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Kobry El-Kobbah
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A STUDY OF HEAD ACCELERATION DURING CRASH TEST SIMULATION USING LS_DYNA SOFTWARE

M. A.El-Moneim*, E. Sh. Jabbour**, M. EL-Maddah***.

ABSTRACT:

A finite element model of a belted-dummy that uses seatbelts as shell elements is modified to include seatbelts defined in LS_DYNA code as seatbelt elements. This action will give the ability to deal with experimental data of seatbelt materials. A comparison between the two cases (shell elements and seatbelt elements) is included to shed light on differences. Head Injury Criterion (HIC) is used to evaluate the head damage coming from resultant acceleration. The output acceleration data of LS_DYNA is manipulated by VB program written for this purpose. Using softer material for the seat at head and back contact area reduced the high values of HIC. But high value of HIC is noticed at initial velocity 10 m/sec according to instant conditions affecting the dummy, which refer to the necessity of using airbag besides seatbelts to get convenient degree of protection. The studies performed indicated the importance of using two seatbelts (the lower seatbelt together with the upper one).

KEY WORDS:

Finite Element Analysis, Vehicle Crashworthiness, Head Injury Criterion.

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* PH.D Eng. of Mechanical Engineering, Ministry of Defense, Cairo, Egypt.
** MSc student, Mechanical Engineering, Syrian Armed forces.
*** Prof. Dr of Mechanical Engineering, Ministry of Defense, Cairo, Egypt.

1. INTRODUCTION:

With the increasingly rapid development of higher-powered computing techniques, computer modeling is becoming a more realistic and credible form of crashworthiness evaluation. Within the last decade, computer analysis of crashworthiness has emerged as a powerful tool, which can substantially reduce the cost and time, required for the development and certification of new designs of vehicles. The Finite Element Method (FEM) is currently the most advanced tool for simulating an impact event. Its advantages over other modeling techniques include accurate geometric representation, advanced contact algorithms, and material models for representation of the large deformations experienced in high-speed impacts. Additionally, FEM allows for the collection of more data than any other type of modeling. This includes quantities such as stress, strain, displacement, velocity, acceleration, energy, etc, at virtually any location in the model. One of the most important FEM software being used is LS_DYNA. With FE analysis, the model can be constructed in a ground up approach with the first generation of the model being very similar to the gross motion simulators. In a collective effort, more detailed segments of joints, limbs, and organs can be transitioned into the model. The priority for this transitioning will be dictated by the current concerns in automobile safety design. For example a detailed model of the head and brain can be placed into the model for more extensive analysis in areas of head injury. A well-orchestrated method for the development will greatly accelerate such a grand challenge problem.

With the large number of transportation devices in use worldwide, one area of biomechanics that receives considerable attention is the development of dynamic simulation models of vehicle occupants. Head injury constitutes approximately 50 percent of all injuries sustained in transportation accidents [1]. While head injury is one of the most common types of injury, the mechanisms of head and brain trauma still have many unanswered questions. King and Chou [2] reviewed the many models that were developed between 1966-1975. One conclusion made by them was that because of the complex geometry and material properties involved, the use of the finite element approach was the best suited for modeling the head.

Probably the most difficult and unascertained area of human modeling is the representation of material characteristics and mechanical behavior. Things that are taken for granted in conventional engineering do not apply to a biological system. The long-term goal in computer simulation is to develop a detailed model of the complete human. Ultimately this model can be used as the ideal human surrogate for vehicle safety evaluation. Over 25 models of human beings were covered, most of which modeled the head as a fluid filled spherical or ellipsoid shell. This became apparent as the FEM models quickly outperformed other types of models when their development began in the mid 1970's. Currently, one of the most advanced FEM head model was developed by Ruan et al. at Wayne State University [3, 4, 5].The modeler must start from the simple and gradually build to the complex in a systematic ground up approach.

In this study, a comparison is made between two models of seatbelts. The first one uses shell elements with linear material properties. In this case, the results are expected to be different than real conditions due to hystericis phenomena arising from nonlinear behavior during crash. Therefore, a model of seatbelt using the LS_DYNA new version capabilities is introduced. In this model, real experimental data of material can be defined. A computer program in Visual Basic is prepared to calculate the head injury criterion (HIC) based on LS_DYNA output acceleration. The influence of head rest material (modulus of elasticity) is also investigated. In addition, the results of using one upper seatbelt are compared to those obtained by using simultaneously two seatbelts :upper and lower.

2. MODEL DESCRIPTION:

A finite element model of a dummy is used in this study, which consists of 15 ellipsoidal rigid bodies connected through 14 cylindrical joints. The model consists of 2043 nodes, 2072 elements (118 discrete elements, 1618 Quads, 332 Trias and 14beams) and 11 interfaces (surface to surface). The base of the seat belts and the seat decelerates backwards relative to the dummy. Discrete springs and dampers between different bodies provide the relative

stiffness and viscosity (Fig.1). The initial velocity of all nodes is defined a priori, while the acceleration of the seat and belt ends follow an acceleration curve in the opposite direction. Because of that, changing the initial velocity values demands defining new acceleration curve each time according to the velocity being used. Three essential values of initial velocity are considered in this study 5.2 m/sec, 10m/sec and 14.8 m/sec. Acceleration and velocity versus time curves are shown in (Fig .2).

The two seatbelts were defined as shell elements (SHED) with linear elastic properties of 0.01 m thick to guarantee the solution stability. However this is unaccepted practically for other approaches away from simulation aims. The contact between seat belts and dummy is defined as surface to surface[6]. To study the influence of a real seatbelt, there was no way from using the update capabilities of a new version of LS_DYNA(960)[6], in which the seatbelt element (SBED) is defined. The contact definition has been replaced in this case to (nodes_to_surface)Instead of (surface_to_surface) . The input data for SBED materials contains two curves:-Load curve describing the relation between Force and Engineering Strain. Another similar curve is entered to describe the unloading behavior. Both load curves should start at the origin and contain positive force and strain values only. Three nodes (18,33,146) have been chosen to study the influence of different models (Fig.3).

3. THEORETICAL BACKGROUND:

3.1. Equations of Motion:

The equations of motion for linear behavior usually lead to a linear set of ordinary differential equations (ODE) in matrix form:

$$\underline{M}\,\ddot{\underline{x}} + \underline{C}\,\dot{\underline{x}} + \underline{K}\,\underline{x} = \underline{F}(t)$$

where

$\underline{M}$	is the mass matrix
$\underline{C}$	is the damping coefficient matrix
$\underline{K}$	is the linear stiffness matrix

$\underline{F}(t)$ is the external force matrix

$\underline{x}, \underline{\dot{x}}, \underline{\ddot{x}}$ are nodal displacement, velocity and acceleration vectors respectively.

However, for the nonlinear behavior common in crash the internal force varies as a nonlinear function of the displacement, leading to a nonlinear set of (ODE):

$$\underline{M}\,\underline{\ddot{x}} + \underline{C}\,\underline{\dot{x}} + \underline{f_{\text{int}}}(\underline{x}) = \underline{F}(t)$$

where

$\underline{f_{\text{int}}}$ is the internal force vector.

For nonlinear problems only numerical solutions are possible. LS_DYNA uses the explicit central difference scheme to integrate the equations of motion. The choice of time step is critical in explicit dynamic FE analysis. Large time step can render the solution unstable while a small time step can make the computation costs high. The critical time step has to satisfy the stability condition of the explicit method; i.e. the time step has to be small enough such that the stress wave does not travel across more than one element at each time increment cycle.

3.2. The Head Injury Criterion (HIC)

The head Injury Criterion (HIC) is based on the average value of the acceleration over the most critical part of the deceleration

The average value of the acceleration *a(t)* over the time interval t_1 to t_2 is given by :

$$\bar{a} = 1/(t_2 - t_1)\int_{t_1}^{t_2} a(t)dt$$

$$HIC = \max\left\{ (t_2 - t_1)[1/(t_2 - t_1)\int_{t_1}^{t_2} a(t).dt]^{2.5} \right\}$$

This formula was proposed to identify the most damaging part of the acceleration pulse by finding the maximum value of the above integral. Head damage danger is to appear when HIC > 1000 [7].

The formula indicates that the HIC is the maximum value over the critical time period t_1 to t_2 for the expression in parentheses. The index 2.5 is chosen for the head, based on experiments.

4. COMPUTER IMPLEMENTATION

A program, written in VB is prepared to manipulate the acceleration curves output of LS_DYNA and store as Access data bases. After reading the numerical data from Access databases that linked to it, the program removes the zero intervals, calculates and then inserts points when intersecting with axis (a(t)=0).The program scans the whole range of acceleration with different time intervals to determine the maximum value. The program finally outputs the HIC value with its duration and draw the acceleration curve with shaded areas at the place where HIC had been calculated.

5. RESULTS AND DISCUSSION:

5.1 The influence of seatbelt model

In order to use realistic values of material properties and behavior, specimens of two different commercial types of seatbelts are tested. These tests were performed at M.T.C material's laboratory using tensile machine MTS, that gives the relationship between applied forces and engineering strain (Fig.4,5). A comparison between the resultant acceleration curves along the frontal movement direction, at the three mentioned nodes , for the two cases SHED & SBED is represented in (Fig.6,7).

5.2. The Influence of Headrest Tenderness

When using rigid seat rest behind the head back, the HIC values take large values, and the reason is that the acceleration of the head takes a large value at the moment of staking. Using softer seat rest(reducing modulus of elasticity) gives values represented in (Fig.8) in which two additional initial velocities 25, 40 m/sec are added to compare HIC values .

5.3. Importance of Using the Lower Seatbelt:

Figure.9. represents the case when using one seatbelt, the upper one only. The three curves are taken for the soft headrest. By comparing the values of table (1) we can easily wind up to the result that using the two seat belts together reduces the HIC value.

Table(1) A comparison between two cases (using the upper seatbelt Only ,using the two seatbelts) at three different velocities

Initial Velocity [m/sec]	HIC for the upper seatbelt	HIC for two seatbelts
5.2	2287.1	397.1
10.0	9448.9	1237.9
14.8	508.2	406.2

A strange result is that the HIC value at initial velocity(Vxi=10 m/sec) is bigger than its value at bigger velocity(Vxi=14.8 m/sec) as it can easily be seen from table(2).

Table(2) The HIC values for initial velocities (10 ,14.8)

Initial velocity [m/sec]	HIC
10.0	1237.9
14.8	406.2

The reason of this phenomena can be explained by noticing that in the case of 10-m/sec initial velocity the whole body is elevated at the moment of head contact. Hence the whole body's inertia participates in the direction of increasing the sudden head load. On the contrary for velocity of 14.8m/sec the body sets at the seat which reduce the load applied on the head at the moment of contact (Fig.10).

6. CONCLUSIONS:

From the present study the following conclusions can be drawn:
1-LS_DYNA can give us the ability to discuss and simulate the behavior of many issues related to vehicle design and safety insurance. It is recommended to use real material properties in order to get accurate results.
2-It is very important to use two seat belts in addition to other safety procedures such as using air bags .
3-The seat rest must be tender and soft enough to reduce the degree of expected damage of head.

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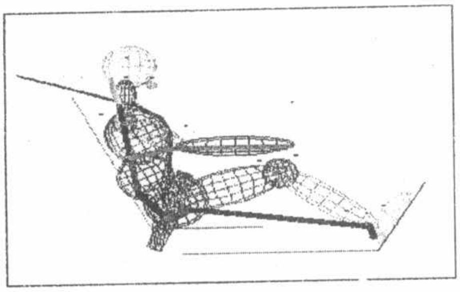
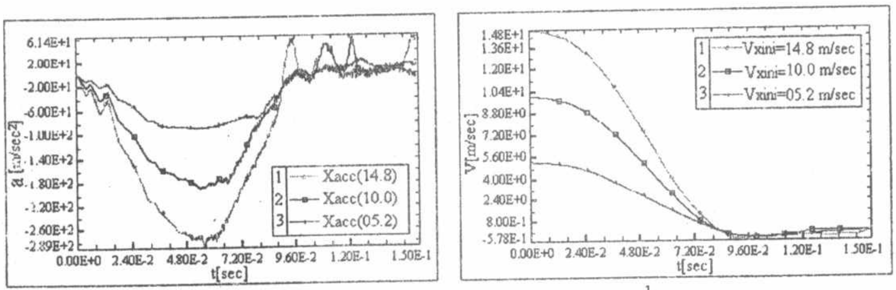


Fig.1. The FE model of the dummy



a b

Fig.2. Acceleration and associated velocity curves

a) acceleration curves
b) associated velocity curves

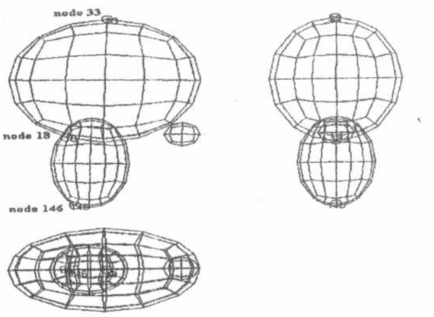
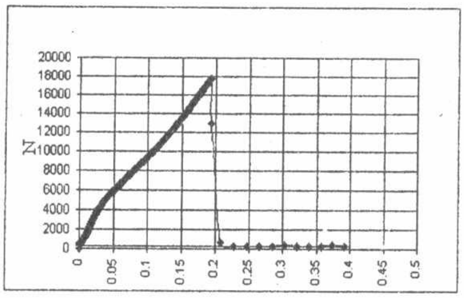
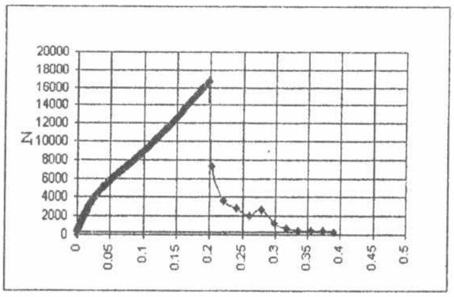


Fig.3. The positions of nodes 18, 33 and 146.

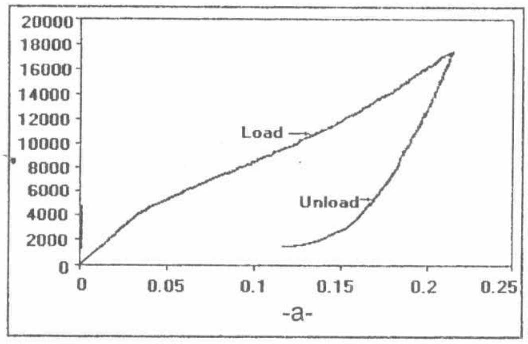


a) Specimen (1):



b) Specimen(2)

Fig.4. Relationship between applied forces and engineering strain for two different commercial specimens.



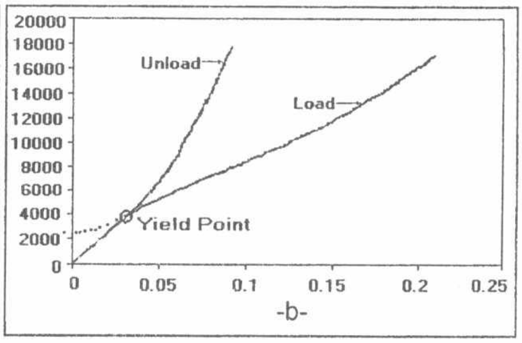
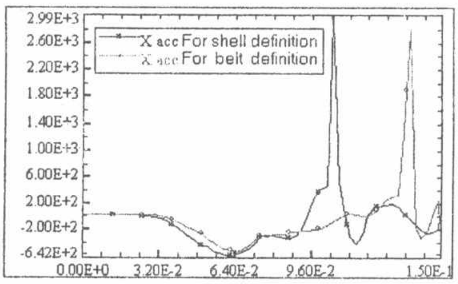
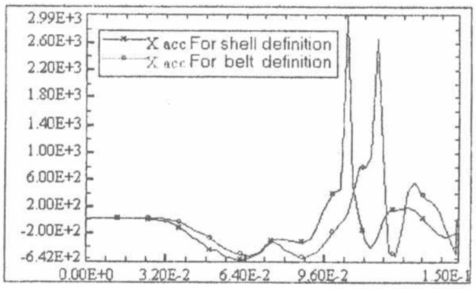


Fig.5. Load and unload curves for specimen(1)
a) experimental curves
b) modified curves according to LS_DYNA.



SBED with load curve only



SBED with load and unload curves

Fig.6. Acceleration along X direction at head CG(node2050)

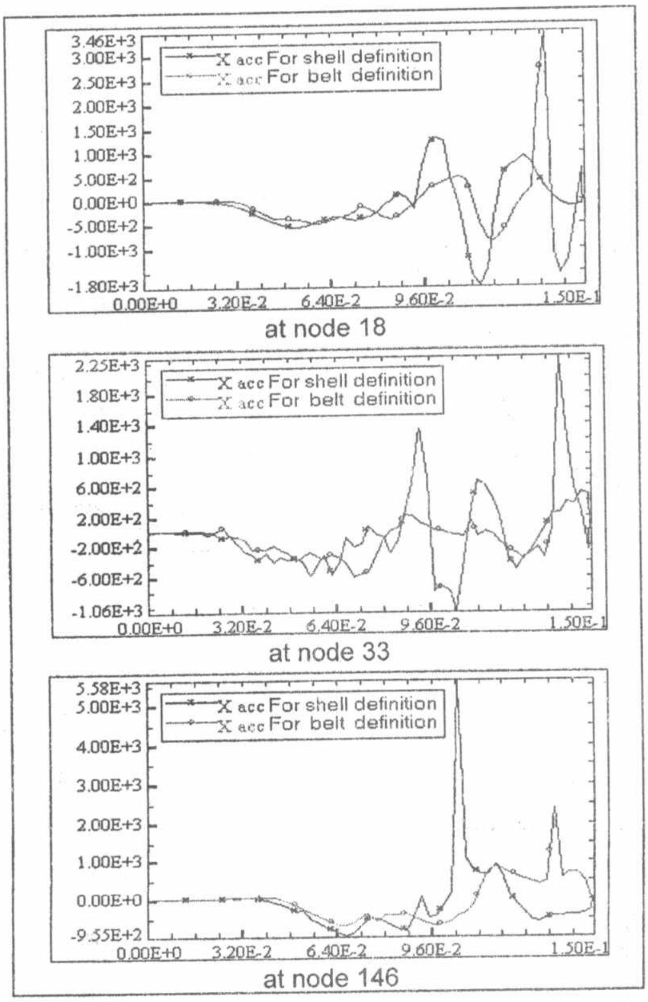


Fig.7. The nodal acceleration curves at nodes 18,33 and 146, each time for both cases. These curves are taken for initial velocity(14.8 m/sec).

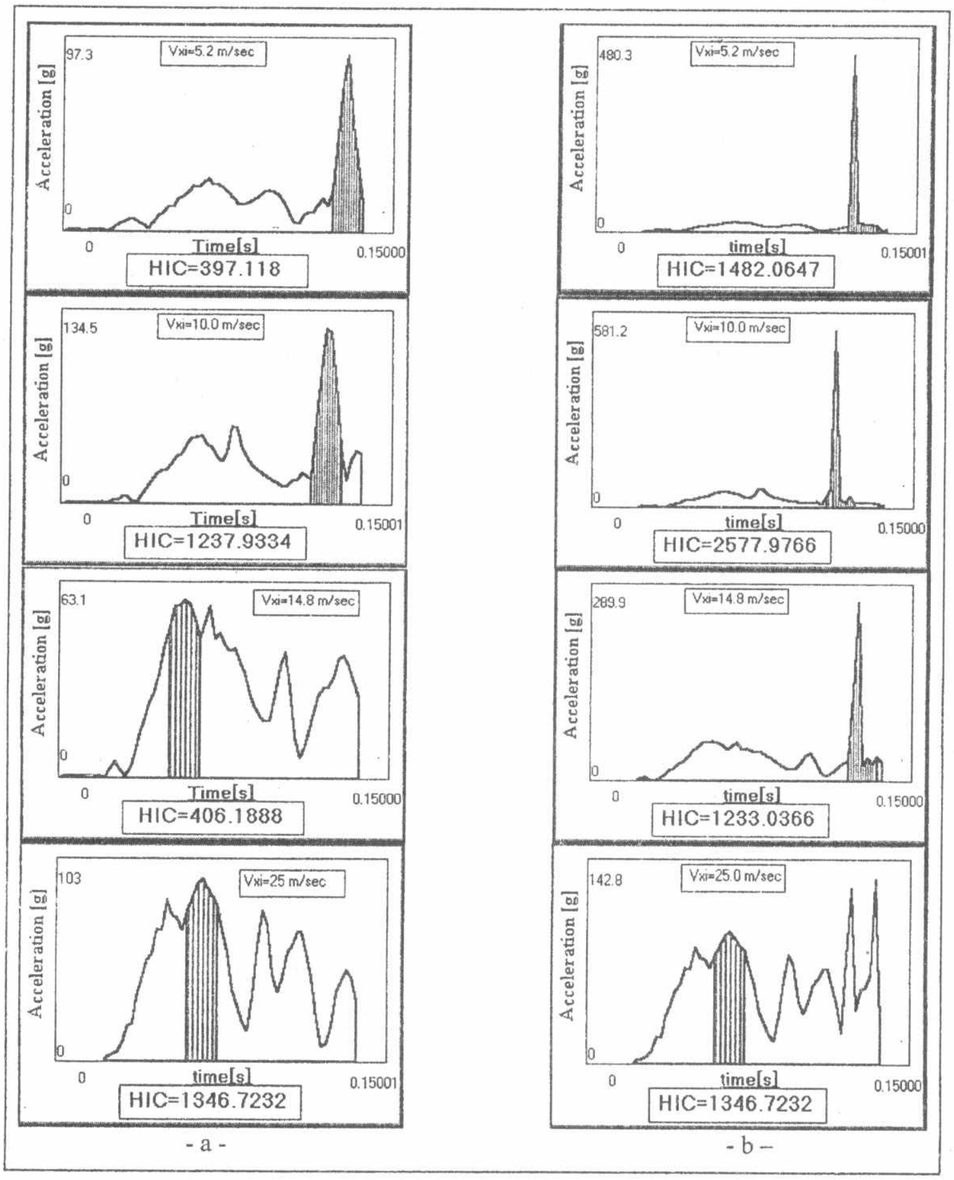


Fig.8. Acceleration versus time curves a-) for soft seat rest b-) for hard seat rest

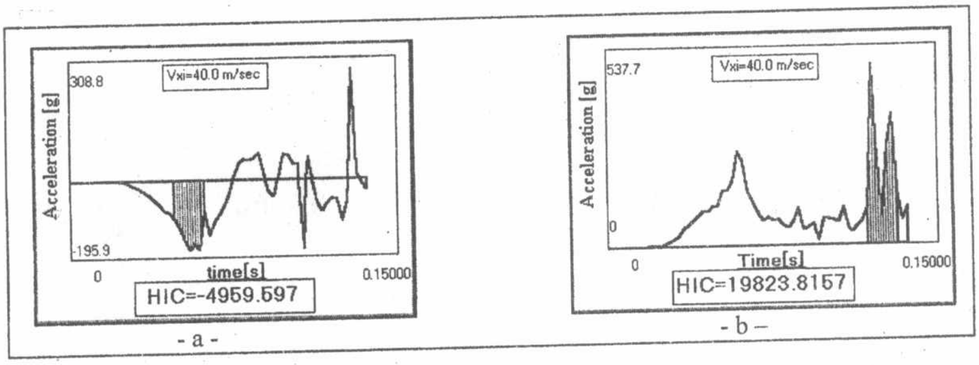


Fig.8. contd.

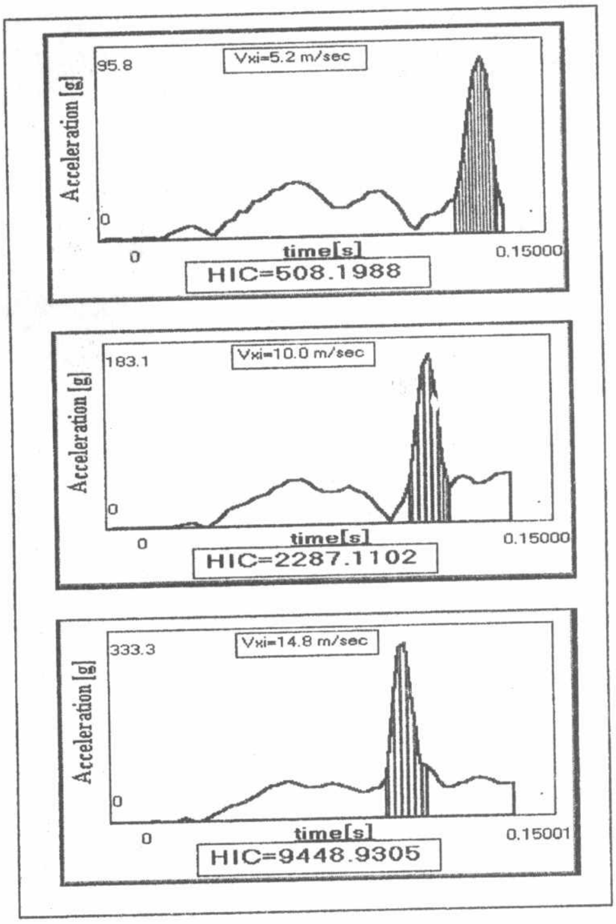


Fig.9. The case when using one seatbelt, the upper one only at three initial velocities (5.2,1C.0,14.8)

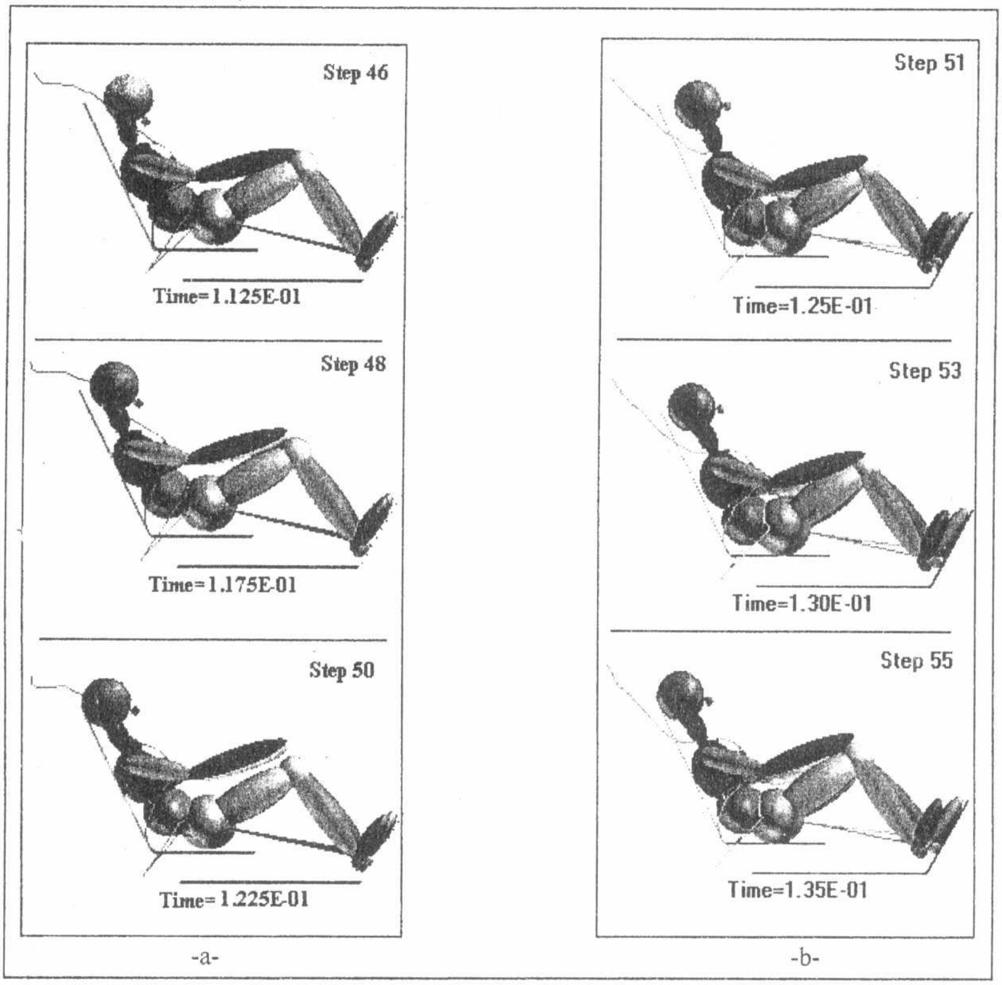


Fig.10. The dummy positions around the time of head stack for two cases
a) For initial velocity Vxi=10.0m/sec
b) For initial velocity Vxi=14.8m/sec