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NUMERICAL MODELING AND EXPERIMENTAL MEASUREMENTS OF THE BUCKET WHEEL EXCAVATOR AT OPERATIONAL LOAD

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Abstract. *Concerning the High Performance Machines, bucket wheel excavators are one of the biggest one and additionally highly exposed to the dynamic loads. The investigations presented in the paper, concerns the excavator over 120m long, 64 meter high and weighs approximately 5000 tons.*

The numerical and experimental models, in most cases did not cover the influence of the operational load on the dynamic characteristic of the construction. In the new, operational approach, the change in the numerical model composition must be reconsidered, while the old one are no longer valid. Modal analysis performed out of the operational load, give good results but do not represents actual state of the construction in operation. In that case, we have two separate system with different dynamic characteristics. Identification of the modal model with use of the Operational Modal Analysis gives the information about the object in operation which is the real point of the interest.

In the paper authors presents attempt to the process of the validation of the numerical model on the basis of the experimental results. The Modal Assurance Criterion between the numerical and experimental model was selected as the indicating factor. Moreover changes in frequencies and the degrees of freedom influencing the most the correlation level were reconsidered.

1 INTRODUCTION

At present, most of the surface mining machines working in the lignite mines in Poland are even twenty or thirty years old. In the case of such complicated structures, proper and sufficient identification of dynamic characteristics was not fully achievable till now. Recent development of mathematical, numerical methods and the power of computers allowed to face with that problem in full scale [1]. Up to now the only reliable method for determination of dynamic characteristics was an experiment. Obtained results gave full information but about the already built object. What is more, proper implementation of the experimental procedure on such objects is not a simple task [2]-[4].

Dynamic characteristic of the object is a useful needle for the operation of the machine [5]. Especially in the case of the big size surface mining machines which are highly exposed to the dynamic load. This type of the machines are spreaders (Figure 1) and bucket wheel excavators (Figure 2) [6].

Figure 1: Spreader A2RSB12500.

In the case of excavators, the high variability of the excavation force is common phenomenon [7]. Additionally, vibrations are generated in drives [8], conveyors [9] and by the transported material (hitting the pulleys and discharge points). Technological movements like travel, rotation or derricking are also source of vibrations. Spreaders are not so exposed to the dynamical loads as bucket wheel excavators, but due to its slenderness it is also easier to excite vibrations.

In reduction of negative results of the vibrations, the knowledge about dynamical characteristics is one of the key factors. As indirect results of the amplitude decrease, is the significant positive influence on durability of the structure. Mainly due to the fatigue phenomenon reduction [10] . There are known cases where dynamical displacements lead to the collision of the machine elements [11]. Proper identification of the modal model allowed to implement changes in construction that will prevent this negative phenomenon. In many other cases operation in resonant areas make the operation difficult.

What is worth noting, the vibrations generated by the machines can also excite human organs vibrations. Permissible accelerations level are defined in the standards [12]-[13]. In the ultimate cases human body organs can vibrate in resonance. Following the general trends of human protection [14]-[16] , also vibrations must be taken under consideration.

2 OBJECT OF INVESTIGATIONS

Preliminary investigations performed on the bucket wheel excavator SchRs 4600.50 [17] revealed that correlation level of numerical and experimental results differ in particular operational conditions. This lead to the conclusion that an attempt to update numerical models should be done in purpose to obtain better correlation. Also the source of differences between experimental models should be investigated. Both of the problems are discussed in presented paper.

The investigated object was the bucket wheel excavator SchRs 4600.50 (Figure 1). This is one of the biggest surface mining machines operating in Poland. The height exceeds 64 meters, length 120 meters and the mass (without discharge bridge) is around 5000 tonns.

Figure 1: Bucket wheel excavator SchRs 4600.50

The necessity of the investigations of the dynamic behavior was caused by the need of modernization of the excavating unit [18]. Excitation generated during machine operation is the key factor influencing the vibrations of the machine. Detailed information about the dynamic characteristics of the object allowed to design new bucket wheel with properly selected number of buckets (direct influence on the excitation frequency).

3 NUMERICAL MODAL ANALYSIS

Discrete model of the complete superstructure of the machine consist of slewing platform, counterweight boom, central part, bucket wheel boom and front and rear tower. In the numerical model undercarriage elements like platform or driving elements assemblies and the discharge bridge were not included. Those elements were taken under consideration while the most important, concerning vibrations problem is the superstructure. However, stiffness of the undercarriage elements must be substituted to the model in other way, while it influences the global modes of the machine. In the described discrete model the bucket wheel excavator SchRs 4600.50 superstructure was supported in the area where railway of the main bearing is assembled. The stiffness of the reduction elements was adjusted to the stiffness of all the undercarriage parts. This approach give only approximated representation of the real conditions. But, even if the whole undercarriage were included to the simulations there is still big unknown of the ground stiffness and even perfectly build model of the whole machine do not give the exact stiffness value. Eventually, results point out that the simplified approach allow to obtain results on the satisfied level.

Results of the performed numerical simulations are presented in the Table 1. Eight main modes were selected and most of them are the global one.

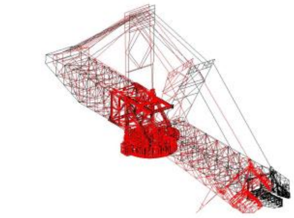
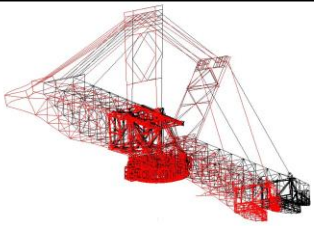
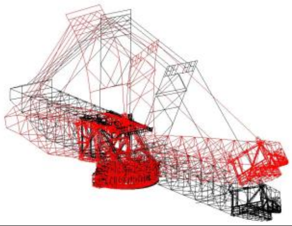
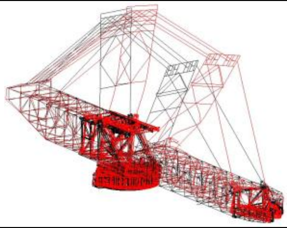
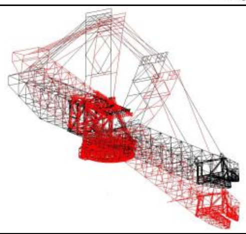
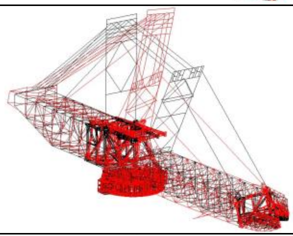
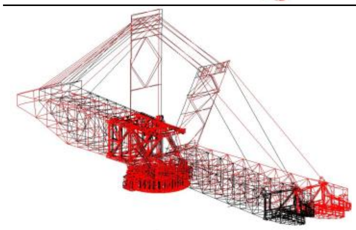
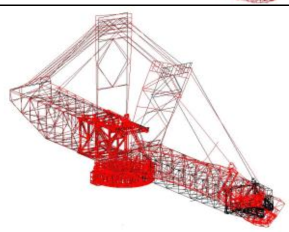
Mode	Description	Mode	Description
	Mode 1–0.28Hz bucket wheel boom torsion		Mode 5-0.53Hz bucket wheel and counterweight boom bending in horizontal plane
	Mode 2-0.32Hz superstructure vibrations in vertical plane		Mode 6-0.82Hz side vibrations of front and rear mast
	Mode 3-0.37Hz superstructure vibrations in vertical plane		Mode 7-0.96 rear mast bending
	Mode 4-0.38Hz superstructure vibrations in horizontal plane		Mode 8-1.68Hz front mast torsion

Table 1: Results of numerical modal analysis.

4 ON SITE MEASUREMENTS AND RELATION WITH NUMERICAL RESULTS

Numerical measurements gave the basis to the preparation of proper modal experiment in real conditions. At first the measurement points were selected (Figure 2).

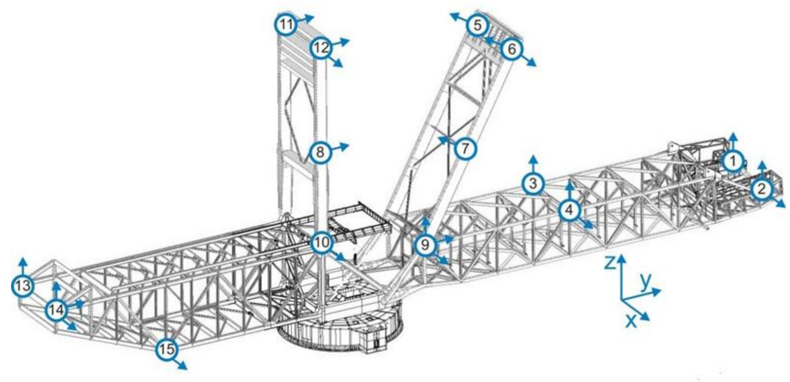


Figure 2: Measurement points [18]

Measurements were taken in several operational conditions which can be observed during lifetime of the excavator. From all the data sets, the three of them (most reliable) were selected for the analysis: upward excavation, downward excavation and machine travel. Comparison of MAC [19] factor for each load case is presented in Figure 3.

While the independently of the load case the correlation with numerical model did not change significantly [1] the attempt for increasing the correlation of the numerical and experimental modal model were performed.

When comparing both model, not only the information about the mode shape similarity, but also the information how it is related the frequency of compared modes is important. For that reason, to make it quick and easy, the author's *generalized correlation factor (k_u)* was used in following form (1)

$$k_u(f_b) = MAC_{ab}\left(1 - \left|\frac{f_a - f_b}{f_b}\right|\right) \tag{1}$$

where f_a is the frequency of the mode from the numerical model, f_b is the frequency of the mode form the experimental model MAC_{ab} is the correlation of numerical (a) and experimental (b) mode.

The modifications of the numerical model covered boundary conditions related to the changes in operational conditions. As main factors influencing dynamics of the machine, circumferential force and damping were assumed (Figure 4). This assumption was made on the basis of the analysis of the experimental results (Figure 3). It is visible that the operational conditions influence mostly the global modes in the vertical plane along the axis of the machine.

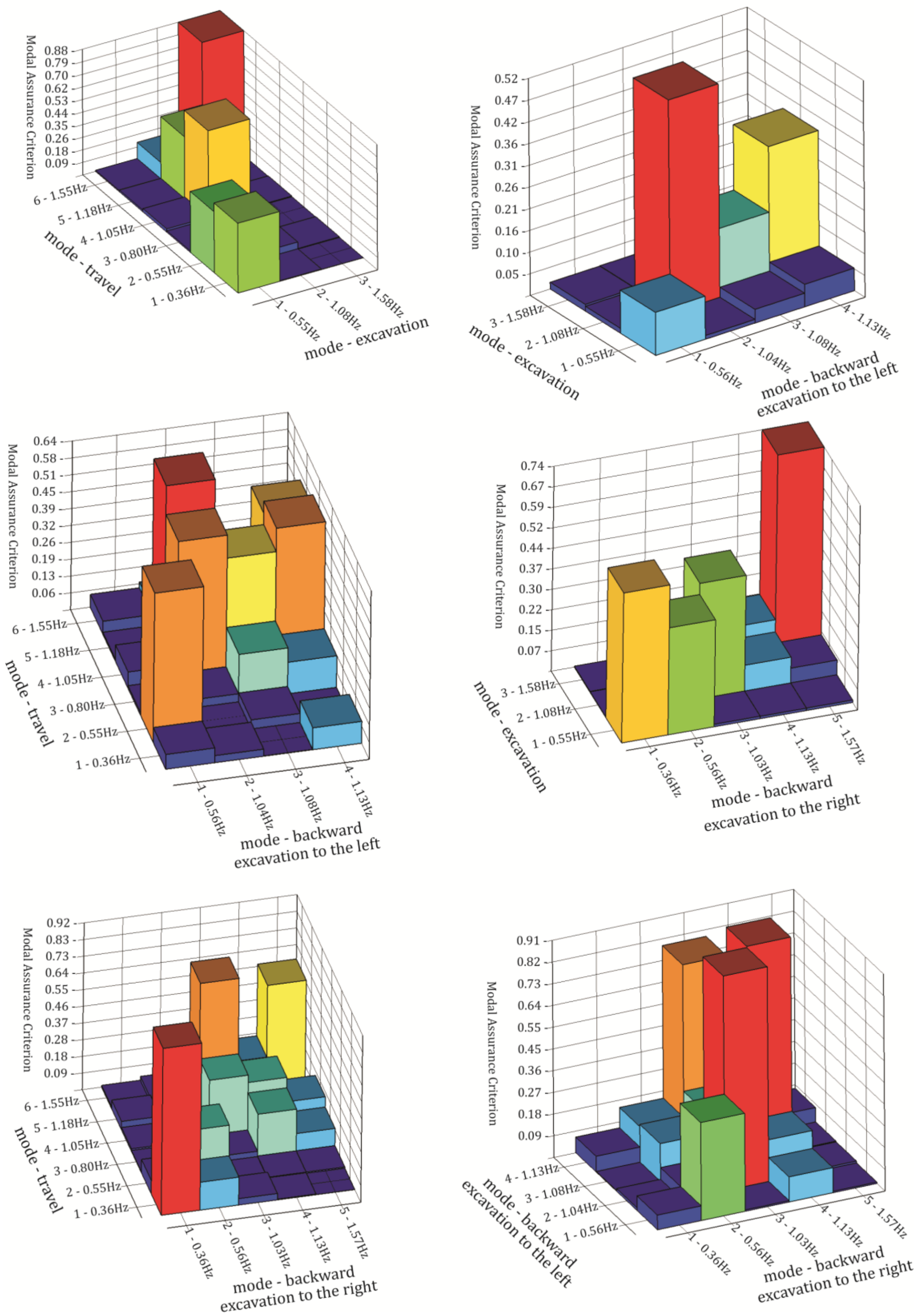


Figure 3: crossMAC factor for particular operational case

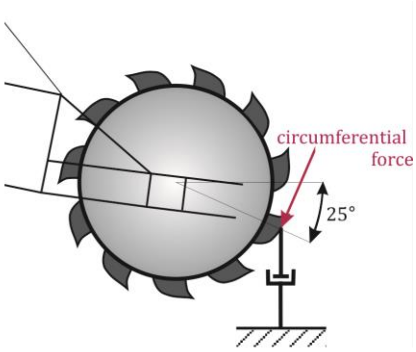


Figure 4: Numerical model boundary conditions scheme.

Table 2: Numerical model boundary conditions.

Lp.	Numerical model boundary conditions			
	superstructure according to the Stability Proof	Overburden and pollution of the superstructure	circumferential force	frequency value [Hz]
1	X	---	---	---
2	X	x	---	---
3	X	x	x	---
4	X	x	---	0,40
5	X	x	x	0,40
6	X	x	---	0,57
7	X	x	x	0,57
8	x	x	---	0,78
9	x	x	x	0,78
10	x	x	---	0,97
11	x	x	x	0,97

The damping coefficient value (c_{kr}) was selected according to the Eq. (2) [20]

$$c_{kr} = 2m\omega_0 \tag{2}$$

which describes the critical damping for the single degree of freedom system. In the case of the global vibration modes along main axis of the machine in the vertical plane, this assumption represents the vibrations motion in proper way.

As a result, diagrams (Figure 5 to Figure 7) of the generalized correlation factor between numerical model (covering all the eleven load cases) and the particular experimental case were prepared. It is visible that non of the change did influence significantly on the correlation level, no matter what is the experimental case. However, those simulations revealed that the simplest model, based on the Stability Proof, is actually the most proper. This indicates additionally that for the proper simulation of the changing operational condition, more complex approach is required. With high probability, the phenomenon of the interaction of the buckets and excavated soil must be included. Realization of that task required complicated experimental studies that will give the basis for further analysis.

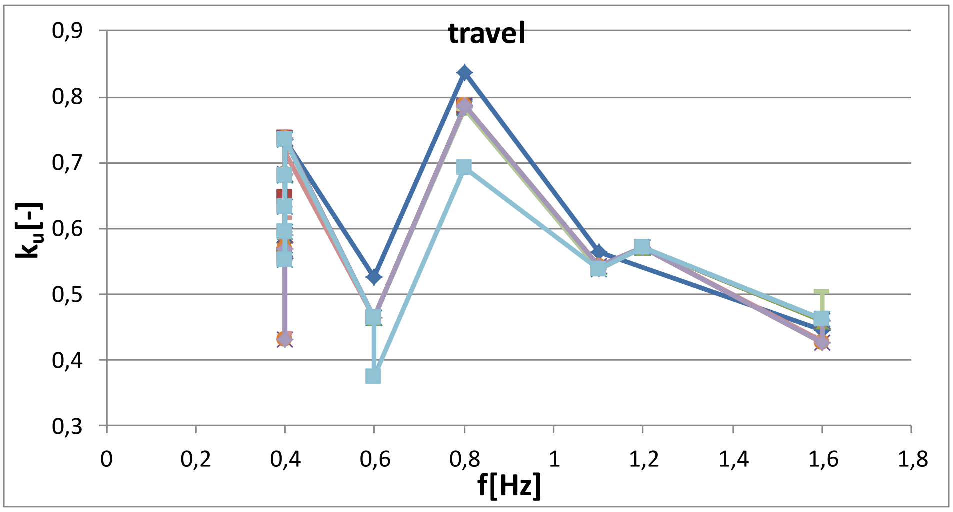


Figure 5: Generalized correlation factor level for travel and numerical model (for every set from table 2)

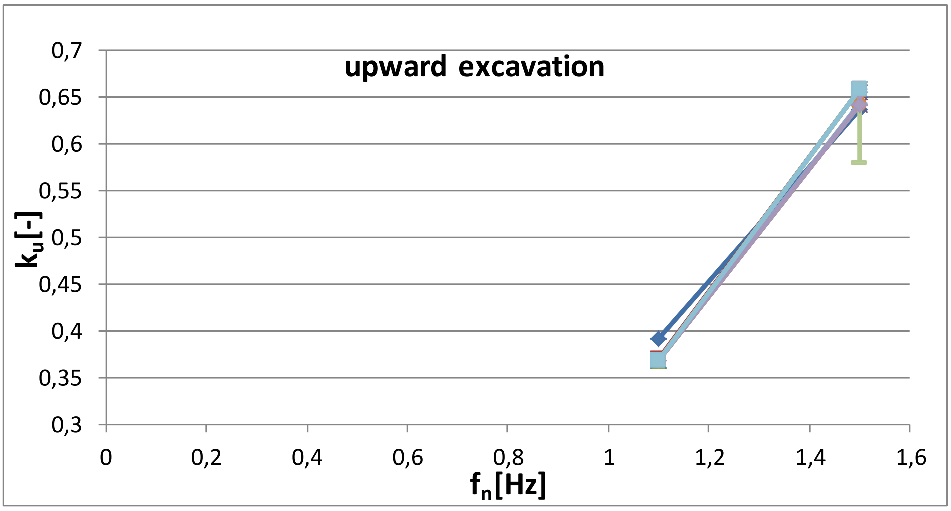


Figure 6: Generalized correlation factor level for upward excavation and numerical model (for every set from table 2)

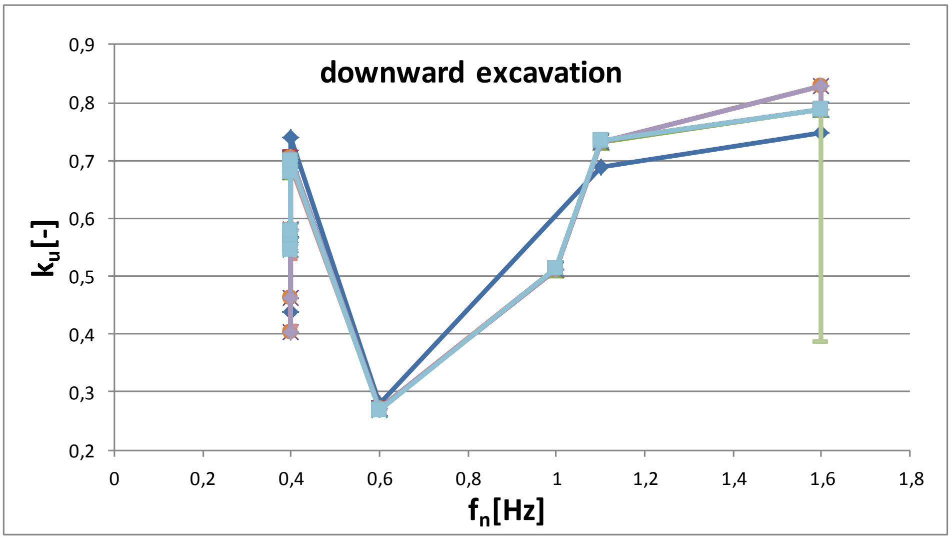


Figure 7: Generalized correlation factor level for upward excavation and numerical model (for every set from table 2)

Additionally, if analyze the response of the machine in case of the operational condition, it is possible to see that there is difference in the band of the excitation. This proves the relation between the operational condition and the presence of the modal modes. If look on the Figure 8 it is visible that the excitation during excavation do not supply enough energy in the lowest range of frequencies. On the other hand, the travel is the case that can excite the modes even in the lowest band. Even not having the characteristics of the excitation it is possible to describe it in general.

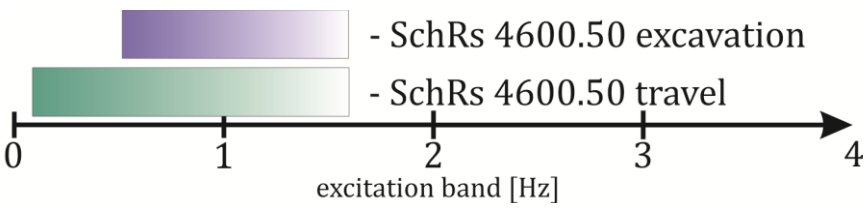


Figure 8: Excitation band for the excavation and travel case

5 CONCLUSIONS

In presented paper differences between particular experimental modal models were presented. The level of the correlation (crossMAC matrices) indicates the presence of every particular mode in terms of operational conditions.

Moreover, the application of the generalized correlation factor shows the simple and very useful method for the comparison of correlation level, both modal deflection shape and frequency. It was applied for the comparison of the modified numerical model and particular experimental modal model which correspond to the particular operational case. No significant changes in the correlation level was observable. This leads to the conclusion that the simplest model, without additional boundary conditions, gives the same results like the modified one. However, this reveals lack of knowledge in field of the exact influence of the boundary conditions, during excavation process, to the dynamic behavior of the machine.

The excitation band for the bucket wheel excavator SchRs 4600.50 was established. Having no information about the characteristics of the excitation signal it was possible to estimate its general character on the basis of the response of the structure.

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