Engineering Structures 118 (2016) 334–343

Contents lists available at ScienceDirect

Engineering Structures

journal homepage: www.elsevier.com/locate/engstruct

# Design of new scaffold anchor based on the updated finite element model

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A R T I C L E I N F O

*Article history:*
Received 20 April 2015
Revised 25 January 2016
Accepted 29 March 2016
Available online 13 April 2016

*Keywords:*
Optimization
Tubular scaffold
Fixing anchor
Facade
Stability
Nonlinear finite element model

A B S T R A C T

In this paper, a new scaffold anchor system is presented. The developed scaffold system overcomes the problems associated with the existing scaffold anchors. The existing scaffold anchors damage the surrounding insulation layers subsequently decreases the stability of scaffold anchors. The developed scaffold system has a new type of the facade anchor and the position pattern used for scaffolding. The developed scaffold system is based on the accurate FE models of the prototype anchor, which have been updated in the light of the experimental results i.e. force–displacement curve. It has been observed that the results of finite element model do not match with experimental results. The modelling of stiffnesses of the joints is considered to be the major source of uncertainty in the finite element model. Subsequently, stiffnesses of joints of anchor have been updated in the light of experimental data. The results have shown that after updating, the predictions of finite element model of scaffold system matches well with experimental results. Subsequently, the loading forces used during the optimization process have been obtained from the updated finite element model of the tubular scaffold construction related to the Eurocode standards. In addition to the problems associated with existing scaffold anchors, the developed scaffold anchor is also effective in transmitting support forces to the facade object along with increasing the stability of scaffold anchors.



## 1. Introduction

Scaffold constructions are generally divided into two groups based on their main bearing components [1]. First group comprises of non-system tubes constructions, where the main components are mild steel tubes with diameter 48.3 mm and 4 mm thickness. Tubes are connected together by couplers. In the European countries, these types of systems are still very popular because of their variability. Based on the same principle, the bamboo scaffolds, which are very often used in East Asia countries, can be also added into this group. Second larger group comprising of prefabricated parts, mostly frames, in the certain system configuration; this group is called proprietary scaffolds.

Scaffoldings in both groups are generally very weak constructions because of the loose connections of parts [2,3]. The stability of scaffold anchor systems can be increased significantly by the anchoring and bracing [4,5]. Many scaffold constructions collapses every year. According to the past research, the majority of failures occur due to inadequate site supervision and poor design [1].

These reasons are compounded, when the scaffold is fixed to a facade with a thermal insulation layer, because there are not many ways how to fix the anchor through this layer [6], and none of them have been sufficiently analyzed yet [7]. The presence of thermal insulating layer increases the possibilities of the failure. In the most of the cases, a long scaffold screw is used to overcome the thermal insulation as shown in Fig. 1. The use of long scaffold screw often results in deformation of the screw during the impact of the high wind load [8], which subsequently results in damage of the surrounding insulation layer and additional repairs are required [7]. Moreover, the deformation of the screw decreases the stability of scaffold anchor systems. To overcome these problems, a new facade anchor has to be developed.

In this paper the developed anchor shapes are presented. One of the shapes, the "Lever Anchor" has been fabricated and experiment has been carried out to determine it's the real load bearing capacity. It has been observed that the force–displacement curve is nonlinear because of permanent deformation of the anchor due to loading. Two FE models (beam model and solid model) have been developed for making out the numerical analyses. The experimental results have been compared with the corresponding predictions of these finite element models. It has been observed that the force–

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http://dx.doi.org/10.1016/j.engstruct.2016.03.064
0141-0296/

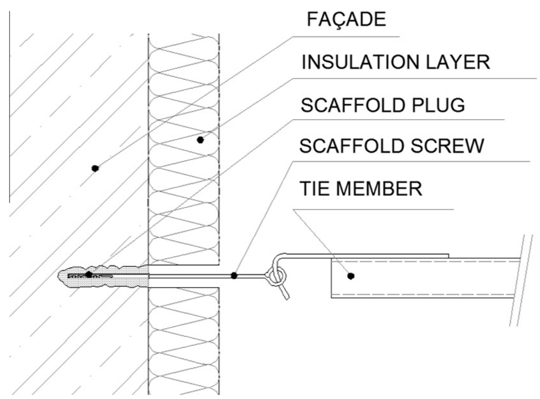


**Fig. 1.** Vertical section of the fixed anchor.

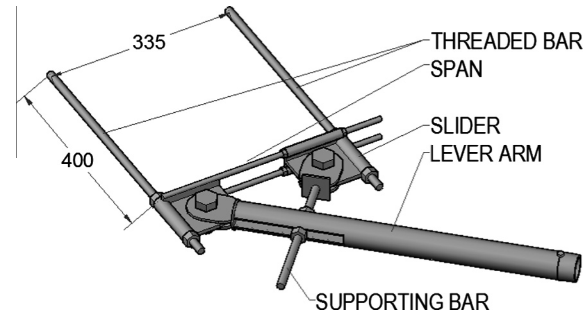


**Fig. 2.** The prototype of the Lever anchor.

displacement curves of these initial finite elements models did not match with the experimental results. It is well known that finite element predictions are often called into question when they are in conflict with experimental results. Inaccuracies in finite element model and errors in results predicted by them can arise due to use of incorrect modelling of boundary conditions, incorrect modelling of joints, and inaccurate size of the mesh, etc. This has led to the development of model updating techniques, which aim at reducing the inaccuracies present in an analytical model in the light of measured experimental data as shown in the surveys by Imregun and Visser [9] and Mottershead and Friswell [10].

Since the geometry of the finite element models have been known well, the stiffness of the joints and material properties have been considered as major sources of uncertainties. To reduce the uncertainties in the joints, the joint stiffnesses have been updated by using parametric optimization approach. The experimental results have been used for parametric optimization to reduce the error between experimental results and predictions of finite element models. The similar process has been used in [11–13]. Arora [14] concluded that parametric iterative optimization of finite element gives better results than direct optimization of finite element model. Subsequently it has been observed from that the experimental and corresponding updated finite element models force–displacement curves matches very well with each other. It can be concluded from the experimental updating of finite element of anchors that the updated anchor represents the reality accurately.

As the developed scaffold anchor system is deformed permanently which results in non-linear behavior, a scaffold anchor system has been redesigned to behave linearly. The loading forces used during the optimization process have been obtained from the finite element model of the tubular scaffold construction related to the Eurocode standards [15,16]. The maximum support force from the scaffold construction has been applied on the anchors finite element models and material and geometrical optimizations have been done. The updated finite element model can be used for design of the structure [17].

As the result of these investigations, the accurate finite element solid model has been created. It carries the support force within the area of linear behavior in all its parts.

## 2. The updating of finite element models of prototype anchor in the light of experimental results

After initial investigations of the scaffolding's stability, three potential shapes of the new anchor [18–20] have been developed by simple basis. Two of them – "The Lever Anchor" and "The Oblique Scaffold Anchor", showed in Figs. 2 and 3, are using innovative oblique arm. The principle of the obliquity is demonstrated in Fig. 4. As it can be observed from Fig. 4 two anchors in the horizontal plane are used for fixing, these two anchors are placed in the opposite orientation to create a notional trapezoid with the surface of the facade. The outer scaffold plane is stiffened because of the vertical *X*-bracing and the inner plane is moved in a direction parallel with the facade [7]. By using the oblique arms, the displacement of the inner plane is significantly restricted, so the scaffold stability is increased. Also the anchors provide minimum deformation in its parallel threaded bars, which are joined into the facade through an insulation layer. This type of mechanism ensures that there is no damage to the surrounding insulation. For a backup there is also "The Rigid Scaffold Anchor", see Fig. 3, which has the conventional straight arm. This shape has been developed for the case of an arm obliquity idea failure.

For the further analysis, only the "Lever anchor" is selected. The reason is that the single parts of this anchor can be adjusted in different positions, so the installation process is easier and the variability of the anchor is greater than in "The Oblique Scaffold Anchor". From the static point of view, the anchor parts "Threaded bars", "Slider" and "Span" create a rigid frame. These parts are shown in Fig. 2. Furthermore, the anchor provides a semi-rigid support along vertical axis. Thus, this paper focuses only on optimizing the value of the torsional stiffness from experiments will be handled in the next stages of the development. In this paper, for further analysis, the anchor is considered as a fixed support in horizontal plane.

After fabricating, the Lever anchor prototype, the pilot experiment on the real masonry wall has been carried out. The forces have been applied at the end of the lever arm in 4 directions as is shown in Fig. 5. These four directions represent all the possible force directions arisen during the standard load combinations [16]. The reason of this pilot experiment is to determine an optional loading direction for the first laboratory experiment and followed by finite element verification. It has been concluded that the +*Y* direction is optional, because only the tension force is applied and the interference of the buckling and imperfections is restricted. It will ensure accurate laboratory experiment set up and verification of initial FE models. The behavior of scaffold anchor system under the compressive force will be investigated in the next stages of the development.

The pictorial view of the experimental set up is shown in Fig. 6 whereas scheme diagram of the laboratory experiment is shown in Fig. 7. The anchor has been loaded continually by tension force only in vertical direction. The range of force varies from 0 to 3 kN and the displacement of the lever arm has been recorded in real time. The anchor has been loaded by the single acting hollow plunger cylinder with the one-handed pump. The cylinder has been situated on the top of the supporting steel construction made from two parallel steel columns with reversed T-shape. Tensometric pressure dynamometer has been placed between the cylinder and the upper surface of the construction, which is connected with