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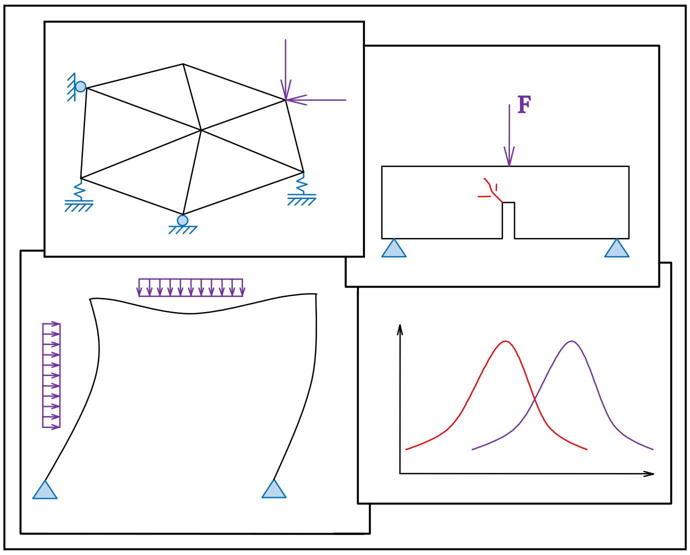


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# THE PURE BENDING TASK IN CASE OF COMPOSITE ROD BASED ON FOUR-ELEMENT MODEL

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***Abstract.*** *In the presented paper is stated at external constant force moment, distribution of deformations and stresses development in the rod with consideration of geometric characteristic as well as the time factor based on the four-element model. The values of the curvature and rotation angle are estimated. Are determined values of deflection of rod with dependence on its coordinate and time. The behavior and distribution of arisen in the cross-section of rod stresses at constant deformation (the case of relaxation) depended on the time is also determined.*

## Keywords

***Composite rod, model, stress, deformation.***

## 1. Introduction

Composites with fiber matrix and ebony (organic) filler are characterized the complex nature of deformation. This is expressed even in the case of constant loading in development of deformations, occurs the creeping phenomenon. They are also characterized by relaxation (at constant deformation arisen in the cross-section stresses are decreased during period of time). The theory of models is often applied to describe the properties of such materials that represent certain combinations of pure elastic and viscous elements. The simplest way of modeling is the two-dimensional Maxwell and Kelvin-Voigt models; although they would not even fully qualitative describe the characteristics of the mentioned composites. Much better results are achieved at considering of generalized models in that the number of simple elements is more than two. In the given case the task is considered based on the four-element (two elastic and two viscous) generalized models that conventionally represents the parallel combination of Maxwell's and Kelvin-Voigt models.

The linear task of the deformation of such model is reduced to the generation of differential dependence (rheological equation) that connects the total stress and deformation, and its solution would be done in a particular case of deformation or stress, for example: to $\sigma = \sigma_c = \text{const}$ correspond the case of creeping and to $\varepsilon = \varepsilon_c = \text{const}$ − relaxation. At this are obtained the specific analytical solutions that more or less well are describing the actual characteristics of such composites.

Due using the four-element generalized model, the task of pure bending of composite rod will be reduced to the task of linear deformation for each layer. In the presented paper is stated the distribution of developed in the rod deformations and stresses at the constant loading with consideration of geometric characteristics as well as taking into account the time factor. The values of curvature and rotation angle are estimated. The values of rod deflection are defined depending on its coordinate and time. The behaviour and distribution of arisen in the cross-section of rod stresses are determined also at constant deformation (case of relaxation).

## 2. Conclusion

The considered task reflects mode of deformation corresponding to the pure bending of made from composite material rectangular rod. Despite of the simplicity of task, in contrary to the metals, will be obtained the complex image, deformation and stresses in the points of cross-section with coordinates will depend also on time. The application of general models and in this case the four-element model gives the possibility for the most cases to write down the solutions in analytical form that is very important for further researches.

 

# On Vectorized MATLAB Implementation of Elastoplastic Problems

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***Abstract.*** *We propose an effective and flexible way to assemble tangent stiffness matrices in MATLAB. Our technique is applied to elastoplastic problems formulated in terms of displacements and discretized by the finite element method. The tangent stiffness matrix is repeatedly assembled in each time step and in each iteration of the semismooth Newton method. We discuss in detail von Mieses and Drucker-Prager yield criteria and linear and quadratic finite elements in two and three space dimensions. Our codes are vectorized and available for download. Comparisons with other available MATLAB codes show our technique is also efficient for purely elastic problems. In elastoplasticty, the assembly times are linearly proportional to the number of integration points.*

## Keywords

***Elastoplasticity, vectorized MATLAB codes, von Mises yield criterion, Drucker-Prager yield criterion.***

## 1. Introduction

Vectorization in MATLAB replaces inefficient loops over long arrays by operations with matrices, mainly with sparse matrices. Vectorized codes are then reasonably scalable and fast for large size problems. In this contribution, we deal with a vectorized MATLAB implementation in 2D and 3D proposed in [1] for solution of elastoplastic problems. The related codes are available for download in [2].

Our implementation arises from a current elastoplastic solution scheme including time discretization by the implicit Euler method, construction of a constitutive operator and its generalized derivatives by the return-mapping algorithm, space discretization by the finite element method, and solution of nonlinear systems of equations by the semismooth Newton method. In [1], there is described in detail the implementation for models including von Mises and Drucker-Prager yield criteria.

Further, one can optionally choose P1, P2, Q1 and Q2 finite elements with convenient quadrature rule for numerical integration. To be the codes universal, crucial functions are written uniformly regardless on the choice of elastoplastic models, finite elements or geometries.

## 2. Conclusion

The paper is focused on an efficient and flexible implementation of elastoplastic problems. We have mainly proposed the innovative assembly of elastoplastic FEM matrices. Additional effort to build the tangential stiffness matrices in each Newton iteration and each time step of elastoplastic problems does not exceed the cost for the elastic stiffness matrix. The smaller is the number of the plastic integrations points, the faster is the assembly.

## References

[1] ČERMÁK, M., S. SYSALA, and J. VALDMAN. Efficient and flexible Matlab implementation of 2D and 3D elastoplastic problems. *Applied Mathematics and Computation*, 2019, vol. 355, pp. 595-614, available at arXiv:1805.04155.

[2] ČERMÁK, M., S. SYSALA, and J. VALDMAN. *Matlab FEM package for elastoplasticity.* https://github.com/matlabfem/matlab_fem_elastoplasticity, 2018.

# NUMERICAL ANALYSIS OF THE PRESTRESSED COMPOSITE SENSOR DESIGNED FOR WEIGH IN MOTION SYSTEM ON ROADS

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***Abstract.*** *The numerical analysis of a composite bending plate as a weight in motion sensor is presented in the article. The deflection of the composite block is measured through the measurement of elongation of the prestressed steel bars. The result shows how big the changes in the prestressed force is. The study is focused especially on comparison of static and dynamic solution. The influence of temperature is also considered.*

## Keywords

***Finite element method, ADINA, weight in motion, composite bending plate, contact analysis.***

## 1. Introduction

Development of the Weight in motion systems (WIM) is the task of engineers and researchers from various institutions for more than 65 years (Norman, Hopkins 1952). The role of the WIM system is to detect the weight of moving vehicles with the accuracy close to the system that detect the weight at rest. The main part of WIM system is the mass (weight) sensor. The most commonly used technologies are load cells, bending plates, fibre optic sensors or quartz piezoelectric sensor. The presented article is focused on the numerical design of the prestressed composite bending plate sensor for high speed permanent WIM system. The proposed bending plate block is designed to be made from material Pertinax Hp 2061 which is a composite material made of paper impregnated with a plasticized phenol formaldehyde resin. first purpose is to prestress the block. The block is designed to be prestressed as it is supposed to be effective to decrease its nonlinear behaviour. The second reason why there are steel rods is to measure the deflection of the bending plate. This is done by measurement of the elongation of them. The strain gauge mounted on them are used for this. The advantage of this idea is that electronic equipment is hidden in the volume of the block and there are better experiences with mounting strain gauges on steel than on other materials. The analysis is focused on dynamic response of the bending plate to the moving wheel.

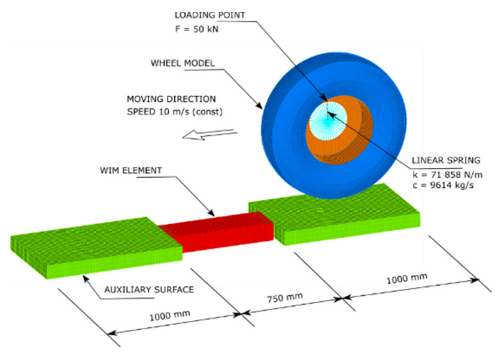


**Fig. 1:** Scheme of the finite element model

## 2. Conclusion

The concept of a composite bending plate used as a weight in motion sensor is presented in the article. Its numerical model is used to investigate how the loading with a moving wheel changes the prestressed force in a steel bar. The result shows that there are similar changes for static and dynamic solution, which means that the dynamic behaviour of the bending plate could not influence the measured results. However, there is important to say that no irregularities on the pavement have been considered in this study.

## Acknowledgements

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# Zkouška brazilským diskem: Porovnání materiálově nelineárních modelů dostupných ve SCIA Engineer

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## Klíčová slova

***Scia Engineer, Brazilský disk, nelinearita, beton, kvazi-křehký materiál.***

## 1. Úvod

Tento příspěvek se zabývá porovnáním odezvy vybraných materiálových modelů, se zahrnutím kvazi-křehkého chování dostupných v softwaru SCIA Engineer [1], který patří k jednĕm z nejrozšířenějších softwarů pro návrh stavebních konstrukcí. Materiálové modely jsou porovnány na tělese typu Brazilského disku. Li & Wong (2013) [1], které může být opatřeno ve středu zářezem Ayatollahi & Aliha (2008) [3], viz Obr. 1.

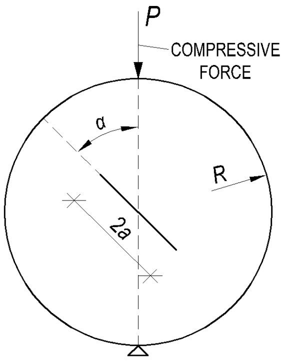


**Fig. 1:** Okrajové podmínky a geometrie tělesa typu Brazilský disk.

## 2. Nelineární Materiálové Modely ve SCIA Engineer

Hlavním tématem toho příspěvku je porovnání několika materiálově nelineárních modelů, které lze použít při návrhu betonových konstrukcí. Implementované nelineární materiálové modely v softwaru SCIA Engineer jsou tyto: metoda normově závislých průhybů odpovídá dle normy EN 1992-1-1 [4], elasto-plastický model Drucker-Prager / Mohr-Coulomb, ale také modifikovaný Mazarsův model poškození [5].

## 3. Závěr

Cílem tohoto příspěvku bylo porovnat různé nelineární materiálové modely dostupné v softwaru SCIA Engineer a vygenerovat zatěžovací křivku tělesa tvaru Brazilského disku. Z provedené studie lze dojít k závěru, že průběh zkoušky Brazilským diskem je nejlépe popsán materiálovým modelem s rozdílnými pevnostmi v tlaku a tahu. Lze tedy tento materiálový model doporučit k modelování nejen zkoušek, ale také i betonových konstrukcí. Dále byla porovnána také pole hlavních napětí generována těmito nelineárními modely.

## Poděkování

Tento příspěvek byl vypracován v rámci projektu „Program národní udržitelnosti I“ konkrétně „Admas UP-Pokročilé materiály, konstrukce a technologie“ (číslo. LO1408) podpořeno Ministerstvem školství, mládeže a tělovýchovy a Vysokým učením technickým v Brně.

## Reference

[1] Scia Engineer 2019: Referenční příručka

[2] LI, D. a L.N.Y. WONG. The Brazilian Disc Test for Rock Mechanics Applications: Review and New Insights. *Rock Mechanics and Rock Engineering*. 2013. Vol, 46 p. 269-287. ISSN: 0723-2632 DOI: 10.1007/s00603-012-0257-7.

[3] R. AYATOLLAHI, M.R.M. ALIHA. Cracked Brazilian disc specimen subjected to mode II deformation, *Engineering Fracture Mechanics*, 2005. Vol. 72 p. 493-503. ISSN 0013-7944. DOI: j.engfracmech.2004.05.002

[4] European Committee for Standardization, Eurocode 2: Design of concrete structures—Part 1-1: General rules and rules for buildings, Brussels, Belgium, (2004).

[5] MAZARS, J. A description of micro- and macroscale damage of concrete structures. *Engineering Fracture Mechanics*. 1986. Vol. 25, Is.5–6, p. 729-737, ISSN 0013-7944. DOI: 10.1016/0013-7944(86)90036-6.

# NÁVRH NOSNÉ KONSTRUKCE MOBILNÍ BUDOVY

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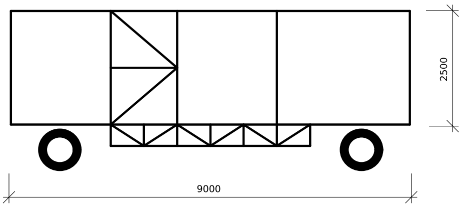
***Abstract.*** *The paper is focused on design and numerical analysis of a rolling chassis of a trailer. The trailer will serve as a mobile building containing sauna. The analysis is made according to dynamical load during motion on rough terrain and deceleration caused by braking.*

## Klíčová slova

***Podvozek, dynamické zatížení, pružinový model.***

Článek popisuje navržení tvaru, vytvoření výpočetního modelu a způsob posouzení nosné konstrukce mobilní sauny na dvounápravovém podvozku, viz obr. 1. Předlohou pro nový návrh byl stávající nevyhovující podvozek maringotky v majetku objednatele.

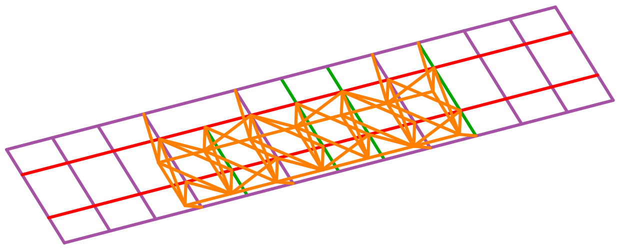
Nově navržená konstrukce, složená z jeklů různých rozměrů, je kombinací rámu a dvojice příhradových ztužidel. Spodní ztužidlo zajišťuje především odolnost vůči kroutícím účinkům vzniklým pojezdem po nerovném povrchu. Horní ztužidlo pak zajišťuje konstrukci zatíženou účinky brzdění. Podvozek je uložen na dvou nápravách odpružených čtveřicí listových per.




**Obr. 1:** Schéma hlavní nosné konstrukce podvozku a umístění náprav.

Schéma na obr. 1 ukazuje trojici obdélníkových otvorů. Otvory nejsou využité k příhradovému řešení, jelikož budou obsahovat velkoformátové výplně (zavětrování je zajištěno diagonálami v příčných rámech). Konkrétně otvory vlevo a vpravo jsou určeny pro okna. Otvor uprostřed pak pro vyklápěcí schodiště. Okenní otvory tvoří z hlediska mezí použitelnosti kritickou část, jelikož bylo třeba zajistit dostatečně malé deformace po extrémním zatížení, které nepřekročí dilatační meze okenních výplní.

Obr. 2 ukazuje axonometrický pohled na spodní nosnou část podvozku. Červenou barvou jsou zde znázorněny hlavní podélníky, fialovou barvou pomocné podélníky a horní pásy těžších příčníků (nesou sloupy horní konstrukce). Oranžovou barvou jsou znázorněny profily spodního příhradového ztužidla a zelenou barvou horní pásy lehčích příčníků (nenesou sloupy).



**Obr. 2:** Schéma spodní nosné konstrukce.

Znázorněná příhradovina tvoří plné příhrady ve stěnách kvádrů, přičemž všechny prostorové diagonály chybí. Tyto kvádry jsou navrženy s ohledem na jejich využití pro skladování materiálu a odpadních látek.

Model podvozku je dynamický, fyzikálně a geometricky nelineární, čímž je zajištěno posouzení konstrukce na porušení, dynamické účinky a ztrátu stability.

Každý prutový segment modelu je rozdělen alespoň na tři části (pružinové elementy), díky čemuž je zajištěna možnost vybočení prutu ve vzpěru, viz obr. 3. Pruty a jejich vazby reflektují skutečné propojení jednotlivých segmentů. Hlavní nosník je tak modelován jako spojitý, ačkoliv se svou částí účastní příhradového ztužidla.

## Poděkování

Tento příspěvek vznikl za finanční podpory projektu LO1408 AdMaS UP – Pokročilé materiály, konstrukce a technologie, podporovaného Ministerstvem školství, mládeže a tělovýchovy České republiky v rámci Národního programu udržitelnosti I.

Děkujeme kolegyni doc. Nikol Žižkové za možnost účastnit se tvorby takto unikátní a podnětné konstrukce.

# VÝPOČET DYNAMICKÝCH ÚČINKŮ ROTORU NA ZÁKLAD

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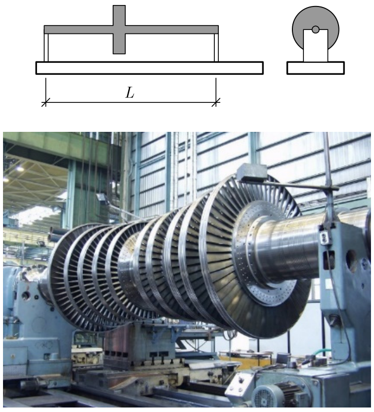
***Abstract.*** *The paper is focused on analysis of dynamical load of a basement caused by a rotor.*

Článek popisuje stanovení dynamických účinků stroje vyvažujícího určené typy rotorů s daným nevývažkem na základovou konstrukci, na níž stojí, viz obr. 1, včetně odhadu vlastních frekvencí soustavy pro zamezení možné rezonanci v pracovním režimu stroje.




**Obr. 1:** Schéma vyvažovací konstrukce s rotorem a ilustrační snímek rotoru [1].

Podkladem pro výpočty byly výkresy zařízení včetně rozpisu hmotností součástek a určené noremní zatřídění možné nevývahy rotoru (stupeň jakosti nevyvážení) $G$ dle ČSN (veličina má jednotky [m/s], viz např. [2]).

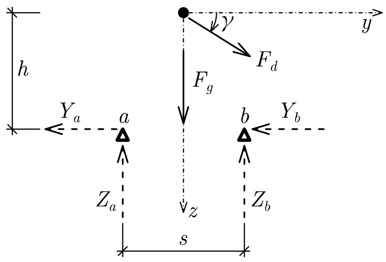
Velikost tzv. nevývažku $U$ [kg m] a excentricita těžiště rotoru $e$ [m] jsou dány výrazy:

$$U = m\,e, \qquad e = \frac{G}{\omega}, \tag{1}$$

kde $m$ je hmotnost rotoru točícího se úhlovou rychlostí $\omega$. Otáčející se rotor zatěžuje základ tíhovou silou $F_g$ a časově proměnlivou silou $F_d$ působící v ose rotace, viz obr. 2 danou výrazem:

$$F_d = m\,a, \qquad a = \omega^2 e, \tag{2}$$

kde $a$ je dostředivé zrychlení.




**Obr. 2:** Působící síly v rovině kolmé k ose rotoru.

Ze zatěžujících sil $F_g$ a $F_d$ dle obr. 2 stanovíme reakce v bodech upevnění $a$ a $b$:

$$Z_{a,b} = \frac{F_z}{2} \mp F_y \frac{h}{s}, \qquad Y_{a,b} = \frac{F_y}{2}, \qquad F_z = F_g + F_d \sin\gamma, \qquad F_y = F_d \cos\gamma, \tag{3}$$

kde $F_y$ a $F_z$ jsou složky výslednice sil zatěžujících základ, síly $Z$ a $Y$ jsou složky reakcí v bodech upevnění. Poznamenejme, že je z hlediska bezpečnosti vhodnější uvažovat prosté uložení, čímž vzroste vodorovná složka reakcí na dvojnásobek.

**Poděkování**

Tento příspěvek vznikl za finanční podpory projektu LO1408 AdMaS UP – Pokročilé materiály, konstrukce a technologie, podporovaného Ministerstvem školství, mládeže a tělovýchovy České republiky v rámci Národního programu udržitelnosti I.

**Literatura**

[1] Foto z archivu Škoda Power, s.r.o., Plzeňský deník, 2008.

[2] PETERKA, Z. Vyvažování rotorů turbin, bakalářská práce, Energetický ústav, FSI VUT v Brně, 2012.

# STRESS ANALYSIS OF BASIC SHAPES OF MEMBRANE STRUCTURES

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***Abstract.*** *Membrane structures are often designed as roofing for temporary and permanent buildings. Advantages of membranes are a low weight, aesthetic airiness, high shape variability, large spans, and the aesthetics of the structures themselves. Three basic types were analyzed in terms of extreme stresses. For the analysis, the computing software RFEM was used. In the form-finding process, the U. R. Brightzer and E. Ramma's Updated Reference Strategy method is applied [1].*

## Keywords

***Stress analysis, membrane, tension structure, fabric construction, numerical modelling, form – finding.***

## 1. Introduction

The aim of this article was analyzing basic shapes in terms of extreme stress after loading the structure. For every shape, there were determined a variable parameter in construction. It was analyzed how changes affect the resulting stresses after the loading.

## 2. Shapes of Membrane Structures

### 2.1. Hyperbolic Paraboloid (Hypar)

The slope of the anchor columns was analyzed as a variable parameter. With the increasing slope up to about 30°, there is a gradual increase in internal forces and stress values in the fabric. Between 30°- 45°, the magnitude of internal forces and stress decreased gradually. For columns at an angle of 60°, the biggest internal forces occurred in supporting steel elements and there is also the greatest stress.

### 2.2. Saddle

As a variable parameter was determine the arc shape with the same span of the anchor columns. The resulting stress in the membrane fabric increases with the decreasing arch. The arches were also modeled with same column span and arching. For parabolic arch, the stresses were more favorable with respect to stress peaks and more evenly distributed around the steel profiles than for semicircular arch.

### 2.3. Cone

The cone was modelled as a one area without any prestressed rods inside the fabric. With the increasing height, the radius of circular profile at the top of the cone needs to be increased also. If not, the equilibrium shape could not be reached. As next, 4 prestressed rods were modelled into the fabric and the equilibrium shape was reached without increasing the radius of circular profile. However, the stress values was higher than in first option.

## 3. Conclusion

The aim of this paper was to analyse the static behaviour of the membrane structure depending on its shape.

## Acknowledgements

This contribution has been completed thanks to the financial support provided to VSB-Technical University of Ostrava by the Czech Ministry of Education, Youth and Sports from the budget for conceptual development of science, research and innovations for the 2019 year and grant program „Support for Science and Research in the Moravia-Silesia Region 2018" (RRC/10/2018), financed from the budget of the Moravian-Silesian Region.

## References

[1] WÜCHNER, Roland and Kai-Uwe BLETZINGER. Stress-adapted numerical form finding of pre-stressed surfaces by the updated reference strategy. Numerical methods in Engineering. John Wiley, 2005, 64(2), 143-166. DOI: 10.1002/nme.1344

[2] RIVERA, Romualdo. Membrane Structures: First Steps Towards Form Finding. Membranas Estructurales, 2014. ISBN 9780986324710.

# STRENGTH TESTS OF CONCRETE SAMPLES EXPOSED TO AN AGGRESSIVE ENVIRONMENTS

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***Abstract.*** *The results of static tests of concrete samples exposed to aggressive environment of agricultural object are presented in this article.*

## Keywords

***Strength tests, samples of concrete, aggressive environments, elastic modulus.***

## 1. Introduction

Agricultural structures built in the second half of the past century in Slovakia nowadays show a high degree of degradation. This leads to the degradation of their static function and it is inevitable to monitor their condition. In order to eliminate degradation impacts, it is necessary to discover reasons of degradation and subsequently to design reconstruction methods.

The aim of the experiment was to evaluate the condition of ceiling panels of K-174 cow-barn structure and to design suitable rehabilitation provisions. In order to evaluate an impact of the aggressive environment, during construction of the cow-barn concrete beams made of various concrete classes were placed into sky-lights to be later analysed for chemical degradation and its impact onto the concrete structure. The original formulation of the concrete mixture is not available, therefore after 27-year-long exposition, the concrete beams were also tested for strength in order to compare contents of chemical substances in samples made of different concrete classes. Static tests results were evaluated in accordance with chemical analysis and were also compared with results obtained from the existing panel fragments.

Strength tests performed on concrete beams were confronted with chemical analysis results. Based on the comparison of aggressive chemicals contents (chlorides, nitrates, ammonium salts, sulphates) between the beams and ceiling panel fragments, and measurements of proved strengths and Elastic moduli in the beams, it can be stated that high-strength concrete is as susceptible to aggressive substance penetration as low-strength concrete. High-strength concrete is not a guarantee of a lower content of unfavourable substances in a structure. This results in necessity to regularly monitor a structure of any kind of concrete placed in an aggressive environment, to monitor chemical substances increase, and to evaluate their impact on the structure. Based on the obtained data, it is inevitable to provide its maintenance and/or reconstruction.

## Acknowledgements

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## References

[1] PRIGANC, S.; and I. HEGEDÜSOVÁ. Assessment of the condition of ceiling panels in an aggressive environment. In: *Czech Journal of Civil Engineering*. 2015/2. ISSN 2336-7148.

[2] HEGEDÜSOVÁ, I. and S. PRIGANC. *Analysis of concrete panel properties in aggressive environment.* TU – SvF 2015. ISBN 978-80-553-2312-1.

[3] PRIGANC, S. and E. TERPÁKOVÁ. *Diagnostics of concrete structure elements.* 1. Košice, TU, SvF, 2003. ISBN 80-7099-937-3.

# Measurement of the Depth of Chloride Penetration – Silver Nitrate Colorimetric Method

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***Abstract.*** *Chloride ions can cause reduction of the durability of concrete structures placed in aggressive environment; mostly highways, bridges and garages or structures in seashore environment. The depth of the chloride penetration can be very effectively measured by colorimetric method with $AgNO_3$ solution. In the article the evaluation of the application of colorimetric method to specimens made of two types of concrete is presented; the penetration depths are qualitatively compared.*

## 1. Colorimetric Method with $AgNO_3$ Solution

The silver nitrate colorimetric method for identifying the presence of free chlorides is very fast and easy to use [1]. Tested circular specimens (Fig. 1a) made of ordinary and high-performance concrete were placed in the fully saturated NaCl solution for 30 days. After this time were rinsed by tap water and let to dry. Then were sawn by 3 cuts of the dry saw and the $AgNO_3$ solution with concentration of 0.1 N was carefully sprayed onto the fresh surfaces [2]. After the application, the photochemical reaction occurred – the area that contained free chloride ions changed its color to light grey, and the area with low or zero concentration of chloride ions transformed to brownish color (Fig. 1b) [1].

The penetration depth is not completely same in every point of the specimen, so 7 measurements in every circa 10 mm were done from the top and the bottom of every specimen, while avoiding the parts with aggregates and the ends of the sample [2]. Penetration depth was calculated as a mean value of these measurements (Table 1).

**Tab.1:** The mean values of the penetration depth of each specimen.

| Specimen | Penetration depth from the bottom [mm] | Penetration depth from the top [mm] | Mean value of penetration depth [mm] |
|---|---|---|---|
| OPC-S-0 | 4.13 | 1.69 | 2.91 |
| OPC-S-1 | 3.37 | 3.46 | 3.42 |
| HPC-S-0 | 8.52 | 6.63 | 7.58 |
| HPC-S-1 | 7.23 | 6.47 | 6.85 |

## 2. Conclusion

The qualitative assessment of penetration depths is presented in the paper. Based on the values given in Table 1 results that the penetration depth is circa two times higher on the specimens made of high-performance concrete. However, it is not possible to identify the concentration of chloride ions by colorimetric method [1].

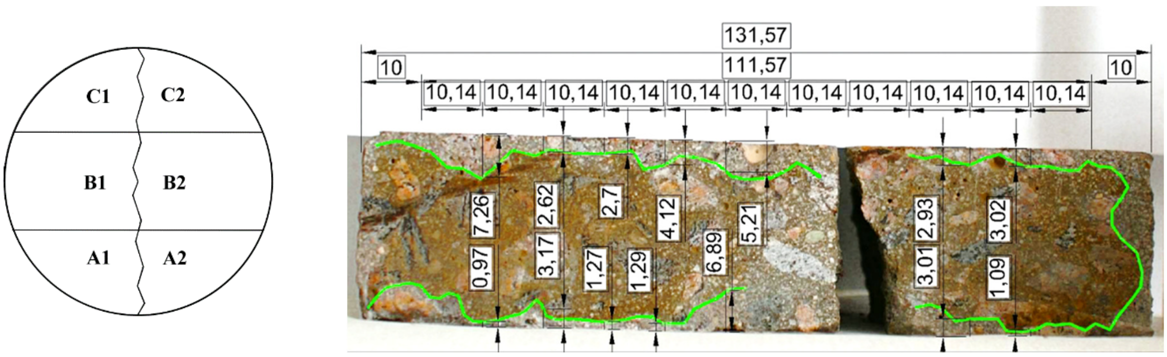


**Fig. 1:** a) Schema of the specimen, b) Measurement of the chloride penetration depth, specimen OPC-S-0, area a1-a2.

## References

[1] REAL, L. V., OLIVEIRA, D. R. B., SOARES, T., & MEDEIROS, M. H. F. (2016). $AgNO_3$ spray method for measurement of chloride penetration: the state of art. Revista ALCONPAT.

[2] NT Build 492. (1999). Concrete, mortar and cement-based repair materials: Chloride migration coefficient from non-steady-state migration

# FINITE ELEMENT MODELLING OF REINFORCED CONCRETE SLAB EXPOSED TO EXTREME LOADS

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***Abstract.*** *Numerical approach using the FEM has been used to determine the mechanical resistance (criterion R) of a reinforced concrete structure exposed to fire. Geometry of the structure is considered as a simply supported slab in one dimension. Fire load has been defined by a nominal standard ISO 834 fire curve. Both, thermal and structural response are obtained using a FEM software ANSYS. Temperature-dependent nonlinear thermal and mechanical properties of concrete and reinforcement are adopted in accordance with Eurocode standards. Nonlinear material model Menetrey-Willam with exponential functions for compression hardening (and softening) and tension softening has been used to describe the behaviour of concrete elements. Discrete option of modelling reinforcement has been considered. Mechanical resistance of the slab is determined by reaching the limit mid-span deformation. Results have been compared with simplified method of isotherm 500 °C described in Eurocode.*

## Keywords

***Extreme loads, mechanical fire resistance, Menetrey-Willam material model, numerical nonlinear analysis, reinforced slab structure, transient fire response.***

## 1. Introduction

In contrast to most of the studies in this field [1], recently implemented non-linear material model for concrete, Menetrey-Willam [2], has been examined. Instead of widely used [1] legacy elements SOLID65 [2] to model concrete, a current technology elements SOLID185 has been used. To provide extra discrete reinforcement, special type of REINF264 elements are applied.

3D model of the slab in simple bending is developed due to more realistic assessment of reinforcement in concrete. To model plane strain, translational constrains have been applied along the transversal sides of the narrow segment of the simply supported slab.

The sequentially coupled thermo-mechanical analysis procedure requires 2 models with the same geometries to be developed. One for a transient thermal analysis and the second to be used in a transient structural analysis. Both have been carried out in Classic APDL environment.

Three different loading history approaches are examined. In the first one, the estimated (Eurocode) limit mechanical load is applied before the fire exposure. Simultaneously applied loads are examined in the second approach, and reverse loading history in the third one.

## 2. Conclusion

Different loading history approaches during non-linear analysis lead towards to different softening of the initial stiffness and different results in calculation convergences.

Compression is rising in concrete surfaces exposed to fire thermal load, even if not directly constrained.

## Acknowledgements

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## References

[1] DŽOLEV, I., M. CVETKOVSKA, Đ. LAĐINOVIĆ and V. RADONJANIN. Numerical analysis on the behaviour of reinforced concrete frame structures in fire. *Computers and Concrete*. 2018, vol. 21, iss. 6, p. 637-647. ISSN 1598-818X. DOI: 10.12989/cac.2018.21.6.637.

[2] ANSYS Inc. *ANSYS® Academic Teaching Mechanical: ANSYS Help Documentation*. Release 16.0, Canonsburg, 2017.

# STABILITY OF RECTANGULAR SANDWICH RIBBED PLATE WITH DISCRETE FILLER

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***Abstract.*** *A sandwich plate loaded along a contour with two outer layers and an intermediate layer as a discrete, ribbed filling is considered.*
*The outer layers are made from fiberglass plastic would be reinforced either with uniformly with fiberglass woven or discretely by separate high-strength threads. The load bearing capacity of the plate is determined not only by its reduced bending stiffness at possible buckling, but also by the degree of stress concentration near the regularity violations due to the attachment of the ribs and arrangement of the reinforcing threads.*
*The results of calculations indicates that when the number of ribs is more than 4 in each of the directions, a continuous plate with reduced bending stiffness would be accepted as a design model. At one or two edges neglect of their discrete arrangement would lead to the completion of the critical load value up to 2-2.5 times.*

## Keywords

***Formating, paper, styles, template.***

## 1. Introduction

Is considered the loaded on contour sandwich plate with two external layers and intermediate layer as discrete ribbed filling. The external layer is made from glass fiber that would be reinforced uniformly by glass wove or discretely by high strength threads. The load bearing ability of plate is determined not only by its reduced bending stiffness at possible buckling but also by degree of stress concentration in adjacent of violations of regularity due attachment of ribs or arrangement of reinforcement threads. The results of analysis indicates that at number of ribs more than 4 in each direction as design model would be accepted continuous plate with reduced bending stiffness. If at one or two ribs is not considered their discrete arrangement it would leads to termination of value of critical loading in 2÷2.5 times.

As object of carried out research is the loaded on contour sandwich plate with two external layers and internal layer as discrete ribbed filling. The external layer is made from glass fiber that would be reinforced uniformly by glass wove or discretely by high strength threads. The load bearing ability of plate is determined not only by its reduced bending stiffness at possible buckling but also by degree of stress concentration in adjacent of violations of regularity due attachment of ribs or arrangement of reinforcement threads

## 2. Conclusion

The initial relations are presented and are obtained decisive equations for plates with cuts and ribs of limited length, parallel to the sides of a rectangular contour. The limited length ribs, smaller than the length of the side of a rectangular contour, are considered as edges of step-variable stiffness. Thus, the obtained dependences and the resolving equations turn out to be general and can be extended to wider, rather steep problems than those studied in the presented paper.

The developed method for analysis of shells with fractures and ribs in linear and non-linear formulation and the resulting calculation formulas allow to describe all the features in the distribution of components of the stress-strain state near the regularity failures, reflect the change and redistribution of forces and moments in the process of loading.

# DOPROC METHOD DEVELOPMENT WITH REGARD TO PARALLELIZATION

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***Abstract.*** *Probabilistic methods allow better account of the randomness of input quantities in the design process and the reliability assessment. The presented DOProC method uses optimized numerical integration to calculate the probability of failure. The main improvement of this method is an increase in the accuracy of calculating the probability of failure by modification of the basic algorithm and reduction of computation time using parallelization. Probabilistic modeling and prediction of fatigue damage is one of the fields where the DOProC method is advantageously utilized and applied.*

## 1. Introduction

Probabilistic methods are used in engineering where a computational model includes random input variables. The DOProC method (Direct Optimized Probabilistic Calculation) is one of many probabilistic methods which uses optimized numerical integration to calculate the probability of failure. The main advantages include: the high accuracy of the failure probability calculation and the high efficiency of the calculation for many probability tasks (e.g. probabilistic prediction of fatigue damage [1]). Principle of the method was published e.g. by [2].

## 2. Parallelization of the DOProC computation

Calculations by DOProC method can be very time consuming. Certain parts of the calculations may take place simultaneously. In the basic computational algorithm, it is possible to divide the total number of computational operations into as many parts as are available number of computing units. After partial calculations, the histogram of the resulting variable (e.g. reliability function $Z$ in probabilistic reliability assessment) can be compiled from the partial results.

## 3. Conclusion

In this paper, it has been presented the improvements of the probabilistic method - DOProC, which is still under development, such as reducing calculation time using parallelization. It turns out that the DOProC method is very suitable for solving various engineering tasks such as modelling of fatigue problems and prediction of fatigue damage.

## Acknowledgment

This contribution has been developed as a part of the research project GACR 17-01589S "Advanced computational and probabilistic modelling of steel structures taking account fatigue damage" supported by the Czech Grant Agency and also has been completed thanks to the financial support provided to VSB-Technical University of Ostrava by the Czech Ministry of Education, Youth and Sports from the budget for conceptual development of science, research and innovations for the 2019 year.

## References

[1] KREJSA, M., L. KOUBOVÁ, J. FLODR, J. PROTIVÍNSKÝ and Q.T. NGUYEN. Probabilistic prediction of fatigue damage based on linear fracture mechanics. *Frattura ed Integrita Strutturale*. 2017, vol. 11, iss. 39, pp. 143–159. DOI: 10.3221/IGF-ESIS.39.15.

[2] JANAS, P., M. KREJSA, J. ŠEJNOHA and V. KREJSA. DOProC-based reliability analysis of structures. *Structural Engineering and Mechanics*. 2017, vol. 64, iss. 4, pp. 413–426. DOI: 10.12989/sem.2017.64.4.413.

# Numerical Study of Flow Around Cylinder in the Range of High Reynolds Numbers

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## 1. Introduction

A numerical study of the flow over a smooth cylinder in the regimes with a character of the flow for four Reynolds numbers ranging from $\mathrm{Re} = 4 \cdot 10^3$ to $\mathrm{Re} = 1.4 \cdot 10^5$ is presented in the article. The results of experiments for Re at the boundaries of this interval are available in the literature[1, 2], but it seems that the region of the intermediate values is not yet sufficiently analyzed.

The task is solved by the finite volume method in the commercial software Ansys Fluent, which allows good parallelization of the computational domain. The calculations are performed on the high performance computing facility, because it is necessary to use an advanced turbulent model (LES model in this study) and a properly fine meshing.

Results are verified using available experimental data. The following characteristics are observed: the velocity profile in the wake behind the cylinder, the distribution of the pressure load on the circumference of the cylinder (pressure coefficient $c_p$), the resistance force of the object (drag coefficient $c_d$), the frequency of the vortex shedding (lift coefficient $c_l$), Strouhal number St.

## 2. Normalized mean stream velocity for selected Re

Normalized mean stream velocities in the wake at the cylinder axis level obtained from both numerical and physical experiments for all monitored Re are recorded in Figure 1.

CFD simulations have shown a shortening of the core of the wake with a growing Re number.

This result represents a good agreement with the experiments presented by [1, 2] for both boundary Re.

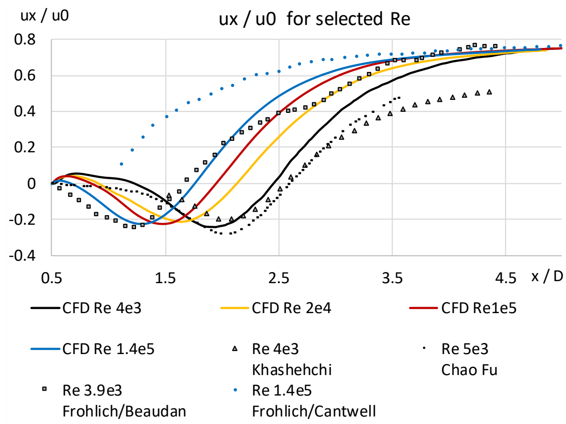


**Fig. 1:** Normalized mean stream velocity for selected Re

## Acknowledgment

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## References

[1] CANTWELL, B. and D. COLES, An experimental study of entrainment and transport in the turbulent near wake of a circular cylinder. *Journal of Fluid Mechanics*. 1983, vol. 136: p. 321, DOI:10.1017/S0022112083002189.

[2] BEAUDAN, P. and P. MOIN, Numerical Experiments on the Flow Past a Circular Cylinder at Subcritical Reynolds Number. *Report TF-62*. 1994.

# SENSITIVITY ANALYSIS OF SIMPLY SUPPORTED LAMINATE PLATE

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***Abstract.*** *An explanation of the sensitivity concept involved in the analysis of composites, the mechanics needed to investigate this concept into a mathematical representation of the physical reality, and numerical solution of the sensitivity analysis of the resulting boundary value problems by using Finite Element Analysis software are included in this paper. The design of a composite laminate is problem with fiber orientation design variables. The continuous-valued design variables as a fiber orientations have changes between 0º and 90º and they are taken into account in the sensitivity problem.*

## Keywords

***Composite laminate, design variables, sensitivity problem.***

## 1. The Sensitivity Problem

In a sensitivity study we need design variables and response quantities, that are functions of the design variables. A sensitivity analysis of 8-layer $[0/\theta/-\theta/90]_S$ Carbon-Epoxy laminate plate due to changes in the ply orientation $\theta$ is solved. The material constants of laminate layer are following: $E_1$ = 140 GPa, $E_2$ = 10.3 GPa, $G_{12}$ = 7.8 GPa, $\nu_{12}$ = 0.3. The bending loading of 5 kPa is applied to the simply supported plate with dimensions 0.8 m x 0.8 m.

## 2. Results and Discussion

In the global sensitivity study, the design variables are fiber angle orientations, that are changed between 0º and 90º in 19 of steps. The sensitivity analysis in the next three figures shows influence of angle changes to the values of the strain vector components $\varepsilon_x, \varepsilon_y, \gamma_{xy}$, respectively.

The best laminate stacking is for angle $\theta = \pm 45$, and therefore $[0/45/-45/90]_S$ laminate is suitable to take into consideration for bending analysis.

The sensitivity analysis of composite structures or structural elements is important analysis for design of structures or structural elements ranging from aircrafts to civil structures.

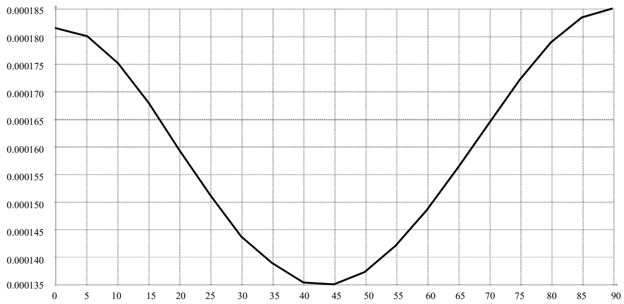


**Fig. 1:** Sensitivity analysis of $\varepsilon_x$ versus fiber angle orientation.

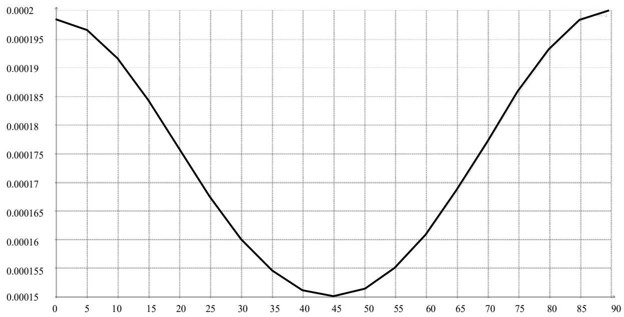


**Fig. 2:** Sensitivity analysis of $\varepsilon_y$ versus fiber angle orientation.

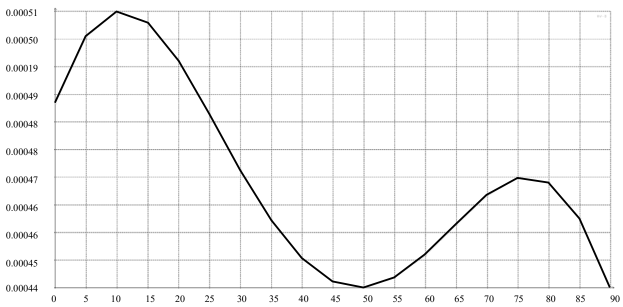


**Fig. 3:** Sensitivity analysis of $\gamma_{xy}$ versus fiber angle orientation.

# NONLINEAR ANALYSIS OF THE EXTREME WIND FRAGILITY OF THE REACTOR HALL FRAME

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***Abstract.*** *This paper describe the methodology and the results of the safety analysis of the Nuclear Power Plant structures under impact of the extreme climatic loads. In the case of the Nuclear Power Plant structures, the design criteria are stronger. The requirements of the international agency IAEA and NRC standards are based on the probability of mean return period equal to one per $10^4$ years. The fragility curve of the extreme wind was determined on the base of the nonlinear probability analysis of the steel hale frame considering material and geometric nonlinearity using ANSYS software. The failure mode of the NPP structures is expressed by High Confidence of Load Probability of Failure (HCLPF).*

## Keywords

***NPP, Nonlinear, Safety, Fragility, Probability, Extreme Wind, ANSYS.***

## 1. Introduction

This paper deals with the resistance of the steel hale frame of the nuclear power plant (NPP) with reactor VVER440. The international organization IAEA in Vienna set up the design requirements for the safety and reliability of the NPP structures. The extreme environmental events (e.g. wind, temperature, snow, explosion...) are the important loads from the point of the NPP safety performance. The extreme wind loads are defined with the probability of mean return period equal to one per $10^4$ years. This paper deals with the analysis of the steel hale frame loaded with extreme wind load. The FEM model of the steel hale frame consist the beam and mass elements of ANSYS program - BEAM188 and MASS21 (fig.1).

The load combination of the probabilistic analysis is based on ENV and JCSS standards requirements for the ultimate limit state of the structure as follows:

$$E = G + Q + W_E = g_{var}.G_m + q_{var}.Q_m + w_{var}.W_{Em} \qquad (1)$$

where $g_{var}$, $q_{var}$, $w_{var}$ are the variable parameters defined in the form of the histogram calibrated to the load combination in compliance with Eurocode and $G_m$, $Q_m$ and $W_{Em}$ are the median values of the permanent dead loads, live loads and extreme wind loads.


**Fig. 1:** FEM model of the steel hale frame.

The extreme wind load (EWL) was determined from the maximum wind speed determined from the SHMU measurements in the NPP locality for the return period $10^{-4}$ by year and the probability of non-exceedance 95%

$$v_b = 53.9 \text{ m/s and pressure } q_b = 1.816 \text{ kPa} . \qquad (2)$$

The probabilistic nonlinear analyses were carried out in the software ANSYS using the approximation method RSM to determine the probability of the frame failure. The geometric and material nonlinearity were taken into account. The elastic-plastic model of steel material was taken in compliance with the Von Mises yield function. The Newton-Raphson iteration method to solve nonlinear equations was taken. The parameter HCLPF was calculated as the maximum wind load determined from the nonlinear probabilistic analysis.

## References

[1] KRÁLIK, J. *Safety and Reliability of Nuclear Power Buildings in Slovakia. Earthquake-Impact-Explosion.* Monograph. Edition STU Bratislava, 305 p. 2009.

# COMPARISON OF S-N CURVES FOR CONCRETE IN EN 1992-2 AND *FIB* MODEL CODE 2010

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***Abstract.*** *The paper is focused on the comparison of Wöhler's curves for concrete in accordance with fib Model Code 2010 and EN 1992-2. It discusses the great difference for bridge fatigue assessment between Model Code 2010 and EN 1992 observed in previous studies. Respective S-N curves were compared with the experimental data for concrete C20. Evaluation is performed for concrete exposed to compression only. Wöhler's curve in fib Model Code 2010 is more complex and can better fit experimental data than the Eurocode model.*

## Keywords

***Fatigue, fib Model Code 2010, EN 1992, Wöhler's curve for concrete.***

## 1. Introduction

The study is based on the practical problem where the great differences for probabilistic estimation of a bridge fatigue life in accordance with EN 1992-2 (EC) and *fib* Model Code 2010 (MC) observed by previous unpublished studies of the authors. Estimation of service life of bridges is significantly affected by fatigue induced by crossings of heavy vehicles and significantly depends on the type of an S-N curve adopted in the assessment. While in common cases fatigue resistance of concrete is assessed indirectly through the check of stresses due to service loads, a more advanced assessment using S-N curves is often needed for slender structures, existing structures failing to comply with the stress limit, or some members of prestressed structures.

All calculations are performed for theoretical minimal and maximum compression in concrete. Mean values obtained by the MC and EC models are critically compared with limited experimental data.

## 2. Comparison of Methods with Data

MC provides a more complex method than EC, i.e. MC Wöhler's curve additionally depends on stress gradient $\eta_c$. The paper provides the critical comparison of methods for different minimum compressive stress level $E_{c,\min}$ with experimental data and discusses the influence of $\eta_c$ on MC Wöhler's curve.

## 3. Conclusion

It appears that:

- For $\eta_c = 1$ the EC model seems to be more conservative for $E_{c,\min} \leq 0.6$; for $E_{c,\min} > 0.6$ the EC and MC models seem to lead to similar results.
- $\eta_c$ decreases a number of constant amplitude cycles for maximum compressive stress level in MC (effect increases with increasing minimum compressive stress level).
- Both models seem to be slightly conservative in comparison with the experimental data; the MC model provides a slightly better fit.

It is foreseen that the achieved experience will be utilised in refinements of fatigue resistance models for concrete structures. The presented approach could be also utilised to validate fatigue resistance models for UHPC where fatigue often dominates structural reliability.

## Acknowledgements

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# DEVELOPMENT OF CORROSION LAYER UNDER INCREASED DEPOSITION OF DE-ICING SALT

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***Abstract.*** *Up to 20% of the bridges on the main roads in the Czech Republic are in unsatisfactory state. One of the main causes of the unsatisfactory condition of steel bridges is the corrosion damage of the main supporting elements. The reasons for corrosion damage are inappropriate design of structural details, defects in the leakage system, inappropriate design of corrosion protection and neglected maintenance. Weathering steel is used for the design of bridge structures placed I the outdoor. This steel can be used outdoor without the corrosion protection. Local type of corrosion damage of bridges designed from weathering steel is due to microclimatic conditions around the bridge due to increased deposition of dust deposits and chlorides on the surfaces of the structure. In order to monitor the amount of chlorides in the surrounding of bridges, experimental tests were carried out on two selected bridge structures in Ostrava (the Czech Republic). The article discusses the relationship between chloride deposition and thickness of the corrosion layer.*

## Keywords

***De-icing salts; weathering steel; maintenance of bridges; layer of corrosion products; wet candle method; dry plate method.***

## 1. Introduction

In the Czech Republic there are 3 353 bridges located on highways and roads Class I., II. and III in either poor, very poor or even emergency condition. One of the most common causes of unsatisfactory condition in bridges with steel structures is corrosion damage [2, 3]. A specific group of bridges with a steel structure are those designed with structural steels with improved atmospheric corrosion resistance, commonly called *weathering steel bridges* [4, 5]. If the road traffic is the reason for a higher deposition of dust particles and chlorides, the environmental parameters of the bridge cannot be changed. The impact of the structure and layout of the bridge on the amount of deposited chlorides should also be studied. Measurement of the chloride deposition rate is specified in ČSN ISO 9225 [6].

## 2. Conclusion

The article discusses the results of the data obtained from the experiment - chloride deposition rates and corrosion layer thicknesses measured on two bridge structures in Ostrava. Bridge structure B1 shows an expected significant effect of chlorides on the development of corrosion layers on the weathering steel surfaces. A highway passes beneath the bridge, which is treated with de-icing salts containing chlorides.

## References

[1] ČSN 73 6221 – Control of road bridges, ČNI, 2/2018.

[2] ABDUL - WAHAB, A. S. Effect of air pollution on atmospheric corrosion of engineering metals, *Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management*, 8(4), 2004.

[3] Alcámtara, J., CHICO, B., DIÁZ, I., de la FUENTE D., MORCILLO, M. Airbone chloride deposit and its effect on marine atmospheric corrosion of mild steel, *Corrosion Science*, 97, 2015.

[4] McCONELL, J. R., SHENTON, H. W., Mertz, D. R. National review on use and performance of uncoated weathering steel highway bridges, *Journal of Bridge Engineering*, 19(5), 2014.

[5] Bethlehem Steel Corporation, *Weathering Steel (Booklet 3791)*, Bethlehem, PA, (1993).

[6] *Corrosion of Metals and Alloys -Corrosivity of Atmospheres - Measurement of Environmental Parameters Affecting Corrosivity of Atmospheres*; ISO 9225; International Organization for Standardization: Geneva, Switzerland, 2012.

# Stress Distribution for Foundations - Numerical Analysis

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***Abstract.*** *In this paper stress distribution in different shapes of spread footing has been discussed. For the analysis purposes comparison of stress distribution has been performed for six different shapes of spread footing. Spread footings has been divided into two groups, where the first contained foundations with rectangular base and in the second one circular base has been considered, respectively. In both groups three different shapes of spread footing have been analysed – prismatic/cylindrical, prism with sloped edges/cut-off cone and stepped footing. For each spread footing in the centre of their top surface a small part of column has been modelled. Presented in this paper comparative analysis has been limited only to the pure axial loading subjected to the top surface of columns.*

## Keywords

***Stress distribution, spread footing, FEM.***

## 1. Model and Analysis

For the comparative numerical analysis of stress distribution, six different shapes of spread footing were chosen [1]. In order to perform numerical analyses SolidWorks software based on FEM was chosen. For each spread footing model with columns, concrete material was represented by linearly-elastic isotropic material model.

The comparative analysis of stress distribution in spread footings was made for three different cases. In the first case Misses stresses was measured as the maximum value from the bottom surface of spread footing. In the second case Misses stress was read-out as the maximum value from the perimeter of column located at the connection between column and foundation. In the third case, comparison concerns shape of foundation stress plots, where minimum value of stress was limited to 0.30 MPa. Numerical results of maximum Misses stress were presented in Fig. 1.

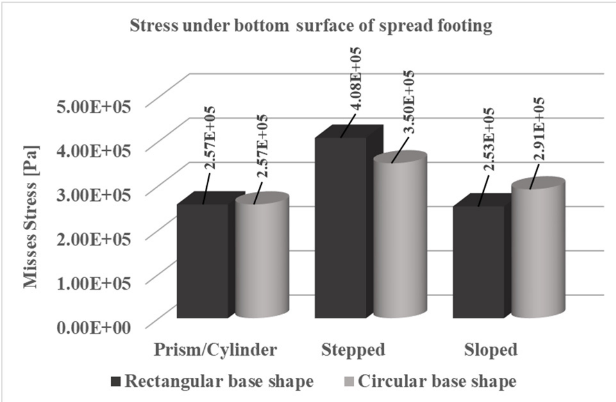


**Fig. 1:** Maximum Misses stress under the analysed foundations bases for different spread footing shapes.

## 2. Conclusion

From six different analysed shapes of foundations it was stated that the most appropriate one would be cut-off cone footing. It was shown that mentioned footing had the lowest weight and Misses stress under the bottom foundation surface was one of the lowest from analysed foundations. Also presented shapes of stress distribution for each spread footing proved that forces distribution in cut-off cone footing was visually comparable with the cylindrical one. In the stepped footings corner stresses were obtained at the connection between footings steps. Moreover, values of Misses stress under the mentioned stepped footings bases were the highest from all analysed foundations, which was connected with the lowest area on which the axial force was distributed from the first footing step.

## References

[1] PN-81/B-03020:1981, *Posadowienie bezpośrednie budowli. Obliczenia statyczne i projektowanie* Warszawa: PKNMiJ, 1981.

# ANALYSIS OF THE MECHANICAL WAVE IN THE COMPOSITE MADE OF CONCRETE AND RUBBER - NUMERICAL ANALYSIS

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***Abstract.*** *The paper presents a numerical analysis of the propagation of a mechanical wave in a composite made of concrete and rubber. It was assumed that both materials are incompressible hyperelastic materials, i.e. nonlinear materials, which are described by the hyperelastic potential. The obtained numerical results made it possible to assess the effectiveness of the composite in question in order to suppress dynamic effects, especially in places where concrete is used as a building material for building walls. This solution is an author's solution that allows an effective way to damp the mechanical wave propagating in the elastic medium. The foundation walls can be an example of using this solution.*

## Keywords

***Mechanical wave, composite, hyperelastic materials, FEM.***

## 1. Model and Analysis

In order to conduct numerical analysis of mechanical wave propagation in the considered rubber-concrete composite with dimensions of 0.47 m in length, 0.25 m in width and 0.22 m in height, a numerical model was made in the ADINA program - Fig. 1.

The dynamic external load was a concentrated force of 5000 N, which was applied to the surface of the front wall. The maximum value was reached for time $t = 1 \times 10^{-5}$ s. After this time, the force was removed and the impact value was 0. It should be noted that the applied load values were treated only as a reference for a comparative analysis between the composite and solid concrete blocks. Three different values of the time step have been included in further considerations about the obtained effective stress $t = 1 \times 10^{-5}$ s, $5 \times 10^{-5}$ s and $9 \times 10^{-5}$ s, respectively.

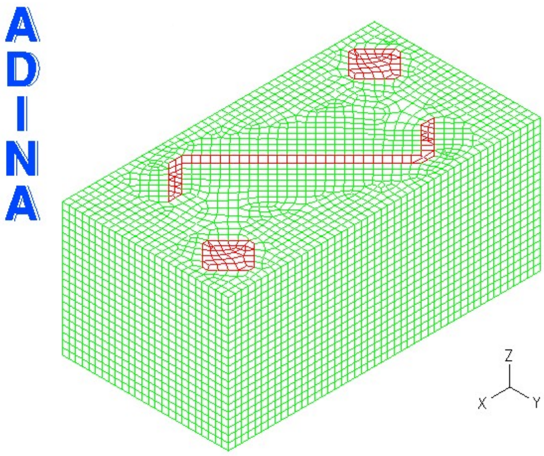


**Fig. 1:** Numerical model of the considered composite block.

## 2. Conclusion

The article discusses the propagation of a mechanical wave in an original concrete-rubber composite, from which a wall with intended strength parameters can be built. According to the numerical analysis, it was shown that propagation of the mechanical wave in the composite block can be significantly suppressed. The propagation wave on the back side of the considered composite has been reduced in the range of about 25-30% compared to a block made of solid concrete. Such values of mechanical wave damping can be obtained thanks to the mechanical energy absorption properties of the rubber used for this composite. From the engineering and design point of view, the composite presented can be easily used in civil engineering, especially in areas exposed to minor shocks, machine vibrations or to reduce acoustic waves. The presented composite gave satisfactory mechanical damping results by means of numerical analysis, and experimental investigations should also be carried out to estimate the actual bearing capacity and other material properties not specified in this document.

# The Determination of Optimal Technological Parameters of Sodium Cation Installation for Water Softening

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***Abstract.*** *In order to protect the environment and the rational use of natural resources, the optimal technological parameters of the process of regeneration of sodium cation exchangers with a solution of sodium sulfate were calculated. Target function accepted the present value of a cubic meter of softened water. Optimization criteria adopted by the transmission rate through the loading of softened water and the specific consumption of reagent. The mathematical expression of the objective function is obtained. Developed is the program for optimizing the operation of sodium cation filter.*

## Keywords

***Optimization, sodium cation filter, water softening.***

## 1. General

Modern coexistence of a man and nature sets lots of tasks for the society in various areas of their activity. Providing needs of the society leads to an increased use of natural resources and as a result causes the environmental pollution. For a comprehensive solution of this task, it is necessary to develop technologies that not only respond to environmental protection issues but also to rational use of natural resources. The solution of these issues is connected with the determination of the optimal parameters of technological processes. The goal of specialists is the development of new technologies in various fields and particularly in the development of water treatment technology for industrial enterprises.

As a rule, in technological tasks, the economic indices are recognized as optimum criterion of the process: the prime cost of the production got or the present value, when the quantity of the production received doesn't change. Such criterion allows to compare with each other and take into account the part of various technological parameters such as the volume of ion exchanger, reagent discharge, pressure loss of the layer and etc. The positive side of this criterion is that it allows not only to calculate the optimum parameters but also to compare various methods and to define the rational field of their use.

For this purpose, the optimal technological parameters of the process of regeneration of sodium cation exchangers with a solution of sodium sulfate were calculated. Obtained is mathematical expression of the objective function to determine the optimal technological parameters of the sodium exchanger installation regenerated with a solution of sodium sulfate. The program for optimization calculation of sodium cation exchanger work was worked out. Target function accepted the present value of a cubic meter of softened water. In the optimization program, in the first variant, the values of the exchange capacity that were got from the mass of the each layer calculation of the regeneration process were used, in the second variant, the values got from the calculation method of the exchange capacity of the cation exchanger were used. As we get the data from the each layer calculation in a discrete form, for convenient comparison the data got from the calculation method of the exchange capacity were also presented in a discrete form. Optimization of sodium cation exchanger work was solved numerically on PC by using standard libraries.

Optimization criteria adopted by the transmission rate through the loading of softened water and the specific consumption of reagent. The mathematical expression of the objective function is obtained. Developed is the program for optimizing the operation of sodium cation filter. Calculation tables and graphs of target functions are given. It has been established that the regeneration of sodium cation filter 1.5-2% with sodium sulfate solution at specific reagent consumption 0.29-1.08 gr-equiv·gr-equiv$^{-1}$ is optimal. Softened water flow rate is 1.25-5.72 m·h$^{-1}$.

The derived mathematical expression of the objective function and the developed program can be used to determine optimal process parameters for reconstruction of the existing design or the design of any new cationic units.

# Spectral and Correlation Characteristics of Road Unevenness

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## 1. Generation of Stochastic Road Profile

For numerical simulations of vehicle movement along the road, it is necessary to generate a random longitudinal road profile $u(x)$ based on the known power spectral density of the unevenness $S_u(\Omega)$. You can use the relationship (1) to generate a random profile

$$u(x) = \sum_{i=1}^{N} \sqrt{2 \cdot S(\Omega_i) \cdot \Delta\Omega} \cdot \cos(\Omega_i \cdot x + \varphi_i). \quad (1)$$

## 2. Spectral and Correlation Functions

In accordance with ISO 8608 [1], the pavements can be classified into eight categories A - H on the basis of Power Spectral Densities, using the relationship

$$S_u(\Omega) = S_u(\Omega_0) \cdot \left(\frac{\Omega}{\Omega_0}\right)^{-k}, \quad (2)$$

where $\Omega$ in [rad/m] denotes the wave number, $\Omega_0 = 1$ rad/m is the reference wave number and the waviness $k = 2$.

The statistical dependencies between individual points of a random profile, or between two random profiles, describe the correlation functions. The auto-correlation function for one random profile $u(x)$ is described by the relationship

$$R_u(\xi) = \lim_{x\to\infty} \frac{1}{2x} \int_{-x}^{+x} u(x) \cdot u(x+\xi) \cdot \mathrm{d}x, \quad (3)$$

where $\xi$ is lengthwise displacement in the $X$-axis direction, $\xi = x_2 - x_1$. An important feature of the auto-correlation function is that its zero point value is equal to the dispersion $D_u$

$$R_u(0) = D_u. \quad (4)$$

This means that the normed auto-correlation function $\rho_u(\xi)$ has a function value for $\xi = 0$ equals 1

$$\rho_u(0) = \frac{R_u(0)}{D_u} = 1\,. \quad (5)$$

The normed cross-correlation function for two random profiles $ul(x)$ and $ur(x)$ is described by the relationship

$$R_{ul,ur}(\xi) = \lim_{x\to\infty} \frac{1}{2x} \int_{-x}^{+x} ul(x) \cdot ur(x+\xi) \cdot \mathrm{d}x. \quad (6)$$

## 3. Conclusion

In the solution of the problem of vehicle roadway interaction the road unevenness represents the main source of kinematical excitation of vehicle. In accordance with ISO 8608 [1], roadways can be classified into 8 categories A – H, on the basis of power spectral densities Long waves predominate in the composition of unevenness. By smoothing the power spectral density shown in the log-log scale a line is obtained. It can be very good approximated by equation (2). On the basis of power spectral density $S_u(\Omega_0)$, for the reference wave number $\Omega_0 = 1.0$ [1/m], the quality of roads surface can be classified into eight categories A – H. But actually on highways and roads of the 1st and 2nd classes , only categories A ÷ E come into consideration. The statistical dependencies between individual points of a random profile, or between two random profiles, describe the correlation functions. The results of the correlation analysis show that there is little statistical dependence between individual points of the random profile. It is clear to see from the correlation functions that the random profile contains a number of periodically repeating components.

## Acknowledgements

This work was supported by the Grant National Agency VEGA of the Slovak Republic, project number 1/0005/16.

## References

[1] ISO 8608. *Mechanical vibration – road surface profiles – reporting of measured data.* International standard, 1995.

# NUMERICAL STUDY OF BRAZILIAN DISC TEST: CONSTRAIN EFFECT FOR VARIOUS NOTCH INCLINATION ANGLES

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## Keywords

***Brazilian disc, Stress Instesity Factor, T-stress, Mixed Mode I/II.***

## 1. Introduction

The Brazilian disc test with a central notch (BDCN) [1] provides information about fracture behaviour under modes I, II and mixed-mode I/II loading. The test performed on the BDCN specimen (circle cut from the core-drill cylinder) is carried out under relatively simple experimental conditions, using only the testing press with sufficient load capacity. The evaluation of the fracture parameters for modes I, II and mixed mode I/II is done by inclining the notch by angle $\alpha$ against the load position (see Fig. 1).

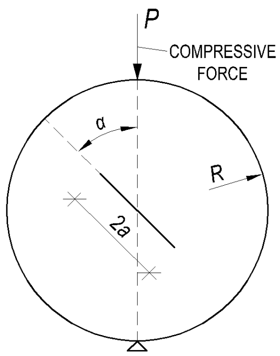


**Fig. 1:** Brazilian disc test with central notch and loading conditions.

The aim of this contribution is to evaluate and compare the values of the SIF under the mixed mode load (combination of mode I and mode II) and find the value of T-stress close to zero. This was done by a numerical model in which the constrain effect was studied and the geometry functions were evaluated.

## 2. Numerical Model

A numerical simulation was performed in the FE software Ansys 17.2 [8] to derive dimensionless geometrical functions for mixed mode of SIFs and to calculate *T*-stress. A two-dimensional (2D) numerical model with a plane strain boundary condition was used to calculate SIFs ($K_I$ and $K_{II}$). Input material properties of concrete used in FE analysis were following the Young's modulus and Poisson's ratio, $E$ = 40 GPa and $\nu$ = 0.2, respectively. Simulated BDCN had radius $R$ = 75 mm and the relative crack length $a/R$ was 0.4. Numerical model was loaded with constant force $P$ = 100 N in all cases.

## 3. Conclusion

In this contribution a numerical study of the Brazilian disc test with central notch was performed with focus set on finding the notch inclination angle $\alpha$, where the T-stress reaches value of zero. The presented T-stress values were compared to literature and shows good agreement.

## Acknowledgements

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The first author is Brno Ph.D. Talent Scholarship Holder – Funded by the Brno City Municipality.

## References

[1] LI, D. and L.N.Y. WONG. The Brazilian Disc Test for Rock Mechanics Applications: Review and New Insights. *Rock Mechanics and Rock Engineering.* 2013 vol. 46 pp. 269-287. ISSN 0723-2632. DOI: 10.1007/s00603-012-0257-7

[2] ANSYS®, Academic research, Crack analysis quide Mechanical APDL Documentation guide. Release 19.1, 2018.

# Probabilistic Reliability Analysis of Industrial Chimneys

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***Abstract.*** *Reliability of a reinforced concrete chimney is analysed considering probabilistic models for the effects of wind loads and the principles provided in Eurocodes. Corrosion of reinforcement due to carbonation is taken into account. Obtained reliability indices are compared with the target levels indicated in the EN and ISO standards. Sensitivity analysis identifies the parameters that have a significant impact on structural reliability, namely wind velocity and time-invariant wind pressure parameters. The values of these parameters can be updated on the basis of measurements and a more economic design can be achieved.*

## Keywords

***Structural reliability, industrial chimney, wind load.***

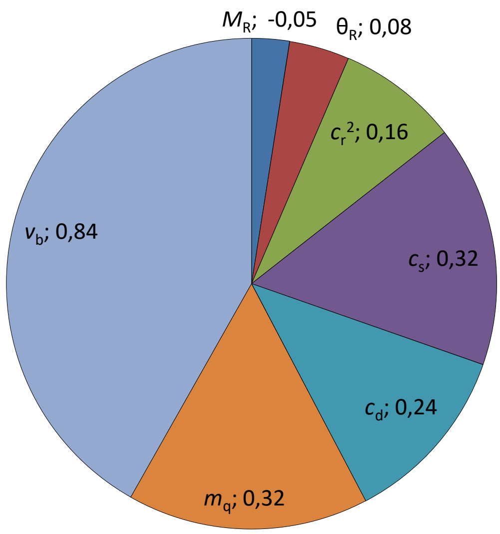


**Fig. 1:** Comparison of sensitivity parameters for individual basic variables.

## 1. Reliability Analysis

The presented analysis is focused on the example of reinforced concrete chimney designed by the partial factor method provided in Eurocodes. The probabilistic reliability analysis is performed with annual parameters of the wind velocity obtained from meteorological measurement. The limit state function reads:

$$\theta_R M_R = A\, c_d c_s c_r^2\, m_q v_b^2 \qquad (1)$$

where $M_R$ is the flexural resistance of a critical cross section and $\theta_R$ is the related model uncertainty, $A$ is the deterministic geometrical parameter to obtain the moment in the critical cross-section from a specified wind pressure distribution, $c_d$ the dynamic factor, $c_s$ the construction size coefficient, $c_r^2$ the roughness factor, $m_q$ the model coefficient considering model uncertainty, and $v_b$ is the annual maximum of basic wind velocity. An axial strength is considered deterministic due to negligible variation when compared to the wind effect.

Sensitivity parameters describing the effect of individual basic variables on reliability are shown in Fig. 1.

## 2. Conclusions

The reliability of the deteriorating chimney designed according to EN 1992-1-1 is critically compared with the recommendations of EN 1990 and ISO 2394. Sensitivity analysis identifies the parameters that have a significant impact on structural reliability - wind velocity and time-invariant wind pressure parameters. These parameters can be updated on the basis of measurements and a more economic design can be achieved.

## Acknowledgements

The study has been supported by the Czech Technical University in Prague under Grant SGS19/164/OHK1/2T/31 and by the Technology Agency of the Czech Republic under Grant TE01020068.

# DYNAMIC BEHAVIOUR OF RAILWAY BRIDGES UNDER MOVING MASS LOAD

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***Abstract.*** *Travelling mass due to its mass inertia has significant effect on the dynamic response of the bridges. This study is devoted to the study of the dynamic response the real steel railway bridge of the length $L_b$ = 38 m for the single locomotive bogie mass load $M_{Lbg}$ = 44 t passing over the bridge with the speed v = 65m/s. The iteration method of the governing partial differential equation of the transverse motion of the bridge structure w(x,t) has been applied. The modal superposition method for the vertical bridge deflection w(x,t) considering the first mode j=1 was used.*

## Keywords

***Dynamics of bridges, mass load, modal analysis.***

## 1. Introduction

Investigating of railway bridges traversed by moving vehicles is one of the important concerns for the structural engineers in the design of highway and railway bridges. By introducing the inertial effects of the moving loads into the problem formulation, more realistic results would be gained especially for loads with relative large weights travelling at high speed.

The problem in which the moving load force $G$ and the beam mass $M$ are both taken into account is far more complicated than the moving load one. This study is devoted to the study of the dynamic response the real railway middle span bridge of the length $L_b$ = 38 m for the single load $M_{Lbg}$ = 44 kN moving the speed $c$ = 65 m/s = 234 km/h, Fig, 3. For the presented example the ratio of the moving mass and the beam mass $m_b$ is $M_{Lbg} / m_b$ = 0,36, Fig.1.

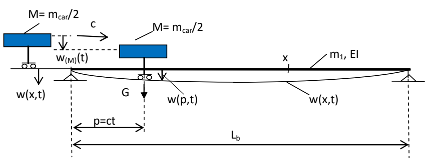


**Fig. 1:** Single mass $M$ moving on the bridge.

## 2. Dynamic Equilibrium Equation and Solution

The main difficulty to deal with moving mass problems is that the unknown displacement $w(x,t)$ in the differential equation subjected to a moving mass $M$ appears on the both sides of Eq. (1). A convenient rigorous solution for the problem has not been found. Commercial finite element solvers applied to the moving mass are also questionable. Therefore, an iterative approach is applied.

The $k$th iteration of the governing equation for the mode of vibration $j=1$ can be written as

$$EI\frac{\partial^4 w_{(1)}^{(k)apx}(x,t)}{\partial x^4}+m_1\frac{\partial^2 w_{(1),(G+M)}^{(k)apx}(x,t)}{\partial t^2}=F_{(1),(G+M)}^{(k)apx}(t)\cdot\delta(x-ct) \qquad (1)$$

where $F_{(1),(G+M)}^{(k)apx}(t)=G^{(k)apx}-M\cdot\ddot{w}_{(1)}^{(k-1)apx}(p,t)$

The modal superposition method for the vertical bridge deflection $w(x,t)$ was applied

$$w_{(1)}(x,t)=q_{(1)}(t)\phi_{(1)}(x) \qquad (2)$$

For the interaction force (the contact force) loaded the beam is

$$F_{(1),(G+M)}^{(k)apx}(t)=G^{(k)apx}-M\cdot\ddot{w}_{(1)}^{(k-1)apx}(p,t)=G-M\cdot\ddot{q}_{(1)}^{(k-1)\mathrm{apx}}(t)\cdot\sin\Omega_{(1dr}t \qquad (3)$$

The modal equation corresponding Eq. (1) for the fundamental mode of vibration $j$=1 can be written as

$$\ddot{q}_{(1)}^{(k)apx}(t)+\omega_{(1)}^2 q_{(1)}^{(k)apx}(t)=\frac{F_{(1),(G+M)}^{(k)apx}(t)\cdot\phi_{(1)}(x)}{m_1\int_0^{L_b}\phi_{(1)}^2(x)dx} \qquad (4)$$

And Eq. (4) in practical form may be written and soluted as

$$\ddot{q}_{(1)}(t)+\omega_{(1)}^2 q_{(1)}(t)=\frac{2\cdot G}{m_1 L_b}\sin\Omega_{(1)\mathrm{dr}}t-\frac{2\cdot M}{m_1 L_b}\ddot{w}_{(1)}(p=ct,t)\cdot\sin\Omega_{(1)\mathrm{dr}}t \qquad (5)$$

## Acknowledgments

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# Submission and Limitations of Civil Engineering Tasks using ANSYS Tool in National Supercomputer Center IT4Innovations

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***Abstract.*** *This article deals with problem of soil-structure interaction on a simplified model using commercial software Ansys on Anselm supercomputer in National Supercomputing Center IT4Innovations in VSB-Technical University of Ostrava. For the purpose of modelling large scale tasks by supercomputer it is useful to know program limitations, area and scope of selected solution. Therefore, numerical model was created with increasing size and therefore degrees of freedom until the calculation was possible until the size maximum size of task was obtained The maximum size of the task solved on supercomputer was compared to the maximum size solved on standard computer station. Several complications appeared during enlargement of task, therefore the article also discuss the problems which occurred during the submission of the jobs and its solution.*

## Keywords

***Ansys, Finite Element Method, Supercomputer.***

## 1. Introduction

An interaction between the soil and the structure is a complex task in which we need to take into account the influence of the physically-nonlinear behaviour of both the soil and the foundation. Therefore, the choice of a computational model is the crucial element to consider.

Use of advanced models that takes into account many nonlinearities usually requires also fine finite element mesh and has increased computing time requirements. The capacity of the standard workstation is insufficient for the research at the moment so the use of parallel computer codes and larger computers (often the supercomputers) is usually required to be able to analyses larger structures. Use of supercomputer provides a wider range of options but adaptation is always needed as in other areas.

## 2. Results

The task was computed distributed to 512 cores. The number of 512 cores was selected due to limitation of HPC licences available on supercomputers in IT4Innovations. Due to this restriction is impossible to distribute the calculation to the bigger amount of cores. The computation times of tasks were recorded. Increasing computation time with increasing degrees of freedom was evaluated into the Fig.1.

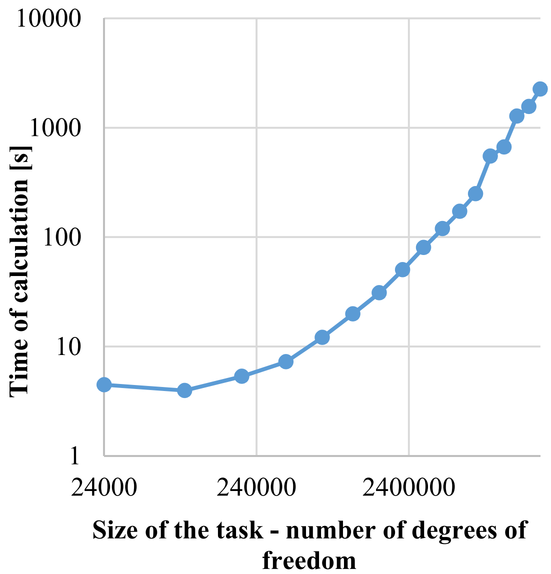


**Fig. 1:** Time of the calculation dependent on size of the task.

## Acknowledgements

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# STOCHASTIC SPECTRAL METHODS IN UNCERTAINTY QUANTIFICATION

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## Keywords

***Polynomial chaos expansion, Sensitivity analysis, Statistical analysis, Uncertainty quantification.***

## 1. Uncertainty Quantification

The mathematical model of physical problem can be represented by a function *M* of the input variables **X**. Generally, the mathematical model *M*(**X**) can be solved in implicit form by various methods e.g. finite element method (FEM), which may be highly computationally demanding, especially in a case of non-linear FEM. Moreover, it is necessary to assume input variables **X** as a random vector to represent natural uncertainty of real physical problems e.g. material parameters. Therefore, a response of model *Y*=*M*(**X**) is a random variable described by a probability distribution. This fact leads us to seek the probability distribution of *Y* instead of a deterministic result. There are several methods for a statistical and sensitivity analysis, commonly called uncertainty quantification (UQ) of *Y*, and the most of them can be generally divided to two groups of different nature: Monte Carlo (MC) simulation techniques and stochastic spectral expansion. There are various forms of MC techniques e.g. crude MC or Latin Hypercube Sampling (LHS). These popular methods are simple to understand and implement but their efficiency is not generally high, thus objective of the full paper is to introduce and present stochastic spectral expansion as an efficient tool for UQ.

## 2. Stochastic Spectral Expansion

Stochastic spectral expansion is a more recent alternative for an uncertainty propagation and it consists in representing the solution by a functional representation of the random variables expansion. Typical stochastic expansion method is Polynomial Chaos Expansion (PCE) originally proposed by the excellent mathematician Norbert Wiener [1]. These methods are typically more efficient in comparison with MC techniques but on the other hand, theory of PCE is more complicated and its implementation is not so straightforward as in case of MC. Moreover, several theoretical issues are still under research, e.g. correlation among random variables.

The full paper is focused on detailed description of PCE as a highly efficient method for an uncertainty quantification. It is shown how to build up a PCE by a simple least square regression. Once the explicit form of PCE is obtained, an efficient statistical analysis is possible via simple analytical processing of deterministic coefficients. Moreover, an extensive description of connection between PCE and Hoeffding-Sobol decomposition is presented and its utilization for sensitivity analysis of variance (ANOVA) is discussed. The practical implementation of theory into the developed software tool [2] is presented and possible numerical issues during implementation are discussed. Such practical information may be beneficial for researchers interested in implementation of PCE. In the last part of the paper, the whole process of UQ using PCE is applied on academic examples with known reference solutions and obtained results are discussed.

## Acknowledgements

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## References

[1] WIENER, N. The Homogenous Chaos. *American Journal of Mathematics*. 1938, 60(4), pp. 897-936.

[2] NOVAK, L. and D. NOVAK. Polynomial chaos expansion for surrogate modelling: Theory and software. *Beton und Stahlbetonbau*. 2018, vol. 113, pp 27-32.

# OCEĽOVÁ KONŠTRUKCIA TRIBÚNY FC NITRA

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***Abstrakt:*** *S podporou Slovenského futbalového zväzu bola realizovaná rekonštrukcia futbalového štadióna v Nitre. Po troch stranách ihriska boli postavené nové tribúny a pôvodná tribúna bola komplexne rekonštruovaná. Použitím valcových škrupín z termoplastového skla sa o 6 m predĺžila strecha pôvodnej tribúny. Táto úprava si vyžiadala spoluprácu architekta a statikov.*

V päťdesiatych rokoch minulého storočia bol v Nitre pod hradom vybudovaný pekný športový komplex pre futbal i ľahkú atletiku. Okolo futbalového ihriska bol 400 metrový antukový atletický bežecký ovál. Komplex obsahoval všetky doplnkové náležitosti pre vrhacie i skokanské disciplíny ľahkej atletiky. Na jednej pozdĺžnej strane sa nachádzala tribúna. Celý komplex bol obohnaný betónovým oválom s osadenými lavicami na sedenie. Postupne upadol záujem divákov o ľahkú atletiku. Všetky prvky viazané na ľahkú atletiku (bežecká dráha, doskočiská, vrhacie sektory) boli zrušené a celá plocha bola zatrávnená.

Takto upravený štadión už nemohol vyhovovať ani najnižším požiadavkám kladeným na moderný futbal. Okrem toho štadión bol silne schátralý. Mesto Nitra s podporou Slovenského futbalového zväzu pristúpilo ku komplexnej rekonštrukcii.

Príspevok Slovenského futbalového zväzu bolo dodanie tribún po troch stranách štadióna. Mesto Nitra dodalo vyhrievaný trávnik a kompletnú rekonštrukciu pôvodnej tribúny so všetkými náležitosťami (šatne, plochy pre umiestnenie televíznych kamier, VIP priestory, informačné tabule a pod).

Strecha pôvodnej tribúny bola krátka a nedostatočne chránila divákov sediacich v dolných radoch. Preto bolo navrhnuté predĺžiť tribúnu o 6 metrov oblúkovými konštrukciami z priehľadného plastového skla.

V úvodnej štúdii vypracovanej architektom sa uvažovalo s použitím silného pozdĺžneho nosníka s krátkym stĺpikom podopreným tiahlami. Statické výpočty ukázali, že ploché tiahlo je málo účinné. Takto koncipovaná konštrukcia by si vyžiadala osadiť mohutné nosníky na strechu tribúny. Po spolupráci statikov (autori predloženého článku) sa postupne vyprojektovala a realizovala konštrukcia pre predĺženie tribúny s použitím zalomeného stĺpa a dvoch tiahel. Takéto riešenie predĺženia strechy si vynútilo zosilniť hornú časť stĺpa. Realizovalo sa to priložením silnej pásnice, ktorá zároveň „prichytávala“ i pridaný stĺp. Vo vnútornej časti tribúny sa pre zosilnenie použilo ½ profilu HEB.

Každá zváraná oceľová konštrukcia obsahuje zvyškové (zvarové) napätia. V mieste zvaru sú tieto napätia ťahové a dosahujú medzu klzu. Konštrukčná oceľ ma výrazné pružno-plastické vlastnosti. Odľahčenie a znovu zaťaženie je ale pružné. Toto je vynikajúca vlastnosť ocele ako konštrukčného materiálu. Treba mať na mysli, že v prvom zaťažujúcom cykle je tuhosť konštrukcie nižšia ako udáva výpočet s predpokladom pružných vlastností ocele. V prípade konštrukcie pre predĺženie strechy tribúny v mieste pripojenia podporného stĺpa bolo realizovaných množstvo zvarov. Navrhol a realizoval sa spôsob pripojenia tiahiel pod napätím, ukázaný na obr. 1. Tento postup čiastočne eliminoval spomínaný nepriaznivý efekt zvarových napätí a zaručoval, že i v prípade veľkého zaťaženia saním od vetra nevzniknú v tiahlach tlakové sily.

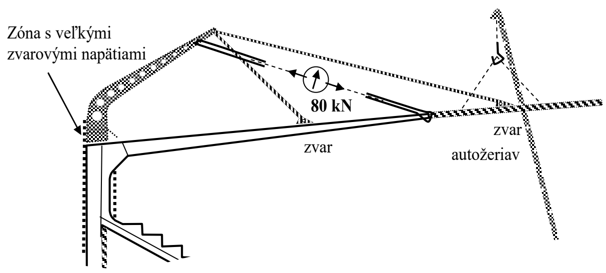


**Fig. 1:** Schéma pre spôsob pripojenia tiahiel.

Celá rekonštrukcia futbalového štadiónu v Nitre stála 7.5 mil. €. (5.2 mil. mesto Nitra a 2.3 mil. SFZ). Medzi slovenskými futbalovými štadiónmi rekonštruovanými v tejto cenovej hladine je tento štadión bez diskusie najkrajší. Autorov článku teší, že prispeli k realizácii tohto vydareného diela

## Poďakovanie

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# Comparison of Constraint Level for WST and Brazilian Disc Specimens Loaded by Mode I

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## Keywords

***Brazilian disk, WST specimens, constraint, T-stress, stress intensity factor.***

Knowledge of quasi-brittle behaviour of civil engineering materials plays key role for numerical modelling in finite element software. One of key parameter is stress intensity factor (SIF), that describe the stress/displacement field in the vicinity of crack tip. From experimental measurement, the maximal value of force for given thickness of specimen and crack length is obtained. The precise knowledge of geometry function gives us possibility to evaluate the critical value of SIF (fracture toughness).

In article, we focused on geometry influence for evaluation of SIF in case of two typical experimental procedure used for measurement of fracture properties in case of concrete.

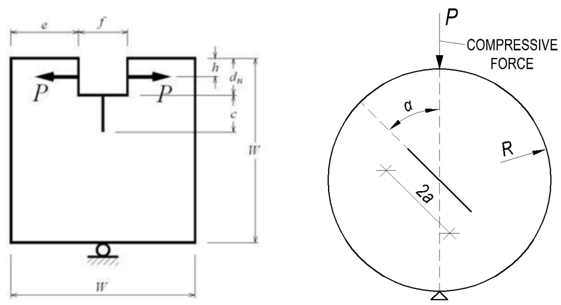


**Fig. 1:** Specimen geometries a) WST and b) Brazilian disc.

Numerical models were created in finite element software (FEM) Ansys 17.2 as a plane symmetric 2D with plane strain boundary conditions. Studied model was meshed with element type PLANE183 and command KSCON to take into account crack singularity. Material properties Young's modulus and Poisson's ratio were $E$ = 30 GPa and $\nu$ = 0.2 for investigated material like concrete.

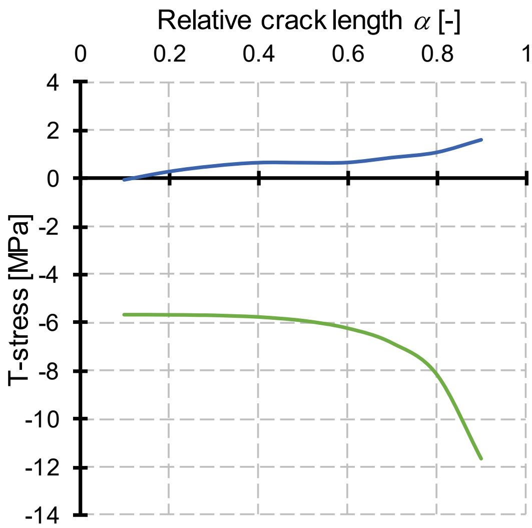


**Fig. 2:** Comparison of B2 for WST (a) and Brazilian disc (b).

Normalized values of $T$-stress $B_2$ can be seen in Fig. 2 for relative crack lengths $\alpha \in$<0.1; 0.9> and various geometries. The WST has always positive values of T-stress while the Brazilian disc with notch has always negative value of T-stress, even though both cracks grow to pressure point.

## Acknowledgements

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## References

[1] SEITL, S., KNÉSL, Z., VESELÝ, V., ŘOUTIL, L. A refined description of the crack tip stress field in wedge-splitting specimens – a two- parameter fracture mechanics approach, Applied and Computational Mechanics 3 (2009) 375–390

[2] SEITL, S., P. MIARKA, a V. BÍLEK. The Mixed-Mode Fracture Resistance of C 50/60 and its Suitability for Use in Precast Elements as Determined by the Brazilian Disc Test and Three-Point Bending Specimens. Theoretical and Applied Fracture Mechanics. 2018. Vol. 97 p. 108119. ISSN: 0167-8442. DOI: 10.1016/j.tafmec.2018.08.003

# Comparison of Selected Mechanical Properties of Old Steel and S235 and S355 Grades

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## Keywords

***Old steel; Steel tests; Change in mechanical properties, Change in strength properties; Long service.***

## 1. Introduction

The pace of knowledge of the operational durability of old steel elements is essential for assessing their condition and remaining service life. The aim of this research was to determine if the mechanical and strength properties of the old steel and compare with properties of S235 and S355.

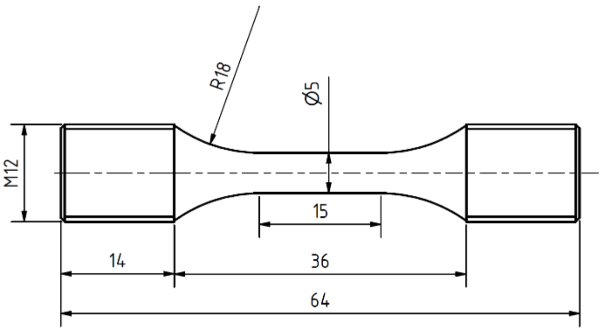


**Fig. 1:** Specimen geometry.

## 2. Results

The test results were subjected to proper measurement in Zwick/Roell machine with following results in Tab. 1.

**Tab. 1:** Mechanical and strength properties of three kinds steels (Old one, S235 and S355).

| Steel | Old steel | S 235 | S 355 |
|---|---|---|---|
| Young's modulus [GPa] | 206.30 ±6.2 | 208.20 ±4.1 | 205.40 ±7.4 |
| Yield stress [MPa] | 271.20 ±2.46 | 276.87 ±0.31 | 381.94 ±6.22 |
| UTS [MPa] | 439.28 ±0.49 | 423.86 ±1.49 | 554.41 ±1.62 |
| Elongation at break [%] | 18.49 ±0.23 | 21.99 ±0.22 | 34.22 ±1.54 |
| Poisson's ratio [1] | 0.3 | 0.3 | 0.3 |

## 3. Conclusions

An analysis of all the presented material properties shows that the tested old steel has now similar mechanical and strength properties like S235.

The presented investigations should be considered as exploratory. It would be essential to compare the effect of the cyclic loads generated by passing vehicles on the mechanical and strength properties of the structural steel for various structure elements. Therefore, it would be worthwhile to carry out such tests when opportunities (etc. demolitions) arise so that the dependence between the changes in the properties of the steel and the operating stress could be unequivocally established.

## 4. Acknowledgements

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## References

[1] European Committee for Standardization: Eurocode 3: Design of steel structures - Part 1-9: Fatigue, 2005

[2] M. KREJSA, J. BROZOVSKY, P. LEHNER, S. SEITL, Z. KALA, Stochastic analysis for short edge cracks under selected loads, AIP Conf. Proc., 1978 (**2018**) 150006, doi:10.1063/1.5043797

 

# IDENTIFICATION OF MECHANICAL FRACTURE PARAMETERS OF ALKALI-ACTIVATED SLAG BASED COMPOSITES DURING SPECIMENS AGEING

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The aim of the paper is to present the results of the experiment focused on the development of the mechanical fracture characteristics of alkali-activated slag (AAS) based composites within the time interval from 3 days to 2 years of ageing. Two AAS composites, which differed only in the presence of shrinkage reducing admixture (SRA), were prepared for the purpose of experiments. The composites were prepared using ground granulated blast furnace slag activated by water-glass with silicate modulus of 2.0, standardized quartzite sand with the particle grain size distribution of 0−2 mm, and water. Commercially produced SRA was added into second mixture in amount of 2 % by weight of slag. The test specimens were not protected from drying during the whole time interval and were stored in laboratory at ambient temperature of 21 ± 2 °C and relative humidity of 60 ± 10 %. The prism specimens made of above mentioned composites with nominal dimensions of 40 × 40 × 160 mm and the initial central edge notch were subjected to fracture tests in three-point bending configuration. The load $F$ and displacement $d$ (deflection in the middle of the span length) were continuously recorded during the fracture tests.

The obtained $F−d$ diagrams and specimen dimensions were used as input data for identification of parameters via the inverse analysis based on the artificial neural network, which aim is to transfer the fracture test response data to the desired material parameters. In this paper, the modulus of elasticity $E_{ID}$, tensile strength $f_{t,\,ID}$ and fracture energy $G_{F,\,ID}$ values were identified and subsequently compared with values obtained based on the direct fracture test evaluation using the effective crack model and work-of-fracture method: modulus of elasticity $E$, effective fracture toughness $K_{Ice}$, specific fracture energy $G_F$.

Both techniques provided comparable results (a similar trend of parameters development during the ageing). The differences in mean values of fracture energy correspond to their different physical meanings – the identified values are primarily related to the material point, whereas the values obtained from the work-of-fracture method are related to the tested specimen, the size and shape of fracture process zone and represent the average fracture energy.

**Tab.1:** Mean values (CoV in %) of selected mechanical fracture parameters obtained by identification – set VIII (without SRA).

| Set VIII | | Age of specimens | | |
|---|---|---|---|---|
| **Parameter** | **Unit** | **3 days** | **90 days** | **2 years** |
| $E_{ID}$ | GPa | 14.4 (13.9) | 16.8 (5.5) | 18.0 (4.9) |
| $G_{F,\,ID}$ | J/m$^2$ | 140.3 (24.4) | 241.5 (29.6) | 147.3 (16.5) |
| $f_{t,\,ID}$ | MPa | 1.5 (9.6) | 1.7 (10.2) | 1.8 (4.3) |
| $E$ | GPa | 12.0 (15.4) | 14.3 (6.9) | 14.1 (5.1) |
| $K_{Ice}$ | MPa·m$^{1/2}$ | 0.541 (12.1) | 0.717 (10.2) | 0.678 (11.5) |
| $G_F$ | J/m$^2$ | 80.2 (21.6) | 142.6 (9.7) | 97.5 (7.7) |

**Tab.2:** Mean values (CoV in %) of selected mechanical fracture parameters obtained by identification – set IX (with SRA).

| Set IX | | Age of specimens | | |
|---|---|---|---|---|
| **Parameter** | **Unit** | **3 days** | **90 days** | **2 years** |
| $E_{ID}$ | GPa | 14.4 (14.1) | 8.1 (4.6) | 19.0 (6.7) |
| $G_{F,\,ID}$ | J/m$^2$ | 82.3 (21.6) | 178.1 (25.8) | 204.8 (10.2) |
| $f_{t,\,ID}$ | MPa | 1.2 (7.1) | 0.7 (12.2) | 2.3 (6.0) |
| $E$ | GPa | 11.6 (13.9) | 6.9 (8.0) | 16.2 (3.8) |
| $K_{Ice}$ | MPa·m$^{1/2}$ | 0.418 (7.4) | 0.279 (12.3) | 0.696 (5.7) |
| $G_F$ | J/m$^2$ | 50.9 (14.2) | 92.4 (18.5) | 119.1 (7.1) |

This outcome has been achieved with the financial support of the Czech Science Foundation under project No 18-12289Y and the specific university research project granted by Brno University of Technology, registered under the number FAST- J-19-6040.

# FULLY STOCHASTIC NONLINEAR ANALYSIS OF SLENDER REINFORCED CONCRETE COLUMN

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***Abstract.*** *The following paper presents nonlinear resistance assessment of a slender reinforced concrete column using commercial FEM software ATENA. Furthermore, three different approaches are used to determine design value of resistance. Firstly, most commonly used method of partial safety factors. Secondly, method ECOV (estimate of coefficient of variation), which is one of the possible options used in fib Model Code to asses design resistance of structures using nonlinear analysis. Eventually, a fully probabilistic analysis is performed using commercial software package SARA.*

## Keywords

***Non-linear analysis, safety formats, reliability.***

## 1. Global Safety Format

### 1.1. Full Probabilistic Analysis

The full probabilistic analysis is the most rational way of assessing the structural reliability. Its principal lies in running the non-linear simulations on many samples of the investigated structure, while chosen parameters of the numerical model (material properties, dimensions, boundary conditions etc.) are systematically varied within the samples according to certain probability distribution functions (PDF).

### 1.2. ECOV Method – Estimate of Coefficient of Variation

ECOV is a simplified probabilistic method. It is based on the idea of determining the coefficient of variation from two samples only and assumes lognormal distribution of resistance. The first sample is calculated using the mean material parameters (50% probability of failure) and the second one uses the characteristic parameters (5% quantile).

### 1.3. Partial Safety Factors

The method of partial safety factors described in most of the design codes can be also applied on global analysis to obtain design resistance of the structure. The design values of material parameters $f_d$ are calculated as $f_d = f_k / \gamma_M$, where $f_k$ is characteristic value and $\gamma_M$ is material safety factor.

## 2. Case Study

The three above mentioned methods of assessing the global structural reliability will be presented on the case study of axially loaded reinforced concrete slender column.

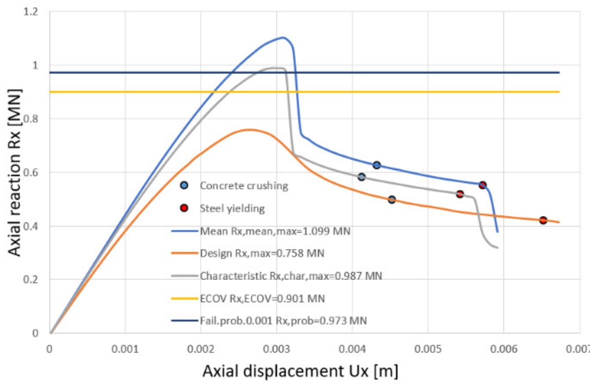


**Fig. 1:** Comparison of three design resistance assessment methods, C50/60.

## Acknowledgements

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# INFLUENCE OF VIBRATIONAL IMPACTS ON THE BELL TOWERS AND THE PROBLEM OF SAFETY

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***Abstract.*** *Due to reconstruction and restoration of the original guise of the landmarked buildings in St. Petersburg the investigators are facing the problems of assessing possible adverse consequences of such sorts of work in the recent years. This article gives consideration to the ways of solving a problem of ensuring safety of buildings and structures in use provided their operating conditions have changed. The measurements of vibrations with simultaneous assessment of robustness and bearing capability of the brickwork have shown that the vibrational impact of chimes of heavy bells cannot adversely affect the bearing structures of the of St. Isaac's Cathedral bell towers. However, there is always a risk of such adverse effect on the structure of the bell tower and stability of soils at its base.*

## Keywords

***Bell tower, cyclic strain-induced creep, dynamic monitoring, safety of buildings and structures, vibrations, vibrational impact, vibrodiagnostics.***

## 1. Introduction

The most problematic are the works requiring dismantling of the bearing and fencing structures built into original scheme. The builders have succeeded to successfully solve these complex problems using the up-to-date methods of technical diagnostics and calculation by means of three-dimensional finite-element models [1]. Another type of works implies a revival of ensembles of bells on the steeples [2]. In order to assess possible adverse consequences of these actions, it is necessary to take into account not only the new load emerging in the structures not being used for direct purpose for long, but the possible consequences of vibrational impact on the soils of bases of structures.

## 2. Results

The acquired results have been analysed and compared with the existing requirements of standards with a view to exceedance of actual loads. The effect of St. Isaac's Cathedral bell tower resonance swinging is not observed during multiple chimes, since the frequencies of clappers swinging and the natural frequency bending oscillations of the bell tower differ significantly. The actual values of velocities and displacements are significantly below the threshold value of vibrational impact, which can adversely affect the soil ground. The obtained assessments of settlements show that they cannot be ignored [3]. It is important to take into consideration that the process of foundation settlement corresponds to quite a durable change, therefore, it is necessary to establish an instrumental monitoring and take the due engineering decisions for soils stabilization.

## References

[1] SAVIN, S. and V. TSAKALIDIS. The use of elastic oscillations of different wavelengths to evaluate the dynamic parameters of buildings and structures and assess the strength of materials of the building construction. In: *COMPDYN 2015. Proceedings of the 5th International Conference on Computational Methods in Structural Dynamics and Earthquake Engineering Methods in Structural Dynamics and Earthquake Engineering, 5. 25-27 May 2015 Crete Island, Greece*. Hersonissos, Crete: National Technical University of Athens, 2015, pp. 706–720. ISBN 978-960-99994-7-2.

[2] SAVIN, S. and E. SMIRNOVA. Evaluation of mechanical safety of building structures using elastic vibrations varying in wavelength. *World Applied Sciences Journal.* 2013, vol. 23, iss. 11, pp. 1448−1454. ISSN 1818-4952. DOI: 10.5829/idosi.wasj.2013.23.11.13161.

[3] VEL'SOVSKIJ, A., B. KARPOV and E. SMIRNOVA. Development of a new method for checking frost heave in roads. *Proceedings of the ICE - Civil Engineering*, 2015, vol. 168, iss. 5, pp. 49–54. ISSN 0965-089X. DOI: 10.1680/cien.14.00036.

# UNCERTAINTY IN CHARACTERISTIC STRENGTH OF HISTORIC STEEL USING NON-DESTRUCTIVE TECHNIQUES

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## 1. Introduction

The mechanical properties of historic metal materials exhibit a considerable scatter dependent on periods of construction and the region of a producer. Assessments of historic structures then need to be based on measurements and tests. The use of non- or minor-destructive tests (NDTs) is often preferred over to destructive tests (DTs) to reduce the cost of structural survey. Limited attention has been paid to the investigation of uncertainties in characteristic strength estimates based on NDTs so far. The contribution thus explores the measurement errors associated with common NDT hardness techniques (Brinell, Rockwell, Vickers, Poldi hammer, Leeb) and quantifies uncertainties in characteristic strength estimates. The measurement uncertainty is assessed considering the database of 119 pairs of NDTs and DTs taken from buildings and bridges from the 19th century.

## 2. Uncertainties in Measurements and Characteristic Strength

The measurement uncertainty $\varepsilon$ is treated here as a random variable. A widely adopted multiplicative format for measurement uncertainty is taken into account, $f_{DT} = \varepsilon f_{NDT}$ (with $f$ denoting material strength). NDT results are compared with respective DTs for all the hardness methods in Fig. 1.

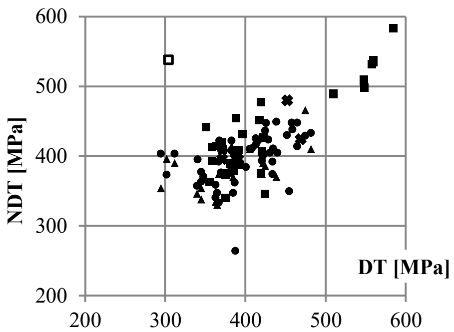


**Fig. 1:** Comparison of NDTs and DTs for all the hardness methods.

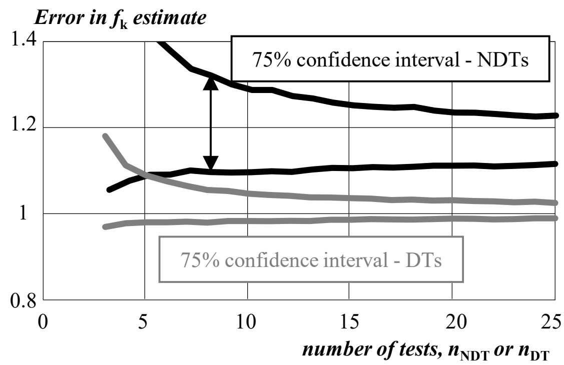


**Fig. 2:** Confidence intervals of error in $f_k$ estimate with $n_{DT}$/ $n_{NDT}$.

The effect of the measurement uncertainty on the estimate of characteristic ultimate strength, $f_k$, is investigated by means of simulations. The confidence intervals of the error in an $f_k$ estimate are shown in Fig. 2.

## 3. Concluding Remarks

- Unity mean and coefficient of variation of 12% might be adopted for the measurement uncertainty of the methods under study as a first approximation.
- While the mean of the error in the estimate of characteristic ultimate strength (5% fractile) approaches unity for a very small number of DTs, the measurement uncertainty results in a scatter of NDT results and the mean of the estimate is far from unity. On average, the true characteristic strength is by ~15% larger than that based on a very large number of NDTs. This represents the expected gain when the characteristic value is estimated from five DTs instead of many NDTs.

## Acknowledgements

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# 3-D Finite Element Analysis of Static Response of the Stress in Pavement Structure under Tire Load

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***Abstract.*** *This article illustrates the applicability of the Finite Element Method (FEM) in the analysis of multi-layer flexible pavement systems subjected to tire loading of a heavy vehicle. For the past few years, the phenomenon of vehicle overload in highway transportation is more and more critical. 3-D simulative static FEM model of flexible pavement with subgrade loaded with standard design axle was adopted. Computational model was made in computer software ADINA, based on the finite element method. A several constitutive material models, such as linear elastic model, are applied in the analysis to describe the behaviour of the pavement structure. The response of the stress in the pavement structure was got by using ADINA/Standard code. The flexible pavement represents a standard pavement, which is used for the regular road structures in road engineering. The standard design axle was chosen for flexible pavements parameters for a 11.5t heavy vehicle. In the results shows that under static load, the surface course of pavement is mainly in three-dimension compressive stress state.*

## Keywords

***Finite Element Method, standard design axle, flexible pavement, stress response analyses, displacement.***

## 1. Introduction

FEM is frequently used to solve actual problems of structural mechanics in engineering tasks. One of the topic witch can be solved by FEM is static problems of structural mechanics. The flexible pavements represent the typical pavement types used for the regular road structures. This article is focused on the analysis of the stress state and the displacements of the pavement induced by the static load from the traffic.

### 1.1. The Design Axle

The design axle is defined by the characteristics to which the axles of each type of vehicle are recalculated. Typically, the design remedy is a axle load, contact pressure on tire and pavement contact and number and shape of loading surfaces and their geometric arrangement. The dimensioning conditions applicable in Slovakia for the 11.5 t design axle. [1].

### 1.2. Model Description

The numerical model of the flexible pavement loaded by design axle was compiled in FEM computational software ADINA. Material properties for particular construction layer were set considering the conventional flexible pavements. The 3-dimensional numerical model of the flexible pavement was modelled to investigate the stress-strain state of the pavement. The intensity of the uniform stress was 0.65 MPa. Each layer of the pavement was modelled separately with predefined material properties. The layers are modelled using 3D solid elements with the possibility of a check in mesh.

## 2. Conclusion

This article demonstrates the applicability of FEM methods for the numerical simulation of the pavements. It is also focused on the synthesis of model and the effectiveness of their use.

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## References

[1] TS 0502 *Navrhovanie netuhých a polotuhých vozoviek*. MDPaT SR, 2002.

# Legion Bridge in Prague – Assessment of Stone Arches

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## 1. Introduction

When assessing existing bridges, the requirement for sufficient mechanical resistance and stability is usually given by the maximum load that the structure is able to carry safely - the maximum weight of the road vehicle which can pass the bridge under the specified conditions, i.e. the load carrying capacity.

In case of masonry vault structures this task is complicated by the structural behaviour and typical property of the material - a negligible tensile strength.

This article deals with the problems of masonry vault bridges, which determine the load carrying capacity: combination of bending moment, normal force and shear, load distribution in transverse direction of the bridge. Calculation methods are shown on the example of Legion Bridge in Prague, mostly its span No. 4.

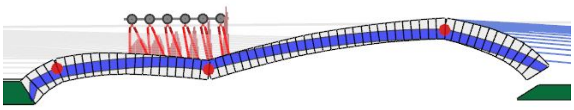

**Fig. 1:** Demonstration of failure mode of span 4. Shear failure can occur as well as plastic hinges

## 2. Methods of calculation - arch

1. Graphical method.
2. Linear calculation.
   (a) Beams – 2D or 3D.
   (b) Plane-stress elements – 2D.
   (c) 3D solid elements.
3. Non-linear calculation (2D – plane).
4. Equilibrium method — LimitState:Ring.

## 3. Comparison of methods and discussion

In the figure 2 we can see the eccentricity from the linear, non-linear model and from graphical solution from the archive documentation. Models were loaded with self-weight.

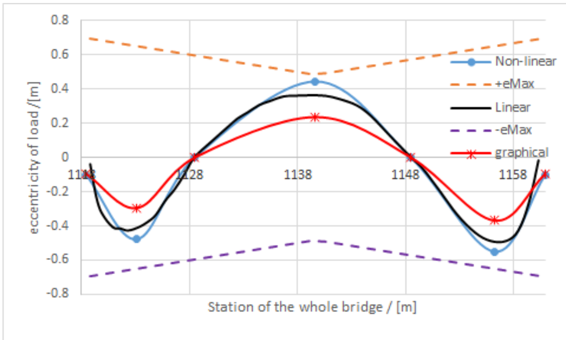


**Fig. 2:** Comparison of linear, non-linear and graphical method for span 4.

Several models of the Legion Bridge were carried out. Results were validated by the static load test. Modelling of arches showed, that the most real behaviour of arches describes the non-linear model. The results from non-linear modelling are non-conservative in comparison to other methods. Modelling of load distribution in transverse direction showed, that 3D solid model gives upper bound (non-conservative), effective width gives the lower bound (conservative results) and 3D beam model is somewhere between.

Verification of shear resistance showed also importance of considering the material non-linearity. The shear forces resulting from linear beam model, which doesn't consider the non-linearity showed to be unreal, the structure collapses even loaded by self-weight.

 

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