CETRA 2014

3rd International Conference on Road and Rail Infrastructure
28–30 April 2014, Split, Croatia

# Road and Rail Infrastructure III

Stjepan Lakušić – EDITOR

Organizer
University of Zagreb
Faculty of Civil Engineering
Department of Transportation

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**EDITOR**
**Stjepan Lakušić**
Department of Transportation
Faculty of Civil Engineering
University of Zagreb
Zagreb, Croatia

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# MOVING LOAD EFFECT ON BRIDGES

**Ľuboš Daniel, Ján Kortiš**
*University of Zilina, Faculty of Civil Engineering, Department of Structural Mechanics, Slovakia*

## Abstract

Vehicle – bridge dynamic interaction represents the actual problem which is solved on many work places. Within the solution of the task the numerical methods are applied mainly. The Finite Element Method is the best-known and widely used. Several commercial systems works with the algorithms based on the FEM principles, for example program system ANSYS. The submitted article is dedicated to the numerical modelling of vehicle – bridge interaction problem in the environment of this system. It compares the numerical accuracy of FEM with other numerical method and illustrates the influence of the speed of vehicle motion on the bridge mid-span deflection.

*Keywords: ANSYS, finite element method, vibration, dynamic analysis, random profile*

## 1 Introduction

Having better possibilities to solve interaction between vehicles and bridge structures can extend knowledge to better understand influence of moving vehicles on bridge structures. The choice of the right model, which represents the moving vehicle with appropriate mathematical formulation, is one of the most important parts [5]. Simple model that describes only a part of dynamic characteristics of the real models are usually preferred. “The fourth-part model” and “the half -part model” are widely used when only the analysis for the plane model of the bridge is required [3]. However, they can be also used for tree-dimensional models of bridges but they cannot describe it properly. So the results of the solution have to be carefully evaluated and interpreted. Discrete models of vehicle with finite degrees of freedom make solution easier from the mathematical point of view. Then partial differential equations change to the differential equations. The article describes the way how to create the right numerical model of the vehicle and also how to create interaction with numerical model of the bridge by using the software ANSYS [1], [6]. For the model of vehicle “the half-part model” is used, created by using spring elements and mass elements. They describe stiffness, damping and mass characteristics of the vehicle. The bridge is modelled by using planar beam elements. Interaction between vehicle and bridge is created by using contact elements node to surface. This task belongs among nonstacionary dynamic actions, which is governed by the following equation:

$$[M]\cdot\{u(t)\}+[C]\cdot\{u(t)\}+[K]\cdot\{u(t)\}=\{F(t)\} \quad (1)$$

One of the possibilities how to solve the previous equation is using numerical solution. Program ANSYS offers many techniques for that purpose. We decided to use Newmark’s method that is widely used to do dynamic numerical simulations. This method is also called implicit because the solution at time t + Δt is not explicitly determined by the state at time t. The relation between displacement, velocity and acceleration is governed by the following equations:

$$\begin{aligned} \{u_{t+\Delta t}\} &= \{u_t\} + [(1-\delta)\cdot\{u_t\} + \delta\cdot\{u_{t+Dt}\}]\cdot\Delta t \\ \{u_{t+\Delta t}\} &= \{u_t\} + \{u_t\cdot\Delta t\} + [(1/2-\alpha)\cdot\{u_t\} + \alpha\cdot\{u_{t+\Delta t}\}]\cdot\Delta t^2 \end{aligned} \tag{2}$$

As a result, the time is also discretized and the solution is given in a form of the functional values for all defined geometrical points in each time steps. The different value for the time step affects the quality of the obtained results. So it is very important to choose the right value of the time step.

## 2 The numerical model of the vehicle

For the purpose of the simulation "the half -part model" was used, which is based on the lorry T815 Fig. 1. Linear damping characteristics and viscous damping are assumed for spring elements that are used to connect mass elements. The dynamic characteristics such as natural frequencies were solved to evaluate the quality of the model. They were compared with natural frequencies gained by experimental measurement [7].

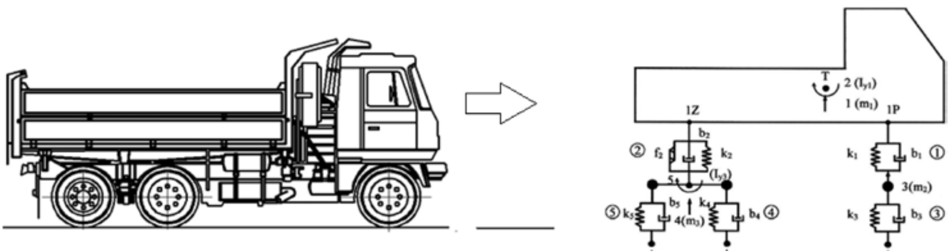



**Figure 1** The numerical model of the lorry T815

It is possible to define the main characteristics of the discrete model by three diagonal matrices. They contain the mass, stiffness and damping characteristics.

Diagonal mass matrix

$$\{m\}_D = \{m_1, I_{y1}, m_2, m_3, I_{y3}\}_D = \{17400, 62298, 910, 2140, 932\}_D \quad [kg,\ kg\cdot m^2]$$

Diagonal stiffness matrix

$$\{k_i\}_D = \{k_1, k_2, k_3, k_4, k_5\}_D = \{247686, 1869724, 3242424, 5095000, 5095000\}_D \quad [N/m]$$

Diagonal damping matrix

$$\{b_i\}_D = \{b_1, b_2, b_3, b_4, b_5\}_D = \{\ 19228, 260197, 2746, 5494, 5494\}_D \quad [kg/s]$$

## 3 The numerical model of the bridge

The goal of the analysis is to analyse the action of moving vehicle on the structure of the road bridge situated between two villages Varín and Mojš in the Slovak republic. The whole length of the bridge is 87 m which is divided into three parts. Each part acts independently as a simple supported beam. The main girders are prefabricated prestressed concrete elements and their length is 29 m. The cross-section of the bridge contains eight girders placed at distance 1.44 – 1.45 m. The shapes of the girders and the layers of pavement are showed on the Fig. 2. The Young's modulus is 3.85 e10 N/m$^2$ and the weight intensity is 19680 kg/m. Both values are defined with the respect of having similar dynamic characteristic than those the real bridge structure has.

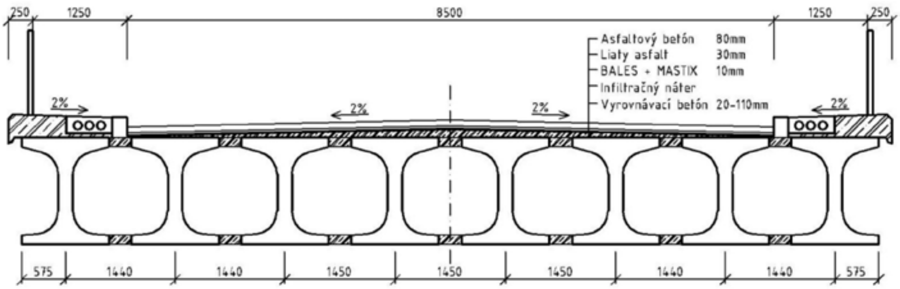
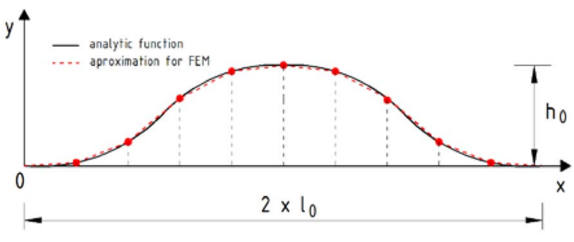



**Figure 2** The cross-section of the bridge situated between two villages Varín – Mojš in the Slovak republic

The analysis is focused on the middle span of the bridge that is modelled using beam elements BEAM3. The boundary conditions are similar to a simple supported beam. Rigid surfaces are defined before and after the model of the bridge and their purpose are to start and finish the movement of the vehicle. Thanks to this, the vehicle moves over the bridge with a constant speed. An obstacle is defined on the surface of the bridge. It is positioned in the middle of the span and its shape is very similar to the obstacle used for the dynamic test of bridges Fig. 3. The main reason for defining of this roughness on the surface of the pavement is to have results which could be compared with results of experimental analysis.




Function that defines the shape of the obstacle

$$h(x) = h_0.(1 - \cos(2\pi x / 2l_0)) / 2$$

where:

$h_0$ = 0,06m ,2. $l_0$=0,940 m

**Figure 3** The shape of the obstacle

The simplified model of the bridge and vehicle at the beginning of the numerical simulation is showed below Fig. 4. The static analysis begins to bend the bridge as an effect of self-weight without causing vibrations. Then the type of analysis is changed to dynamic analysis. The inertial forces are active for the rest of the numerical simulation.

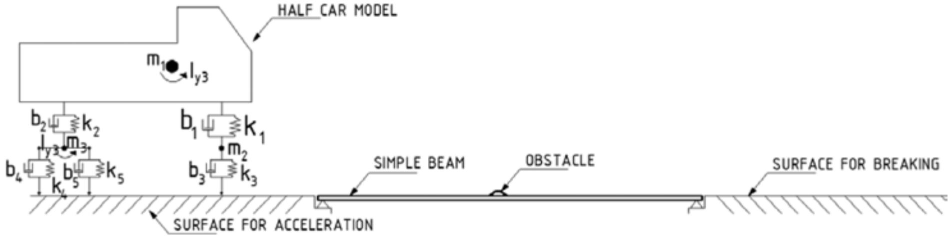



**Figure 4** The numerical model of the vehicle and the bridge

## 4 Analysis of the results

The displacement in the middle of the beam is used to analyse the influence of the obstacle situated on the surface of the bridge. The first solution was done without the obstacle, thus the smooth surface was assumed. The results were nearly the same as it is expected for the static analysis. The displacement changes only by changing the position of the vehicle. The influence of inertial forces is very small. The next solution was done with the defined obstacle in the middle of the bridge. As a result, the displacement changes in time and the maximal value increased. The Fig. 5 shows how it influences the displacement.

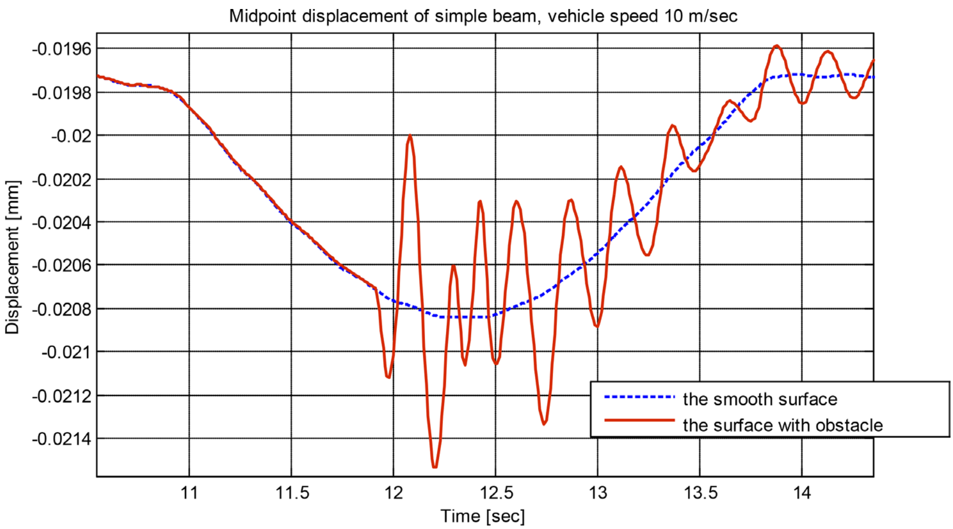



**Figure 5** The influence of the obstacle on the displacement in the middle of the span

It was also valuable for this kind of solution to know how the different values of damping can change the displacement. So another analysis was done where the results for model without damping and with damping are compared. Damping was defined by two numbers $\alpha$ =0.03 and $\beta$ =0.002. These values are derived from the results of experimental analysis. The change of displacement in time is showed in figure 6. It is obvious that the maximal value of the displacement did not change significantly, but the vibration disappears faster.

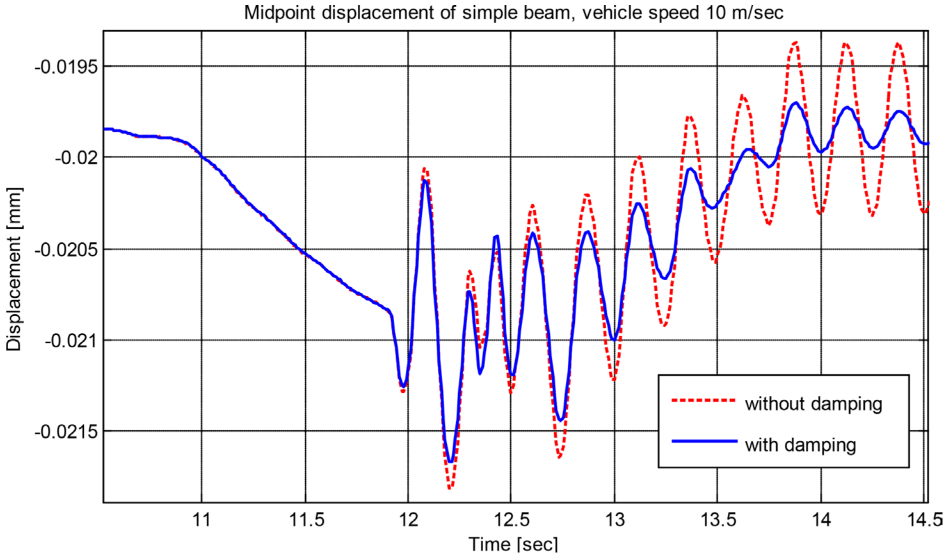



**Figure 6** The influence of damping on the displacement in the middle of the span

## 5 Conclusion

The numerical simulation of the moving vehicle acting on the bridge structure needs many simplifications if we want to use it for solving some practical issues. That is even more important for solving that simulation with prescribed roughness of the road on the bridge structure. For that reason the simple plane model of vehicle and bridge was chosen. The comparison between simulation with smooth surface on the bridge and simulation with obstacle in the middle of the span shows significant changes in the values of displacement. For the smooth surface the results are comparable with static analysis. On the other hand the displacement with obstacle on the bridge increases. There is also important to define right value of damping especially if fatigue phenomenon is analysed.

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