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Model analysis of complex structures – advantages of physical sub-scaled model testing and shortcomings in physical model production

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Abstract

The possibilities of testing real constructions strength are often limited, especially in case of large constructions. Testing on the model, instead of the actual construction, results in a great saving of money and time. Sub-scaled model of the construction of the substructure, the slewing platform and the lower part of the pylons of the bucket wheel excavator SchRs630 is made. Numerical calculations (using Finite Element Method) and experimental testing of the model were performed. Experimental testing is performed using classical strain gauge method and Digital Image Correlation Method (Aramis system). Once again, advantages of Digital Image Correlation method compared to classical measurement methods are confirmed. The negative impact of conventional manufacturing methods in some zones is noticed.

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Keywords: Model testing; Sub-scaled physical model; Finite Element Method; Digital Image Correlation Method.

1. Introduction

The possibilities of testing real constructions are often limited, especially in case of large ones, e.g. bucket wheel excavator. It is well known that the number of failures of these machines should be reduced to the minimum because the cancellation of such a machine implies a double "cost", the cost of repair and cost because production process is stopped. Anyhow, if a machine is already stopped, it is primarily necessary to find out the cause in order to

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prevent its recurrence. Thus, about construction can be learned from the work life and then the adopted knowledge can be applied to similar constructions, Dreyer (1995). In order to get the machine returned to exploitation, there are several steps in case of a failure of those machines. First, it is necessary to find the reason why failure occurred. The cause may be one of the following four: errors in the design (geometry) of a particular part of the structure, a fault in the production of parts (error in material or in welded joints), an error in exploitation, or unexpected circumstances (unexpected workloads). The modern approach to finding the cause of failure is the conjunction of numerical calculations and experimental research, that are applied simultaneously, Daničić et al. (2010). Experimental testing of the construction itself is the problem, because the construction shouldn't be endangered at any point. Most often, confirmation of the proposed solution (based on the calculation by the Finite Element Method) and performed on the construction of the excavator, instead of experimental testing, provides a certain number of cycles without failure (indirect evidences). If necessary, a verification of the derived solution can be performed using so-called experiment during the operation of the excavator (with the current workload), as performed by Jovančić et al. (2011) and Bošnjak et al. (2011). Sometimes it is possible to do experimental testing of the original and redesigned part of the structure, but not the whole construction, as performed by Bošnjak et al. (2010). Those are the problems of checking of the proposed solution. But there could be problems at the very beginning. Usually, starting point in diagnostic is performing Finite Element Method calculations using workloads with the aim to indicate weak spots. Most often, the places of cracks (failure) are the spots of the highest stress concentrations. Therefore, it was first necessary to identify which circumcision leads to the appearance of a crack at a given site, as performed by Petrović et al. (2018).

For all of the above, the idea was making a sub-scaled model of the construction itself, which will provide the possibility of numerical-experimental "learning" about the strength and rigidity of this and similar constructions. In most cases, testing on the model instead of the actual construction results in a great saving of money and time. Recommendations for creating scaled models are performed by Shehadeha et al. (2015). Some examples of model testing of simple structures are performed by Ramu et al. (2013) and Prabhu et al. (2013). Model testing allows testing in a laboratory "clean" environment, which also allows the application of sensitive test equipment. Such equipment is, for example, system for non-contact stress and strain measurement aka Digital Image Correlation Measuring System (Aramis system). Some of the most successful examples of application of this method are performed by Mitrović et al. (2012) and Tatić et al.

2. Sub-scaled model

2.1. Sub-scaled model production

As a test example, the construction of the substructure, the slewing platform and the lower part of the pylons of the bucket wheel excavator SchRs630 is taken, because strength of supporting structure has a crucial importance for proper functioning of these machines. It turned out to be meaningful and justified to make model 10 times smaller than the real structure. Model (Fig.1) is made of steel S355J2+N.


Fig. 1. Substructure (left) and slewing platform with pylons (right) under construction

2.2. FEM calculation of sub-scaled model construction, static loading

The basic procedure in diagnostics of the structure is its computer modeling and the corresponding static and dynamic calculation using the numerical method FEM. The most sensitive, the most important and most difficult manageable procedure of the calculation process is structure modeling. Modeling, in fact, is mapping the physical to computational model according to technical documentation, selection of the type or types of finite elements and defining of physical model discretization by finite elements, nodal points, boundary conditions and loads. Taking into account the appearance of the excavator SchRs630 structure, the structure was modeled by plate elements. Axial bearing that connects the slewing platform and undercarriage is modeled by beam elements (168 beam elements). Support in caterpillar positions are presented using boundary conditions. Dead load and vertical forces of total amount of 20 000N (symmetrical loading) are taken into calculation. Numerical model (including boundary conditions and loads) and results of static loading (stress field) are shown in Fig.2.

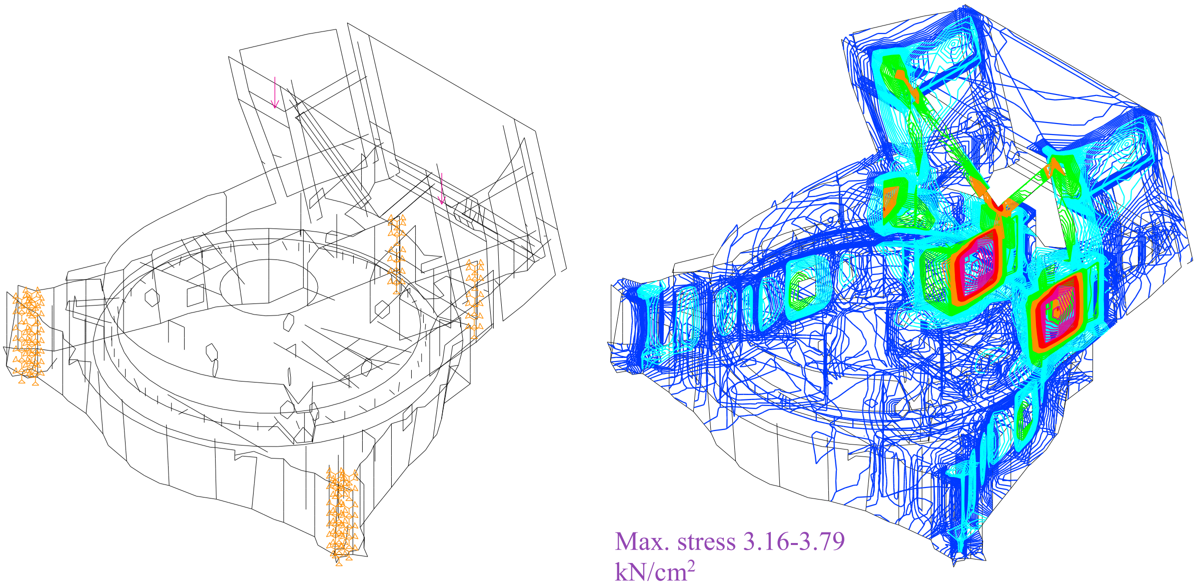

Fig. 2. Numerical model (left) and results of calculation (right)

2.3. Experimental testing of sub-scaled model

The experimental methods used are the strain gauge method and the method for non-contact displacement and strain measurement (Digital Image Correlation Measuring System). The symmetric load allowed (along with the already existing symmetry of the construction itself) parallel measurements using those two different methods (Fig. 3). In Fig. 3. can be seen specially prepared surfaces for testing using the Aramis system. Loading is the same as in numerical model (dead load and vertical forces).

Fig. 3. Parallel measurements using strain gauges and Aramis system

3. Discussion of numerical and experimental results

In most of measuring spots numerical and experimental method gave the same results, which confirmed the accuracy of physical sub-scaled model and verified that those structures can be tested in this way (model testing).

One measuring place is especially interesting; a spot where vertical truss meets upper horizontal plate of slewing platform (Fig.4.). In this example all the advantages of Aramys system will be shown, as well.

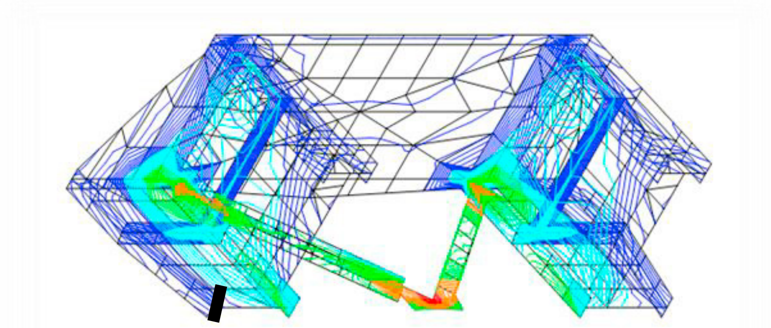

Fig. 4. Measurement location of special interest

Results, obtained using the Aramis system, are shown in Fig. 5. Equivalent displacement field (shown in Fig. 5.) is the first result that can be obtained using the Aramis system. Practically, numerical model can be verified just using those results. Matching of displacement obtained using numerical method and displacement obtained using Aramis system is enough to declare that one method confirmed another.

Another element should be noticed in Fig. 5. and that is yellow line, which represents virtual strain gauge. Virtual strain gauge has the same function as a regular strain gauge, it measures the distance between two points before and after the loading. Once again, to use the Aramis system, the only one requirement is that the surface is prepared for filming, and that the system is calibrated, which doesn't require a lot of money and time (comparing to some other methods). The results obtained using numerical calculations, strain gauge and virtual strain gauge (Aramis system) are shown in Table 1.

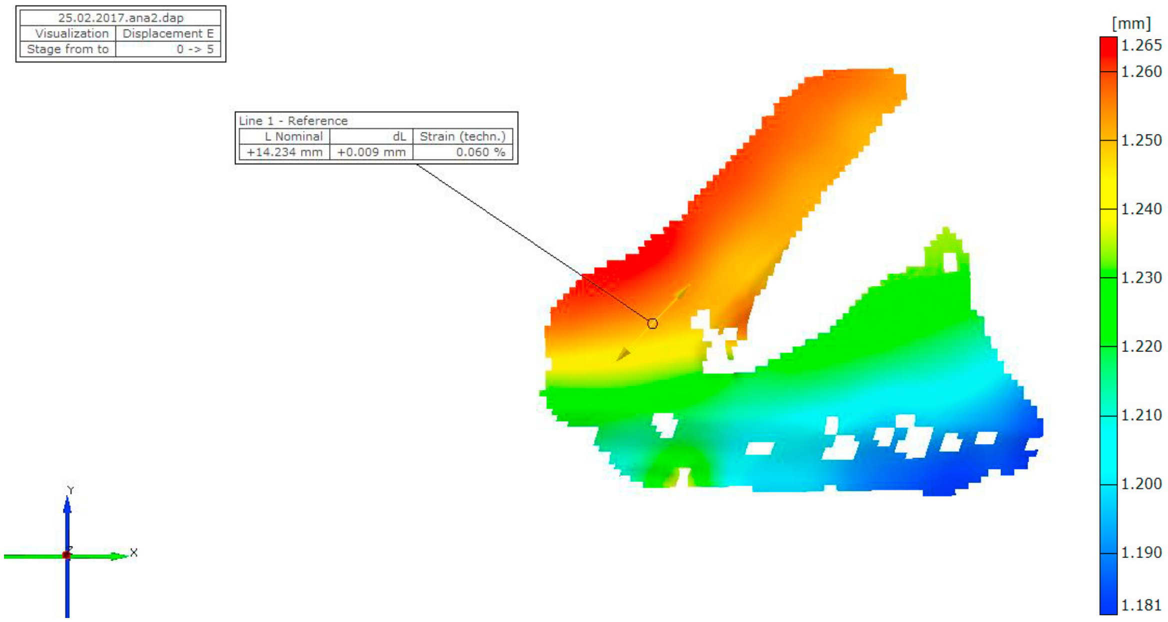

Fig. 5. Results obtained by the Aramis system in a spot where vertical truss meets upper horizontal plate of slewing platform, equivalent displacement field

Table 1. The results obtained using numerical calculations, strain gauge and Aramis system.

An example of a column heading	Vertical displacement (mm)	Deformation (μm/mm)	Stress (kN/cm^2)
Finite Element Method	0,11	/	4,18
Strain gauge	/	299,2	5,98
Aramis system	0,166	632,3	12,65

As can be seen from Table 1 three different methods don't give the same results. A significant stress concentration was identified at this location. Strain gauge show a 42.97% increase in stress compared to numerical calculations, and the Aramis system shows a stress of 111.36% higher than strain gauges. The only reason for this could be concentration of stress caused by the presence of a welded joint, which is large, compared to the dimensions of this zone (objective error in model production). This is also the cause of different (unsymmetrical) indications of strain gauge and Aramis systems. The explanation of these phenomena is simple: this zone is closer to the mock-up than the model and is not suitable for model testing. For some future models, this negative impact of manufacturing methods can be avoided by using alternative methods, including industrial adhesives with high tensile strength.

4. Conclusion

In this paper it is shown that:

- The 10 times sub-scaled model can be tested experimentally, results being in agreement with numerical results;
- The negative impact of conventional manufacturing methods in some zones is noticed, and potentially eliminated in some future models;
- Model analysis allows the use of the Aramis system, which can measure displacements and deformations (virtual strain gauge) in as many points of the model as needed.

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