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# MEASUREMENT OF THE HUMAN BODY DAMAGE CAUSED BY COLLAPSED BUILDING

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## SUMMARY

The objective of this study is to measure and evaluate of the human body damage caused by the collapsed building or the inversion furniture due to the earthquake. We had investigated records of the casualties in the 1995 Hanshin-Awaji Earthquake, and made clear the typical death pattern and serious injury pattern. Based on these findings, we have developed the trial dummy for human body damage measurement and the virtual dummy for human body damage evaluation as the simulation using finite element method. We carried out CT scanner experiments on a human body with the simulation for validation.

## INTRODUCTION

The immediate victims of the 1995 Hanshin-Awaji Earthquake included 5,502 dead and 41,527 wounded. The death rate among victims in collapsed buildings was purported to be as high as 90%. However, we have no way to examination how the victim got dead or wounded, except for autopsy and an interview with the bereaved. We need knowledge in detail about what part of building or furniture caused casualty and how it was occurred.

We generated the database of casualties and obtained data from it to support the development of a prototype dummy which is based on a crush test dummy of automobile to measure human body damage due to collapsed buildings or toppled furniture. This dummy will be used in large-scale fracture tests of buildings.

In addition, we developed the virtual dummy for human body damage evaluation as the simulation using finite element method. Why we did it, we can conduct the large scale fracture test using real dummy rarely and the simulation is indispensable to estimate the impact on human body.

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## THE DATABASE OF CASUALTIES DUE TO THE EARTHQUAKE

**Records of the casualties in the 1995 Hanshin-Awaji Earthquake**

The number of immediate victims (not included the relation death) is 5,502 dead and 41,527 wounded. Medical examiner of Hyogo Prefecture examined the bodies of those deceased in the earthquake. The task force for examination of an early emergency treatment gathered medical records of hospitalized patients for the purpose of investigation of crush syndrome.

But, these records consist of only human contents. Therefore, we integrated records of building damage to the medical records and built two (death serious injury) "Comprehensive Casualties Database". Items of these are "age, sex distinction, contents of hazard, struck part of body, object that caused casualty, building damage, building structure, etc". [1] [2] [3]

Table1. Total number of the comprehensive databases

| | Total Number |
|---|---|
| The dead | 4,956 |
| The serious injured | 1,349 |

*Deaths*

Using our database of deaths and structural damage caused by the Great Hanshin-Awaji Earthquake, the following investigations were conducted. Valid data were obtained from 4,956 cases. Figure 1 shows that the most common direct cause of death was compression (suffocation) (n=3,156, 64%), followed by trauma (bone fracture) (n=862, 17%), and burns (n=451, 9%). More specifically, the actual cause of death was compression in 1,339 people, nasal obstruction in 60 people, nasal compression in 21 people, and airway obstruction in 11 patients. Hence, of 1,665 people in whom cause of death is known, 1,431 people (86%) died of suffocation due to compression or obstruction.

Furthermore, the object that directly caused death was clear for 3,071 people: building materials for 3,038 people and furniture for 33 people. In other words, most deaths are attributable to structural damage, while toppled furniture only accounted for 1% of all deaths.

The comprehensive database used in the present study includes data about the severity of structural damage and the type of structures that sustained damage. Figure 3 shows the relationship of human casualties with structural damage and type. Of the 4,956 people, 4,369 were in buildings that were not reinforced (mainly wooden buildings), and only 506 people were in buildings that were made of reinforced bricks or steel. These results suggest that most people died in wooden buildings. Furthermore, as shown in Figure 3, except for injuries caused by burning wooden buildings, the overwhelming majority of the people died in completely collapsed or severely damaged buildings.

In order to computer-simulate human casualties in earthquakes, as discussed later, it is necessary to clarify the common sites of lethal injury. Therefore, we utilized the above-mentioned database to analyze the relationship between the site of injury and the length of time until death (Table 1). The results showed that injuries to the chest were the cause of death in 693 people, while injuries to the chest/abdomen were the cause of death in 421 people. These two areas accounted for 67% of the total. In addition, 94% (1,048 people) of people died due to compression, and we believe that most of these people were suffocated to death.

The common mode of death resulting from the Great Hanshin-Awaji Earthquake was as follows: The earthquake caused wooden buildings to collapse, thus trapping people and their chests were compressed

by building materials, which resulted in suffocation within a short period of time (less than 15 minutes). In the present study, "total collapse" refers to the destruction of the first and/or second floor of buildings, eliminating all living space.

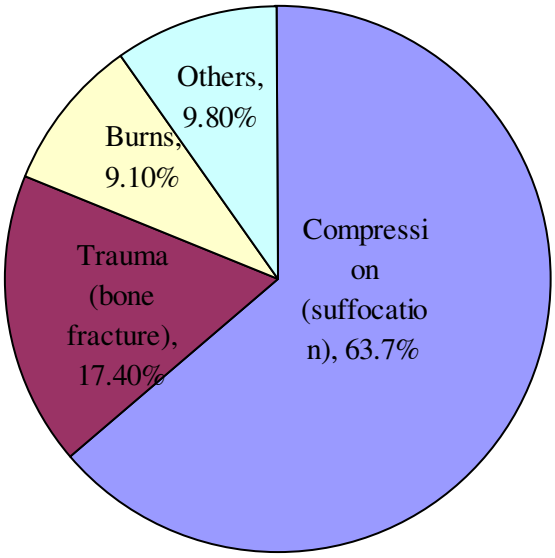


Figure1. Distribution of direct causes of death

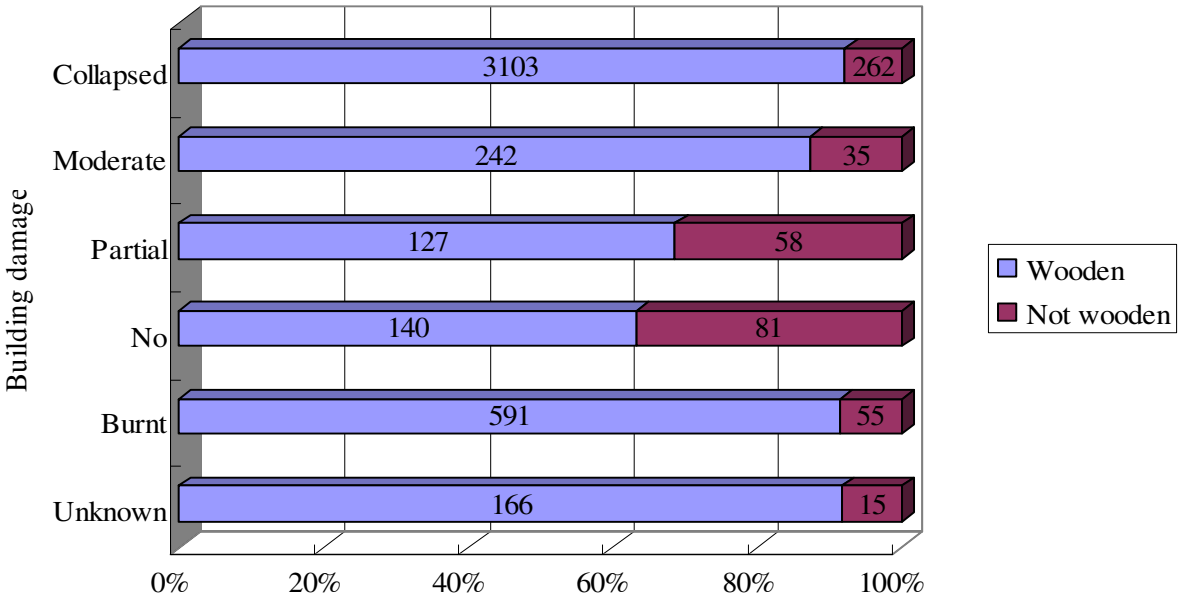


Figure2. Relationship between structural damage and type among deceased cases (N=4,875)

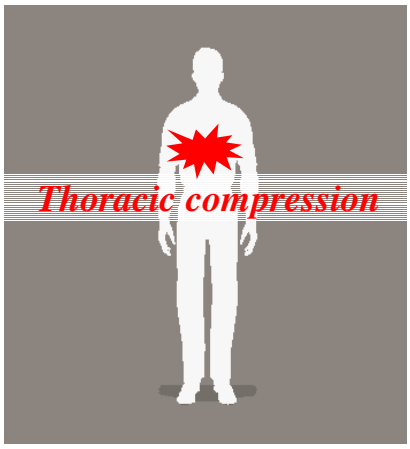

Figure3. Principal struck part (Deaths)

*Severe injuries*

The above-mentioned database includes the results of a study on people with severe injuries. This study investigated the relationship between severe injury and structural damage, and the results are summarized in the present study in order to compare death and severe injury.

A total of 1,349 cases were studied. Building materials caused severe injuries in 428 people. Similarly, furniture caused severe injuries in 443 people. The most common form of injury was fracture (n=750, 56%), followed by contusion (n=368, 27%). These two forms of injury accounted for 83% of the total. With regard to the relationship between injury type and injury-causing object, bone fracture was caused by building materials in 230 people, bone fracture was caused by toppled furniture in 264 people, contusion was caused by building materials in 137 people, and contusion was caused by furniture in 127 people.

Figure 4 shows the relationship between the severity of structural damage and the type of structure among the people with severe injuries. While most of these people were injured when wooden buildings collapsed completely, some were injured in buildings that sustained relatively mild damage (partial collapse or less). In structurally strong buildings, people were injured even when the building sustained minor damage, and the greatest number of people (n=121) were injured in buildings that sustained no structural damage. In contrast to what was observed for lethal injuries, building materials and furniture caused similar numbers of severe injuries. Hence, severe injuries can occur due to toppling furniture in buildings with mild structural damage.

In order to simulate human casualties in earthquakes as discussed later, it is necessary to clarify the major sites of injury among people with severe injury. The major sites of human injury were the abdomen/lumbar, legs and chest. Therefore, earthquakes most often cause severe injuries when building materials (especially wooden buildings) or furniture cause fractures or contusions to the abdomen/lumbar, legs or chest.

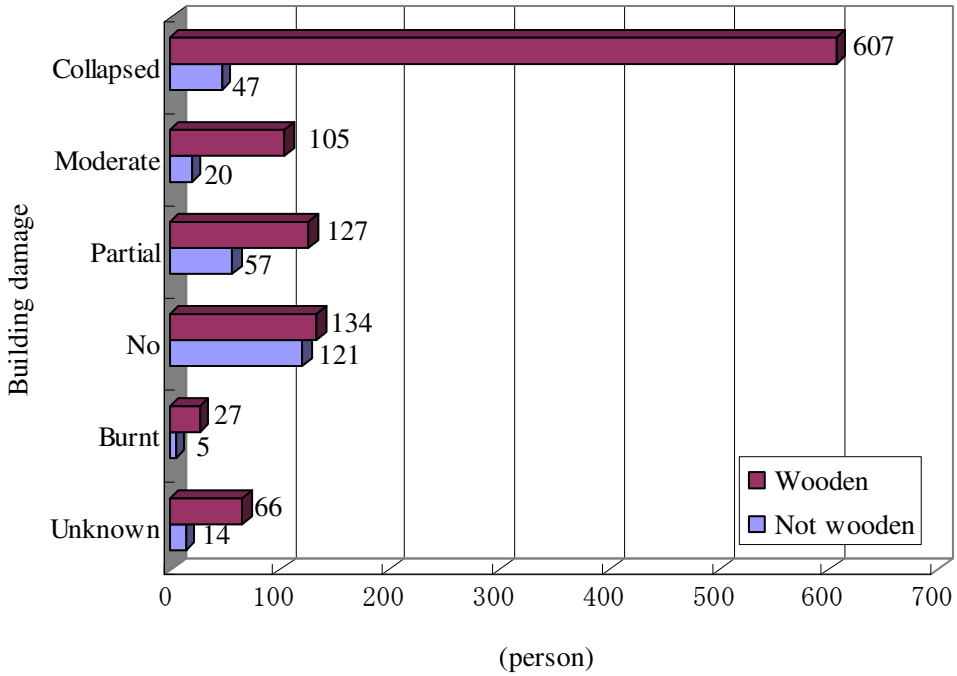


Figure4. Relationship between structural damage and type among people with severe injuries (N=1,330)

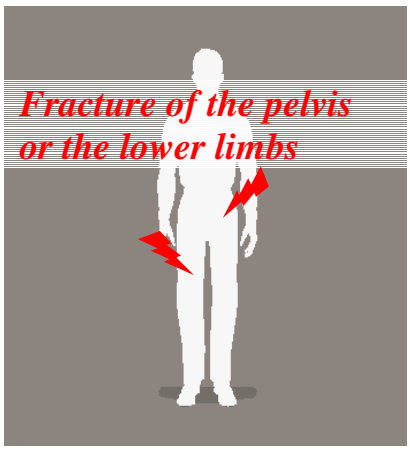


Figure5. Principal struck part (Severe injury)

## REAL AND VIRTUAL DUMMY DEVELOPMENT

**Real dummy based on a crush test dummy of automobile**

Based on the findings from "Comprehensive Database", we developed the trial dummy which was set sensors on the dummy of automobile crush test as necessity.

This dummy was put in a wooden house when the fracture test was done, but we couldn't measure damage correctly. This real dummy is now trial stage and need to improvement. (Figure6)

Figure6. Trial dummy

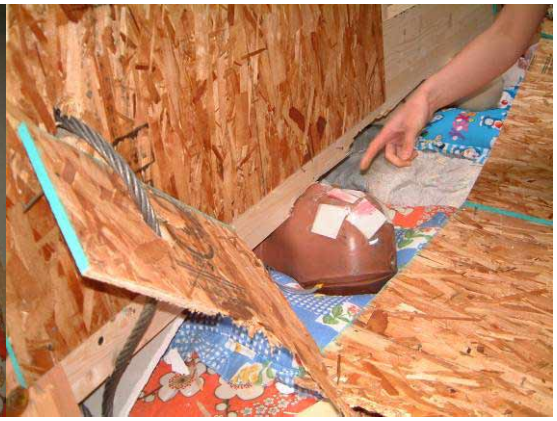

Figure7. Fracture test of wooden house

**Analysis of a human thoracic compression model by a CT scanner**

When analyzing damage to the human body caused by structural destruction, death due to suffocation caused by thoracic compression is an important issue. The objective of this study is to analyze deformation of the thorax and intrathoracic organs using a CT scanner in an attempt to establish the necessary conditions for death due to suffocation caused by thoracic compression for use in computer simulation.

*Methods*

The thoracic region of a healthy adult (26-year-old man) was compressed using a cylinder weighing 0, 10, 20 or 30 kg, and the entire thoracic region in the state of maximum inspiratory and expiratory phases was analyzed by a CT scanner (Toshiba Asteion-multi, Figure8). CT was performed under the following conditions: slice width 3 mm, tube voltage 120 KV, and tube current 120 mAs. Based on CT data, horizontal images were made in a 1.5 mm interval along the body axis, and three-dimensional images were reconstructed using an image processing workstation (Tera Recon Inc., Aquarius Workstation). Lung volume and thoracic cage diameter were measured. Lung volume was calculated by extracting the lungs from the reconstructed thorax by volume rendering. Thoracic cage diameter was measured by ascertaining the anteroposterior, transverse and longitudinal diameters on the thorax based on transverse, sagittal and coronal images.

Figure8. CT scanner experiment

*Results*

In order to maintain respiration, a certain level of tidal volume (lung capacity during inspiratory phase - lung capacity during expiratory phase) is needed. A comparison of reconstructed CT images during inspiratory and expiratory phases showed that changes in the lung volume were mostly attributable to the longitudinal movement of the diaphragm and anteroposterior changes in the thoracic cage diameter attributable to elevation of the ribs (Figures 9 and 10). Therefore, changes in each parameter caused by different levels of thoracic compression were assessed.

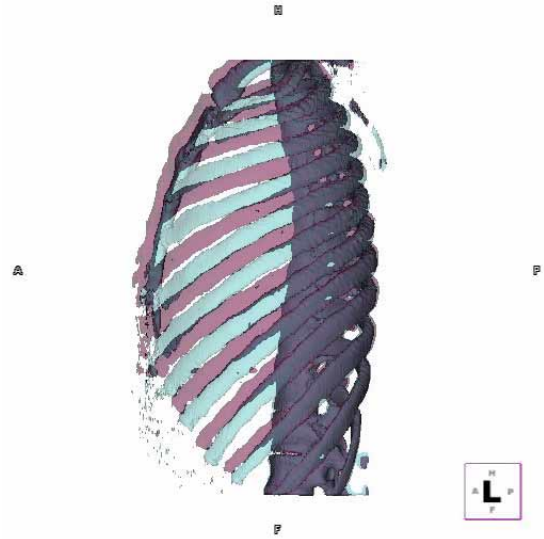


Figure9. Anteroposterior changes in the thoracic cage diameter

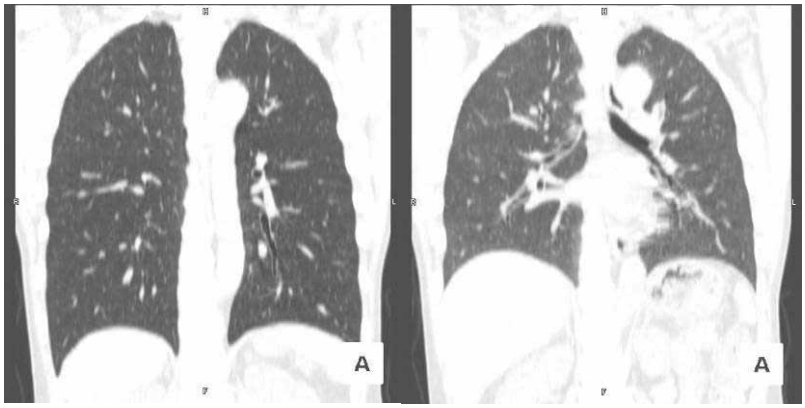


Figure10. Longitudinal movement of the diaphragm

(1) Changes in lung volume (Figure 11.1)

Both inspiratory and expiratory volumes decreased as the cylinder weight was increased from 0, 10 and 20 kg, but the vital capacity (the difference between inspiratory and expiratory volumes) was maintained at a comparable level. However, with 30 kg of compression, the inspiratory volume was further decreased, thus causing the vital capacity to decrease.

(2) Changes in the anteroposterior diameter of the thorax (Figure 11.2)

At the level of the tracheal bifurcation, the distance between the sternum and spine was measured. During inspiration and expiration, the greater the compression, the smaller the distance. Also, the greater the compression, the smaller the degree of change in the anteroposterior diameter of the thorax between inspiration and expiration. These findings suggest that the anteroposterior diameter of the thorax decreases in a weight-dependent manner, thus lowering the vital capacity

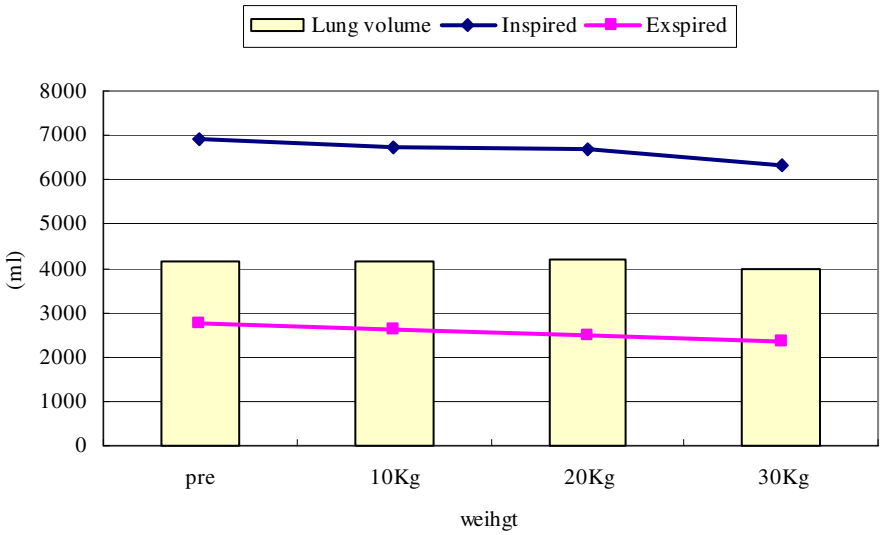


Figure11.1. Changes in lung volume

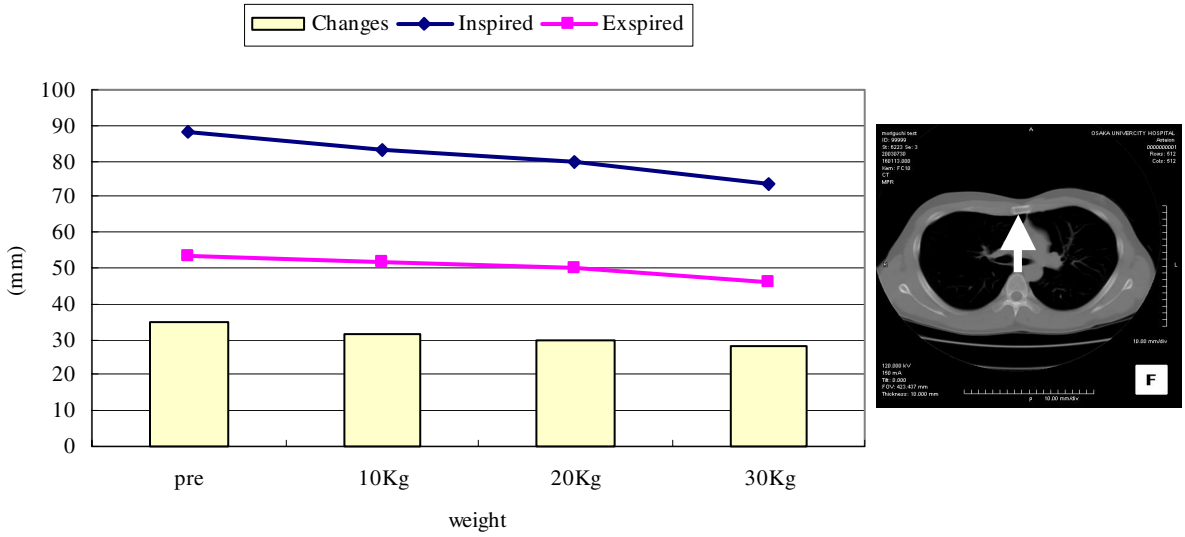


Figure11.2. Changes in the anteroposterior diameter of the thora

(3) Changes in the distance from the pulmonary apex to diaphragm (Figure 12.1)
The distance between the pulmonary apex and diaphragm was measured. During inspiration and expiration, this distance decreased gradually with increasing compression. Also, the degree of diaphragm movement associated with respiration decreased in a weight-dependent manner. Hence, restricted movements of the diaphragm due to thoracic compression also contributed to decreased vital capacity.

(4) Changes in the transverse diameter of the thorax (Figure 12.2)
At the level of the tracheal bifurcation, the transverse diameter of the thorax was measured. Thoracic compression did not affect the transverse diameter of the thorax.

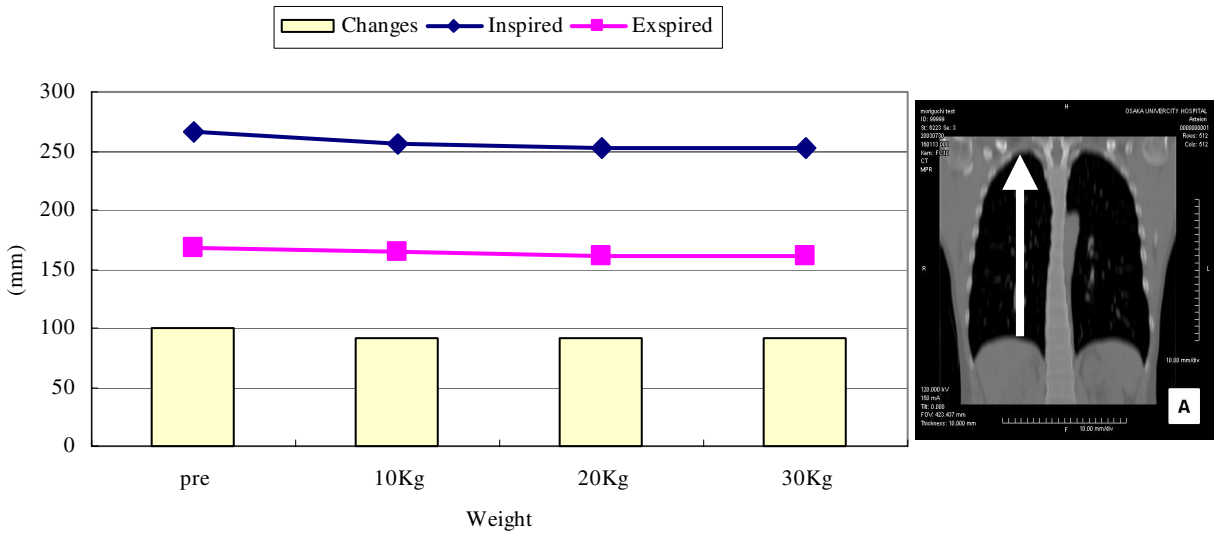


Figure12.1. Changes in the distancefrom the pulmonary apex to diaphragm

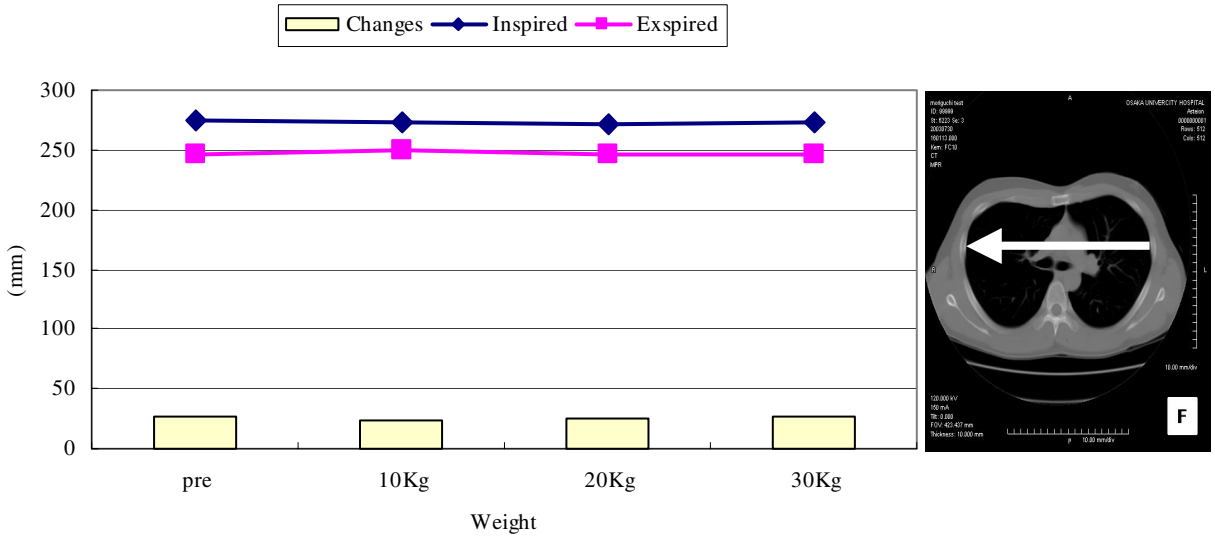


Figure12.2. Changes in the transverse diameter of the thorax

*Future issues*

Firstly, the upper limit of thoracic compression in the present experiment system was about 30 kg. Although 30 kg compression decreased the vital capacity, this capacity was still maintained. In other words, this level of compression was not sufficient to simulate death due to suffocation. In the future, we are planning to investigate a means to increase compression and to ascertain the necessary conditions for death due to suffocation by studying more cases.

Secondly, 30 kg of compression did not bring about marked changes in the vena cava. If we were to find that higher levels of thoracic compression affect the vena cava, we will then consider the effects of thoracic compression on the vena cava when ascertaining the necessary conditions for death due to suffocation.

**Virtual dummy using finite element method**

*Software*

In the present study, we used LS-DYNA, which is general-purpose software. LS-DYNA is a general-purpose program used for analyzing nonlinear problems utilizing explicit time integration based on the central difference method and spatial discretization based on the finite element method. LS-DYNA is applicable to a wide variety of fields, from dynamic analyses of shock and impact problems to quasi-static analyses of plastic forming.

*Model*

We got a geometric shape data (Human thorax) from Digimation, Inc. Then, we convert the data for FME simulation and separate to half for reducing simulation period. Model meshing and element preparation were carried out. We input physical properties and various conditions. (Figure13)

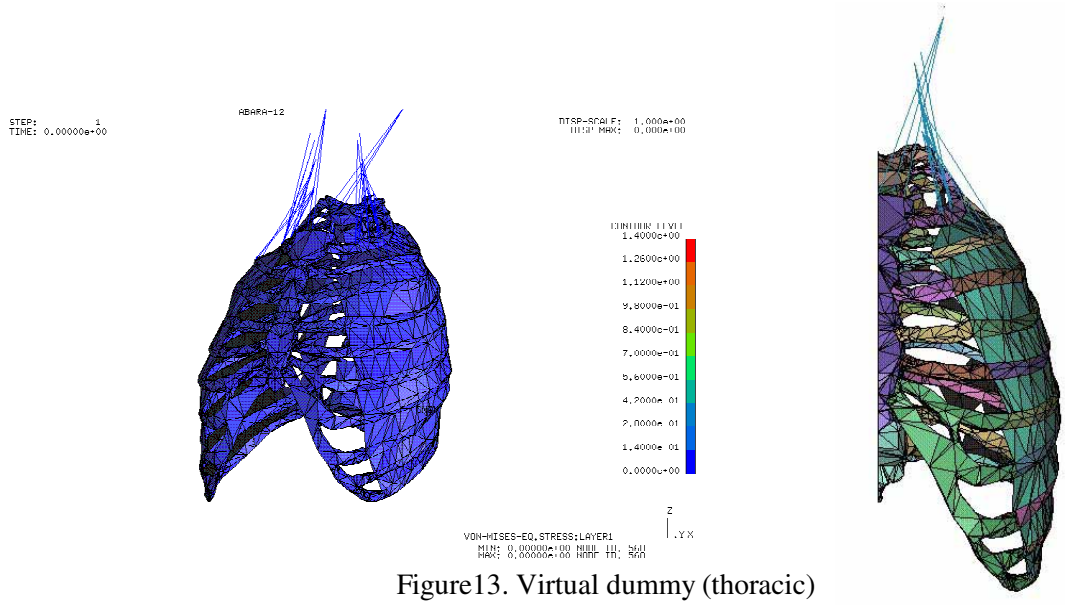


Figure13. Virtual dummy (thoracic)

*Simulation*

This simulation was conducted on same condition of CT scanner experiments. Model is laying and put a weight on a thoracic. Figure 14 shows the animation of this simulation at 30kg load.

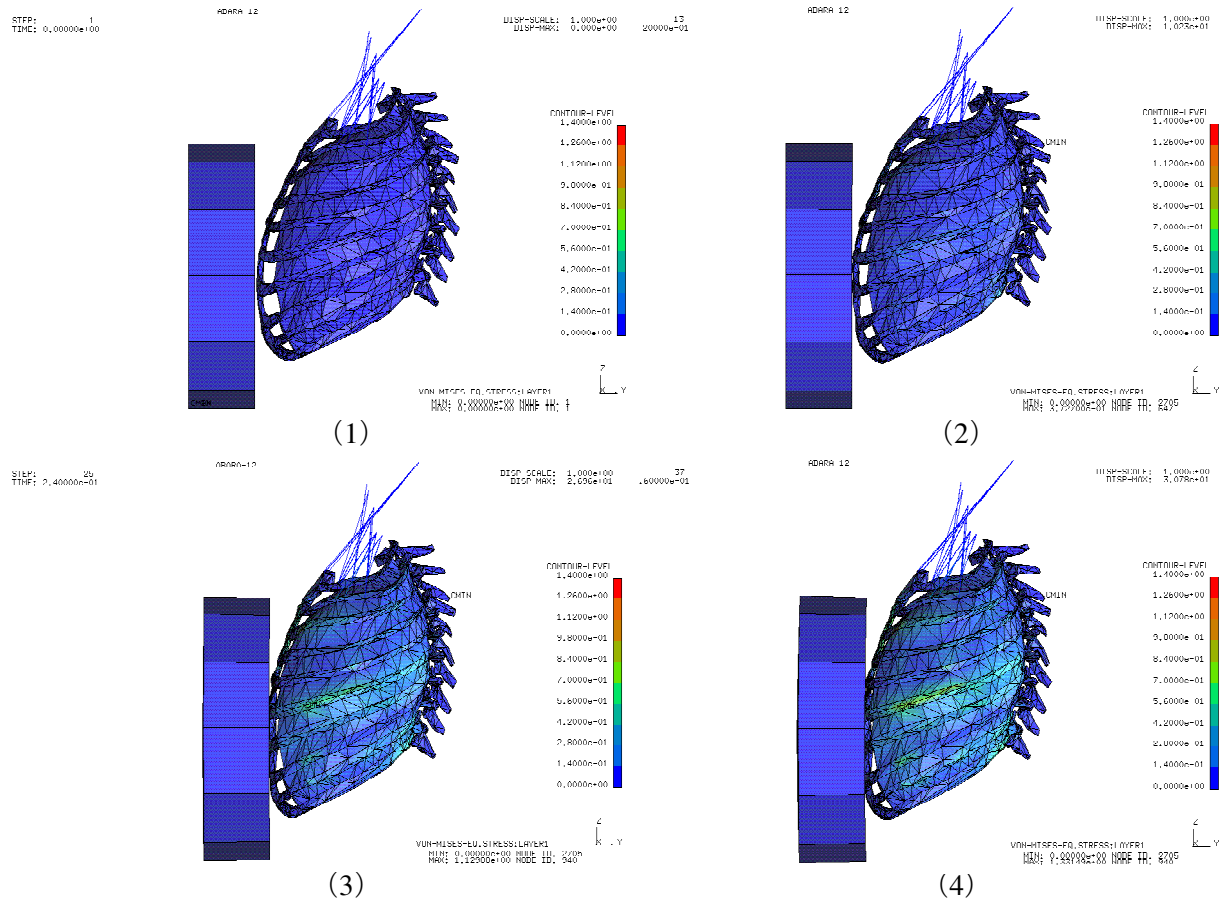


Figure14. Animation of the simulation (30kg)

## DISCUSSION

Behaviors of thoracic of this FEM simulation and result from CT scanner experiments are very similar. Compressed on thoracic, the whole ribs moved down with rotation. (Figure15)

The displacement of sternum is similar at inspired phase and expiratory phase as each load; 0kg, 10kg, 20kg, 30kg. (Figure16)

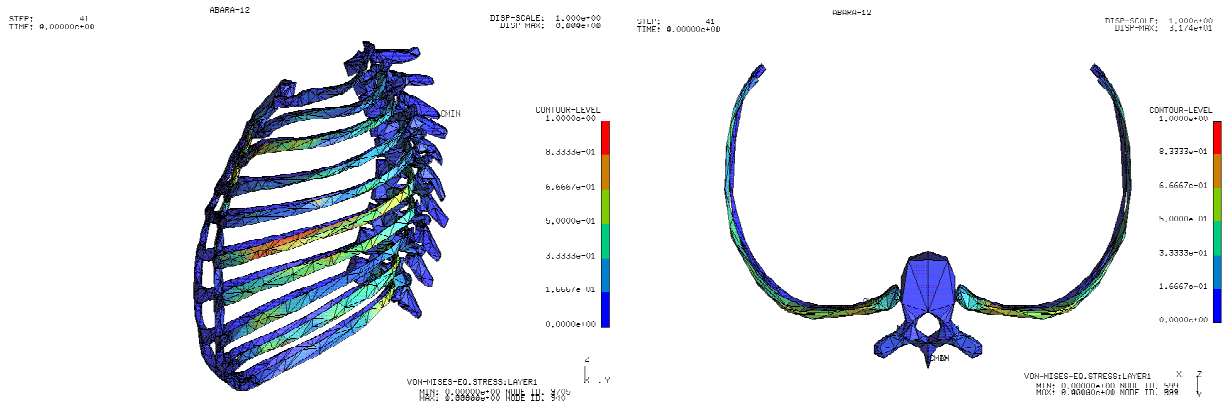

Figure15. Behavior of thoracic at compressed and not (Left; left side, Right; 6th rib)

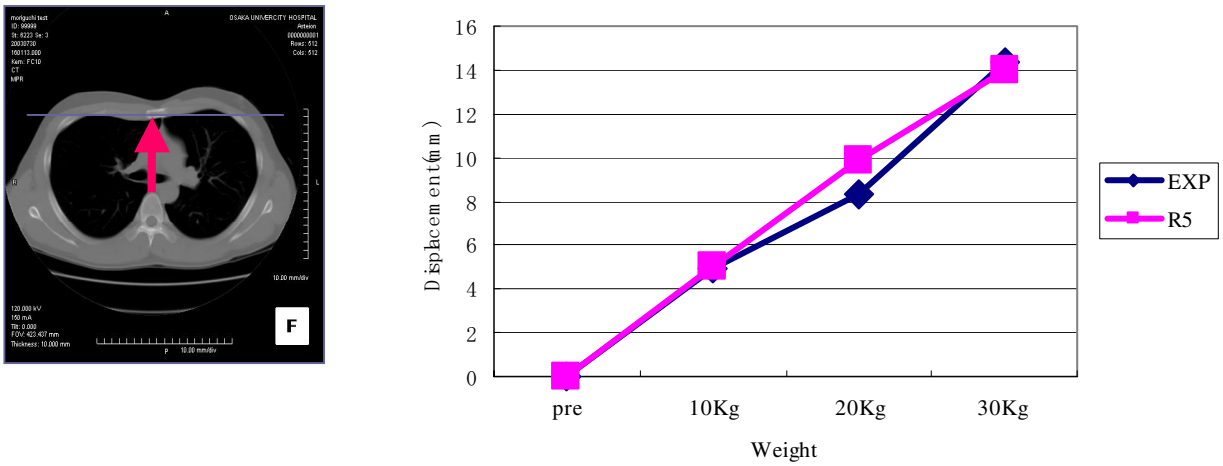


Figure16. Displacement of the sternum at each weight

## CONCLUSION

In the present study, based on the comprehensive database for the structural damage and human casualties caused by the Great Hanshin-Awaji Earthquake, we investigated injury-causing objects, injury sites and activities during the earthquake. Based on the results, a typical mode of injury was recreated using LS-DYNA, which is general-purpose impact response analysis software, in order to investigate the suitability of the present numerical analysis.

The results of the present study and future tasks are as follows:

1) One of the typical modes of death caused by the Great Hanshin-Awaji Earthquake was that people in totally collapsed wooden buildings died within a short period of time due to chest compression.

2) Building materials (particularly with wooden buildings) and furniture were the two main objects that caused severe injuries; bone fractures and contusions to the abdomen/lumbar, legs or chest.

3) Mostly favorable findings were obtained by the LS-DYNA simulation of semi-static problems, such as death due to suffocation.

4) The result from simulation of the compressed thoracic behavior accords with CT scanner experiments nearly. Therefore, this simulation is actual for human body damage.

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