Adaptive Modeling and Optimization of Pilot Helmets for Different Kinds of Impacts With Hard Obstacles

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This paper presents a simulation model of absorption effects during helmet collision with a hard obstacle.It is based on a necessity to predict undesired consequences that may occur in case of helemet colision and impact with a hard obstacle. The primary aim of the paper is to determine real deformations during helmet collision with a hard obstacle by method of simulation of energy absorption effects and to establish a successfull model of optimum helmet design, from the aspect of engineering purposes, which corresponds to helmet behaviour in real conditions. Finite elements of the thin laminar shell type are used in helmet discretisation. Boundary conditions and loads are applied in such a way to simulate impact in the most realistic way.

The idea of helmet modeling and energy absorption effects simulation is based on a necessity to replace expencive experiments by contemporary structural analysis and applicable computer resources in primary design stages. The helmet model is supposed to be designed of multilayer laminar composite materials taking into account fiber orientation, possible impact directions and interlaminar-normalized value of dynamic strength. Also, attention is paid to the overall helmet strength and the ability of kinetic energy absorption. Finite elements of the thin laminar shell type are used in helmet discretisation. Boundary conditions and loads are applied in such a way to simulate impact in the most realistic way. The nonlinear finite element method is applied, and also nonlinearities in geometry are taken into account.

When passive safety parameters are to be determined it is interesting to determine maximal force which element or structure can support when exposed to damage loads or so called looping. In static safety tests, relation force – displacement is interesting while in dynamic tests relations force – time, displacement – time and force – displacement are interesting. Simulation has been done for different initial conditions, composites of different characteristics and it has been applied to different models. The common characteristic of all models is that high approximation levels applied enable obtaining of very usefull information in different design stages. Numerical analysis, tested static and dynamic models and results presented in this paper, according to the theoretical considerations, can successfully be applied with high accuracy in helmet design that will fulfill real life requirements.

In the construction, structural analysis and standard engineer practice, in order to support structure functionality, tree basic criteria must be satisfied:

(1) The first criterion is that supporting structure must be capable of carrying external load, while stresses greater than allowed stresses for given material must not appear.

(2) The second criterion is that displacement of certain structure points must stay bellow certain level (if that level is given by constructor's demands) when structure is exposed to external loads.

(3) The third criterion is that when structure is exposed to external loads there mustn't be any stability loss of some of its elements or global stability loss.

However, in addition to its primary function, which is to satisfy these tree criteria, the structure often has secondary function, which is sometimes as important as its primary function. That secondary function is its capability to carry certain amount of mechanical energy in proper manner when exposed to designed damage loads.

The secondary function is especially important in passive safety design process. The finite element nonlinear method is used for determination of these relations in practical applications. The finite element nonlinear method can include material, geometric and contact nonlinearity.

Fig.1 Simple of the very expencive experiments in primary helmet design

The finite element analysis has linear calculation process and it is predictable in sense of certain successful calculation ending and results achievement. Unlike the linear, this is not the case in nonlinear finite element analysis. In order to complete one nonlinear analysis successfully it is necessary to adjust adequately relevant parameters, that is, certain analysis coefficients, before or during the process of calculation. The practical use of nonlinear finite element analysis demands following activities before start and during the calculation:

(1) Adequate material model selection.
(2) Adequate convergence criterion selection.
(3) Selection of allowed number of iterations in increment - iterative procedure.
(4) Selection of adequate procedure for problem solution. In case of the system not having load limit point and in case of system load limit point, different solution strategies are selected.
(5) Selection of adequate events in accordance to the system nature.
(6) Selection of adequate increments in each event.
(7) Change of solution strategy and change of convergence criterion in case of bad current result.

Analytical model is formed by using analytical solution, displacement control method, Arc-Length method and adaptive system stabilization method, while Newton-Rapson procedure is used for nonlinear finite element analysis. For a given system

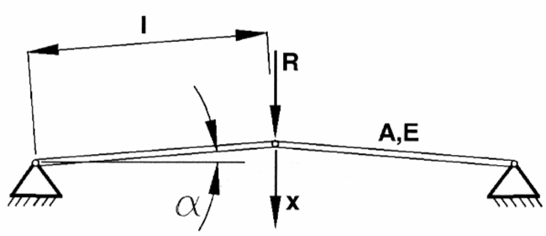


Fig.2

analytical solution is given by the following eqation

$$R = 2 \cdot E \cdot A \left[\frac{1}{\sqrt{1 - 2 \cdot \frac{x}{l} \cdot \sin\alpha + \left(\frac{x}{l}\right)^2}} - 1 \right] \cdot \left(\sin\alpha - \frac{x}{l} \right)$$

This relation is given on the chat at Fig. 3.

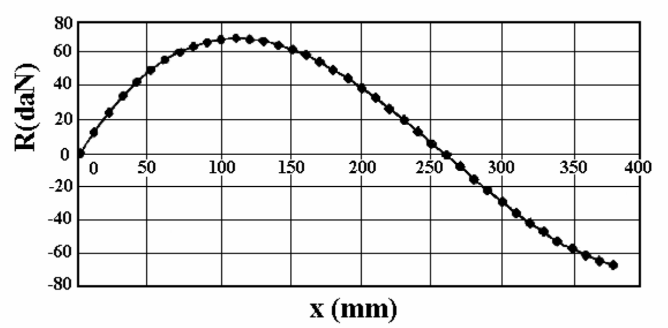


Fig.3

The displacement control method gives good results in solution of the problems related to load limit. However, this method can’t be applied successfully to structures showing snap-back effect.

Relatively new Arc-Length Method is based on the idea to create vector? from increment disturbance vector and external load and to limit it. It means that in vicinity of the load limit point the uncontrolled increment disturbance can not exist, therefore, there can not be convergence problems. Approaching the load limit point smaller and smaller load increments are achieved when negative pivot is registered in triangle factorization of tangent rigidity matrix and then unloading, that is, post critical area analysis begins.

At the beginning of the analysis initial load increment ${}^{(1)}\Delta\lambda$ is defined and Newton-Rapson method gives the initial displacement increment ${}^{(1)}\Delta X$, Then Arc-Length can be written as:

$$ds^2 = {}^{(1)}\Delta \underline{X}^T \cdot {}^{(1)}\Delta \underline{X} + \left({}^{(1)}\Delta X\right)^2$$

and then the iteration path follows the plane normal to the tangent (Fig. 4) so that scalar product of tangent ${}^{(1)}\Delta \underline{t}$ and increment displacement vector $\Delta X^{(i)}$ equals zero. This product contains the unknown load increment u and unknown displacement increment

$$\underline{t}^{(i)T} \cdot \Delta \underline{X}^{(i)} = 0$$

That is

$${}^{(1)}\Delta \underline{X}^T \cdot \Delta \underline{X}^{(i)} + {}^{(1)}\Delta\lambda^{t+\Delta t}\Delta\lambda = 0$$

In the same manner as in the method of displacement control it is possible to write displacement increment as

$$\Delta \underline{X}^{(i)} = {}^{t+\Delta t}\Delta\lambda \cdot \Delta \underline{X}^{(i)I} + \Delta \underline{X}^{(i)II}$$

where

$${}^{t}[K]_T^i \Delta \underline{X}^{(i)I} = {}^{\Delta t}\underline{R} \qquad \text{and} \qquad {}^{t}[K]_T^i \Delta \underline{X}^{(i)II} = {}^{t+\Delta t}\underline{F}$$

In the same manner as in the method of displacement control it is possible to write displacement increment as

$${}^{t+\Delta t}\Delta\lambda = -\frac{\Delta \underline{X}^{(1)T} \cdot \Delta \underline{X}^{(i)II}}{\Delta \underline{X}^{(1)T} \cdot \Delta \underline{X}^{(i)I} + {}^{(1)}\Delta\lambda}$$

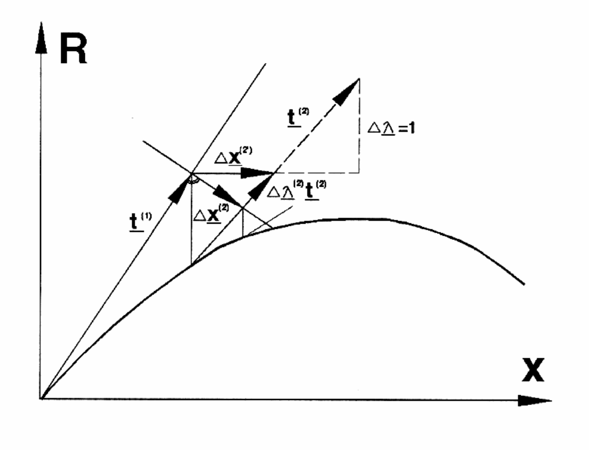


Fig.4

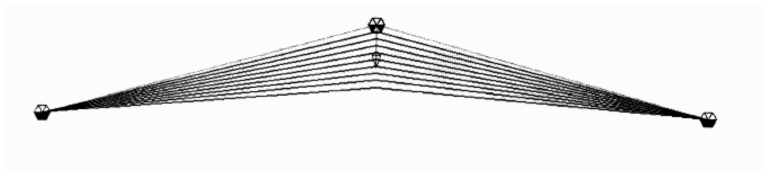


Fig.5 Newton-Rapson procedure nonlinear finite element analysis.

Discretisation of the helmet model is supposed to be designed of multilayer laminar composite materials taking into account fiber orientation, possible impact directions and interlaminar-normalized value of dynamic strength. Also, attention is paid to the overall helmet strength and the ability of kinetic energy absorption. Finite elements of the thin laminar shell type are used in helmet discretisation (Fig's. 6,7,8)

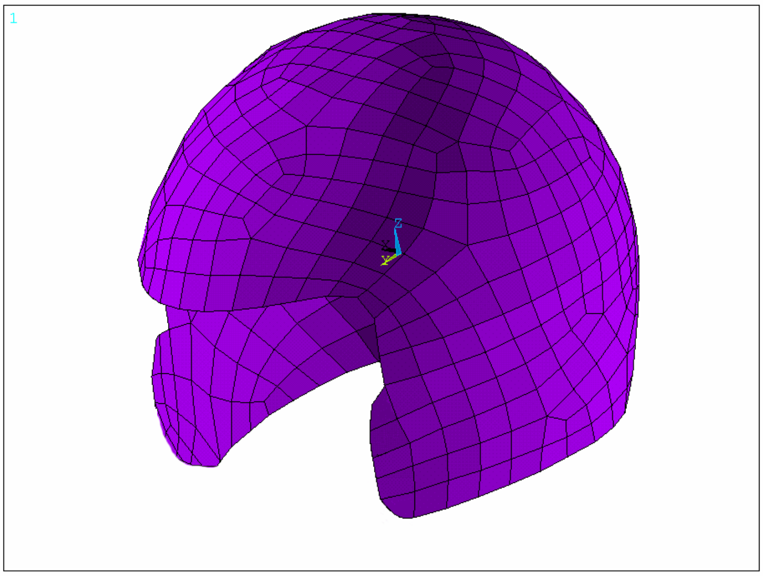
Fig.6

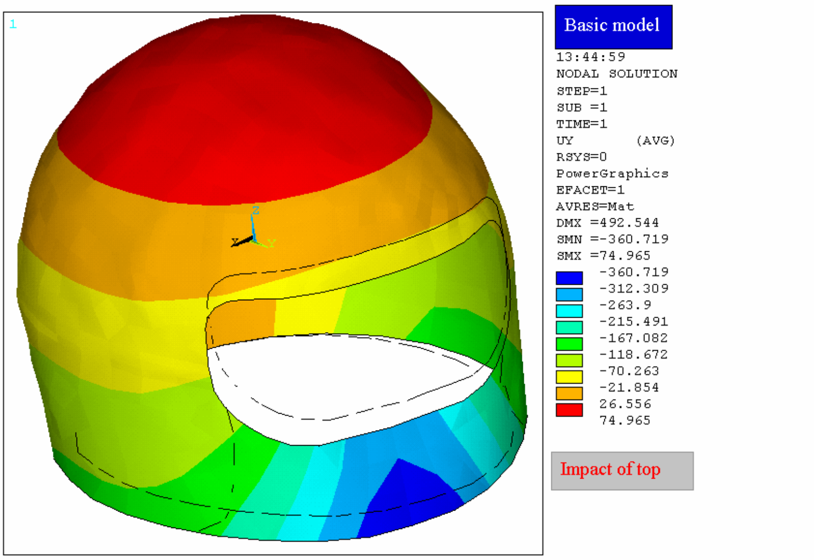
Fig.7

Fig.8

Simulation has been done for different initial conditions composites of different characteristics and it has been applied to different models. The common characteristic of all models is that high approximation levels applied enable obtaining of very usefull information in different design stages. Several computer software package is used for the simulation of helmet collision with a hard obstacle.

This method can be considered as standard crash-test for laboratory and numerical testing. It can be seen that, it during the loading the material has remaind in elastic domain, such helmet structure will recover me initial shape. Chats of impact force versus displacement follow. Numerical analysis tested static and dynamic models and results presented in this paper, according to the theoretical considerations, can successfully be applied with high accuracy in helmet design that will fulfill real life requirements. By designer the strinhtemd composite helmet it has the capacity to snap trough the post artical cidnition (Snap Trough).

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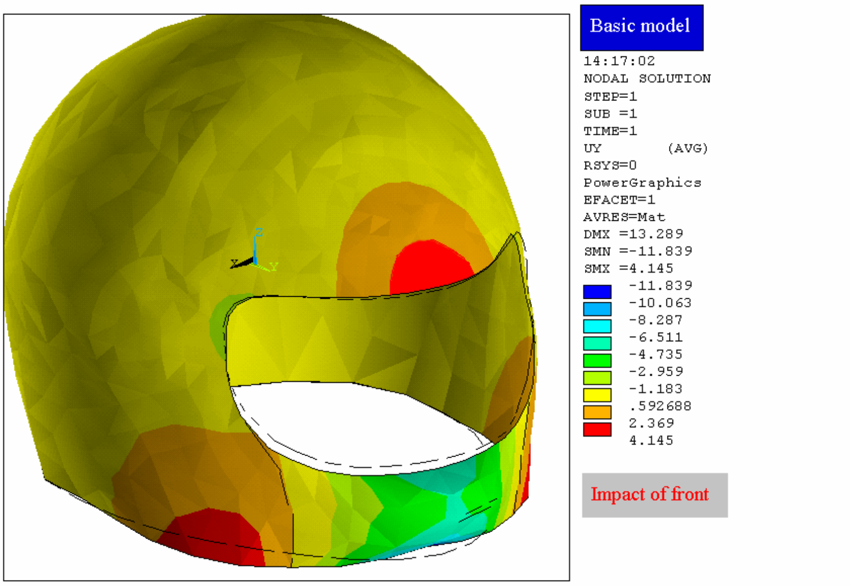
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Impact of front

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