Modeling and Identification of Building's Construction Defects

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Abstract— **The present work presents results of analysis of strength and dynamics of a floor structure model. Model geometry, materials and loads are assumed according to the model's geometrical and physical parameter transformation coefficients and conditions of accuracy of measured values. The work presents results of structure drift and deformations, natural vibration frequency and form modeling results, changes of deformation state and relative parameters under artificial defects. The received results create opportunities for development of diagnostics algorithms.**

Index Terms— **building condition, deformation, model, dynamics, diagnostics, monitoring**

I. INTRODUCTION

IN recent years sudden collapses of buildings of different purpose in Germany in 2006, in France in 2005, in Russia in 2004/2006 [1], in Lithuania in 2005/2009 [2] and elsewhere as well as specific features of modern unique buildings (in the context of height, load, crowdedness, etc.) urged to activate research in building load-bearing structure deformation state and its control. Lithuania up to date has not seen yet consistent research in monitoring and diagnostics of buildings, this is why in the framework of the national priority project STATIMON (2010-2011) it is expected to conduct a set of researches and establish a unique building monitoring concept, structure models and stability criteria, condition monitoring system structure and prototypes to implement it.

Accidents with unique (special design) buildings occurred around the world and in Lithuania for the last decade confirm urgency of the issue of condition monitoring of such buildings and of tasks relevant to that issue.

Building collapses of different scale occurred in Austria (Europabrücke, Floridotower Highrise Building, St. Marx Bridge, etc.), in Canada (Beddington Trail Bridge, Brookside Cemestery, Hall‘s Harbour Wharf, etc.), in France (Roberval Bridge, Saint – Jean Brdge), in Germany (Lehrter Bahnhof, Zittau Viaduct, etc.), in USA (140 Bridge, etc.), in England (Huntingdon Railway Viaduct), in Russia (Bolshoj Moskovoretsky Bridge, „Sokol“ Ice Arena in Krasnoyarsk, etc.) [3]. On 14 February 2004 in Moscow, capital of Russia, during collapse of roof of the biggest in Europe indoor water park Transvaal-park 28 people died, 200 were injured. The cause of the collapse was fatal errors of the building design made by architects.

Not once in Lithuania supporting columns fell, roofs collapsed due to snow buildup. On 2 January 2002 the roof of Vilnius Ice Arena built by Ekama company collapsed after the roof structures did not sustain weight of snow. Around 2 thousand square meters of the roof area fell into the building. In 2005 an accident (collapse) occurred in an industrial building of Karige joint stock company. Due to long-term (more than 40 years) effect of frost, rain, humidity, variations of atmosphere weather conditions, vibrations, reconstruction work, awkward use of vehicles stability of the structure was diminished. In 2008 in Lithuania collapses of 4 buildings in use or their structures occurred, whereas in 2009 in Lithuania already 7 buildings in use or their structures collapsed. Fatalities were avoided; nonetheless three people were injured not speaking of loss of property. In 2009 in Kaunas during construction of Žalgiris Arena drift of columns due to building settlement was timely identified, they had to be urgently reinforced.

In 2007 a Russian civil engineering journal [3] pointed attention to building defects by presenting the following statistics: 50% and more of defects occur during construction work; 30% - due to errors of designers and geological research and only 20% of defects of buildings occur while in service. It can be assumed that the defects of the first and the second categories are hidden and can show up operating the building under extreme conditions (heavy snow loads, rain impact to the foundation and structures, etc.). This is why more buildings with a large floor structure area or other special structural features become objects of research and specialized automated monitoring system companies.

Modeling and analysis of building structure deformation state and its dynamic properties as well as defects affecting rigidity characteristics allows examining relationship between structure condition and diagnostic parameters from a systemic point of view. It has been addressed in many scientific publications: in the past [5-7] and recently [8,9], however in spite of a common methodology of mathematical modeling, it still has multiple aspects to examine.

The brief overview above reveals the following:

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- Building collapse is relatively frequent occurrence, facts have taken place in different countries with different economy development level;
- Design and construction errors, structure wear and external loads (most often snow buildup) are frequently mentioned among causes of the accidents;
- Especially painful accidents with buildings are related to crowded sports arenas, entertainment center, etc.;
- The presented factual material confirms urgency of development of building condition monitoring methods and measures;
- The issue of safe operation is complex, its solution inevitably requires systemic researches, modeling of defect conditions and identifying correlations between the condition and tarp diagnostic parameters.

This work presents results of research in building structure models describing stable state and its changes, including creation of building structural elements' mathematical modeling based on BEM and ensuring its adequacy to physical modeling, results of modeling of structure drifts and deformations as well as modeling of natural vibration frequencies and forms, changes of deformation state and relative parameters under artificial flaws.

II. STATIC STRUCTURE MODELS

Reliability of forecasting static structure strength is sensitive to all structure condition research stages and results. Conclusions on strength of structures can precisely match the reality, when breaches, deformations and their causes are identified correctly, mathematical models of all processes taking place in a real structure are well prepared and they are properly applied to foreseen structure monitoring procedures and measures. Geometrical form of structure elements can be very complex and different. Its precise reproduction in a numerical model sometimes can require very detailed division into finite areas. It significantly increases volumes of solved tasks and extends duration of solution. A numerical model should be as simple as possible, however it should accurately enough reflect the modeled object. Preparation of it is difficult due to numerous parameters and settings required to define. For instance, loads are random values and their estimates are defined by characteristics of probability distributions – medians and dispersion. Consequently, structure strength analysis results are also random values, whereas their probability distributions characterize probability of accident risk.

In numerical solutions, just as in analytical, some irregular forms, which do not strong impact on results, better be avoided, thus in computing schemes a majority of objects of irregular form can be simplistically presented as rods, panels, shells and blocks.

For analysis of the simplified models a model of floor structure was analyzed with formed defects, the impact of which was estimated by measuring parameters of a corresponding physical model: deflections and deformations occurring due to effect of static and dynamic loads. Floor structure is made of panels and pillars. Their dimensions were selected according to coefficient of deformation and accuracy conditions of measured values [10]. Dimensions (in mm) of the flooring model are presented in Fig. 1.

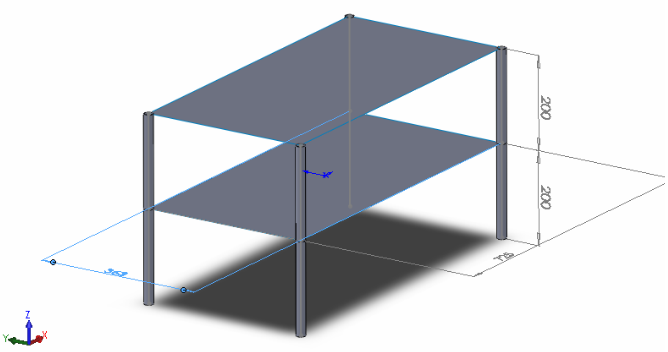

Fig. 1. Flooring structure model

Floor thickness – 8 mm. Pillar cross-section dimensions – Ø20 x 1.5 mm.

Floors and pillars are made of construction steel with elasticity modulus E = 200 GPa, Poisson ratio ν = 0.3, density ρ = 7800 kg/m^3. It is planned to load the structure with weights, which dimensions are 65 x 250 x 120 mm, and total weight of 4.2 kg. By loading gradually the floors with a single layer of weights the maximum possible pressure achieved is 5385 Pa.

III. STRUCTURE FINITE ELEMENT MODEL

The flooring structure strength properties were calculated using finite element model prepared in SolidWorks Simulation system. The floors were modeled from flat bending triangular elements, whereas pillars were modeled from dimensional framework elements that could be stretched/compressed, bent and twisted. The pillars are set perpendicularly to the base and the floors. The load is evenly distributed for both floors.

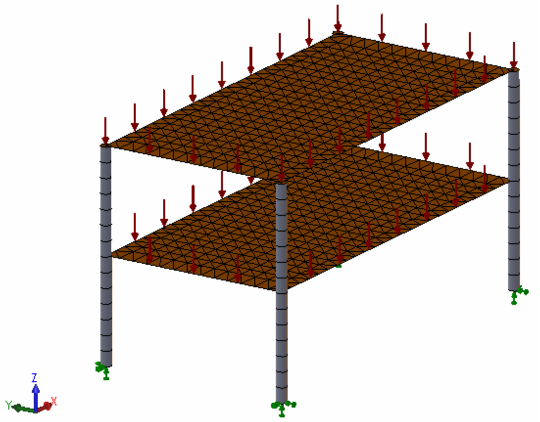

Fig. 2. The structure's finite element model

The structure's finite element model is shown in Fig. 2.

IV. STRUCTURE MODEL ANALYSIS

The flooring structure model strength analysis was performed with SolidWorks Simulation software. Further results of strength, rigidity, stability and dynamic natural vibration analyses of the elastically deformed statically loaded structure are presented.

Deformations and stresses of statically affected structure. Structure model deflections are presented in Fig. 3, equivalent deformations – in Fig. 4, maximum and minimum normal stresses – in Fig. 5 and Fig. 6. Deformations of the pillars are calculated by the formula:

$$\varepsilon_k = \frac{\sigma_k}{E} . \qquad (1)$$

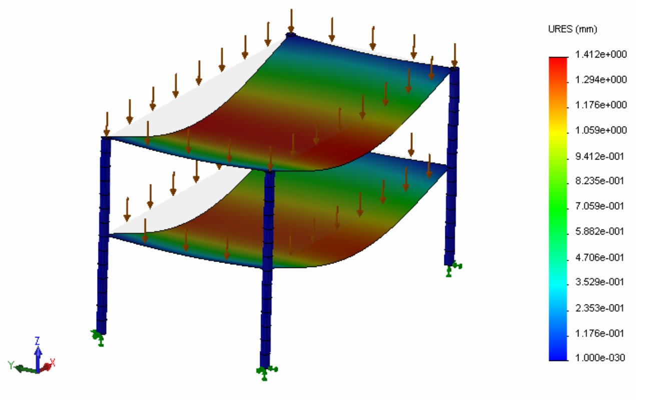

Fig. 3 Structure model deflections

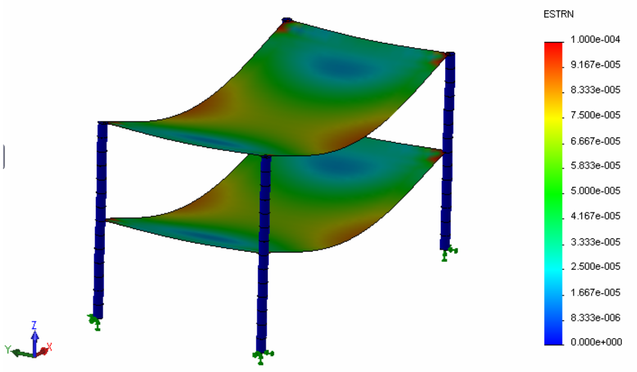

Fig. 4. Structure model equivalent deformations

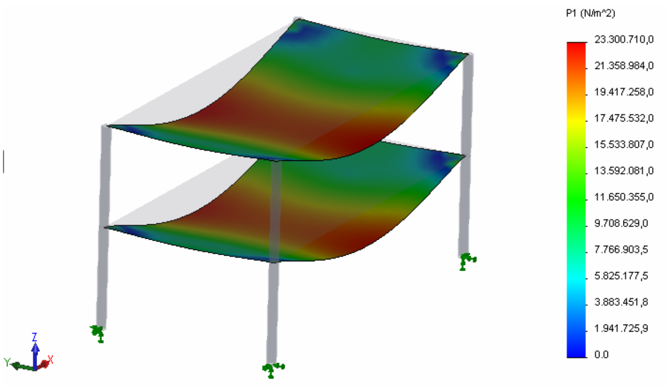

Fig. 5. Structure model floor maximum normal stresses

The pillar stresses are presented in Fig. 7.

It should be pointed that the presented pillar stresses correspond to the most loaded cross-section point. When the floors are connected with the pillars rigidly, the bending moment transferred to the pillars from the floors and stress distribution in cross-section become uneven. It also should be noted that there is also a significant increase of local stresses in the rigid floor-to-pillar connection locations. Due to these causes, depending on the nature of fixation, plastic deformations can occur in small areas of the floors.

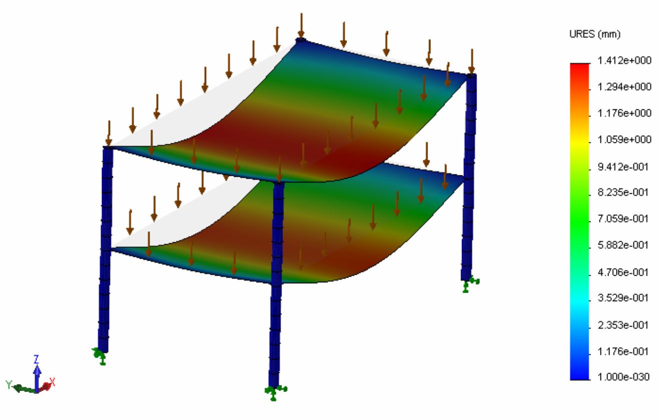

Fig. 6. Structure model floor minimum normal stresses

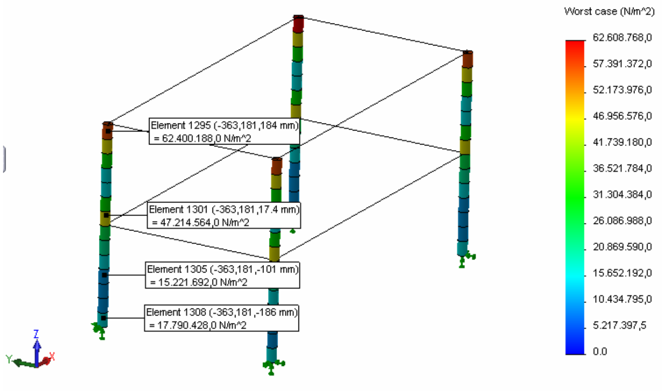

Fig. 7. Structure model pillar stresses

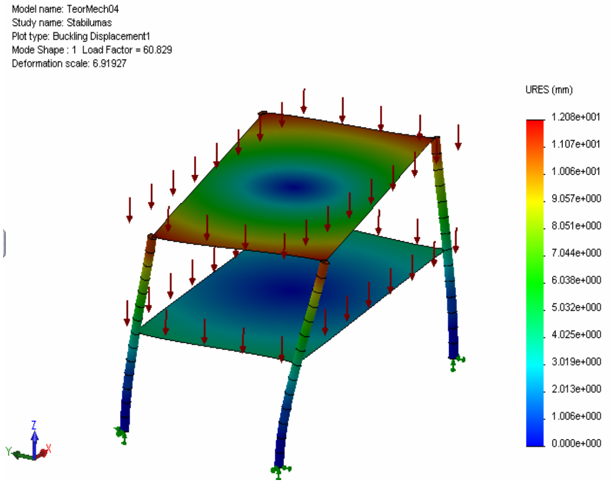

Fig. 8. Structure model floor minimum normal stresses

Estimation of stability of statically affected structure. A pattern of loss of the structure stability is presented in Fig. 8.

Structure model natural vibration analysis. 6 lowest frequencies of natural vibrations of the flooring structure model are presented in Table 1.

Table 1

FLOORING MODEL NATURAL VIBRATION FREQUENCIES

Mode No.	Frequeny (Rad/sec)	Frequency (Hertz)	Period (Seconds)
1	144.03	22.922	0.043625
2	151.19	24.062	0.041559
3	252.48	40.184	0.024886
4	277.3	44.133	0.022659
5	288	45.836	0.021817
6	624.93	99.46	0.010054

V. MODELING OF STRUCTURAL DEFECT

During construction of the floors through-crack defects were artificially created: with a single 60 mm crack at a support, with two 60 mm cracks at nearby supports and with 160 mm crack in the center. Deformations, deflections and stresses of such floors – without defects and with the mentioned defects – are presented in the present section. It was assumed that the floor in the pillar connection places was attached rigidly, and the floor was under even load of 5385 Pa. Difference in results compared to those presented above is explained through differences in the floor attachment locations and rigidity.

Qualitative and quantitative pictures of deflections and deformations are presented in Fig. 9 – 16.

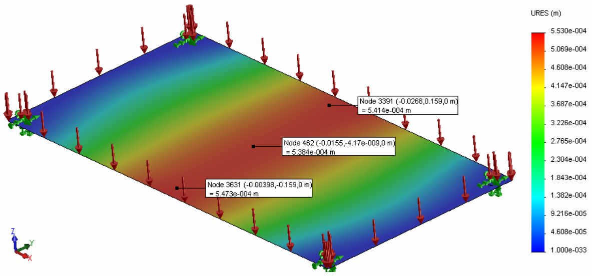

Fig. 9. Deflections of the floor without defects

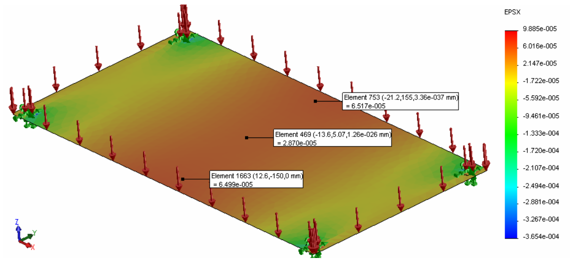

Fig. 10 Deformation of the floor without defects in x direction

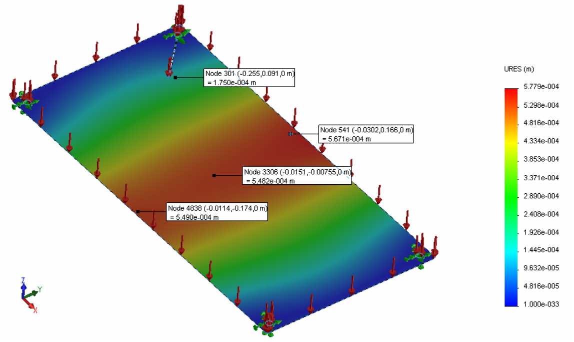

Fig. 11 Deflection of the floor with a single defect in support

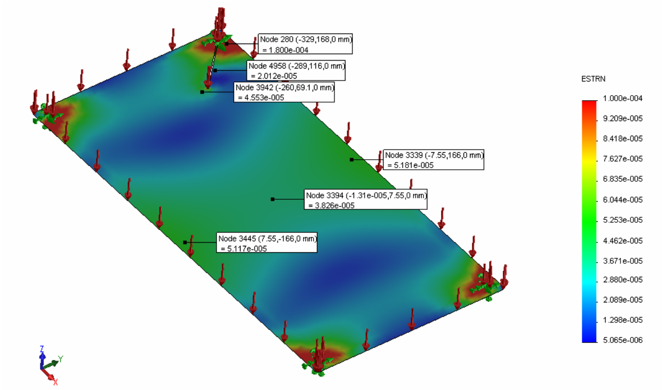

Fig. 12 Deformation of the floor with a single defect in support

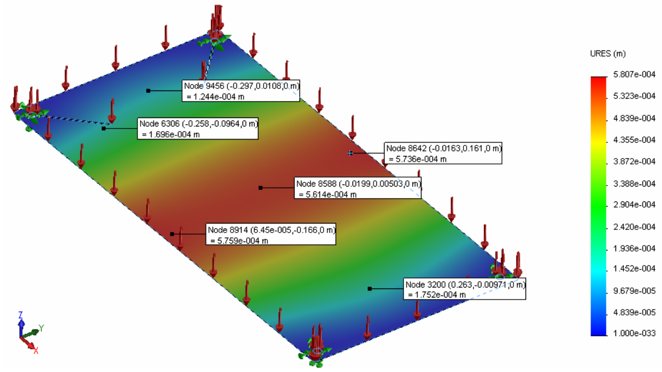

Fig. 13 Deflection of the floor with two defects in supports

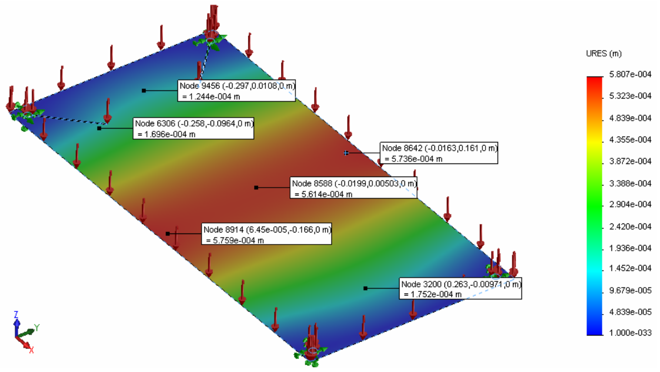

Fig. 14 Deformation of the floor with two defects in supports

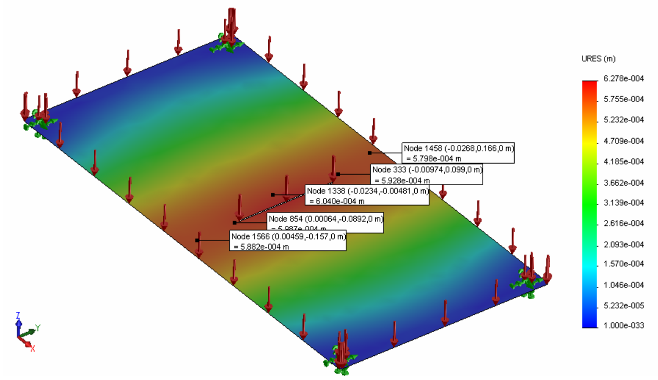

Fig. 15 Deflection of the floor with a single defect in the center cross-section

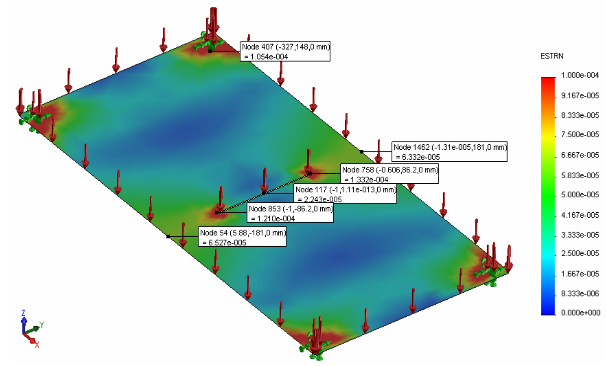

Fig. 16 Deformation of the floor with a single defect in the center cross-section

5 lowest frequencies of natural vibrations of the flooring structure model with defects are presented in Table 2.

Table 2

FLOORING WITH DEFECTS MODEL NATURAL VIBRATION FREQUENCIES, HZ

Vibration mode	Floor without defects	Floor with a single defect	Floor with two defects	Floor with a defect in the center
1	71.698	71.007	70.125	68.158
2	139.02	136.85	134.54	138.91
3	201.62	200.16	198.15	200.15
4	319.07	315.53	312.32	318.17
5	324.01	322.35	319.49	320.09

VI. CONCLUSIONS

Results of analysis of the flooring with initiated defects are presented herein. The following can be concluded summarizing them:

- Maximum deflections of the floor with defects in the pillar attachment points increase in the middle cross-section of the floor by approximately 5% compared to the floor without defects;
- Maximum deflections of the floor with a defect in the center cross-section increase in the middle cross-section of the floor by approximately 10% compared to the floor without defects;
- Maximum deformations of the floor with defects in the pillar attachment points increase by approximately 5% compared to the floor without defects;
- Maximum deformations of the floor with a defect in the center cross-section increase in the middle cross-section of the floor by approximately 100% above the defect top compared to the floor without defects.

The presented research results create opportunities for development of the diagnostics algorithm and selection of measuring devices while arranging automated monitoring of condition of buildings.

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