of practice for noise and vibration control on construction and open sites, states that most complaints of vibration relate to blasting. Blasting should only be used there is no viable alternative. Practical measures, including good blast design to reduce vibration are:

- designing each blast to maximize its efficiency and reduce the transmission of vibration,
- accurate settings out and drilling,
- using delay detonation to ensure smaller maximum instantaneous changes.

### 5.2. Quality and standards

In this paper referred standards DIN, ÖNORM and SIA are very good to protect the facilities and environment from the adverse impact of blasting. Above DIN 4150 standard is in this view very strict and the most widely used in Slovenia. The bad side of these standards is certainly that they completely exclude the effect of vibration on human population. As an exception in this area we can only cite Australian Standard AS 2670.2 – Evaluation of Human Exposure to Whole Body Vibration (1990). Unfortunately, this standard in EU is often not used.

### 5.3. Vibration management

Vibration can occur as a result of earthmoving activities, particularly compaction, which if excessive can cause damage to nearby buildings and structures. Due to the isolated nature of the site and absence of heritage structures, vibration is not considered to be an issue [11].

To prevent damage to nearby facilities should be subject to the rules and have experience. A special problem is protection of facilities against vibrations, in particular, it is necessary to investigate the exposure of human population.

Consideration is necessary above all:

- the work time must be strictly between 7 and 19 hour,
- on Sundays and public holidays is no drilling and blasting activities,

- size of the vibrations must be kept below the thresholds, which ensure the well developed blasting plan and
- at the lowest possible level is necessary to reduce the dynamic effects of machinery.

## 6. CONCLUSIONS

With very good blasting plan which are defined blasting activities in the construction of the tunnel Leščevoje are almost completely fulfilled the requirements of standard DIN 4150. This standard was based on the environmental impact assessment and it was binding for all participants. The facility, which was originally scheduled for demolition was with the reduction of explosives in blastholes, optimizing the triggering interval and constant monitoring protect against damage. Unfortunately, taking into account the regulations we did not sufficiently protect the people who were at the time of blasting in the observed object. As the EU and Slovenia do not yet have regulations prescribing the maximum levels of harmful vibrations, the obligation is to prepare this regulations in short time.

## 7. REFERENCES

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