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Analysis of Exploitation Damages of the Frame Scaffolding

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Abstract. The analyzes and classifications presented in the article were based on the research carried out in the years 2016 to 2018 on a group of over one hundred scaffoldings assembled and used on construction sites in different parts of Poland. During scaffolding selection process efforts were made to maintain diversification in terms of parameters such as scaffolding size, investment size, type of investment, location and nature of conducted 5works. This resulted in the research being carried out on scaffoldings used for church renovation in a small town or attached to the facades of classic apartment blocks, as well as on scaffoldings used during construction of skyscrapers or facilities of the largest power plants. This variety allows to formulate general conclusions about the technical condition of used frame scaffoldings. Exploitation damages of the frame scaffolding elements were divided into three groups. The first group includes damages to the main structural components, which reduce the strength of the scaffolding elements and hence the whole structure. The qualitative analysis of these damages was made based on numerical models that take into account the geometry of the damage and based on computational nonlinear static analyzes. The second group focuses on exploitation damages such as the lack of a pin on the guardrail bolt which may cause an imminent threat to people using scaffolding. These are local damages that do not affect the bearing capacity and stability of the whole structure but are very important for safe use. The last group consider damages that reduce only aesthetic values and do not have direct impact on bearing capacity and safety of use. Apart from qualitative analyzes the article will present quantitative analyzes showing how frequently given type of damage occurs.

1 Introduction

Scaffoldings are present at almost every stage of the investment process in construction business. At present, system scaffoldings are the absolute majority of the assortment used at construction sites, i.e. the ones made of prefabricated elements in which the dimensions of the main structural grid are unambiguously imposed.

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Of all types of scaffoldings, one can identify those that play a leading role. In Poland, such are certainly frame scaffoldings that owe their popularity and widespread use to simplicity and speed of assembly and other economic factors. Fig. 1 shows an exemplary structure made of elements of a scaffolding framework system in a classic application, i.e. used as working scaffolding during the finishing of the outer facade of a residential building.

Fig. 1. Frame scaffolding.

In this study, all analyzes will be carried out on the elements of the scaffolding framework system. Scaffoldings made of frame system components are most often used as the ones, whose basic function is to provide a safe workplace and a safe access, according to the work being done [1]. The presented research is part of a project implemented by a consortium of research units from Poland, whose aim is to develop a model for assessing the risk of a disaster or a dangerous situation during works using construction scaffoldings. All data presented was obtained based on an inventory of real structures during its operation. The research was carried out in various regions throughout almost all of Poland and selected research results were presented in such works as [6, 7, 8, 9, 10]. Such a research was also a subject of scientific research of teams from Spain [2] and USA [3]. During the implementation of own tests, it was clearly stated that the elements used to create scaffold structures usually have damage. Scaffoldings, due to the basic requirements set for them, protect people's safety, which is something extremely valuable and special attention should be paid to it during the implementation of each undertaking. Therefore, it is necessary to check whether it is acceptable to use items with damage conditionally and in which situations it is possible.

Damage to the scaffolding can arise due to local overload caused by unevenness of the designed load. However, it seems that damage is more often caused by the occurrence of an exceptional load occurring during the scaffolding operation. Scaffoldings at construction sites are often located near temporary communication routes, which is associated with the risk of being hit by vehicles. Another threat of this type is heavy construction equipment that performs tasks near the scaffolding or a fall from the height of objects of considerable weight. These are of course incidental events and it is difficult to predict the magnitude of such a loading. Unfortunately, in such a case, even if there is no failure of the whole structure, single elements usually have permanent damage. Another factor that has a very large impact on the technical condition of scaffolding elements is their usage as temporary structures. This results in a frequent assembly and disassembly process, in some cases even every few days. During these processes, connections between elements are particularly vulnerable to damage. Damage also occurs during transport and accompanying loading and unloading of scaffolding elements.

2 Methodology of Acquiring Data for Analysis

Inventory of damage to scaffolding elements was one of many tasks carried out by the research teams involved in the project. Since scaffolding tests at the construction site were carried out by different teams from different scientific centers, and additionally even within one team, tasks were not rigidly assigned to specific people, there was a need to develop instructions and guidelines according to which this task should be carried out. So, evaluation sheets were created allowing the intuitive implementation of the task by each member of the research team. The created guidelines systematize the collected data and allow the compilation of all collected data and more detailed analysis regarding the assessment of the technical condition of scaffolds in use. The basis of the instructions was the recognition of four groups of elements. This partition suggested the importance of individual scaffolding elements, which resulted in greater precision in the finding and determination of defects in those elements in which they can be of the greatest importance. It is obvious that, apart from the type of damage, its size is a very important factor. One of the basic guidelines when collecting data was that the damage should be visible to the bear eye, that is, its occurrence can be determined without the use of any measuring instruments. In the work [4], the example of damage to the steel frame scaffolding in the form of bending the stand was demonstrated. A series of numerical simulations and laboratory experiments were conducted to show that the damage in some initial size ranges has negligible influence on the load and static work of the element. It seems that considering defects of small size or extent in quantitative research could lead to distortions and formulating improper conclusions. Therefore, it was decided that the inventory would be subject to only damage of size that could have a significant impact on the load capacity of the structure and the safety of its use.

The first group of elements in which damage was searched consisted of “steel frames”. Steel frame is the scaffolding main structural element consisting of two standards, i.e. vertical elements and horizontal beams connecting them. The standards are made of a tube with a diameter of 48.3 mm with a length of 2 m and this is an absolute world standard. However, when it comes to the remaining elements forming the frame, you can already notice significant differences depending on the manufacturer both in the profiles used and in the methods of shaping the nodes connecting these elements. According to the created guidelines, within the steel frames particular attention should be paid to damage to the frame standards. According to the scheme shown in Fig. 2, the measured values were: deflection of the standard in the frame plane indicated as A, deflection of the standard from the frame plane indicated as B and deformation of the cross-section of the standard tube (dent) indicated as C.

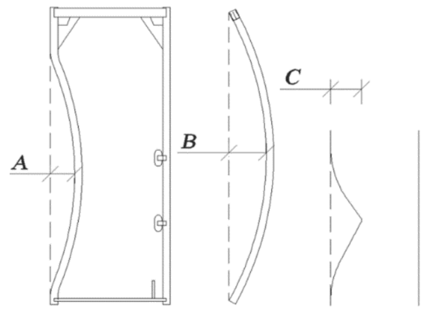


Fig. 2. Damage scheme of the steel frame standard.

Next, damages in the form of corrosion as well as cracks and material discontinuities of both, profiles and welded joints, were specified. Then, it was necessary to pay attention to the integrity of the frame, mainly in terms of elements such as pivots or bolts fixing other elements to the frame. The last column in the damage inventory sheet of the steel frames was “other damage”. All the damage noted, in addition to the description with dimensions, was documented by an illustrative photograph.

The second group consisted of decks. There are two basic types of decks in frame scaffolding. Their basic difference is the material from which they are made. We distinguish decks made entirely of metal perforated cold bent sheets and timber decks with metal fittings to a frame. Of course, such a different construction of individual types of decks determines the formation of completely different damages. Nevertheless, in both cases the first parameter to check was whether platforms had permanent plastic deformations which caused deflection of the longitudinal axis of the platform. This damage is schematically shown in Fig. 3, where the magnitude of this damage in the inventory sheet was determined as A. The other two measured parameters B and C concerned only steel platforms. These are the magnitudes of permanent plastic deformation of the cross-sections of platforms.

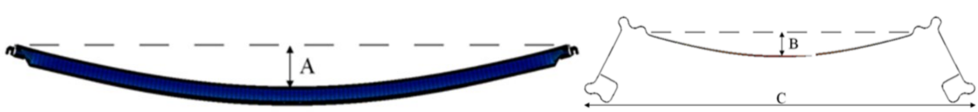


Fig. 3. Damage of decks.

Next, as in the case of steel frames, damage in the form of corrosion, as well as cracks and material discontinuities were distinguished. Additionally, the column for undefined damage was introduced, which in the opinion of the persons conducting the research, has a significant impact on the element behavior.

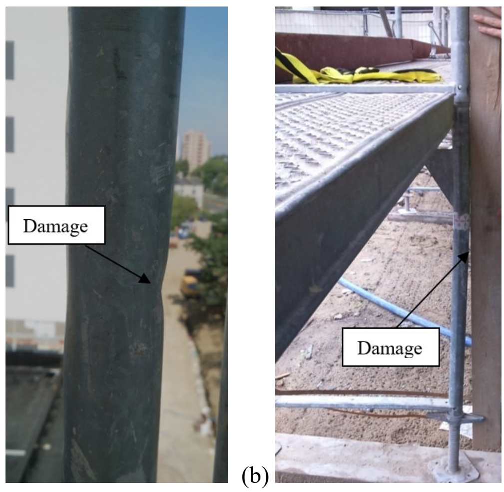
The third group included bracings and handrails. They were placed there together because of the similarity in construction. In all systems, both elements are made of a pipe, and they differ in their ends which are connected to the frame. Similarly to the previous groups, special attention is paid in the inventory sheet to the curvature of the element's axis both in the plane and from the scaffolding plane, and subsequently to: corrosion, cracks, integrity of connections, and other visible damages.

In the first three groups, the entire of main and most numerous groups of frame scaffolding elements were included. In the fourth one there were included “other elements”. The other elements usually complement the system and are definitely less numerous. In addition, in the systems of different manufacturers they may have very often different construction and shapes. This causes the lack of possibility to define characteristic damages for elements of this group, therefore in this group general recommendations were made, and each instance of damage was individually described.

3 Classification of damage

In all of the mentioned groups in the previous chapter, individual defects that have been identified on a given type of elements may have different effects on its properties. Therefore, a classification was also developed in which the significance of a given type of damage to scaffolding elements is indicated. Within this classification, three groups were specified.
The first group consists of damages which cause the threat of lowering the bearing capacity of the entire structure. In consequence this can lead to a structural disaster.

The most dangerous ones are the ones to the frame standards as the basic load-bearing elements. It should be noted that during the use of scaffoldings the standards are the most often elements with the greatest effort. In the research, a very large variety of damages in the steel frame was shown. This is due to the fact that the scaffolding elements a rebuilt of several different sections and complementary elements.



(a) (b)

Fig. 4. Damage of steel frame standard: (a) point indentation, (b) deflection of the standard axis.

The damage to the frame standards in the form of deformation of the pipe cross-section as a result of dynamic external action (point indentation) shown in Fig. 4 (a) was included in the first discussed group. Another damage of this type is the curvature of the pipe axis which is shown in Fig. 4 (b). It is worth mention that if the first type of damage occurs far from the nodal point then the second type occurs simultaneously. A similar phenomenon is described in [5]. In this situation, the adverse effects affecting the load-bearing capacity of the structure are reinforced. Another basic element in which damage can be extremely dangerous is vertical bracing. Vertical braces are made of smooth pipes and between the various systems differ only in the shape and type of mountings located at their ends. The defects classified in the first group identified in bracings are in most cases identical to those observed on the frame standards. Mainly we deal with the deflection of the axis of the bracing tube as well as with spot deformations. Frame standards have a fixed length of 2 m. The connections in the frame between vertical and horizontal elements are very often shaped with use of large gusset plates, which reduces the buckling length. In contrast, bracing pipes in the most commonly used modules typically have a length of approx. 3.5 m and are not reinforced in any way. Moreover, in many systems, the bracings are made of pipes of smaller diameter than the frames standards. All this causes that these elements are slenderer and more due to it are much more exposed to mechanical damage, e.g. during transport. Fig. 5 (a) shows the bracing at which two bends in one plane are seen in two opposite directions.

This is most likely caused by an attempt to “straighten” the element which had a very large damage obstructing assembly.

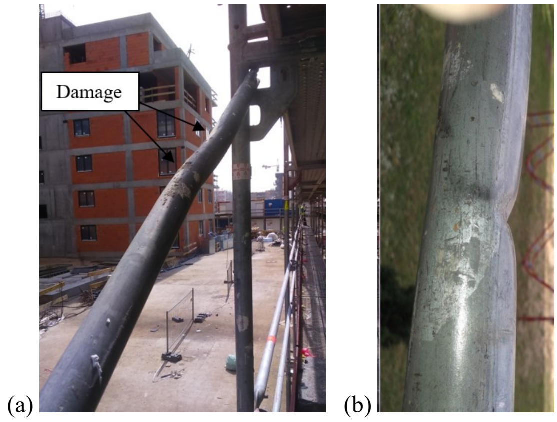


Fig. 5. Damage of vertical bracing: (a) deflection of pipe axis, (b) point indentation.

Interestingly, no other types of damage were noted in concentrations. In other elements of scaffolding where bolts or wedge connections occur, it is very often to see incomplete elements. This may indicate that higher amount of attention is applied to bracings and the use of defective elements is usually disallowed.

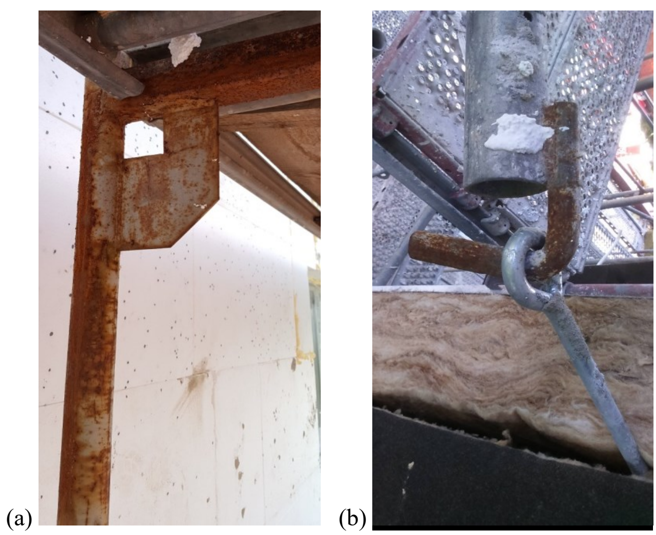


Fig. 6. Corrosion on scaffolding elements: (a) steel frame, (b) anchor connector.

Another damage classified in the first group is corrosion. All steel scaffolding elements are protected against corrosion by galvanizing. This is definitely one of the most effective and long-lasting anti-corrosion measures. However, during the research different degrees of corrosion of the elements were detected. Corrosion in scaffolding elements is most often initiated by local mechanical damage of the protective coating. There are also cases of defective protective coating, which results in the corrosion covering whole elements or significant parts of it. Of course the initial phases of surface corrosion should be included in the subsequent groups described, however, over time, corrosion in the elements progresses and a situation such as shown in Fig. 6 (a), where corrosion begins to have a pitting effect definitely affects the lowering of the bearing capacity of the elements, including the most important ones due to the bearing capacity and stability of the entire structure. The occurrence of corrosion on welded joints and elements with smaller cross-sections seems to be particularly dangerous, as shown in the example of an anchor connector whose hook and connection with the pipe is corrosion-coated (Fig 6 (b)). The loss of load capacity of such a connection located at a critical point can also lead to a disaster.

(a)  (b) 

Fig. 7. Lower cross-bar: (a) complete frame, (b) frame with lower cross-bar cut out.

The last listed type of damage in this group is the lack of the frame integrity. Among these damages, one of the most numerous is the absence of the lower crossbar of the frame. As it was determined, this is a deliberate action by the assembly workers and it happens in a situation when in the initial frame the lower bar collides with elements of the building structure located at the base of the structure (e.g. a wall that can be bracketed with standards after removing the lower crossbar). Unfortunately, after the scaffolding disassembly, these frames are not eliminated from further use and are treated as fully valuable and are used again. Operation is so deliberate that a small section of the lower crossbar with the mandrel to which timber curbs are fixed is left. So the assumption is that the element will be reused and not in such special situations, but just like any other complete frame. In Fig. 7 (a) and (b), the frame is shown in the middle level of the scaffolding with the bottom bar, i.e. the correct situation and underneath with the cut bar.

(a)  (b) 

Fig. 8. Fixing of a vertical bracing: (a) damaged, (b) complete.

A very similar danger is caused by not completely attached vertical bracing. Fig. 8 (b) shows the complete fixing. Assembling the braces involves sliding the element with the corresponding hole at the end of the bracing to the bolt welded to the frame standard. The possibility of detachment of the bracing is blocked by the automatically falling cotter pin. Thus, the lack of this small element shown in Fig.8 (b) creates the possibility of a very dangerous situation. If the occurrence of damages does not affect the load capacity of the structure, then they are included in the second group. These damages, even if they lead to the destruction of any of elements, have a very local coverage. Nevertheless, they are still very dangerous, and their presence poses a direct threat to life and health of people staying on the scaffolding. In this group, the greatest danger is damage of decks.

Platforms in scaffolding constitute a direct support for all vertical external loads, including for people's weight. Through decks, loads are transferred to other structural elements. In all types of decks, damages having a direct influence on their bearing capacity were identified during the inventory.

Fig. 9. Broken timber deck.

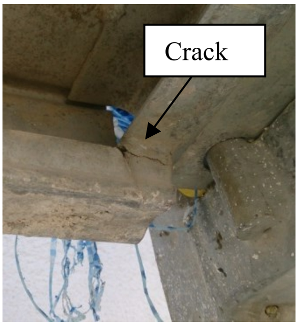
During the tests, aside from the elements with damage, broken decks such as the timber one shown in Fig. 9 were found. Such a failure unfortunately is very difficult to remove because a bridge from the central scaffolding field cannot be easily removed and replaced. For this purpose, it would be necessary to dismantle all the frames above this platform, which in the case of the scaffolding with the damaged deck shown here meant that it would be necessary to dismantle almost the whole scaffolding. In such a situation, it is most often possible to exclude the danger zone from the use if it is possible. In practice, unfortunately, it turned out that in this case, it was limited to drawing the attention of employees to this place. Damage to timber decks resulting in such events is mainly caused by timber corrosion, for example shown in Fig 10 (b) and splitting of glued timber Fig. 10 (a).

(a)  (b) 

Fig. 10. Damaged timber decks: (a) splitting of elements consisting the deck, (b) corrosion of timber.

Fig. 11. Damaged steel deck.

In the case of steel decks, a very large number of permanent plastic strains was observed causing deflections along and across the bridge. Such were the ones shown in Fig. 11, most likely due to the fall of a large mass from a height. However, in the case of these bridges, damages in the area where the platform is attached to the frame appear much more dangerous. In particular, damages such as weld crack shown in Fig 12, and deformations of the elements causing the disconnection of the elements.

(a) 

(b) 

Fig. 12. Damage of steel decks in support zones: (a) weld crack, (b) deformation of a perforated steel sheet.

The second basic deck type found in frame scaffolding is a communication deck. These are decks wider than those mentioned earlier and for this reason they have aluminum-plywood structure which allows them to be created much lighter. Their structure is based on an aluminum frame and thin plywood sheathing.

(a) 
(b) 

Fig. 13. Damage of communication decks: (a) defects in plywood sheathing, (b) detached beam supporting the sheathing.

Decks built in this way allow for the replacement of the most sensitive element, such as a thin layer of plywood, which can be easily damaged by mechanical action. However, as it can be seen in Fig 13 (a), this operation is not always carried out. As in the case presented, it is seen that the entry flap made of plywood is in a dramatic condition and evidently poses a threat. Another very dangerous damage to these bridges is the cracking of connections between the elements. Fig. 13 (b) shows a failure in the form of a side detachment of the supporting beam of the plywood sheathing.

This group also includes damages to steel frames consisting in the lack of movable elements for fixing handrails. The scaffolding structure can be assembled without a handrail. The only task of handrails in scaffolding is to protect people from falling. Therefore, handrails are obligatory to be installed in every scaffolding zone intended for human presence. Handrails assembly errors are quite a large group of defects, although they can be easily repaired and thus the threat that is associated with these errors can be fully eliminated.

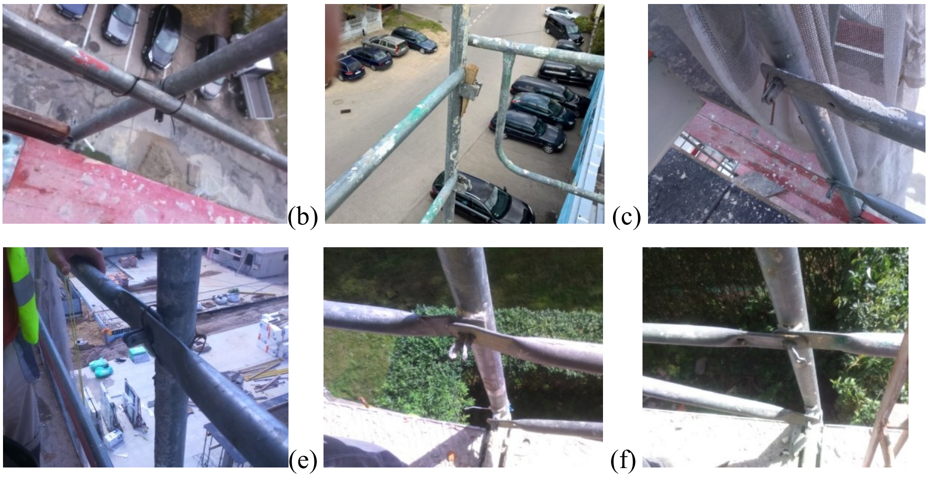


Fig. 14. Damage in handrails fitting.

Fig. 14 shows several situations in which the fastening of a handrail is incomplete. As can be seen in Fig 14 (a) - (d) the damaged fixture was replaced by a plastic band, a wooden wedge, a curved nail, a piece of steel wire. All these are provisional solutions and one can get an impression that the assembly workers solve this problem with what they currently have at hand. It is not known how this replacement will behave in the event of an item being loaded, so this should not be realized because it still poses a potential threat. Fig. 14 (e) shows a situation in which the blockage against sliding the handrail from the spindle is realized by folding its ends. This solution, of course, also does not guarantee fully safe use. In order to remove the handrail, the ends of the spindle must be bent back. Repetition of this operation several times results, of course, in the occurrence of cracks and consequent breaking of the elements of this element as shown in Fig 14 (f). Unfortunately, such a procedure additionally leads to a situation in which fixing cannot be easily repaired.

The third group includes damages to scaffolding elements that do not pose a threat to the load-bearing capacity of the structure and the safety of its use, but only reduce its aesthetic value. These damages may possibly affect the subjective feeling of user safety. They occur mainly in safety elements and most often if they appear then it is on a large number of elements.

Fig. 15. Damage of toe boards.

Such defects certainly include damages on the edges and longitudinal cracks in safety toe boards (Fig 15). These elements prevent falling of tools or materials left at the edge of the platforms. They do not carry almost any loads. Therefore, the occurrence of these defects even in all elements does not reduce their performance values. However, these are quite large elements, which is why their poor condition may lead to an unjustified understated assessment of the technical condition of the entire structure.

Fig. 16. Handrails damage.

Like in the case of toe boards, a large amount of damage in the handrails may give the impression of poor technical condition of the scaffolding, more so that here we deal here with steel elements that are considered to be much more durable than timber ones. During the inventory, a very large number of damages in these elements were found, consisting mainly in bending (deflection of the pipe axis) and indentation (point deformation) shown in Fig. 16. In many cases, there were several such damages on one element. Nevertheless, if the handrail is properly fixed, damage of this type does not affect its performance. The last damage included in this group is surface corrosion with a small coverage. Corrosion was already included in the first group, but only in main structural elements that during usage have a high degree of cross-section effort. An example of corrosion which does not affect the scaffolding capacity and safety of use is shown in Fig. 17 (a) and (b) where surface corrosion with very small extent occurs on the horizontal element of the front frame and the fixing bolt of the handrail. However, as previously stated, corrosion is a progressive phenomenon and over time these damages can turn into a dangerous hazard, especially in the case of a handrail fixing.

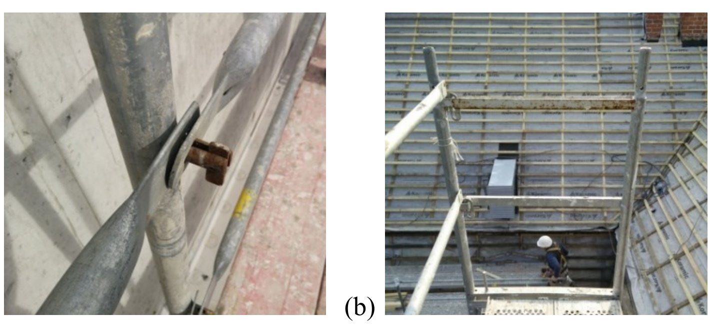
(a)  (b)

Fig. 17. Surface corrosion of elements.

4 Analysis of results

The data on the occurrence of damages in the frame scaffolds collected during the inventory were compiled and shown in Fig. 16. The horizontal dimensions of the tested scaffoldings were marked on the horizontal axis. It should be noted that the inventory carried out, due to the very wide range of activities performed on scaffolding, included only one elevation treated as representative for the selected building. Very often “the same scaffolding” was located on other façades or other buildings within the given construction site. By saying “the same scaffolding” it is meant that it had one owner, was used for the same purpose and in the overall assessment had the same degree of wear. Therefore, it is most appropriate to give the amount of damage per unit of area.

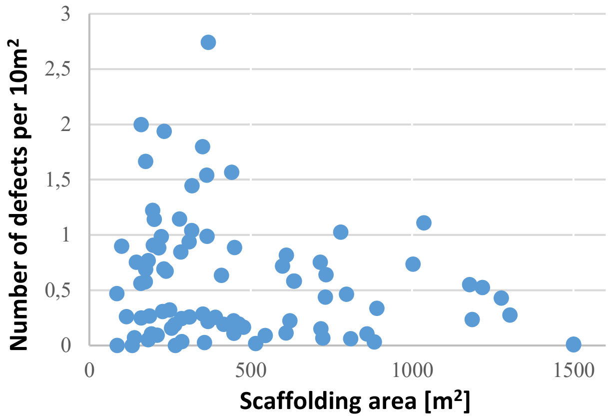


Fig. 18. Number of defects identified at scaffoldings.

In Fig. 18, it is assumed that the unit surface will be 10 m^2, and in relation to such a surface, the number of defectsidentified is summarized. It should be mentioned that the basic dimensions of the frame scaffolding module are 2 m by 3 m. It means that the result of 1.67 on the vertical axis of this graph means that statistically there was a defect in every module of a given scaffold. And as it was stated above, only damages of the size that could have a significant impact on the load-bearing capacity and safety of scaffoldings were registered.

The graph shown in Fig. 19 is a transformation of the previous one. On the horizontal axis the division into groups depending on the number of damages per unit area with spacing of 0.25 is denoted. On the vertical axis, the number of scaffoldings in each group was indicated. The list includes data from 80 scaffoldings. As it can be seen, the first group is the most numerous. This group includes scaffoldings that have no damage or number of defects is small, so it is a group in which the problem of damage in its elements is not significant. However, it constitutes only one third of all analyzed scaffoldings. This means that the problem of damage in scaffolding elements is very serious.

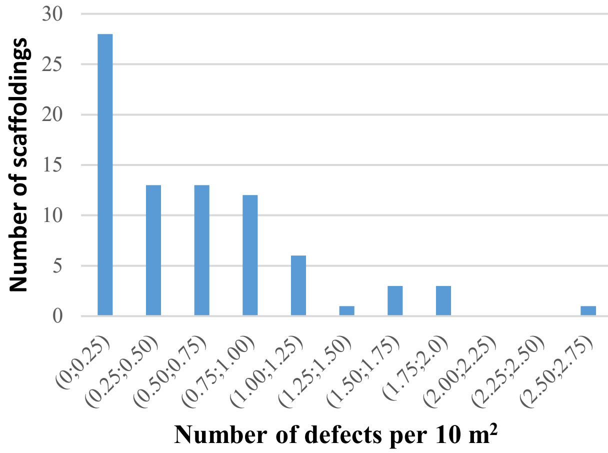


Fig. 19. Number of scaffoldings with defects.

5 Conclusion

In the conducted tests, many different types of damage have been demonstrated. Among these damages there are those that occurred very often on many objects, so you can say that they are characteristic for a given element. A classification was made, in particular, taking into account damages that may have a significant impact on the scaffolding capacity and safety of use. The number of damages on particular objects shows that almost 70% of scaffolding structures are also erected from elements that pose a threat to its load-bearing capacity or safety of use. The examinations carried out on individual elements show that damages in some size ranges have negligible influence on the behavior of the element during load.

However, after exceeding a certain size of damage, we observe a significant decrease in load capacity. Therefore, the impact of all damages should be thoroughly researched, which would allow to create unambiguous instructions to help control the technical condition of components and to eliminate those that may pose a risk by their occurrence.

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