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The Influence of the Explosive Ordnance Disposal Suit on the Bomb Squad Safety

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Abstract. The article presents a study on the influence of shock wave on a Hybrid III anthropomorphic test device (ATD HIII) equipped with an explosive ordnance disposal (EOD) suit. The shock wave was generated by the detonation of SEMTEX 1A plastic explosive, formed in the shape of a 250 g, 500 g, and 840 g sphere, at a distance of 0.5 m, 1 m, and 2 m. The use of ATD allowed for determining parameters of damage to the human body as a result of the impact of overpressure wave. The experiments also included a measurement of such parameters as forces and moments on lower extremities, acceleration of head and pelvis, and forces and moments on a neck simulator. Chest Wall Velocity Predictor (CWVP), calculated from the pressure measured on ADT's chest, was adopted as the most critical parameter.

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It was revealed that the allowed distance of explosion of a 500 g pure explosive, which does not cause exceeding the allowed parameters, is 1 m.
Keywords: mechanics, plastic explosive, EOD suit, blast, shock wave, anthropomorphic test device

1. INTRODUCTION

Hazards related to bomb explosions are increasingly common threats used by terrorists to exert a sense of danger among the civilian population. Additionally, military operations often force NATO countries troops to use bomb disposal units to defuse threats posed by improvised explosive devices (IEDs), anti-tank mines or anti-personnel mines. Bomb disposal units are equipped with an advanced tools allowing for detecting, identifying and defusing explosive devices without risking lives or health. These are, among others, remote controlled vehicles, bomb containment chambers or missiles for remote disarming of explosive charges.

However, there are cases when an EOD technician's direct approach to a discovered threat is justified. Such cases involve the use of explosive ordnance disposal (EOD) suits to protect the EOD technician against the consequences of detonation.

During detonation, the explosive charge undergoes rapid decomposition reaction, which results in releasing energy and an enormous volume of gas products. High-energy detonations are the source of conversion of potential energy to kinetic energy in a very short time. This conversion causes extreme compression of air particles forming a band of local pressure increase. The wave of increased pressure, moving from the explosion epicentre at a velocity which exceeds the speed of sound, is called a shock wave.

As a result of detonation, aside from the shock wave, detonation products are formed, which include gases, heat, primary shrapnel (coming from materials which were used to make the detonated object) and secondary shrapnel (lifted once pressure wave passes) [1-3]. Both these phenomena, i.e., the shock wave and detonation products, cause different damage to the human body. These were divided into four types [1, 2]:

– the first type of damage is the result of direct impact of the shock wave, i.e. overpressure applied to the human body - causes damage to lungs, heart, organs of hearing and sight,
– the second is caused by secondary or primary shrapnel with velocity exceeding even 800 m/s; the most common damage in this case is the penetration of the human body by high-energy elements, as well as traumatic amputation of extremities,
– the next grade is related to blunt trauma to the head or abdomen, limb fractures or traumas to internal organs, which are the result of falling or hitting other objects,

– the fourth grade of bodily injury is related to long-term consequences of an explosion’s impact on the human body; these include poisoning, burn, respiratory problems related to dust, etc.

If it is necessary for an EOD technician to approach a potential threat, every effort must be made to eliminate all types of damage to the human body. For that purpose, extensive studies must be carried out on EOD suits, which are used by bomb disposal units all over the world.

2. ORIGIN OF THE STUDIES

Most studies, conducted for the safety of EOD technicians equipped with EOD suits, consist only in checking the suit and its elements against the impact of a shrapnel. These include, among others, studies presented in the documents of the National Institute of Justice (NIJ) [4, 5], MIL-STD 662F [6], or the STANAG 2920 standard [7]. Therefore, studies on the influence of such factors as overpressure wave on a person wearing an EOD suit are well-grounded.

In this article, the authors present the results of studies on the influence of shock wave on individual parts, imitating the human body, of an anthropomorphic test device (ATD) equipped with an EOD suit. Literature review shows that there are no specified requirements which should be met by such suits in terms of protection against shock wave. Only based on insight into the literature it is possible to determine approximate limit values for indices of damage to the human body.

Information presented in articles [2, 8] show that the value of pressure up to which the organ of hearing is not damaged is approximately 150 kPa. Above the value, up to 350 kPa, the shock wave causes moderate strain, however, it is not sufficient to cause primary lung damage. Lungs may be damaged only once pressure reaches the range of 350-550 kPa. Above this value the body sustains injuries leading to death. Articles [9, 10] present a number of studies on damages to various parts of the human body under strain. They were used as a basis for the Allied Engineering Publication standardisation agreement (AEP-55, vol. 2) [11], which stipulates the human body damage criteria. However, these are applied only in studies on the safety of vehicle crews.

Studies on the levels of damage consist in assuming the probability of damage to a given body part. In RTO-148, the probability of an injury was assumed at the level of 10% AIS3 scale (Abbreviated Injury Score–AIS scale is the most widely known and commonly accepted anatomical scale of human body damage).

Areas such as the head, neck, chest, thoracic and lumbar spine, upper and lower extremities are considered the most important in the assessment of damage to the body.

Injury criteria and levels of tolerance of low risk to life or health have been established for the above-mentioned areas. These criteria are related to the anthropomorphic test device Hybrid III (ATD HIII) which is used to gather data from individual sensors corresponding to individual body parts. This allows determining limit values for damage to the human body.

3. OBJECTIVE AND METHODOLOGY

The aim of the study was to determine a safe distance at which an EOD technician wearing a suit may approach, assuming various weights of the explosive, as well as to determine the level of pressure reduction for the best chance for survival of the suit's user. This is what the anthropomorphic test device ATD HIII was used for.

3.1. Anthropomorphic test device ATD HIII

Understanding the phenomena of detonation of an explosive charge and their effects on nearby objects is a method which allows for determining dynamic loads on the human body. All data in this area are mainly determined by the use of ATD (anthropomorphic test device) which is the Hybrid III 50^{th} percentile ATD dummy. The 50^{th} percentile anthropomorphic test device is a complex multi-sensor measuring system for recording dynamic loads. Sensors are located inside the head, nape, chest, abdomen, pelvis, pubic symphysis, thighs, tibiae, etc.

ATD with instrumentation may measure acceleration, force, and moments in individual body parts, and the data are analysed by suitable numerical programmes used to determine the level of damage to individual body parts in relation to the AIS scale. Estimated injury values, included in the STANAG 4569 standardisation agreement, are determined on full-scale objects during tests with the use of the anthropomorphic test device and supporting instrumentation. Test results are deemed positive or negative once they are related to the adopted levels of tolerance, where 10% risk of damage to the human body is allowed.

3.2. Experimental setup

The test subject was an ATD HIII in a standing position equipped with a protective suit (Fig. 1). The suit included some jacket and trousers, shrapnel-resistant panel, safety shoes, and helmet with a shield.

The tests were carried out at the testing ground with the use of Semtex 1A plastic explosive. This material's weight equivalent, relating to the weight of trinitrotoluene (TNT), equals 1.19 of the weight of Semtex.

Explosive charges have the shape of spheres and were detonated from the ground at the d_2 distance (0.5 m, 1 m and 2 m) from the dummy (Fig. 2). The charge weights *m*, which were used during the tests, were respectively: 250 g, 500 g, and 840 g of Semtex. The last charge weight value corresponded to the energy of 1000 g of TNT.

Fig. 1. Anthropomorphic test device equipped with an EOD suit,
a – view with a pencil sensor, b – front view, c – view with an explosive charge

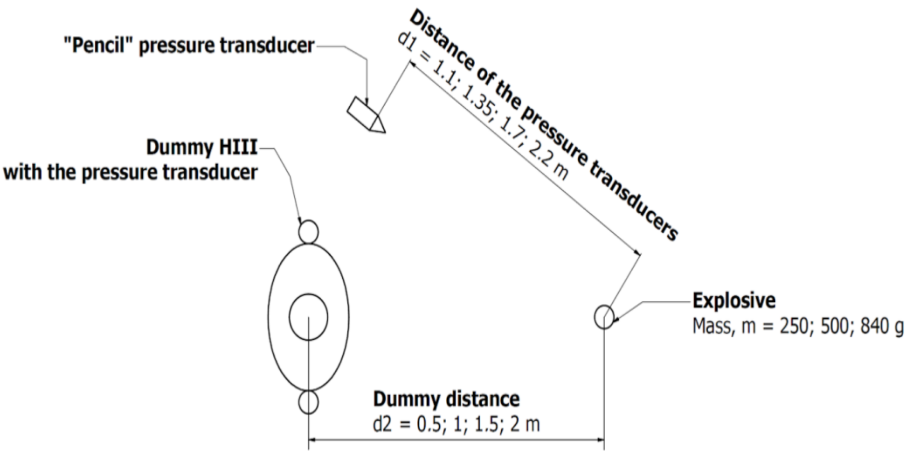

Fig. 2. Schematic layout of detonated charges and pressure sensor in relation to the dummy

Two types of sensors were used for measuring the pressure. One of them was placed on the dummy's chest, directly under the suit and shrapnel-resistant panel, while the other sensor (pencil sensor) was placed at the same distance from the explosive charge as the sensor which was placed on the dummy's chest. Their distance d_1 was respectively 1.1 m, 1.35 m, 1.7 m, and 2.2 m from the explosive charge.

It allowed a comparative measurement of the pressure of the wave generated by the detonated charge and the wave affecting the dummy equipped with the EOD suit. Based on literature overview [8], the dummy was equipped with a witness attire, i.e., internal suit made of thin interfacing non-woven fabric.

The use of such a witness allowed assessing if and where the under-pressure wave and flames could 'enter' the suit. A list of experimental conditions and the numbers of tests are presented in Table 1.

Table 1. Baseline test condition

Test No.	Charge weight, *m*, *g*	Distance of the charge from HIII, d_2, m	Distance of the charge from pressure sensors, d_1, m
1.	250	0.5	1.10
2.	250	1.0	1.35
3.	250	1.5	1.70
4.	250	2.0	2.20
5.	500	1.0	1.35
6.	500	1.5	1.70
7.	500	2.0	2.20
8.	840	1.0	1.35

4. INSTRUMENTATION, RECORDING, AND ANALYSIS OF THE RESULTS

The speed of the acquisition of data from sensors, located in ATD, was 20 kHz. The data obtained from the dummy had the same time constant, which facilitated the subsequent analysis. Apart from acceleration, forces and moments, the dummy was also used to measure the pressure on the chest. Acquisition of the pressure measurement data, recorded by the pencil sensor, was also carried out at the speed of 20 kHz with the HIOKI 8842 recorder. In the tests, two types of pressure transducers were used:

– piezoresistive (model 8515C-50) attached to ATD HIII, made by Endevco company

– piezoelectric pencil transducer (model 137B23) placed next to ATD, made by PCB company.

The measurement data, thus obtained, were the subject to signal filtering, in accordance with the AEP-55 procedure [11], and then they were used to calculate indices of damage to the human body.

Additionally, the Phantom v12 high-speed camera was used to observe the dispersal of the shock wave, its influence of the dummy and the phenomenon of shrapnel lifting by the overpressure wave.

4.1. Criteria of damage to the human body

The establishment of criteria of damage to the human body was presented in such works as the reports RTO-90 and RTO-148 [9, 12].

The main criteria adopted in this paper are: head injury criterion (HIC), lumbar and thoracic spine injury criterion (DRI), chest injury criterion (TCC and VC) internal organs injury criterion (CWVP), and forces and moments on lower extremities. Limit values of individual tolerance levels are presented in Table 2.

Table 2. Limit values of tolerance of damage to the human body

Body part	**Damage criterion**	**Tolerance level for ATD**
Head	Head injury criterion (HIC_{15})	250
Femur	Compressive force (-Fz)	6.9 kN
Tibia	Compressive force (-Fz)	5.4 kN (HIII leg)
Spine	Dynamic response index (DRIz)	17.7
	Dynamic response index (DRIx)	40
Neck	Compressive force (-Fz)	4 kN in 0 ms
	Tensile force (+Fz)	3.3 kN in 0 ms
	Shear force (Fx+-/Fy+-)	3.1 kN in 0 ms
	Bending moment; flexion (My)	190 Nm
	Bending moment; extension (-My)	57 Nm
Chest	Frontal compression criterion ($TCC_{frontal}$)	30 mm
	Viscous criterion ($VC_{frontal}$)	0.70 m/s
Internal organs	Velocity (CWVP)	3.6 m/s

4.2. Head injury criterion (HIC)

The HIC coefficient was determined using the experimental dependence of acceleration from the time measured in the centre of gravity of the head. It is proportional to the average value of the acceleration operating in a defined time interval raised to the power of 2.5.

Time intervals for the integral are predefined in order to determine the same criteria. In order to estimate damage to the head, interval values were assumed for 15 ms, designated as HIC_{15}. The value of HIC is calculated from the Eq. (1):

$$HIC = \left[\frac{1}{(t_2-t_1)}\int_{t_1}^{t_2} a(t)dt\right]^{2,5}(t_2-t_1) \tag{1}$$

where: a – resultant of linear acceleration of headform, (t_2-t_1) – time interval (15 or 36 ms).

4.3. Lumbar and thoracic spine injury criterion (DRI)

The level of tolerance for lumbar and thoracic spine was labelled as DRI (dynamic response index). Equation for this model takes the following form (2):

$$\ddot{z}(t) = \ddot{\delta} + 2\cdot\zeta\cdot\omega_n\cdot\dot{\delta} + \omega_n^2\cdot\delta \tag{2}$$

where: $\ddot{z}(t)$ – vertical acceleration measured from the position of initiation, δ – relative displacement of the system, ζ – attenuation coefficient $\zeta = \frac{c}{2\cdot m\cdot\omega_n}$, ω_n – frequency $\omega_n = \sqrt{\frac{k}{m}}$

DRI is calculated for the relative displacement δ_{max}, ω_n and the gravitational acceleration g (3):

$$DRIz = \frac{\omega_n^2\cdot\delta_{max}}{g} \tag{3}$$

The analysis presented in [12] shows that DRI is the best lumbar and thoracic spine injury index. Due to relatively small probability of lumbar and thoracic zone injury towards the forces direction along the *z* axis, only the *x* and *y* directions were assumed. Assuming a 10% spine injury risk index, the value of DRI was estimated at 17.5. In the case of measuring in accordance with the axes *x* and *y*, the value is 40.

4.4. Chest deformation criterion

This criterion is used when a human's chest is in contact with obstacles. It consists in the calculation of the maximum chest bend.

In the case of a the frontal hit ($FCC_{frontal}$), the maximum value of displacement resulting from the ratio of measurement of chest displacement on the ATD to the displacement constant (0.229) takes the value of 30 mm.

The other criterion is the viscous criterion (*VC*), depending on the chest displacement velocity. Its maximum value is 0.7 m/s.

4.5. Internal organs injury criterion

Chest wall velocity predictor (CWVP), which depends on overpressure at the test location, was assumed as the suitable internal organs injury criterion during tests presented in this article. Velocity (CWVP) at which no damage to internal organs occurs was determined at the level of 3.6 m/s.

Axeisson's model (4) is used in literature to determine tolerance for damage to internal organs.

The model's equation is as follows:

$$M \cdot \frac{d^2x}{dt^2} + C \cdot \frac{dx}{dt} + K \cdot x = A \cdot \left[p(t) + P_0 - \left(\frac{V}{V - A \cdot x}\right)^{\gamma} \cdot P_0\right] \quad (4)$$

where: A – reaction field (0.082 m^2), M – effective mass (2.03 kg), V – initial gas volume in lungs (0.00182 m^3), x – displacement (m), C – attenuation coefficient (696 Ns/m), K – elastic constant (989 N/m), P_0 – ambient pressure, $p(t)$ – overpressure in time, γ – polytropic exponent for gas in lungs (1, 2).

From the above equation, it is possible to calculate the chest displacement speed by inserting the overpressure course in the pattern over time affecting the sensor.

5. ANALYSIS OF TEST RESULTS

5.1. Effect of the suit on the reduction of overpressure wave

Tests carried out on overpressure wave, generated as a result of detonation of various weights of explosive charges, affecting the body of a person wearing an EOD suit, showed a significant reduction of overpressure wave penetrating the suit in the chest area. Even an 85% decrease in overpressure value was observed in the case of an 840 g charge detonated at the distance of 1 m from the dummy (Fig. 3).

For this case, the value of overpressure recorded at the pencil sensor reached the value of 472.7 kPa, while the overpressure measured with the sensor on the dummy's chest reached the value of 67.1 kPa.

The graph presented in Fig. 3 shows that overpressure of the blast wave passing outside the protected area exponentially decreases as the distance increases.

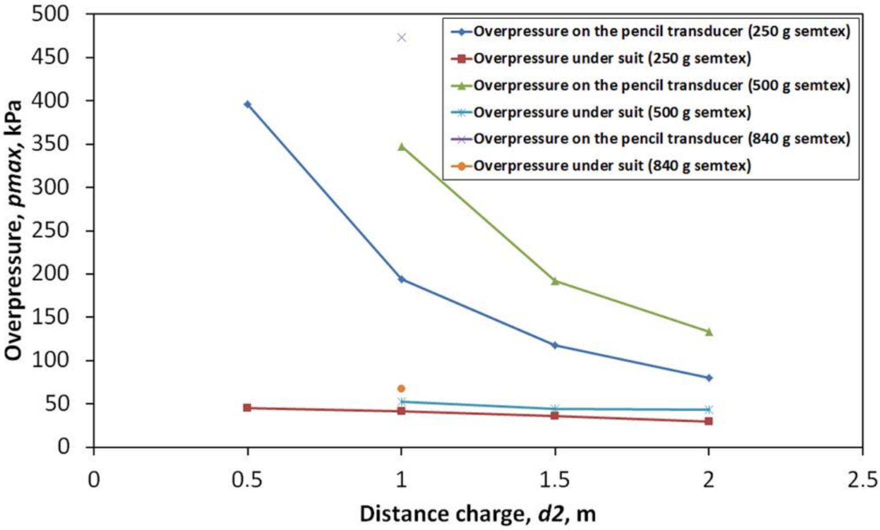

Fig. 3. Overpressure measurement results as a function of distance

The CWVP is the criterion for the damage to internal organs under the influence of the overpressure wave. When comparing the values of overpressure obtained from the sensor beyond the protected area (Fig. 4-a), it may be assumed that the detonation of a 250 g charge at the distance of 0.5 m from the dummy (test No. 1) and generating approximately 396 kPa overpressure, as compared to an 840 g charge (test No. 8) detonated at the distance of 1 m (472 kPa), will result in a comparable value of CWVP.

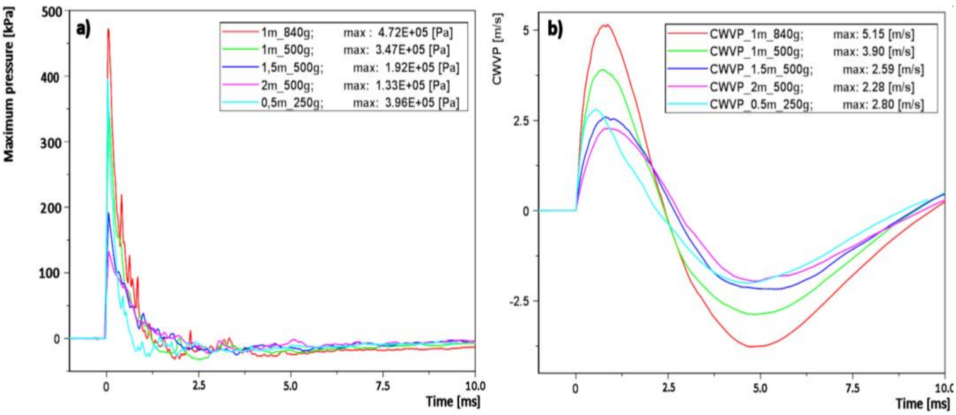

Fig. 4. Comparison of results of maximum overpressure for selected tests, measured at the pencil sensor – a; and the calculated CWVP values for individual cases – b

It was observed, however, that a considerably lower value of overpressure, generated by the detonation of a 500-g explosive (test No. 5) at the distance of 1 m from the dummy (347 kPa), will result in a higher increase in CWVP than it could have been anticipated (Fig. 4-b). CWVP calculated for 840 g and 500 g charges, detonated from the distance of 1 m, reached a level above the standard (respectively, 5.15 m/s and 3.90 m/s). The value of chest wall velocity predictor calculated from overpressure, recorded by the uncovered sensor, generated during the detonation of a 250-g explosive from the distance of 0.5 m (396 kPa) was 2.8 m/s.

According to the Axeisson's model (4), the duration of overpressure has a considerable influence on the value of CWVP. The recorded duration of positive pressure for test No. 5 is higher than for test No. 1.

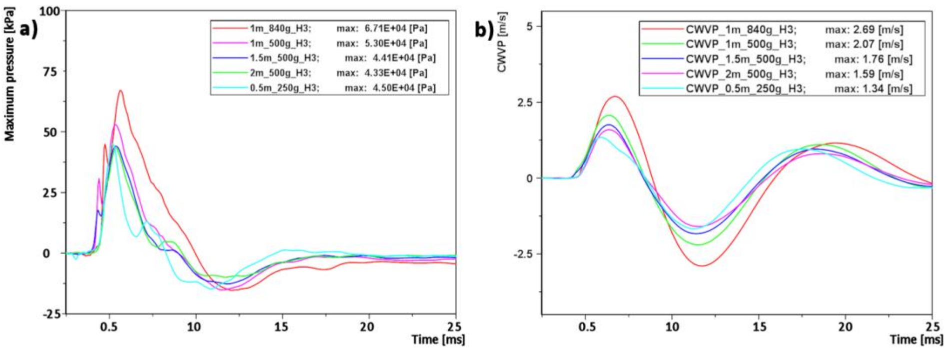

Fig. 5. Comparison of results of maximum overpressure for selected tests, measured at the reflected wave sensor under the suit – a; and the calculated CWVP values for individual cases – b

A similar phenomenon occurred when the suit was used (Fig. 5). It was observed that the duration of an overpressure pulse on the dummy in a suit was prolonged due to the surface affected by the force. The maximum overpressure value recorded under the suit reached value 67.1 kPa, which corresponded to 2.69 m/s of CWVP.

The study on overpressure wave did not include the measurement of the wave which would penetrate the suit's helmet. However, analyses resulting from literature overview show that hearing loss is not considered for survivability on the battlefield. Measurement of pressure under the helmet will be the subject of further studies.

5.2. Influence of the suit on the reduction of effects of EOD technicians' injuries

The studies on the influence of the suit on mechanical damage to the human body include the following criteria as mandatory ones: forces and moments on lower extremities, chest bend, and dynamic response index (DRI) and forces and moments on the ATD's neck.

5.3. Lower body

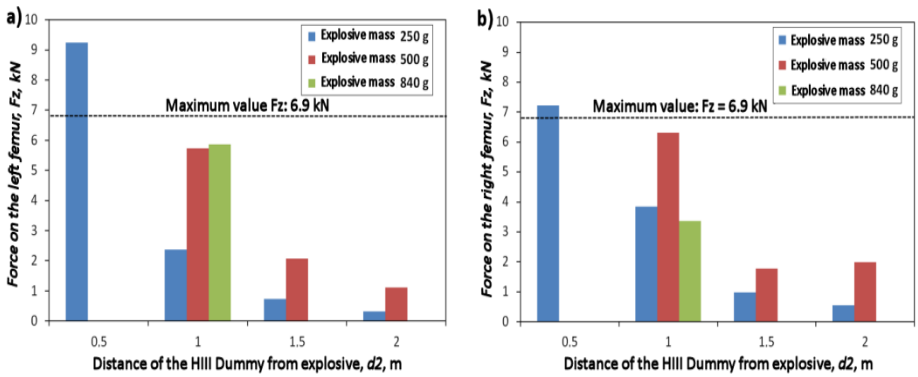

Fig. 6. Values of forces recorded on the thigh; a – left, b – right

It was assumed that parts of human body most vulnerable to injuries are lower extremities. They are closest to the explosive charge. Femur injury criterion was assumed in accordance with allowed values presented, among others, in [7, 9, 11].

It was shown that even a 250 g explosive detonated at the distance of 0.5 m from the dummy may result in both femurs injury (Fig. 6). Force on the left thigh exceeded the allowed value even by 25%, which corresponded to 9.25 kN. Despite the fact that the value of force recorded on the thigh in the case of detonation of a 500 g and 840 g charges at the distance of 1 m is below the allowed value of 6.9 kN (respectively 5.74 kN and 5.87 kN), non-woven fabric and on lower extremities under the protective suit hand protectors sustained damage (Fig. 7).

The results of forces and moments measured on the lower measurement sections of tibiae, showed that axial force recorded along the tibiae (*F*z) is considerably lower than the force affecting the front of the shins (*F*x). *F*z is a mandatory force used to determine the level of damage to the shins in accordance with AEP-55, and its value may not exceed 5.4 kN.

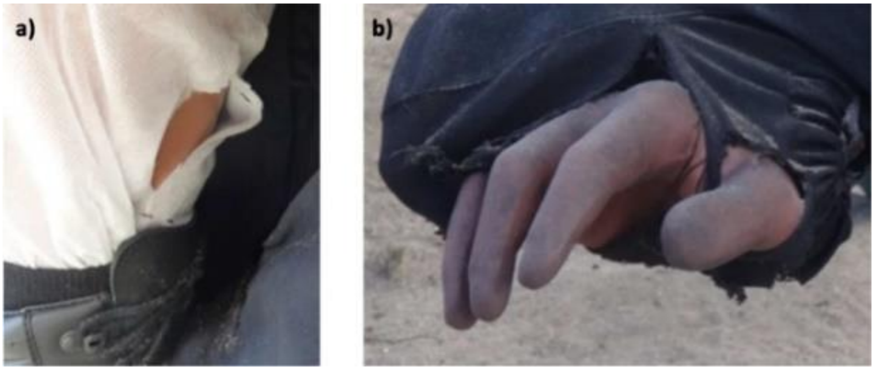

Fig. 7. Visual signs of bodily damage; a – damage to the witness material on legs, b – damage to the hand

In the studies presented, among others, in [13] for the studies on maximum force which causes tibia cracking the average value of shear force is 5.8 kN. Another lower limb injury criterion is the bending moment. In [14], the average maximum value of tibia injury is 207 Nm in statistical studies and 280-320 Nm in dynamic studies. Tibia injury is characterised by TI (tibia index), however it is usually applied in vehicle crash tests. These studies mainly assume model of car collisions with passers-by, where the impact of the car on lower extremities is determined. The main cause for injuries is knee ligament rupture due to forces and bending moments and fracture of tibiae and fibulae. No allowed value of shear force in accordance with the AIS 2 scale, to which individual bodily injuries are compared, was found.

Comparative studies assume the force *F*x and the bending moment *M*y. Shear force exceeding theoretical force assumed for tibia fracture (Fig. 8-a), was not recorded in any of the tests, however, such a phenomenon may not be ruled out.

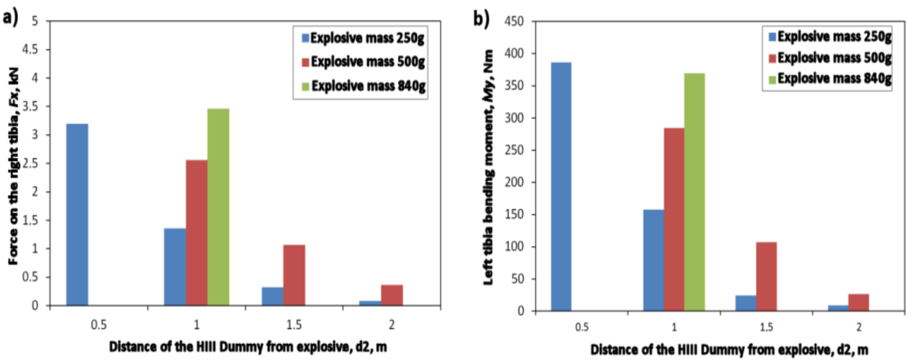

Fig. 8. Values of forces and moments recorded in the lower part of tibia

A more probable bodily damage to a human wearing the protective suit, who is located near the detonated charge, is knee ligament rupture and even fracture due to a bending moment. Probability of damage to lower extremities appears in the case of the detonation of a 500 g charge at the distance of 1 m. The recorded bending moment exceeded 250 Nm (Fig. 8-b), which, according to literature overview, exceeds the allowed value.

Analysis of the results of dynamic response index (DRI) showed that for each test a higher value of the coefficient in the *x* direction compared to the *z* direction was obtained (Table 3).

However, even for this direction, the maximum value which was recorded is only 10.81, which corresponds to approximately 25% of the allowed value towards *x*.

Table 3. Results of parameters measurement in lower parts of the measuring device

Test No	Spine		Femur		Tibia					
	DRIx	**DRIz**	***F*z-Left**	***F*z-Right**	***F*z-Left**	***F*z-Right**	***F*x-Left**	***F*x-Right**	***M*y-Left**	***M*y-Right**
	-	-	**kN**	**kN**	**kN**	**kN**	**kN**	**kN**	**Nm**	**Nm**
1.	3.323	1.479	9.25	7.23	1.57	1.54	2.89	3.2	332.1	386.16
2.	2.327	0.895	2.37	3.85	0.623	0.635	1.69	1.36	113.95	157.93
3.	1.271	0.447	0.725	0.977	0.324	0.24	0.392	0.329	26.96	24.39
4.	0.535	0.261	0.315	0.545	0.261	0.262	0.104	0.087	8.78	8.97
5.	5.1	1.17	5.74	6.32	1.08	1.12	2.59	2.56	257.13	284.57
6.	2.826	1.07	2.08	1.77	0.578	0.807	1.04	1.07	82.68	107.26
7.	1.136	0.591	1.11	1.99	0.233	0.249	0.335	0.369	22.39	26.56
8.	10.81	1.35	5.87	3.37	1.59	1.87	3.61	3.46	376.48	369.45

5.4. Upper body

It was showed that no criteria obtained for upper parts of ATD were exceeded. Head is the outermost part of the human body. The helmet and collar design stopped the head from bending it back, and moments, forces and acceleration recorded on the neck and the head, did not result in exceeding the indices described in Table 2.

A list of results for upper body is presented in Table 4. The acceleration of head center of the gravity graph (Fig. 9) shows that, despite the higher recorded head acceleration value for the 250 g charge detonated from the distance of 0.5 m, the value of HIC_{15} is lower than for the 840 g detonated from the distance of 1 m.

Table 4. Results of parameters measurement in upper parts of the measuring device

Test NO	Head	Neck						Chest	
	HIC15	**Fz-**	**Fz+**	**Fx+-**	**Fy+-**	**MocY+**	**MocY-**	**TCC**	**VC**
	-	**kN**	**kN**	**kN**	**kN**	**Nm**	**Nm**	**mm**	**m/s**
1.	3.23	0.67	1.66	1.39	0.086	29.14	11.1	5.11	0.0713
2.	0.91	0.347	0.641	0.629	0.059	13.76	9.07	3.67	0.0244
3.	0.3	0.195	0.318	0.316	0.025	8.13	8.44	2.44	0.012
4.	0.15	0.225	0.211	0.224	0.021	5.82	5.82	1.94	0.00646
5.	2.68	0.522	1.68	1.45	0.059	30.64	12.4	7.69	0.0938
6.	0.47	0.239	0.521	0.515	0.036	12.58	10.32	5.26	0.0631
7.	0.52	0.282	0.392	0.391	0.044	9.1	8.75	3.67	0.0301
8.	4.75	0.848	1.395	1.227	0.119	27.48	12.2	13.04	0.234

This results from the duration of the maximum value of acceleration and formula (1) on the value of HIC. The maximum value of HIC_{15} was 4.75, which corresponds to only 1.9% of critical value presented in AEP-55.

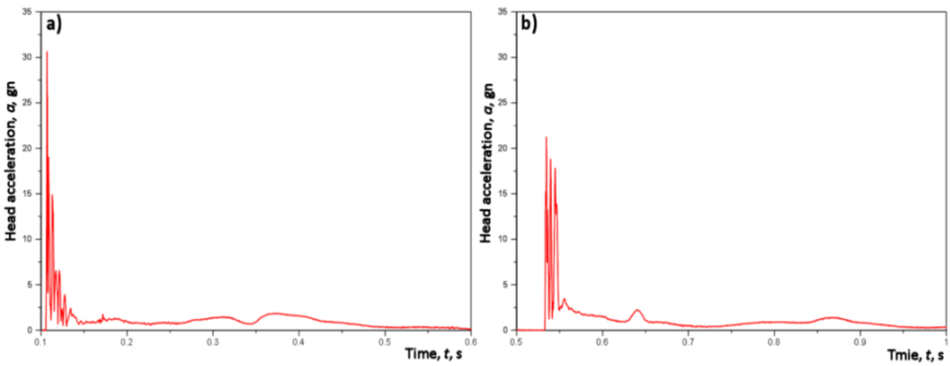

Fig. 9. Resultant of the acceleration of head centre of gravity; a – 250 g at the distance of 0.5 m, b – 840 g 1 m

The measured values of forces affecting the neck (Table 4) showed that the tensile force *F*z+ and the shear force *F*x+/- are considerably higher (even by order of magnitude) than the compressive *F*z- and the shear force *F*y+/-, which is reflected in the nature of the effect of overpressure wave on the human body.

Due to overpressure wave from the detonated charge, affecting the ATD's head, the head bends back and the neck simulator is stretched, which is tantamount to the increase in the forces *F*z+ and *F*x+/-. Dispersal of overpressure wave is presented in Fig. 10. Stop-motion photographs show that the overpressure wave first reaches the lower extremities and hands, and then the chest and head. Due to the large surface of the chest and the use of a hard shrapnel-resistant panel, also reflection of overpressure wave from its surface was observed.

The parameter determining blunt abdominal injuries and rib fractures is defined with TCC and VC. The maximum value of the given parameters was achieved for the 840 g charge detonated from the distance of 1 m (Table 4). The value of TCC reached approximately 43% (i.e. 13 mm) of the allowed value, while VC reached 0.234 m/s, which corresponds to 33% of the allowed value.

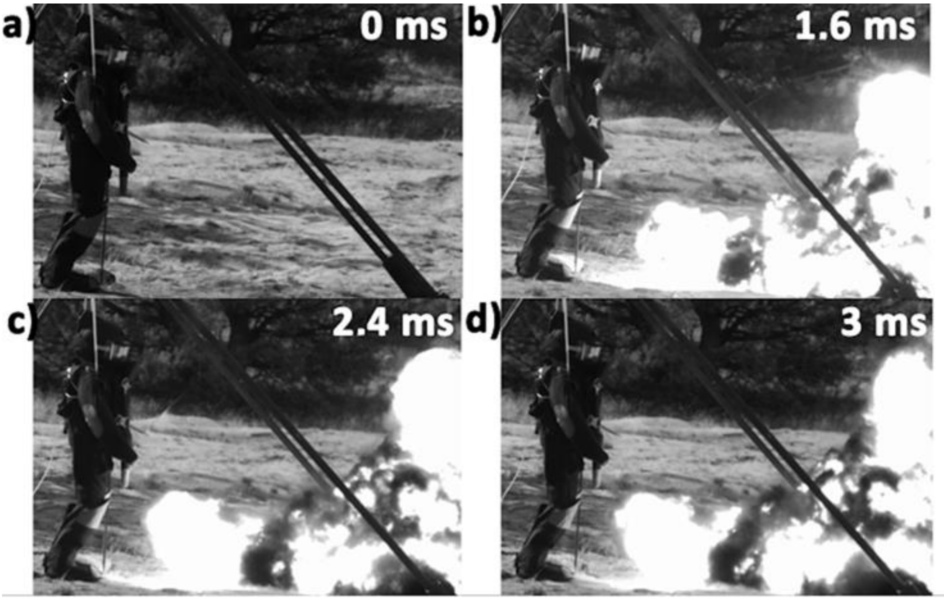

Fig. 10. Stop-motion sequence of detonation of a 250 g charge from the distance of 2 metres

6. SUMMARY

The studies presented in this article allowed for determining the weight of a pure charge and safe distance at which human body, equipped with an EOD suit, will not sustain damage. The studies reveal the problems which should be solved in order to increase the safety of humans against risks related to explosive charges.

The studies have shown that the primary cause for injuries, sustained by person exposed to overpressure wave, originating from a pure charge detonated from the ground, may be injuries to lower and upper extremities. Despite the fact that the value of overpressure for 840 g and 250 g charges, at the distance of 1 m and 0.5 m, respectively, recorded underneath the EOD suit, was below the acceptable value of CWVP, forces recorded in lower extremities were exceeded.

The studies show that the minimum distance, at which an EOD technician wearing an EOD suit may approach a 500 g charge, is 1 m. At this distance and this size of the charge, damage to the body may be minimal.

7. CONCLUSIONS

1. The use of a suit significantly reduces the effect of a shock wave on the human body, at the same time reducing CWVP to a safe value.
2. The design of the studied suit must be modified in order to improve safety of upper and lower extremities.
3. The minimum distance at which an EOD technician wearing an EOD suit may approach a 500 g charge is 1 m.
4. Even a small explosive charge (250 g), detonated at the distance of 0.5 m from an EOD technician wearing the suit, may cause serious damage to lower extremities.
5. Analysis of videos captured with the use of a high-speed camera shows that during detonation, the secondary shrapnels lifted from the ground become very significant, since they hit directly in the chest and collar of the studied suit.

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Wpływ kombinezonu saperskiego EOD na bezpieczeństwo pracy pirotechnika

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Streszczenie. W artykule przedstawiono badania wpływu oddziaływania fali uderzeniowej na Antropomorficzne Urządzenie Testowe Hybrid III (ATD, HIII) wyposażone w kombinezon saperski EOD. Falę uderzeniową generowano poprzez detonację z odległości 0,5 m, 1 m, 1,5 m i 2 m plastycznego materiału wybuchowego SEMTEX 1A uformowanego w kule o masie 250 g, 500 g i 840 g. Zastosowanie ATD umożliwiło określenie parametrów uszkodzenia ludzkiego ciała w wyniku oddziaływania fali nadciśnienia. W trakcie eksperymentów mierzono takie parametry, jak siły i momenty na kończynach dolnych, przyspieszenia głowy, miednicy oraz siły, i momenty na symulatorze szyi. Za najbardziej krytyczny parametr przyjęto CWVP (*Chest Wall Velocity Predictor* – wskaźnik prędkości ugięcia ściany klatki piersiowej) wyliczany z ciśnienia zmierzonego na klatce piersiowej ATD. Wykazano, że dopuszczalna odległość eksplozji czystego ładunku wybuchowego o masie 500 g, który nie powoduje przekroczenia dopuszczalnych parametrów, to 1 m.

Słowa kluczowe: mechanika, plastyczny materiał wybuchowy, kombinezon EOD