Mõõdistamistunnistus
MEASUREMENT CERTIFICATE

Akrediteeritud L151

Mõõdistamistunnistuse nr: *Number of Measurement Certificate:*	3-065-14
Kuupäev: *Date:*	12.02.2015
Tellija: *Customer:*	OÜ TerraMil
Objekt: *Measurement site*	**Estonian Defence Forces central proving ground November 2nd, 2014**
Aadress: *Address:*	Kuusalu parish, Harjumaa county
Töö sisu: *Content of work:*	**Measurement of acoustic parameters in defence structures and assessment of health impact**
Mõõdistusparameetrid: *Measurement parameters:*	Mürataseme määramine (M302:09.10.2014) *Determination of sound power level (M302:09.10.2014)* Vibratsiooni mõõtmine (M304:09.09.2013) *Vibration measurement (M304:09.09.2013)*

Euroopa Liit
Euroopa
Regionaalarengu Fond

Eesti tuleviku heaks

Allkirjad:
Signatures:

M. Oja
TÜ Töökeskkonnalabori juhataja
Head of Work Environment Laboratory

S. Kinnas
Koostaja
Compiler

Dokument koosneb mõõdistamistunnistusest ja -tulemuste kokkuvõttest kokku 11 lehel ning on välja antud ühes (1) allkirjastatud eksemplaris.

The document consists of a Certificate of Measurement with a Summary of Results on a total of 11 pages in one (1) signed copy

Sisukord

1 Introduction

This document presents the results of measurements of acoustic parameters conducted at the central military training field of the Defence Forces on November 2, 2014. Its objective was to evaluate the conditions in a trenched defensive structure (a bunker) under conditions, where it is hit by long-range fire (explosive charges).

The measurements were carried out by Andres Laur, a measuring technician of the Laboratory of Work Environment of the University of Tartu. The measurement results, together with references to the relevant regulatory documents and a short analysis of the measurement results[1], have been provided in the following chapters.

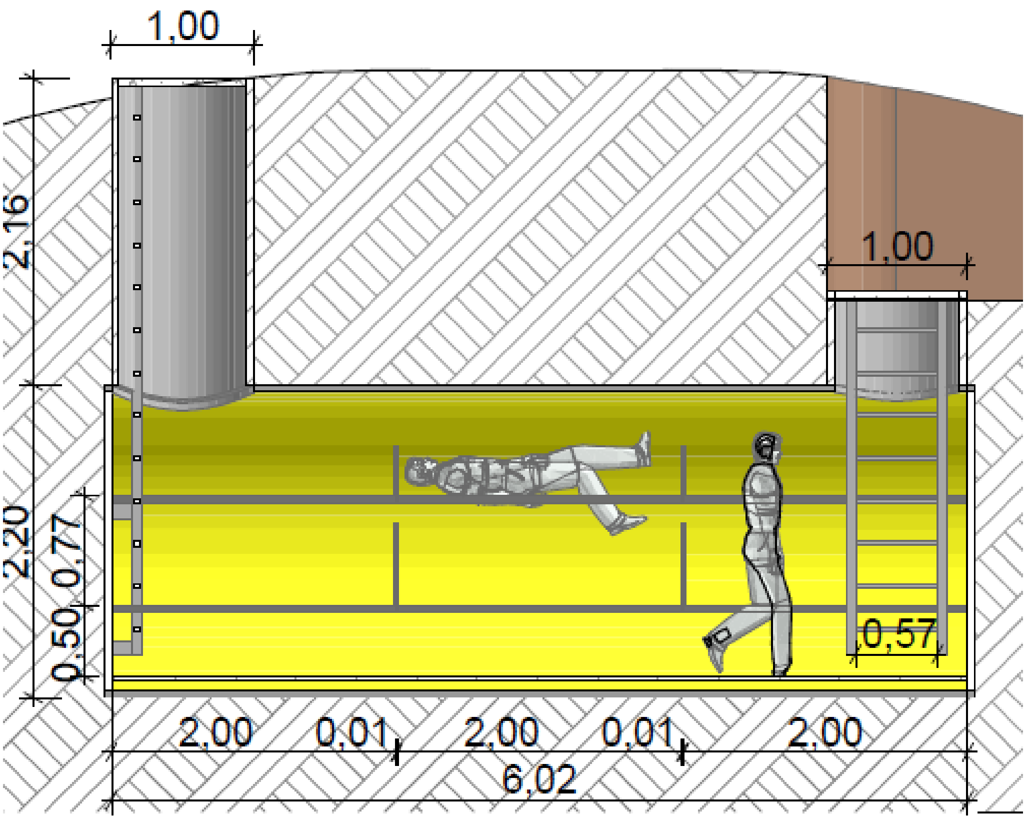

Figure 1: the conceptual schematics of the bunker (an excerpt from the materials provided by the contracting entity). The left entrance aperture did not really exist in the tested structure.

In order to simulate the long-distance fire from different heavy weapons that might hit the bunker, explosive charges with different power were positioned around and on top of the bunker, the blasting of which imitated a hit on or near the bunker. Some of the charges were also placed under ground near the bunker to imitate anti-trench projectiles that had penetrated the earth.

1.1 Measurement Equipment Used

To measure the conditions (sound pressure, vibration, impacts and shocks) in the bunker during the blasting of the charges, the devices listed in Table 1 were used. The devices have

[1] The analysis of the measurement results has not been included in the laboratory's scope of accreditation, the existing limit values and the accompanying explanations have been provided as information for the contracting entity that has ordered this document.

been calibrated and the results can be monitored according to international standard, in accordance with accreditation licence No. L151 of the Testing Centre of the University of Tartu.

Table 1: measurement equipment used

Name/make and model of the measuring device		Measurement range	Traceability
Noise analyser Brüel & Kjaer (S313)	Type 2260	31.5:16k Hz, 44.4…95 dB	OÜ Tehnokontrollikeskus, No. KL-15-1-029 → Calibrator B&K 4226, Danish national standards
Noise dosimeter set Casella (S309)	CEL-350/K5	70…140 dB(A)	Inspecta Estonia OÜ, No. KL-165-2-131 → Calibrator B&K 4226, Danish national standards
Vibration measurement set Brüel & Kjaer (S308)	WB 3461	0.306…5 m/sec^2, WBV: 0.4…100 Hz HAV: 31.5-1000 Hz	Inspecta Estonia OÜ, No. KL-165-3-016 → Standard vibration sensor B&K8305, Danish national standards

Also, ShockWatch Corporation’s calibrated stickers were used to qualitatively evaluate the health effects of shocks and blows. The use and evaluation of these stickers have not been included in the laboratory’s scope of accreditation.

1.2 Measurement Procedure

To simulate a battle situation, the inspected defensive structure (bunker) was buried under 2 metres of sandy earth, in accordance with the procedures of use. An entrance aperture, which had been covered with a thermoplastic polymer cover, was located on the surface of the earth. The cover was destroyed during measurements, and further measurements were then performed in “open-door” conditions. This situation is similar to scenarios that may occur in real-world use..

1.3 Presentation of measurement results

In this measurement certificate, all of the measurement results have been provided with an estimation of measurement uncertainty. None of the measurement results presented herein can and must not be regarded without taking into account the estimated measurement uncertainty.

Generally, the measurement results are depicted as a 95% probability range, or as expanded measurement uncertainty. Based on measurement theory, the actual value X_{real} of the measured element X remains within the X-U...X+U range, whereas none of the values in this range can be considered “more true” than any other. E.g. when then the measurement result has been presented in the following way:

Table 1: an example of presentation of measurement results

X	U(X)
59.2	8.3

it means, that with a probability of 95%, the real value of X remains between 50.9 and 67.5, whereas no values within this range are preferred to another. Meaning that, if the tolerances prescribed for X remain within the described range of values, it cannot be conclusively claimed that the result exceeds or remains below the limit (as it cannot be verified that the limit *has not* been violated). In that case, the result is conventionally evaluated using the worst case method – the value with the most harmful effects to the health in the range of results shall be considered the most likely outcome and the criterion for deviation from the standard.

2 Noise Level

2.1 Definitions

The terms and abbreviations used in this chapter, this text, the tables and the figures have been explained below:

$L_{pA,eq,T}$, $L_{pC,eq,T}$	The equivalent noise level that has been corrected with the A or C filter; the energetic equivalent of a sound (sound exposition) that is present for a certain time period, expressed in dB(A)
$L_{pA,max}$, $L_{pC,max}$	The maximum noise level measured as the root-mean-square of the 125 µs measuring window registered, and corrected with A or C filter, during the whole measurement period
$L_{pC,peak}$	The absolute maximum value of the sound pressure, corrected with the C filter, during the measurement period.

2.2 Normative documents

2.2.1 Work health and work safety requirements for an environment affected by noise, the noise limits in a work environment, and the noise measurement procedure. Regulation No. 108 of April 12, 2007, from the Government of the Republic of Estonian.

Excerpt from 2.1.1.

§ 3. Noise limits and the action values of measures in a work environment

(1) The daily noise exposure level affecting a worker (in case of an 8 hour work day) may not exceed 85 dB(A), and the peak sound pressure of noise (also in case of impulsive sound) may not exceed 137 dB(C).

(2) If the noise exposure level of a worker exceeds 80 dB(A) or the peak sound pressure 135 dB(C) (hereinafter the action value of measures), measures for reducing the effect of noise must be implemented.

/---/

(6) In determining the daily noise exposure level affecting a worker, the attenuation provided by the individual hearing protectors worn by the worker shall be taken into account.

End of excerpt

2.3 Measurement method

The measurement method used for measuring the noise levels is in accordance with international standard ISO 1996-1:2006. Integrating noise analysers that satisfy the Class 2 requirements provided in standard EVS-EN IEC 60804:2001, Electroacoustics – Integrating-averaging sound level meters, were used to evaluate the noise level inside the bunker caused by explosives detonated in the surroundings of the bunker. The noise analysers registered the peak sound pressure and the equivalent sound pressure in 10 second intervals in the 70-145 dB range.

The layout of the noise analysers in the structure has been described in Table 3. The measured and calculated results have been provided in Table 4. The measurement and calculation results have been compared, in accordance with the recommendations provided in international standards, to the limit values provided in the standard documents above based on the worst case method (see section 1.1). The measurement results that exceed the limit values, when taking into account the measurement uncertainty, have been marked with a shaded cell base in the measurement results tables. In case a measurable value exceeded the measuring capacity of the measuring device, it has been marked with a red background in the measuring results table.

Table 3: layout of noise level measuring locations in the defensive structure

Measuring device	Description of the measuring location
CEL460-2	Middle left stack, top bunk
CEL460-3	Front left stack, top bunk
CEL460-1	Rear right stack, top bunk
CEL460-4	Rear left stack, top bunk

2.4 Measurement results

As the first test, a 44 kg explosive charge was detonated in front of the entrance to the bunker, which destroyed the plate covering the entrance to the bunker. The pressure wave exceeded the measuring ranges (approx. 145 dB(C)) of all of the noise measuring devices, thus it also exceeded applicable noise limits set forth in 2.2.1[2] (see Table 4, line 1).

As the second test, a 120 mm mortar shell bomb was detonated on the surface above the bunker (that had lost its entrance cover). The peak sound pressure in the bunker remained below the limit provided in section 2.2.1 for all of the noise measuring devices.

For the remaining measurements, the peak sound pressure exceeded the measuring range of the measuring devices and thus the sound pressure level was more than tenfold the legal limit provided in section 2.2.1.

From this it should be concluded that in case of a an explosive device exploding near an uncovered aperture, creating a pressure wave greater than one generated by a 120 mm mortar shell, the peak sound pressure inside the bunker will be significantly higher than the recommended safe level. Hearing protection should therefore be used in operational situations.

[2] Please note: as section 2.2.1 provides the limits for the work environment, but the measured object and its field of application is seriously different from a work place in its usual definition, this comparison should be regarded as mostly informative.

Table 1: Measurement results, noise levels

No.	Event description	Time [hh:mm:ss]	Measurement device / Measurement results								Legal limit (see 2.2.1)
			CEL460-1		CEL460-2		CEL460-3		CEL460-4		
			$L_{pC,peak,t}$ [dB(C)]	$L_{pAeq,t}$ [dB(A)]	$L_{pC,peak,t}$ [dB(C)]	$L_{pAeq,t}$ [dB(A)]	$L_{pC,peak,t}$ [dB(C)]	$L_{pAeq,t}$ [dB(A)]	$L_{pC,peak,t}$ [dB(C)]	$L_{pAeq,t}$ [dB(A)]	$L_{pC,peak,t}$ [dB(C)]
1	44-50 kg explosive charge next to entrance of bunker	10:44:10	>145[3]	107,1	>145	105,8	>145	105,7	>145	106,6	137
2	120 mm mine on top of bunker	10:58:20	117,1	84,2	115,7	84,6	116,2	84,4	114,3	84,2	
3	120 mm mine on the side of bunker	11:21:40	>145	113,6	>145	112,6	>145	111,8	>145	111,6	
4	122 mm shell on top of bunker	11:36:20	>145	115,8	>145	114,6	>145	115,2	>145	114,9	
5	122 mm shell on the side of bunker	11:45:50	>145	111,8	>145	109,9	>145	109,3	>145	110,5	
6	122 mm shell, 1 m deep underground, on the side of bunker	12:06:30	>145	112,4	>145	110,7	>145	110,5	>145	111,2	
7	10 kg explosive charge on top of bunker	12:26:40	>145	123,4	>145	122,2	>145	122,2	>145	121,8	

[3] The sound pressure exceeded the measurement range of the measurement device.

3 Vibration level

3.1 Normative Documents

3.1.1 *"Work health and work safety requirements for an environment affected by vibration, the vibration limits in a work environment, and the vibration measurement procedure", regulation No. 109 of April 12, 2007, from the Government of the Republic of Estonia*

Excerpt from 3.2.1.
§ 3. Vibration limits and the action values of measures in a work environment
(1) The daily limit for a worker's exposure A(8) to whole-body vibration is 1.15 m/sec^2.
(2) If the daily exposure to whole-body vibration A(8) exceeds 0.5 m/sec2 (hereinafter the application value of whole-body vibration measures), measures that reduce the effect of vibration must be implemented.
(3) The daily limit for a worker's exposure A(8) to hand-arm vibration is 5.0 m/sec^2.
(4) If the daily exposure to hand-arm vibration A(8) exceeds 2.5 m/sec2 (hereinafter the application value of hand-arm vibration measures), measures that reduce the effect of vibration must be implemented.

End of excerpt

3.2 Measurement method

The used measurement method is in accordance with standards EVS-EN 14253:2004+A1:2007, EVS-ISO 2631-1:2002 (evaluation of exposure to whole-body vibration), and ISO 2631-2:2003 (evaluation of vibration in buildings).

To measure the vibration level, a sensor was placed on the floor of the structure. A weight was placed on it to ensure contact with the surface of the floor. The measurement signal of the sensor was registered within the 0.4...100 Hz range with a multi-channel integrating analyzer simultaneously in three orthogonal axes. The reference X-axis was horizontally perpendicular in relation to the longitudinal axis of the structure, the Y-axis was parallel in relation to the horizontal level of the longitudinal axis of the structure, and the Z-axis was vertical in relation to the longitudinal axis.

3.3 Measurement results

The measurement results have been provided in Tables 5 and 6. The tables have an identical content, but for informative reasons, the weighted root mean square acceleration values in Table 6 have been provided as multiples of the gravity acceleration (as G-s: 1 G = 9.81 m/sec^2), which is a common method for evaluating high-energy vibrations, shocks and shakes.

Due to a technical issue it was not possible to set up the measurement device in a way that enables to distinguish between separate explosions after the initial one. For this reason, only the data concerning the highest impulse of that series is visible, which remained at 1.7 G and is completely harmless for humans in the short-term (see also chapter 4).

For more precise data, the test should be repeated.

Table 2: Measurement results, whole-body vibration, SI units

No.	Event	Time [hh:mm:ss]	Measurement duration [hh:mm:ss]	Measurement results					
				X-axis		Y-axis		Z-axis	
				$a_{max,x}$ [m/s^2]	U($a_{max,x}$) [m/s^2]	$a_{max,y}$ [m/s^2]	U($a_{max,y}$) [m/s^2]	$a_{max,z}$ [m/s^2]	U($a_{max,z}$) [m/s^2]
1	44-50 kg explosive charge next to entrance	10:57:29	1:03:22	1,30	0,04	8,39	0,25	10,68	0,32
2	Rest of duration	12:02:16	1:39:13	16,74	0,50	12,70	0,38	14,41	0,43

Table 3: Measurement results, whole-body vibration, acceleration equivalents

No.	Event	Time [hh:mm:ss]	Measurement duration [hh:mm:ss]	Measurement results					
				X-axis		Y-axis		Z-axis	
				$a_{max,x}$ [G]	U($a_{max,x}$) [G]	$a_{max,y}$ [G]	U($a_{max,y}$) [G]	$a_{max,z}$ [G]	U($a_{max,z}$) [G]
1	44-50 kg explosive charge next to entrance	10:57:29	1:03:22	0,13	0,004	0,86	0,03	1,09	0,03
2	Rest of duration	12:02:16	1:39:13	1,71	0,05	1,29	0,04	1,47	0,04

1 Shocks and blows

An evaluation of the effects of shocks and blows caused by the explosions was performed to obtain qualitative information on the possible health effects for persons located inside the bunker.

Please note: The described method is not within the laboratory's scope of accreditation.

1.1 Methodology

A pressure wave resulting from the explosion of an explosive charge propagates through the environment as single pulses that may cause a mechanical shift when transferring from the ground into the bunker, which can be felt as single shocks or blows. If the shock or blow is strong enough, it may cause damage to the health. To carry out this evaluation, the "ShockWatch Label" shock-sensitive stickers from the ShockWatch Corporation were used. The sensitivity of these devices to acceleration and its duration is similar to that of the human body.

Figure 2: ShockWatch Label with a burst ampoule

The stickers contain calibrated ampoules that shall break under a shock or blow with a predetermined strength and duration, painting the ampoule red (see Figure 2). To qualitatively evaluate the strength of shocks and blows felt by the users of the bunker, several stickers with a different sensitivity setting were used:

Table 5: The colour and calibrated sensitivity of the ShockWatch Label stickers

Colour of the sticker	Calibrated sensitivity	Proportional health effect[4]
Grey	15 G[5]	5% probability of damage
Yellow	25 G	Danger of serious health damage
Red	50 G	High probability of health damage
Orange	75 G	
Green	100 G	Car crash

Stickers were placed on the walls of the bunker and the bunks of the middle stack, presuming that the amplitude of any pressure wave is the highest at the middle of any cylindrical body. The layout of the stickers has been provided on Figure 3. In case any of the stickers are activated during the

[4] Kazarian LE, et al, ìThe Dynamic Biomechanical Nature of Spinal Fractures and Articular Facet Derangementî, Aerospace Medical Research Division, AMRL-TR-71-17, August 1971
[5] G – shock or blow (vibration) acceleration. 1 G is equal to gravity acceleration. Please also see http://www.hse.gov.uk/research/hsl_pdf/2003/hsl03-09.pdf for more information

course of the test, but a sticker with a higher nominal value remains intact, it can be concluded that the felt shock remains between these two values.

Figure 3: The layout of the ShockWatch stickers on the walls and bunks of the bunker.

1.2 Results

After the end of the exercise, the condition of the stickers was inspected, and it was determined that none of them were broken. Thus, it can be concluded that the shocks and blows inside the bunker remained within limits that are safe for the health during the whole of the testing period.