PROJECT FOR RESEARCH AND DEVELOPMENT OF DEMINING RELATED EQUIPMENT IN CAMBODIA

No. 3

SURVIVABILITY TEST

KOMATSU MACHINE

8. INTRODUCTION

This measurement test intends to evaluate the safety of cabin crews in demining machines. The sound pressure and vibration/acceleration in the machine cabin at mine blast will be measured in this experimental study. Sound overpressure can damage the ears of the machine operator and excess vibration and acceleration can cause injuries to his/her foot, ankle and spine. We follow the test procedures and safety criteria defined in the FMV（Swedish Defense Material Administration）document1). This paper reports on-site test results in Cambodia, analyses the measurement data collected, and examines the safety of demining machines.

9. TEST METHOD

9.1. DEMINING MACHINES UNDER TEST

Demining Machine #3: Made by KOMATSU (Referred as KOMATSU)

9.2. MEASUREMENT SYSTEM CONFIGURATION

The configuration of the measurement system is shown in figure below. The sound pressure and vibration/acceleration in the cabin of demining machines are measured in the following locations;

- Sound Pressure: Place a pair of pressure sensors and a probe of sound-level meter about the height of the operator's ear,
- Vibration/Acceleration: Set one accelerometer on the cabin floor and another on the top of the weight of 60 kg placed on the operator seat to emulate a human weight.

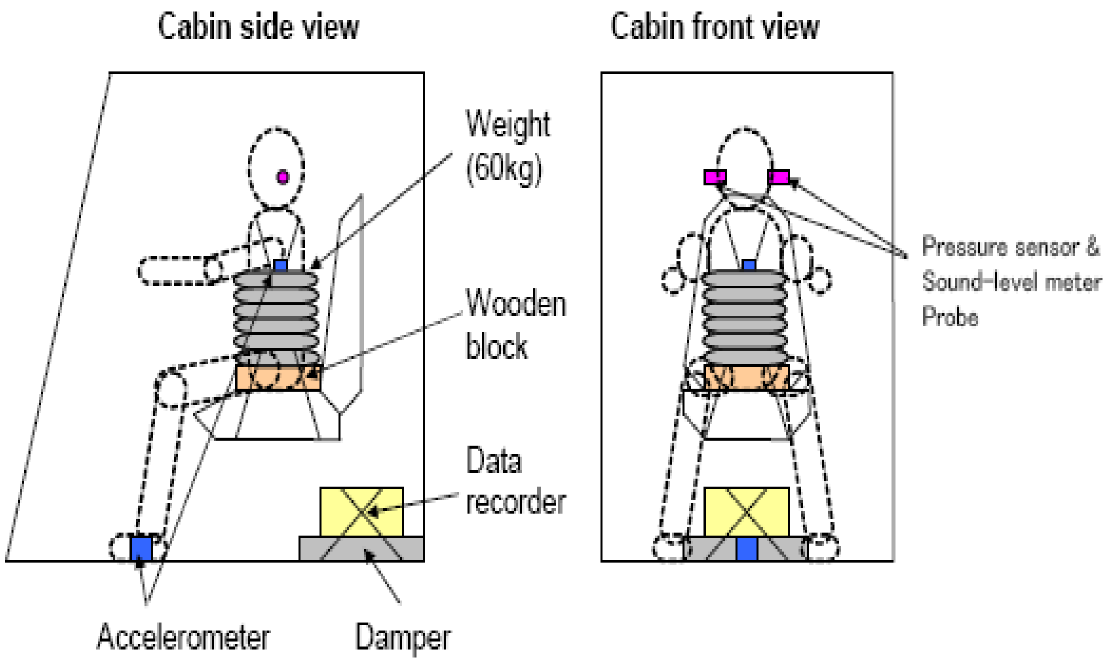

Figure 82: Measurement System Configuration

9.3. TEST EQUIPMENT

- Sound-Level Meter: NA-42 (RION)
- Pressure Sensor: PHL-A-1MP（KYOWA）, Full-Scale 200 kPa
- Accelerometer: AS-100HA (KYOWA), Full Scale 100G
- A data recorder is placed in the demining machine cabin and the measurement data with the equipment listed above are logged. The sampling rate is set no lower than 20 kHz.
- Data Recorder: EDX-2000A-32（KYOWA）

- Maximum number of data channels: 32ch, A/D Resolution: 16 bit
- Maximum Sampling Rate: 200 kHz
- Bandwidth: DC to 50 kHz（Pressure Sensor Amplifier）
- DC to 20 kHz（Accelerometer Amplifier）

9.4. EXPLOSIVES USED

The explosives listed below are used in the experiments.

- Anti-personnel Mine: C4 equivalent to TNT 100g
- Anti-tank Mine: A combination of a mine (equivalent to TNT 6kg) & C4 (equivalent to 2kg)
- CMAC (Cambodian Mice Action Center) mine specialists are responsible for all the explosive handling

Figure 83: a combination of Anti-tank and C4 to be exploded
Under the tiller system

10. ON-SITE TEST

10.1. TEST SITE

(The same place with test No.1)

- Province: Siem Reap province
- District: Sort Nikum
- Commune: Porpel
- Village: Porpel kandaal

10.2. TEST PREPARATION

The machine is place 300m from the command and control point (also house a visitors). Surrounding the machine is high pile of earth protected by sand bags. All the arrangement and preparation is made according to CMAC safety standard operating procedure.

Figure 84: Survivability test spot of the machine

10.3. TEST SCHEDULE

Table 53: Test Schedule

Date	Place	Mission
Aug. 25, 2006	-	Transportation (Leave from Tokyo)
Aug. 26, 2006	CMAC Test Site (Siem Reap Vicinity)	Unpacking and preparing for tests
Aug. 27, 2006	CMAC Test Site (Siem Reap Vicinity)	Anti-personnel Mine Tests
Aug. 28, 2006	CMAC Test Site (Siem Reap Vicinity)	Anti-tank Mine Tests
Aug. 30, 2006	CMAC Test Site (Siem Reap Vicinity)	Test site cleaning, equipment packing and staff meeting
Aug. 31, 2006	Hotel (Siem Reap)	Data validity check
Sept. 1, 2006	Hotel (Siem Reap)	Data review, Packing
Sept. 2, 2006	-	Transportation
Sept. 3, 2006	-	Transportation (Arrive in Tokyo)

10.4. MEASUREMENT WORK DETAILS

Table 54: Measurement Work Details

Date	Work Details
Aug. 26, 2006	Unpacked and checked test equipment Installed cables Preliminary test - Installed equipment - Checked sensor signals - Uninstalled equipment
Aug. 27, 2006	Installed cables Anti-personnel mine test - Installed equipment - Checked sensor signals - Collected data at an anti-personnel mine blast - Checked quickly measured data - Uninstalled equipment Prepared for a test - Installed equipment - Checked sensor signals - Uninstalled cables
Aug. 28, 2006	Installed cables Anti-tank mine test - Checked sensor signals - Collected data at an anti-personnel mine blast - Checked quickly measured data - Uninstalled equipment

11. EXPERIMENTAL RESULTS

11.1. MEASUREMENT SYSTEM INSTALLATION

The views of measurement system installed in the test machine cabins are shown in figures illustrated in next page. The pressure sensors, the sound-level meter and its probe, and data recorder are strapped down to the cabin interiors. The weight made of 6 pieces of 10kg iron disk and the wooden block are also bound to the operator seat with strings. The accelerometers are glued to the cabin floor and seat weight surfaces.

Figure 85: Equipment Installation in KOMATSU [1/4]

Figure 86: Equipment Installation in KOMATSU [2/4]

Figure 87: Equipment Installation in KOMATSU [3/4]

Figure 88: Equipment Installation in KOMATSU [4/4]

11.2. TEST RESULTS

11.2.1. SOUND PRESSURE

- Measured sound pressures in the machine cabin for anti-personnel mine

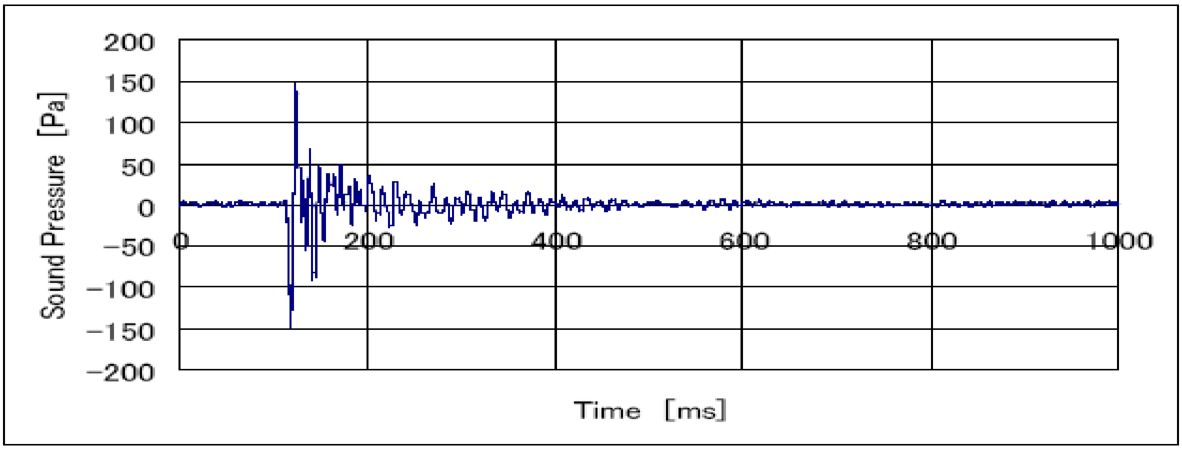

Figure 89: Sound Pressure in Machine #3 (KOMATSU) - Anti-personnel Mine [1/2]

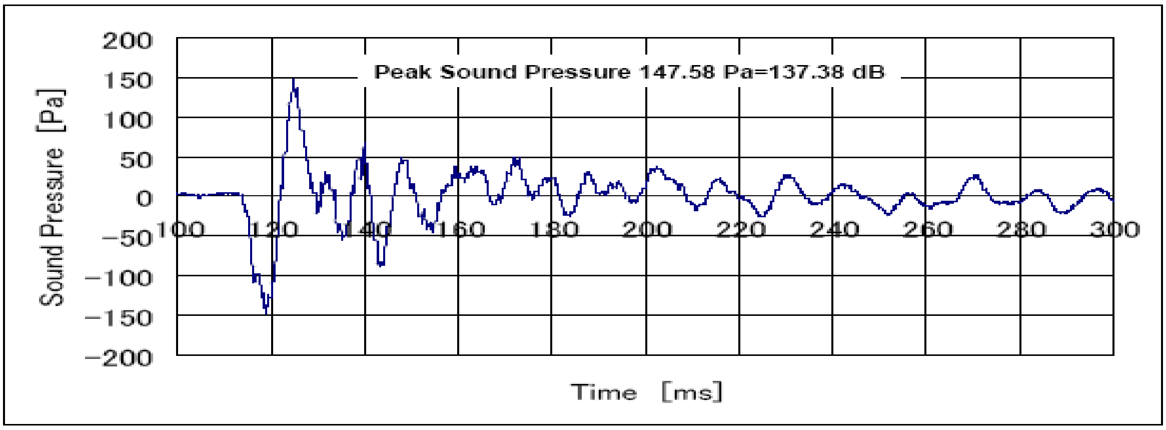

Figure 90: Sound Pressure in Machine #3 (KOMATSU) - Anti-personnel Mine [2/2]

- Measured sound pressures in the machine cabin for anti-tank mine

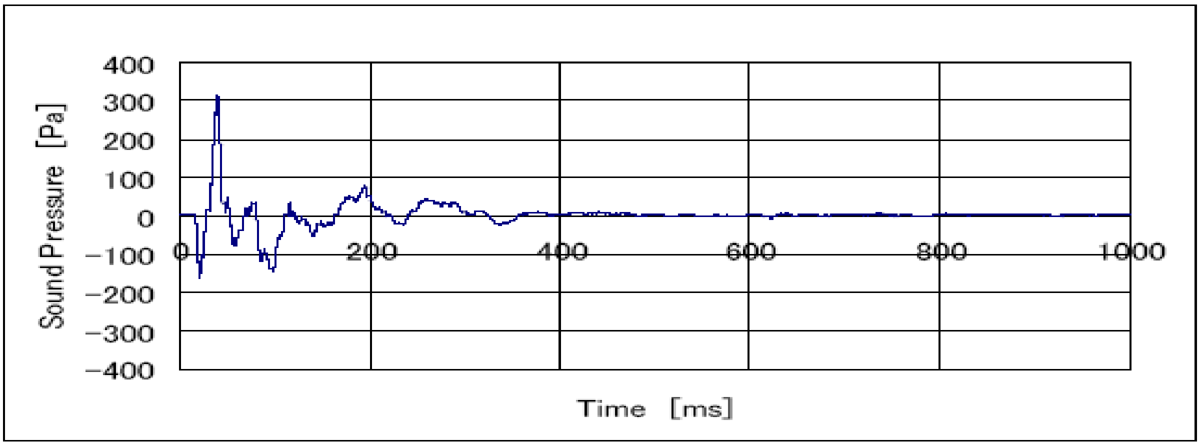

Figure 91: Sound Pressure in Machine #3 (KOMATSU) - Anti-tank Mine [1/2]

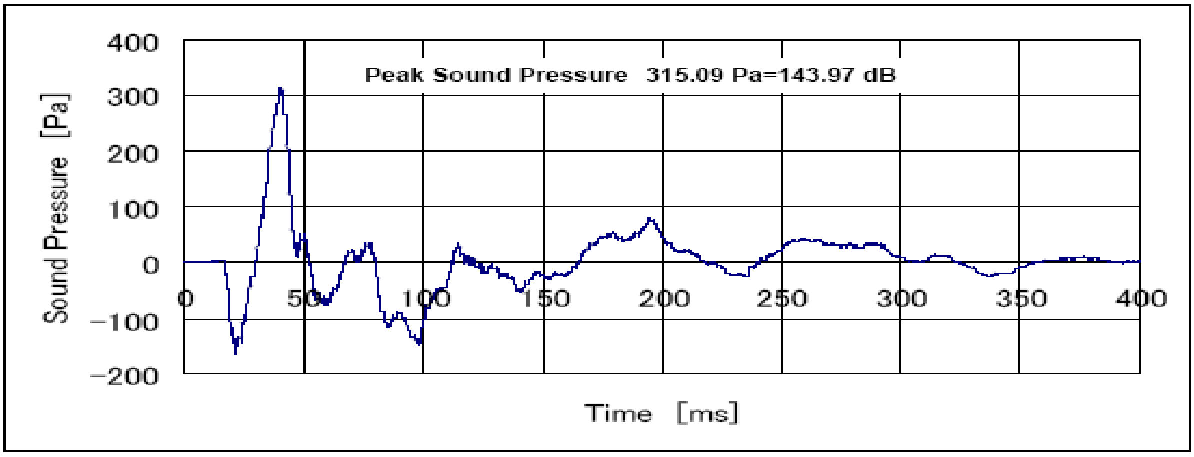

Figure 92: Sound Pressure in Machine #3 (KOMATSU) - Anti-tank Mine [2/2]

11.2.2. CABIN PRESSURE CHANGE

- Measured cabin pressure changes are shown in figure below for Anti-Personnel mine:

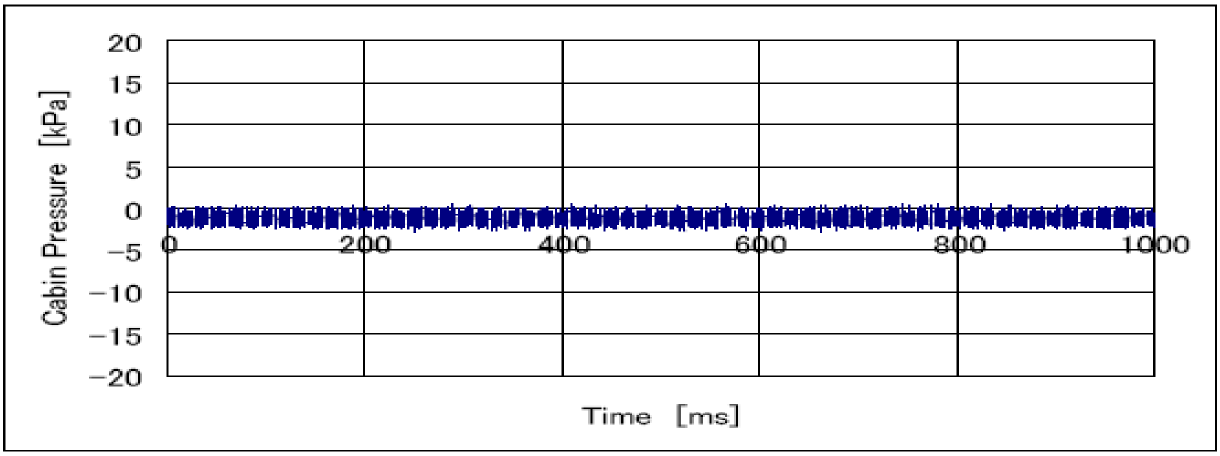

Figure 93: Cabin Pressure in Machine #3 (KOMATSU) - Anti-personnel Mine

- Measured cabin pressure changes are shown in figure below for Anti-tank mine:

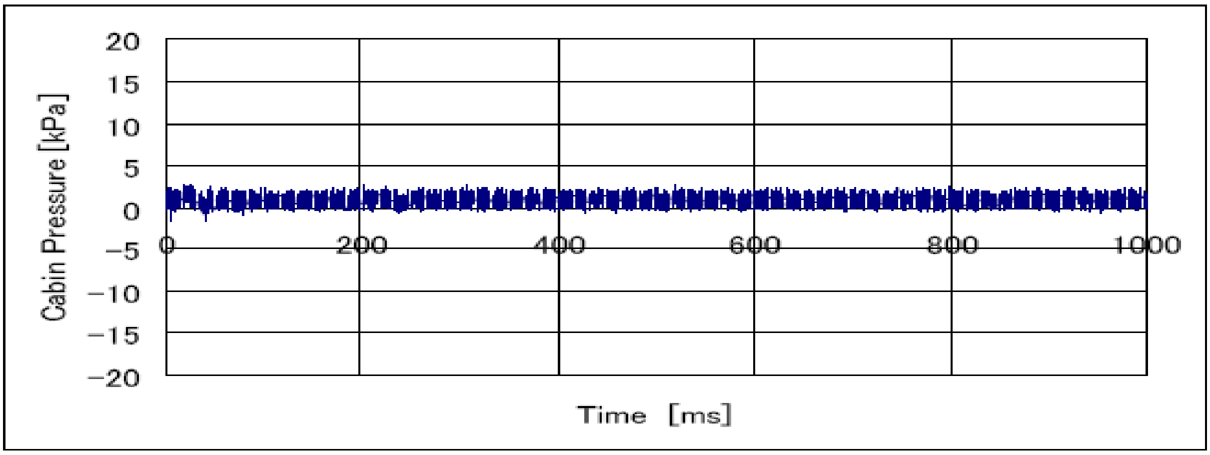

Figure 94: Cabin Pressure in Machine #3 (KOMATSU) - Anti-tank Mine

11.2.3. FLOOR ACCELERATION

- Acceleration data measured on the cabin floor for Anti-Personnel mine are shown in figures below:

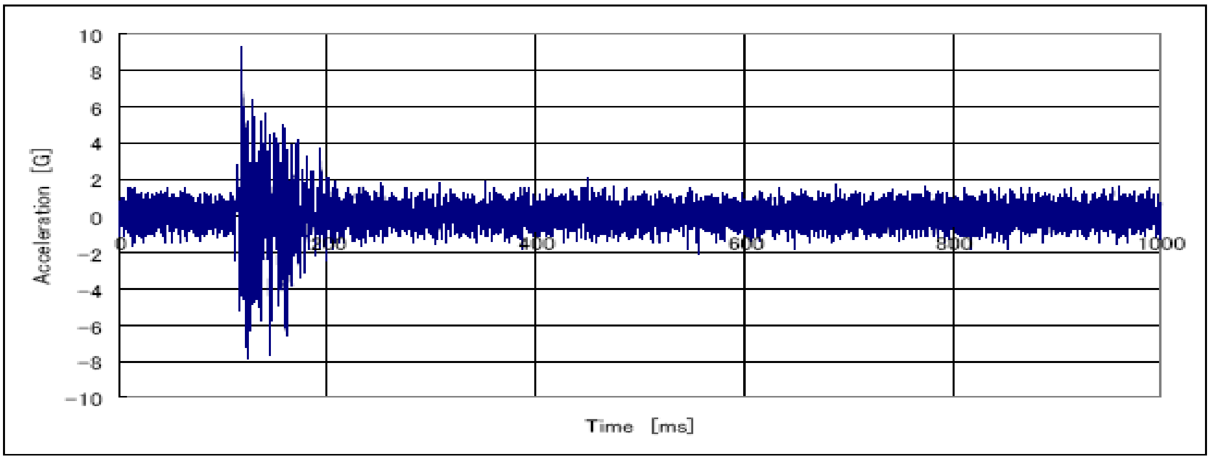

Figure 95: Floor Acceleration in Machine #3 (KOMATSU) - Anti-personnel Mine [1/2]

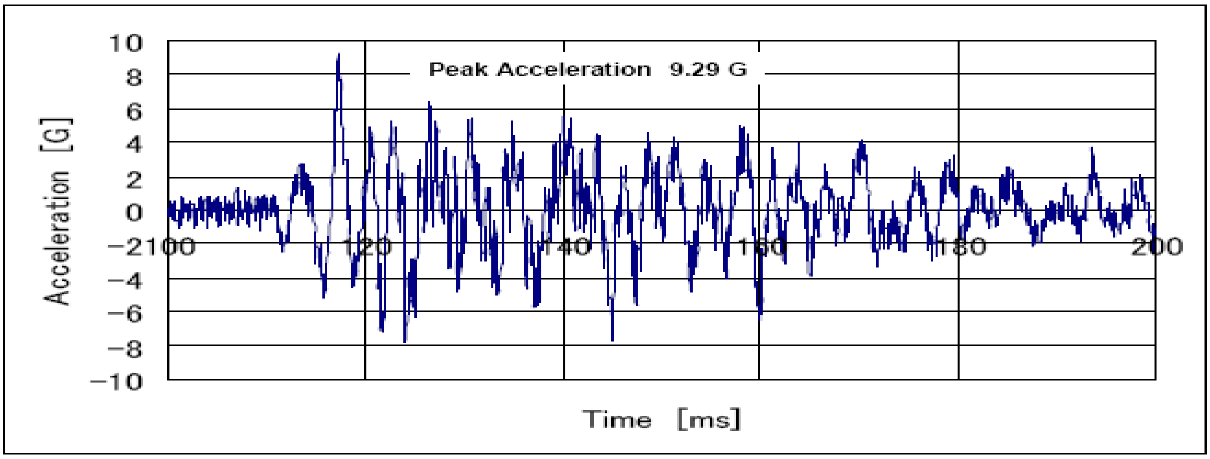

Figure 96: Floor Acceleration in Machine #3 (KOMATSU) - Anti-personnel Mine [2/2]

- Acceleration data measured on the cabin floor for Anti-tank mine are shown in figures below:

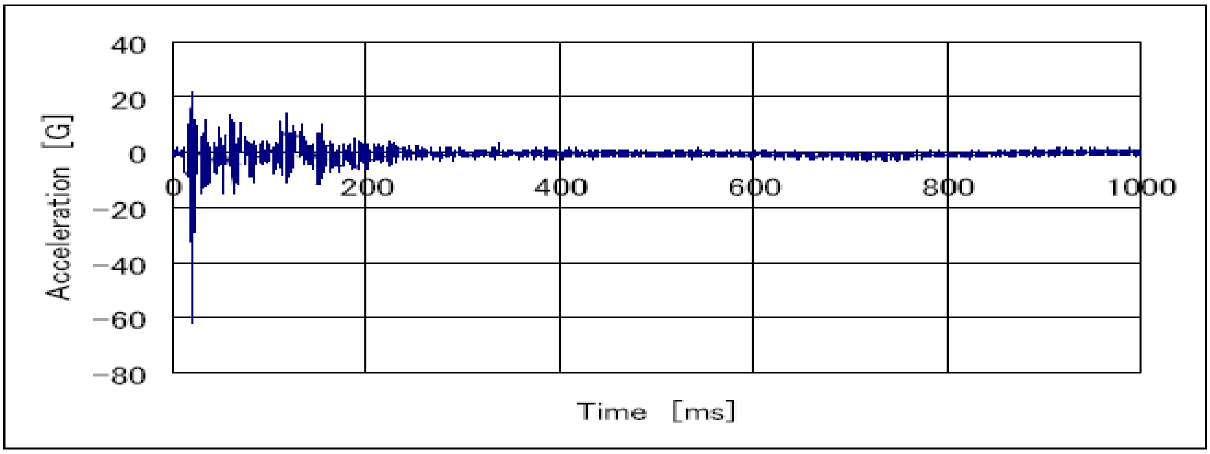

Figure 97: Floor Acceleration in Machine #3 (KOMATSU) - Anti-tank mine [1/2]

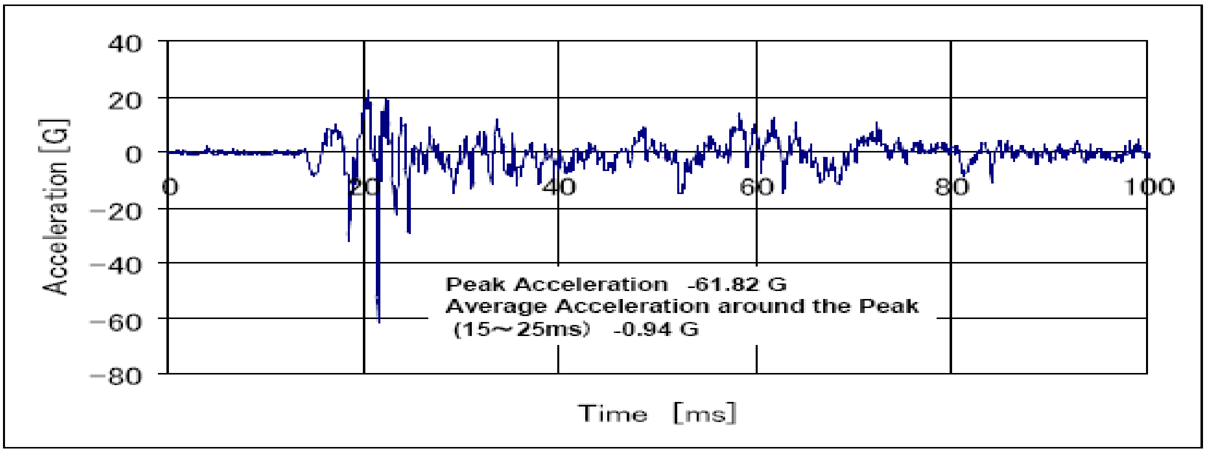

Figure 98: Floor Acceleration in Machine #3 (KOMATSU) - Anti-tank mine [2/2]

11.2.4. SEAT ACCELERATION

- Acceleration data measured on the cabin seat for Anti-Personnel mine are shown in figures below:

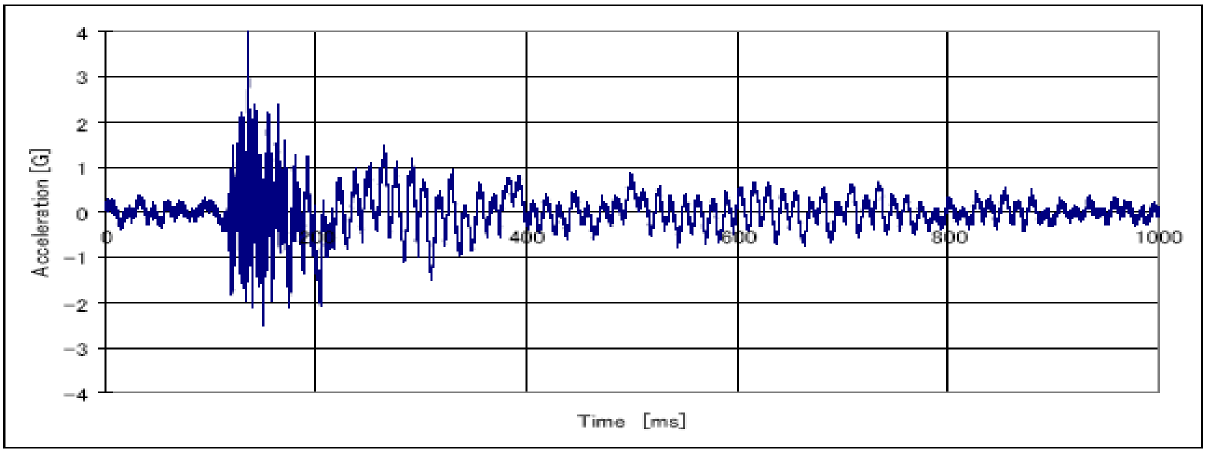

Figure 99: Seat Acceleration in Machine #3 (KOMATSU) - Anti-personnel mine [1/2]

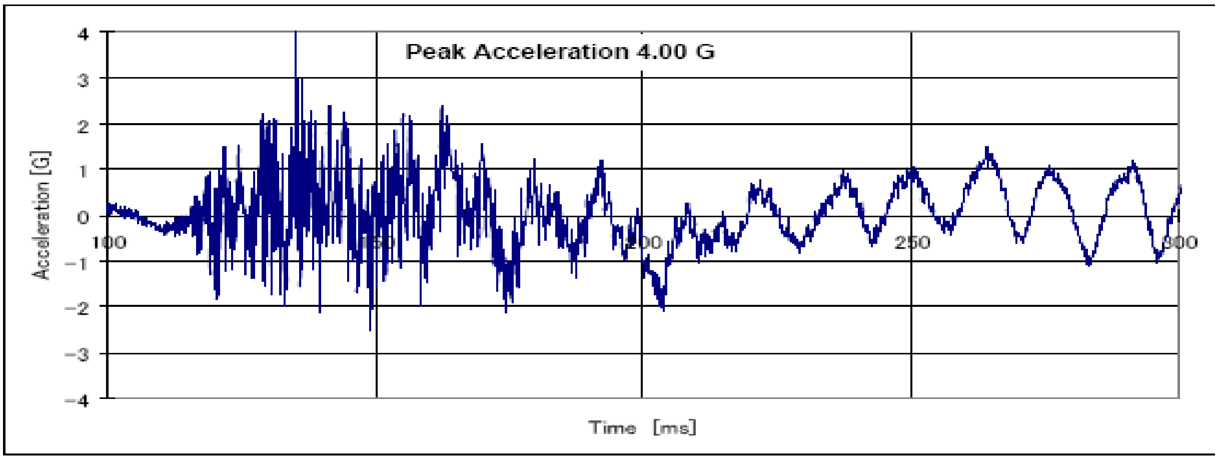

Figure 100: Seat Acceleration in Machine #3 (KOMATSU) - Anti-personnel mine [2/2]

- Acceleration data measured on the cabin seat for Anti-tank mine are shown in figures below:

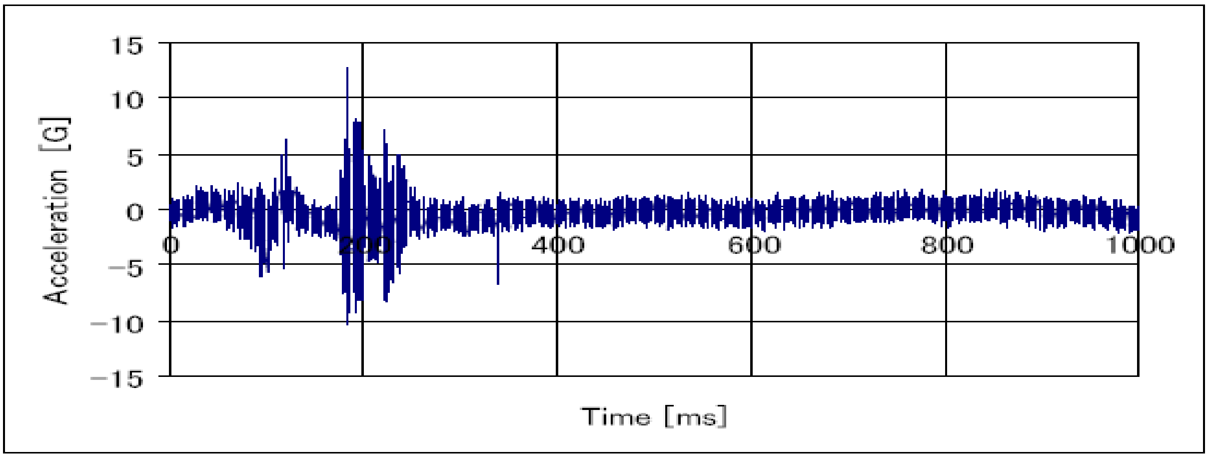

Figure 101: Seat Acceleration in Machine #3 (KOMATSU) - Anti-tank mine [1/2]

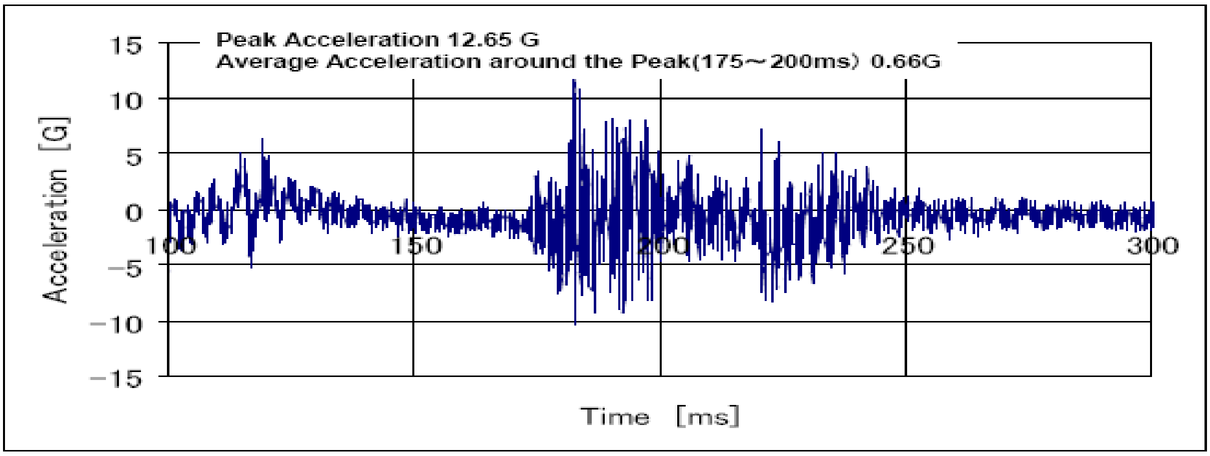

Figure 102: Seat Acceleration in Machine #3 (KOMATSU) - Anti-tank mine [2/2]

11.3. VERIFYING TEST RESULTS

11.3.1. CABIN PRESSURE CHANGE MEASUREMENT

In this measurement a pair of pressure sensors (with full-scale of 200 kPa) are used assuming poor noise shielding in machine cabins. The sensors measured very little deviation from a noise level at each anti-personnel mine blast. The sensors detected some fluctuation in the cabin pressure at anti-tank mine blast. The pressure data was insignificant and no explosion yielded a pressure change that exceeded 2kPa (=160dB). The cabin pressure change was found to be no more the 160dB, and therefore, the measurement data with the sound-level meter will be used for the analysis in the following chapters.

11.3.2. CORRUPTED DATA

There is no corrupt data in this machine. All the equipments function well despite strong explosion.

12. DATA ANALYSIS

12.1. ANALYSIS METHOD

Following the procedures, methods and safety criteria described in the FMV document1)and MIL Standard2) , we analyze the measured data in order to find if they are in the acceptable level with respect to injuries at ear, foot/ankle and spine. The data analysis methods are discussed below.

12.2. EAR INJURY

The peak value of the sound pressure in cabins and B-duration (accumulated duration of excess sound pressure) are extracted from the measurement data.

12.3. FOOT AND ANKLE INJURY

The average and maximum of the floor acceleration and maximum velocity change are examined. (See Remark below.)

12.4. SPINE INJURY

The average and maximum of the seat acceleration and maximum velocity change are examined. (See Remark below.) The differential equation (1) is to be analyzed in order to find the DRI(Dynamic Response Index). (See Appendix for the numerical analysis.)

$$\frac{d^2b}{dt^2} + 2\zeta\omega_n \frac{d\delta}{dt} + (\omega_n)^2 \delta = a_c(t) \qquad (1)$$

Where:

δ : Displacement (of a human body modeled as a second order system)
ζ : Damping coefficient (of the second order system)
ω_n : Natural angular frequency (of the second order system)
a_c : Applied (=measured) acceleration (to the second order system)

DRI is defined as:

$$DRI = (\omega_n)^2 \delta_{\max} / G \qquad (2)$$

Where:

$\delta_{\max}$: Maximum displacement
$G = 9.8m/s^2$: Acceleration of Gravity

In DRI calculation, use the values below for the human body model.

$\zeta = 0.224$
$\omega_n = 52.9 rad/s (= 8.4 Hz)$

The maximum value of DRI that yields no injury to spines is 16. The equation (2) is rewritten as the equation (3) to find the maximum value of acceptable displacement

$$\delta_{maz} \leq \frac{DRI \times G}{(\omega_n)^2} = \frac{16 \times 9.8m/s^2}{(52.9rad/s)^2} = 56mm \quad (3)$$

Thus, we found the maximum value of the acceptable displacement on the operator seat is 56mm.

REMARK

The FMV Reports refers to A.E. Hirsch's paper of the dynamic modeling of human body (published in 1967), and details very little about shock motion. We are unable to access the Hirsh paper and have to leave the terminology "max velocity change" unclear. Here we assume the shock motion last fairly short period of time and use 10 ms as its typical duration of the shock. Then, "max velocity change of 3m/s" in 10ms is identical to an average acceleration of 3m/s/10 ms = 300m/s/s =30.61G. In this report we examine velocity-time charts and look for an abrupt velocity change, i.e., large average acceleration.

12.5. DATA ANALYSIS ON KOMATSU

12.5.1. EAR INJURY

- **ANTI-PERSONNEL MINE**

The peak sound pressure for Anti-personnel mine shown in section 11.2.1 is below 200 Pa (=140dB). Thus, no protection is required for this sound level.

- **ANTI-TANK MINE**

The peak sound pressure for Anti-tank mine as shown in section 11.2.1 exceeded 200 Pa. The B-duration of this pressure-time history is shown below:

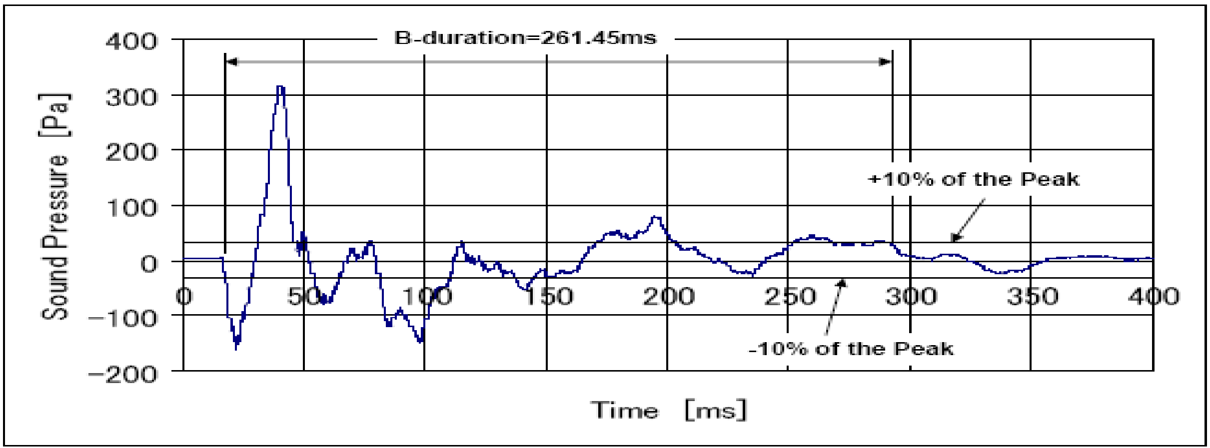

Figure 103: B-duration of Sound Pressure in Machine #3 (KOMATSU) - Anti-tank Mine

12.5.2. FOOT AND ANKLE INJURY

- **ANTI-PERSONNEL MINE**

Integration of the floor acceleration for Anti-Personnel mine in section 11.2.3 is shown below:

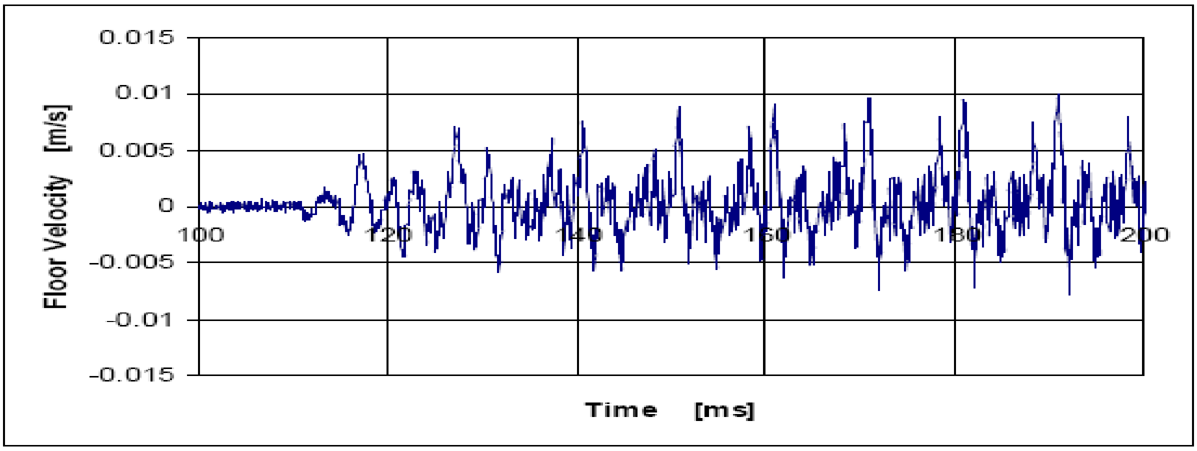

Figure 104: Floor Velocity-Time Chart for Machine #3 (KOMATSU) - Anti-personnel Mine

- **ANTI-TANK MINE**

Integration of the floor acceleration for Anti-tank mine in section 11.2.3 is shown below:

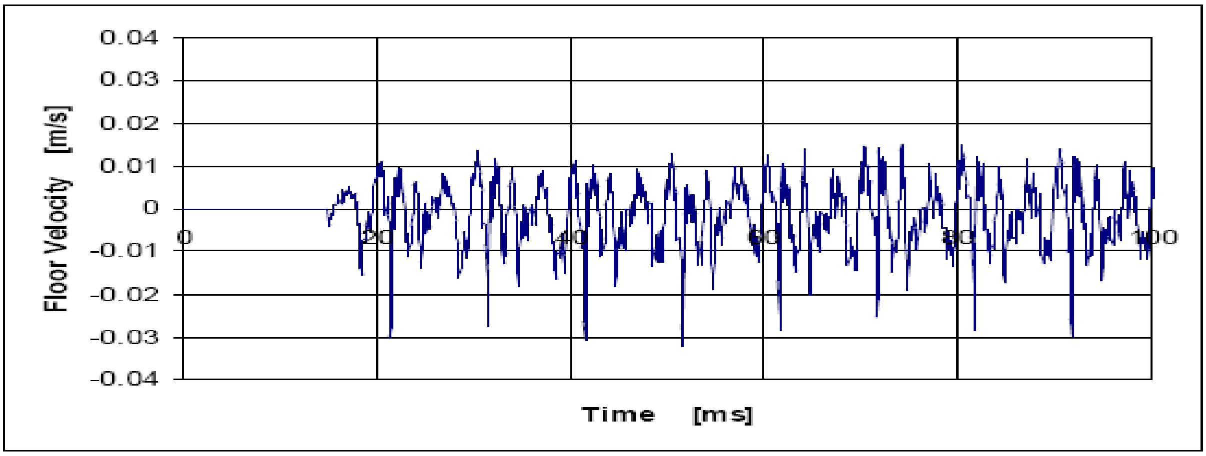

Figure 105: Floor Velocity-Time Chart for Machine #3 (KOMATSU) - Anti-tank Mine

12.5.3. SPINE INJURY

- **ANTI-PERSONNEL MINE**

  o Velocity-time chart

Integration of the seat acceleration by Anti – Personnel mine in section 11.2.4 is shown below:

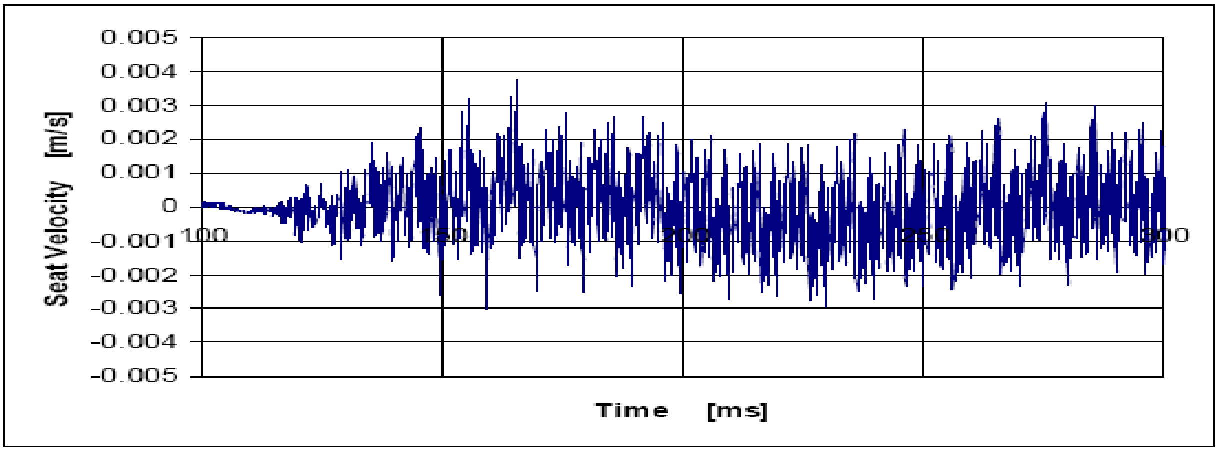

Figure 106: Seat Velocity-Time Chart for Machine #3 (KOMATSU) - Anti-personnel Mine

  o Dynamic human body model

An analysis result of the human body displacement derived from the differential equation (1) is shown below:

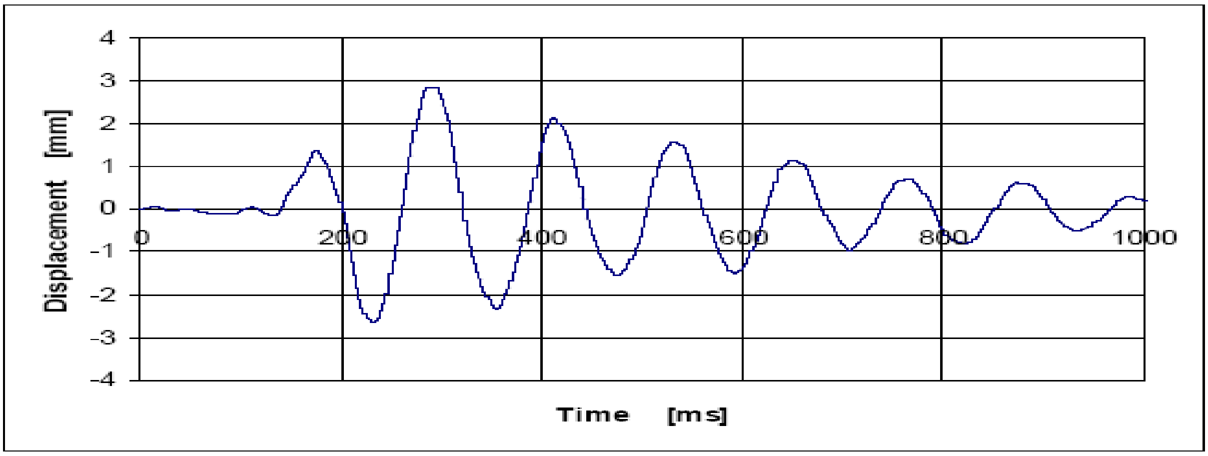

Figure 107: Simulated Human Body Displacement in Machine #3 (KOMATSU) - Anti-personnel Mine

- **ANTI-TANK MINE**
  - Velocity-time chart

Integration of the seat acceleration in by Anti-Tank mine in section 11.2.4 is shown in below:

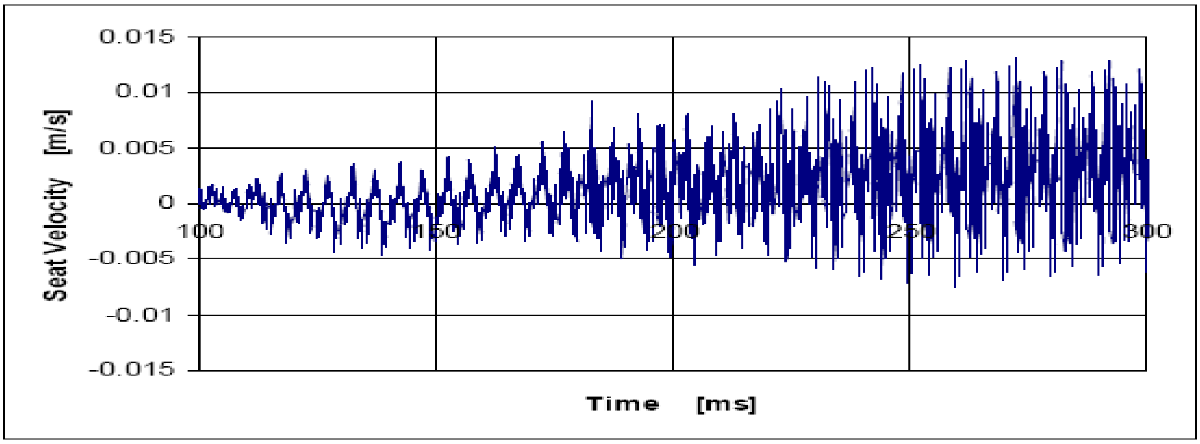

Figure 108: Seat Velocity-Time Chart for Machine #3 (KOMATSU) - Anti-tank Mine

  - Dynamic human body model

An analysis result of the human body displacement derived from the differential equation (1) is shown below:

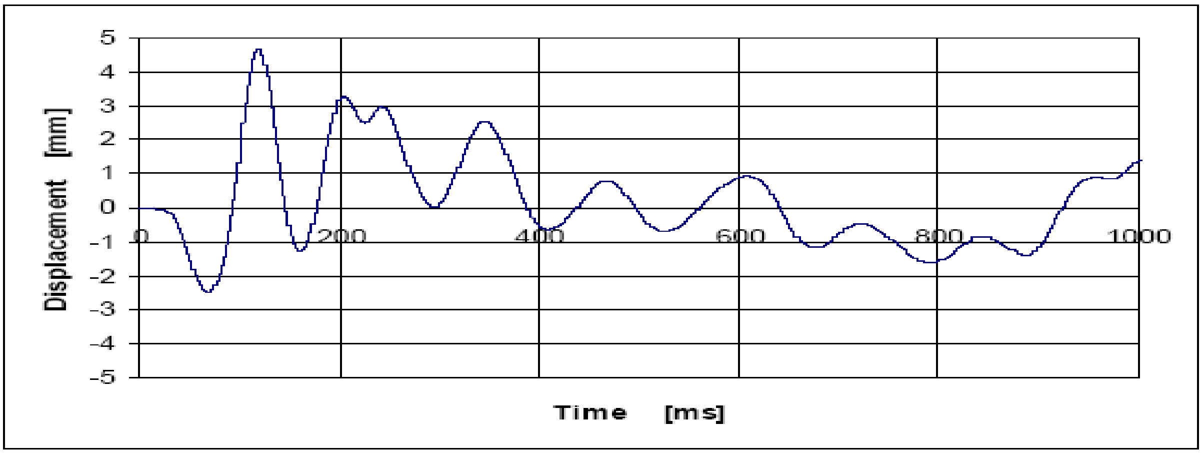

Figure 109: Simulated Human Body Displacement in Machine #3 (KOMATSU) - Anti-tank Mine