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RAPID PROTOTYPING OF A DEVICE FOR TESTING THE CONNECTION OF REINFORCED CONCRETE AND ANCHOR BOLT

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Abstract: *In this paper the prototype of the device for field testing of the connection between reinforced concrete and anchor bolt was developed. Anchor bolts are often used in construction and mechanical structures or equipment to fasten them to the base: concrete, stone or some other building material. The basic factors that are important for the safe functioning of anchor bolts are the condition of the base, the operating load, the influence of the environment and proper installation. That is why it is very important to carry out adequate testing of the connection between the anchor bolt and the base after their installation, because this is the only way to make sure that they will perform their critical role. The paper presents the original solution of the testing device, which will enable the testing of installed anchor bolts in a wide range. The device enables monitoring of the most important parameters related to the quality of the base in which they are installed, the quality of the installation and the quality of the anchor bolt. The initial solution of this device was given, which meets the current technical directives and was validated by the Finite Element Method (FEM), in order to check the capacity under the static load and determine potential stress concentrations. The model was optimized in several iterations, using the Topology Optimization method, in order to obtain a lightweight construction, and the obtained results were compared with the initial model. The models are made using additive technology Fused Filament Fabrication (FFF), with the application of Computer-Aided Design (CAD) and Computer-Aided Engineering (CAE). The device is ergonomically designed based on the operating load through the use of eco-friendly materials, optimization of mass and shape.*

Keywords: *Field testing device, Anchor bolts, CAD/CAE, Ergonomics, Topology optimization*

1. INTRODUCTION

Rapid prototyping includes a set of techniques that are used for the rapid

formation of a physical model, which enables fast and economically efficient testing of the form and function of the product without the use of complex tools, which is most often achieved by some of the additive technologies [1,2]. The resulting prototype can be fully functional if its function is not too demanding.

Much more often, prototypes are partially functional because the materials used do not have the necessary properties to fulfill their function. Such prototypes are useful for experimental tests related to the geometry of the prototype [3] for which there are a large number of formats [4]. The use of this approach significantly affects the production time and the price of the product [5]. The application of advanced CAD/CAE approaches such as Topology Optimization enables obtaining light structures [6-10]. The rapid prototyping method in this paper will refer to the development of a device for testing anchor bolts in field conditions. Anchor bolts are mechanical elements that provide a solid and reliable connection between the structure and the base, and they function on the mechanical principle of expansion using a taper.

For the proper functioning of the anchor bolts, it is necessary to choose a type that can respond to the given working conditions, proper assembly, as well as the quality of the base in which they are installed. That is why it is very important to perform a field test of the anchor bolts after their installation. The main process and reference quantities for this test are load force and anchor bolt displacement. Their measurement will be carried out through an integrated information measurement system that will contain reliable sensors, which can measure these quantities in a wide range of values, with high accuracy and repeatability.

The development of the initial prototype solution begins with the adoption of input parameters (type of anchor bolt, dimensions, geometric shape, expected load, examined spatial position and quality of the base), as well as output parameters that give a valid image of the behavior of the connection between the anchor bolt and reinforced concrete, i.e. the base (displacement and axial force). Based on the adopted parameters, dimensioning, design and technical drawings were carried out. When designing this device, particular care was taken with the ergonomics of the device, with the aim of improving comfort, safety, efficiency, easier handling and test performance.

2. INITIAL MODEL

The device consists of a support plate, on which there is a modified hydraulic cylinder that has a multipurpose role. A threaded spindle passes through it, at the upper end of which there are levers with a nut, through which the user applies a load that is transferred to the cylinder by means of a suitable rolling bearing, with the aim of transferring the axial load. At the lower end of the spindle is a receiving claw through which the load is transferred to the anchor bolt itself.

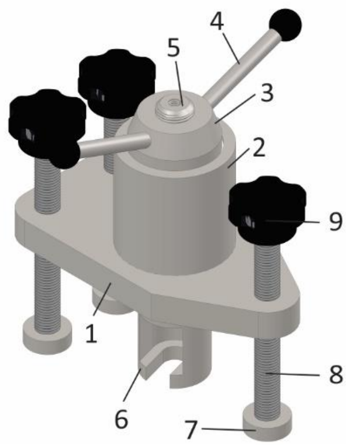

Figure 1. Initial model of the device for testing anchor bolts (1 - Support plate; 2 - Hydraulic cylinder; 3 - Nut; 4 - Lever; 5 - Threaded spindle; 6 - Claw; 7 - Pad; 8 - Support; 9 - Knob)

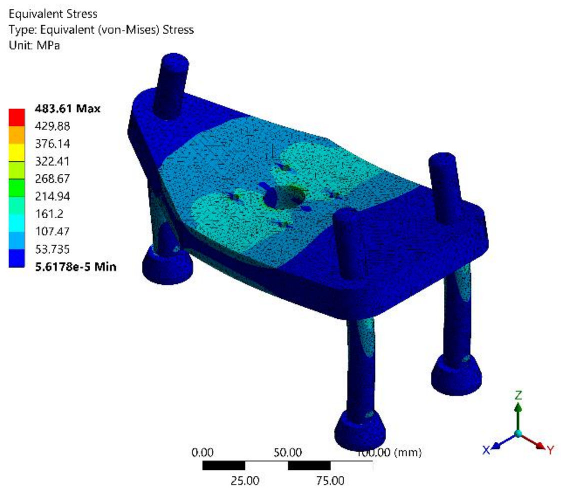

Figure 2. CAE analysis of the initial model

During loading operations, special attention was paid to the ergonomic and robust design, so the user can apply very large loads with little use of manual work. The mentioned components are supported on three adjustable supports, each of which has three degrees of freedom, so in this way it is ensured that the given load is uniaxial for different types of foundations. The formed CAD model is shown in Figure 1.

A CAE analysis of the critical (stressed members) parts of the structure was performed using FEM (Figure 2).

Increased stress values occur only locally, and in the critical section the highest stress is $\sigma \approx 230$ *MPa*. The support plate will be made of aluminum alloy AA7075-T6, whose mechanical properties are $R_{p0.2}$=480 *MPa* and R_m=570 *MPa*, which gives a safety factor of about S=2.1.

The formed initial model was made predominantly using FFF additive technology and is shown in Figure 3.

Figure 3. The Iteration 1 of the prototype anchor bolt testing device

After the production of the Iteration 1, in addition to the over-dimensioning of the cylinder, support plate and its large mass (≈ 5.9 *kg*), poor ergonomics and unaesthetics, other defects were noticed. The structure has a large free movement when it is not under load, which is mainly due to the adopted axial ball bearing, which is separable and cannot be made fixed in a simple way. This bearing was chosen because it has the highest axial load capacity. The buckling support check was also performed according to Johnson's formula:

$$P_{cr} = \frac{\pi^2 EI}{(kL)^2}$$

Where: P_{cr} – critical load, E – Young's modulus for adopted material, I – area moment of inertia of the section, which for a circular area is $I = \frac{\pi}{2} r^4$, k – effective length factor, which for fixed support is k=0.65 and length of the support L=150 *mm*, and L_e=97.5 *mm* is an effective length of support. For adopted thread M16, the root diameter is 13.8 *mm*, and Young's modulus for the adopted A2 stainless steel is E=190 *GPa,* and yield strength is 640 *MPa*, where I=1780.27 mm^4, and cross sectional area is A=37.39 mm^2.

The critical load according to Johnson's formula is P_{cr}=23.52 *kN* per support, which means that there is no risk of their buckling.

3. TOPOLOGY OPTIMIZATION

In order to reduce the mass of the construction, Topology Optimization was applied to the most massive part, the support plate. The optimization criterion was the retention of stiffness with a mass reduction of 50%. A boundary condition related to the obtaining technology called extrusion is also set, because it allows us to obtain a geometry of constant cross-section in the plane of choice. The optimization result is shown in Figure 4.

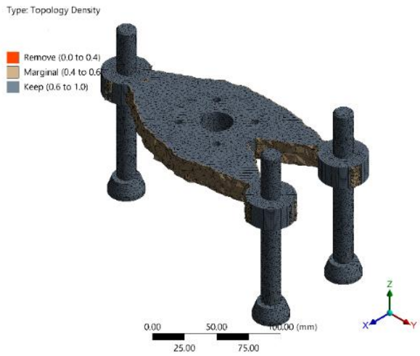

Figure 4. Support plate with supports of the Iteration 2 of the prototype

The resulting model was numerically tested using FEM, and the result of the numerical simulation is given in Figure 5.

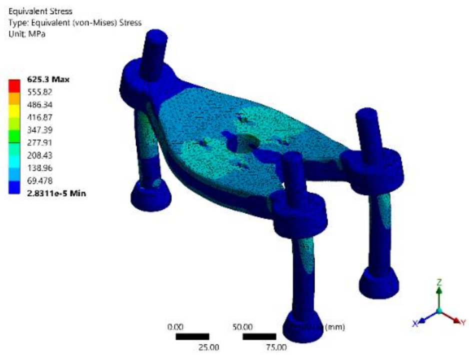

Figure 5. CAE analysis of Iteration 2.

Increased stress values occur only locally, and in the critical section the highest stress is $\sigma\approx 270$ *MPa*, which indicates that we still have a satisfactory level of safety of around S=1.9.

Since this cylinder is a pressure vessel and represents a critical element, its FEM analysis was performed. The surfaces exposed to pressure are shown in Figure 6, the fixed support is on the lower surface of the cylinder, and the results of this analysis are given in Figure 7.

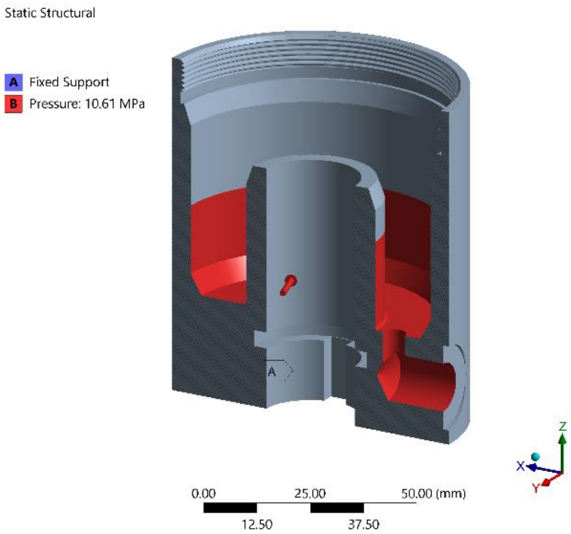

Figure 6. Surfaces exposed to pressure in a hydraulic cylinder

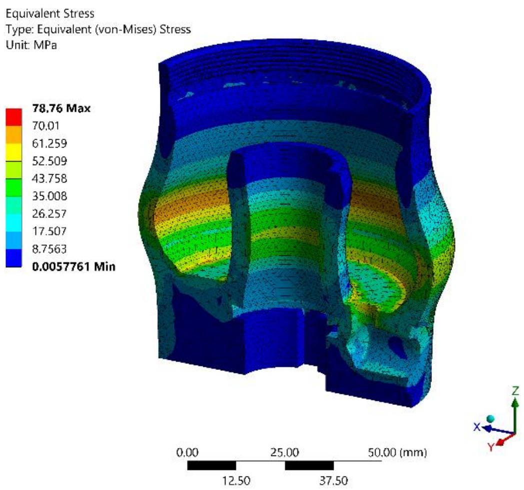

Figure 7. CAE analysis of a hydraulic cylinder

The maximum stress occurring in the material is far below the conventional yield stress for the selected AA7075-T6 alloy, which opens the possibility for further mass optimization. This was not pursued because the obtained result would not greatly affect the total mass of the structure, and would significantly complicate the technology.

The formed model of the Iteration 2 was made using FFF technology and is shown in Figure 8.

Figure 8. The Iteration 2 of the prototype anchor bolt testing device

By applying the Finite Element Method, the dimensions of the hydraulic cylinder were significantly reduced, and by using Topology Optimization, the support plate was improved. In addition to weight reduction, we also got a more aesthetic and better ergonomically adapted design. This shape gives it a characteristic and originality. The mass of the resulting construction is $\approx$4.4 *kg* without sensors.

When it comes to the free movement problem of the ball thrust bearing, it is overcome by using a four-point contact ball bearing which is a bearing adapted to the axial and radial load and by simply fixing it with a bushing on which it rests. This was not structurally possible to achieve with an ordinary axial ball bearing. The disadvantage of the newly chosen bearing is the reduced load capacity compared to the axial ball bearing.

4. INFORMATION MEASUREMENT SYSTEM

For the created prototype, an information measurement system was developed for this type of device through the application of modern electrical sensors in order to reduce measurement uncertainty and solve the problem of data transmission through the use of wireless transmission. The third iteration of the prototype with measuring elements, ergonomically adapted supports and handle is shown in Figure 9.

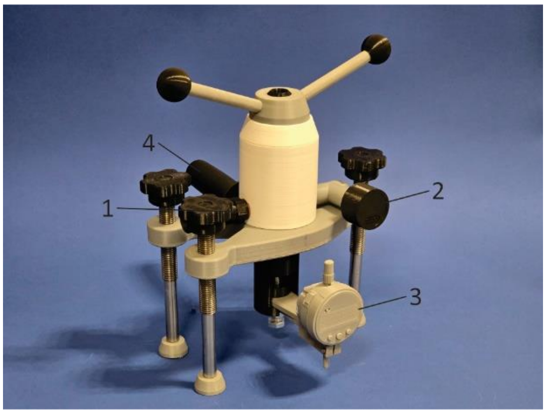

Figure 9. The third iteration of the prototype device for testing anchor bolts (1 - wireless pressure sensor; 2 - analog pressure gauge; 3 - wireless displacement sensor; 4 - handle for carrying the device)

The information measurement system consists of a pressure sensor that allows us to monitor the force value and a displacement sensor that is placed so that it touches the surface. Both sensors have the possibility of wireless data transmission, the acquisition of which is performed on a computer using a program obtained in *LabVIEW* software. Force and displacement were measured, and the results were obtained in graphic and *DATA* form. The diagrams obtained in this way are the force (*kN)* as a function of displacement (*mm*), and values of individual quantities in time (*s*).

The use of an information measurement system that uses wireless sensors offers a number of advantages for field testing which can be a very dynamic environment. It enables the elimination of power and communication cables, which simplifies installation and shortens testing time, especially in hard-to-reach and risky locations. The absence of cables also contributes to the ergonomics of this solution, as it reduces the risk of potential indirect injury to the operator or damage to the device during installation and testing.

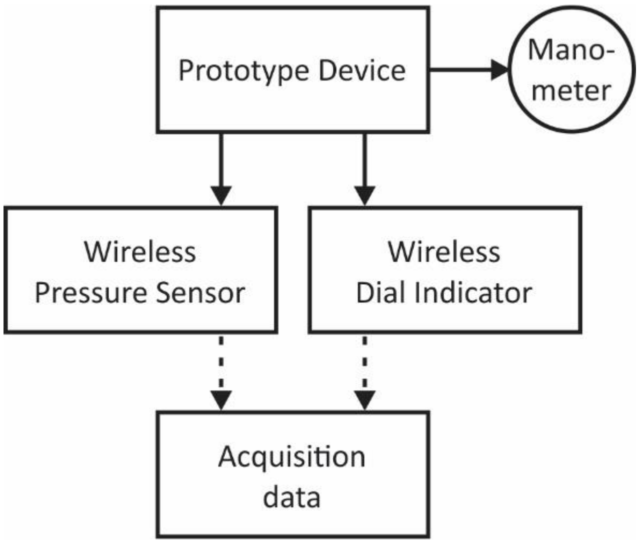

Figure 10. Block diagram of the information measurement system

5. CONCLUSION

The developed device for field testing of installed anchor bolts provides precise control of the tensioning force and movement of the anchor bolt, which enables a later assessment of the mechanical stability between the anchor bolt and the concrete (base). The optimized solution is ergonomically adapted using CAD/CAE tools, where the mass of the initial structure is reduced by 25*%*.

The developed prototype is current and applicable, especially when applied to test the connection of anchor bolt and concrete in an overhead position for a wide class of nominal diameters of the anchor bolt.

Application of the developed information measurement system enables more reliable measurement, simpler and safer work.

Future research will be related to the construction, which should provide an increase in the range of supports in order to test with the destruction of the material.

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