NUMERICAL SIMULATION OF THE WOOD RESPONSE TO THE HIGH VELOCITY LOADING .

J.Buchar[1]* , J.Voldřich[2]

[1]Mendel University of Agriculture and Forestry , Zemedelska 1, 613 00 Brno, Czech Republic,phone : (+4205) 43 24 21 66, e – mail : buchar@mendelu.cz

[2] Research Center of the West Bohemia University, 306 14 Plzeň, Czech Republic, phone : (+4205) 74 91 314, fax : (+4205) 742 14 19

Abstract

The experiments where the freely supported spruce beams have been loaded by the detonation of an explosive charge have been evaluated using of the numerical simulation. The explicit Lagrangean finite element code LS DYNA 3D has been used to analyse the beam response. The wood has been considered as global orthotropic linear elastic material with a material damage. The material damage has been described by the strain at the wood failure. This simple material model seems be better than the Tsai - Wu model widely used in another numerical simulations.

Spruce wood , beam , material damage, explosive loading, finite element , numerical analysis

Wood is an anisotropic cellular material such as honeycombs, metal ring systems, polymeric foams and some others . These materials are very convenient for the design of impact energy absorbers and as core materials in lightweight structures. Their behaviour under static loading is well summarised in the book (Gibson and Ashby 1988). Wood in particular has also been used as a protective material for high velocity impact events for many centuries (Johnson 1986a, 1986 b) and is very often used as an impact energy absorbing material at the design of the transportation flasks for nuclear fuel etc. There have been only a few systematic studies of the behaviour of wood under high rates of loading following from some impact events (Johnson 1986a). Recently the extensive impact test data have been obtained for some wood species (Reid and Peng 1997, Harrigan et al. 1998) . These data have been used for the development of the models of the macro – deformation and micro – deformation modes resulting from the dynamic uniaxial compression at the specimen impact.

The present paper focuses on the other kind of the dynamic loading which is the effect of the detonating explosive. The study of this problem has some practical applications . Wood may be successfully used as a part of a structure which should absorbed most of the energy of the mine explosion etc. It is obvious that there is a variety of different arrangements, kind of wood, thickness of wood layer etc. In order to reduce the number of expensive experiments some reliable numerical simulation is necessary. The present paper deals with the problem of such numerical analysis using of the finite element code LS DYNA 3D.

MATERIAL AND EXPERIMENTAL PROCEDURE.

The spruce beams (100 x 100 x 1500 mm) have been loaded by the detonation of the TNT charge - see Fig.1.

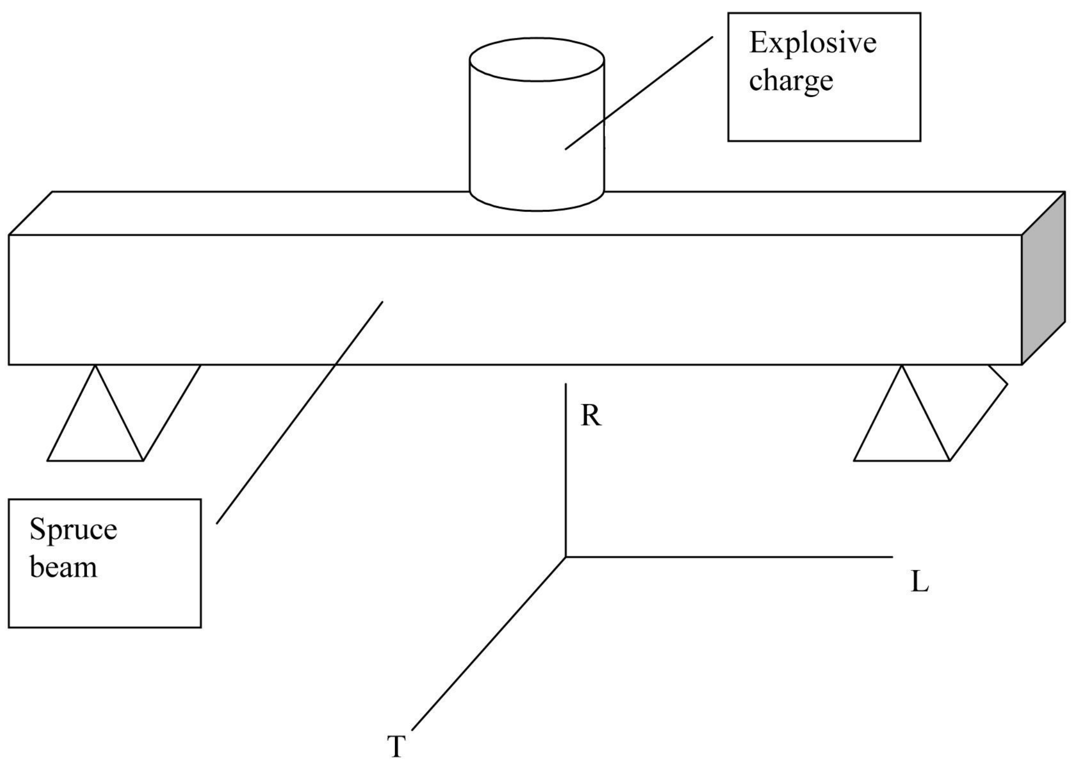


Fig.1. Schematic of the Spruce beam loading.

In the given Figure the orientation of the beam is also outlined. (L is the longitudinal, R radial and T tangential direction). The charge has the form of the cylinder, 40 mm in diameter and 30 mm in height. The properties of the explosive are given in the following chapter. The tested beams have been completely broken into two pieces. The detail description of the experiments are given in (Buchar et al., 2000).

DESCRIPTION OF THE MATERIAL BEHAVIOUR.

The numerical simulation of the problem shown in Fig.1 has been performed using finite element code LS DYNA 3D. The wood has been considered as the orthotropic elastic solid with a failure. The failure is achieved if a very simple criterion is yield :

$$\varepsilon_1 \geq \varepsilon_{max},$$

where ε_1 is the maximum principal strain , and ε_{max} is the principal strain at the failure . The elastic constants have been determined from the ultrasound measurements (Buchar and Slonek 1994) . Their values are :

Young`s moduli

E_L = 9.56 GPa, E_R = 1.04 GPa, E_T = 0.487 GPa

Shear moduli

G_{LR} = 0.750 GPa, G_{RT} = 0.039 GPa, G_{TL} = 0.720 GPa

Poisson`s ratio

ν_{LR} = 0.029, ν_{RT} =0.039 ν_{TL} = 0.250

The failure strain has been chosen as 5% . For higher values of this strain no complete fracture of the beam occurred.

The behaviour of the TNT detonation gas products, the Jones - Wilkins - Lee (JWL) equation of state has been used, together with the programmed burn model - the detonation velocity has been assumed to be 6930 m/s (Adamík and Buchar, 1999). The JWL equation has the form :

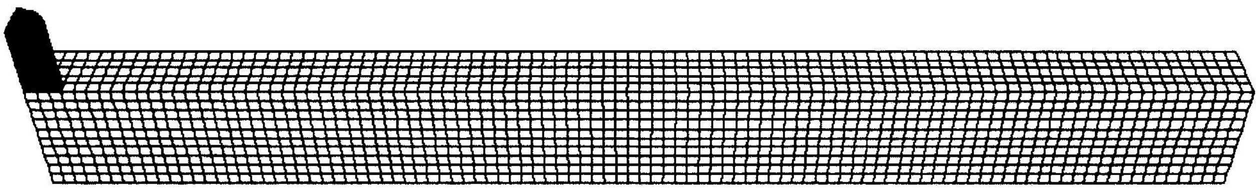
$$p = A\left[1 - \frac{\omega}{R_1 V}\right]\exp(-R_1 V) + B\left[1 - \frac{\omega}{R_2 V}\right]\exp(-R_2 V) + \frac{\omega E}{V}$$

Where p is the detonation pressure, V is the relative volume and E is the internal energy density. The parameters has been taken from (Dobratz and Crawford, 1985) :

A=272.7 GPa, B= 3.231 GPa , R_1 = 4.15, R_2 = 0.95, ω = 0.3

Initial density of the explosive was 1630 kg/m^3.

The finite element model of the charge and the beam is introduced in Fig.2.

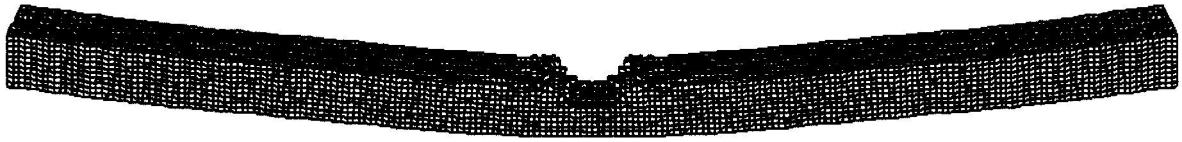


2: Finite element model of the experiment shown in Fig.1.

With the respect to the real geometry from the Fig.1 the 1/4 geometry has been used.

NUMERICAL RESULTS.

In the first step the maximum of the strain at which the beam failure occurs has been determined. In our first paper (Buchar et al, 2000) we have found that at the impact bending of the spruce wood this strain is 11%. If we use this value we can see that no damage of the beam occurs - see Fig.3.



3: The final shape of the spruce beam (time t = 8 ms).

The experiments showed that all beams were broken into two parts. By the gradually decreasing of this strain we achieved the value of 5%. Just above this strain no failure occurs. In Figs.4-7 the development of the beam failure is shown.

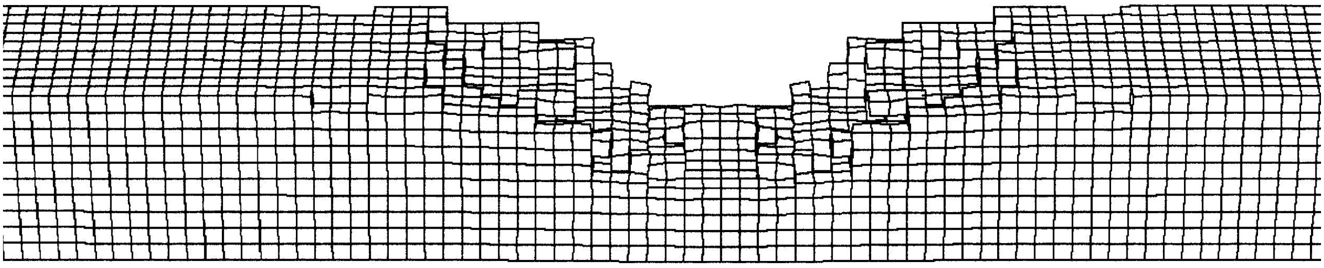


Fig.4. Damage of the spruce beam at the time 50 ms.

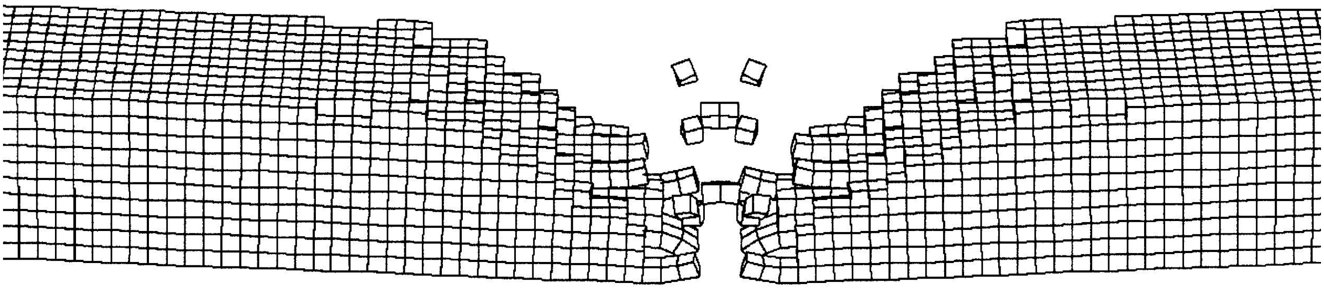


Fig. 5: Damage of the Spruce beam at the time 1 ms.

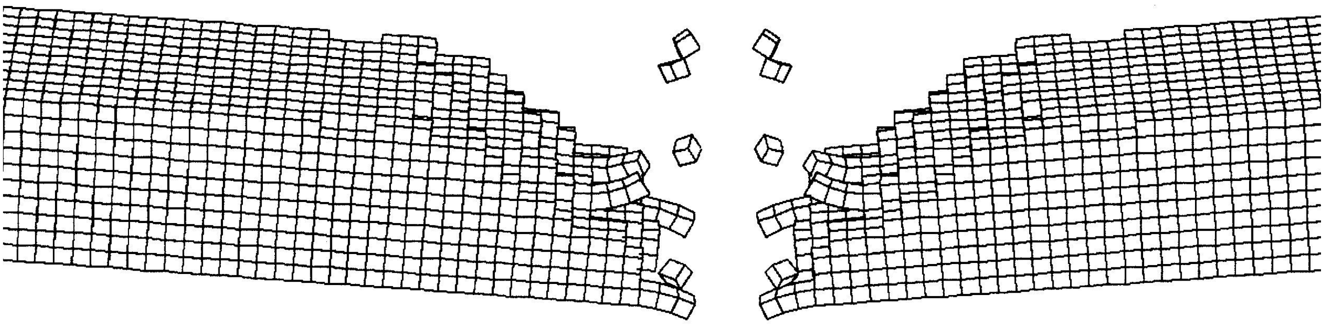


Fig.6. Damage of the Spruce beam at the time 2 ms.

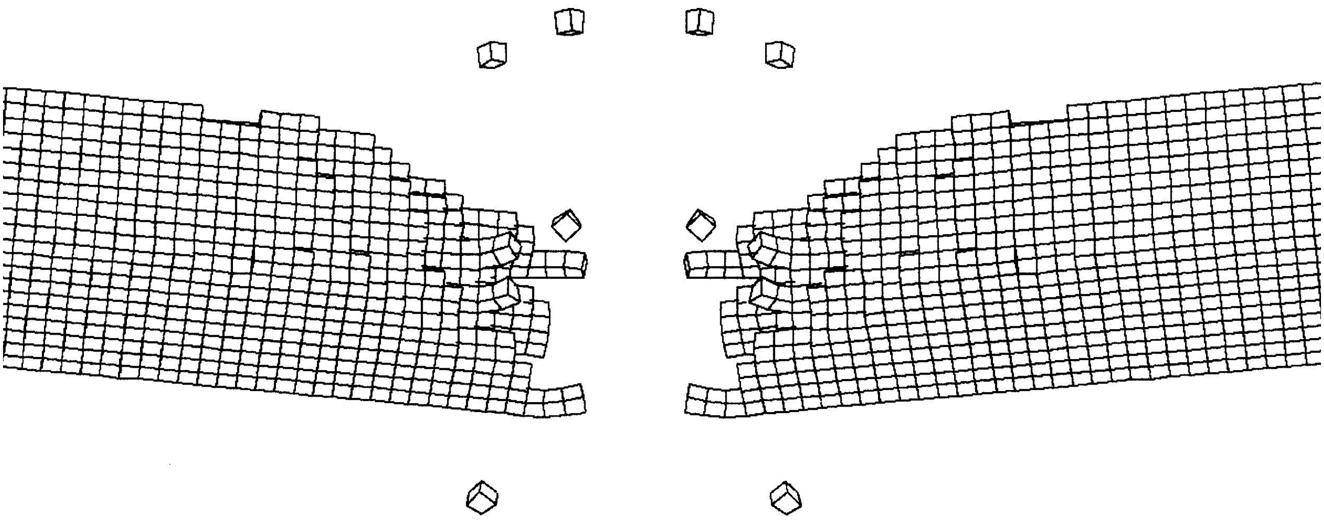


Fig.7. Damage of the Spruce beam at the time 3 ms.

Even if the model of the wood behaviour is very simple the resultant beam damage is very similar to the experimentally observed beam fracture. If we used the Tsai - Wu model (Tsai and Wu,1971) of the wood damage as in our previous paper (Buchar et al. 2000) the numerical analysis led to the results that the fragmentation of the beam should occurs. It means this model is inconvenient for the analysis of the given experiment.

The main computation has been focused on the highlighting of the stress pattern in the beam. In the Fig.8 the time development of the normal stress in the L direction is displayed.

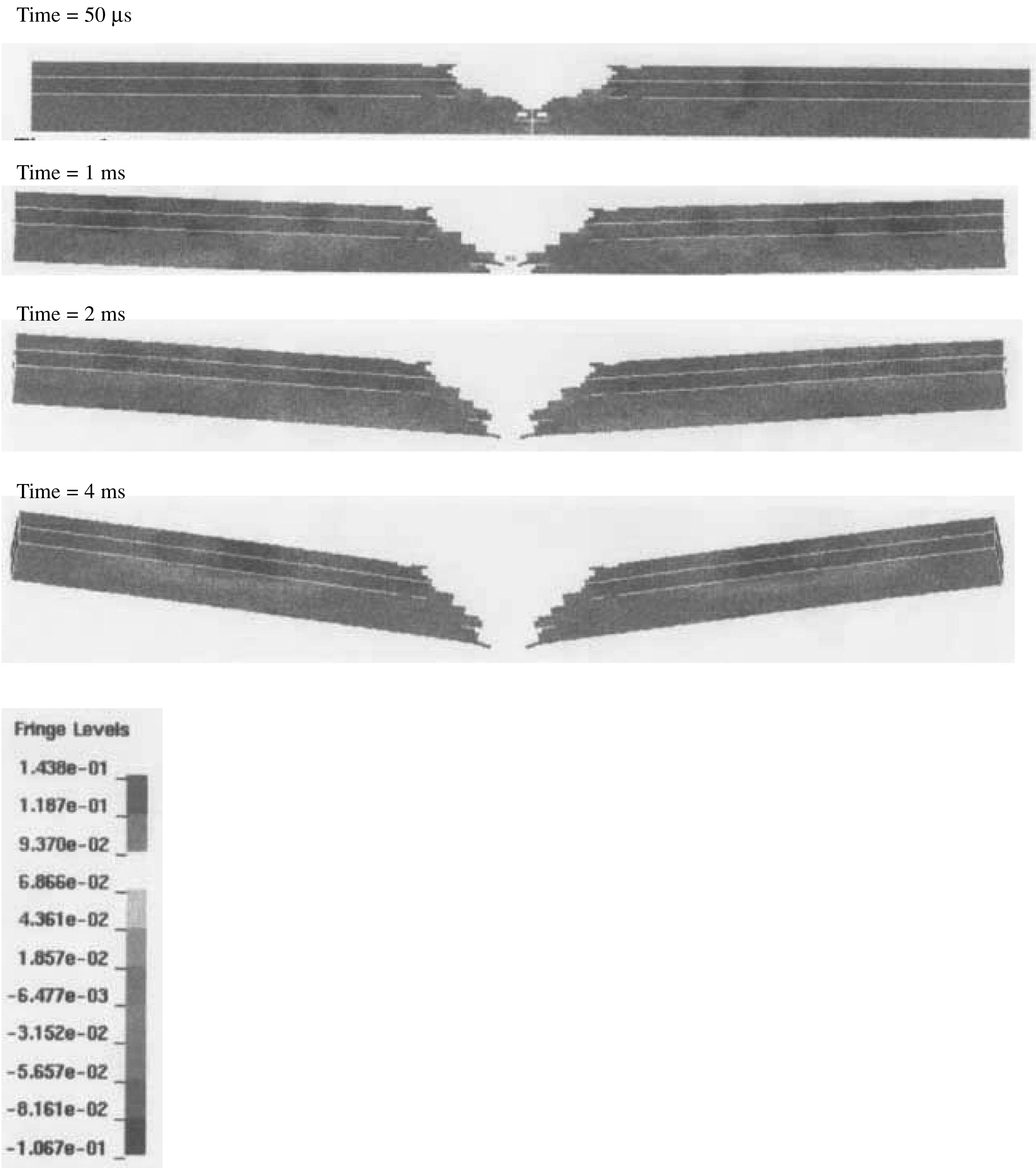


Fig.8. The time development of the normal stress (in GPa) in the L direction.

The detail analysis indicates that the complete fracture of the beam occurred at the time 0.9 ms. The values of these stress component are significantly higher than the strength of the Spruce wood in the L direction at the static loading. This phenomenon manifests the role of the strain rate at the deformation of the wood. The stresses in the R and T directions are.

The loading has the wave character. It means there is no chance to use the quasi - static analysis like in the case of the dynamic three point bending. The loading exhibits a local character . The resulting force in the contact area between the spruce beam and the explosive charge is shown in Fig.9.

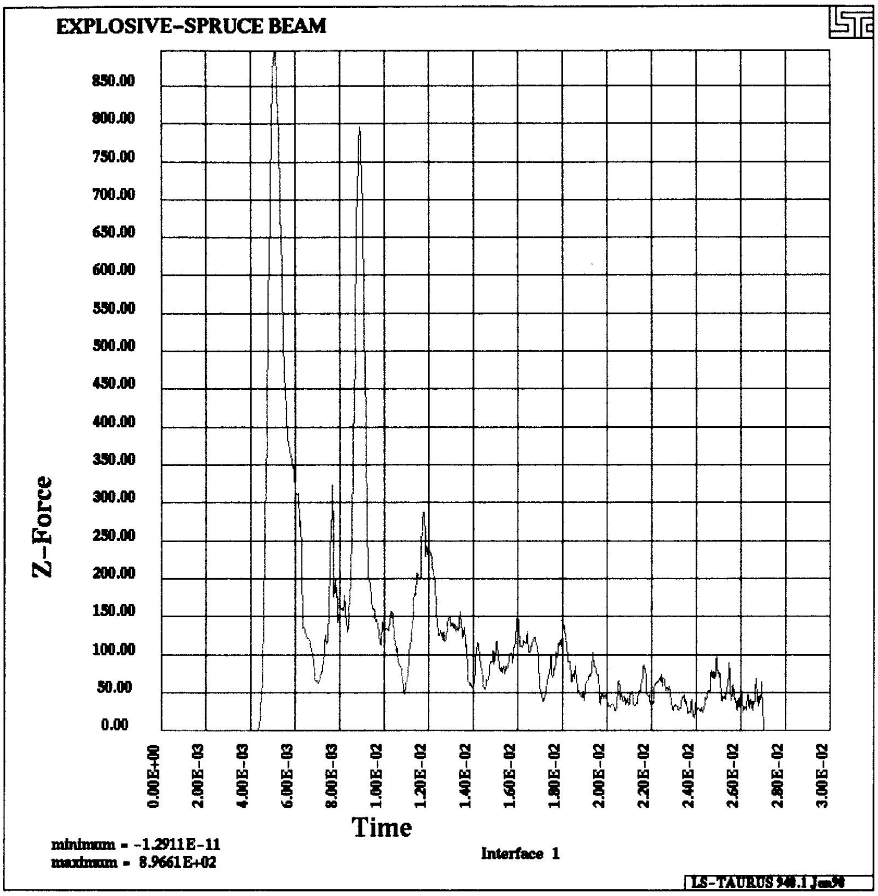


Fig.9. The dependence of the resulting force(in kN) in the contact area on the time (in ms).

This force exhibits two significant peaks. At the same time the force acting on the support (the support is considered as an rigid body) is much more lower compared to a loading force in Fig.9. The time dependence of the force in the point of the support is displayed in Fig.10.

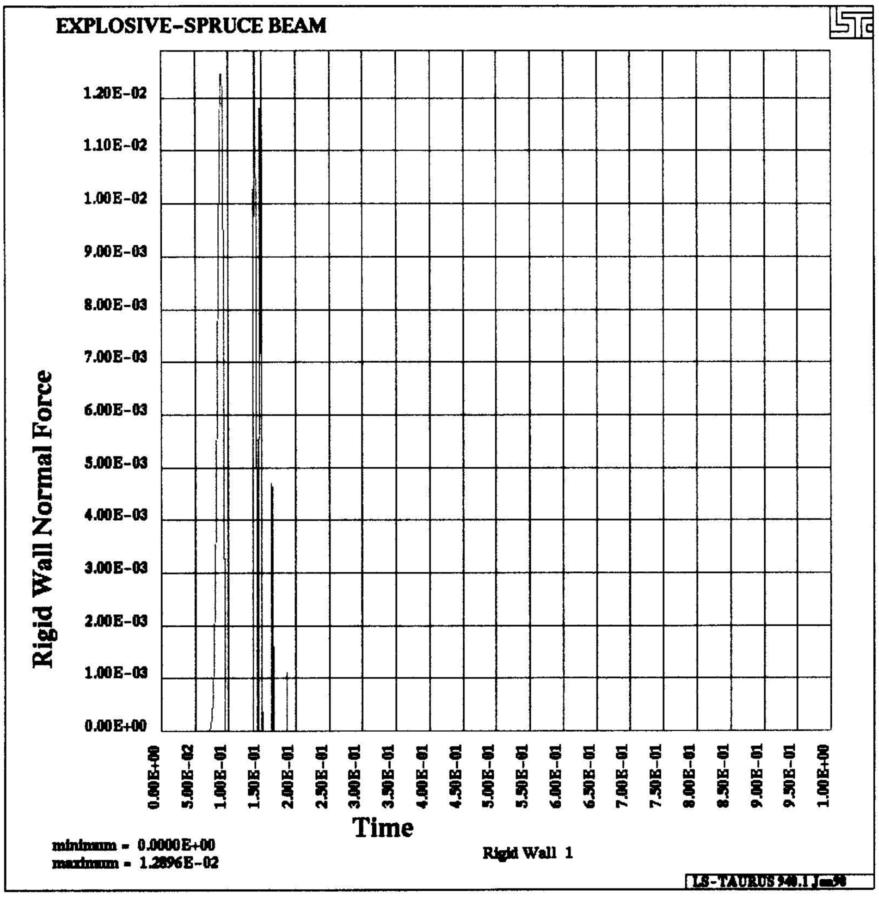


Fig.10. Dependence of the force (in kN) acting on the beam support on the time (in ms).

CONCLUSIONS.

The numerical analysis performed in the given paper suggests that the finite element code LS DYNA 3D is capable to analyse a problem of an explosive loading of a wood structure. The behaviour of wood is relatively satisfactory described by a simple model, where the material damage is characterised by the maximum of the strain. The non - linear wood behaviour which is remarkable e.g. at the static loading of the wood (namely in the compression) probably plays no or only minor role during the extremely rapid loading . This phenomenon should be verified by next both experimental and theoretical research. The reasonable agreement between the results of experiments and numerical simulation promises the use of the given software for the analysis of much more complicated structures than that in the given paper.

ACKNOWLEDGEMENT.

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