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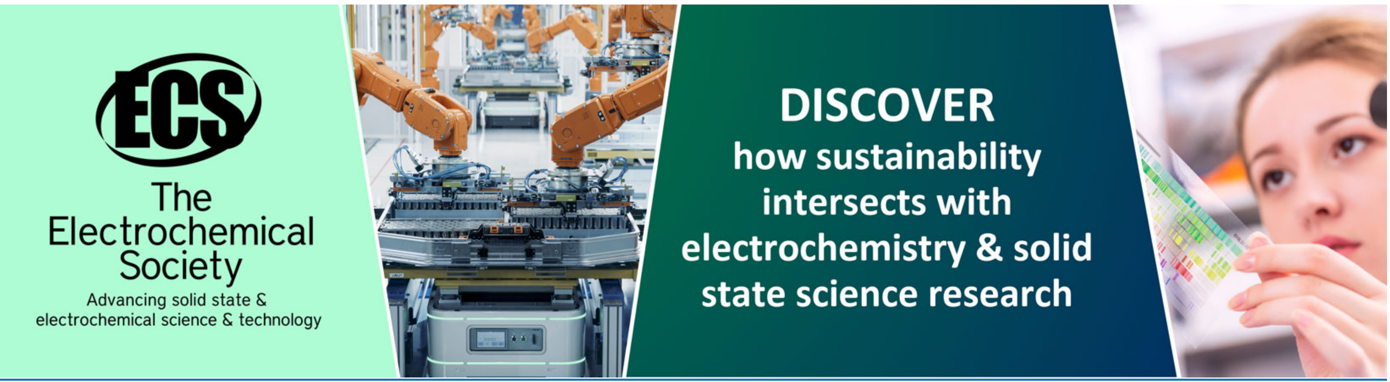

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Validation of Finite Element Updated Models of the Developed Façade Scaffold Anchor

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Abstract. The paper focuses on the updating of the finite element models of the newly developed facade scaffold anchor in the light of the experimental results. The experiments (force-displacement curves) have been carried out on the anchor. The façade scaffold anchor overcomes the problems arising in the process of joining them to the facades through the thermal insulation layers. Using the current methods, the wind load cannot be effectively transferred into the façade and scaffolding stability is decreased. Experimental results are presented and the finite element models of the anchor are developed using non-linear beam and solid elements. It has been observed that the predictions of finite element models that is force-displacement curve do not match with the experiment results. Subsequently, the finite element models of the developed anchor have been updated in the light of experimental results by using the parameter-based finite element model updating method. In case of an anchor, modelling of stiffness of the joints and values of the materials are expected to be dominant sources of inaccuracy in the FE model, assuming that the correct geometric parameters are known. After updating joint stiffness of the anchor joints and material properties, the finite element predictions match with experimental results. The outcomes show that there is a good correlation between the updated finite element models and the experimental data. The accuracy of the updated finite element models is demonstrated by overlaying force-displacement curves with the curve from the experiment, it can be concluded that the updated finite element models of the anchor accurately represent reality.

1. Introduction

To use a thermal insulation layer on the building façades is quite a common practice. But the current methods used for the fixing of scaffold anchors do not consider these thermal insulation layers. In the most common way, the distance provided by the insulation layer is crossed by the thick scaffold screw

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as shown in figure 1. Under the influence of the wind load, the screw is being deformed [1]. Due to that fact, the long scaffold screw can hardly transmit the forces from the scaffold construction into the façade, which results in a deformation of the screw as well as the damage of the surrounding thermal layers; the stiffness of the whole scaffold system is considerably decreased. It should be also mentioned that for the safety reasons scaffolds systems are covered with nets or planks. However, the cladding increases horizontal force acting on the anchors under the impact of the wind load, which is crucial in most of accident cases [2, 3].

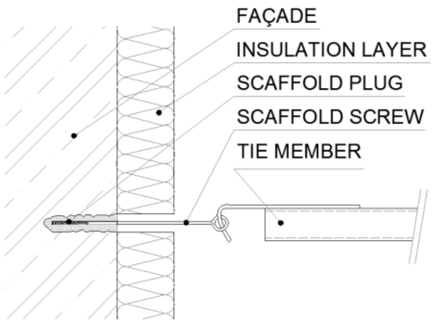

Figure 1. Vertical section of the fixed anchor – because of an insulation layer a long scaffold screw is used.

Figure 2. The fixing of an anchor to the insulated façade.

The scaffolds are generally weak systems, because of the loosened connections of components [4]. This results in instability of the anchor systems [5]. The stability of the scaffolding has been investigated in many papers [6, 7]. Scaffold constructions are generally divided into two wide groups based on their main bearing components [5]. First there are non-system tubes constructions, where the main components are mild steel tubes with diameter of 48.3 mm and 4 mm thickness. Tubes are connected together by couplers. In the European countries, these are still very frequently used because of their variability. Based on this principle, the bamboo scaffolds, which are very often used in the countries of East Asia, can be also added to this group. Second large group is represented by using prefabricated parts, mostly frames, in certain system configurations. This group can be also called proprietary scaffolds. In case of the non-system tubes constructions, the stability is provided only by the anchoring and bracing. For those reasons, the importance of the anchoring should not be underestimated.

It is necessary to develop a new scaffold system, which overcomes the problems connected with the existing scaffold anchors. These problems include damage of the façade thermal insulation layers surrounding the scaffold fixing and related decrease of scaffold stability.

2. The stability investigations and the basic principles of the new anchor

One of the most appropriate stability investigations has been provided by Dolejs in his thesis [1]. Dolejs analysed a typical non-system tubes scaffold construction with 12 storeys. The scaffolding has been modelled according to the netted cladding, see figure 3, and the values of loading and load combinations have been based on European standard EN12 811-1 [8]. The load class is set as 2, so the uniformly distributed load, which is part of the service loads, has the value of 1.50 kN/m^2. According to the standard, there are 4 loading combinations. First two represent the service condition while the second two represent the out of order condition. The 3rd combination is important, which represents the out of order condition with the maximum value of the wind load perpendicular to the façade. The anchors have been modelled as pinned supports according to the standard [8 and 9]. The scaffold tubes have been connected by semi-rigid joints respecting M – φ relation obtained by the previous experiment. Generally, the semi-rigid connections as well as initial imperfections affect the results [10]. Critical load coefficients for each combination have been computed. The values vary in the range from 1.68 to 2.74, while the value of the 3rd combination is 1.80.

2.1. The stability of the scaffolding using long screws in fixing

For the purpose of demonstrating the phenomenon of the long scaffold screw used in fixing (as show in figures 1 and 2), the previous Dolejs' model has been enhanced by adding these screws. The screw is added as a rod with 12 mm diameter and 300 mm in length. After that the stability analysis has been computed again. The critical load coefficient of the 3rd combination has the value of only 0.38, which is acceptable by considering the fact that most of the accidents happen during the strong wind conditions [2, 3]. The stability shape of this combination is shown in figure 4.

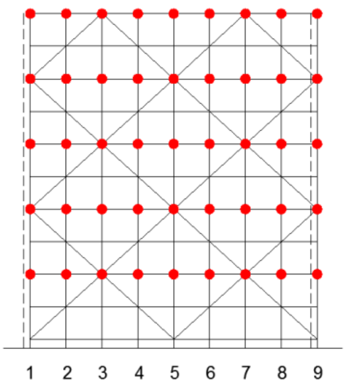

Figure 3. The front view on scaffolding – the anchor position pattern for the netted scaffolding. The dots represent anchors.

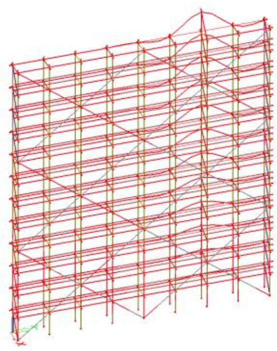

Figure 4. The first stability shape of the scaffolding fixed with long scaffold screws

2.2. The stability of the scaffolding using the proposed new anchor

For the purpose of increasing the scaffold stability, the parametrical study on the existing scaffold model has been carried out. The parameters include the position patterns of the anchors and the degree of freedom of supports.

It has been concluded that one of the most important parameters, which affect the final critical coefficient, is the support rigidity. Also it has been observed that even the semi-rigid support has a large influence on the critical constant value. Because of that it has been determined that for the next investigations, the new anchor will be considered as being rigid in the horizontal plane. For this type of support the optional position pattern has been developed as it is shown in figure 5.The final critical load coefficient has risen up to 3.24. The stability shape of this value is represented in figure 6. Also from this model the maximum values of the support forces have been computed by geometrical non-linear analysis with imperfection (GNIA) like in the case of the Dolejs' model [1].

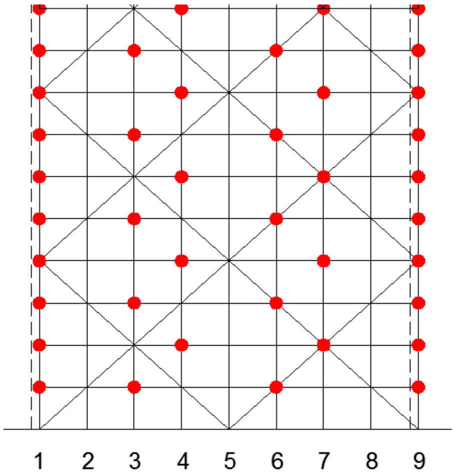

Figure 5. The developed position pattern for the new anchor.

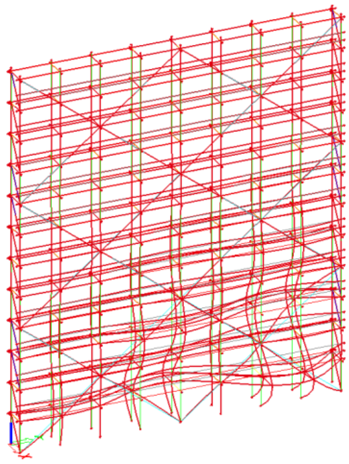

Figure 6. The first stability shape of the scaffolding using new anchors (supports are rigid in the horizontal plane).

2.3. The developed shape of the anchor

Considering the previous investigations, a new anchor shape has been developed and officially registered. The shape of the new anchor is termed Lever Anchor. The anchor consists of a rigid frame, which is connected to the facade in the horizontal way. The frame columns lead through the facade insulation layer. The frame is stiff enough to carry out the forces from the scaffold construction without deformations, so the insulation layer is secured. The anchor consists of several parts, because it has to provide variability during installation on the façade.

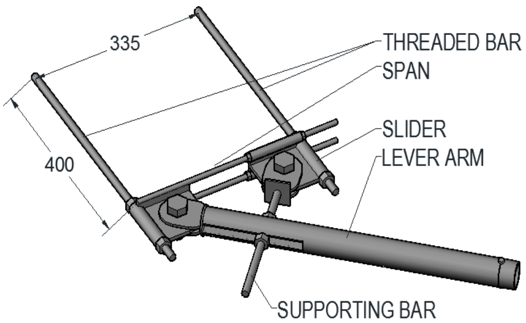

Figure 7. The developed new anchor shape – The Lever Anchor.

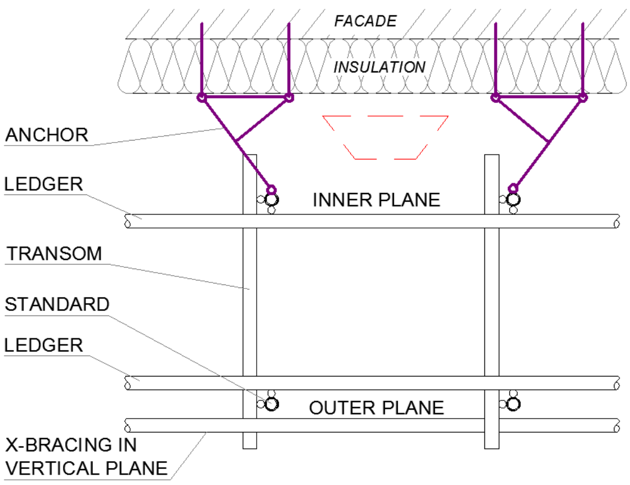

Figure 8. The plane view on the scaffolding with the anchoring by two Lever Anchors.

3. The experimental verification of the Lever Anchor

It is necessary to develop an accurate finite elements model, which will be used during the optimization. The accuracy of the finite element model is confirmed by the experimental verification. The prototype of the Lever Anchor has been created and an experiment has been carried out. The scheme diagram of the laboratory experiment is shown in figure 9.

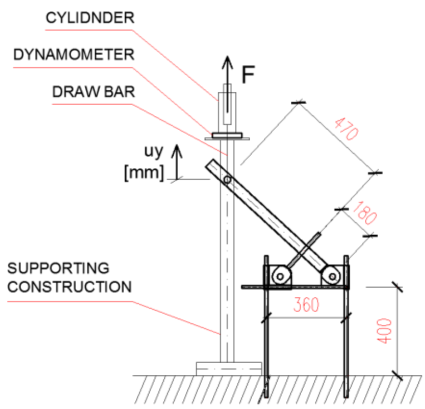

Figure 9. The scheme of the laboratory experiment.

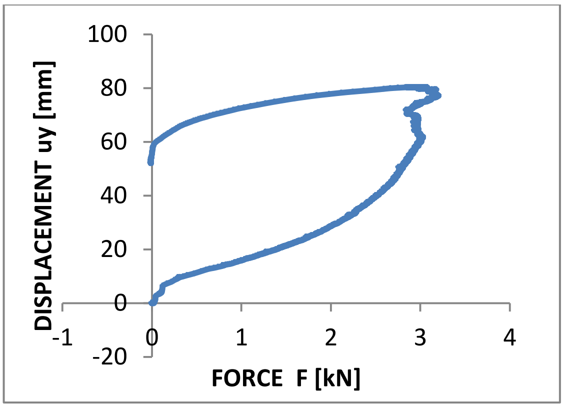

Figure 10. The force-displacement curve as a result of the laboratory experiment.

The anchor was loaded continually by tension force in vertical direction. The force magnitude rose from 0 to 3 kN. The displacement was measured at the end of the lever arm. The result was the force-displacement curve as shown in figure 10.

The force was provided by the single acting hollow plunger cylinder with the one-handed pump. The cylinder was situated on the top of the supporting steel construction made from two parallel columns with reversed T shape. The pressure was measured by tensometric dynamometer. The steel draw bar connected a hydraulic cylinder to the end of the lever arm. The values of vertical displacement were measured by the common absolute potentiometer sensor.

In the beginning, the member Span (the description of the anchor is shown on figure 7) reached the plastic behavior. After applying the force of approximately 3.0 kN, the first small cracks on the span's bars were detected, so the weakest part of the anchor was the Span member.

4. The finite element models of the tested anchor

Two accurate finite element models have been developed in the software Ansys. These models have difference in the used finite elements. The first is a 2D beam model and the second is a 3D solid model.

4.1. The initial 2D model

In the beam model all parts are connected with longitudinal and torsional stiffness. The stiffness values have been computed by using empiric equations. The real values of the joint stiffness are unknown and they are considered to be the source of error in the finite element model as well as the material properties. The defection profile is calculated using the applied force and subsequently plotted along with the experimental results. It can be observed from figure 11 that the finite element results do not match with the experimental results.

4.2. The initial 3D model

The solid final element model of the anchor has also been developed. It can be observed from figure 11 that the deflection curve does not match the experiment as well. Cross sections and material properties have been used the same as in the beam model. The only important difference is that in the solid model, the stiffness of the connections is provided by the rigidity of the solid bodies itself. Therefore, the material properties are the only source of errors.

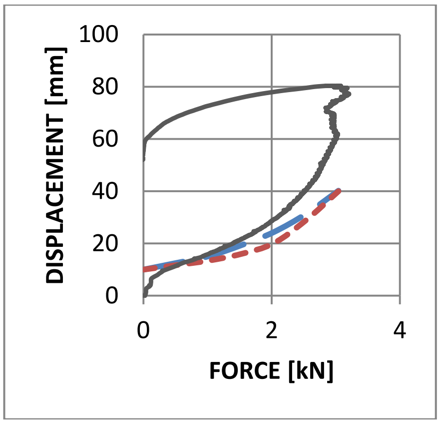

Figure 11. The force-displacement curves of the initial models. Solid line – experiment, Dot line – beam model, Dash line – solid model.

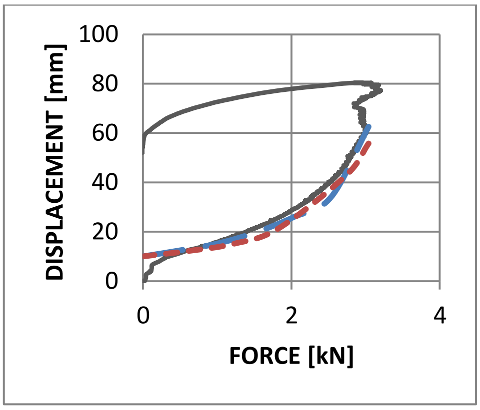

Figure 12. The force-displacement curves of the updated models. Solid line – experiment, Dot line – beam model, Dash line – solid model.

4.3. The accurate models

The choice of updating parameters on the basis of engineering judgment about the possible locations of modelling errors in a structure is one of the strategies to ensure that only meaningful corrections are made. In case of an anchor, modelling of stiffness of the joints and the values of the material properties are expected to be a dominant source of inaccuracy in the FE model, assuming that the correct geometric parameters are known. The values of stiffness of joints and values of the material parameters are updated in the light of experimental results. The same method has been used in many papers, see [11, 12]. In both models the parameter studies have been carried out, finally both force-displacement curves of the solid and beam model match the experimental curve well, as demonstrated in figure 12. For more detailed description, the updated parameters in both models follow.

In the updated 2D (beam) model, the important parameters include the torsional stiffness of the joints; see figure 13 and Table 1. The longitudinal stiffness in both axes (X, Y) has been left with no change to the initial model. Also the material yield strengths have been updated. The threated rod's Structural Steel 4.8 has been adjusted from 300 MPa to 275 MPa and in the case of the Structural Steel 8.8 the 580 MPa value has been decreased to 550 MPa. The plate's Structural Steel S235 has been left without change at the value 200 MPa.

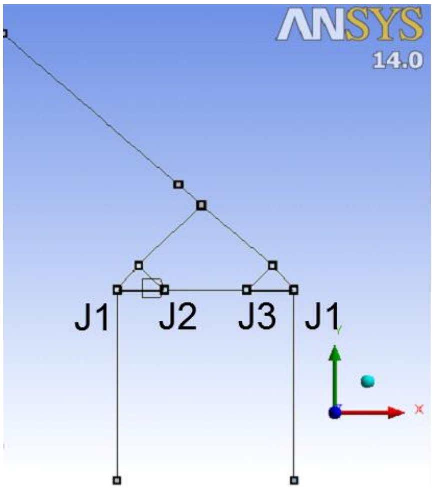

Figure 13. The description of the most important joints in 2D beam model according to the final force-displacement curve.

Table 1. The updated torsional parameters of the joints in [MNm/rad].

Name	**Initial**	**Updated**
J1	0.10	2.41
J2	0.01	0.34
J3	0.10	0.11

In the updated 3D (solid) model, only the material yield strengths have been updated. The threated rod's Structural Steel 4.8 has been lowered from 300 MPa to 260 MPa and Structural Steel 8.8 from 580 MPa value to 500 MPa value. The plate's Structural Steel S235 has also been left without change and stayed at the value 200 MPa.

5. The optimized anchor

Based on the accurate finite element models, the optimization process has been carried out. The dimensions have been adjusted for the safe transmitting of the support forces. These forces have been obtained from the scaffold construction, which has been previously shown in figures 5 and 6.

The final optimized anchor is shown in figures 14 and 15. The geometry of the anchor has been changed according to the standard [8] and some parts have been split up to ensure better manipulating and ease of the production process. The cross sections of all parts have been fortified. In these conditions, the Lever Anchor should be able to carry a pressure force up to 18 kN, which is directed to the end of the lever arm.

Subsequently, the anchor will be experimentally tested again. In this experiment the force will be placed in all 4 horizontal directions for the best description of the behaviour and for accurate specifying of the support semi-rigidity.

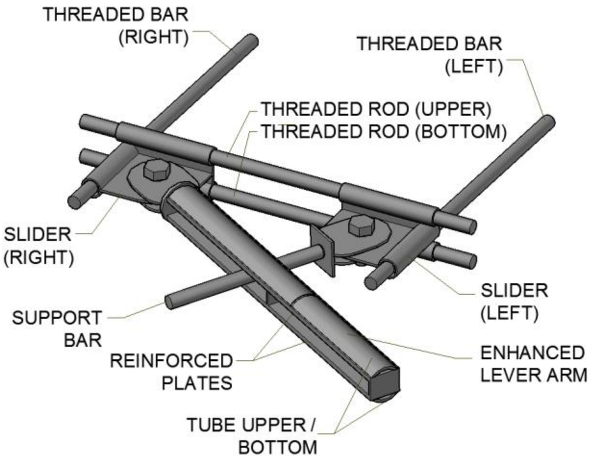

Figure 14. The description of the optimized Lever Anchor.

Figure 15. The created optimized Lever Anchor (with the wrist watch in the bottom right corner as a scale).

6. Conclusions
In this paper the new type of the scaffold anchor with the unique position pattern on the scaffolding as well as the finite elements models of that anchor have been developed. It has been observed that the finite element models do not match with the experimental results. After updating joint stiffness of the joints and the material properties of the anchor, the finite element prediction matches with experimental results. Subsequently, the result of the following optimization process is also presented. The paper is a part of the long-term project aimed at developing a new fixing system for the façade scaffolding.

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