

Safety Conditions Analysis of Scaffolding on Construction Sites

M. Pieko, A. Robak, E. Błazik-Borowa, J. Szer

Abstract—This paper presents the results of analysis of 100 full-scale scaffolding structures in terms of compliance with legal acts and safety of use. In 2016 and 2017, authors examined scaffolds in Poland located at buildings which were at construction or renovation stage. The basic elements affecting the safety of scaffolding use such as anchors, supports, platforms, guardrails and toe-boards have been taken into account. All of these elements were checked in each of considered scaffolding. Based on the analyzed scaffoldings, the most common errors concerning assembly process and use of scaffolding were collected. Legal acts on the scaffoldings are not always clear, and this causes many issues. In practice, people realize how dangerous the use of incomplete scaffolds is only when the accident occurs. Despite the fact that the scaffolding should ensure the safety of its users, most accidents on construction sites are caused by fall from a height.

Keywords—Façade scaffolds, load capacity, practice, safety of people.

I. INTRODUCTION

SCAFFOLDING is a structure whose main purpose is to allow work at height while providing the safety of its users. Unfortunately, the safety of people is usually highly neglected, which leads to accidents or construction disasters resulting in deaths or substantial material losses. In spite of a number of regulations which define the rules of assembly and use of scaffolds, in many cases, the quality of the real scaffolding structure differs from the requirements. Because of their temporary nature, scaffoldings are treated as a secondary structure; therefore, the attention which is paid to them is not sufficient. Falls from height are the largest number of accidents on construction sites. The authors decided to carry out research on the full-scale scaffoldings located in Poland to develop the model of risk assessment of accidents and dangerous incidents at workplaces using scaffoldings. This type of survey was carried out in Spain [1] and in the United States [2]. The safety of scaffolding, as well as methods of preventing construction disasters, is an increasingly frequent topic of scientific work [3], [4]. Also, methods of monitoring scaffoldings used as support structures of the formwork [5], have been developed to alert users of potential hazards.

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Structures with complex shapes require an individual approach to their design. Proper design of the structure requires detailed knowledge of the load capacity of the individual components and the working conditions of the joints [6], [7]. Repeated use of the same components leads to their deformations and local damages. The best way to determine the scale as well as the frequency of occurrence is to study full-scale scaffoldings directly on construction sites. This approach allows to obtain reliable results showing the actual state of the scaffolding. This paper presents the abnormalities in scaffolds assembling and usage that were found during the studies of 100 scaffold structures located in Poland.

II. METHODOLOGY OF RESEARCH

Five teams consisting of employees of the Lublin University of Technology, Lodz University of Technology and Wrocław University of Science and Technology conducted research in the Polish provinces indicated in Fig. 1. The study covered three research areas: 1. research in the archives of national institutions concerning accidents at work on height; 2. counting scaffolds in selected areas and cities; 3. inventorying of scaffolds and measurements of physiological parameters of employees and working environment conditions. Because the scope of the research was very extensive and included many factors affecting safety at workplaces while using scaffoldings, this article describes only the part of research conducted directly on the construction sites.



Fig. 1 Polish map with the regions of measurements

This part of studies included detailed inventory of scaffolding such as local damages, operational loads and

imperfections measured using total station. Environmental parameters such as light intensity, sound intensity, wind speed, pressure, humidity and temperature were also measured. Measurements were made for each scaffold for five consecutive days at three-hour intervals, at measurement points evenly distributed on the scaffold. The parameters of soil bearing capacity, measurements of load capacity of anchors and pressure applied on the ground by scaffolding stands were also determined. In addition, measurements of physiological parameters of employees were carried out together with surveys and general information about the scaffolding. Since scaffolds can be made from different systems and materials, the tests are limited to single plane scaffolding made from steel facade systems. The scaffolds were selected based on the location according to the areas shown in Fig. 1 and after obtaining permission to conduct the research from companies using scaffoldings. In addition, each of the research teams carried out five surveys on scaffolds with areas in the range of: 50-300 m², 300-600 m², 600-900 m² and at least two scaffoldings over 900 m². The remaining scaffolds were selected on the basis of their availability. Each team was trained on the principles of the measurements as well as how they were archived, so that they could be compared to each other.

III. ASSEMBLY AND USAGE ERRORS

The main task of scaffolding is to ensure the safety of its users during work at height. The level of safety depends on many factors, including legal, social, economic, environmental, technical, organizational and human factors. In this paper, only technical factors are discussed. This group of factors is especially important because it has a direct impact on the load bearing capacity of the scaffolding and therefore the possibility of failure.

A. Supports

The quality of the scaffolding support depends on the condition of the soil substrate. Scaffolding in many cases is placed on pavement or concrete. Such type of support guarantees that the frame will not subside. If the scaffold is planned to be set directly on the ground it should be leveled and compacted earlier. The research shows that ground substrate is usually not properly prepared, especially not compacted. When the scaffold was placed on ground, the quotient of the minimum value to the maximum compressibility modulus was in the range of 0.1 to 0.75. Such differences in soil compaction result in very large differences in subsidence between each scaffold frameworks. Normally structure of a scaffolding is not sensitive to such differences because of looseness in connections between elements. But, if the scaffold has bracing, differences in subsidence of stands placed on two separate base plates, lead to suspension of the frame on the other frame. Fig. 2 shows examples of errors in scaffolding supports. The extreme case is the situation shown in Fig. 2 (a). The 54-m high scaffolding was set on a base plate put out beyond the concrete ceiling of the underground garage. We can see strained base plate. Such a situation can

result in a complete loss of supports thus leading to collapse of the construction. The set of base plate depicted in Fig. 2 (b), in which the scaffold is supported, looks quite stable, but the individual elements can move without guaranteeing the transfer of horizontal forces. In the situation illustrated in Fig. 2 (c), due to vibration caused by machines operating in the immediate vicinity of the structure, a landslide can occur. The ground substrates have not been prepared in any way and have not been profiled to discharge rainwater. The situation shown in Fig. 2 (d) seems to be appropriate, however, due to differences in the levels between the curb and the pavement, the base jack is based on a very small surface that does not provide the load transfer.



Fig. 2 Errors in scaffolding supports; (a) strained mudsill, (b) multi-level wooden mudsills, (c) unstable substrate, (d) base jack without support

B. Anchors

Anchors are the one of the most important elements on which stability of scaffolding is dependent. According to the norms, the scaffolding should be anchored vertically every 4 m and horizontally around every second frame joint. In practice, the implementation of these recommendations is very difficult, as anchoring cannot be made in the vicinity of

windows, in many cladding materials and in hollow spaces of skeletal structural systems. Problems with anchoring according to standard requirements also apply to historic buildings [8], [9] for which the number of drills that can be made in structure is limited to the minimum or completely forbidden. As a result of the fact that the area of building façade where the anchors can be placed is limited, they are often mounted to the stands at a considerable distance from the platforms as shown in Fig. 3. This way of anchoring causes bending moments in the vertical stands, which increase stresses and reduce stability of structure. Scaffolding with an unusual anchor system should always be checked by static-strength calculations. The task of anchoring is to transfer the perpendicular to the façade load caused by wind, especially in the case of clad scaffoldings [10], [11].

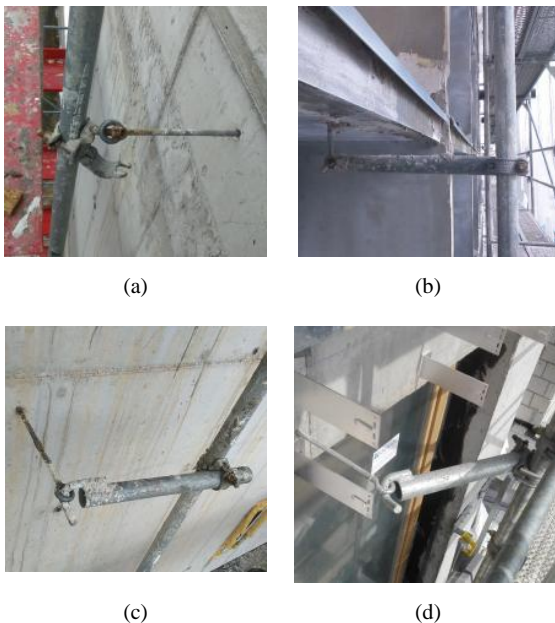


Fig. 3 Errors in anchorage; (a) long anchor, (b)-(d) lack of collinearity

Capacity of anchor system should be higher than forces caused by the wind. Limit values are given in the scaffolding technical documentation for the anchor system. The teams tested the anchoring force of the anchors on the construction sites using the BUK-02p dynamometer. The test results show that the anchoring force depends primarily on the material in which it is mounted. A common mistake in anchoring is the use of very long anchors to pass by (leave the space for) insulation layer Fig. 3 (a) or not collinear attachment of the scaffold screw and tie member as shown in Fig. 3 (b-d). Unfortunately, such anchors do not fulfill their role of blocking the horizontal movement of the frame. Scaffolding with such system of anchoring is also sensitive to all kinds of dynamic loads, e.g. induced by wind or workers moving around the platforms. These loads can cause the discomfort of the scaffolding users.

C. Guardrails

The elements which have a direct impact on safety of the scaffold workers are guardrails. The task of the guardrails is to prevent the possibility of going outside platform edge and falling. Most of the tested scaffolds had two external guardrails at high 0.5 m and 1.0 m above the platforms. Unfortunately, their quality does not always ensure safety. In many tested cases, the guardrails were bent both in plane and out of scaffolding plane as shown in Fig. 4 (a). The permanent dismantling of the guardrails in the area of transport was common. Particularly dangerous situations are shown in Figs. 4 (b) and (c) where guardrails have not been assembled correctly. Unfortunately, the presented assembly method can cause a more dangerous situation than the total absence of a guardrail because it creates a false sense of safety. The user thinks that in a dangerous situation the guardrail will stop him/her from falling. The safety standards on scaffoldings are even often neglected concerning the lack of internal guardrails. In accordance with the Polish requirements for scaffolding, in the case when distance between the wall and scaffold is more than 20 cm, the internal guardrails should be used in addition to the external ones. In the case of small scaffolds in the range of 50-300 m², this requirement has always been ignored. Even if they were assembled, the users of scaffolding dismantled them justifying it by the need of work zone. Not all scaffolding systems are suitable for quick assembly of internal guardrails (no handles inside), what makes it more time-consuming and entails additional costs.

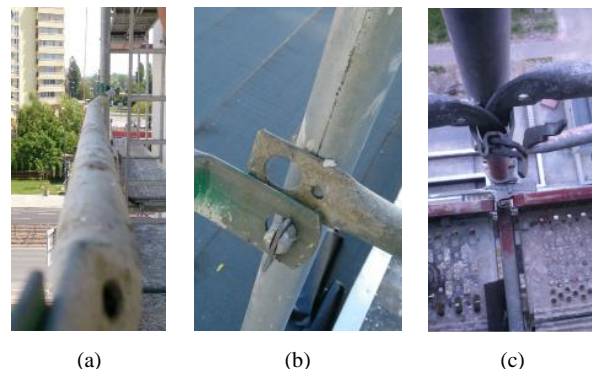


Fig. 4 Errors in guardrails; (a) bent guardrail, (b) incorrect assembly (c) damaged railing coupling

D. Imperfections

The problem of inaccurate assembly, which results in the turnover and displacement of frames on their connections, in this work is being called imperfections. In the study [12], imperfections of frame up to 4 cm were analyzed. It has been confirmed that imperfections in the case of a typical scaffold can cause decrease of the load capacity due to bending of the scaffolding components which are not adapted to this. In addition to the increase in normal stresses in the bent elements, another negative effect is the eccentric load. The problem of eccentric loading of the scaffolding structure, in detail, has been described in study [13]. Additionally, if the

scaffolding is set on separate mudsills, the frames are loaded differently due to differences in subsidence. Therefore, it seems that the problem of inaccuracies in scaffolding assembly has the greatest impact to stability of scaffolding, especially since the authors research shows that the imperfections in the scaffolding can significantly exceed 15 cm. Imperfections were measured using total station and magnetic markers (adapted to the diameter of the stands pipe), applied to each node of scaffolding. The test station layout is shown in Fig. 5 (a).

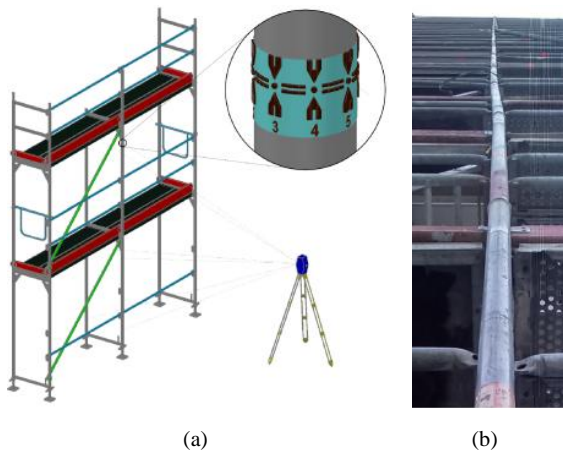


Fig. 5 Imperfections; (a) scheme of measurements, (b) sample of real imperfections

The measurement procedure and its accuracy were described in [14]. The results of the measurements and the special program written for the project allowed to create a numerical model of the scaffold including the imperfections in three directions and define their influence on the load capacity of the scaffolding structure. The study of real imperfections occurring in the construction of scaffolds and analysis of their influence on the load carrying capacity of the structure was also carried out in work [15], but imperfections were measured using special device instrumented with a dial gauge adapted to the support scaffold systems.

E. Local Damages

Another factor which determines the functionality of the scaffolding is the technical condition of the used elements. Fig. 6 shows examples of defects which affect the load capacity of the structure and reduce the safety of the scaffolding users. Fig. 6 (a) presents lack of a step in the ladder used for communication between the various scaffold levels. It is dangerous situation because during the descent from the scaffold the user may do not see the missing ladder step and can instinctively place the leg at this level. Damages that reduce the load capacity of the scaffolding are: bent bracings, bent or even cut lower cross pieces of the frame, cut gusset plate of the frame (Fig. 6 (b)), damage and corrosion within support of steel (Fig. 6 (c)) or destroyed plywood platform (Fig. 6 (d)). Platforms are scaffolding elements in the worst technical condition. During the research, it was found

that most of the decks were damaged and their role in creating horizontal stiffness was not fulfilled. Besides the direct influence on the carrying capacity of the scaffolding, damaged platforms undergo higher deflection so the workers using them feel discomfort.

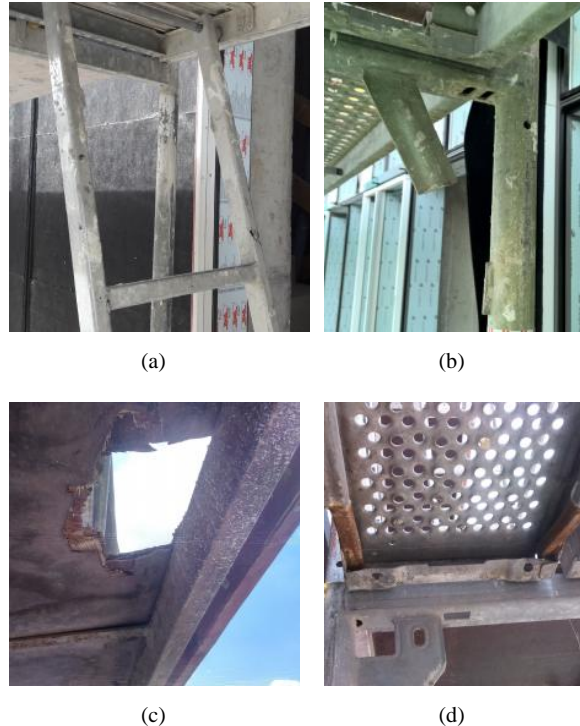


Fig. 6 Local damages; (a) no ladder step, (b) gusset plate, (c) destroyed plywood platform, (d) damage and corrosion within support of steel platform

F. Usage

Proper use and loading of the scaffolding structure are another aspect which directly affects safety of its users. The scaffolding shown in Fig. 7 (a) satisfies the constructional requirements as well as the safety requirements associated with the installation of the internal guardrails; however, the worker stands directly on the inner rail, causing a load to which the component is not adjusted and may be damaged. In addition, the person leans over the scaffolding, exposing himself to falling from a height. The unacceptable use of the guardrails is also shown in Fig. 7 (d). The employee sat down on the outer railing, causing its excessive flexion. In the situation shown in Fig. 7 (b), the pipes used for pumping concrete or parget are suspended on the scaffold. The dynamic load caused by these pipes and may loosen screw joints in the scaffolding. The typical anchoring system is not adapted to this type of load and therefore the stability of the entire structure may be compromised. Additionally, scaffolding users may feel discomfort caused by this type of load. A dangerous situation for people on the scaffolding as well as those working at its vicinity is shown in Fig. 7 (c). Vertical transport is carried out by a non-system jib mounted on a scaffolding with a single coupling. Attaching the material to

the jib results in large bending moments in coupling which may lead to its destruction and fall of the materials on the ground. This is an especially dangerous situation when we transport material down. Presented solution does not allow the jib to rotate around the axis of vertical pipe, as it is in the case with system solutions. Therefore, the person receiving or attaching material to the rope must lean over the scaffolding and also in such a dangerous position pick it up.

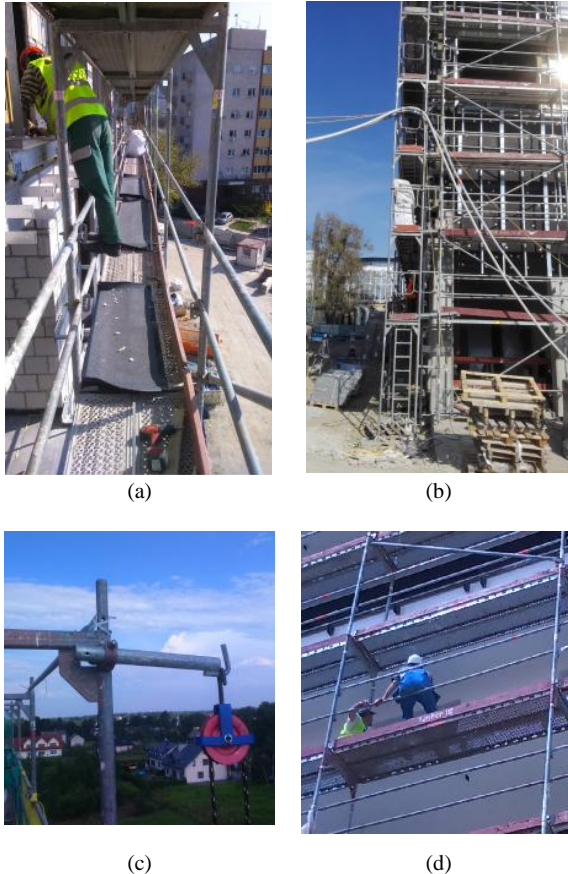


Fig. 7 Improper use of scaffolding: (a) standing on railing, (b) attaching pressure hoses to scaffolding, (c) makeshift jib, (d) sitting on railing

If the frame on which the makeshift jib has been mounted has not been additionally anchored, it may be overloaded as it was in the situation described in article [16]. The frame was not additionally anchored during the dismantling of the scaffold. The frame with jib was overloaded and the vertical connecting pin of frame broke off. Unfortunately, a broken frame pulled out a worker from the scaffolding, causing a fall from the tenth floor and death on the spot.

IV. CONCLUSIONS

The conducted research provides information on the real technical condition of scaffolding structures used in Poland. Fig. 8 presents the scheme of the interdependence between quality and safety of use. Scaffolds used for small investments

are in the worst technical condition because they are most often assembled directly by contractors' employees rather than by professional companies.

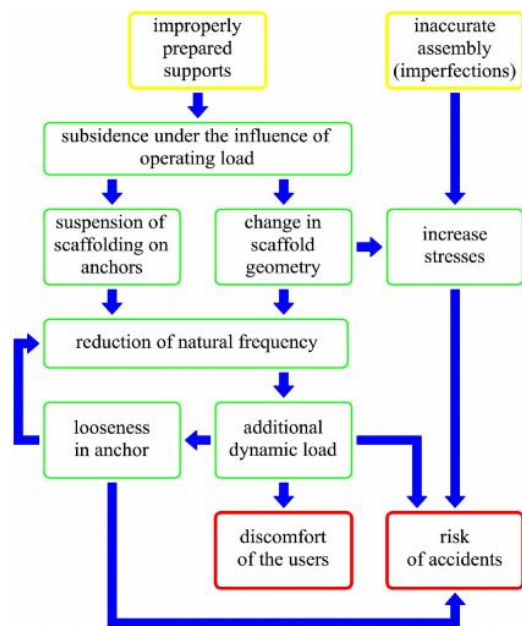


Fig. 8 Scheme of the interdependence between quality and safety of use

The obtained results will be used in numerical analyses of static strength of scaffoldings in further parts of project. Complex scaffolding structures require good collaboration between the three entities: designers, scaffolds erectors, and users. Only in this case the basic qualities of scaffoldings: capacity, safety and comfort of use would be fulfilled.

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