MATHEMATICAL MODELLING OF THE AUTOMOBILE OCCUPANT

USE AND LIMITATION OF THE MODEL

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INTRODUCTION

Experimentally putting into shape a restraint system adjusted to a vehicle is long and expensive. Therefore it is advisable to use mathematical modelling. Then it is possible to, quickly, at little cost, compare a large number of combinations that will guide us for further research work. The purpose of this study is to show how to use mathematical modelling to determine the influence of parameters such as seat stiffness or anchorage points position.

Computation results allow us to take our choice among various solutions. Some have been carried out and tested. We shall compare computation predictions with test results.

We have used our eleven degrees of freedom plane model (1) for this study. At first we did our utmost to reproduce a test, after measuring seat and safety belt parameters. Then we let those parameters vary.

This paper is composed of two parts. First concerns seat, second anchorage points position. We shall study the influence of these parameters upon the following results : Forces in safety belt, resultant accelerations of head, torso and pelvis, horizontal displacements of head, pelvis and knee.

I - STUDY OF THE SEAT

I.1 - Influence of the cushion stiffness

Our purpose in this first part of the study is to improve the seat cushion, to give it some characteristics making possible a better contribution to the restraint of the pelvis, by limiting its horizontal movement and avoiding its rotation.

I.1.a - Curves of stiffness used

The curve 1 from figure 1 represents the curve : crushing versus force of a prototype cushion from the CITROEN VISA and has been determined by the method described in a previous paper.

By multiplying, for each value of force, the corresponding crushing by a coefficient k we obtain seats :

- Stiffer than the reference seat if k < 1 (curves 2 and 3)
- More flexible than the reference seat if k > 1 (curves 4 and 5)

We will their add curve 6 which represents a seat, having an initial stiffness equivalent to that of the reference seat and a crushing limited to 0,075 m under 3 000 N by the addition of a rigid stopper.

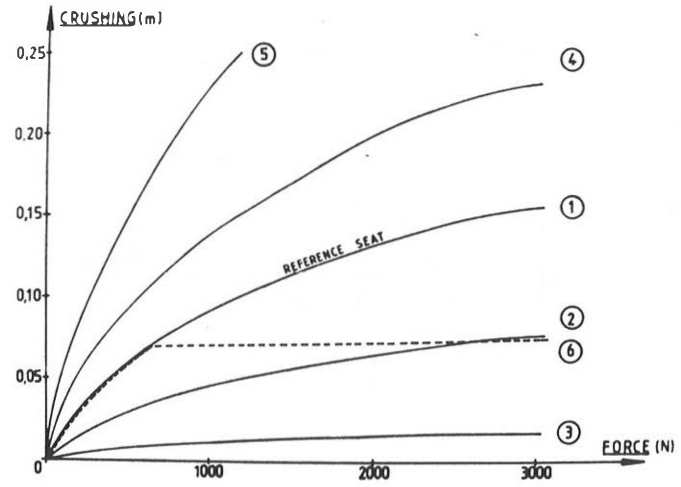

Figure 1 : Crushing of the Cushion

Concerning the stiffness of the seat, we recall that we have assumed that the proportional coefficient between horizontal and vertical forces was the same for all the seats.

I.1.b - Results

With each of the seats defined in the previous paragraph, we have simulated a frontal crash at 50 Km/h. The curves from figures 2 to 5 show the variation of the results function of the coefficient k which characterizes the stiffness of the cushion.

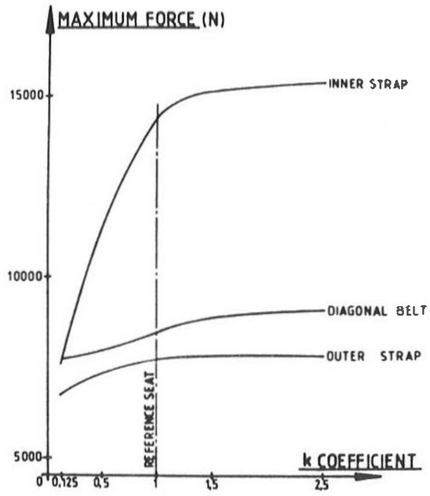

Figure 2 : Belt Forces

- Forces in the safety belt. They decrease when the stiffness of the seat increases. Mostly the one of the inner side strap (Fig. 2).
- Resultant accelerations. An increase in the stiffness of the seat appreciably decreases the maximum resultant accelerations concerning torso and pelvis. There is rather little difference with that of the head (Fig. 3).

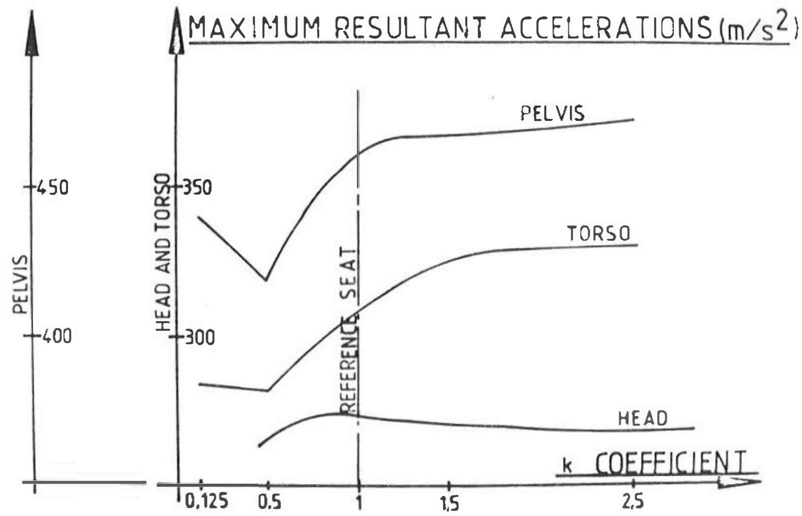

Figure 3 : Resultant Accelerations

- Horizontal displacements. An increase in the stiffness of the seat decreases the horizontal displacements of the pelvis and knee, whilst that of the head is only slightly modified (Fig. 4)

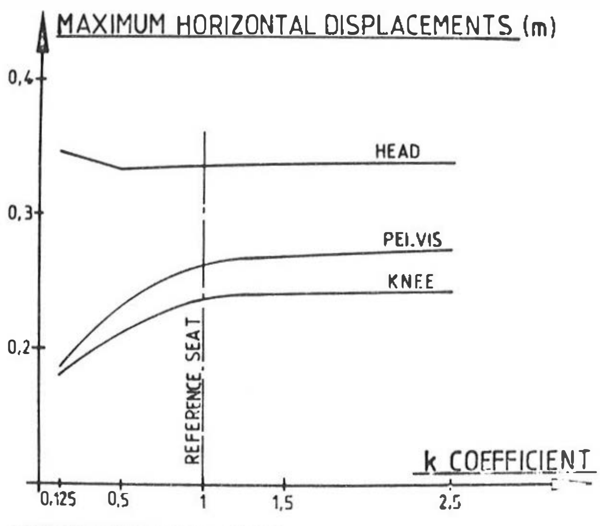

Figure 4 : Horizontal Displacements

I.1.c - Seat with rigid stopper

With the aim of limiting the pelvis movement, another solution has been considered. It consists in adding a rigid stopper to the seat cushion, which limits the crushing without disturbing the comfort of the passenger.

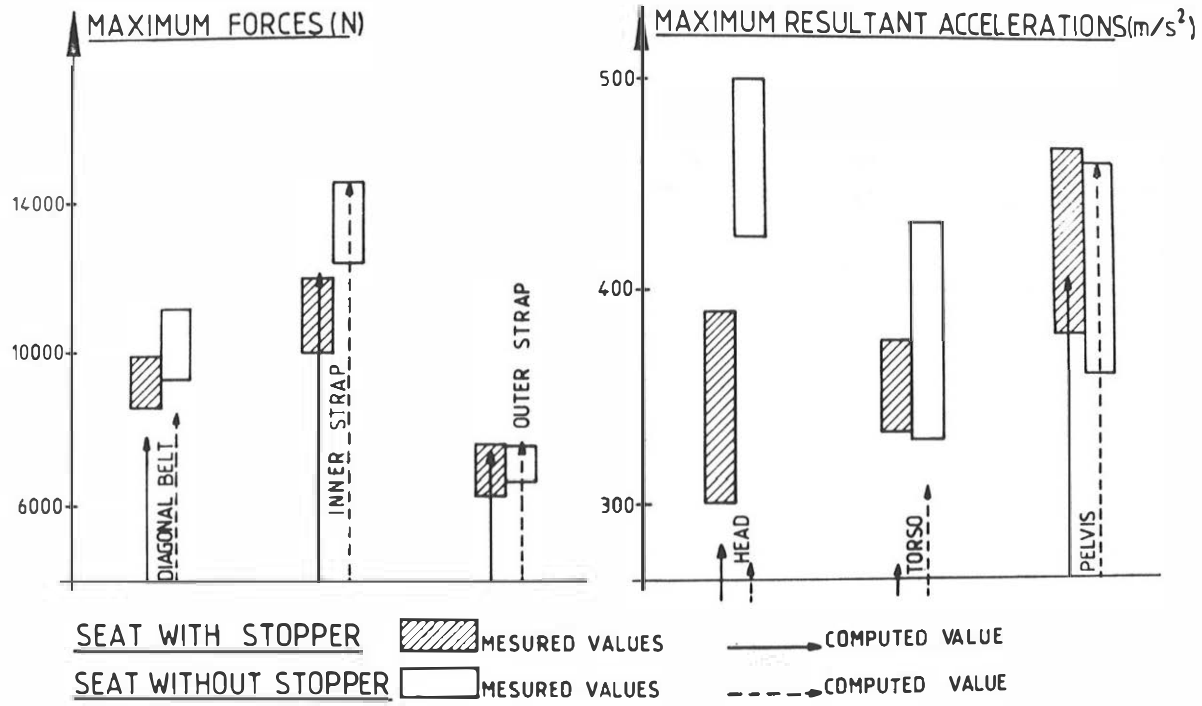

Figure 5 : Seat Improvement (2 x 4 tests and simulation)

For each type of seat (with or without a stopper) we have made a series of 4 tests with the catapult of the "Laboratoire des Chocs et de Biomécanique de l'O.N.S.E.R." at BRON. Results are shown in figure 5 with those of the corresponding computations. We notice a good correlation between the computation and the tests concerning the seat modification influence, except for the resultant acceleration of the head. Roughly speaking, the seat with the stopper can be considered the best because of the decreasing maximum resultant accelerations of the torso and head (which can be observed in the tests). We did not represent the displacements, for their variation is too small to be significant.

In figure 6, one can see the comparison between two tests that are characteristic of each seat.

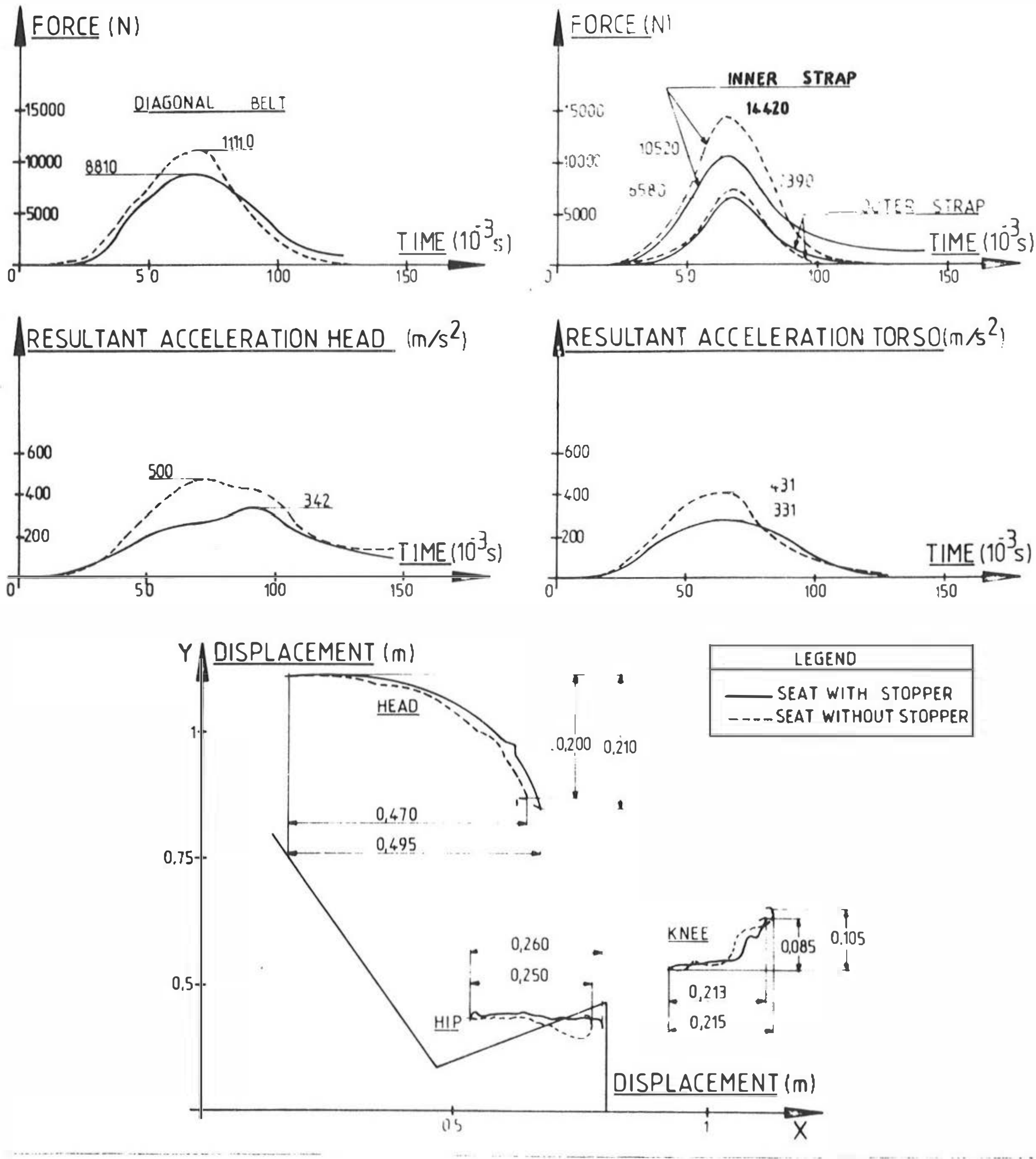

Figure 6 : Seat Improvement (comparison of 2 tests)

I.2 - Forces applied to the seat

It is necessary for the designer to know the maximum contact force between the seat and the dummy during an impact. This force, difficult to measure, is computed in the mathematical model. We have represented its variation, for the same configuration of the safety belt anchorages, as function of :

- The speed of the impact
- The mass of the dummy
- The stiffness of the seat

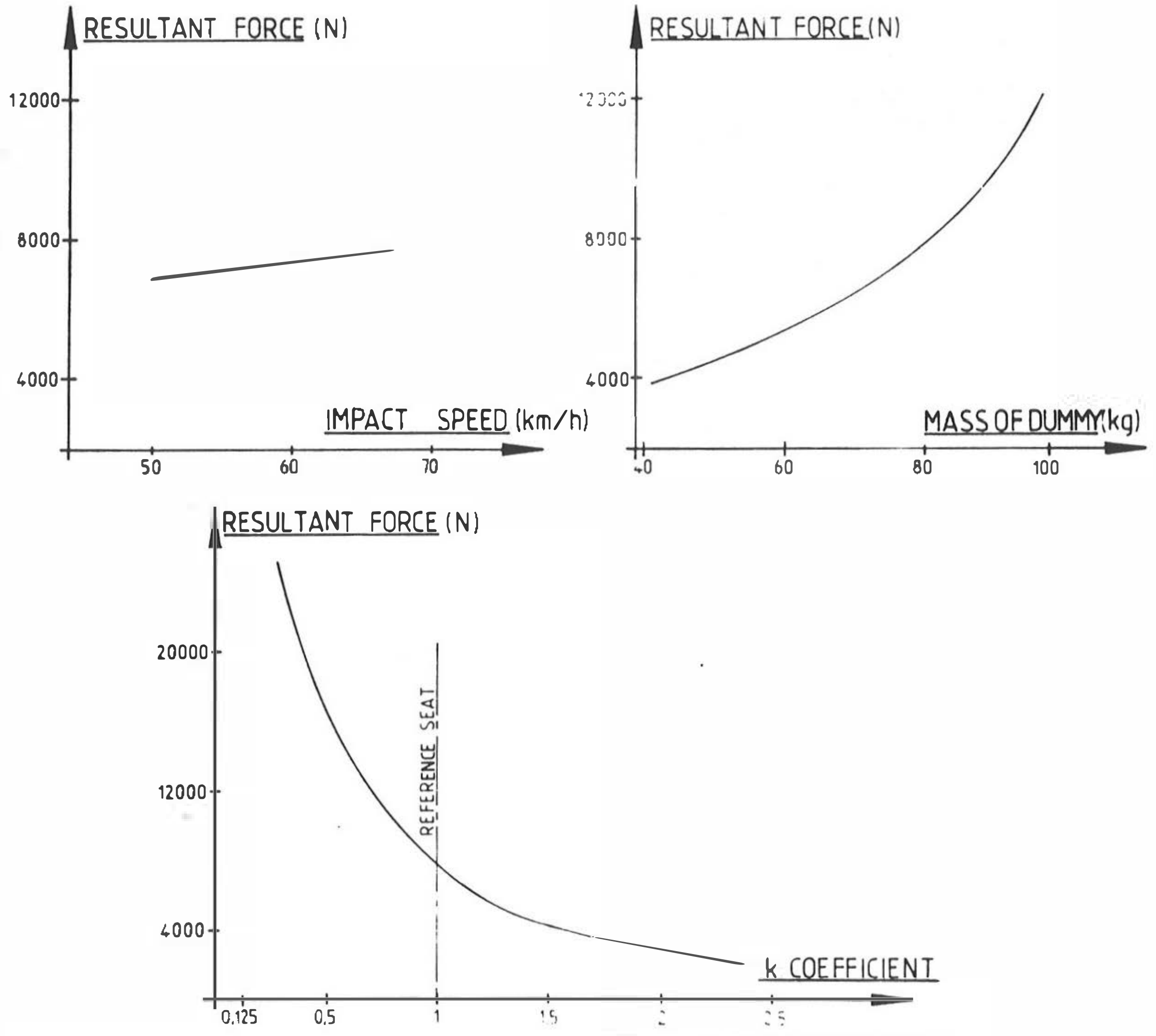

Figure 7 : Seat-Dummy Resultant Force

One can see that the speed has relatively little influence, in comparison with the stiffness of the seat and the dummy's mass.

Remark : The seat with the stopper re-acts like a seat of great stiffness.

II - STUDY OF SAFETY BELT ANCHORAGE POSITIONS

The research to obtain the best position for the safety belt anchorages is a problem in which the use of a mathematical model can be fruitfull. However some difficult problems arise from this use, because each variation of position modifies :

1 - The lengh of the belt, and consequently the stiffness and plastic elongation curves which characterize it.

2 - The action zone of the belt on the dummy (reduced to a point in the mathematical model).

To take into account these variations, it is necessary, normally, to measure the belt characteristics for every studied position. But that is unreasonable, so we have a choice between :

1 - Limiting the variation of anchorage positions to a sufficiently small zone so that the modification of the belt characteristics be negligible.

2 - Taking into account the variation of the strap stiffness by introducing the particular characteristics of the belt corresponding to each position. These characteristics having been found experimentally.

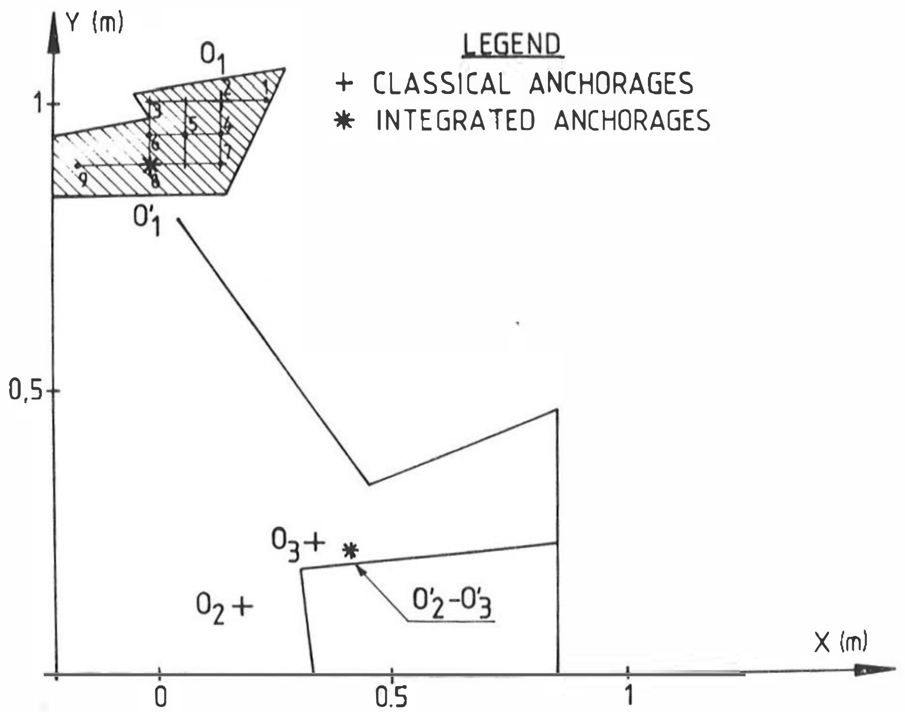

Figure 8 : Anchorage Positions

In the following example we have compared two anchorage configurations of different design :

1 - The first (Fig. 8) in classical : two lower anchorages O_2 , O_3 on the floor and an upper anchorage O_1 on center pillar.

2 - The second (Fig. 8) is a project of anchorages integrated to the seat. The geometry of which has been defined in a paper presented at the 7th International Technical Conference in June 1979 (2). The lower anchorages O'_2 and O'_3 are situated on the sliding rails, and the upper anchorage O'_1 can be eventually integrated to the seat back.

II.1 - Influence of the lower anchorage position

Given the small length of the two parts of the lap belt (inner and outer) the variation of the anchorage positions here is considered important. We have therefore taken into account the variation of the strap stiffness.

The results of the computation are presented in a table figure 9.

ANCHORAGE CONFIGURATIONS	MAXIMUM BELT FORCES (N)			MAXIMUM RESULTANT ACCELERATIONS (m/s^2)			MAXIMUM HORIZONTAL DISPLACEMENTS (m)		
	DIAGONAL BELT	INNER STRAP	OUTER STRAP	HEAD	TORSO	PELVIS	HEAD	HIP	KNEE
$O_1-O_2-O_3$	9580	11180	5350	319	354	364	0,412	0,205	0,185
$O_1-O'_2-O'_3$	9900	17260	7050	342	395	489	0,409	0,270	0,247

Figure 9 : Influence of Lower Anchorage Positions

This change of the lower anchorages gives more important forces and accelerations, but we would like to point out to the reader that the choice of points O'_2 and O'_3 has been taken from the geometrical criteria (2) guaranteeing a good position of the lap belt under the iliac crests and thus a much better orientation of the forces applied to the occupant whatever his height or weight.

The mathematical model does not take into account injuries due to a bad positioning of the belt inducing submarining.

II.2 - Influence of the upper anchorage position

For the continuation of study we have kept the same points O'_2 and O'_3 as lower anchorages, and we have moved the point O_1 in the normalized zone represented in figure 8. The lengh of the shoulder belt being small we have assumed that the variation of the strap stiffness, consecutive to the displacement of the upper anchorage is negligible. We have therefore inserted in the computation program, the characteristics of the belt configuration O'_1 , O'_2 , O'_3 .

The considered points are numbered from 1 to 9 (with O_1 = 2 and O'_1 = 8). We can see from figures 10 to 12 the results evolution.

(The numbers of the points are indicated on the curves).

- Forces in the belt. The backward displacement and the lowering of the upper anchorage from the reference point 1, decrease the forces in the shoulder and inner straps of the belt. They hardly modifie the force in the outer strap.

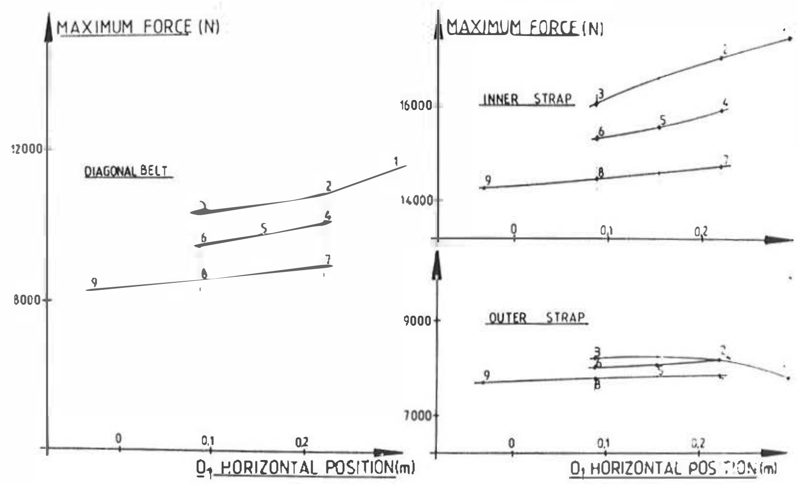

Figure 10 : Upper Anchorage Position Influence (belt forces)

- Resultant accelerations. The lowering of the upper anchorage appreciably dicreases the resultant accelerations of the dummy. The backward displacement has very much less influence, except on the acceleration of the torso for the front points 1, 2 and 3.

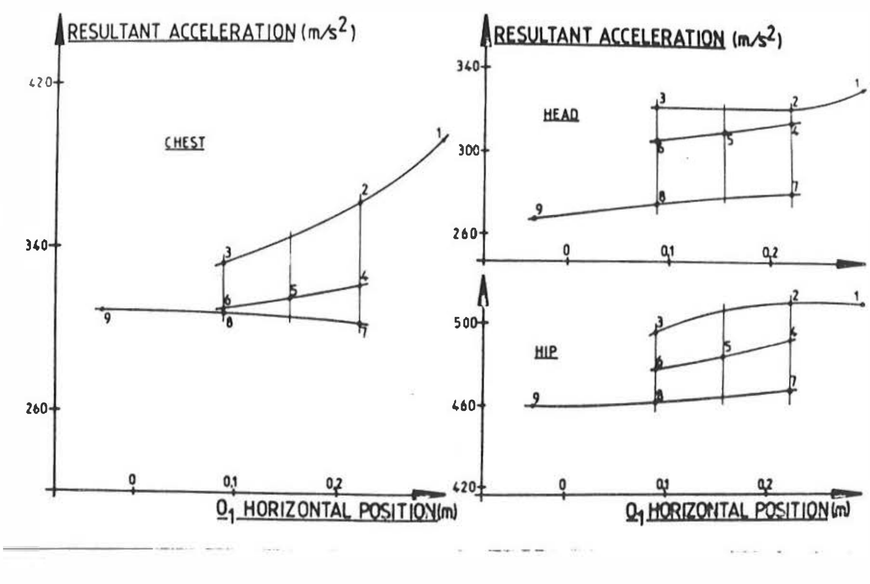

Figure 11 : Upper Anchorage Position Influence (resultant accelerations)

- Horizontal displacements. Backward displacement and lowering of upper anchorage point acts favorably on horizontal displacement of head, hardly changing those of pelvis or knee.

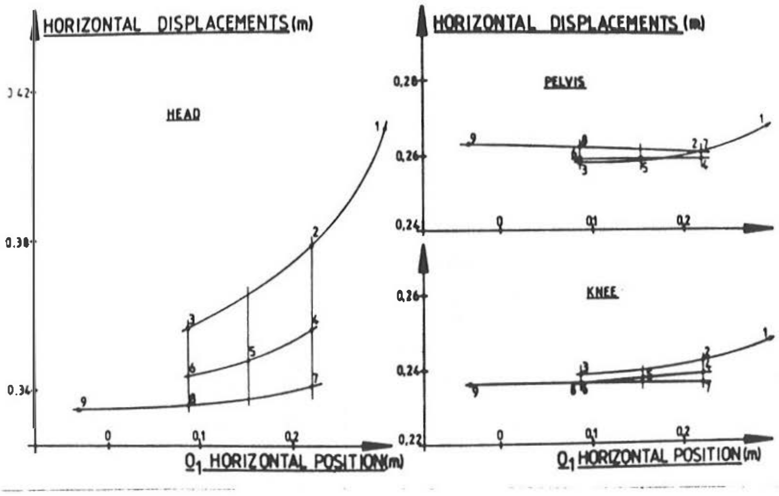

Figure 12 : Upper Anchorage Position Influence (horizontal displacements)

Among the 9 points chosen to study the upper anchorage position influence, points 8 and 9 are the one that give the best results. We've kept point 8 (O'_1) because it satisfiesgeometric criteria that assure correct positioning of shoulder belt on clavicle and chest for subjects of both sexes, whose height may vary from 1,53 m to 1,91 m (2), and it can be integrated to the seat. We shall see that amelioration brought by moving the upper anchorage point shall make up for increase of forces and accelerations due to changing lower anchorage points.

II.3 - Comparison of two anchorage configurations

For each anchorage configuration a series of 4 tests has been carried out by the "Laboratoire des Chocs et de Biomécanique de l'O.N.S.E.R." at BRON. Results are presented on figure 13 with those of corresponding computations. Apart from head resultant acceleration, there is a very good computation - tests correlation. Concerning evolution of the chosen parameters, that stay mostly the same in both cases. The integrated anchorages solution decreases horizontal displacements, force in shoulder belt and torso acceleration ; and increases forces in lap belt.

Figure 14 shows the comparison between two characteristic tests of each configuration.

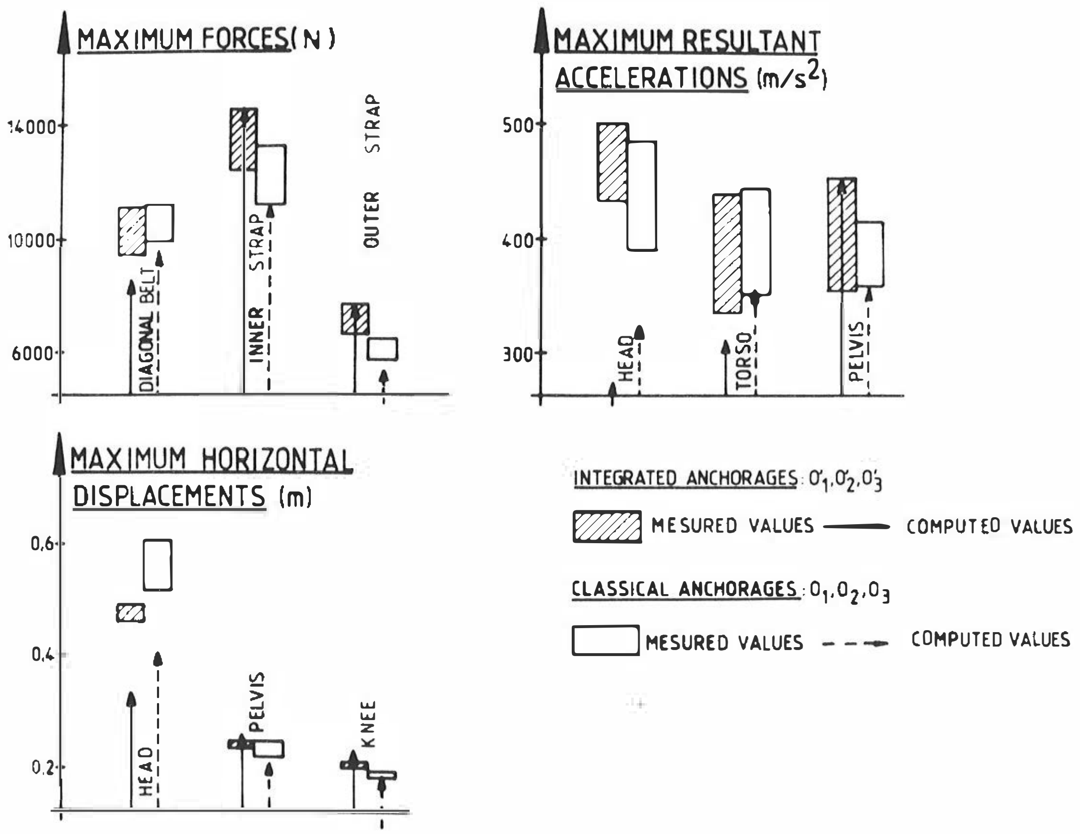

Figure 13 : Comparison Between Two Anchorage Configurations

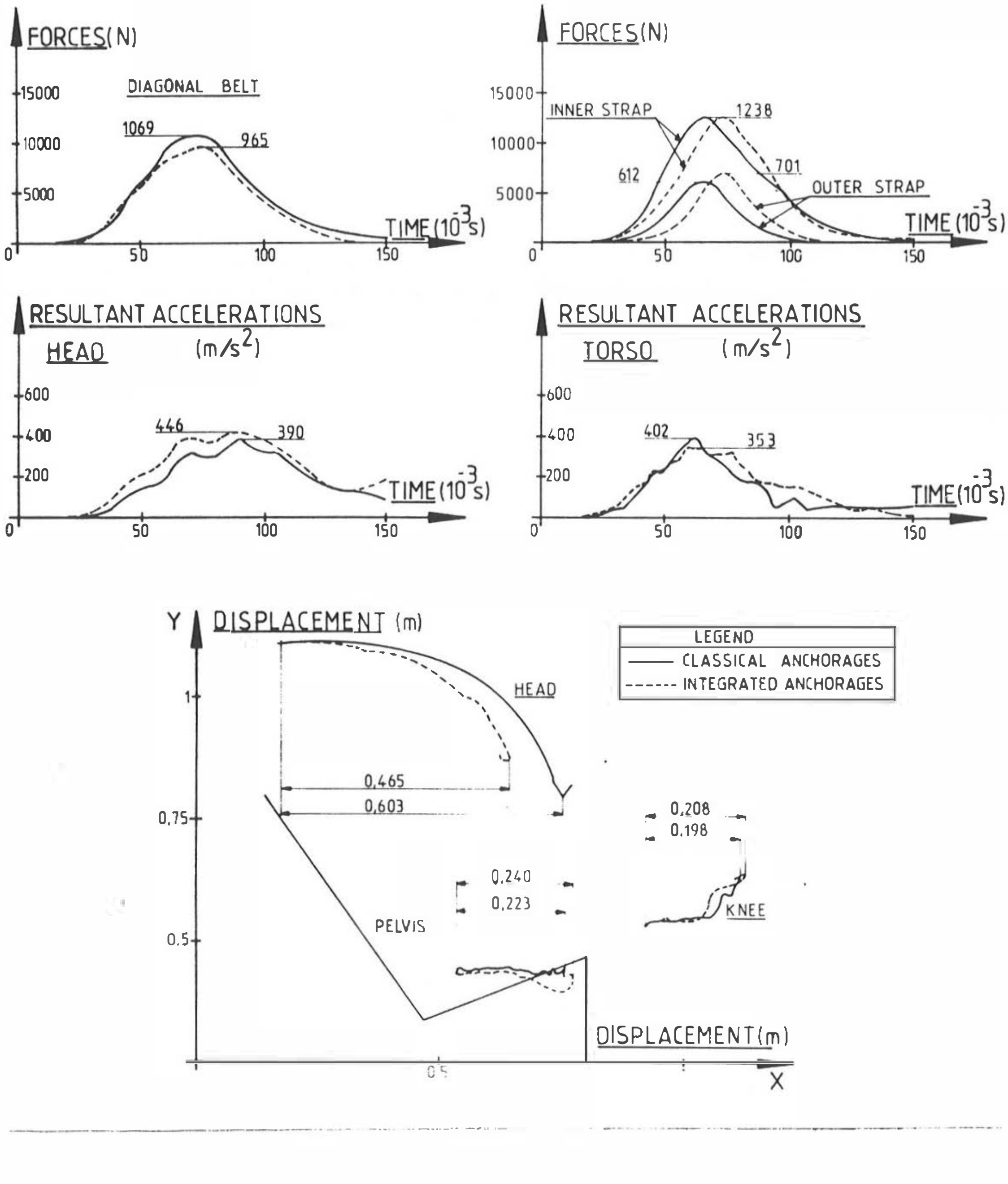

Figure 14 : Comparison Between Two Anchorage Configurations (test results)

CONCLUSION

From this study of the influence of seat stiffness and anchorage point position parameters, we gather the following conclusions for our mathematical model usage :

1 - For qualitative analysis of results, there is correlation. Results vary in the same way. (Except for head acceleration). But there, where two computations are sufficient to etablish direction of variation, it took in each case 8 tests to get them, because of entry parameters dispersion (seat or belt characteristics, dummy's position at the beginning of impact).

2 - For quantitative analysis we get values that are not very close to measurements, but are generally sufficient at the preliminary design stage. Model also makes it possible to get some hard to measure parameters that are necessary for the designer (forces in seat for example).

3 - There is not good correlation between tests and computation concerning the head. Direction of acceleration variations are different and computed displacements are much smaller than that of tests. We don't understand the first flaw, that we still have not etablished. The second has two causes. First the initial plane movement hypothesis. (In fact torso turns around diagonal strap, bringing head with it, which largely increases head displacement). Second, dummy can slip on belt (difficult to be modelled).

   We think that the modelling of the head will always remain the main difficulty for a simple model, due to the very fact of the technological design of the dummy. (Rubber block for the neck).

4 - The advantage of the mathematical model is the possibility to let only one parameter vary each time, all others staying strictly the same thoughout different computations. This is hardly feasible with tests. It follows that computation can more clearly than tests show the influence of a given parameter.

5 - One should not forget that results showing a given parameter influence are valid for a particular set of values of all other impact parameters. One should thus be cautious not to generalize too quickly. Thus for the studied anchorage configuration, a higher seat stiffness is favorable, that is not necessarily true for other anchorage configurations.

6 - In these impact studies, mathematical modelling, has the advantage to quickly yeald directions to guide experimental research. It helps interpret results and facilitates the choice between technological solutions.

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