SUSTAINABLE DEVELOPMENT
OF AUTOMOTIVE INDUSTRY

BOOK OF ABSTRACTS

INTERNATIONAL CONGRESS
MOTOR VEHICLES & MOTORS
www.mvm.mfkg.kg.ac.yu

8th - 10th OCTOBER 2008.
KRAGUJEVAC
SERBIA

Faculty of Mechanical Engineering

Dept. Of MOTOR VEHICLES AND MOTORS, FME Kragujevac & Journal " Mobility &Vehicles Mechanics "

ZASTAVA
R&D Institute

International Congress – Motor Vehicles & Motors 2008

Sustainable Development of Automotive Industry

BOOK OF ABSTRACTS

October 2008.
Kragujevac, Serbia

Publisher: Faculty of Mechanical Engineering in Kragujevac
Serbia, 34000 Kragujevac, Street. Sestre Janjić 6

For Publisher: Prof. dr Miroslav Babić – Dean

Editors: Prof. Dr Dragoljub Radonjić
Prof. Dr Aleksandra Janković

Technical preparation: M. Sc. Danijela Miloradović, assist.
M. Sc Jasna Glišović, assist.
Vesna Maksimović, ME

Print: INTERAGENT
Grafički centar, Kragujevac
ISBN 978-86-86663-39-9

Year of publication: 2008.
Number of copies printed: 300

CIP - Katalogizacija u publikaciji
Narodna biblioteka Srbije, Beograd

629.3(048)
621.43(048)

INTERNATIONAL Congress- Motor Vehicles & Motors (2008; Kragujevac)

Sustainable Development of Automotive Industry: book of abstracts / International Congress – Motor Vehicles & Motors 2008, [8th-10th] October 2008., Kragujevac, Serbia; [congress organizers Department for MotorVehicles and Motors FME, International Journal "Mobility and Vehicle Mechanics", Zastava Automobiles; editors Dragoljub Radonjić, Aleksandra Janković]. – Kragujevac: Faculty of Mechanical Engineering, 2008 (Kragujevac: Interagent). – 82str. : 24 cm

Tiraž 300. — Napomene uz tekst.

ISBN 978-86-86663-39-9

1. Faculty of Mechanical Engineering (Kragujevac) Department for Motor Vehicles and Motors
2. International Journal Mobility and Vehicle Mechanics (Kragujevac)
3. Zastava Automobiles (Kragujevac)
а) Моторна возила – Апстракти
б) Мотори са унутрашњим сагоревањем – Апстракти

COBISS.SR–ID 151893516

Publishing of this book is supported by:

Ministry of Science and Technological Development, Republic of Serbia

Scientific Board

Organizational Board

President: Vladeta Kostić, "Zastava Automobiles Marketing office"

Secretaries: Milan Stanojević, "Zastava Automobiles - Car development office ",
Zoran Petrović, "Zastava Automobiles - Marketing office"

Members:
Prof. Dr Aleksandra Janković, FME Kragujevac
Milan Popović, "Zastava Automobiles - Car development office "
M. Sc. Zoran Bogdanović, " Zastava Auto"
Dr. Branislav Nedeljković, " Zastava Automobiles"
Zoran Stošić, "Zastava AGeM"
M. Sc. Vladimir Vučković, City Hall of Kragujevac
M. Sc. Dušan Pućа, Regional Economic Council Kragujevac

Congress Organizers

- Department for Motor Vehicles and Motors, FME Kragujevac
- International Journal "Mobility & Vehicle Mechanics"
- "Zastava Automobiles – R & D Institute "

Congress Sponsors

- Government of the Republic of Serbia
- " Zastava Automobiles "
- City Hall of Kragujevac
- Faculty of Mechanical Engineering

Content

Introductory Lectures

Section A Power Train Technology

Section B Vehicle Design and Manufacturing

Section C Vehicle Dynamics and Intelligent Control Systems

Section D Driver/Vehicle Interface, Information and Assistence Systems

Section E Transport Challenges in Emerging Economies

FOREWORD

Traditional organizing of international "MVM" Symposium became the brand Faculty of Mechanical Engineering and the University from Kragujevac. This ye also, a considerable number of papers from the country and from abroad were omitted, as same as the traditional support from Ministry of Science, the city Kragujevac, our friends and contributors in manufacturing or servicing activit correlated to automobiles.

This time also, the papers from many scientists and researchers in the field motor vehicles gave a specific impression to this meeting, though the presence increased number of papers from similar branches is also noticeable. Mo vehicles from their origin had a considerable attention both from the mechani engineers and the business people, and in the process of vehicles development a implemented scientific achievements from various scientific fields. Motor vehicl have a wide user population, and they, with their own demands, impose n classes and new car categories. According to technical and technological tre development, same as with different needs of the customers, a focus of c manufacturers is displaced towards to specific car types or car classes, but the c in general, as the actuality, a challenge and the need is still at the "stage".

It is quite clear that the car as the multidisciplinary object of progress and resear from one side and as the object of need or prestige from the other one, is actua the target for development and investment. Besides, car is the means th connecting distant destinations more and more faster, and at the same time it h improved mobile performances within the city driving, and therefore as the object traffic planning and traffic regulation take, without any doubt, the most significa place. Therefore there is the tendency of spreading of the participated pap outlines, namely, except of vehicles mechanics and the processes within the engi itself, a certain area is dedicated to fields such are management, recyclir regulations, auto-electronic, economy, traffic.

In Kragujevac, October 8th-10th, 2008

Scientific and Organizational Board
MVM 2008

International Congress Motor Vehicles & Motors 2008

Kragujevac, October 8th-10th, 2008

MVM20080073

Nenad Đorđević [1]
Vladimir Milovanović [2]
Miroslav Živković [3]

EXPLICIT DYNAMICS ANALYSIS IN WAGGON CRASH APPLICATION

ABSTRACT: This paper represents a set of knowledge and experience that the authors obtained through becoming acquainted with software package LS-DYNA, as well as with the kinds of problems that can be successfully be solved in this software. Due to developed algorithms for contact problem solving, LS-DYNA found a huge practice in the car industry, especially in the crash tests simulating. This paper contains analysis of the waggon-cistern crash into a still rigid barrier.

KEYWORDS: explicit dynamic, crash analysis, FEM

1 Nenad Đorđević, School of Engineering Cranfield University, Cranfield Bedfordshire MK43 0AL England, UK, n.djordjevic@Cranfield.ac.uk

2 *Vladimir Milovanović, Faculty of Mechanical Engineering, Sestre Janjić 6, 34000 Kragujevac, vladicka@kg.ac.yu*

3 *Miroslav Živković, PhD, Faculty of Mechanical Engineering, Sestre Janjić 6, 34000 Kragujevac, zile@kg.ac.yu*

ISBN 978-86-86663-39-9

International Congress Motor Vehicles & Motors 2008

Kragujevac, October 8th-10th, 2008

MVM20080073

Nenad Đorđević[1]
Vladimir Milovanović[2]
Miroslav Živković[3]

EXPLICIT DYNAMICS ANALYSIS IN WAGGON CRASH APPLICATION

ABSTRACT: This paper represents a set of knowledge and experience that the authors obtained through becoming acquainted with software package LS-DYNA, as well as with the kinds of problems that can be successfully be solved in this software. Due to developed algorithms for contact problem solving, LS-DYNA found a huge practice in the car industry, especially in the crash tests simulating. This paper contains analysis of the waggon-cistern crash into a still rigid barrier.

KEYWORDS: explicit dynamic, crash analysis, FEM

INTRODUCTION

LS-DYNA is multipurpose software for explicit and implicit numerical integration of construction dynamic analyses and represents one of the most famous and best softwares that solves multiphysical problems.

The first part shortly presents the theoretical basis that the algorithms implemented in the software are based on. At the beginning, motion equations are presented and then the method of central differences is shortly described, so in the end we reach the modified method which is used in the software and the criteria to be fulfilled. In the very end of the theoretical part, there are basis of contact problems theory.

The second part of the paper processes the example of crash analises, waggon-cistern crash into a rigid wall. The end of the paper is a general impression based on the up-to-date experience as well as some guidelines for the future work/tasks.

THEORETICAL BASIS

System motion equations

We observe a simple system with one degree of freedom, fig. 1, as well presenting the forces that influence the mass m.

[1] *Nenad Đorđević, School of Engineering Cranfield University, Cranfield Bedfordshire MK43 0AL England, UK, n.djordjevic@Cranfield.ac.uk*
[2] *Vladimir Milovanović, Faculty of Mechanical Engineering, Sestre Janjić 6, 34000 Kragujevac, vladicka@kg.ac.yu*
[3] *Miroslav Živković, PhD, Faculty of Mechanical Engineering, Sestre Janjić 6, 34000 Kragujevac, zile@kg.ac.yu*

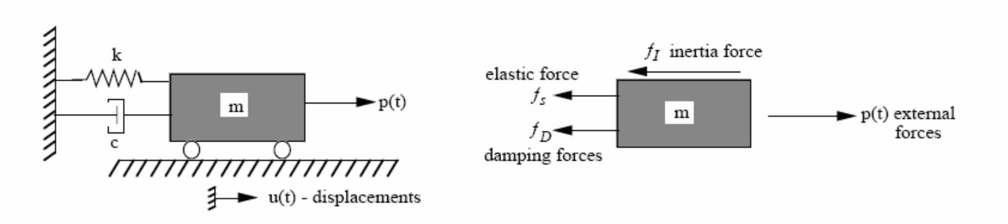

Figure 1 *System with muffling with one degree of freedom; figure of system and forces that influence it*

Equilibrium equation, derived from the use of d Alamber's principle is [1, 2, 3]:

$$f_I + f_D + f_S = p(t) \tag{1}$$

where the inertial force f_I , muffling f_D and rigidness force f_S are presented with the equations (2)

$$\begin{aligned} &f_I = m\ddot{u} \qquad \ddot{u} = \frac{d^2u}{dt^2} \quad \ddot{u} - acceleration \\ &f_D = m\dot{u} \qquad \dot{u} = \frac{du}{dt} \quad \dot{u} - velocity \\ &f_S = ku \quad u - displacement \quad k - stiffness \end{aligned} \tag{2}$$

Motion equation for linear problems is presented with equation (3), whereas the equation (4) is for nonlinear case:

$$m\ddot{u} + c\dot{u} + ku = p(t) \tag{3}$$

$$m\ddot{u} + c\dot{u} + f_S(u) = p(t) \tag{4}$$

Analitical solution is possible to determine only in linear differential motion equation. Dynamic response of unmuffled system under the influence of harmonious load is presented with equation:

$$u(t) = u_0 \cos(\omega t) + \frac{\dot{u}_0}{\omega}\sin(\omega t) + \frac{p_0}{k}\frac{1}{1-\beta^2}(\sin(\overline{\omega}t) - \beta\sin(\omega t)) \tag{5}$$

where $u_0, \dot{u}_0$ is the initial displacement and initial velocity, $\frac{p_0}{k}$ is static displacement, $\frac{1}{1-\beta^2}$ is a dynamic factor. In this case, harmonious displacement is defined with the equation

$$p(t) = P_0 \sin(\overline{\omega}t) \tag{6}$$

In the equations above circular frequency $\omega = \sqrt{\frac{k}{m}}$ and load frequency $\beta = \frac{\overline{\omega}}{\omega}$ are figurating.

<u>Integrations of differential motion equations</u>

The only possible way to solve nonlinear problems is numerical. There are two methods of direct integration of differential motion equations. They are implicit and explicit methods of integration. The fundamental difference between these methods is the fact that in the algorithm of implicit integration the equation for time step t_{n+1} is being solved, while in the case of explicit method the equation for time step t_n is being solved. Besides that, implicit integration is unconditionally stable, regardless the size of the time step, whereas the explicit methods are conditionally stable, since it is necessary to choose a very small time step.

In LS-DYNA software the algorithms for numerical integration are developed that are based on explicit methods, or to say, on the central differences method. Practically, LS-DYNA uses the modified method of central differences.

Central differences

Discretization in method of central differences is presented on fig. 2.

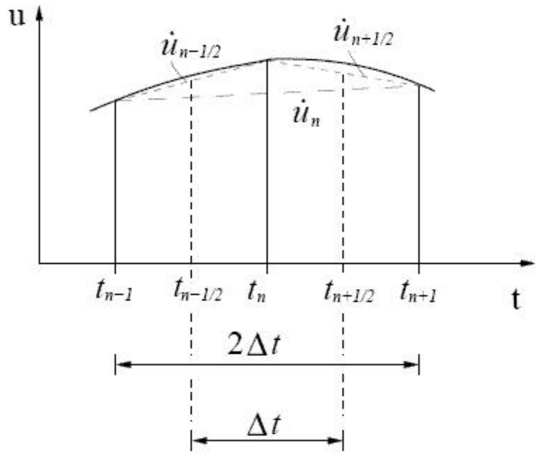

Figure 2 *Discretization by central differences method*

According to fig. 2, velocity and acceleration in the moment t_n are in the eqautions:

$$\dot{u}_n = \frac{1}{2\Delta t}(u_{n+1} - u_{n-1})$$
$$\ddot{u}_n = \frac{1}{\Delta t}(\dot{u}_{n+\frac{1}{2}} - \dot{u}_{n-\frac{1}{2}}) \tag{7}$$
$$\ddot{u}_n = \frac{1}{(\Delta t)^2}(u_{n+1} - 2u_n + u_{n-1})$$

Equilibrium eqaution in the matrix form in the moment t_n is:

$$\mathbf{M}\ddot{\mathbf{u}}_\mathbf{n} + \mathbf{C}\dot{\mathbf{u}}_\mathbf{n} + \mathbf{K}\mathbf{u}_\mathbf{n} = \mathbf{P}_\mathbf{n} \tag{8}$$

where $\mathbf{M}$ is mass matrix, $\mathbf{C}$ is muffling matrix, $\mathbf{K}$ is stifness matrix, and $\mathbf{P}_\mathbf{n}$ is vector of outer forces. By replacing equation (7) in the equilibrium equation (8),we get:

$$(\mathbf{M} + \frac{1}{2}\Delta t\mathbf{C})\mathbf{u}_{\mathbf{n}+1} = \Delta t^2 \mathbf{P}_\mathbf{n} - (\Delta t^2 \mathbf{K} - 2\mathbf{M})\mathbf{u}_\mathbf{n} - (\mathbf{M} - \frac{1}{2}\Delta t\mathbf{C})\mathbf{u}_{\mathbf{n}-1} \tag{9}$$

In the moment $t = 0$, considering the initial conditions $\mathbf{u}_\mathbf{0}$ and $\dot{\mathbf{u}}_\mathbf{0}$, as well as $\ddot{\mathbf{u}}_\mathbf{0}$, we get:

$$\mathbf{u}_{-1} = \mathbf{u}_0 - \Delta t\dot{\mathbf{u}}_0 + \frac{\Delta t^2}{2}\ddot{\mathbf{u}}_0 \tag{10}$$

As it was lraedy said, method of central differences is conditonally stable, so the size of the time step is restricted.

Stability of central differences method

Stability of central differences method is defined by stability of the linear system. We are starting from coupled system of linear motion equations in modal equations.

$$\mathbf{u} = \phi_1 x_1 + \phi_2 x_2 + ... + \phi_N x_N = \mathbf{\Phi x} \tag{11}$$

Vector of eigen value, $\mathbf{\Phi}$, is normalized regarding the mass matrix and stiffness matrix:

$$\mathbf{\Phi^T M \Phi} = \mathbf{I}$$
$$\mathbf{\Phi^T K \Phi} = \omega^2 \qquad (12)$$

With this normalization we get the equation for viscous muffling:

$$\mathbf{\Phi^T C \Phi} = 2\xi\omega \qquad (13)$$

Motion equation for generalised displacements are:

$$\ddot{x} \ + 2\xi_i \omega_i \dot{x} + \omega^2 x = Y_i \qquad (14)$$

where

$$\mathbf{\Phi^T p} \ = \mathbf{Y} \qquad (15)$$

Equations for generalised velocities and displacements towards central differences are:

$$\dot{x}_n = \frac{x_{n+1} - x_{n-1}}{2\Delta t} \quad \ddot{x}_n = \frac{x_{n+1} - 2x_n + x_{n-1}}{\Delta t^2} \qquad (16)$$

By replacing the equation 16 in motion equation 14, we get

$$x_{n+1} = \frac{2 - \omega^2 \Delta t^2}{1 + \xi\omega\Delta t} x_n - \frac{1 - \xi\omega\Delta t}{1 + \xi\omega\Delta t} x_{n-1} + \frac{\Delta t^2}{1 + \xi\omega\Delta t} Y_n$$
$$x_n = x_n \qquad (17)$$

Or to say, in the matrix form we have:

$$\begin{bmatrix} x_{n+1} \\ x_n \end{bmatrix} = \begin{bmatrix} \frac{2 - \omega^2 \Delta t^2}{1 + \xi\omega\Delta t} & -\frac{1 - \xi\omega\Delta t}{1 + \xi\omega\Delta t} \\ 1 & 0 \end{bmatrix} \begin{bmatrix} x_n \\ x_{n-1} \end{bmatrix} + \begin{bmatrix} \frac{\Delta t^2}{1 + \xi\omega\Delta t} \\ 0 \end{bmatrix} Y_n$$
$$\mathbf{\hat{x}_{n+1}} = \mathbf{A\hat{x}_n} + \mathbf{LY_n} \qquad (18)$$

where $\mathbf{A}$ is the operator of the motion equation integration. After m time steps and $\mathbf{L} = 0$ we get:

$$\mathbf{\hat{x}}_m = \mathbf{A}^m \mathbf{\hat{x}}_0 \qquad (19)$$

When $m \to \infty$, operator of the integration $\mathbf{A}$ has to stay restricted. By special decomposition of operator decomposition $\mathbf{A}$ we get:

$$\mathbf{A}^m = \left(\mathbf{P}^T \mathbf{J} \mathbf{P}\right)^m = \mathbf{P}^T \mathbf{J}^m \mathbf{P} \qquad (20)$$

where $\mathbf{P}$ is orthonormed vector which contains eigen matrix $\mathbf{A}$, and $\mathbf{J}$ is Jordan's form with eigen matrix values $\mathbf{A}$ on the diagonal. Stability criterium is defined through radius of eigen values spectrum, $\rho(A)$, as:

$$|\rho(A)| \leq 1 \qquad (21)$$

This way, criterium for $\mathbf{J}^m$ to be restricted is fulfilled.
Eigen matrix values $\mathbf{A}$ for unmuffled system are obtained from: za neprigušeni sistem dobijaju se iz:

$$Det\left(\begin{vmatrix} 2-\omega^2\Delta t^2 & -1 \\ 1 & 0 \end{vmatrix} - \lambda\begin{vmatrix} 1 & 0 \\ 0 & 1 \end{vmatrix}\right) = 0 \qquad (22)$$

where λ represents eigen matrix value $\mathbf{A}$. Solving the equation 2.2.14 for λ, and solving inequation:

$$\lambda \leq 1 \qquad (23)$$

We get a critical value of the time pace, for a system without muffling,

$$\Delta t \leq \frac{2}{\omega_{\max}} \qquad (24)$$

For system with muffling, critical time step is

$$\Delta t \leq \frac{2}{\omega_{\max}}\left(\sqrt{1+\xi^2} - \xi\right) \qquad (25)$$

By comparing the equations 24 and 25 it can be concluded that muffling reduces the size of critical time step. The following is valid for the variable size of time step:

$$\begin{aligned} \Delta t^2 &\leq \frac{4\delta_i}{\omega_i^2} \\ \delta_i &= \frac{\Delta t_i}{\Delta t_{i-1}} \\ 0 \leq \delta_i &\leq 1 \end{aligned} \qquad (26)$$

Time integration is stable if the time step is being reduced. Time step is restricted by the biggest natural frequency of the system.

Time integration in LS-DYNA software

Discretization in LS-DYNA software is done for actual geometry, instead for the displacement. The principle of discretization is on the fig. 3.

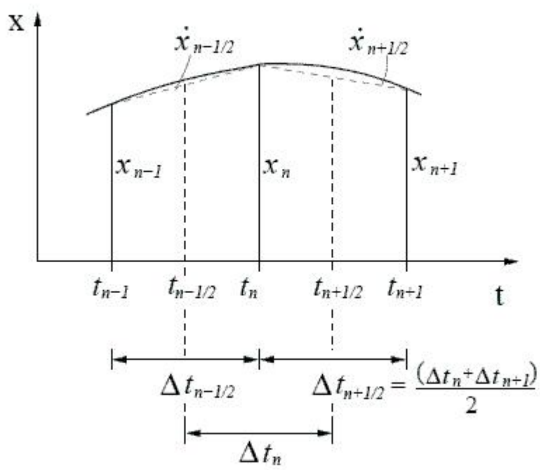

***Figure 3** Discretization used in LS-DYNA software*

Velocity is defined by the equation 27 and it is not a central difference, unlike the acceleration that represents the central difference 28.

$$\dot{x}_{n+1} = \frac{1}{\Delta t_{n+1}}(x_{n+1} - x_n) \tag{27}$$

$$\ddot{x}_n = \frac{1}{\Delta t_n}(\dot{x}_{n+\frac{1}{2}} - \dot{x}_{n-\frac{1}{2}}) \tag{28}$$

Motion equation for nonlinear case for the moment t_n is:

$$\mathbf{M}\ddot{\mathbf{x}}_n = \mathbf{P}_n - \mathbf{F}_n^{\text{int}} - \mathbf{C}\dot{\mathbf{x}}_n \tag{29}$$

where $\dot{\mathbf{x}}_n$ is unknown velocity in the moment t_n. As in central differences presented in the previous section, the matrix $\mathbf{A}$ from the equation 2.2.12 . should be analysed here.
From the equation 29 we derive acceleration $\ddot{x}_n$, and from equations 28 and 27, $\dot{x}_{n+\frac{1}{2}}$ and x_{n+1} should be derived respectively. Considering the initial conditions in the equation 30., we get an equation 31 for the initial acceleration $\ddot{\mathbf{x}}_0$ and velocity $\dot{x}_{\frac{1}{2}}$.

$$\begin{aligned} x_0 &= \bar{x}_0 + u_{stat} \\ v_0 &= \frac{1}{2}(\dot{x}_{-\frac{1}{2}} + \dot{x}_{\frac{1}{2}}) \end{aligned} \tag{30}$$

$$\begin{aligned} \ddot{x}_0 &= M^{-1}(P_0 + P_{stat} - F_0(u_{stat}) - Cv_0) \\ \dot{x}_{\frac{1}{2}} &= v_0 + \frac{1}{2}\Delta t_0 \ddot{x}_0 \end{aligned} \tag{31}$$

In the equations 30 and 31 $\bar{x}_0$ is the original geometry, u_{stat} is the initial displacement from the static load.

There are no precisely defined stability conditions for integration in nonlinear problems. LS-DYNA uses standard method of central differences for boundary size approximation of the time step. Thus, LS-DYNA uses the size of the time step as:

$$\Delta t = 0.9\Delta t_{critical} \tag{32}$$

Here $\Delta t_{critical}$ is the time step determined according to the equation 26, or:

$$\begin{aligned} \Delta t_{crit}^2 &\le \frac{4\delta_i}{\omega_i^2} \\ \delta_i &= \frac{\Delta t_i}{\Delta t_{i-1}} \\ 0 \le \delta_i &\le 1 \end{aligned} \tag{33}$$

For different types of elements time step is determined according to the equation form 34, where l is the element length, and c is the sound velocity. Equations for the specific types of elements can be found in [3]

$$\Delta t = \frac{l}{c} \tag{34}$$

CONTACT IN LS-DYNA SOFTWARE

As it was mentioned in the introduction, LS-DYNA is world-known software used for nonlinear dynamic problem solving. A big group of nonlinear problems represent as well contact problems. Contact analysis is the integral part of many problems in the field of big deformations. Precise modeling of the contact pair between the bodies is a key point considering the simulation possibilities using the finite element method.

There is a large number of contact types that are implemented or developed in LS-DYNA software. Certain types are developed and are used in specific problems, such as airbag contacts, edge contacts, and other, but also the types used in the general cases.

In LS-DYNA software, contact is defined by location identifying of slave segments that potentially penetrate into master segment. Identification is done through the parts, segments, sets of segments, sets of nodes, etc. Check of the penetration by using one of many algorithms is being done in each time step. In the case of penalty-based contact, when it comes to penetration, resistance force is given that is proprtional to the penetration depth and finally eliminates the penetration. If it is not emphasized differently, we are talking here about penalty-based contact and besides it. there is the constrained-based contact as well. With this kind of contact a rigid body can be used, but it is recommended for the density of the rigid body not to be the same as of a deformable body, so that the force could be distributed realisticly.

In crash analyses, deformations can be very big and the assumptions about where or how the contact will happen are difficult to make, sometimes even impossible. Thus, the automatic contact is recommended as a contact where the orientation is not defined, or to say, where the penetration can be detected at both sides of shell elements. Contact algorithm used in the case of automatic contact is better than the old type contact for working with separated nets.

AN EXAMPLE OF WAGGON CRASH TEST

This part presents an example of waggon-cistern crash into the still rigid wall. We are starting from a ready-made model, or in other words, from the finite element net that is made in FEMAP v9.0 software. Waggon crash is simulated with the 80km/h velocity, into still rigid wall. Waggon model is presented on figs. 4 and 5.

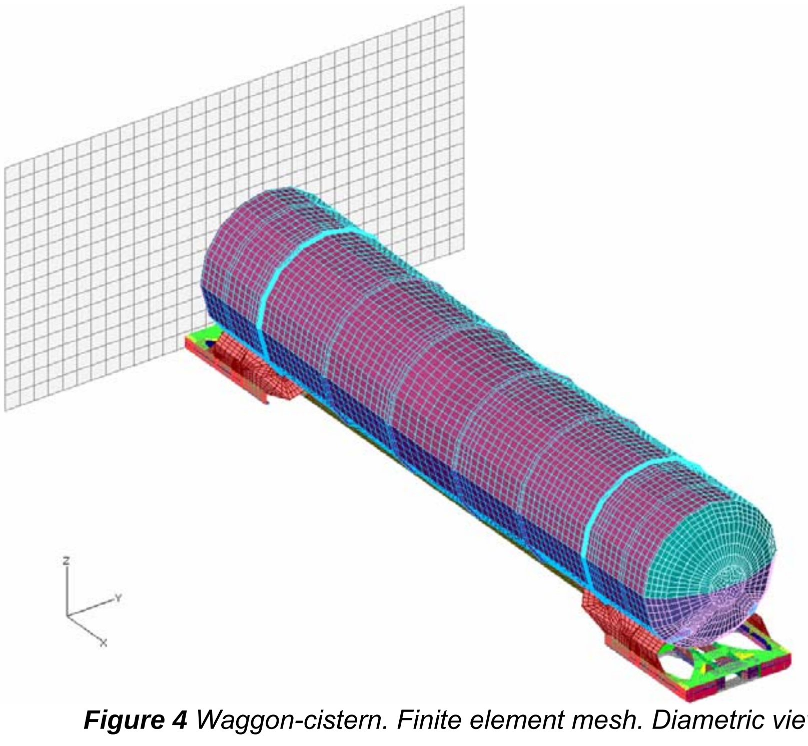

Figure 4 *Waggon-cistern. Finite element mesh. Diametric view.*

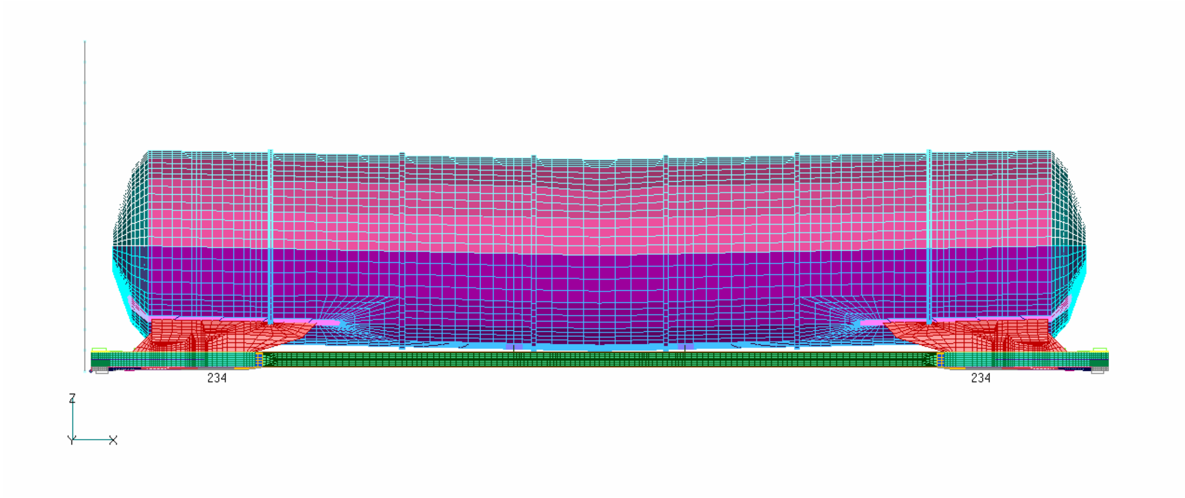

***Figure 5** Waggon-cistern. Finite element mesh. ZX view*

Waggon and the wall are modeled by elements of the shell. The whole model has 54324 elements, or 53578 nodes. Cistern model consists of 39 parts, or in other words, properties, which are defined by elements of different thickness shell, or by material that has the same ID as the property. The part determined by a property or material with ID= 40 is rigid wall model.

The analyses is done in LS-DYNA software, and then the achieved results are imported into FEMAP. Results of the analyses, or the field of effective stress in the last step of the analyses, are showed in figs. 6 – 8.

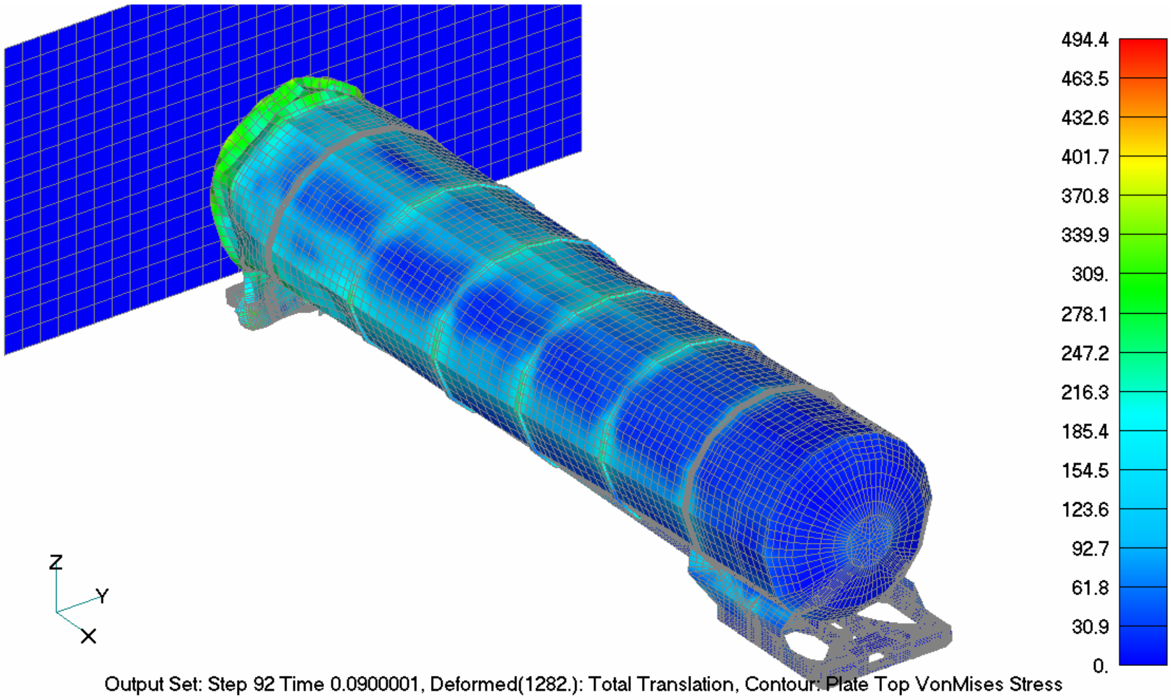

***Figure 6** Crash test waggon-cistern; Effective Stress Field – Dimetric*

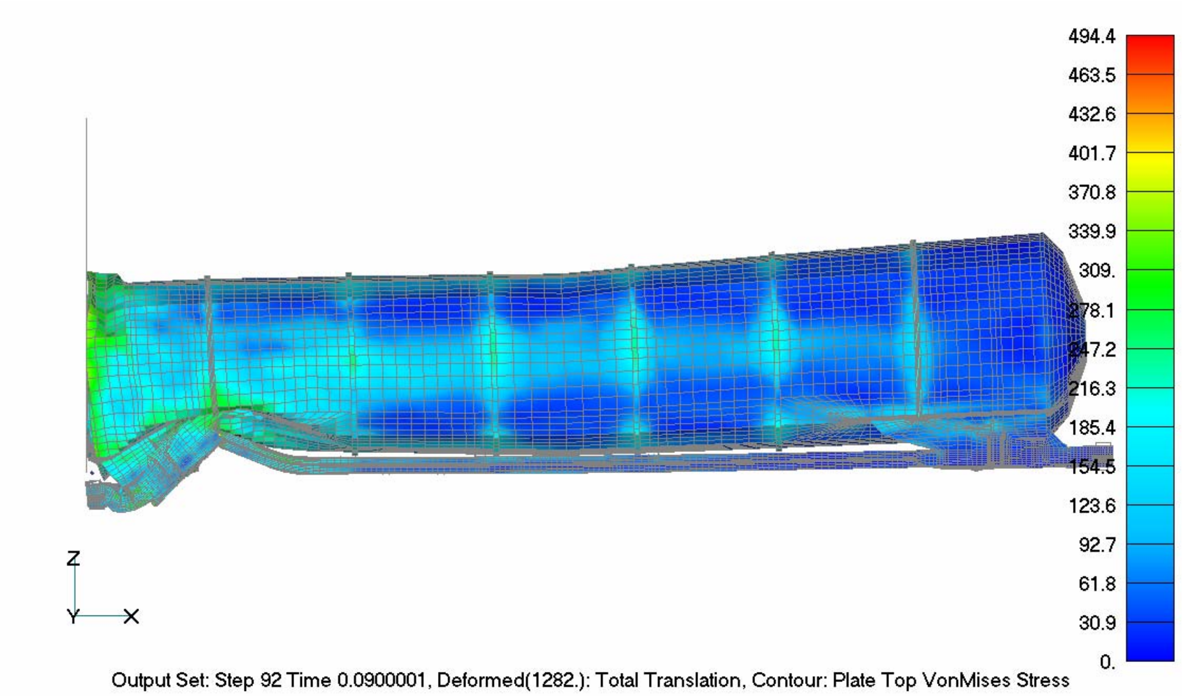

Figure 7 *Crash test waggon-cistern; Effective Stress Field – ZX view*

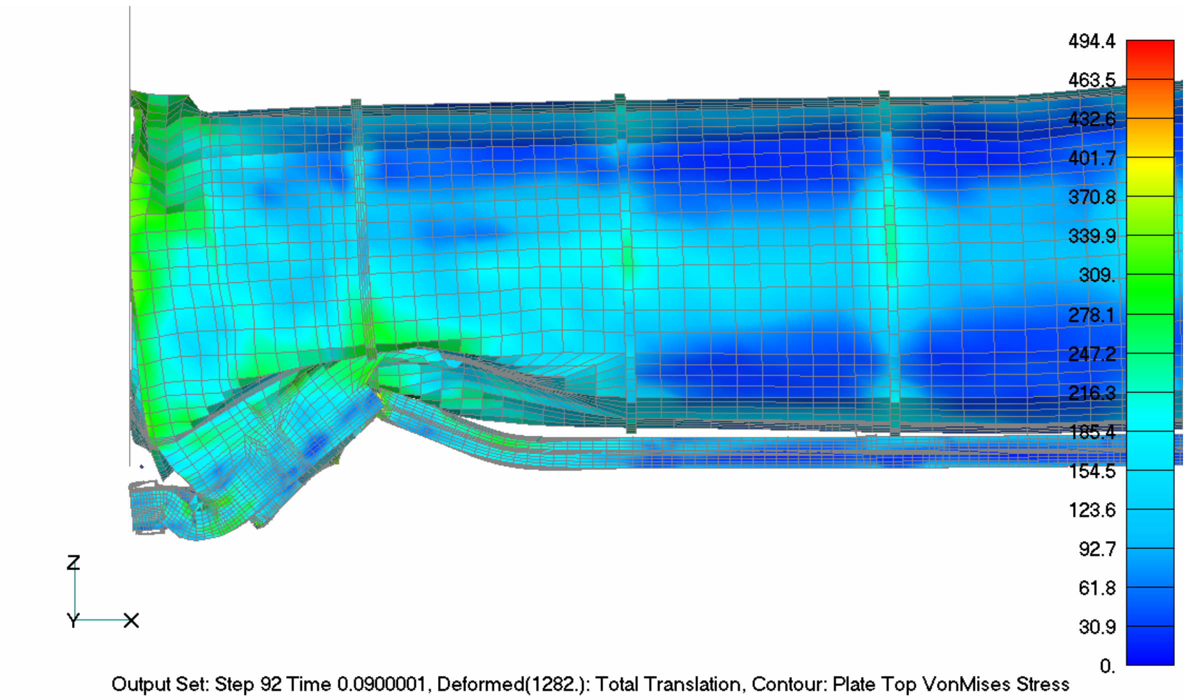

Figure 8 *Crash test waggon-cistern; Effective Stress Field – ZX detail*

CONCLUSIONS

The main goal of this paper was the synthesis of knowledge and data, that will help new users to become familiar with the functions and possibilities of LS-DYNA software, as one of the most developed and most frequently used in the world.

Within the theoretical basis the important facts are presented conserning solution stability as well as the mechanisms for determining the time step that will fulfill defined criteria. According to the analysed examples, the conclusion is that the time step is extremely small in solving problems by using explicit method of integration. For example, in the case of waggon-cistern crash into the still rigid barrier, time step was 10^{-7} seconds.

Further work on this topic would be expanding the field of use, primairly in the field of contact problems, but in the other fields of LS-DYNA software usage as well. In the field of contact problem solving, capacity of the software is extraordinary, so the parameters should be well adjusted to obtain reliable results. Besides that, the software also supports solving of the multiphysical coupled problems, so that is the direction to follow.

REFERENCES

[1] Kojić M., Slavković R., Živković M., Grujović N., *Metod konačnih elemenata I, Linearna analiza*, Kragujevac, 1998,
[2] Hallquist, J., *LS-DYNA Theoretical Manual*, Livermore CA, USA, 1998,
[3] dynaspport.com/Support/tutorial/users.guide,
[4] *LS-DYNA Keyword User's Manual*, Volume I, Livermore CA, USA, 2001,
[5] *LS-DYNA Keyword User's Manual*, Volume II, Livermore CA, USA, 2001,
[6] arasvo.com/crash
[7] *FEMB User's Manual, A pre-procesor for use with LS-DYNA*, Livermore CA, USA, 1999,
[8] *Eta/PostGL POST TUTORIAL, A post-processor compatible with LS-DYNA/PC*, Livermore CA, USA, 1999,
[9] *Eta/PostGL GRAPH TUTORIAL, A post-processor compatible with LS-DYNA/PC*, Livermore CA, USA, 1999,
[10] LSPOST A New Post Processor for Use LSDYNA, Livermore CA, USA, 1999,
[11] *FEMB Training Manual, A pre-procesor for use with LS-DYNA*, Livermore CA, USA, 1999,
[12] lstc.com,
[13] dyna-portal,
[14] dynamax-inc.com,
[15] ncac.gwn.edu.