TEST REPORT

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Verification of Mine Clearance Vehicle 1 /T deep mine clearance machine.

Effect on the driver in the detonation of a 10 kg mine.

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FMV, TEST REPORT

The following report is a result from blast tests performed by the FMV (Swedish Defence Material Administration) in order to verify that the ScanJack 3500 meets the specified tolerance requirements with regard to effect on the driver.

The report has been translated into English by the Scandinavian Demining Group AB (SDG) and SDG make a reservation for the content and translation and refer to FMV for questions concerning the content of the report.

Contents

Annex:

1 Photographic recordings (CD containing high-speed video and stills)

1 Summary

A blast test has been performed with the Mine Clearance Vehicle 1 /T deep mine clearance machine (ScanJack 3500) to verify that the vehicle meets the specified tolerance requirements with regard to effect on the driver. The requirement is that the vehicle can withstand a 10 kg pressure-action mine which detonates under one of the rear wheels on the driver cab part without having harmful consequences for the driver (‘non-injury’).

The test shows that effect of pressure and impact on the driver will not injure him and that work tasks can be continued in another undamaged vehicle.

2 Introduction

The purpose of the test was to verify that the Mine Clearance Vehicle 1 /T deep mine clearance machine (ScanJack 3500) with mine and splinter protection fulfils specified tolerance requirements with regard to effect on humans, in this case the driver of the vehicle. The vehicle has to withstand a 10 kg pressure-action mine without having harmful consequences for the driver (non-injury). The scenario is that the mine-clearer must reverse and then during a turn drive over a mine with one of its rear wheels. The requirement is that after the mine blast he must be able to evacuate the vehicle and continue his task in another mine clearance machine. The requirement levels are specified in Axelsson, 1999 but also in Rickerli, 2003.

A test was performed on 17 June 2003 at the FMV Karlsborg test range with a 10 kg TNT charge under the right rear tyre.

On 26 – 27 September 2001 blast tests were performed with the vehicle during clearance and with 5 and 10 kg charges detonating under the clearance unit (Sundqvist, 2001). The accelerations and pressures measured inside the cabin pointed to a negligible effect on the driver.

3 The vehicle

3.1 Type

The Mine Clearance Vehicle 1 /T deep mine clearance machine is a vehicle weighing approximately 40 tonnes and just over 14 m in length which is intended to clear mines down to a maximum depth of 35 - 40 cm and to a width of 3.5 m (Figure 1). Clearance is performed by two rollers fitted with chains at the front of the vehicle churning up the ground. The clearance unit weighs approximately 8 tonnes. The cab part with the driver weighs approximately 13900 kg. There was an additional track weighing 800 kg on the right rear wheel in the test. The military registration number of the vehicle is 150493.

Figure 1: Mine Clearance Vehicle 1 /T deep mine clearance machine

The ground clearance under the cab part was 670 mm and the distance between the insides of the wheels was 1740 mm. In addition, the distance between the driver's cab and the clearance unit is approximately 10 m. The integrated frame and V-shaped belly plate of 8 mm steel in the cab part is a strong structure and largely prevents the pressure from the mine reaching the cab floor.

In this report, forward is defined as the direction in which the mine clearance unit is located. The cab is thus along the rear of the vehicle. When the right and left sides of the vehicle are indicated, this is in relation to the rear - front direction.

3.2 Cab

The cab was of a standard type and reinforced with pressure and splinter protection in the sides, floor and roof. On the roof there was a 12 mm thick rubber mat. On the floor there was also an extra shock-diverting footrest in the area where the driver puts his feet. The rest was 660 mm wide and 300 mm deep. The footrest consisted at the top of a 4 mm aluminium sheet, which in turn was secured to a 5 mm thick steel sheet. This was bent at its front edge into a U shape and screwed down to the floor. The sheet assembly could thus oscillate like a diver's springboard.

Helmet, jacket and combat belt are normally kept in a compartment in front of and above the driver. These were omitted in the test as the space was needed for the measuring equipment.

3.3 Driver's seat

The driver's seat was of a standard model with air suspension but without a head restraint and wings. The anthropomorphic crash dummy Hybrid III weighing 78 kg was positioned in the seat (Figure 2). The dummy was clamped in place with the four-point belt. For the dummy to be able to have its feet on the footrest and the upper legs resting on the seat, the level of the seat was adjusted so that it was only a few centimetres from its lowest position.

At the right lower part of the seat there was a fire extinguisher and behind the driver on the wall an AK 4.

Figure 2: Crash dummy Hybrid III in driver's seat.

3.4 Damage inspection

After the blast, the mechanical damage to the vehicle and the effect on weapons etc. were inspected. This will be reported separately by FMV:KC ILS.

4 Charge

4.1 Type

The mine comprised a caseless cylindrical (pie-shaped) charge of 9.820 kg cast TNT, which was initiated in a booster located centrally in the lower part of the charge. The charge had a diameter of 290 mm and a height of 95 mm (D/H = 3). NONEL was used as the initiation system.

4.2 Location

The charge was placed lying in a pit dug under the right rear wheel, half under the track and have in towards the mid-line of the vehicle (Figure 3). Sand was filled on top of the mine so that the top of the mine was 10 cm above ground level.

Figure 3: Location of the mine under the right rear wheel.

5 Measuring equipment

5.1 Photograph

A G-protected measuring video camera and a monochrome digital high-speed camera (250 frames per second) were fitted internally. The windows were covered with cardboard so that the light from the detonation would not interfere. Necessary light for the interior cameras came from two halogen spotlights located in fixtures next to the cameras. The equipment was supplied with power partly from the vehicle's own batteries and partly from external batteries located behind splinter protection outside the vehicle. The task was to ensure the movement of the dummy and other measuring transducers during the course of the detonation and consequently be able to validate collected measurement data.

The blast was filmed externally with a digital high-speed camera (1000 frames per second) to provide an overview visually of the progression of the blast and hut movement.

5.3 Hybrid III

A crash dummy Hybrid III with the individual number 38, from Volvo Car Safety Centre (VCSC) in Gothenburg sat in the driver's seat. The dummy has been developed to be used in crash tests in the automotive industry and is intended for loads in head-on collisions (horizontal loads). It is, however, used in mine-blast tests (vertical loads) throughout the world in the absence of a dummy made for vertical loads.

The dummy contained 29 measuring channels, which were registered by VSCS with the experiment number 03806. Only a small number of these were used as support in the evaluation, such as forces in the spine and tibia and accelerations in the pelvis, foot and ankle. The main purpose of the presence of the dummy was to collect data for future use.

The dummy's feet rested entirely on the footrest. Both feet had shoes on them. The body was held in a four-point belt with the shoulder straps joined at shoulder height behind the backrest of the seat (Figure 2).

Preliminary drop tests at Volvo (Axelsson & Svensson, 2002) have shown that the acceleration in the pelvis can be used to calculate the dynamic response index (DRI) for the spine. However, a DRI which is 20% too great is obtained. No correction has been made for this in the tests with the mine clearer.

It also appears reasonable to use the force in the tibia to assess the risk of injuries to these parts of the body.

5.4 Acceleration

The acceleration in the z-direction in the driver's seat was measured in the pelvis of Hybrid III and in the flat seat cushion which was located between the seat and the posterior part of the dummy. A three-axis accelerometer (Figure 4) is mounted in the seat cushion, a circular disc of rubber with diameter = 205 mm and thickness = from 3 to 12 mm. The acceleration in the pelvis and seat cushion are used to calculate a dynamic response index (DRI), which is a measure of damage in the lower part of the spine. The acceleration in the pelvis and the seat cushion can be integrated once, whereupon velocity as a function of time is obtained. Another integration gives the displacement.

Figure 4: Seat cushion with accelerometer located in the seat, viewed from above.

Four different accelerometers were installed on the left side of the footrest (Table 1) and on the right one under Volvo's control. In addition, an accelerator was installed on the floor at the accelerator pedal. These accelerations can obviously also be integrated once and twice as above. The reason for using five different accelerometers was to obtain some redundancy in the measurement, inasmuch as accelerometers do not always measure correctly and are adversely affected by various disturbances.

5.5 Pressure

The pressure-time progressions inside the cab were measured with a microphone (Table 1) close to the right ear of Hybrid III in order to determine the risk of hearing damage. A pressure transducer of the blunt model was located on the dummy’s chest, so that a notional rib-cage velocity could be calculated from the measured pressure-time progression, where its maximum value is a measure of the degree of damage to the internal organs of the body.

Table 1: FMV pressure and acceleration transducers with amplifiers.

Measuring point	Measured parameter	Transducers			Amplifiers		
		Model	**Serial number**	**Sensit-ivity**	**Model**	**Serial number**	**Filter**
Floor	Accelera-tion	B&K8309	1531626	0.046 pC/g	Kistler 5011	471473	LP 10 kHz
Footrest 1	”	”	1689386	0.045 pC/g	”	471471	”
” 2	”	Endevco 7270-60KM6	F20839	2.424 µV/g	Endevco 106 K1	AH26	”
” 3	”	Endevco 7270-20K	F19917	8.774 µV/g	Endevco 106 K2	AH26	”

” 4	”	Endevco 7264-2000g	BB40	0.3308 mV/g	Kyowa CDV230B	HB8676	”
Seat cushion Z	”	B&K 4322	2261763	9,94 pC/g	Kistler 5011	471472	”
Blunt chest	Pressure	PCB 102M190	8503	68300 Pa/V	PCB 482A06	756	LP 40 kHz
Micro-phone head	”	B&K 4938	2239280	587.2 Pa/V	Nexus 2690	2069714	”
Seat cushion X	Accelera-tion	B&K 4322	2261763	9.64 pC/g	B&K 2635	1588521	LP 10 kHz

Note: Volvo Car Safety Centre dealt with the recordings of Hybrid III measurement signals.

5.6 Cab movement

No specific measurement of cab movement were included, but the high-speed filming from outside was used in order to obtain an overview picture of the progression if possible.

6 Risk criteria

6.1 Pressure damage

The Swedish armed forces apply an American risk/tolerance criterion for hearing exposed to the pressure effect of a detonating charge or in the firing of weapons. This criterion (MIL-STD-1474D, 1997) is used in this report.

The criterion is used for firing and blasts and indicates the total number of rounds (exposures) a serviceman may be exposed to as a function of maximum positive pressure (Pmax) and a characteristic time (B-dur) in the measured pressure-time progression. The number of permitted exposures also depends on whether ear protectors are worn or not (Table 2).

Table 2. Limits for the number of permitted exposures to firing noise.

Maximum permitted number of exposures per day			
Limit curve	**Without ear protectors**	**Plugs or muffs**	**Plugs or muffs**
W	Unlimited	Unlimited	Unlimited
X	0	2000	40000
Y	0	100	2000
Z	0	5	100

If Pmax exceeds 140 dB (the W curve in Figure 5), ear protectors (plugs and/or muffs) must be worn to avoid damage to hearing. For Pmax lower than 140 dB (the W curve), a serviceman may be subjected to an unlimited number of exposures and without ear protectors.

The Z-curve constitutes the upper limit of what a human may be exposed to without incurring hearing damage. The X and Y curves are between the W and Z curves. Methods are indicated in MILSTD-1474D for calculating the number of exposures between the curves W – Z.

For the other pressure-sensitive organs of the body, such as the lungs and gastro-intestinal system, damage occurs at levels well in excess of the Z-curve, the maximum pressure must at least be greater than 70 kPa (Axelsson & Yelverton, 1996). These levels are not relevant in this study unless large holes are opened up in the cab by the pressure load.

Maximum positive pressure Pmax in kPa can be converted to dB according to:

$$\text{Pmax (dB)} = 20 \cdot \log(\text{Pmax (kPa)}/P_0) \text{ with } P_0 = 2 \cdot 10^{-8} \text{ kPa}$$

or

$$\text{Pmax(dB)} = 154 + 20 \cdot \log \text{Pmax(kPa)}.$$

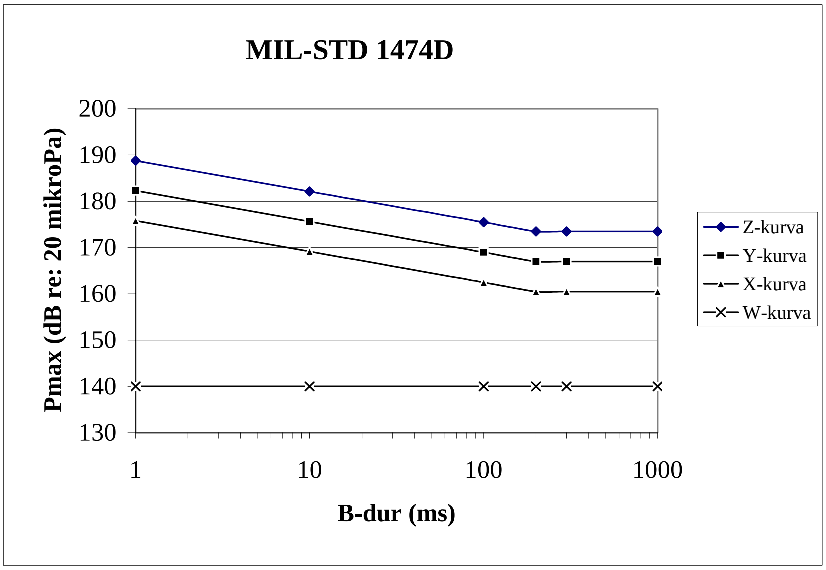

Figure 5: Limits for maximum positive pressure (Pmax) and durations (B-dur) applicable to the tolerance of pressure waves from firing and blasts of the human ear. The degree of protection of hearing and the maximum number of exposures are shown in Table 2.

6.2 Impact injuries

6.2.1 Spine

The Dynamic Response Index (DRI) is a measure of the risk of a seated person suffering a detectable compression injury to the spine when exposed to accelerations along the spine. The mechanical properties of the spine are described mathematically with an oscillating one-degree-of-freedom system containing a mass, a spring and a damper (Coltman et al., 1989). The measured acceleration in the seat, in our case the seat cushion and in the Hybrid III pelvis, constitutes the load on the oscillating system. The oscillating system is described mathematically as

$$d^2z/dt^2 + 2\xi\omega dz/dt + \omega^2 z = a(t)$$

where z is the displacement of the system, , ξ the damping ratio, ω the natural oscillation frequency and a(t) the measured acceleration in the z-direction. The maximum compression of the spine z_{max} is calculated, giving

$$DRI = z_{max}\,\omega^2/g$$

with

$$g = 9.81\ m/s^2$$

$$\omega = 52{,}9\ rad/s\ (8{,}4\ Hz)$$

$$\xi = 0.224$$

The method has been devised for use in the development of rescue systems in catapult ejections of pilots from aircraft, at SAAB among other places.

American experience (Coltman et al.,1989), in both real and simulated ejections, has shown that there is a close correlation between DRI and the risk of sustaining a detectable compression injury in the spine. Unfortunately there are no studies showing that the method is valid for mine detonations of vehicles, but it is widely used for this purpose.

In our experiment, DRI = 16 is used as the limit which must not be exceeded. DRI = 16 corresponds to a 1% risk of sustaining a detectable compression injury in the spine.

An alternative, but older, method for assessing whether spinal damage arises or not is that the mean acceleration of the seat must be < 15g or that its maximum change of velocity is < 4.5 m/s for damage not to arise (Hirsch, 1964).

6.2.2 Foot and lower leg

The foot and lower leg are sensitive to impact loads in the longitudinal direction of the lower leg. The injuries comprise fractures in the foot and lower leg. The injuries are exacerbated with increasing loads.

It has not been possible to find any model for how great the degree of damage is as a function of load. A model with elements of practical experience from the early sixties is therefore used (Hirsch, 1964). This model applies to a standing person with straight, rigid legs and shows that the risk of injury is small if the mean acceleration in the floor is less than 20g or the maximum change in velocity is less than 3 m/s. The model is applied here to a seated person with feet on the floor.

We have also made use of the measured force in the longitudinal direction in Hybrid III lower legs to obtain a preliminary determination of the risk of injury. If the force is < 3 kN, the risk of foot/ankle fractures is < 5% (Yoganandan, 1996).

6.2.3 Head

Here too there is a lack of good criteria for head injuries in mine blasts, i.e. when the head strikes the walls or roof of the vehicle. The criterion in safety work in the car industry for approval is that the skull and brain sustain injuries which far exceed the FMV requirement of "stand up and walk".

Gurdjian et al., 1949 state that fractures are obtained on the skull if the impact velocity against a rigid surface exceeds 4.5 m/s. This damage may be severe if haemorrhaging occurs in the tissues inside the cranium. A velocity of 4.5 m/s is obtained if the head is allowed to fall from a height of 1 m.

It is unclear what happens at lower velocities, and FMV has therefore decided that the skull must not strike the walls or roof of the vehicle.

7 Results

7.1 Movement of the vehicle and injuries

The violent throwing-up of sand and detonation gases largely made it impossible to follow the movement of the vehicle, and only its final position could be established. The cab part had twisted to the left around the articulated steering and was at a slope of around 45 degrees (Figure 6), which meant that the mine-clearance part had been raised at the rear and the front edge of the unit rested on the ground. It could be seen from tracks in the sand that the four wheels of the mine-clearance part had not moved but remained in their original position.

Figure 6: The vehicle viewed from the rear.

Some of the damage was that the right rear wheel, under which the charge was positioned, had loosened but was entangled in the track under the front right wheel of the cab part (Figure 7). In addition, the belly plate under the engine had been pressed in and had damaged the oil sump, after which it had dropped down. The pressed-in belly plate made it possible for the pressure to some extent to act on the floor of the cab.

Figure 7: The vehicle viewed from the left with loose engine belly plate.

7.2 Damage assessment – man

7.2.1 Compressive damage

When the explosive charge detonates, an air shock wave is created which spreads under and around the vehicle. The compressive load on the sides, floor and roof of the vehicle set these in oscillation, which in turn generates pressure waves inside the cab. This, together with any holes present or arising in the cab, where the pressure can leak in, gives rise to a pressure-time progression which lasts for about ten milliseconds. The maximum pressure at the head which is measured is below the z-curve, which will not result in any damage to hearing if ear protectors are worn.

The maximum pressure on the chest of the dummy measured is well below the tolerance requirement of 3.6 m/s.

7.2.2 Impact injuries

7.2.2.1 Spine

The oscillations in the floor, together with the global movement of the whole cab, affects the movement of the seat and therefore the calculated DRI. The global movement of the cab is slow, with a typical frequency of a few Hertz while the seat with its suspension, damping and load (78 kg Hybrid III) is oscillating at a frequency of approx. 8 Hz. The oscillation frequency in the DRI model itself is approx.8 Hz.

The driver’s seat with Hybrid III had a DRI below the tolerance limit DRI = 16.

The risk of back injuries to the spine is non-existent according to Hirsch, 1964 if the mean acceleration is < 15 g and the maximum change of velocity < 4.5 m/s. The measured results from the detonation test show that no injuries are to be expected.

7.2.2.2 Foot and lower leg

According to established criteria, the mean acceleration must be < 200 m/s^2 (20 g) or the maximum change in velocity must be < 3 m/s i.e. to the left of below the Hirsh tolerance curve. In all cases the mean acceleration is less than 20 g.
The measurement of the force in the lower part of the tibia of Hybrid III points to values well below 3000 N (5% risk of fracture injury).

7.2.2.3 Head

As well as the right part of the cab moving upwards, it rotates 45 degrees to the left around the articulated steering. The left wheels dig down into the sand a few decimetres (Figure 8).

The measuring video camera with lighting was knocked out due to a power failure in the vehicle. The high-velocity camera registered from the moment of detonation onwards..
The filming inside the cab shows that Hybrid III moves both upwards and sideways without striking the roof or the side walls. Volvo’s calculations of HIC (head injury criteria) shows very low values, which are judged by Anders Kling of Volvo Cars Safety Centre as being non-harmful.

It must be remembered, however, that for a tall person with the seat set at its highest position there is a risk of striking the roof.

Figure 8: The vehicle viewed from the left.

8 Summary of damage - man

With reference to the risk criteria in Section 6, Table 3 shows whether the measured values of the pressure and shock effect on man are below or above set tolerance levels and therefore whether the vehicle is approved (YES) or not (NO) for each form of effect separately.

The vehicle is approved in all cases.

Table 3: Approval of the vehicle (YES) or no (NO) according to stated tolerance criteria with each form of effect taken separately.

Place	Pressure		Shock		
	Hearing (with ear protectors)	Other internal organs	Spine	Foot/ankle tibia	Head
Driver	YES	YES	YES	YES	YES

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