VIII International Conference on Computational Plasticity
COMPLAS VIII
E. Oñate and D. R. J. Owen (Eds)

MULTI-POINT OPTIMISATION METHODOLOGIES FOR ENHANCEMENT OF COACH PASSIVE SAFETY IN ROLLOVER ACCIDENTS

G. Belingardi, G. Chiandussi, I. Gaviglio, A. Giorda

Department of Mechanical Engineering

Politecnico di Torino

Corso Duca degli Abruzzi 24 Italy.

Key words: Optimisation methodologies, rollover, passive safety, biomechanical injuries.

1 INTRODUCTION

The international organisms of regulation, in collaboration with universities and research centres, are developing an intense and continuous labour to establish new safety requirements for coach homologation. An important result was reached with the emanation of regulation ECE 66 in 1986 which prescribes that during and after the rollover test no part of the vehicle structure has to intrude into a previously defined residual space and no part inside the residual space has to project outside the deformed structure. Regulation ECE 66 does not considerate the presence of the passengers during the rollover test. Otherwise it is important to consider the presence of the passengers because their added mass influences the structural behaviour during rollover. The simulation of the coach rollover by including dummies allows to estimate the biomechanical injury indexes and to compare them with the maximum allowed values for surviving. The aim of this study is to improve coach structural strength to ensure passenger safety by contemporary fulfilling regulation prescriptions. A multi-point optimization methodology has been applied on a mixed multibody-FEM model simulating a coach module in rollover accident. An anthropomorphic dummy EuroSID-1 for side impact tests has been introduced in the module in order to evaluate the injury indexes. A new parameter called RIP (Rollover Injury Parameter) defined as the weighted linear combination of some injury parameters (HIC, TTI, VC, SPF) calculated on the dummy has been introduced as objective function to be minimized. Six mechanical and geometric properties of the lateral pillars of the coach have been used as design variables. The preservation of the survival space and the limit value (as stated by the standards) of each biomechanical parameter contained in the RIP have been used as constraints.

2 THE MODEL

A portion of a coach between two consecutive pillars, called module, has been used as a reference in the construction of the numerical model (fig. 1). Experimental data obtained by the Cranfield Impact Center within the ECBOS European project allowed to validate the results of the numerical model[1]. An EuroSID-1 dummy developed to evaluate occupant protection during lateral impacts has been positioned on the most dangerous seat, using three points seat belt systems[2]. The presence of other passengers has been considered by introducing three equivalent masses, one at each of the other seats (fig. 1). With virtual dummies it is possible to evaluate some injury parameters that measure the injury level reached in a particular human body region[3]. Injury parameters considered in present work are: the Head Injury Criterion (HIC), the Thoracic Trauma Index (TTI), the Viscous Criterion (VC) and the Pubic Symphisis Force (PSF).

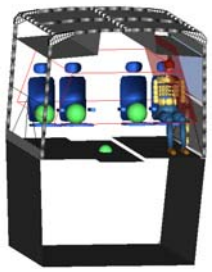

Figure 1: Numerical model with dummy

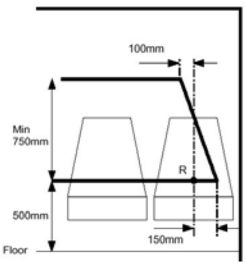

Figure 2: ECE66 regulation. Definition of survival space

3 THE OPTIMIZATION PROBLEM

The optimization problem has been set up on the minimization of the parameter RIP. Parameter RIP (Rollover Injury Parameter) as been defined by the authors as the weighted linear combination of some injury parameters:

$$\mathrm{RIP} = 0.3 \cdot \frac{\mathrm{HIC}}{1000} + 0.25 \cdot \frac{\mathrm{TTI}}{85} + 0.25 \cdot \frac{\mathrm{VC}}{1} + 0.2 \cdot \frac{\mathrm{PSF}}{6000} \tag{1}$$

The same four injury parameters have been used as constraint by imposing a maximum allowable value (prescribed by regulation) corresponding to serious injury or death for the passenger. Another constraint has been set up considering the minimum distance of the centers of the lateral pillar elements from the plane representing the survival space violation (fig. 2). Since negative distances indicate intrusion in the survival space, this value has to be greater than zero.

Pillars have been studied with particular attention: in fact the greatest part of the kinetic energy involved in the accident is transformed in plastic deformation energy by these structural elements. Five optimization variables have been used to control the cross section geometry of the pillar thin-walled box beam in three different areas, near the pillar extremities, in the middle of the pillar and in the intermediate areas. A sixth design variable has been used to control the material yield stress, considered equal for all the three sections.

The optimization problem has been solved with the code OPTISTAT which is based on multi-point optimization methodologies. The overall optimization process is structured as a

sequence of local optimization problems defined on a restricted portion of the space of admissible variables[4,5,6,7].
The disadvantage of the high number of analyses needed to evaluate response surfaces has been reduced by using a system working simultaneously on more computational units.

4 RESULTS ANALYSIS

The optimization led to the identification of a solution that represents a valid compromise between the two requirements: the survival space is preserved and the injury parameters keep being under the maximum allowed requirements values. As can be seen on table 1 the most significative variations between the initial values and the optimized ones have been obtained on the Intrusion, the HIC (-32%) and the PSF (-38%) parameters. This is due to the fact that the initial value of these parameters was the nearest or over the allowed limit.

	RIP	Int [m] (>0)	HIC (<1000)	TTI [g] (<85)	VC [m/s] (<1)	PSF [N] (<6000)
Initial values	0.695	-6.3e-2	941	62	0.13	5852
Optimized values	0.496	9e-3	642	53	0.11	3606
Variation	**-29%**	**-114%**	**-32%**	**-15%**	**-15%**	**-38%**

Table 1: Values obtained for the different parameters.

The best solution shows a tendency to move towards sections with a lower maximum collapse load than the maximum allowed (section of reduced dimensions), but able to absorb a great amount of energy during the formation of the plastic hinges (the thickness reaches the maximum allowed value).

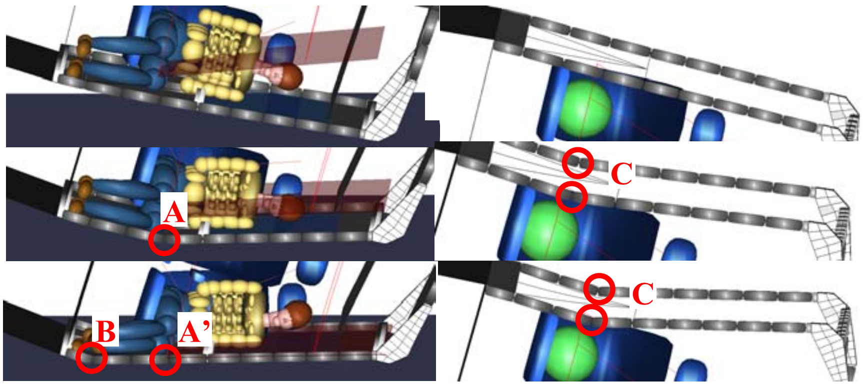

Figure 3: Plastic hinges formation during impact.

The interesting results obtained for the biomedical parameters are related to the particular process of pillar deformation that brings to an elevated absorption of energy due to the formation of many plastic hinges. On the impact side pillar it is possible to distinguish a first phase where there is the formation of a plastic hinge at the third joint (point A in fig. 3) and a second phase where this hinge bends back (point A' in fig. 3) and there is the formation of a second hinge (point B in fig. 3) in the first joint. In the pillar on the not impacting side there is the formation of a single plastic hinge (point C in fig. 3).

5 CONCLUSIONS

The problem of the design of the lateral pillars between the windows of a coach has been faced in order to find a solution that satisfies ECE66 regulation (coach rollover). The presence of dummies has been considered fundamental from the beginning of this work. A problem with opposite requirements has been faced: the non violation of the survival space requires a very stiff structure, while the respect of the limits on the biomechanical parameters needs a structure with large energy absorption capability. The formation process of plastic hinges along the pillars is fundamental for an adequate energy absorption.

The use of an optimization program based on the exploration of the response surfaces with fractional factorial plans (DOE) allows to obtain a design solution satisfying each request.

The biomechanical parameters are used alone as constraints and are opportunely combined to calculate the objective function RIP. The HIC and the maximum force on the pubic symphisis resulted the most critical while VC and TTI were in all the cases lower than prescribed.

The feasibility of this type of studies with adequate models and reasonable elaboration times is subordinated to the use of distributed computational resources.

ACKNOWLEDGEMENTS

This work is part of research activity done within the frame of COFIN 2001. The support of the Italian Ministry of Research is gratefully acknowledged.

REFERENCES

[1] J. C. Anderson, "Rollover crashworthiness of a new coach structure", *Cranfield Impact Center Ltd., Truck and Bus Meeting and Exposition*, Portland, Oregon, 4-6 December, 2000.

[2] S. Vincze "Occupant and rollover safety tests on coaches", *NATO Advanced Study Institute – Crashworthiness of Transportation Systems: Structural Impact and Occupant Protection*, Tròia, Portugal, 1996.

[3] D. Kecman "Occupant protection in minibus and coaches", *NATO Advanced Study Institute – Crashworthiness of Transportation Systems: Structural Impact and Occupant Protection*, Tròia, Portugal, 1996.

[4] G. Chiandussi, M. Avalle, G. Belingardi, "Design optimization by response Surface Methodology: application to crashworthiness design of vehicle structures", *Structural Optimization*, Vol. 24, 2002, pp. 225-332.

[5] G. Chiandussi, R. Fontana, F. Urbinati, "Design sensitivity analysis method for multi-disciplinary shape optimization problems with linear and non-linear response", *Engineering Computations*, Vol. 15, 1998, pp. 391-417.

[6] Haftka, R. T. , Gurdac, Z. , Kamat, "M. P. Elements of structural optimization", *Kluwer Academic Publishers*, 1990.

[7] Box GEP, "Draper NR. Empirical Model-Building and Response Surfaces", *New York: John Wiley & Sons*, 1987.