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Influence of wind loads on façade scaffolds covered with different types of nets

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Abstract. In the process of the structural design of the working and façade scaffolds, the self-weight of the elements, the service load and the wind load should be taken into account. The wind load on a covered façade scaffold is determined by many factors, including the wind velocity, the solidity ratio of the building's façade, the geometric characteristics of the scaffold' components and the type of cladding – netting or sheeting. The paper investigates the effects of wind loads on both types of façade scaffolding – with and without claddings. A computational finite element model was developed to study the specifics of the scaffoldings in the function of the nets permeability and the solidity ratio of the façade. Load combinations, according to the requirements in EN 12811-1, were considered to obtain the internal forces and stresses of the scaffold elements subject to wind actions. Based on the numerical analyses, it was found that the porosity and air permeability of the nets have a significant effect on the internal forces and stresses of the façade scaffolds elements, which also depend on the anchorage patterns and solidity ratio of the façade. In conclusion, recommendations are given regarding the application of specific structural schemes and anchoring patterns, depending on the permeability of the different façade scaffold nets.

1. Introduction

Working scaffolds are used primarily in the execution of various types of finishing works on buildings and facilities. Their purpose is to provide convenient platforms enabling work at higher levels while addressing fall arrest and protection against falling tools and objects. [1]. Specific requirements for scaffoldings are described in several public documents, guidelines and standards.

According to Regulation № 2 from 22.03.2004 (Bulgaria) [2], to execute construction/installation work at height using a scaffold, it should comply with the instructions from the manufacturer for installation, operation, allowable loads, dismantling and the requirements for health and safety during work. On the other hand, Regulation № 7 from 23.09.1999 (Bulgaria) [3] also stipulates that structural design for the scaffolding is to be carried out to evaluate its stability and bearing capacity should the manufacturer's documentation is missing or the intended structural configurations are not covered in the manufacturer's guidelines. The specifics of individual design solutions for scaffoldings, designed according to European standards, are discussed in many publications and monographs [4-7].

When the design of scaffolding is deemed necessary, the design should be under the requirements of EN 12811-1 [8]. According to the standard, in the structural design of working and façade scaffolds, the self-weight of the elements, the service load and the wind load should be considered. The wind load on a covered/clad façade scaffold is determined by many factors, including the wind velocity, the solidity ratio of the façade of the building, the geometric characteristics of the components of the scaffold and the type of cladding - netting or sheeting.

According to EN 12810-1 [8], the manufacturer must declare a standard set of system configurations between 24 m and 25,5 m in height for all the scaffold components as well as anchoring patterns/schemes [9]. The analysis of the standard sets of façade scaffolding configurations declared by different manufacturers shows that they provide configurations for unclad scaffoldings, scaffoldings clad with permeable nets and scaffoldings clad with impermeable sheeting, for both solid and partially open facades [10]. However, the different manufacturer configurations for scaffoldings with nets do not take into account the permeability of the possible netting options, nor the possible solidity ratios of the facades.

There are numerous papers in the literature related to wind loads on scaffoldings. An assessment of the wind action on a façade scaffolding, based on full-scale data measurements, was presented in [11]. The wind effect on clad (covered) façade scaffoldings was principally investigated, and one of the conclusions was that in general, the wind affects mainly the anchors, as this load–causes the most significant stresses in the stands (standards), located in the bottom frames and their base jacks. The results from wind tunnel experiments, based on a prototype of scaffolding covered with nonporous cladding showed that the wind pressure on the inner surfaces of scaffolding plays a crucial role in wind loads on a clad scaffolding [12]. Irtaza et al. [13] used wind tunnel test to investigate the permeability of two types of nets, called Type A and Type B, where the Type B net was made by double folding the Type A net. It was concluded that the wind forces, acting on scaffolds, transferred from the covering materials to the scaffold structure, depended mainly on the air permeability of the netting and the building. Beale [14] presented a detailed review and summary on the research of scaffold structures. Special attention was paid to the wind impact on clad façade scaffolds. The latest research on wind effect on temporary structures was analysed and discussed in detail in [15].

Some other studies also show that different types of nets, e.g. nets for covering façade scaffoldings, nets for agricultural facilities or other, exhibit different air permeability and therefore cause different wind pressures on the clad structures [16-18].

The study presented in this article aims to determine the influence of nets with different permeability accompanied by different façade solidity ratios on typical façade scaffolds configurations.

2. Materials and methods

2.1.Typical façade scaffolding configurations and load combinations

The research was done on three typical types of façade scaffolds configurations: Scheme 1, Scheme 2 and Scheme 3 (Figure 1). They resemble the configurations according to different manufacturers' schemes. Scheme 1 is recommended for unclad scaffoldings, Scheme 2 is recommended for scaffoldings clad with permeable safety nets, and Scheme 3 is recommended for scaffoldings clad with impermeable sheetings [10]. Computational FE models representing each of the three schemes were developed. Scaffold frames were modelled as frame elements with tubular cross-section ϕ48,3 with a thickness of 2,7 mm. The diagonal elements were modelled as frame elements with tubular cross-section ϕ42,2 and a thickness of 2,7 mm. The characteristic yield strength f_{yk} of the main scaffolds elements was taken as 235 N/mm^2. The scaffold platforms in the FE model were modelled as shell elements - one shell element per platform. The three scaffold schemes showing the monitored points and standards are presented in Figure 1. The denoted points and standards were chosen to represent the most loaded elements of the scaffold structure. It has to be mentioned that due to the differences in the anchoring patterns, the location of the most loaded anchor varied: the most loaded anchor in (a) is at different location compared to (b) and (c).

The calculations were performed for scaffold load class 3 according to the load combinations stated in [8], which comprise: a) Service condition, b) Out of service condition. The wind load was determined, considering the influence of the five different types of scaffolding nets, which characteristics are presented in 2.2.

Linear FE analysis was performed to determine the maximum internal forces in the most loaded elements of the scaffolding in the three schemes at different façade solidity ratios. It was considered only the wind load, perpendicular to the façade plane, acting on the clad surface of the scaffold as well as on its structural elements. The wind design was done for the territory of Sofia, Bulgaria, where the base value of the wind load is 0.43 kN/m^2 at a basic wind speed of 26.1 m/s [19].

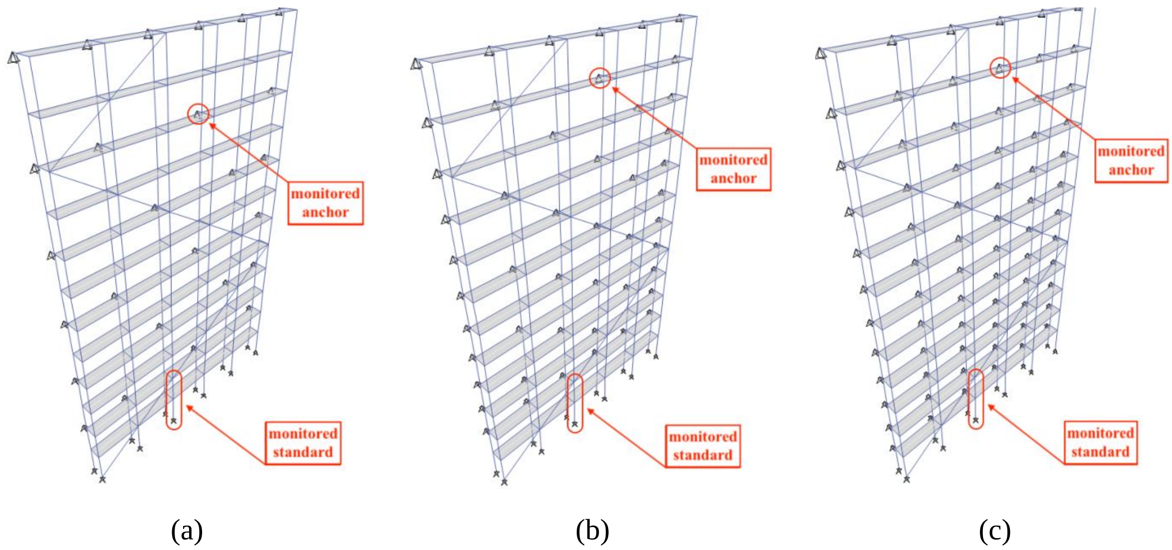
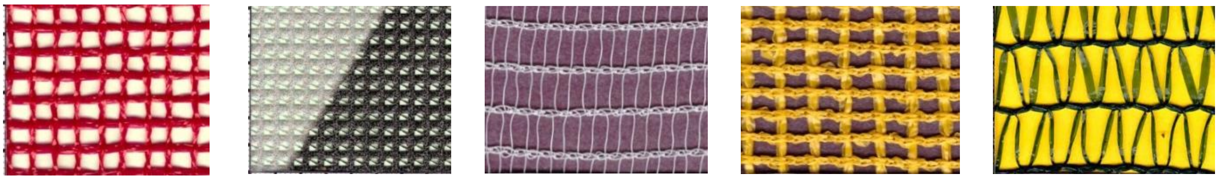


Figure 1. Static scheme of the scaffolds: (a) Scheme 1, (b) Scheme 2, (c) Scheme 3.

2.2. *Characteristics of the façade scaffold nets.*

Five types of scaffold nets were studied - type “A” (Figure 2a), type “E” (Figure 2b), type “F” (Figure 2c), type “G” (Figure 2d) and type “L” (Figure 2e). The net, type “F”, is designed to cover a façade scaffolding to protect against falling objects. The nets type “A” and “G” are mainly used during an external façade insulation installation to prevent falling object hazards, but also to protect the thermal insulation layers from the weather. The net, type “E”, is used for advertisements, which is one of the modern trends in the recent years, i.e. to utilise the available façade surfaces for commercial purposes [20]. The pressure on the nets is determined at different wind speeds using an open wind tunnel. The research methodology is presented in [21].

The porosity of the nets was determined by image analysis, using the method in [22]. The method, based on the processing of binary images, was developed for textile layers with the irregular shape of the pores. The method was successfully applied for the scaffold nets under consideration. The measured porosity (an average value of 10 single measurements) was determined as: 34.5% (net type “A”), 21.8% (net type “E”), 73.6% porosity (net type “F”), 40.2% (net type “G”), and 57.6% (net type “L”).



(a) (b) (c) (d) (e)

Figure 2. Samples of nets: (a) net type "A", (b) net type "E", (c) net type F", (d) net type "G", (e) net type "L". Images are indicative and not to scale.

3. Results and discussion

The results from the linear static FEA for determining the maximum forces and stresses in the most loaded anchors and standards of the scaffolding in Scheme 1, Scheme 2 and Scheme 3 are presented below. The study was done without cladding and with a clad with the five net types. The solidity ratio of the façades was taken into account implicitly by the site coefficient c_s [8]. The site coefficients c_s used corresponds to solidity ratios of the façade with values from 0.1 to 1. Only the results of wind acting perpendicular to the façade - from the building towards the scaffolding (suction) are given.

3.1. Influence of the porosity of the nets on the pressure drop

Figure 3 presents a comparison between the porosity and pressure drop on the nets. The results show that there is a high correlation between nets' porosity and the pressure from wind action: the value of the coefficient of determination from the linear regression equation is very high (R^2 = 0,91). Every single thread is an obstacle for the passage of the fluid, thus influencing the pressure drop between the two sides of the net. The shape and the size of the net pores, as well as the thickness of the net, could also influence the pressure drop. Further research would be dedicated to the characteristics of the nets that could influence their behavior under different wind loads.

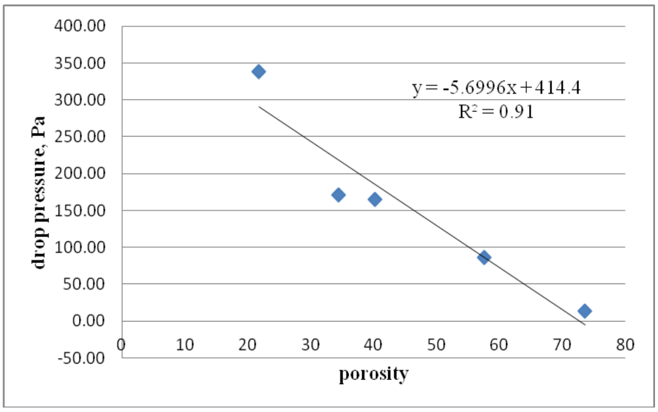
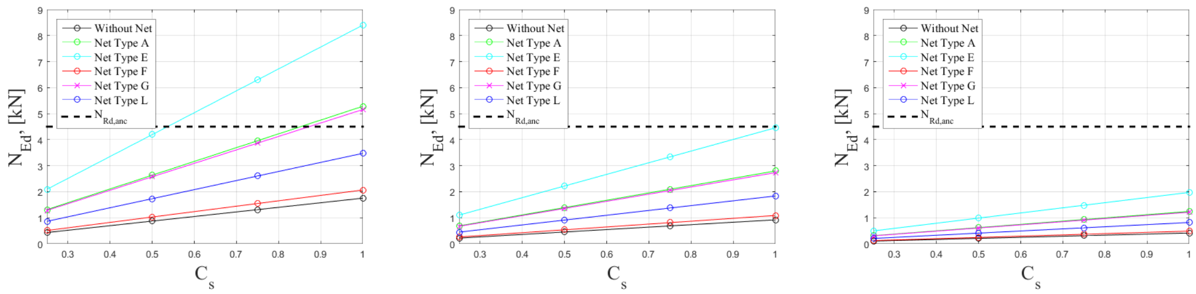


Figure 3. Relationship between porosity and pressure drop on nets at wind speed 26,1 m/s.

3.2. Internal forces in anchors at different anchoring schemes at nets with different porosity

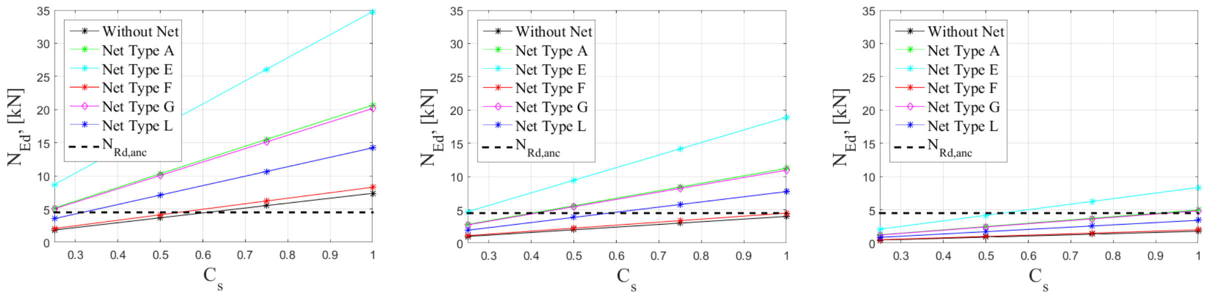
The tensile forces in the anchors are presented in Figure 4 for the most loaded anchors for each scheme for load combination a) Service condition, and in Figure 5 for load combination b) Out of service condition. It has to be noted that the most loaded anchors are different in different schemes. For the current analysis, the maximum pull-out capacity of the anchors is assumed to be 4.5 kN.

The performed analysis shows that larger forces in the anchors occur in load combination b) Out of service condition, which is caused by the higher values of the wind load. As the porosity of the nets used decreases, the tension forces in the anchors' increase. It is observed that the increment is proportional to the porosity of the nets. Also, it is apparent that when the solidity ratio of the façade increases (resulting in decreasing of the site coefficient c_s) the tension forces in the anchors decrease.



(a) (b) (c)

Figure 4. Axial tension forces in most loaded anchors in load combination a) Service condition: (a) Scheme 1, (b) Scheme 2, (c) Scheme 3.



(a) (b) (c)

Figure 5. Axial tension forces in most loaded anchors in load combination b) Out of service condition: (a) Scheme 1, (b) Scheme 2, (c) Scheme 3.

In Scheme 1 at load combination b), Out of service condition, at values of c_s bigger than 0.6, at nets type “A”, type “E” and type “G”, in the most loaded anchors tension forces are observed with values greater than 4.5 kN. With the pull-out capacity of the anchors thus assumed, a relevant reduction of the spacing between the anchors and/or application of another anchoring scheme is necessary. In Scheme 1 clad with the net with the highest porosity (net type “F”), at c_s with values up to 0,55, it was observed that lesser internal forces than the assumed allowable bearing capacity of the anchors occurred. This implies that at high values of the solidity ratio of the facades (meaning low values of the coefficient c_s), Scheme 1 can be applied only in case of using very low porosity nets. It should also be noted that even in the case of unclad scaffolding and site coefficient c_s values above 0,55, the bearing capacity of the anchors is exceeded and usage of additional anchors or anchors with higher pull-out resistance is required.

In Scheme 2, the use of a high porosity mesh does not lead to exceedance of the bearing capacity of the anchors. However, when the porosity of the nets decreases, and the coefficient c_s increases, the internal forces in the most loaded anchors have higher values than the assumed values for their bearing capacity.

In Scheme 3, the use of nets with smaller porosity and different site coefficient c_s values does not lead to exceeded pull-out resistance of the anchors. Only in the case of the net with the lowest porosity

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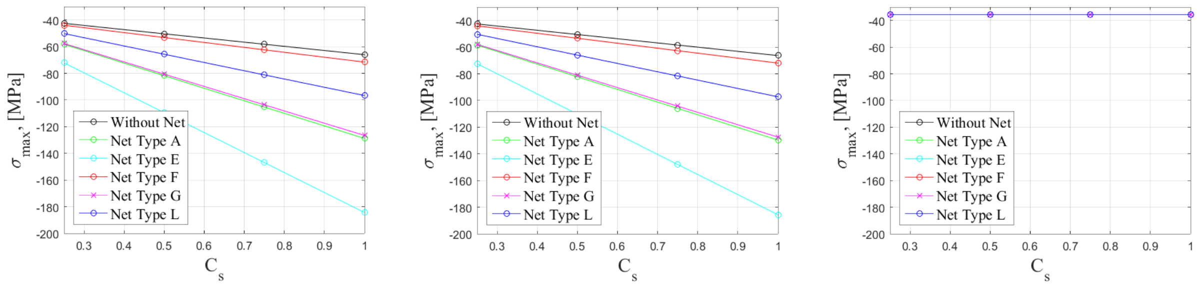
(net type "E") and at values of the coefficient c_s above 0,55, the anchors fail in tension as the forces are about twice the resistance (4,5 kN). In these cases, it is necessary either to use anchors with greater pull-out capacity or to change the structural arrangement of the scaffolding or to change its anchoring pattern. Combinations of the listed measures are also possible, which is considered as a good engineering practice.

The use of different nets with different porosity for claddings leads to an increase in the forces in the anchors compared to the forces in an unclad scaffolding, as follows: in Scheme 1 – an increase from 12,5 % (for net type "F") up to 373,2 % (for net type "E"); in Scheme 2 – an increase from 12,4 % (for net type "F") up to 376,7 % (for net type "E") and in Scheme 1 – an increase from 12,4 % (for net type "F") up to 373,7 % (for net type "E). In general, it can be concluded that several factors have a significant adverse impact on the anchor forces induced by wind loads: namely the anchoring scheme, the solidity ratio of the façade, the net porosity and the air permeability related to it.

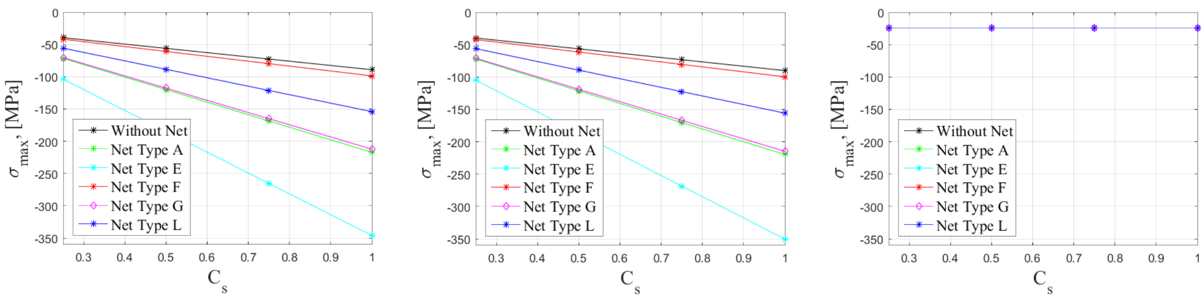
3.3 Stresses in the vertical standards at the different schemes clad with nets with different porosity

Figures 6 and 7 show the compressive stress range in the most loaded standards denoted in Figure 1. Load combination a), Service condition, proves to lead to the highest values of compression stresses in the vertical standards. When determining those stresses in the standards, it turned out that in Scheme 1 and Scheme 2, not only the normal forces but the bending moments in the plane perpendicular to the façade increased as well.



(a) (b) (c)

Figure 6. Maximum normal stress (compression) in most loaded standards in load combination a) Service condition: (a) Scheme 1, (b) Scheme 2, (c) Scheme 3.



(a) (b) (c)

Figure 7. Maximum normal stress (compression) in most loaded standards in load combination b) Out of service condition: (a) Scheme 1, (b) Scheme 2, (c) Scheme 3.

In Scheme 1 and Scheme 2, it is also evident that when the porosity of the net decreases, the stresses in the vertical scaffold standards increase, but the values remain the same in both schemes. Normal stresses rise significantly at nets with low porosity and at high values of the coefficient c_s.

In Scheme 1 and Scheme 2, the use of nets with lower porosity (e.g. nets type "F" and type "L") results in stresses, which are lower than the admissible ones for the chosen steel grade. However, when using nets with low porosity and lower values of the solidity ratio of the facades, the observed stresses in the scaffolding standards could happen to be higher than the admissible ones. This can be easily noticed at the nets with low porosity, e.g. nets similar to type "E". It is observed that the smaller the porosity of the nets is, the greater the increase in stresses becomes. The use of different nets with lower porosity for scaffold cladding leads to a stress increase in the standards compared to those in the unclad scaffoldings, as follows: in Scheme 1 – the increase varies from 6 % (for net type "F", and C_s = 0,25) up to 288 % (for net type "E", and C_s = 1,0); in Scheme 2 – the increase varies from 6,1 % (for net type "F", and C_s = 0,25) up to 288,8 % (for net type "E", and C_s = 1,0).

In Scheme 3, the permeability of the nets does not lead to a change in the forces in the vertical load-bearing members of the scaffolding (standards), regardless of the values of the site coefficient c_s. The main reason for this is that all anchoring pipes are connected to every scaffolding node and thus in the vertical standards bending moments do not occur, which normally would increase the normal stresses in them.

It can be concluded that the porosity of the façade scaffolding nets affects both the forces in the anchors and the stresses in the scaffolding standards.

4. Conclusions

This paper presents a study of the influence of nets with different porosity on the elements of three types of schemes for façade scaffoldings with a height of 24 m. Scheme 1 is recommended for unclad scaffoldings, Scheme 2 is recommended for scaffoldings clad with permeable safety nets, and Scheme 3 is recommended for scaffoldings clad with impermeable sheetings. The results of the static linear elastic finite element analyses were used for determining the internal forces and stresses of the most loaded elements of the scaffolding – the anchors and the vertical standards.

For the façade scaffold nets used in the present study, the relationship between their porosity and the imposed wind load was established. The analysis of the different types of façade scaffold nets shows that there is a high correlation between the porosity of the nets and the imposed wind loads associated with them. However, further research is needed to take into account all the nets' characteristics that affect their air permeability and thereof the wind loads on the scaffold.

It was found that the use of nets with lower porosity leads to an increase in the anchors' forces regardless of the adopted anchoring scheme. Nets with lower porosity also lead to an increase in stresses in the scaffold standards in Scheme 1 and Scheme 2. The internal forces in the scaffolding elements are particularly large when using nets with low porosity and low values of the solidity ratios of the façade.

In general, it can be concluded that several factors have a significant impact on the internal forces and stresses in the scaffold elements under wind load conditions. Those comprise the anchoring pattern scheme, the solidity ratio of the façade, the net porosity and the air permeability related to it.

As a result of the conclusions and findings of the study, the authors recommend not to apply the manufacturers' schemes for anchoring directly, but to prepare structural design project for the implementation of the façade scaffolding.

References

[1] Kirov N 2006 *Formwork and Scaffolds* (Sofia: Daniel SG) p 30.
[2] Regulation No. 2 of 22.03.2004 for minimum requirements on health and safety during construction and mounting work, Official Journal 2004, No. 37, item 87, 2004 (in Bulgarian).
[3] Regulation No. 7 of 23.09.1999 for minimum requirements on health and safety on working places and with use of working equipment, Official Journal 1999, No. 89, item 215, 1989 (in

IOP Conf. Series: Materials Science and Engineering **951** (2020) 012024 doi:10.1088/1757-899X/951/1/012024

Bulgarian).
[4] Błazik-Borowa E and Pieńko M 2017 *Scaffoldings* (Lublin: Lublin University of Technology) pp 73-108.
[5] Robak A, Pieńko M and Błazik-Borowa E 2015 Civ. Env. Eng. Rep. **18** 3 115-120.
[6] Kuzhin M and Kuzhin B 2016 MATEC Web of Conferences **86** 07007.
[7] Hrischev L and Slavchev V 2018 *Annu. Univ. Archit. Civ. Eng. Geod.* **51** 10 29–44.
[8] EN 12811-1 Temporary works equipment. Part 1: Scaffolds - Performance requirements and general design.
[9] EN 12810-1 Façade scaffolds made of prefabricated components. Part 1: Product specifications.
[10] Hrischev L, Dinev D and Tepeliev V 2018 *Proc. 10th Jub. Int. Conf. Civ. Eng. Design and Constr.* Varna pp 136-145.
[11] Lipecki T, Jamińska-Gadomska P, Bec J and Błazik-Borowa E 2020 *Arch. Civ. Mech. Eng.* **20:27** 1–15.
[12] Wang F, Tamura Y and Yoshida A. 2013 *Wind Eng. Ind. Aerodyn*. **120** 37–50.
[13] Irtaza H, Beale R, Godley M and Jameel A 2014 *IOSR J. Mech. Civ. Eng.* **4** 54-62.
[14] Beale R. 2014 J Constr Steel Res **98** 188–200.
[15] Beale R and Andre J 2017 Design Solutions and Innovations in Temporary Structures (Hershey: IGI Global) 52-124.
[16] Agarwal A and Irtaza H 2018 *J. Inst. Eng. India Ser. A* **99** 2 311–320.
[17] Castellano S, Starace G, De Pascalis L, Lippolis M and Mugnozza G 2016 *Biosyst. Eng.* **150** 131-141.
[18] Briassoulis D, Mistriotis A and Giannoulis A 2010 J. *Wind Eng. Ind. Aerodyn.* **98** 919–928.
[19] EN1991-1-4/NA Eurocode 1: Actions on structures - Part 1-4: General actions-Wind actions/ National annex.
[20] Ivanova E and Boyadzhieva D 2020 Proc. of Int. Scient. Conf. Tech. Techn. Educ. Saf. Borovets **1** 38-41.
[21] Hrischev L, Markov D, Tepeliev V and Dinev D 2019 *Annu. Univ. Archit. Civ. Eng. Geod.* **52** 3 929–943.
[22] Angelova R 2020 *C. R. Acad. Bulg. Sci.* **73** 1 96-102.