19th International Conference
ENGINEERING MECHANICS 2013
Svratka, Czech Republic, May 13 – 16, 2013

INFLUENCE OF THE REINFORCEMENT ON THE IMPACT RESISTANCE OF A BRIGDE PIER

P. Jiříček*, M. Foglar**

Abstract: *The paper presents results of a numerical study focused on the influence of different types of reinforcement arrangement of a bridge pier on its impact resistance. Four types of reinforcement arrangement are evaluated. The vehicle impact at the bridge pier is modeled with the use of ANSYS Autodyn. A nonlinear material model of concrete with damage and strain-rate effect was chosen. The paper concludes the topic introduced at the EMM2012.*

Keywords: ***concrete, RHT concrete model, impact.***

1. Introduction

Traffic intensity increase leads to higher risk of traffic accidents. In 2010 and 2011 about 1250 accidents involving bridges and tunnels happened in the Czech Republic. Heavy trucks (above 30t) hitting the bridge substructure can lead into progressive collapse of the bridge superstructure thus causing severe fatalities, therefore this loading case should be considered especially at the motorways.

The European design standard EN 1991-1-7 prescribes two methods for determination of vehicle impact loading. The first simplified method is based on an equivalent static force. The second method is based on accurate input data and requires a special dynamic analysis for evaluation of the impact loading.

The bridge pier truck impact is considered according to EN 1991-1-7 (vehicle - 30tonnes; 90kph). The whole vehicle impact is modeled with the use of ANSYS Autodyn software. Four options of reinforcement arrangement are compared and evaluated within the paper.

2. Vehicle impact loading

According to EN 1991-1-7 (Appendix C), the vehicle impact forces are evaluated by dynamic analysis which gives nearly 3 times higher values than simplified method based on tabular impact forces (Jiříček & Foglar, 2012). Previous research showed similarities between Appendix C input data and a full-scale computational model, see Fig. 1.

The detailed geometry modeling was the only way to define the impacting vehicle with lack of clear input data in Appendix C. But the main issue of the full-scale modeling, and the use of a realistic model of the impacting truck (Fig. 2), was the computational time (approximately 100 hours). Also it was difficult to prepare the proper mesh for the model.

Due to the boundary conditions and resultant similarities, the authors decided to simplify the impacting vehicle.

* Ing. Pavel Jiříček: Faculty of Civil Engineering, Czech Technical University in Prague, Thákurova 7; 166 29, Prague 6; CZ, e-mail:pavel.jiricek@fsv.cvut.cz

Ing. Pavel Jiříček: Faculty of Civil Engineering, Czech Technical University in Prague, Thákurova 7; 166 29, Prague 6; CZ, e-mail:pavel.jiricek@fsv.cvut.cz

** Ing. Marek Foglar, Ph.D.: Faculty of Civil Engineering, Czech Technical University in Prague, Thákurova 7; 166 29, Prague 6; CZ, e-mail: marek foglar@fsv.cvut.cz

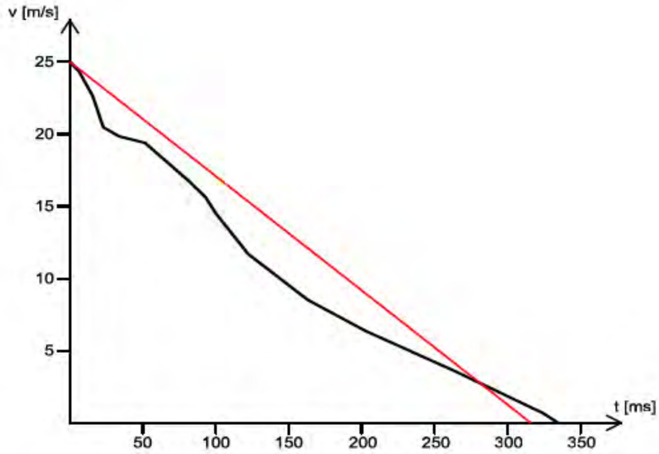


Fig. 1: Schematic diagram of bridge pier truck impact velocity/time dependence. Black line – numerical simulation; Red line – EN 1991-1-7 Appendix C

Fig. 2: Computational model of the truck

2.1 Characteristics of the impacting object

The complex geometry of truck was replaced with a block (W x H x L;2,0 x 1,0 x 10,0 m) made of equivalent elastic material model with linear EOS. Equation of state (EOS) describes the dependence of pressure and density. The stiffness was set to 300 kN/m according to EN 1991-1-7. Unlike the current design standards, the height of the impacting face of the block was enlarged from 0,5 m to 1,0 m.

3. Description of the analyzed bridge pier

The dimensions of the bridge pier are 1000 x 4800 x 6700 mm (width x length x height), concrete class C30/37. The deflections at the bottom and at the head of pier are restricted. For illustration see Fig. 3.

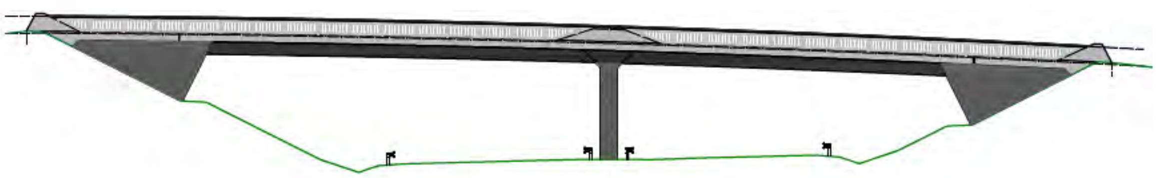


Fig. 3: View of the assessed bridge

The main bending reinforcement is formed by vertical bars Ø20/200mm, the shear reinforcement is formed by bars Ø10/300mm. In the case of the second layer of reinforcement, the distance of this layer to the first one is 100mm.

3.1 Material model of the pier

The material of the bridge pier was chosen to describe its behavior when subjected to the vehicle impact; the two main aspects are:

- Damage of the material when subjected to ultimate loading

- Increase of the strength (both tensile and compressive) depending on the speed of loading (dynamic increase factor)

ANSYS Autodyn provides many material models, some can be used for description of the behavior of concrete elements subjected to impact loading. The material model RHT for quasi - brittle materials with damage was chosen for the pier. This model incorporates the strain-rate effect, which describes the increase of strength with the speed of loading. There are many existing and published RHT model input data (Rempling, 2004; Brannon & Leelavanichkul, 2009), the data provided by Leppänen (2003) are used for this modeling.

When defining material model in Autodyn, it is important to choose proper equation of state. In this case combined P-Alpha and polynomial EOS was used, see Fig. 4 and Tab. 1.

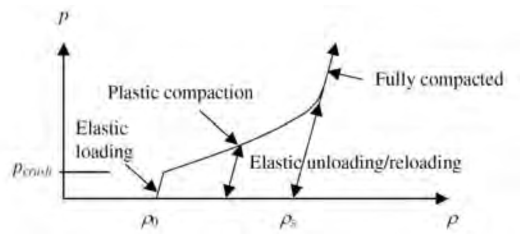


Fig. 4: Equation of state (EOS), for concrete, combined P-Alpha and polynomial; based on AUTODYN

Tab. 1: Concrete EOS input data (Leppänen, 2003).

P – Alpha EOS	
Parameter	**Value**
Porous density [g/cm^3]	2,37
Porous soundspeed [m/s]	2920
Initial compaction pressure [kPa]	$2{,}33\cdot 10^4$
Solid compaction pressure [kPa]	$6\cdot 10^6$
Compaction exponent	3
Solid EOS	Polynomial
Bulk Modulus A1 [kPa]	$3{,}527\cdot 10^7$
A2 [kPa]	$3{,}958\cdot 10^7$
A3 [kPa]	$9{,}04\cdot 10^6$
B0	1,22
B1	1,22
T1 [kPa]	$3{,}527\cdot 10^7$
T2 [kPa]	0

As next step main RHT model (Fig. 5) has to be set up. Main values of input data are shown in Tab. 2.

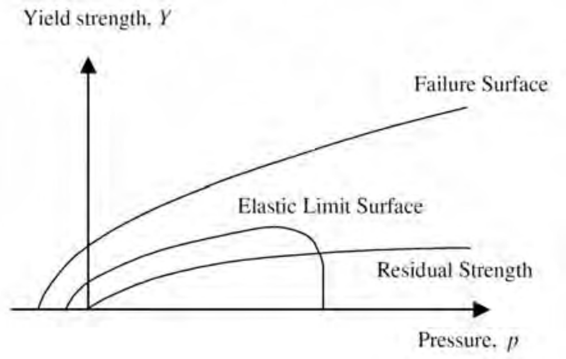


Fig. 5: RHT model used for concrete; based on Riedel (2000)

Tab. 2: RHT Concrete input data (Leppänen, 2003).

RHT Concrete - Strength	
Parameter	**Value**
Shear Modulus [kPa]	$1,433 \cdot 10^7$
Compressive Strength f_c [kPa]	$35 \cdot 10^3$
Tensile Strength (f_t/f_c)	0,078
Shear Strength (f_s/f_c)	0,18
Intact Failure Surface Parameter A	2
Intact Failure Surface Parameter N	0,7
Tens./Com. Meridian Ratio (Q)	0,6805
Brittle to Ductile Transition	0,0105
G(elas.)/G(elas-plas.)	2
Elastic Strength/f_t	0,7
Elastic Strength/f_c	0,53
Residual Strength Const. B	1,5
Residual Strength Exp. M	0,7
Comp. Strain Rate Exp. Alpha	0,032
Tens. Strain Rate Exp Delta	0,025
Max. fracture strength ratio	$1 \cdot 10^{20}$
Use cap on elastic surface	YES
RHT Concrete - Failure	
Damage Constant D1	0,04
Min. Strain to Failure	0,01
Residual Shear Modulus Frac.	0,13
Tensile failure model	Hydro tens.

3.2. Reinforcement types of the pier

For reinforcement bars material model of common structural steel with yield stress 500 MPa and linear EOS was chosen.

3.2.1. The pier without reinforcement

This option is taken from the previous steps of the research (Jiříček & Foglar, 2012), mainly considered for the evaluation of the vehicle impact force. In this paper, it has only comparative purpose (Fig. 9a).

3.2.2 The pier with longitudinal reinforcement

Only bending reinforcement is considered. Reinforcement is formed by longitudinal bars Ø20/200mm (Fig. 6). The damage of this arrangement of the reinforcement is shown in Fig. 9b.

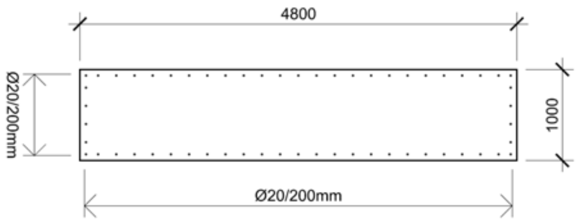


Fig. 6: Vertical reinforcement in two layers (cross-section).

3.2.3 The pier with vertical and shear reinforcement

In this case, the reinforcement is formed by longitudinal bars Ø20/200mm, the shear reinforcement is added (bars Ø10 each 300mm; Fig. 7). The damage of this arrangement of the reinforcement is shown in Fig. 9c.

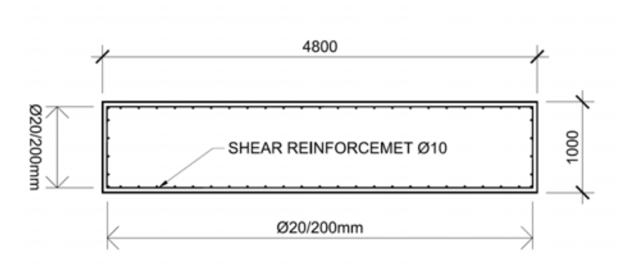


Fig. 7: Vertical and shear reinforcement (cross-section).

3.2.4 The pier with vertical and shear reinforcement in two layers

This arrangement of reinforcement is recommended by German design standards (DIN-Fachbericht 102), which considers bending and shear reinforcement in two layers (Fig. 8). The damage of this arrangement of the reinforcement is shown in Fig. 9d.

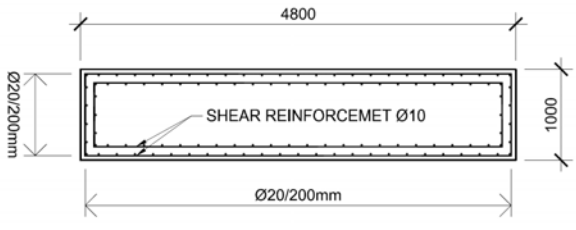


Fig. 8: Vertical and shear reinforcement in two layers (cross-section).

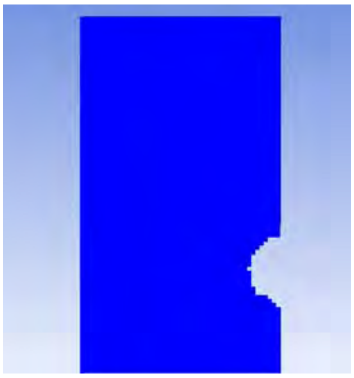
4. Results of the numerical modeling

Reinforcement arrangement significantly affects damage of the pier, see Fig 8. It is obvious that pier without any reinforcement is damaged the most; only plain concrete deals with the impact of the vehicle. As mentioned before, it has only comparative purpose, therefore the area of eroded concrete will be considered as 100% (Fig. 8a).

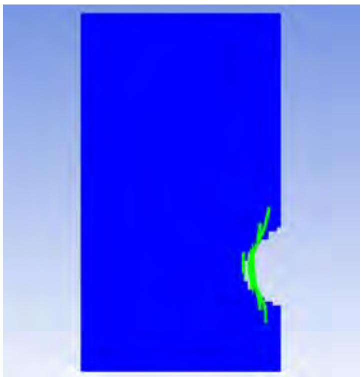
The damage of the pier reinforced only with vertical bars (Ø20/200mm) is very similar (Fig. 8b) to the damage of the concrete pier without reinforcement. The volume of eroded the concrete is about 85% compared to the pier without reinforcement. It is obvious that fully anchored longitudinal bending reinforcement transmits some impact force and therefore enlarges impact area in the height of the pier. It has to be mentioned that this type of reinforcement is not actually used in real designs (similar to plain concrete).

The main difference of the area of the eroded concrete can be seen in the model where shear reinforcement is added (Fig. 8c). The shear reinforcement confines the concrete surrounded by the longitudinal bars and limits the erosion of concrete. As the main result of added shear reinforcement is the increase of the height of eroded area at the expense of its depth. Reduction of the depth of concrete spalling is a positive phenomenon, larger area of cross-section of the pier is resisting vertical the loading. The volume of the eroded concrete is about 60% compared to the pier without reinforcement and 70% compared to the pier reinforced only with vertical bars.

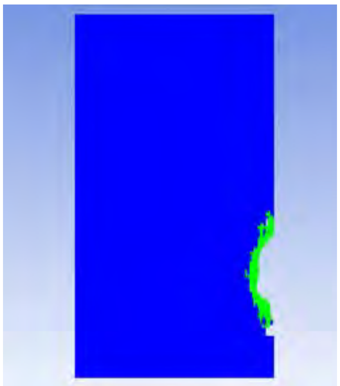
As the last option, the reinforcement according to German design standards (DIN-Fachbericht 102) was considered. In the case of placing reinforcement in two layers, the main damage and erosion of concrete takes place in the area of the first layer. The concrete behind the second layer remains mainly uneroded. Character of damage of the pier is very similar to the vertical and shear reinforcement in only one layer. The volume of eroded concrete is about 55% compared to the pier without reinforcement, 65% compared to the pier reinforced only with vertical bars and 90% compared to the pier reinforced with vertical and shears reinforcement in one layer.



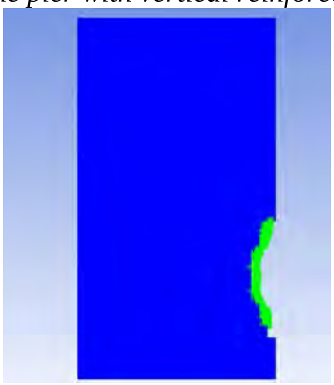
a – The pier without reinforcement



b – The pier with vertical reinforcement



c – The pier with vertical and shear reinforcement



d – The pier with longitudinal and shear reinforcement in two layers

Fig. 9: Damage of the pier

5. Conclusions

The four types of pier reinforcement were evaluated in this paper. It's obvious that fully anchored longitudinal bending reinforcement transmits some impact force and therefore enlarges impact area in comparison to the plain concrete. The shear reinforcement confines the concrete surrounded by the longitudinal bars and limits the erosion of concrete. In case of placing reinforcement in two layers, the main damage and erosion of concrete takes place in the area of the first layer. The concrete behind the second layer remains mainly uneroded. In general, the increase of reinforcement area in the spot of the impact enhances the resistance of the pier to impact loading.

Acknowledgement

The financial support of CTU grant 13/035/OHK1/1T/11, the Ministry of Interior of the Czech Republic project VG20132015114 and Czech the Republic Grant Agency project No. 13-30441S are kindly acknowledged.

References

Jiříček, P. & Foglar, M. (2012) Numerical analysis of a bridge pier subjected to truck impact. *Engineering Mechanics 2012*, Institute of Applied Mechanics Academy of the Czech Republic, Prague, pp. 143-143.

Jiříček, P. & Foglar, M. (2012) Numerická analýza nárazu nákladního vozidla do mostního pilíře. *Stavební Obzor č. 9*, Prague, pp. 266-271.

Rempling, R. (2004) Concrete wall subjected to fragment impacts. *Department of structural Engineering and Mechanics, Concrete Structures*. Chalmers University of Technology, Master's Thesis, Göteborg.

Brannon, R. M. & Leelavanichkul, S. (2009) Survey of Four Damage Models for Concrete. *Sandia Report*. Sandia National Laboratories, Albuquerque & Livermore.

Leppänen, J. (2003) Numerical Simulation of Projectile Penetration in Concrete. *Department of structural Engineering and Mechanics, Concrete Structures*. Chalmers University of Technology, Göteborg

Riedel, W. (2000) Beton unter dnymiscchen Lasten Meso- und makromechanische Modelle und ihre Parameter. *Institut Kurzzeitdynamik*, Ernst – Mach – Institut, der Bundeswehr München, Freiburg.

ČSN EN 1991-1-7: *Zatížení konstrukcí, Obecná zatížení – Mimořádná zatížení*. ÚNMZ, 2007.

AUTODYN Manuals (2001) *Version 4.2, Century Dynamics, Inc. 2001*. Sam Ramon.