706. Modeling of the interaction between the damaged construction and acoustical environment

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Abstract. Acoustic properties of various structural systems of the buildings are becoming the major field of investigation among scientists, designers and manufacturers dealing with noise reduction. The causes of noise, which propagates in the air and structural medium, are human activities, audible expression of human emotions and operation of the machinery. The model of interaction between the acoustic field and building structure is investigated in this paper. A 3D model is developed in order to analyze a two-storey floor-column structure by applying both acoustical and mechanical excitation including consideration of different structural non-homogeneities. Mechanical defects (reduction of rigidity due to floor flaw) have been simulated in the study. The results indicate that the acoustic load of the same magnitude and frequency during harmonic excitation may lead to larger deformations of the structure containing a mechanical defect.

Keywords: acoustical field modeling, damaged structure vibration, FEM, acoustical loading, noise.

1. Introduction

Recent years show the growth of unique buildings for industry, leisure and sports and the need for prediction of structural system behavior subjected to various types of loads, including acoustical loads. It is becoming more and more important during design, construction and exploitation. For predicting the interaction between building structure systems [1 - 3] and various loads the modeling of closed space structure (wall, ceiling, flooring, partition walls) geometry and physical properties influence is performed. The investigation of such influence can be accomplished by applying both mathematical and physical modeling, which can be realized by analytical or numerical method, evaluating different physical and mechanical properties of the closed space structure of the building, including possible damages.

In the sense of diagnostic purpose of unique buildings [4] the results of performed investigation demonstrated that among different types of loads acting on the structure, pure acoustical loading has influence on the structure deformation state [5]. It stated that acoustic load of the same magnitude and frequency (using harmonic excitation) can trigger heavier deformations of certain types of structure with defect.

Considering what was said above, we suppose that it is purposeful to create the model which describes the interaction between acoustic field and the damaged structure. It will help to evaluate the sensitivity of the structure state to the mechanical and acoustic load and determine the influence of the last to the critical construction load.

With the help of the developed acoustic field 3D model, the interaction between acoustic field and damaged structure will be investigated using real exploitation and structural conditions (e.g. existence of mechanical defect in the system).

2. FEM model of acoustic field and building structure

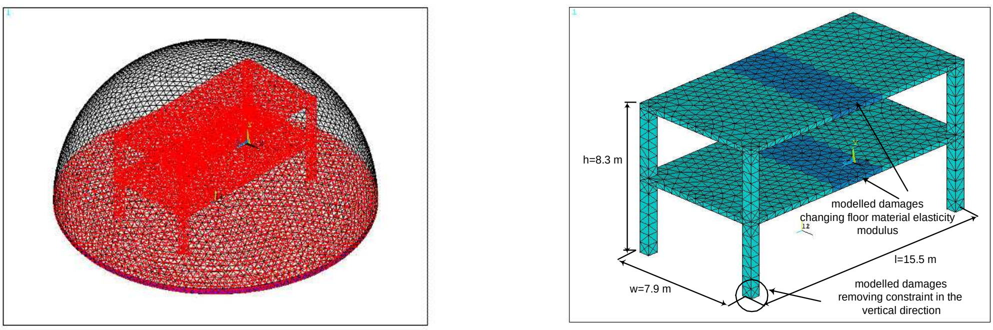
The three dimensional model, which is used to analyze two floor–column structure, using acoustic and mechanical excitation and different non-homogeneity degrees of the structure has been created and investigated. Possible mechanical system defect – reduction of rigidity due to floor flaw, has been modeled. In order to completely describe the fluid-structure interaction problem, the fluid pressure load $\{F_e^{pr}\}$ acting at the interface is added to the structural equation:

$$[M_e]\{\ddot{u}_e\}+[C_e]\{\ddot{u}_e\}+[K_e]\{u_e\}=\{F_e\}+\{F_e^{pr}\} \tag{1}$$

In the finite element statement the discretized wave equation accounting for losses at the interface is given by:

$$[M_e^P]\{\ddot{P}_e\}+[C_e^P]\{\dot{P}_e\}+[K_e^P]\{P_e\}+\rho_0[R_e]^T\{\ddot{u}_e\}=0 \tag{2}$$

where $[M_e^P]$, $[M_e]$ are matrices of the mass of the acoustic medium and structure respectively; $[C_e^P]$, $[C_e]$ are damping matrices of the acoustic medium and structure; $[K_e^P]$, $[K_e]$ are stiffness matrices of the acoustic medium and structure; $\rho_0[R_e]^T$ is relation matrix of the acoustic medium and the structure; $\{P_e\}$ is vector of pressure in the nodes and its derivatives $\{\dot{P}_e\}$, $\{\ddot{P}_e\}$ with regard to time; $\{\ddot{u}_e\}$ is vector of nodal displacement and its derivatives $\{\dot{u}_e\}$ $\{\ddot{u}_e\}$ with regard to time; $\{F_e\}$ is the load vector; ρ_0 density of air medium. In the model the meshing was chosen according to the rule of six elements per wavelength [6]. The ANSYS 10 software package has been used for the model. The created three dimensional model consisted of acoustic and structural mediums. FLUID30 and SOLID45 elements have been used for the modeling. The model consisted of 35763 nodes and of 207304 elements. Condition of the structure has been altered during analysis, i.e., a structure made from concrete without defect and with defect has been modeled. The defect has been modeled changing floor material elasticity modulus and removing constraint in the vertical direction. The value of the elasticity module was diminished by 30% for the first and second floor in a width of 1.6 m along its symmetry axis across the whole thickness.



a) b)

Fig. 1. FE model of building structure: a) - two floor–column structure in acoustic environment; b) - structure with damages

The distance between excitation source and the partition wall was 1 m. Physical properties of the model components were the following: air density ρ = 1.2 kg/m^3; sound wave propagation speed c = 335 m/s; sound damping factor of the air μ = 0; density of the floors and columns ρ = 2,400 kg/m^3; elasticity modulus E = 20.7e+9 Pa; sound propagation speed in the structure material c_p = 2,960 m/s; sound damping factor of the partition wall μ = 0.01 [7].

2. 1. Modal analysis of the damaged structure

Since the natural frequencies and mode shapes are important parameters in the design of a structure for dynamic loading conditions, the modal analysis of building structure has been performed. During modal analysis the changes of natural frequencies and probable acoustic field were been estimated considering different non-homogeneity (damage) degrees of the structure. The first five natural frequencies and mode shapes were determined for created finite element model of the building structure.

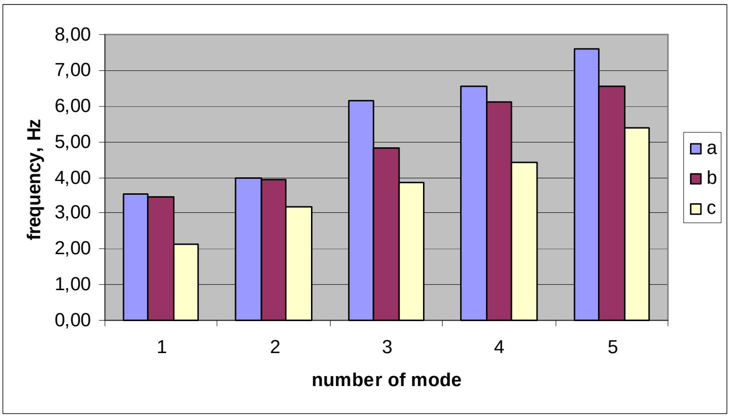
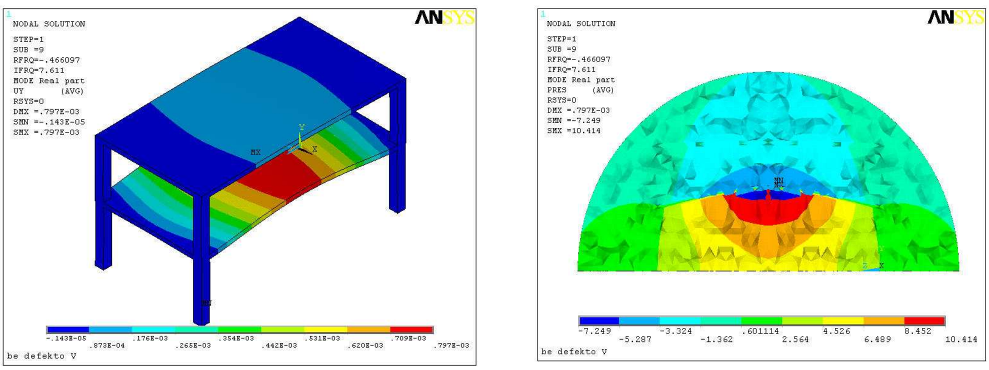


Fig. 2. Frequency of modes depending on damage degree of structure: a - structure without defect; b - the first floor with defect; c - both floors with defect and column with removed constraint in vertical direction

The results of the modal analysis indicate that the maximum structural deformations are induced when it is excited with the fourth or the fifth mode. When the construction vibrations are of these modes, the maximum deformations are at the middle of both floors in the vertical direction. The same can be said about acoustic pressure in the environment of the construction - the values of acoustic pressure become maximum when the mode of the construction vibration becomes the fourth and the fifth.



a) b)

Fig. 3. Vertical displacements of structure without defect a) and acoustical field in its environment; b) in the case of the fifth mode shape

The modal analysis of the two storey flooring construction allowed determining natural frequencies of the construction and natural vibration modes for the different states of the construction. The results revealed the most sensitive locations in the construction for deformations when there is a potential mechanical and acoustical load during exploitation. These deformations influence the acoustic field in the environment of the construction.

2. 2. Harmonic analysis of the damaged structure

Harmonic analysis gives the ability to predict the sustained dynamic behavior of the structure. The idea was to calculate the structure's response at several lower frequencies and obtain a graph of displacements response versus frequency. During this analysis, the system has been excited with harmonic sound and mechanical pressure load of particular magnitude. Acoustical load was modeled as airborne sound source when the distance between excitation source and floors was equal to 1 m. Condition of the structure has been altered during analysis, i.e., a structure made from concrete without defect and with defect has been considered. The results of the theoretical experiment are presented below.

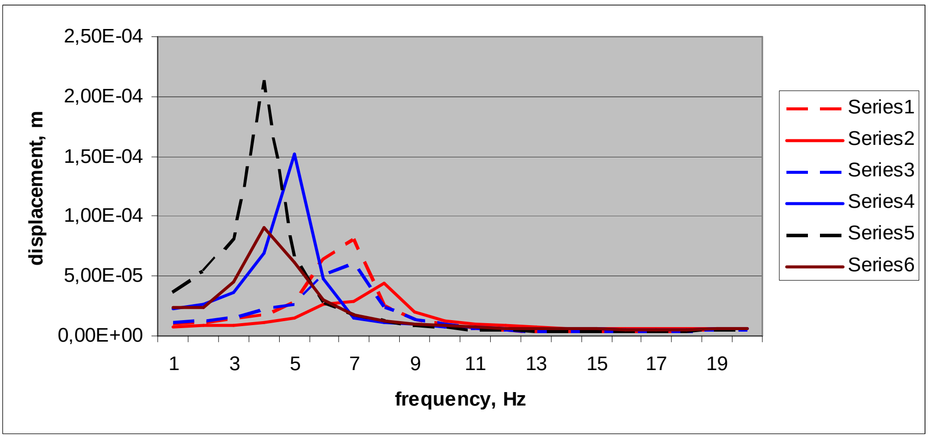
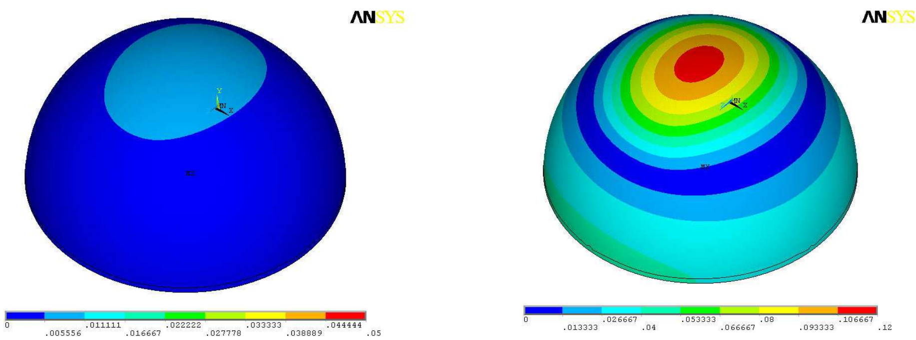


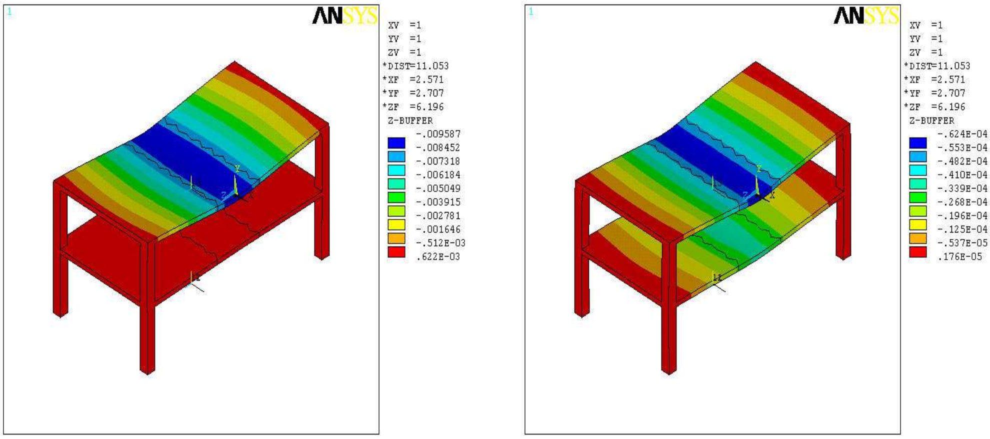
Fig. 4. Vertical displacements of the middle points of floors with different level of damage versus frequency of excitation: red - homogenous (without defect) structure; blue - the first floor with defect; black - both floors with defect and column with removed constraint in vertical direction. The solid line is middle point of the first floor; dashed line - middle point of the second floor



a) b)

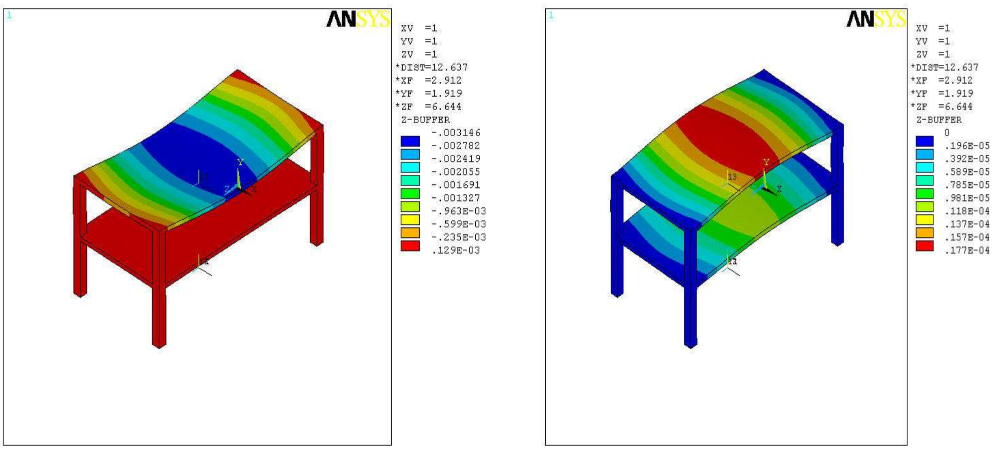
Fig. 5. Acoustic field due to vibration of the structure: a) - structure without damages, b) - both floors with damages and column with removed constraint in vertical direction

It is observed that the acoustic load of the same magnitude and frequency (using harmonic excitation) can trigger heavier deformations of the structure with defect.



a) b)

Fig. 6. Vertical displacements of structure with damages in the case of: a) - static pressure p = 3000 N/m^2 on the second floor and b) - harmonic sound pressure excitation p = 40 Pa



a) b)

Fig. 7. Vertical displacements of the structure without damages in the case of: a) - static pressure p = 3000 N/m^2 on the second floor and b) - harmonic sound pressure excitation p = 40 Pa

In the case of both static and acoustic load, construction deformation is three times larger for construction with defect than for the case of construction without the defect. Comparing influence of static pressure and acoustic load for the construction, considering different states, it is obvious that the acoustic load causes deformations smaller than 1%, while the latter emerge due to the static pressure. The results revealed that the acoustic load does not have significant influence on the deformation state of the construction. The influence of acoustic load depends on the structure state: as the degree of the defect increases, larger structural deformations are induced when the acoustic field is changing in the environment of the construction.

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3. Conclusion

The results of the research presented here have theoretical and practical importance. Theoretical models reveal the effects of acoustic field formation of the damaged structures. In practice these results can be used to reduce the noise in the environment of structures and identify the condition of mechanical system (in this case – damaged structure) more accurately using diagnostic algorithms, for example, during automated monitoring of the buildings condition with increased noise pressure bursts (such as sports arenas).

Acknowledgments

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