Vibration Control in Urban Drill and Blast Tunneling

ITAtech Activity Group
Excavation

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1 >> Introduction

Blasting is an integral part of the excavation process in underground construction and civil engineering. Due to the high energy content of explosives it is an inexpensive and highly effective method for rock breaking. As explosives have continually been developing due to a high level of research, they have also become remarkably safer. However, it would be careless to ignore the negative side-effects of blasting operations. Due to urbanization, blasting operations are executed more often in populous areas. For this reason it is important to perform the blasting works so that the possible effects on the environment and people nearby are minimized. One of the inevitable negative side-effects of excavation with blasting is blasting-induced vibrations.

The aim of this paper is to discuss the general aspects of blast vibrations and it should give an overview of the blast vibration regulations and legislations in Europe. Furthermore, this paper should also outline modern methods which can be used to efficiently reduce blast vibrations. The first method which is discussed, is improving the delay design by using non-electric detonators. With these detonators, it is possible to set up an efficient system of detonators with a large number of delay times. The paper also treats the importance of the drilling accuracy and choosing the right explosive type. The last method which is shown is the vibration isolation of sensitive equipment. This method is easy to implement and very useful in urban drill and blast tunneling.

Blasting-induced vibrations depend on many factors. Some of these factors can be influenced, some are given. One of the factors that can be influenced is the charge per ignition time. The most obvious way to perform this is to decrease the amount of explosives in holes or to shorten the hole, i.e. the round length. Decreasing the charge weight is not always as straightforward as one could imagine. When the amount of explosives is reduced, it is important to avoid under-loading situations, i.e. the drilling pattern design and placement of the holes play an important role in such cases. Modern detonators, on the other hand, make it possible to set up a nearly infinite number of ignition times.

In addition there are factors which cannot be influenced, such as the distance from the blast area to the sensitive objects e.g. infrastructure, buildings, foundations etc. Usually the blasting location is fixed and is not possible to change. Typically, also the foundation material or soil is fixed. The design of the structure and the overall importance of it, such as cultural values, need to be taken into account as well. Different structures tolerate vibrations in different ways. For example, an industrial building of reinforced concrete can bear more vibrations than a listed monument. Naturally there are differences in human behavior too. Psychological factors need to be considered since people react to vibrations differently.

2.1 EFFECTS OF VIBRATIONS

In some cases blast vibrations can cause damage to structures. These can be divided into minor or significant damage. There are various studies which investigate blasting vibrations and the tolerance that structures and people have for it. An international survey shows that particle velocity (mm/s) is the best and most practical description for defining potential damage to structures. But also the effects of the frequency of the vibrations are not negligible, especially if the frequency of the vibrations is equal to the natural frequency of the structure, which could cause resonance and, in further consequence, damage. In most cases, when tunneling in an urban environment, a risk analysis is conducted in order to avoid damage to the existing structures so that the contractor has limits and can define the maximum instantaneous charge in different places. Risk analysis is usually conducted using a vibration and blasting consultant or someone with considerable experience and knowledge.

When tunnel quality is considered, blast vibrations cannot be ignored. Tunnel quality is often evaluated based on waterproofness, cracking zone and the shape of the excavated profile. When tunneling with the drill and blast method, small charge rates prevent micro cracks in rock. On the other hand, if a high degree of charging is used both in the contour holes and in the aid row, most likely the tunnel profile will suffer and more micro cracking could potentially result in an increased amount of water flowing into the tunnel.

Due to the nature of drill and blast excavation, especially when excavating under urban areas, people nearby might have some concerns regarding the excavation. It is very rare that blasting-induced vibrations cause any physical harm to surrounding structures or people but more often the “harm” is instead psychological. This should always be taken into account when excavating under populated areas. Careful planning and communication with people play an extremely important role.

2.2 MEASUREMENT METHODS

When designing a tunnel project, the environment and the existing structures have to be thoroughly examined. If the tunneling is done in an urban environment, the existing structures have to be inspected and documented before blasting. The inspection is usually conducted by structure and/or vibration specialists and they map, for instance, the existing cracks on the walls and the type of foundation of the building. This process is called a pre-blast inspection. Afterwards specialists calculate and set the maximum values for the particle velocity so that the structures are safe. The specialist can create a schematic presentation of the house and an analysis of zones which are likely to be stressed, so that the possible cracking can be acknowledged. These analyses are a vital proof if the property owner begins to suspect cracking in the walls. If these cracks are observed in the pre-blast inspection, the proof is undisputed. When the limits are set, the contractor can calculate the project. As the PPV (peak particle velocity) allowed is set for each structure, the contractor can calculate the maximum charge per delay. The requirements for specialists cannot be strictly defined, but process knowledge and experience are important properties, which should be considered when choosing the specialist.

Most European states have their own standards for measurement equipment. In general, the equipment has to measure and record the velocity of the vibrations and the frequency. Additional requirements, which, for example, record the acceleration of the vibrations, can also exist. The accelerations can be necessary for the evaluation of the possible effects on persons and sensitive equipment. The best place to set up the sensors is either the foundation of the structure or a place near the foundation. In some cases, the measurement should also be set up at the top of structures.

If the excavation is done under sensitive places, such as hospitals or laboratories equipped with sensitive equipment, the specialists carry out a specific analysis for each piece of equipment and define the limits for particle velocity and acceleration. In addition, the equipment manufacturers of sensitive equipment often set limits of their own. Even though these limits are very low, they could be used as a basis for the analysis.

3.1 AUSTRIA

The standard ÖNORM S 9010, published in 1982, dealt with the effects of whole-body vibrations on persons. It was replaced by the international standard ISO 2631 in 2005. The latest ISO 2631 standard entitled "Mechanical vibration and shock – Evaluation of human exposure to whole-body vibration" was published by the International Organization for Standardization in 2003. Two parts were taken and issued by the Austrian Standards Institute, the ÖNORM ISO 2631-1 and the ÖNORM ISO 2631-2. Part one deals with the general requirements for the assessment of the effects of mechanical vibrations on persons. It defines methods for the measurement and main factors for the admissibility of vibrations. The second part is about the effects on buildings with regard to the harassment of persons.

The Austrian standard ÖNORM S 9020 entitled "Building vibrations; blasting vibrations and comparable immissions of impulse shape" was published in 1986 by the Austrian Standard Institute. The target of this standard is the protection of buildings from damage that could be caused by blast vibrations.

In December 2015, the Austrian Institute for Standardization published a new standard. It is named ÖNORM S 9020:2015 "Vibration protection for buried and surface facilities". It concerns all types of vibrations and not only blast vibrations. Regarding blast vibrations, the main changes are the new building classes and the new evaluation procedures. Table 1 shows the new procedures.

In the standard, minor vibrations are defined as vibrations with a velocity of less than 2.5 mm/s. The minimum distance (D in m) for minor blast vibrations can be calculated with equation (1) and equation (2) for homogenous, and equation (3) and equation (4) for non-homogenous geological conditions. The crucial factor is the maximum charge per ignition time (L in kg).

EVALUATION	BASIS FOR THE EVALUATION	CONSIDERATION OF THE CONSTRUCTION	CONSIDERATION OF THE SOIL
minor vibrations	experience	-	-
vibration measurement	vibration measurement in the foundation	Classes	-
stress/strain measurement	vibration measurement in the foundation and in the area of the highest vibrations	velocity of propagation in the construction	velocity of propagation in the soil

Table 1: new evaluation steps ÖNORM S 9020:2015

CLASS	DESCRIPTION	EXAMPLES	FACTOR E_F
0	Very low sensitivity	tunnels machine foundations bridges	15
1	Low sensitivity	buried parking garages industrial buildings	8
2	Average sensitivity	cavities without lining residential buildings schools, hospitals, churches	3.5
3	Increased sensitivity	medium voltage cables buildings made of aerated concrete	1.8
4	Particularly high sensitivity	high voltage cables listed monuments	1

Table 2 : new building classes. Adapted from: ÖNORM S 9020:2015

Distance 15 m–50 m:

$D = 7.85 \times L^{1,085}$ (1)

$D = 15.8 \times L^{1,085}$ (2)

Distance more than 50 m:

$D = 17.2 \times L^{0,625}$ (3)

If the expected vibrations exceed 2.5 mm/s or if the distance is too small, the second step has to be applied. The limit for the velocity of the vibrations (v_{RW} in mm/s) can be calculated using equation (5) below. For this evaluation, the new building classes are used. An overview of the new classes, including examples, can be seen in Table 2. The factor AF considers the influence of the frequency of the vibrations. In case of blast vibrations AF = 1.0.

$$v_{RW} = v_B \times E_F \times A_F$$

with v_B = 9 mm/s (5)

In addition to this, blast vibration limits in Austria are also regulated by law, but the scope of this regulation is only on mining and quarrying works. The limits are based on the German standard DIN 4150. These values can be found in the Appendix of the ordinance "Bergbau-Sprengverordnung" and these values must not be exceeded. The limits are shown in Table 8 in chapter 3.7

3.2 BOSNIA AND HERZEGOVINA

Bosnia and Herzegovina have adapted the international standard ISO 4866. The Institute for Standardization of Bosnia and Herzegovina published the standard in 2014 with the number BAS ISO 4886. It deals with the effects of vibrations on structures.

3.3 BULGARIA

In Bulgaria the international standard ISO 2631 was adapted and published by the Bulgarian Institute for Standardization in 2004. This standard with the number ISO 2631-1, deals with the effects of vibrations on persons. Bulgaria does not have a standard that evaluates the effects on structures.

3.4 CROATIA

The Croatian Standards Institute (HZN) has adopted the full German standard DIN 4150 and published it in 2011. The Croatian standards are named HRN DIN 4150-1, HRN DIN 4150-2 and HRN DIN 4150-3. They are translated into Croatian but are equal to the German standard. Article 111 of the Croatian legislation NN RH 55/96 deals with safety distances during blast operations. It decrees that the seismic safety distance is determined by the corresponding Croatian standard.

3.5 FINLAND

The vibration guideline values are defined in RIL 253-2010. The guideline value is set for PPV allowed (mm/s). According to RIL 253-2010, the guideline value affects all directions of the shock wave. A qualified consultant may use higher building coefficient factors. The consultants are defined by FISE (Quality of Professionals in Building Sector) to be AA- or A-class vibration specialists. The PPV limits are defined in Table 3 and can be increased or decreased with the factor Fk, which is defined in Table 4.

	PPV LIMITS (MM/S)			
DISTANCE (M)	SOFT CLAY SHEAR RESISTANCE <25 KN/M	HARD CLAY, SILT, LOOSE SAND	COMPACT SAND, GRAVEL, MORAINE, BROKEN OR LOOSE ROCK	SOLID ROCK
1	9	18	35	140
5	9	18	35	85
10	9	18	35	70
20	8	15	28	55
30	7	14	25	45
50	6	12	21	38
100	5	10	17	28
200	4	9	14	22
500	3	7	11	15
1000	3	6	9	12
2000	3	5	7	9

Table 3 : PPV limits for different ground materials. Adapted from: RIL 253-2010

STRUCTURE	BUILDING TYPE COEFFICIENT F_K AA-COMPETENCE CLASS	BUILDING TYPE COEFFICIENT F_K A-COMPETENCE CLASS
Heavy structures, bridges, piers etc	2.00	1.75
Industrial structures and storages of reinforced concrete, steel or wood, shotcreted rock caverns or nonresidential structures in common	1.50	1.25
Structures laid on pile foundations made of reinforced concrete elements, offices, residential and other buildings of steel and wood, cables and wires	1.20	1.00
Massive walls of brick, lightweight block, industrial, office and residential buildings with reinforced concrete frame, glasswall-steelframe buildings and brick-covered wooden frame buildings, non-shotcreted rock caverns	1.00	0.85
Buildings with lightweight block, limestones and brick or other easily damaged material, old buildings sensitive to vibration and oscillation like churches and structures with high arches	0.65	0.55

Table 4 : example of Finnish structural coefficient factor. Adapted from: RIL 253-2010

3.6 FRANCE

The situation in France is that there are two recommendations for the limitation of blast vibration immissions. The first one was published by the A.F.T.E.S. (Association Française des Tunnels et de l'Espace Souterrain). The second recommendation is provided by the Ministry of the Environment. Both of them deal with the effects of blast vibrations on buildings.

The publication of A.F.T.E.S. was presented in 1974 in the journal "Tunnels et Espace Souterrain". It defines three building classes:

- type A: buildings with low mechanical quality
- type B: buildings with average mechanical quality
- type C: buildings with high mechanical quality

The frequency-dependent limits for the velocity of the blast vibrations for each building class are shown in Figure 1:

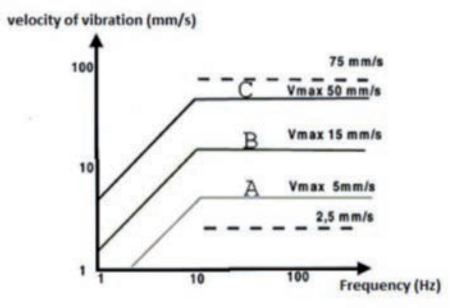

Figure 1: limits A.F.T.E.S.
Source: Borges V., José E., 2004

If there is information about the soil, the A.F.T.E.S. recommends that the values should be adapted. The crucial property is the velocity of propagation of longitudinal waves. The customized values are shown in table 5.

VELOCITY OF PROPAGATION OF LONGITUDINAL WAVES (M/S)	MAXIMUM VELOCITY OF VIBRATIONS (MM/S)		
	BUILDING TYPE		
	A	B	C
1500	2.5	7.5	25
3000	5	15	50
4500	7.5	22.5	75

Table 5 : soil depending limits A.F.T.E.S. Source: Borges V., José E., 2004

The recommendation of the Ministry of the Environment was published in 1986 and expanded in 1993. It also subdivides into three building classes. There are resistant, sensitive and very sensitive buildings. The vibration limits depend on the frequency. The Ministry of the Environment sets three frequency bands in its recommendation. In Table 6 are the maximum values for each construction type and frequency band shown.

TYPES OF CONSTRUCTION	MAXIMUM VELOCITY OF VIBRATIONS (MM/S)		
	4-8 Hz	8-30 Hz	30-100 Hz
Resistant construction	8	12	15
Sensitive construction	6	9	12
Very sensitive construction	4	6	9

Table 6: limits Ministry of the Environment. Source: Borges V., José E., 2004

In 1994, the Ministry of the Environment adopted a decree for quarrying and raw material processing with the number NOR: ENVP9430348A. In this decree the vibrations on adjacent buildings caused by blast operations, must not exceed 10 mm/s. But the scope of this decree only covers quarrying works.

3.7 GERMANY

One of the most comprehensive norms, DIN 4150 “Erschütterungen im Bauwesen”, is published by the German Standard Institute Deutsches Institut für Normung. This standard is divided into three parts. The first part explains the principles for predetermination of vibrations and measurement methods, part two evaluates the effects of vibrations on persons and the third part the effects on buildings.

For the evaluation of the effects of vibrations on persons, according to part two of DIN 4150, the maximum value of the velocity (vmax in mm/s) and the frequency of the vibration (f in Hz) have to be recorded. With these values KB can be calculated using equation (6).

$$KB = \frac{1}{\sqrt{2}} \times \frac{v_{max}}{\sqrt{1+\left(\frac{f_0}{f}\right)^2}} \qquad \text{with } f_0=5.6 \text{ Hz}$$

with f_0=5.6 Hz (6)

This KB value multiplied with the factor c_F results in the value $KB_{F\,max}$. If $KB_{F\,max} < A_o$, then the requirements of the DIN 4150-2 have been complied with. The factor c_F for blast vibrations with resonance is 0.8 and 0.6 without resonance. The reference values A_o are shown in table 7.

Part three of the German standard concerns the effects on structures. The crucial vibration types for blast operations are the short-term vibrations, which are included in chapter 5 of the DIN 4150-3. The velocity and the frequency of the vibrations have to be measured. The evaluation of the vibrations is based on the maximum of the three individual components $(|v_i|_{max}$ with i=x,y and z). Table 8 presents the guideline values of the velocity of the vibrations according to DIN 4150-3. If these values are not exceeded, no damages can be expected.

BUILDING AREA	REFERENCE VALUES (A_o)	
	day	night
Industrial area	6	0.6
Commercial area	6	0.4
Industrial area		
Commercial area	5	0.3
Central area		
Residential area	3	0.2
Special areas (hospitals, health clinic, etc.)	3	0.15

Table 7: A_o reference values. Adapted from: DIN 4150-2 1999, p. 7

TYPE OF STRUCTURE	GUIDELINE VALUES FOR VELOCITY, VI IN MM/S			
	VIBRATION AT THE FOUNDATION AT A FREQUENCY OF			VIBRATION AT HORIZONTAL PLANE OF HIGHEST FLOOR AT ALL FREQUENCIES
	1 Hz - 10 Hz	10 Hz - 50 Hz	50 Hz - 100 Hz *	
Buildings used for commercial purposes, industrial buildings, and buildings of similar design	20	20-40	40-50	40
Dwellings and buildings of similar design and/or occupancy	5	5-15	15-20	15
Structures that, because of their particular sensitivity to vibration, cannot be classified under lines 1 and 2 and are of great intrinsic value (e.g. listed buildings under preservation order)	3	3-8	8-10	8
* at frequencies above 100 Hz, the values given in this column may be used as minimum values				

Table 8 : vi guideline values. Source: DIN 4150-3 1999, p. 4

Nº.	BUILDING TYPE		ACCELERATION (MM/S^2)		
			A_o	A_m	A_{max}
1	Sensitive areas (e.g. operating room)		3.6	3	100
2	Residential building	day	12	10	200
		night	6	5	100
3	Cultural and religious facilities, nursery, etc.		12	10	200
4	Cultural, educational, administrative and office buildings, etc.		24	20	300
5	Commercial buildings, sports centers, public buildings, etc.		36	30	600

Table 9: acceleration limits. Adapted from: 27/2008 (XII. 3.) KvVV-EüM

STRUCTURE	PPV (MM/S)
Construction of reinforced concrete which is founded on solid rock.	150
Buildings that stand on concrete foundations of hard consolidated rock types. Concrete floors and walls.	130
Construction on hard rock (usually the maximum velocity allowed by the government and insurance companies in the event of explosions)	70
Construction including hard rock. Repeated explosions in towns where more than state buildings prevail.	50
Construction on soft rock. Repeated explosions.	30
Construction on soft base (sand and clay). Repeated explosions.	20
For avoiding discomfort to people (at a frequency of 10Hz).	15
For avoiding discomfort to people (at a frequency of 25Hz).	5

Table 10 : PPV limits Iceland. Source: http://www.reglugerd.is/interpro/dkm/WebGuard.nsf aa0d47377abc977400256a090053ff91/fda13fad19c734a200256a62004cf40a?OpenDocument&Highlight=0,684%2F1999

3.8 GREECE

In Greece the RMQW "Regulations Concerning Mining and Quarrying Work" is treated as the national norm. In it, the limit for the velocity of blast vibrations is 50 mm/s. In some projects in Greece, the RSR specification is applied, which refers to public construction projects. The RSR sets the limits for the vibrations at 20 mm/s and 35 mm/s. The smaller value is for foundations on soft material and the higher value is for foundations on hard bedrock. These specifications are not very modern, as a result of which many projects in and around Athens apply the German standard DIN 4150. As a result, a process is underway to include the German standard in the RMQW (Baliktsis, 2000).

3.9 HUNGARY

For the effects of vibrations on buildings, the Hungarian Standards Institution (MSZT") published a standard, the MSZ 13018. The limits for the vibrations, which are listed in this standard, are based on the German standard DIN 4150-3.

The protection of persons from vibrations is included in decree 27/2008 KvVV-EüM which was released in 2008. This decree sets the limits for the acceleration of the vibration in buildings. In case of blast vibrations, the limit for the vibration is 1.5 times Amax, which is shown in Table 9.

3.10 ICELAND

In Iceland, there are not many tunneling or underground projects in urban areas. The projects usually concern energy and road projects. The Icelandic standardization in determining vibration limits is simpler than those of other Scandinavian countries. In Table 10, Icelandic PPV allowed values are presented.

3.11 ITALY

The Italian Standard Institute, Ente Nazionale Italiano di Unificazione, has published two standards that deal with the effects of vibrations. The standard UNI 9916 deals with the effects on buildings and UNI 9614 deals with the effects on persons.

UNI 9916 "Criteria for the measurement of vibrations and the assessment of their effects on buildings" sets no limits for the velocity of vibrations to prevent damage to buildings. It is a guideline for measurement and data processing methods, such as for the evaluation of vibration phenomena.

For the evaluation of the effects of vibrations on persons, the Italian Standard Institute published the standard UNI 9614 "Vibration measurement in buildings and annoyance evaluation", which deals with the effects of vibrations on persons. Significant factors in terms of annoyance of persons are the acceleration and the vibration direction. The standard defines three directions in relation to a person.

Directions of the acceleration according to UNI 9614:

- z-axis: through tailbone and head
- x-axis: through back and chest
- y-axis: through the two shoulders

In the case of short time vibrations, defined as impulsive vibrations in the standard, the maximum measured value of acceleration is crucial. This value has to be frequency weighted and multiplied with the factor 0.71. This results in the effective acceleration. The limits for the impulsive vibrations also depend on the area where they occur. Table 11 provides an overview of the limits.

3.12 NORWAY

Norwegian vibration guideline values are defined in the Norwegian standard collection. The new standard is NS8141-1:2012+A1:2013. The limits of vibrations are calculated using equation (7). The factors for the calculation are defined in Table 12, Table 13, Table 14 and Table 15, which can be found below.

with v_0 = 35 mm/s (7)

$$v_f = v_0 \times F_b \times F_m \times F_t \times F_v$$

OCCURRENCE OF THE VIBRATIONS	MAXIMUM ACCELERATION (M/S^2)	
	z-axis	x- and y-axis
Critical area (operating rooms, laboratories, etc.)	5.0×10^{-3}	3.6×10^{-3}
habitation at night	7.0×10^{-3}	5.0×10^{-3}
habitation in daytime	0.30	0.22
offices and factories	0.64	0.46

Table 11 : acceleration limits. Source: UNI 9614 1990, p. 10

TYPE OF BUILDING	BUILDING FACTOR F_B
Heavy structures, such as bridges, piers, etc.	1.7
Industrial and commercial buildings	1.2
Normal buildings, residential etc.	1.0
Special buildings, such as long span arches, marble staircases etc.	0.7

Table 12 : defining building factor Fb. Source: Norwegian standard collection, p.7

TYPE OF STRUCTURE	STRUCTURE FACTOR F_M
Reinforced concrete, steel and wood	1.2
Plain concrete, brick, concrete hollow blocks, lightweight-aggregate concrete	1.0
Autoclaved aerated concrete etc.	0.8

Table 13 : definition of structure factor Fm. Source: Norwegian standard collection, p.7

BUILDING CONDITION	BUILDING CONDITION FACTOR F_T
Normal	1.0
Fragile	0.8

Table 14 : defining building condition factor Ft. Source: Norwegian standard collection, p.7

TYPE OF WORK	WORK FACTOR F_V
Construction	1.0
Mining and quarry	0.7

Table 15 : definition of blasting time factor, Fv. Source: Norwegian standard collection, p.8

3.13 PORTUGAL

The Portuguese standard NP-2074 was published by the Portuguese standards institute and it deals with the effects of blast vibrations and similar types of immissions. The limits for the velocity of vibrations depend on three factors. The first factor is the property of the soil. It is described by the velocity of propagation of longitudinal waves. The second factor is the type of construction and the third factor depends on the number of blast operations a day. If there are more than 3 per day, the permitted limits are decreased by 30% (=> γ=0.7). These permitted limits are shown in Table 16 below.

CONSTRUCTION TYPE	LIMITS OF THE VELOCITY OF VIBRATIONS (MM/S)					
	VELOCITY OF PROPAGATION OF LONGITUDINAL WAVES					
	≤ 1000 M/S		1000 - 2000 M/S		≥ 2000 M/S	
	γ = 1.0	γ = 0.7	γ = 1.0	γ = 0.7	γ = 1.0	γ = 0.7
sensitive construction	2.50	1.75	5.00	3.50	10.00	7.00
current construction	5.00	3.50	10.00	7.00	20.00	14.00
reinforced construction	15.00	10.50	30.00	21.00	60.00	42.00

Table 16 : velocity of vibrations limits. Adapted from: Bernado P., Dinis da Gama, 2006

3.14 ROMANIA

In Romania, the situation is that there only exists a standard for traffic and machinery-induced vibrations, the two-part standard SR 12025. The first part, SR 12025/1-94 “Vibration effects produced by road traffic on buildings or building parts (Measurement methods)”, concerns measurement methods. The second part, SR 12025/2-94, contains the limits of vibrations for buildings and for occupants.

3.15 RUSSIA

Since 2008, Russia has had in place a valid standard, GOST R 52892 “Vibration and shock. Vibration of buildings. Measurement of vibration and evaluation of its effects on structure”. It was published by the Russian Standard Institute (GOST).

The standard concerns principles for the evaluation of vibrations, damage risks and the influencing factors, and it recommends measurement and data analysis methods. For the assessment of the measured values, the Russian standard refers to several European standards and the OSM standard of the United States in Appendix B. The mentioned European standards are the German DIN 4150, the British BS 7385-2 and the Norwegian NS 8141.

3.16 SERBIA

For the evaluation of the effects of vibrations on persons, the Institute for Standardization of Serbia, (ISS) has adapted the first part of the international standard ISO 2631. It was published with the number SRPS ISO 2631-1 in 2012. In 2014, the ISS published a translated version. In Serbia there is no standard for the evaluation of the effects on structures.

3.17 SLOVENIA

In 2003, the Republic of Slovenia published an official journal, which includes the safety distances for buildings, depending on the explosive quantity. If the explosive charge per ignition time is higher than these limits, vibration measurement has to be set up. For this measurement and evaluation of the vibrations, the Slovenian journal requires the use of a standard of the latest state of technology. Table 17 presents the limits for the charge per ignition time depending on the distance.

DISTANCE M	CHARGE KG	DISTANCE M	CHARGE KG	DISTANCE M	CHARGE KG	DISTANCE M	CHARGE KG
15	0.95	60	3.9	250	38	700	200
16	1	61	4	257	40	800	245
20	1.25	70	5	295	50	905	300
25	1.5	80	6.2	300	51	1000	350
30	1.8	100	8.8	380	75	1080	400
34	2	108	10	400	81	1250	500
40	2.4	150	17	455	100	1500	670
43	2.5	167	20	500	116	1600	750
50	2.9	200	27	585	150	1900	1000
52	3	215	30	600	155	2000	1060

Table 17 : safety distances Slovenia. Source: Uradni List No. 111 2003, p. 15213

3.18 SPAIN

The Spanish Association for Standardization and Certification (AENOR) published a standard for the effects of blast vibrations in 1993, the UNE 22381 "Control of vibrations made by blasting". In the Spanish standard three building groups are defined, which are shown in Table 18 below.

BUILDING GROUP	TYPE OF BUILDINGS
I	Buildings and industrial buildings with metal structures or reinforced concrete
II	Residential buildings, shopping centers, offices and Buildings and structures of archaeological, architectural or historic value, which do not show particular sensitivity to vibrations
III	Structures of archaeological, architectural or historic value, which may be sensitive to vibrations

Table 18 : Building types. Source UNE 22381 1993, p. 2

The Spanish standard defines, in addition to the building groups, three frequency bands. The frequency-dependent limits for the blast vibrations, according to UNE 22381 are shown in Table 19.

BUILDING GROUP	FREQUENCY (HZ)		
	2-15	15-75	>75
	velocity (mm/s)	displacement (mm)	velocity (mm/s)
I	20	0.212	100
II	9	0.095	45
III	4	0.042	20

Table 19 : Building types. Source UNE 22381 1993, p. 2

The maximum velocity (v in mm/s) for the frequency band 15 Hz–75 Hz can be calculated from the displacement (d in mm)

$$v = 2\times\pi\times f\times d \qquad (8)$$

and the frequency (f in Hz) with equation (8

To find out whether a vibration control or even a preliminary study is necessary, the standard recommends a method with the "corrected charge". This value depends on the explosive charge per ignition, the building group and the soil, which is subdivided into three classes:

- hard bedrock: velocity of propagation of longitudinal waves >4000 m/s
- medium rock: velocity of propagation of longitudinal waves 2000-4000 m/s
- soft rock: velocity of propagation of longitudinal waves <2000 m/s

The ratio of the "corrected charge" and the distance show whether further actions have to be taken. In the first case the ratio is so small that there are no effects, but if the ratio exceeds the limits, further steps have to be taken. The next steps are vibration control and a preliminary study. The calculation of the "corrected charge" and the necessary assessment method are shown in Figure 2:

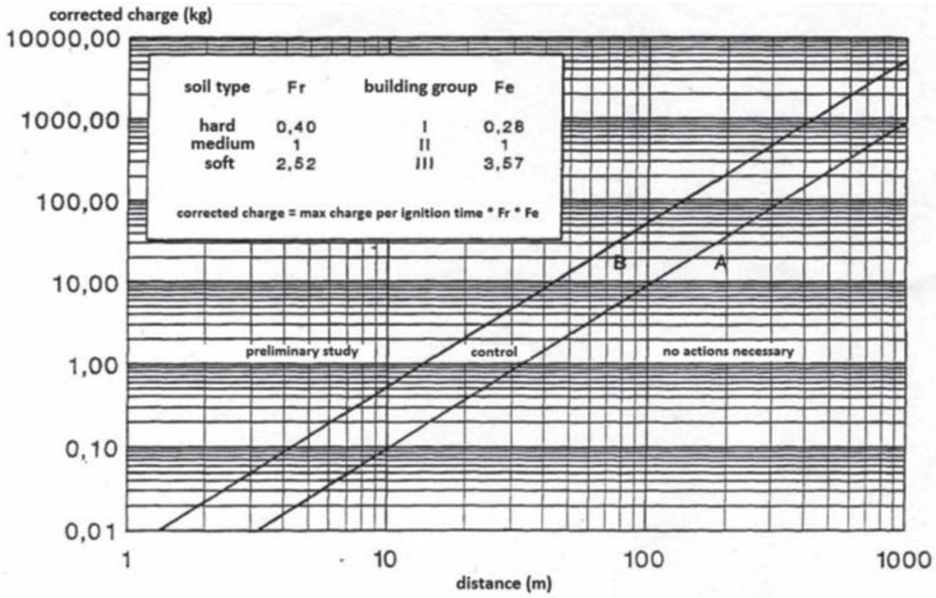

Figure 2 : selection of the assessment method. Source: UNE 22381 1993, p. 8

For the evaluation of the effects of vibrations on persons, the Spanish Association for Standardization and Certification has adopted the international standard ISO 2631. The first part, UNE ISO 2631-1, is about general requirements and the second part, UNE ISO 2631-2, deals with the effects in buildings with regard to the harassment of persons.

In the Royal Decree 863/1985, the minimum distances from the blasting area to buildings have been examined. This distance depends on the type of the buildings. If this distance is not maintainable, the authority may require the application of UNE 22381. The scope of this Royal Decree only extends to mining and quarrying works.

3.19 SWEDEN

Swedish vibration guideline values are defined in SS4604866: Vibration and shock – guidance levels for blasting included vibrations in buildings and other structures. This value is PPV (mm/s) and it concerns the vertical direction. It is calculated using equation (9) below. The factors for the calculation, with the exception of F_d, are defined in Table 20, Table 21, Table 22 and in Table 23. The factor Fd, which depends on the distance (d in m), can be calculated using equations (10), (11), (12), and (13).

$$v = v_0 \times F_b \times F_m \times F_d \times F_t \qquad (9)$$

$F_d = 1.91 \times d^{-0.28}$
distance from 0 to 10 meters (10)

$F_d = 1.56 \times d^{-0.19}$ for clay (11)

$F_d = 1.91 \times d^{-0.29}$ for moraine (12)

$F_d = 2.57 \times d^{-0.42}$ for rock (13)

SUBSTRATA	SUBSTRATUM	VERTICAL PPV, V_0, MM/S
Loosely layered moraine, sand gravel, clay	Clay	18
Compactly layered moraine, schist, soft limestone	Moraine	35
Granite, gneiss, hard limestone, quartzitic sandstone, diabase	Rock	70

Table 20 : Guideline limits for vertical PPV (v0) in different substrata. Source: Jonson D., 2012

CLASS	BUILDING	BUILDING FACTOR, FB
1	Heavy constructions such as bridges, quays, defense installations, etc.	1.70
2	Industrial and office buildings consisting mainly of prefabricated elements	1.20
3	Normal residential buildings	1.00
4	Especially sensitive buildings and buildings with high vaults or constructions with large spans	0.65
5	Guideline values for especially sensitive heritage buildings, installations or environments identified in the investigation shall be determined separately. (per special investigation.)	$F_b \leq 0.5$

Table 21 : Vibration sensitivity factors for different buildings. Source: Jonson D., 2012

CLASS	MATERIAL	MATERIAL FACTOR, F_M
1	Reinforced concrete, steel, wood	1.20
2	Plain concrete, brick, concrete hollow blocks, lightweight-aggregate concrete	1.00
3	Autoclaved aerated concrete, plaster, lath- and-plaster, stucco, render, etc.	0.75
4	Sand-lime brick, tiled oven with sensitive joints	0.65

Table 22 : defining material factor. Source: Jonson D., 2012

CLASS	BLASTING-WORK DURATION FACTOR, F_T
For the construction of tunnels, rock chambers, road cuttings, foundations etc.	1.0
For permanent works such as rock quarries and mines	1.0 – 0.75

Table 23 : blasting duration factors. Source: Jonson D., 2012

3.20 SWITZERLAND

The Swiss standard SN 640312 "Shock-Vibration Effects on Structures" was developed by the "Swiss Association of Road and Traffic Professionals" and published by the Swiss Association of Standardization. The standard concerns all types of vibrations, also including blast vibrations. To evaluate the effects of these vibrations, four sensitivity classes of buildings are defined. Table 24 presents an overview of the classes with examples.

Table 25 shows the frequency-dependent reference values for the individual sensitivity classes, according to SN 640312. If these reference values are respected, no damage can be expected.

CLASS	SENSITIVITY	EXAMPLES
1	Very low sensitivity	Bridges, tunnels in hard rock, crane and machinery foundations, etc.
2	Low sensitivity	Industrial and commercial buildings, tunnels in soft ground, gas and water pipes, etc.
3	Average sensitivity	Residential buildings, offices, schools, hospitals, sensitive cables, etc.
4	Increased sensitivity	Timber-framed buildings, historical buildings, listed buildings, newly built buildings of class 3, etc.

Table 24 : building classes. Adapted from: SN 640312 2013

CLASS	EXPOSITION	REFERENCE VALUES FOR THE VELOCITY OF THE VIBRATION MM/S		
		FREQUENCY		
		< 30 Hz	30 Hz - 60 Hz	> 60 Hz
1	occasionally	up to 3 times the values of class 3		
	frequently			
	permanently			
2	occasionally	up to 2 times the values of class 3		
	frequently			
	permanently			
3	occasionally	15	20	30
	frequently	6	8	12
	permanently	3	4	6
4	occasionally	0.5 to 1 times the values of class 3		
	frequently			
	permanently			

Table 25 : velocity of vibrations reference values. Adapted from: SN 640312 2013

3.21 TURKEY

In Turkey the blast vibration limits are regulated by law. The regulation, with the number 27601, "Regulation Regarding Evaluation and Management of Environmental Noise" was finalized in 2010. Before this regulation had been published, the German DIN 4150 was applied for most projects.

The frequency-dependent limits for the velocity of the vibrations are shown in Table 26 below. The values between the given frequency band can be interpolated.

FREQUENCY HZ	MAXIMUM VELOCITY OF VIBRATIONS MM/S
1	5
4-10	19
30-100	50

Table 26 : velocity of vibration limits Turkey. Source: Turkish Environmental Regulation N°. 27601 2010

Limits for blasting-induced vibrations are important but naturally it is even more important to obey the limits during excavation. Modern blasting methods and technologies enable efficient blast vibration control. Modern technology and experienced and skilled people allow the excavation to be carried out efficiently and economically while taking the surrounding environment into account as well. Hereinafter are listed some best practices to optimize blasting operations which should serve the purpose of reducing the blasting-generated vibrations.

4.1 DELAY DESIGN

An important factor for reducing blast vibrations, which is also considered in many standards, is the charge per ignition time. When setting up a high number of ignition delays, it is possible to optimize the amount of explosives initiating at the same time. One alternative is to use electronic detonators, which can be programmed and fired in millisecond steps. The main disadvantage of these detonators is the high cost.

More commonly non-electric detonators are used. Due to the restricted variation of delay times, in many cases the face has to be divided further into sectors. In each sector every charge or hole has an individual delay time and additionally an extra delay provided by the surface delay detonator used for each sector. The surface delays are used as a “group detonator” to give an additional delay time for each individual non-electric detonator. The challenge is to design the sequence of initiation carefully and to charge the whole face.

This non-electric sector initiation method can be simplified with a special type of detonator, which is used in open pit mining. Each of the detonators has a high delay time and an additional surface delay. The surface delay should be 42 ms, 100 ms or 200 ms and the delay of the detonators itself 9000 ms. In case of 100 ms surface and 9000 ms detonator delay, there are 90 ignition steps available. Figure 3 shows an example of a simplified non-electric sector initiation design:

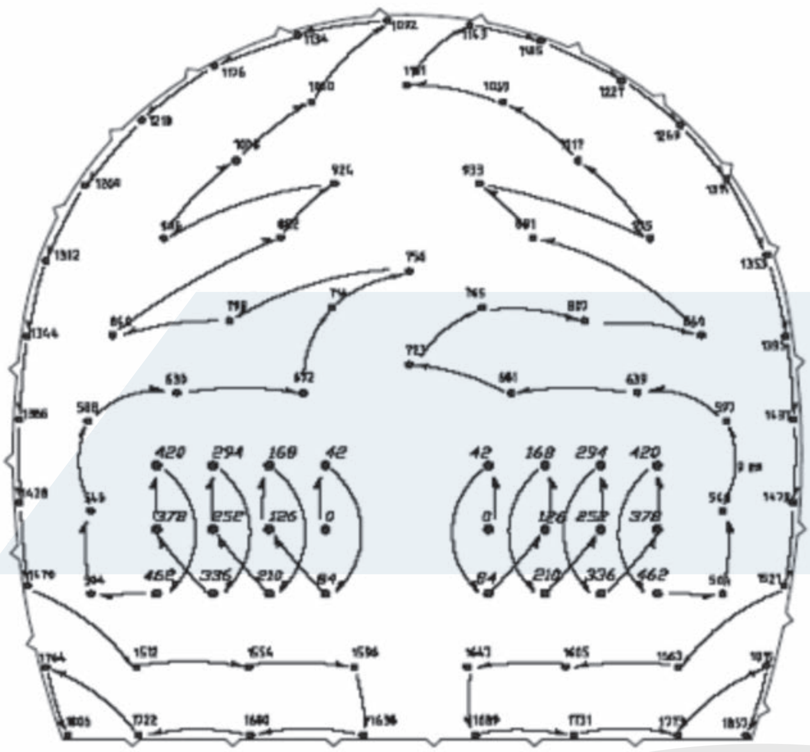

Figure 3 : Initiation design. Source: Ganster M., 2011

4.2 DRILLING ACCURACY

The length of a round is usually limited by the drilling accuracy, but additionally another aspect needs to be considered. An inaccurately drilled borehole could cause additional blast vibrations. If the distance (or spacing) between the holes is not as it was designed, the energy of the explosives is not correctly utilized for breaking the rock as planned but causes extra vibrations or other immissions such as noise. When trying to reduce vibrations in a critical area, one alternative is to increase the accuracy of drilling by using more developed drilling technology or, for example, reducing the round length.

An important element for the execution of the drill pattern design is the drilling machine. The accuracy of the drilling machine is a combination of several factors which have to be considered. It is necessary to adjust the machine to reduce these errors. Factors which influence accuracy are, for example, the bending of the booms or the mechanical tolerances of the machine. Another point is the navigation and placement of the machine. There are different types of navigation systems, which are more or less accurate. Also mistakes made by the surveyor or the operator have to be taken into consideration. With state of the art drilling machines and navigation systems it is possible to drill the round very accurately and with a high level of repeatability. The data collection and analysis features available nowadays enable the drilling and blasting designer to fine tune the process efficiently and to optimize the whole excavation process.

4.3 EXPLOSIVE TYPES

What is important when choosing explosives in tunneling is to optimize the blasting energy so that the blast itself is effective taking rock conditions into account but also so that the remaining rock mass stays as intact as possible. When a tunneling site is located in an urban area, the effects of vibration, storage of explosives and blast timing are often strictly limited. The most common explosives used in tunneling in urban areas are cartridge products (pipe charges) and emulsion. These explosives are suitable for sensitive environments because of their precise degree of charging.

Use of cartridge products ensures a precise degree of charging and they are easy to use. The charger fills blasting holes with different explosives, depending on the quality of rock, tunnel conditions and the blasting plan. Especially pipe charges are simple and fast to use and available in different dimensions. However, choosing cartridge products as explosives in tunneling requires facilities to store the explosives at the tunneling site, which may be problematic because of laws and restrictions concerning excavation in urban areas.

Emulsion explosives are becoming more common at tunneling sites. Emulsion consists of an emulsion matrix and sensitizing additives. The emulsion matrix is produced at a production plant and transported to the tunneling site. The emulsion matrix and additives are mixed at the tunneling site with appropriate a charging vehicle and it achieves its exploding capability normally approximately 15 minutes after it has been pumped into blast holes. The emulsion charging vehicle can be altered from truck or charging platform. With an automation unit it is possible to save different charging grades to ensure different powder factors for different types of blast holes. Charging with an emulsion is therefore easy, also ergonomically, time efficient and it allows the charger to charge the whole tunnel face with only one product.

Transportation and storage of emulsion matrix is more practical because it is considered to be an oxidative substance before sensitizing is completed, Honkanen et al. (2011).

The explosive type can also influence the occurring vibrations. One reason is the under loading of blast holes. A space between the borehole wall and the explosive has a negative effect on vibrations. Bulk explosives, for example site mixed or site sensitized emulsions are one option to minimize the risk of this. On the other hand, the use of bulk explosives creates a risk of the existing joints in the rock mass being filled. In this case, the borehole is overloaded, which also causes additional vibrations.

4.4 VIBRATION ISOLATION

For the protection of sensitive equipment or for not exceeding the vibration limits given by the equipment manufacturers, it can be isolated from the vibrations. To isolate the equipment, elastic material can be placed under it. The success of this isolation depends on several factors, for example the frequency of the vibrations and the mass of the equipment.

5 >> Summary

Tunnel and underground excavation using the drilling and blasting method always influences the surrounding environment. When excavating rock by blasting, some negative side effects such as vibrations always exist. The geology, rock properties and rock mass properties vary a great deal and all of these need to be carefully taken into account when excavation with drilling and blasting is used.

The legislation and norms for blasting-induced vibrations vary country by country but many similarities can be found. An international survey shows that the particle velocity (mm/s) is the best and most practical description for defining potential damage to structures. Due to this, in most countries, the norms give the limit values for velocity. Performing a risk analysis prior to excavation is a good practice for defining sensitive structures and objects near the excavation and for defining the maximum degree of charging values or maximum charge per delay values.

With the help of modern technology, developed excavation methods and careful planning, tunneling and underground excavation can be carried out in urban areas and extremely close to sensitive structures or equipment. When the amount of the explosives is optimized and the boreholes correctly placed, the energy of the explosives can be utilized as planned, i.e. to break the rock mass and not to cause excessive vibrations.

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