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Scaffoldings

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CONTENT

1 Introduction

Construction scaffolds are temporary structures, used to all works at a height and in places with difficult access. Their main task is to provide safety to their users. Scaffolds are primarily used in a construction sector as working platforms and to protect all types of construction works, yet they are also used in other branches of economy e.g. during repair works of assembly lines, shipyards, as support structures of advertisements, covers of mass events, stages, temporary hall constructions, decorative elements, etc. So many different applications, and frequently complicated construction solutions of scaffolds result in multiplied possibilities of the occurrence and development of dangerous situations, understood as all unforeseen sequences of events threatening people on scaffolds or in their vicinity. In many cases, the users of scaffolds are people having little knowledge on the specificity of scaffold use. Not to mention the fact that scaffolds as temporary objects are treated as structures of little importance, and thus little attention is paid to their proper assembly and use.

Thus it is so significant to shape the awareness of the importance of scaffolds, manner of their design, assembly and disassembly rules and usage among students in the field of Civil Engineering who in future will have an influence on proper and safe use of scaffolds at construction sites. The knowledge within the scope of legal acts concerning scaffolds, assembly and disassembly rules, operating rules with special emphasis on safety regulations, the discussion of laboratory tests of scaffolds, the rules of designing untypical constructions of scaffolds as well as problems which occur while developing a scaffold will be presented in the paper.

The authors hope this knowledge fulfills the gap in the education of civil engineers, and enables developing appropriate attitudes of civil engineers in their professional careers.

2 Definitions and legal regulations

The discussion of the rules of scaffolds application at construction sites will be proceeded by basic definitions as well as the description of legal circumstances of scaffold application. Among the legal acts regulating scaffold functioning in Europe there are: Directive 2009/104/EC of the European Parliament and of the Council of 16.09.2009 concerning the minimum safety and health requirements for the use of work equipment by workers at work [Directive 2009/104/EC, 2009], Council Directive 92/58/EEC of 24.06.1992 on the minimum requirements for the provision of health and/or safety signs at work [Directive 92/58/EEC, 1992], Directive 2001/45/EC of the European Parliament and of the Council of 27.06.2001 amending Council Directive 89/655/EEC concerning the minimum safety and health requirements for the use of work equipment by workers at work [Directive 2001/45/EC, 2001]. In Poland among legal acts introducing previously mentioned directives or regulating, among others, scaffold use, there are such legal acts: Act of 26.06.1974 – The labour code [J. Law 1996, 21], Act of 7.07.1994 – Construction Law [J. Law 1994, 89], Regulation of Minister of Labour and Social Security of 26.09.1997 on general health and safety rules [J. Law 1997, 169], Regulation of the Minister of Infrastructure of 6.02.2003 on health and safety during construction work [J. Law 2003, 47], Regulation of Minister of Economy of 20.09.2001 on health and safety in exploitation of earthmoving, construction and road-building machines and technical devices [J. Law 2001, 118], Regulation of Minister of the Economy of 21.12.2005 on essential requirements for personal protective equipment [J. Law 2005, 259], Regulation of the Minister of Infrastructure of 23.06.2003 on the information on the safety and health protection and the health and safety plan [J. Law 2003, 120], Regulation of the Minister of Economy, Labour and Social Policy of 30.10.2002 on minimal requirements for occupational safety and health as far as the use of machines by workers during working hours [J. Law 2002, 191], Regulation of the Minister of Economy, Labour and Social Policy of 30.10.2002 on minimum on occupational safety and health requirements in the scope of use of machinery by employees at work amended by the Regulation of the Minister of Economy of 30.10.2002 [J. Law 2003, 178], Regulation of the Minister of Economy of 20.10.2001 on occupational safety and health while operating machines and other technical instruments for earth moving, construction and road-building works [J. Law 2001, 118]. Whereas, in order to provide the application of proper technical solutions during the development and design of scaffolds, the following set of standards is prepared: [EN 12810-1:2010, EN 12810-2:2010, EN 12811-1:2007, EN 1811-2:2008, EN-12811-3:2003, EN 12811-4:2014-02, EN 12812:2008, EN 12813:2005, EN 74-1:2006, EN 74-2:2009, EN 74-2:2009, EN 39:2003 and EN 1004:2005] ,which are valid across Europe.

2.1 Basic definitions

Before the problem of scaffold usage is addressed, the definition of scaffold itself shall be explained. It seems that the best definition is as follows: "*Scaffold is a temporary support structure, assembled from reusable elements, aiming at temporary transfer of loads evoked by people, building materials or equipment while erecting a construction or engineering facilities.*" However, in various legal documents, other definitions of scaffolds can be found depending on the purpose of a particular document. Hence according to an item 3.26 of a standard EN 12811-1 [EN 12811-1:2007] working scaffold is *"a temporary structure necessary to provide safe work place while erecting buildings, performing maintenance works, repair or demolition of buildings and other structures as well as providing necessary access"*. In §1 of Regulation of the Minister of Infrastructure of 6.02.2003 on health and safety during construction work [J. Law 2003, 47] there is a division of scaffolds and definitions of particular types which are as follows:

- *"working scaffold – it is understood as a temporary building structure from which works at a height can be performed, used to hold people, materials and equipment",*
- *"protective scaffold – it is understood as a temporary building structure used to protect people and objects against fall from heights",*
- *"system scaffold – it is understood as a temporary building structure in which the dimensions of construction net are unambiguous, imposed by the dimensions of scaffold elements, used to hold people, materials and equipment".*

In order to systematize the nomenclature related to particular components of scaffolds, in a standard EN 12811-1 [EN 12811-1:2007], the names of particular elements are given as follows (Fig. 2.1):

- bracing in vertical plane (transverse diagonal) – 1,
- bracing in horizontal plane – 2,
- side protection – 3,
- bracket brace – 4,
- node – 5,
- bracing in vertical plane (longitudinal diagonal) – 6,
- standard – 7,
- transom – 8,
- ledger – 9,
- coupler – 10,
- tie member – 11,
- platform – 12,
- bracket – 13,

- bridging ledger – 14,
- base plate – 15,
- platform unit – 16,
- horizontal frame – 17,
- anchorage – 18,
- vertical frame – 19,
- fencing structure – 20,
- principal guardrail – 21,
- intermediate guardrail – 22,
- toeboard – 23,
- post – 24,
- base jack – 25.

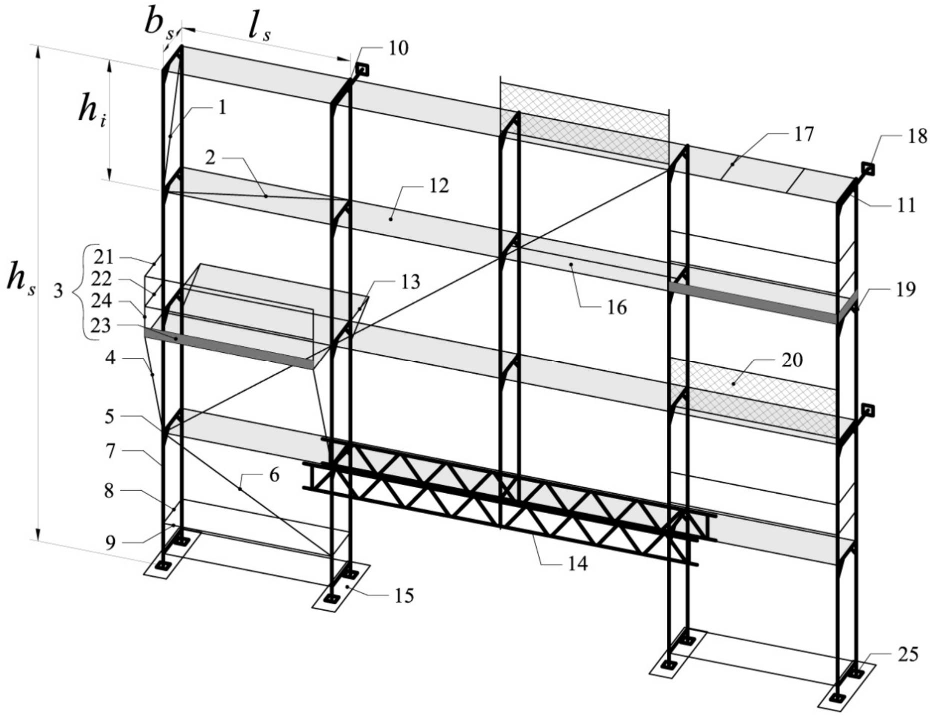


Fig. 2.1 The scheme of scaffold with marked elements [EN 12811-1:2007]

Above names are applied to all types of scaffolds. Within the frame of particular systems, different nomenclature or other elements which do not occur in basic sets can be found. Hence three types of base jacks can be distinguished: base jack, screw base jack and swivel base jack. The following types of couplers can be distinguished: right angle coupler to connect tubes mutually perpendicular, swivel coupler to connect tubes at any angle as well as parallel coupler to connect horizontal tubes, creating one line. A great diversity of elements occurs among platforms. Elements of platforms differ in materials which they are made of, width, the way of usage (ordinary platforms, transition platforms with a ladder, transition platforms without a ladder) as well as bearing capacity. The number of platforms types depends on the scaffold system.

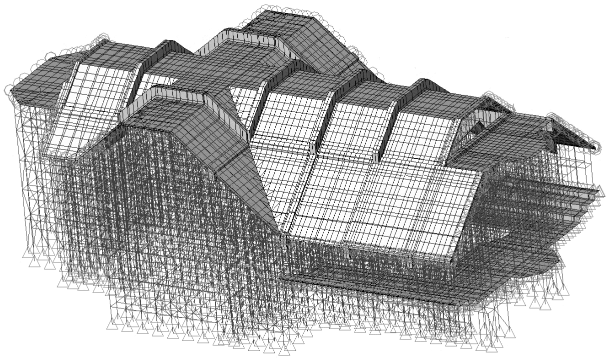


Fig. 2.2 The supporting structures of frameworks for the church in Rzeszów

Scaffolds are especially used at construction sites and above definitions describe scaffolds as structures applied to secure building works. It should be noted that scaffolds are such structures which can have different applications, for instance they might be used as:

- supporting structures of frameworks (Fig. 2.2),
- supporting structures of advertisements,
- suspended platforms (Fig. 2.3),
- circulation paths,
- temporary stages,
- mass events fencing,
- temporary halls constructions,
- decorative elements constructions ,
- construction elements of street exhibition (Fig. 2.4),
- the ramp for disabled persons (Fig. 2.5).

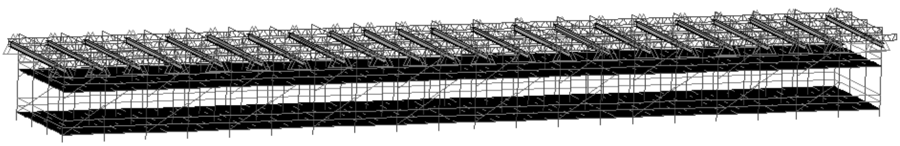


Fig. 2.3 The scheme of the suspended platform in Płock

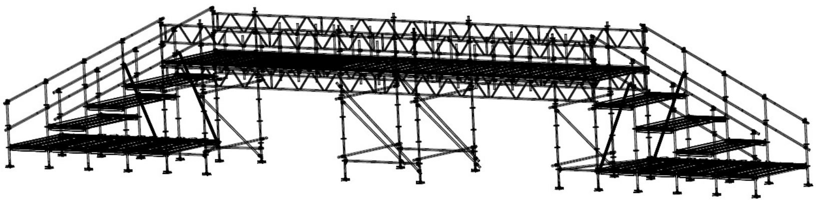


Fig. 2.4 The temporary footbridge used during the event of the sixth death anniversary of John Paul II

Fig. 2.5 The ramp for disabled persons

Scaffolds are characterized by diversity due to a material from which they are made, as well as due to applied technical solutions. In terms of a material, scaffolds can be divided into:

- steel,
- aluminum,
- bamboo,
- wooden.

Whereas, due to applied technical solutions as well as applied construction elements, scaffolds are divided into:

- tube and coupler scaffolds (Fig. 2.6),
- *„warszawskie”* (Fig. 2.7),
- façade scaffolds (Fig. 2.8),
- modular scaffolds (Fig. 2.9),
- mobile scaffolds (Fig. 2.10),

- tower scaffolds (Fig. 2.11).

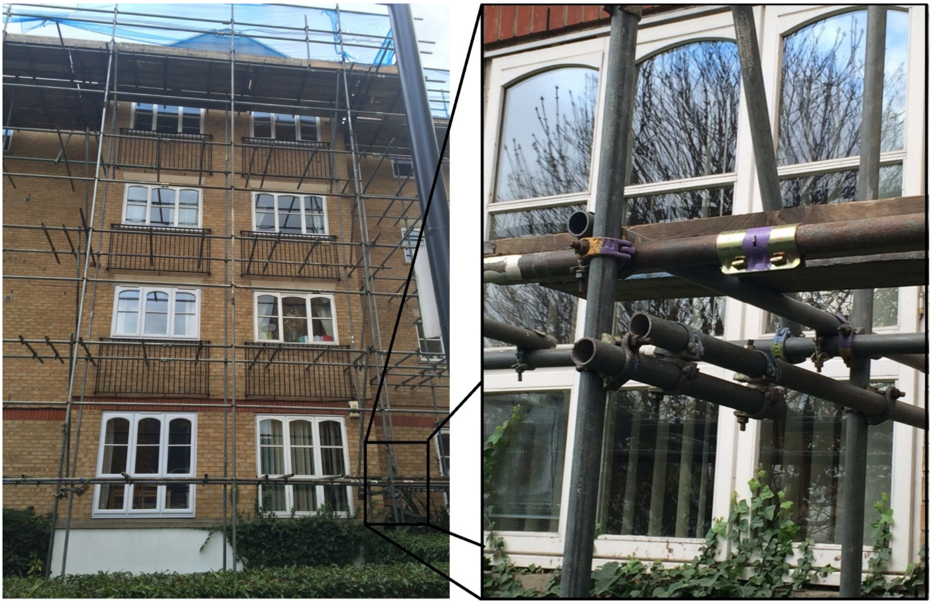


Fig. 2.6 The example of tube and coupler scaffolds

Fig. 2.7 The example of *"warszawskie"* scaffold

Fig. 2.8 The example of façade scaffold

Fig. 2.9 The example of modular scaffold

Fig. 2.10 The example of mobile scaffold (fot. Altrad Mostostal)

Fig. 2.11 The example of tower scaffold

A wooden scaffold is not treated as a system scaffold and thus, it is currently becoming less and less popular due to more difficult control of the structure capacity, and hence the safety of its users. Bamboo scaffolds are widely applied in Asian countries. Bamboo is a very durable material that enables producing tall structures of complicated geometry. Moreover, bamboo scaffolds are cheaper than steel scaffolds. Due to the considerable number of accidents on bamboo scaffolds at work [Fanga, 2003], the pros and cons of scaffolds made from both materials were studied, and it was stated that people's safety is the first priority and it is recommended to use steel and aluminum scaffolds.

The first steel scaffolds were tubular ones. The name of this type of scaffolds results from the fact that they are assembled from tubes. They are joined to each other by couplers. The assembly of such a scaffold is tedious and time-consuming.

In the case of works at low heights, it is common to use a frame scaffolding. This is a scaffold that consists of frames containing guardrails and vertical standards. One level of scaffold is produced by assembling four frames, which are joined by fixing the sleeves of upper frames to pivots of bottom ones or the other way round

In the case of scaffolds used as work platforms, the system metal scaffolds have been recently applied. Nevertheless, if these are works at wall planes, façade scaffolds are most frequently used, and in the case of very wide platforms, e.g. suspended ceilings or skylights, and to works at the facilities of complex geometry, modular scaffolds are applied. Façade scaffolds consist of frames which contain standards and bars, in the same time being the support for platforms. Guardrails as well as bracings in vertical planes are attached to frames. Horizontal stiffness is guaranteed by the platforms which are placed at every level. Modular scaffolds contain singular elements, such as standards, transoms and bracings. The rosettes, placed on standards at constant distance (most frequently every 0.5 m), enable the installation of transoms and bracings. Among the transoms, the tubular ones can be distinguished or the ones whose cross-section is adjusted so that the platforms can be placed on them. These latter transoms are often reinforced by additional elements so that they could transfer operational loading. Transoms of tubular cross-section can be used as standards fittings, as bracings in vertical plain as well as guardrails. Platforms in modular scaffolds are usually located only at two upper levels, and at lower levels, the stiffness of construction is provided by the bracings installed in horizontal plains.

Mobile scaffolds are used at works in which workers frequently have to change their location. These scaffolds are mounted on wheels, instead of base jacks, which enable to move.The scaffold consists of frames containing standards and guardrails that can serve as ladders. Mobile scaffolds are frequently assembled from the elements of façade or modular scaffolds, and only mounting it on wheels is indicative of a mobile scaffold.

Tower scaffolds are system scaffolds in the form of towers consisting of four poles, bars and bracings. Elements are placed on top of one another to achieve appropriate height. The scaffolds of this type most often serve as support structures to boardings.

Due to the safety of users as well as to the rapid assembly, currently system scaffolds are being applied most frequently. Until now, these were mainly steel scaffolds, yet currently, together with technological advancement, light aluminum scaffolds can be found at building sites. They are more willingly used in industrial factories where the substances leading to corrosion of steel are used.

2.2 Overview of legal acts

In relation to the fact that scaffolds should primarily provide safety to their users and other people being in the vicinity of works at a height, the basic document of the European Union which contains minimal requirements in terms of occupational safety and health while using work equipment is Directive 2009/104/WE, 2009. Basically, the whole directive can be referred to the application of scaffolds, since there are provisions e.g. concerning equipment inspection. Nevertheless, attention shall particularly be paid to point 4, devoted to the usage of work equipment applied to temporary works at a height including section 4.3 which is solely devoted to the usage of scaffolds. This directive imposes on European countries several simple rules for using scaffolds at building sites, such as:

- scaffolds shall be assembled in accordance with the common norm or the structure of scaffold must be subjected to calculation tests, in both cases, the structure has to meet the conditions of load bearing capacity,
- the instruction of assembly and disassembly of scaffolding shall be prepared by a competent person, however, in the case of unusual solutions applied to scaffolds, the instruction must contain assembly details concerning unusual elements of construction,
- a scaffold must comply with the ergonomic principles and need to be structured so that it provides safety to workers, e.g. the surface of platforms shall be protected from slipping, platforms shall be immobilized during works, breaks between particular elements cannot occur on platforms,
- elements of scaffold which are not used, must be marked with general warning signs, in accordance with national provisions transposing Directive 92/58/EWG, 1992,
- scaffolds can be assembled, disassembled or significantly altered solely under the supervision of a competent person.

Among the regulations, it is important to emphasize that scaffolds shall be designed as well as assembled by competent people, whereas it can signify quite another thing in different European countries. Moreover, it should be stated that the elements of scaffolds that are not yet ready-to-use must be marked. In accordance with Directive 92/58/EWG, 1992, it means marking not only the structure itself but also marking the warning signs or audible signalization, informing about danger at a given area, since e.g. stocked materials can fall down, the entry to the construction site is dangerous, or elements can be transported at a given time etc. Furthermore, Directive 92/58/EWG, 1992 concerns the situation in which a scaffolding is used. The area of scaffold influence should be properly secured and marked, e.g. places in which there is the risk of fall or collision with obstacles must be permanently marked by safety colors and/or signs. The way of marking such places is thoroughly described in Appendix V of Directive 92/58/EWG, 1992, and the most important information from this appendix is:

- *"Places, in which there is the risk of collision with obstacles, fall or fall of objects, shall be marked alternately by yellow and black stripes or red and white ones at built-up areas in enterprises where workers have access during work.*
- *Dimensions of marked signs must be commensurate and proportionate to the dimensions of referred obstacle or dangerous area.*
- *Yellow-black or red-white stripes must be at the angle of 45 % and approximately of the same dimensions".*

On the basis of above directives, every European country introduces its own regulations. The list of these regulations can be found e.g. on the website http://eur-lex.europa.eu, where all the regulations related to EU law can be found. In Poland, regulations resulting from directives [Directive 2009/104/EC, 2009, Directive 92/58/EEC, 1992, Directive 2001/45/EC, 2001] are placed, among others, in such legal acts as: [J. Law 1996, 21, J. Law 1994, 89, J. Law 1997, 169, J. Law 2003, 47, J. Law 2001, 118, J. Law 2005, 259, J. Law 2003, 120, J. Law 2002, 191, J. Law 2003, 178].

As in the case of EU regulations, thus in Poland the main acts which refer to the principles of functioning, are the acts and regulations concerning compliance with health and safety regulations. The basic act is the Regulation of the Minister of Labour and Social Policy of 26.09.1997 on general principles of health and safety at work [J. Law 1997, 169], in which, among others, there are requirements in terms of health and safety at construction works. According to § 109 of this directive *„at construction works on scaffolds at a height above 2 m from the surrounding ground level or external area as well as mobile suspended platforms, special attention should particularly be paid to: 1) ensuring the safety of vertical communication and access to workplace, 2) ensuring stability of scaffolds and appropriate durability to anticipated load capacity, 3) technical acceptance must be performed before the use of scaffold in the mode specified in separate provisions."* Moreover, among others, the recommendations in § 110 of the directive, refer to scaffolds, in which it is stated that *"at works on poles, masts,* *tower structures, chimneys, building structures without ceilings, as well as at assembly and disassembly of scaffolds and at works on ladders, brackets at a height of 2 m above external area level or ground, special attention should particularly be paid to: 1) a technical condition of construction or equipment should be checked before their use, including their stability, durability to anticipated bearing capacity as well as protection from unexpected change of position, as well as technical condition of fixed elements of construction or equipment used to mount safety cords, 2) workers shall be provided with, appropriately to the performed tasks, safety equipment protecting from the fall from heights, such as safety harness with a cord attached to fixed elements of construction, safety harness with a lap belt (to the support works – on poles, masts etc.), 3) workers shall be provided with protective helmets."*

The regulation [J. Law 1997, 169] concerns the cases of health and safety at work in all fields of economy. Whereas, in reference to construction works Regulation of the Minister of Infrastructure of 6.02.2003 on health and safety during construction work [J. Law 2003, 47] was prepared. Chapter 8 is basically devoted to safety at works on scaffolds and mobile platforms including paragraphs from §108 to §132. From the above regulation, it is concluded that:

- the scaffold shall be assembled, operated and disassembled, in the case of typical system, according to the manufacturer's documentation; and in the case of untypical system, according to an individual design,
- scaffold can be assembled and disassembled only by skilled assemblers,
- after assembling a scaffold, technical acceptance should be performed by a person with relevant construction qualifications, and acceptance is confirmed by the entry to construction logbook or to the certificate of technical acceptance,
- during the acceptance, permissible load bearing capacity should be established on the basis of scaffold documentation and it should be placed on the board,
- scaffolds should be safe and ergonomic,
- scaffolds should possess a toeboard of 15 cm height and guardrail at 1.1 m height; the exception are system scaffolds where a guardrail can be placed at the height of 1.0 m and additionally at 0.5 m,
- in the case when the distance between a scaffold and a wall is more than 20 cm, guardrails should also be placed on the inner face of the wall,
- as a part of a scaffold, vertical communication should be done so that the distance between the plumb line and the farthest work place is no more than 20 m, and between plumb lines no more than 40 m,
- scaffold structure cannot protrude more than 3.0 m above the highest line of anchors,
- calculated force pulling an anchor cannot be less than 2.5 kN,

- lifting capacity of ascenders to transport materials as well as the load capacity of the structure itself, to which the ascender is attached shall ensure the transportation of materials of calculated weight not exceeding 1.5 kN,
- scaffolds made of metal elements should be grounded and possess lightning protection installation,
- an area around a scaffold should be fenced and signed, where the distance of this fencing from a scaffold should be at least 6 m, but not less than 1/10 of scaffold height,
- scaffolds located at streets with pedestrian crossings should have protective fans and a cover made of safety nets (Fig. 2.12),
- protective fans shall be placed at the height of at least 2.4 m and have an angle of inclination of 45^{o} sloping towards a scaffold (Fig. 2.12).

Fig. 2.12 The scaffolds with a safety net and protective fans

Regulations concerning scaffolds do not take up too much space in the Construction Law [J. Law 1994, 89]. Only in Act. 73. p.1, containing the definition of construction disaster, it is stated that a construction disaster is an unintended, violent destruction of building facility or its part, including, among others, structural elements of scaffolds.

In compliance with Directive 2009/104/WE, 2009, all activities related to the operation of scaffolds shall be performed by competent persons. Before the assembly of a scaffold, proper technical documentation shall be prepared. In Poland, it is nowhere directly stated which construction qualifications shall have a person who prepares manufacturer's documentation or individual design (further called as a technical design). On the other hand, in Regulation of the Ministry of Infrastructure and Development of 11.09.2014 on the independent technical functions in the construction industry [J. Law 2014, 1278] within the framework of building-construction specialty, there is a specialization *"scaffolds and multi-functional formwork"*. It enables posing a hypothesis that in order to perform technical designs of scaffolds, it is necessary to have qualifications in building-construction specialty. The second argument in favour is Act. 12 of Construction Law [J. Law 1994, 89], in which in Sec. 1 it is stated that *"Activity related to the necessity of expert assessment of technical phenomena or stand-alone solution of architectural and technical as well as technical and organizational issues can be regarded as stand-alone technical function…"*. Designing scaffolds can be included to the activities related to solving technical and organizational issues, hence, which require possessing construction qualifications.

Also the assembly and disassembly of scaffolds can only be carried out by persons having appropriate qualifications. In compliance with Directive 2009/104/WE, 2009 such requirements are in force all over Europe. In Poland, the possession of these qualifications results from the following douments: Regulation of the Minister of Infrastructure of 6.02.2003 on health and safety during construction work [J. Law 2003, 47], Regulation of the Minister of Economy, Labour and Social Policy of 30.10.2002 on minimal requirements for occupational safety and health as far as the use of machines by workers during working hours [J. Law 2002, 191] and Regulation of the Minister of Economy of 20.10.2001 on occupational safety and health while operating machines and other technical instruments for earth moving, construction and road-building works [J. Law 2001, 118]. The latter regulation classifies scaffolds to the group of *"various machines and other technical equipment"*, which means that they can be assembled only by persons who obtained positive results of tests performed by a committee appointed by the Institute of Construction and Rock Mining Mechanization in Warsaw. The acceptance of a scaffold shall be conducted by a person with building license in construction and building specialty. This follows on the one hand the range of activities they undertake independent functions in the construction industry, on the other the responsibility of the construction manager, including the safety and health at work in the construction site, which performed during the operation, should also be carried out under the supervision of having a building license.

During assembly, operation, and disassembly of scaffolds, the machinery is frequently mounted which is mainly used to vertical transport. Mounting of such equipment requires the supervision of a person who possesses an appropriate qualification certificate issued in compliance with Regulation of the Minister of Economy, Labour and Social Policy of 20.02.2003 amending regulation on the procedure to check the qualifications required for the operation and maintenance of technical equipment [J. Law 2003, 50].

Another significant aspect of scaffold functioning concerns the inspection of scaffolds and their use. Institutions which can control building sites, with particular consideration of scaffolds, are National Labor Inspectorate in terms of compliance with health and safety regulations, Building Supervision authorities (the District Inspectorate of Building Supervision) in terms of compliance with a technical design of building and appropriate entries into the construction logbook as well as the Office of Technical Inspection, yet only when there is machinery on scaffolds, e.g. winches, lifts (elements of vertical transportation) subjected to supervision in compliance with Regulation of Ministers Ordinance of 7.12 2012 on the types of technical devices subjected to technical inspection [J. Law 2012, 1468]. Since the most entries on scaffold functioning are found in the scope of health and safety regulations, thus the most important role in scaffold supervision plays the authorities of National Labor Inspectorate.

2.3 Overview of standards

As it has been previously stated, at present standard regulations in terms of shaping, designing and using scaffolds contain thirteen standards, including:

- EN 12810-1:2010. Façade scaffolds made of prefabricated components. Part 1: Product specifications – [EN 12810-1:2010],
- EN 12810-2:2010. Façade scaffolds made of prefabricated components. Part 2: Particular methods of structural design – [EN 12810-2:2010],
- EN 12811-1:2007. Temporary works equipment. Part 1: Scaffolds – Performance requirements and general design – [EN 12811-1:2007],
- EN 12811-2:2008. Temporary works equipment. Part 2: Information on materials – [EN 12811-2:2008],
- EN 12811-3:2003. Temporary works equipment. Part 3: Load Testing – [EN 12811-3:2003],
- EN 12811-4:2014-02. Temporary works equipment. Part 4: Protection fans for scaffolds – Performance requirements and product design – [EN 12811-4:2014-02],
- EN 12812:2008. Falsework — Performance requirements and general design – [EN 12812:2008],
- EN 12813:2005. Temporary works equipment. Load bearing towers of prefabricated components. Particular methods of structural design – [EN 12813:2005],

- EN 74-1:2006. Couplers, spigot pins and baseplates for use in falsework and scaffolds. Part 1: Couplers for tubes – Requirements and test procedures – [EN 74-1:2006],
- EN 74-2:2009. Couplers, spigot pins and baseplates for use in falsework and scaffolds - Part 2: Special couplers. Requirements and test procedures – [EN 74-2:2009],
- EN 74-3:2007. Couplers, spigot pins and baseplates for use in falsework and scaffolds. Part 3: Plain base plates and spigot pins. Requirements and test methods – [EN 74-2:2009],
- EN 39:2003. Loose steel tubes for tube and coupler scaffold. Technical delivery conditions – [EN 39:2003],
- EN 1004:2005. Mobile access and working towers made of prefabricated elements. Materials, dimensions, design loads, safety and performance requirements – [EN 1004:2005].

Standards EN 12810-1, 2010 and EN 12810-2, 2010 are primarily devoted to façade scaffolds. In the first part, minimum requirements in reference to material properties, descriptions of scaffold configurations which can be treated as system scaffolds, the requirements related to designing in majority in the form of references to other standards, the description of the research on steps durability, content of technical documentation, were described. In the standard EN 12810-2, 2010, the rules for designing scaffolds as systems are included. In the standard [EN 12810-2:2010], the stages of strength calculations are placed, the rules of the study on couplers, struts, platforms as well as the study on representative configuration of a system, so-called global test, are described.

Three parts of the standard EN 12811:2007, EN 12811-2:2008 and EN 12811-3:2003 are more general and concern all the types of scaffolds. In the standard EN 12811-1:2007 one can find the nomenclature of particular elements of scaffolds, width classes of work areas, clearance classes, loading classes, the rules for shaping working scaffolds, the rules for their designing (the rules for taking loads, introducing imperfections that model slack in couplers, the conditions for ultimate limit state loading), and in the annex C, characteristic values of strength of tubular couplers are included. The standard EN 12811-2:2008 contains information on material properties in which scaffolds can be performed, hence on steel, cast iron, aluminum alloy, plywood and wood. The last part of the standard EN 12811:2003, in compliance with the name, regulates the rules for conducting the research on particular elements. The types of studies as well as the way of analysis of obtained results are described in the standard.

The standard EN 12812 describes the rules for constructing and designing a structure from scaffolds elements which can be used as support of formwork platform structures for machines or stocks of materials. Particular attention is paid to shaping scaffold foundation, geometry imperfections of scaffolds as well as the rules for taking loads. The information from standard EN 12811-1:2007 on the ultimate limit state as well as on the requirements in terms of couplers bearing capacity from the standard EN 74-1:2006 is repeated. Another standard EN 12813:205 is devoted to designing tower scaffolds. In this standard, in terms of strength calculations, the references to EN 12810-2:2010 are included. In the references, more detailed descriptions of calculations considering geometric nonlinearity as well as laboratory tests of tower fragment, a so called global test, can be found.

Despite the fact that tubular scaffolds are time-consuming, thus both couplers and tubes are included in the standards. The set of standards EN 74:2006, EN 74-2:2009, and EN 74-2:2009 refers to the methods of research and requirements for couplers, centering of piston pins and base jacks. The classes of couplers, along with requirements, as well as the schemes of test stands, are described in standards. Couplers are significant elements of scaffolds. They are essential in tubular scaffolds, yet they occur also in system scaffolds, when the structure geometry is complicated or requires reinforcement. This common application of couplers is mounting frames of façade scaffolds to truss girders.

In the standard EN 39:2003, the requirements concerning tubes made from non-alloy steel used for temporary structures and working scaffolds can be found. Moreover, the requirements referring to long-term marking of tubes, and protective shell as well as demanded control and tests are determined in the standard.

The standard EN 1004:2005 describes the rules for shaping and designing mobile scaffolds as well as the methods of research. The rules for taking loads to calculations, the way of applying loads in static schemes, the rules for a model creation considering imperfections as well as the conditions of ultimate limit states for mobile scaffolds are described in the standard.

Furthermore, the standards which are solely connected to security devices shall also be mentioned, and these are for example:

- EN 13374:2013-08. Temporary security systems at the edge of the buildings. Technical description of the product, test methods,
- EN 1263-1:2015-02. Temporary works equipment. Safety nets. Safety requirements, test methods,
- EN 1263-2:2015-02. Temporary works equipment. Safety nets. Safety requirements for the positioning limits,
- EN 1868:2004. Personal protective equipment against falls from a height. List of equivalent terms,
- EN 353-1:2015-01. Personal fall protection equipment. Guided type fall arresters including an anchor line. Guided type fall arresters including a rigid anchor line,

- EN 353-2:2005 Personal protective equipment against falls from a height. Guided type fall arresters including a flexible anchor line,
- EN 354:2012 Personal fall protection equipment. Lanyards,
- EN 361:2005 Personal protective equipment against falls from a height. Full body harnesses.

Scaffolds standards include a lot of references to other ones from this set or repeat information from other standards. Yet, despite this fact, these are very useful studies while developing new systems or designing untypical scaffolds.

2.4 Conclusion

In the chapter, sixteen legal acts and over twenty standards are mentioned. Such a wide range of legal regulations and standards results from the fact that scaffolds play a very significant role in building engineering, and their functionality and bearing capacity determine people’s safety.

3 Functioning of scaffolds in building sites

3.1 Introduction

Scaffold can be treated as a product. It is also a technical device, but it is also an engineering structure which should provide safety to people. The variety of possible approaches to scaffolds is visible in standards and legal acts regulating their functioning. In order to confirm the complexity of issues related to the presence of scaffolds in different fields of economy, the photos of sample structures are presented in Fig. 3.1.

Actions undertaken during scaffold operation can be divided into stages which are shown in Fig. 3.2. Every stage is separately discussed in further part of this chaper.

Fig. 3.1 The exemplary scaffolds: a) platform, b) platform for material, c) suspended scaffold, d) mobile platform

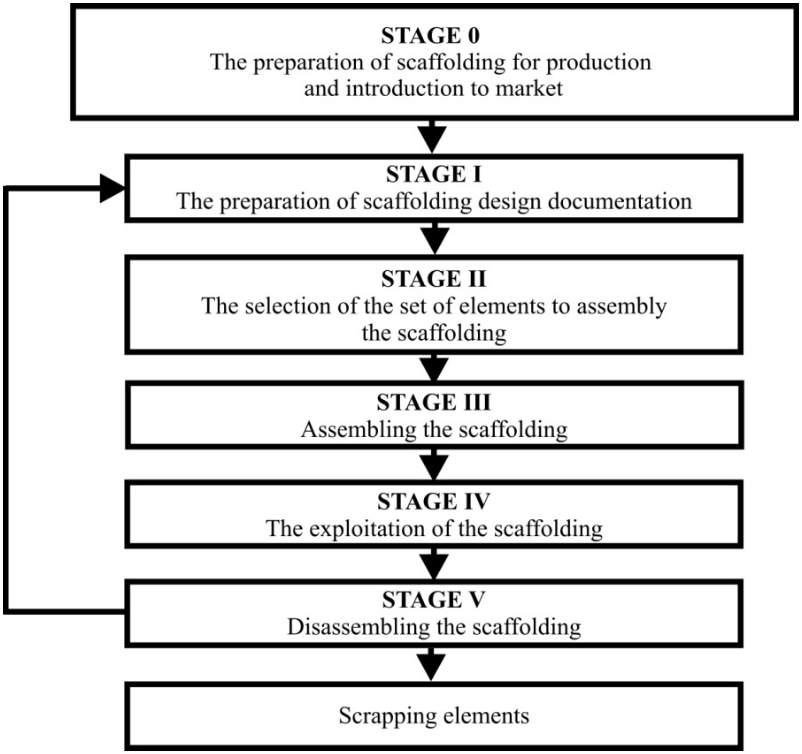


Fig. 3.2 Stages of scaffold functioning [Błazik-Borowa, 2015].

3.2 The preparation of scaffold for production and introduction to market

A scaffold is equipment which has to be designed, produced and introduced to the market and then it can be used as an engineering facility consisting of multiple application elements. The stage of scaffold 'birth' has been called as Stage 0. The effectiveness of assembly and disassembly as well as safety of assemblers depend on technical solutions applied to scaffolds and technology applied to production, and also the interest of potential purchasers of sold product.

Scaffolds shall be prepared in a way to secure people against the risk of fall from them as well as to secure people around against objects falling from this scaffold. Apart from that, a scaffold shall meet the requirements of ergonomics and it is assumed that they are met, if the requirements listed in standards [EN 12810-1:2010, EN 12810-2:2010, EN 12811-1:2007, EN 12811-2:2008, and EN 12811-3:2003] are also fulfilled. The dimensions of a scaffold have to meet minimum requirements defined in the standard EN 12811-1:2007 and the structure of scaffold shall be stable, of a proper bearing capacity, also classified in the standard EN 12811-1:2007. The most significant requirements and classifications are mentioned below.

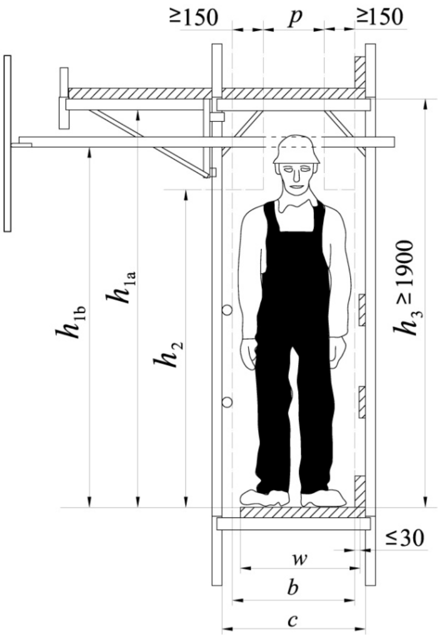


Fig. 3.3 Designations of working area dimensions [EN 12811-1:2007]

According to the standard EN 12811-1 [EN 12811-1:2007] minimum width of clearance between stand is 600 mm (comp. Fig. 3.3). Depending on the width in defined in EN 12811-1:2007 seven width classes are distinguished, summarized in Table 3.1.

Table 3.1 Width classes for working areas [EN 12811-1:2007]

Width class	W [m]
W06	$0.6 \leq W < 0.9$
W09	$0.9 \leq W < 1.2$
W12	$1.2 \leq W < 1.5$
W15	$1.5 \leq W < 1.8$
W18	$1.8 \leq W < 2.1$
W21	$2.1 \leq W < 2.4$
W24	$2.4 \leq W$

Subsequent important geometric parameters of scaffolds are: the height of clearance *h*3 which shall equal to at least 1.90 m, as well as the dimensions defining the distribution of guardrails and width of toe boards, shown in Fig. 3.4. The classification of scaffolds due to the height of clearance is presented in. Table 3.2

Table 3.2 Headroom classes [EN 12811-1:2007]

Class	Clear headroom		
	Between working areas h_3	Between working areas and transoms or tie members h_{1a}, h_{1b}	Minimum clear height at shoulder level h_2
H_1	$h_3 \geq 1.90$ m	$1.75\text{m} \leq h_{1a} < 1.90$ m $1.75\text{m} \leq h_{1b} < 1.90$ m	$h_2 \geq 1.60$ m
H_2	$h_3 \geq 1.90$ m	$h_{1a} \geq 1.90$ m $h_{1b} \geq 1.90$ m	$h_2 \geq 1.75$ m

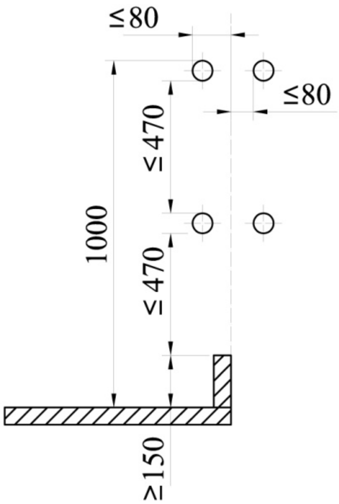


Fig. 3.4 Dimensions for vertical side protection with one intermediate guardrail [EN 12811-1:2007]

Important information on a scaffold is a load class. The division into load classes and corresponding values of continuous loads and concentrated loads which are capable of carrying a scaffold of a given class, is compiled in Table 3.3. This parameter decides on the distance between standards along platforms and shapes itself in the range from approx. 1.0 m to approx. 3.0 m.

If a scaffold complies with the requirements of a standard EN 12811-1:2007 and standard EN 12810-1:2010 it shall be marked in a way shown in Table 3.4. The name contains classification of scaffold to classes mentioned in Table 3.1, Table 3.2 and Table 3.3 as well as information of tests performance of platforms, on span, on the protection nets and the type of communication. The requirements related to the bearing capacity of construction are verified by strength calculations which are one of the problems raised in chapter 5 as well as laboratory tests, which chapter 4 is devoted to.

Table 3.3 Service loads on working areas [EN 12811-1:2007]

Load class	Uniformly distributed load q_1 [kN/m^2]	Concentrated load on area 500 mm × 500 mm F_1 [kN]	Concentrated load on area 200mm × 200mm F_2 [kN]	Partial area load	
				q_2 [kN/m^2]	Partial area factor a_p
1	0.75	1.50	1.00	-	-
2	1.50	1.50	1.00	-	-
3	2.00	1.50	1.00	-	-
4	3.00	3.00	1.00	5.00	0.4
5	4.50	3.00	1.00	7.50	0.4
6	6.00	3.00	1.00	10.00	0.5

Table 3.4 Designation of scaffolds according to the standard EN 12810-1:2010

Scaffold EN 12810	Service load class	Drop tests on platforms	System width class: see Table 3.1/ by length	Headroom class	Information about cladding	Information about communications
	See Table 3.3	(D) with drop tests (N) without drop tests	See Table 3.1/ by length in cm	See Table 3.2	(A) – without cladding (B) – with cladding	(LA) – with ladder (ST) – stairs (LS) - both

Table 3.5 The compilation of the most popular systems of scaffolds

Manufacturers or distributors	Façade scaffolds	Modular scaffolds	Tower scaffolds
Altrad Mostostal	Mostostal Plus (Fig. 3.6 a), (Fig. 3.7 b),	Rotax (Fig. 3.5 a), Rotax Plus, Alurotax	
Altrad Plettac assco	Plettac SL 70/100, Assco Quadro 70/100, Plettac Connect 70/100,	Plettac Contur, Assco Futuro	
Delta Rusztowania	DELTA 65/70/73, DELTA B70	DELTA Moduł	
Huennebeck	Bosta 70 (Fig. 3.7 c), d) Bosta 100	Modex (Fig. 3.5 c),	Shoring tower
Layher sp. z o.o.	Blitz	Allround (Fig. 3.5 d), i Allround Lightweight	TG 60
Omega Rusztowania	Omega I/II/III		
Peri	Peri Up T70/T100	Peri Up Rosett (Fig. 3.5 b) Peri Up Flex	ST 100, Multiprop
PIONART	BAL (Fig. 3.6 c), RR-08 (Fig. 3.6 b) (Fig. 3.7 a), PUM		
RUBO Konstrukcje		Rubo RK i Skyer	
Scafom-rux Polska	RR Termosprzęt, PUM70, Rux Super 65/100, FrameScaff	Ringscaff	
ULMA	DORPA	BRIO	T-500, MK, tower BRIO

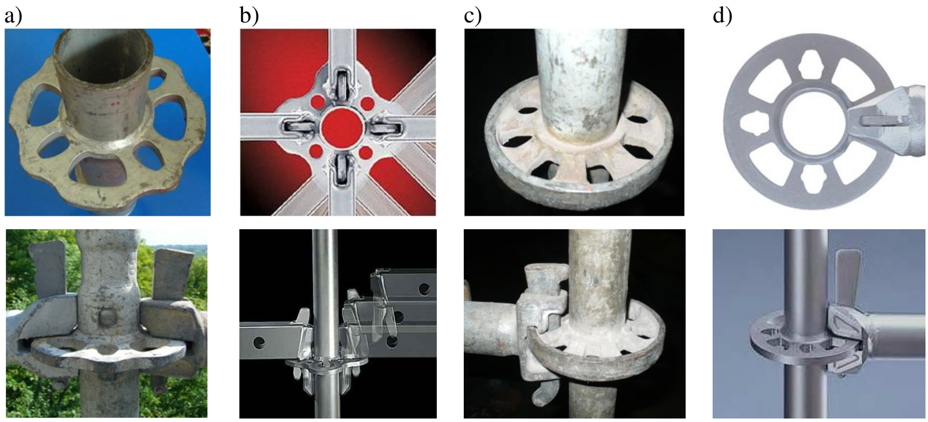


Fig. 3.5 Nodes of modular scaffolds: a) Rotax, b) Peri UP Rosett, c) Modex, d) Allround

Currently, a lot of systems of scaffolds are operating, according to previously described rules, on the European market. The most popular manufacturers of scaffolds in Europe are mainly, Peri, Layher, Altrad. In Poland scaffolds are produced by such companies as, Altrad-Mostostal, Rubo, PIONART, Delta Scaffolds, Omega Scaffolds and many more. Manufacturers or distributors of scaffolds and offered systems are summarized in Table 3.5.

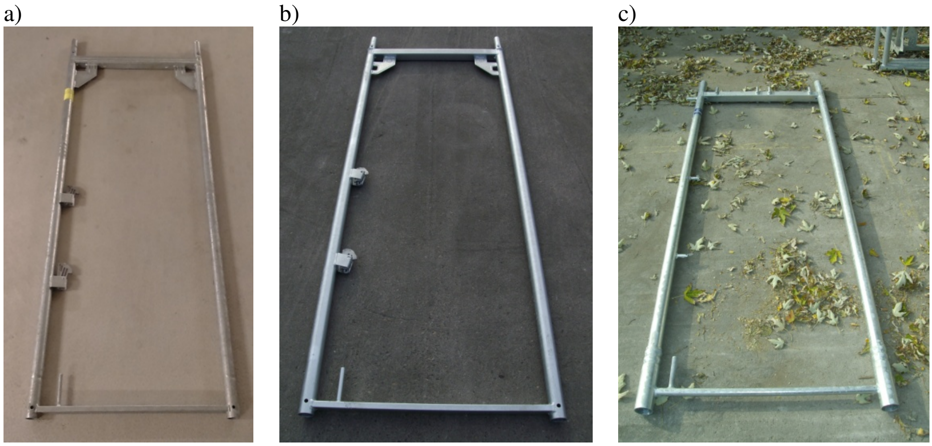


Fig. 3.6 Frame of façade scaffolds: a) Mostostal Plus b) BAL c) RR-08

Technical solutions and technology of production are developed by a manufacturer. The correctness of applied solutions shall be verified according to the regulation [J. Law 2003, 47], i.e. a scaffold shall be subjected to "tests on compliance with construction and material requirements, defined in assessment criteria of products in terms of safety". Despite the fact that a number of standards concern designing of scaffolds as well as rules for performing laboratory tests, in

Poland there is no obligation to have any certificates confirming the verification of requirements of regulation [J. Law 2003, 47] and standards [EN 12810-1:2010, EN 12810-2:2010, EN 12811-1:2007, EN 12811-2:2008 and EN 12811-3:2003]. An engineering scaffold is not a construction product, hence it cannot be marked by sign CE. Nevertheless, companies which take care of their public image attempt at possessing a safety mark B which in Poland is issued by the Institute of Construction and Rock Mining Mechanization in Warsaw. However, it must be clearly stated that marking of scaffold elements by a safety mark B is voluntary.

a) b) c) d)

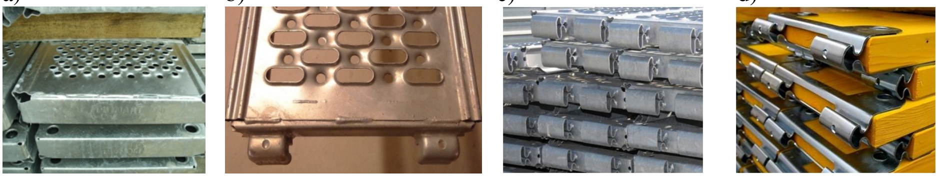


Fig. 3.7 Scaffolds decks: a) R-08, b) Mostostal Plus, c), d) Bosta 70

In Europe, in the majority of countries, scaffolds require certification, where: Sweden, Great Britain, Germany, Czech Republic, France, and Italy demand certification conducted in their country. Other countries of the European Union do not demand independent certification of own country and elements of scaffolds verified in the producer's country can be admitted to marketing.

No matter whether certification is required, checking laboratory tests of bearing capacity of particular elements, clearance values and nodes susceptibility, shall be conducted. The basic goal of tests is verification of the elements quality. Only the laboratory tests can point the shortcomings in anchoring, micro-cracks, or other faults which are not visible, and their effect is bearing capacity reduction of the whole system, in which this element will be mounted. Thus, conducting tests before introducing a system on the market, and then supervision of scaffolds during production is essential. The quality of production primarily influences the safety of scaffold users.

3.3 The preparation of technical documentation

It is not enough to produce the component parts of scaffolds. The introduction of a system on the market requires transferring information to a customer which allows him to assemble from particular elements, a whole, frequently complicated construction. Thus, very important stage of scaffold creation, is the preparation of technical documentation (Fig. 3.8). Technical documentation, in the case of scaffolds of a typical shape and arrangement of elements for every system, thus such scaffolds for which the tests on compliance with construction and material requirements were performed and which were then repeatedly assembled, in accordance with the regulation [J. Law 2003, 47] is a manufacturer's documentation (e.g. mobile and technical documentation commonly known as

DTR documentation). This type of information shall be found in the documentation:

- the list of component parts of a system,
- the instruction of a system assembly and disassembly,
- the plans of all standard configurations of a system, including a loading class, the way of anchoring and joining support component parts such as, consoles, truss girders etc.,
- the list of operating limitations in reference to environmental loading actions such as, wind, snow and icing,
- forces in anchorages acting on elevation, as well as forces in base jacks transferred to ground,
- all the instructions concerning the ways of storing, conservation and fixing of system elements,
- construction data of component parts and couplers such as, durability and stiffness whose values were determined with the use of tests.

DTR documentation shall be prepared so that a ready system of scaffolds can be selected. On the basis of pressure in jack base F and surface A of baseplate on which they are placed, pressing on ground equal to $2F/A$ shall be determined and compared to bearing capacity of soil. If bearing capacity is lower than baseplate pressure, soil should be strengthen e.g. by arranging scaffolding on concrete plates.

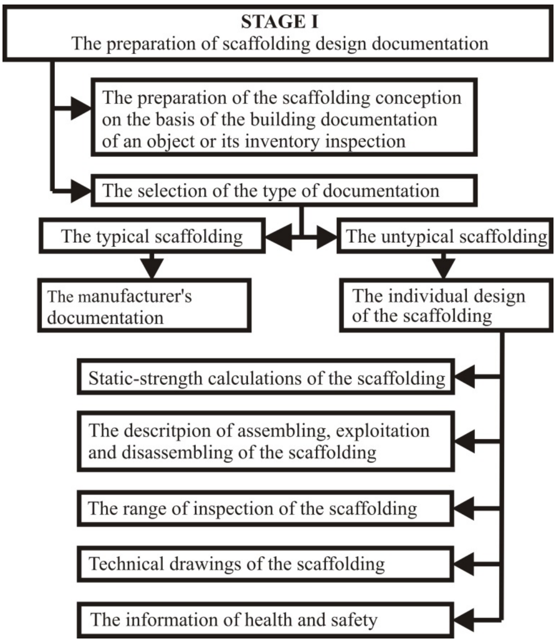


Fig. 3.8 Scheme of works during the preparation of scaffold documentation [Błazik-Borowa, 2015]

In the case when a ready system of scaffolds cannot be selected from documentation DTR, thus an untypical scaffold need to be used and then an individual design has to be done, called, in the further part, as a technical design (actually law does not define how such a design should be called). This design shall contain: technical description of scaffold, static-strength analysis, assembly and disassembly description, the scope of activities covered by the supervision of a scaffold, information HSE (Health and Safety Executive), technical drawings of a scaffold. Individual elements of design are discussed in chapter 5.

3.4 The selection of component sets to scaffold assembly

Another stage of scaffold creation is the selection of component sets (Fig. 3.9). After choosing the system of scaffolds or preparing a design, elements for scaffold construction shall be selected. The number of particular elements directly results from a design, but another influential factor concerns technical condition of particular elements. The technical condition of scaffold depends on the time of if operation. The more frequently elements are used, the worse are their state. However, the way of their use during operation, storing and transporting also affects their condition. In the case of scaffold operation, it is crucial to adjust loading to bearing capacity of scaffold as well as secure an area where the scaffold is assembled, so that there appears no mechanical damage caused by machines. Nevertheless, mechanical damage most frequently occurs during inappropriate disassembly, vertical transport and inappropriate storage of scaffold elements. Further assembly of damaged elements increases the risk of construction failure. Another problem related to the selection of elements concerns mixing elements of various systems. The best example may be couplers which are unified. Companies buy couplers made of both certified materials and cheaper ones of worse quality. Provided that several subcontractors work at the same building site, thus after the completion of construction it turns out that the couplers are mixed up. A similar problem concerns also other component parts of scaffolds.

In order to eliminate faulty elements of scaffolds, hence decreasing the risk of work on it, an inspection of particular elements is conducted during its admission to a warehouse as well as while issuing elements from a warehouse. Assessment of technical condition shall be performed also by assemblers at a building site during the assembly of elements into the construction.

The way of technical condition assessment depends on procedures applied in a company in reference to a given system of scaffolds, yet most frequently it consists in visual evaluation of shape and cracks of elements, and in the case of couplers also checking their place of origin. Since assessment is performed on the large lots of elements, it is subjective assessment of a person assessing a technical state, and there are no clear criteria and rules which elements should be rejected, unfortunately, these are quite often damaged elements that are put on building sites, substantially decreasing bearing capacity of scaffolds. Summing up, the selection of elements consists in gathering essential number of elements of one system in a good technical condition, and damaged elements must be eliminated during the inspection in the course of admission, issuing and assembly. Damaged and mixed elements cannot be used to assembly. If a renting company or scaffold owner does not possess a given set of scaffolds (too low number of elements, lack of given elements, poor technical condition of component parts), the scaffold shall be redesigned so that it can be assembled from accessible elements e.g. elements which are in stock, which can be rented from other enterprises or completed with new elements.

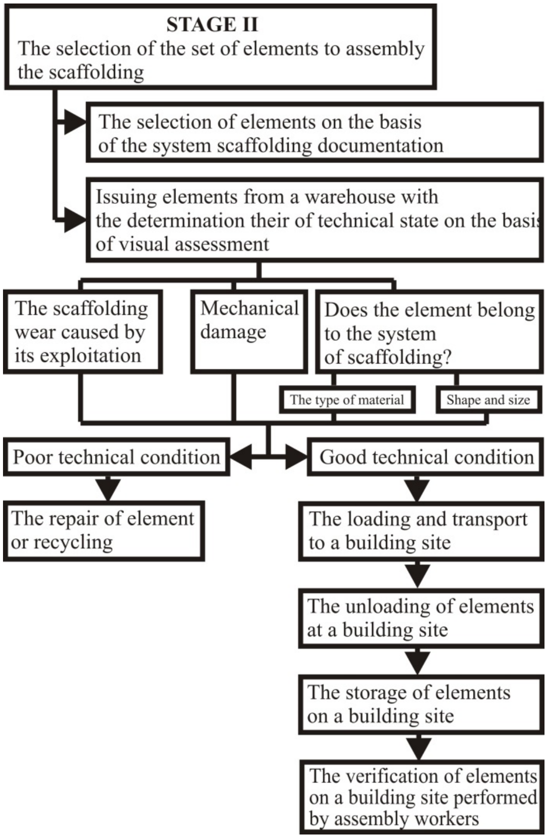


Fig. 3.9 Works related to the selection of scaffold elements [Błazik-Borowa, 2015]

3.5 The scaffold assembly

Detailed rules of scaffold assembly depend on the solutions applied to a system, on the type of a system, as well as the shape of construction. Scaffolds' manufacturers provide the assembly instruction together with equipment, in which, apart from general information, there are detailed rules for assembly, specific for a given system. Due to the substantial number of systems on market, only general information common for the majority of scaffold systems is given below. Particular phases of scaffold assembly are shown in Fig. 3.10.

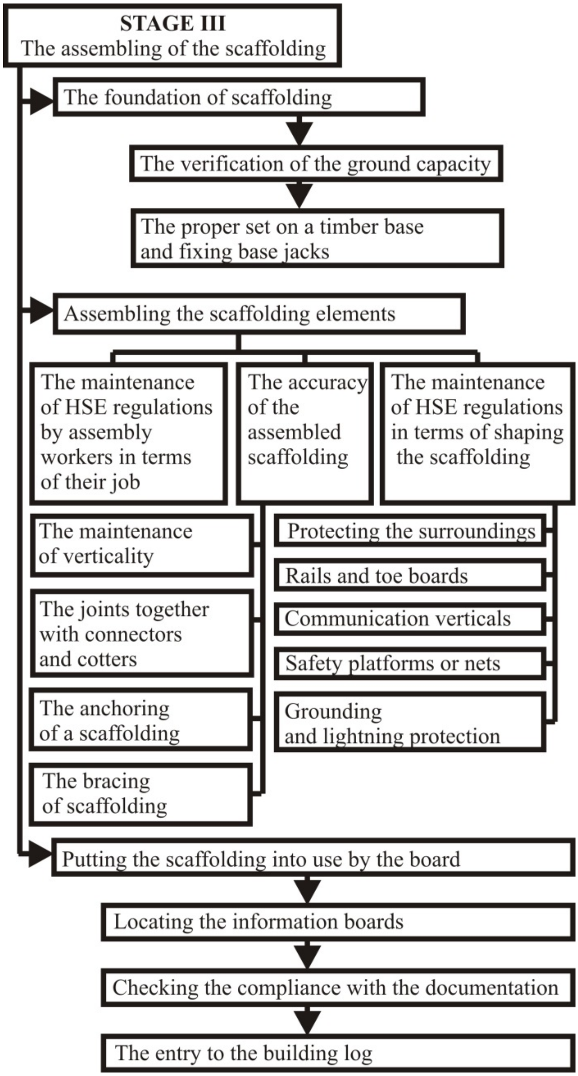


Fig. 3.10 The order of works during scaffold assembly [Błazik-Borowa, 2015]

Assembly can only be performed by assemblers having a certificate, issued by the Institute of Construction and Rock Mining Mechanization in Warsaw. Due to safety measures, assemblers shall use personal protective equipment protecting against falls from a height (Fig. 3.11), including safety harness, shock absorbers, retractable type fall arresters and security cables of the length adjusted to working height. More information on the way of selecting personal equipment, protecting against falls from a height can be found in a work [Dobrzańska, 2012].

Fig. 3.11 The scaffold assembly

Apart from protection, assemblers need such devices as, 500-g hammers used for wedging particular elements into a whole structure, spanners 19/21 to tighten clamps, couplers and anchoring as well as spirit levels. Individual workers cannot carry out assembly, but the group of workers under the supervision of a foreman can.

Before mounting a scaffold, ground shall be appropriately prepared, i.e. it shall be smoothed out and possible objects shall be removed. In case of insufficient bearing capacity of soil, i.e. less than 100 kPa or less than it results from the forces in base jacks, it shall be strengthen by arranging concrete plates.

Assembly of façade scaffold shall be proceeded by arrangement of timber sleepers perpendicularly to wall plane. The distance between sleepers shall be measured by guardrails or ledgers arranged on the ground. Base jacks should be arranged on sleepers, however, at least two plates should be placed on one sleeper. Depending on a system, initial elements and frames or directly frames are put on base jack studs. If there is a level difference, between heights of frames it should be equaled, by the regulation of base jacks, or by the insertion of regulating frames. The assembly of scaffold shall be launched from the highest level of area. Scaffold frames are joined by guardrails which should be mounted in specially intended handlers. Handholds of guardrails should be placed at further side of vertical element of frame, looking from the building wall by which a scaffold is assembled. The way of installation in these handholds depends on a system. Subsequently, working platforms are mounted on such a system of two frames. The complement of one module is a bracing mounted on the external part of a scaffold. A bracing can also be temporarily mounted before placing platforms, yet it cannot be tighten securely. A bracing shall be tighten securely to a frame after placing platforms. Moreover, the distance of a scaffold from a wall, which cannot be greater than 20 cm, shall be checked.

Adding subsequent segments of a scaffold over the ground level consists in assembling elements of neighbouring modules in a similar order with the use of already mounted elements of a previous module. In the indicated fields in documentation, bracings are placed most frequently so that the distance without bracings is less than 10 m. In the field where vertical communication are planned instead of platforms, temporary platforms with a ladder shall be placed. In a vertical communication, special attention should be paid to hatches in platforms which shall mutually intersect, and not occur one by one. If documentation does not impose other way of vertical communication intersection, the distance between them cannot be greater than 40 m, and the distance between working place cannot be greater than 20 m.

After assembling the first layer of scaffold, it should be verified whether the platforms are horizontal, frames – vertical, and whether the entire system creates a plane. At the height of the first level of platforms in their corners and at every second frame, a scaffold should be anchored. As in the case of bracings and vertical communication, also in the case of anchoring, documentation of scaffold may contain different recommendations. Under such circumstances, recommendations from documentation shall be applied.

After mounting the first bottom level of scaffold, another level need to be assembled. Assembly operations should be performed in the above mentioned order, however, from the second level, toe boards shall be put and scaffold sides shall be additionally secured by side guardrails.

In order to secure the highest floor of scaffold, special frames of the shape L shall be mounted which on one hand, secure platforms from movement, and on the other, they are the structure to assemble guardrails and toe boards.

In the course of scaffold assembly, elements need to be provided to increasingly greater height. The transport of mounted elements can be realized by the use of winches or manually, under the condition of fixing safety rails as well as bracings in compliance with recommendations included in the instruction of a system.

After assembling the structure of scaffold, bearing capacity of wall anchoring should be subjected to verification. The results of measurements shall be documented by the person who performed tests. Places which are subjected to tests shall be defined by the person responsible for the assembly of scaffold. Force acting on an anchor during sample loading shall equal to 1.2 times of required anchoring force. The verification of anchoring should be performed successively during the assembly of scaffold. The results of tests should be written down by a commission and they have to be stored during the operation of scaffold.

The assembly of modular scaffold differs from the assembly of façade scaffold due to solutions applied to this type of structures. Moreover, modular scaffolds almost always are applied to untypical solutions, thus they require a technical design. It means that the system of standards, bracings in perpendicular planes and in a vertical plane, platforms, as well as anchoring need to be conducted in accordance with a design.

As in the case of façade scaffolds, the assembly starts from arranging base jacks on timber sleepers in a distance regulated by girders arranged at one side. Depending on a system, initial elements are put and subsequently standards, or at first standard tubes are placed on base jack studs. Next, subsequent elements are assembled. The assembly of girders and bracings is usually based on putting heads of standards rosettes and blocking them by wedges. Four standards are connected by wedges at half height and at the height of approx. 2 m. If at a given level it is planned to put a platform, thus it shall be mounted and a module shall be braced in perpendicular planes. If in a given module it is not planned to mount platforms, it should be additionally strengthen in a horizontal plane with the use of bracing. Such an arrangement shall be levelled with the use of screws of base jacks, verticality of standards and angles between wedges shall be checked. After assembling a stiff fragment, subsequent modules of the first layer are added by mounting standards and girders, in the indicated fields of bracings in a design. In one of the braced perpendicular, platforms with ladders shall be placed in order to create a vertical communication. Moreover, from the height of 2 m, scaffold anchoring shall take place. At this point, it should be noticed that modular scaffolds are frequently used to build platforms which do not need to be anchored at all or they are anchored e.g. solely in the upper part. Also the platforms are erected at the last level assuming that workers use personal protective equipment, or at the two last levels assuming that the lower platform is a protection for works at the highest level. If there are no platforms at all levels of scaffold, thus the bracings have to be mounted at every 4 m in a horizontal plane.

After mounting the first layer of scaffold, platforms shall be placed at several fields in order to protect the works at assembling higher levels. Due to the security, assembly shall be performed using platforms which can be moved on ongoing basis together with the progress of works. During further works, subsequent layers shall be mounted preserving previously described order of scaffold elements. Around the vertical communication, girders shall be mounted at the height of 0.5 m and 1.0 m above platforms. Girders located in such a way serve as guardrails. In the case when working platforms are to be placed at a given level, they shall be put before bracings of fields. Subsequently, the fields are braced in compliance with a documentation. Working platforms need to be secured by guardrails made of girders at the height of 0.5 m and 1.0 m as well as toe boards. Furthermore, platforms need to be protected against falling according to the solution applied to a given system. The protection of platform is particularly significant when there is the possibility of raising the platforms by the wind.

Since the objects can fall from platform, thus the dangerous area around a scaffold shall be fenced and marked, however, the distance of this fencing from a scaffold shall equal to at least 6 m, yet not less than 1/10 of scaffold height. In the case when maintaining these distances is not possible e.g. when a scaffold is situated by a street with crossings or pedestrian crossings, a scaffold shall contain protective canopies and a cover made of safety net. Protective fans shall be at the height of at least 2.4 m and inclined at an angle of 45^{o} sloping in the direction of scaffold. In accordance with the regulation [J. Law 1997, 169], dangerous areas shall be marked by diagonal stripes – yellow and black in turns, or red and white. The dimensions of markings shall be appropriate to the dimensions of obstacle or a dangerous area. Yellow and black or red and white stripes shall be drawn at the angle of 45° and shall have similar dimensions. Dangerous area shall also be appropriately marked. Appropriate warning signs shall be hanged e.g. *"Caution", "Works at heights", "Caution, the risk of falling objects"* and if necessary appropriate warning lights shall be provided, especially at night time.

Independently from the type of scaffolds during their assembly, it is important to be accurate while making connections (proper tightening of couplers, using cotter pins, etc.), which also refers to scaffold geometry. According to works Błazik-Borowa, 2012 and Błazik-Borowa, 2014 the introduction of permissible derivations, defined in a standard [EN 12811-1:2007] for one level as 0.01 of the height of this level, does not affect bearing capacity of construction, yet further increase of values of imperfections can lead to substantial drop in bearing capacity by introducing additional bracings resulting from bending of scaffold elements.

Since while performing construction works, electric equipment is often used, lights or electric welding is conducted, thus scaffolds shall be grounded. Scaffolds assembled outdoors shall also be equipped with lightning protection system.

In order to ground the scaffold, existing grounded equipment and naturally existing grounds shall be used (having essential contact with grounded metal and reinforced concrete constructions, metal devices), and in the absence of such a possibility, new grounding equipment shall be mounted. In order to join a scaffold to the grounding equipment the following devices can be used: flexible ground wires, metal tapes, steel angles or pipes whose dimensions are as follows: cross-section of not isolated copper conductor, not less than 6 mm^2 (d = 2.76 mm), cross-section of steel cable, steel wire not less than 10mm, cross-section of metal tape not less than 36 mm^2 and thickness of 3 mm; the thickness of steel angle wall (pipe) not less than 2.5 mm. Scaffolds with grounding equipment shall be connected to ground at least at two different places. After performing a ground connection, the measurement of the resistance of grounding equipment and circuits between grounds and grounded devices shall be conducted. These measurements shall be performed by authorized staff of electro-technical facility. The results of measurements shall be written down into the protocol. If there are no shortages, and the results of measurements comply with requirements, the authorized person from electric-technical staff shall note grounding in logging control protocol of a scaffold.

Assembly of scaffold ends with the acceptance of it by a site manager or other person with construction qualifications and this fact shall be put down to a construction logbook or the protocol of technical acceptance shall be written down. The inspection of scaffold before acceptance consists of checking the condition of ground and in particular, whether bearing capacity is greater than 100 kPa, verifying the foundation of scaffold, construction net and compliance with the documentation, verifying the accuracy of scaffold assembly, verifying the distribution of bracings, and anchorings (it shall be performed by the tests of pulling out anchors in line with the assembly instruction or technical design of a scaffold), verifying working and security platforms, communication, lightning protection systems (the measurement of resistance), verifying the scaffold location in relation to power lines, verifying if scaffold protection meets the health and safety requirements (guardrails, toe boards, securing pins, etc.).

In compliance with the regulation [J. Law 2003, 47] entry to the construction logbook or, in the case when works do not require construction permit, the protocol of technical acceptance of scaffold shall include: a scaffold user, the destination of scaffold, contractor of scaffold assembly with name and surname or name and telephone number, permissible loadings of platforms and scaffold structure, the date of scaffold acceptance, the resistance of lightning protection system and the dates of subsequent scaffold reviews.

After the implementation of listed activities, an information board shall be placed on a scaffold which shall contain information on the contractor of scaffold assembly giving the name and surname or name and telephone number and permissible loadings of platforms and a scaffold structure.

3.6 The exploitation of scaffolds

The subsequent stage of scaffold ‘life’ is its operation (Fig. 3.12). According to work [Gawęcka, 2011] at this stage, 50% of accidents occur at scaffolds. It results from the fact that the usage period is most frequently longer than the assembly or disassembly of construction. Moreover, scaffolds are used by construction workers of different specialities, not only assemblers who are prepared to work at heights. All irregularities resulting in tiredness e.g. improper work organization, exposure to environmental impacts, a scaffold subjected to vibrations, etc. and cause that construction workers are less concentrated upon work and forget about protection which often interferes with work. Additionally, for many workers work at heights is not tightly related to occupation which they perform. Frequently they are seconded to help other construction workers, or a particular situation demands conducting an activity at places with difficult access.

Tiredness reduces concentration on implementing tasks. This results in that workers lean against scaffold elements, attempt at making work easier by resigning from personal protection equipment, they carry out their work not paying attention that their actions can cause damage of scaffold, they leave objects on platforms etc. In the paper [Błazik-Borowa, 2015] it is stated that almost 50% of accidents at construction sites are related to falls from scaffolds, and almost 20% of accidents are related to objects falling from scaffolds.

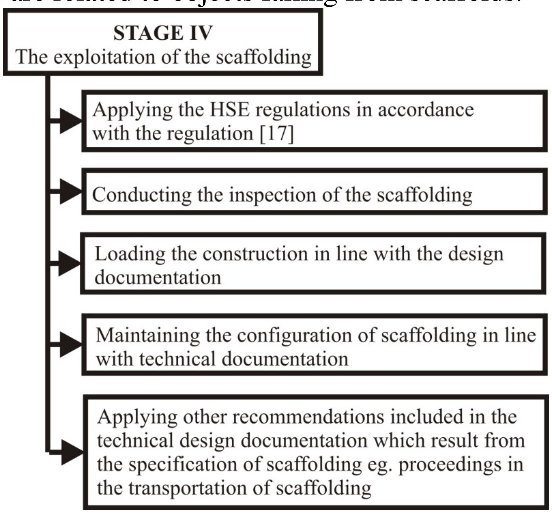


Fig. 3.12 The operating of the scaffolding

During the operation period, another problem appears independently from users. This issue concerns vandalism. Not always is it possible to isolate a scaffold from third parties. Unfortunately, even the smallest theft attempt of scaffold elements or just disassembling elements poses the danger of scaffold emergency and thus results in that a scaffold does not fulfil its role which is ensuring the security of workers. In relation to serious hazard connected to work on scaffolds, a lot of recommendations mentioned in chapter 2 are listed in regulation [J. Law 2003, 47]. Whereas, independently from them, it should be bear in mind that:

- in relation to performed works first-aid kit shall be placed at a building site and an information board with emergency telephone numbers shall be placed in a visible place,
- a board defining a contractor of scaffold assembly giving name and surname or name and telephone number as well as permissible loadings of platforms and scaffold structure shall be placed on a scaffold in a visible place,
- an area around scaffold need to be secured against other parties as well as against building machines,
- works at heights shall be conducted applying personal and collective protection, in compliance with health and safety regulations,
- workers need to have valid medical examinations in terms of performed works,
- workers need to undergo health and safety training for works at heights organized in the form of on-site instruction,
- work shall be organized in a proper manner by proper division of work, appropriate number of workers to perform a task, organizing ergonomic work stand with easy access to work place, providing proper equipment.

Other recommendations, related to the operation of scaffold, are listed below and these are:

- it is not allowed to load platforms of scaffolds by materials above bearing capacity given at an information board or in a technical design, usually permissible loading equals to 2 kN/m^2 in compliance with 3^{th} class of loading, according to the standard EN 12811-1:2007,
- work at two working platforms in one upright, and one above the other is prohibited,
- simultaneous work on two working platforms in one upright is permitted provided that appropriate protection e.g. a tight roof is applied,
- it is not allowed to gather on platforms,
- it is not allowed to collect materials and devices at one side of scaffold,
- it is not allowed to lean against the wall of building by the persons standing on platforms,
- it is not allowed to climb the standards, longitudinal stiffeners, transoms and guardrails of scaffolds,
- it is not allowed to drop disassembled elements of scaffolds,
- it is not allowed to disassembly scaffold elements,
- it is not allowed to leave tools at the edges of scaffold platforms,
- it is not allowed to make sudden movements, lean over guardrails,
- closing lids of hatches after every crossing to neighboring level of scaffold,

- during vertical transport, other scaffold users shall be informed about our activities e.g. with the use of acoustic signaling,
- a scaffold shall be cleaned on ongoing basis from dirt as well as unnecessary materials and tools,
- in the case of snowfalls, a protection net and snow from platforms shall be cleaned,
- it is not allowed to carry out construction works on an iced construction,
- it is not allowed to carry out works on scaffolds during thick fog, precipitation, sleet and strong winds.

A scaffold is a temporary structure in which there are a lot of elements that can cease to serve their function during operation time because of different reasons. These are primarily couplers and handles. Couplers loosen, which results in the decrease of connections bearing capacity. Handlers of platforms break under the influence of loads and mechanical damage, which can cause the collapse of a platform. Another issue concerns loosening of anchors in walls. At any stage of operating time, a scaffold can be overloaded, and thus it can result in its damage. In relation to these problems, inspections of scaffolds are essential during their operation. According to an old standard PN–M-47900-2:1996, three types of inspections shall be performed: on daily basis, decade per 10 days and ad-hoc ones. Since these are the entries of invalid standard, thus in line with law, these recommendations are not in force. However, the recommendations of regulation are in force where it is stated that *"§ 127. 1. Scaffolds and mobile working platforms shall be checked by a site manager or qualified person every time after strong winds, precipitation as well as other factors posing a thread to safety of performed works, and working breaks longer than 10 days, as well as periodically, not less than once per month. 2. The scope of activities coved by inspection, which are mentioned in Art. 1, is defined by a manufacturer's instruction or an individual project"*. Despite the fact that a standard PN–M-47900-2:1996 is invalid, due to safety reasons, it seems reasonable to perform inspections on daily basis. Daily inspections can be conducted by a company worker who operates a scaffold. Other inspections, i.e. main inspections (these ones which shall be performed at least once a month), ad-hoc inspections after the action of factors which can damage a scaffold and inspections after a break in scaffold operation shall be conducted by a site manager or a person having construction qualifications. During an inspection it should be checked if [Kmiecik, 2008]:

- base plates of scaffold are flooded,
- a scaffold is damaged of deformed,
- a scaffold is properly anchored,
- connections are not loosened,

- the condition of working and communication platform surface is appropriate (tidiness of platforms, in winter conditions – anti-slip protection on platforms, the condition of platforms fixation),
- electric conductors are well insulated and do not contact with a scaffold construction,
- there is no shortage of elements securing workers on a scaffold and people around scaffolds, such as guardrails, toe boards, canopies, etc.,
- an area around a scaffold is properly secured and marked.

If assembled scaffolds are operated longer than 10 days, thus inspections of the quality of scaffolds earthing shall be performed every 10 days, and it shall be written down in the blank part of control logbook.

Defects noticed during controls shall be removed after every inspection before getting to work. The results of controls shall be recorded in a construction logbook or control protocol by persons performing inspections.

These are the most important rules of scaffold operation, yet there is one more significant aspect, i.e. disassembly of individual elements of scaffold. It can happen that one element impedes work so it is removed. As an effect, health and safety regulations are violated, when e.g. a guardrail is removed, or the decrease of construction bearing capacity, e.g. when a bracing and an anchor is removed. While operating a scaffold, uncontrolled alterations to scaffold structure are inadmissible The basic role of a scaffold is to provide security and comfort of work. Nevertheless, without the application of above operating rules as well as common sense in workers' behavior, it will not serve its role.

3.7 The scaffold disassembly

After disassembly of scaffold it is the end of its use. The disassembly stage (Fig. 3.13), similarly to assembly stage, is very risky for assemblers since elements providing security and stability of construction are removed from a structure. Disassembly of elements shall be conducted in an opposite way to assembly. Disassembly shall be launched from the highest level. Only after finishing one layer, the disassembly of elements of lower level can be started. The disassembly of anchoring shall be conducted simultaneously with a construction disassembly. Once the disassembly is completed, all elements shall be cleaned, reviewed and segregated depending on their state of damage

In the course of disassembly, some irregularities can occur, which affects further application of particular elements of scaffold. Damage of elements can occur as a result of hammer strokes, throwing elements from a substantial height as well as improper storage of elements. The significance of these factors for the safety of workers at subsequent scaffolds is described in a subsection 3.4.

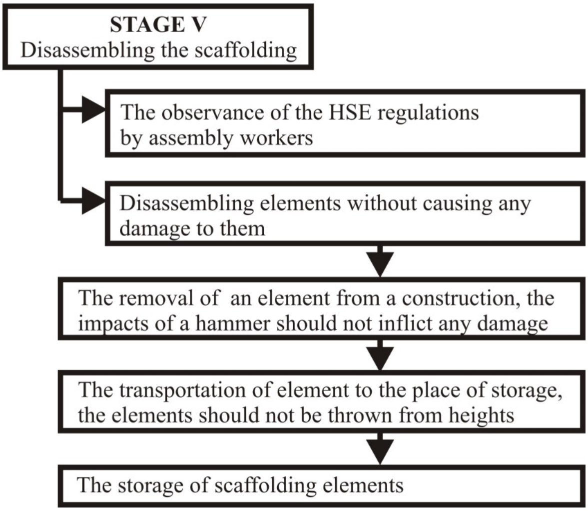


Fig. 3.13 The disassembling the scaffolding.

3.8 Conclusion

This chapter contains the knowledge useful primarily at construction sites. Nevertheless, research and design works need to be performed to prepare a scaffold for serving its role. Thus subsequent chapters will be devoted to these issues.

4 Laboratory tests on construction scaffolds

4.1 Introduction

The preparation of production of new scaffold system, and then its introduction to the market, in the majority of European countries, need to be proceeded by tests resulting in the certification. In Poland, the certification is not obligatory, yet in line with the Regulation on Health and Safety at work during construction works [J. Law 2003, 47] a scaffold must comply with the assessment criteria of materials in terms of safety. The practice of companies producing scaffolds shows that independently from this entry, scaffold manufacturers are aware of the scaffold importance for the safety of their users and attempt at meeting the requirements of ergonomics and work safety as well as appropriate load bearing capacity. Thus the one of preparation stages of a new system to be introduced to the market are laboratory tests, completed with computer-aided calculations which enable determining strength parameters of scaffold components.

The basic document on the basis of which lab tests of scaffolds shall be conducted, is the standard EN 12811-3:2003. This standard defines which types of tests shall be conducted, in which scope of loads, which ones shall be determined by tests as well as the way in which static analysis shall be performed whose results are the ultimate values characterizing examined elements, e.g. the value of maximum acceptable force acting in the center of a ledger span. However, information on which elements or sets of elements shall be examined can be found in the standard EN 12810-2:2010, EN 74-1:2006 and EN 74-2:2009. Information on workplace schemes which can be used to test couplings can be also found there. Independently from the type of examined systems, materials of which a scaffold is made shall always be tested. Nevertheless, in reference to the research on scaffolds, five types of these tests can be distinguished (cf. EN 12811-3:2003):

- examining structure of representative section of system configuration from the bottom part of a scaffold, evoked by vertical and horizontal static loads, acting within one cycle, called as global loads,
- tests with static loads acting within several cycles, required for all the elements, such a test is called as a low-cycle test in this paper,
- fatigue tests (repeated loading), required for elements which can be subjected to loads of considerable number of cycles within the operation period, e.g. stair steps,
- dynamic tests (vibration tests), required only in the cases when there is a risk that a scaffold is subjected to dynamic excitation,
- tests at impulse load (impact load), required for elements which can be subjected to strikes, e.g. toe boards and platforms, due to serving the protective role.

Among listed tests, low-cycle tests for scaffold components as well as tests on their load bearing capacity at impulse load are most frequently performed. In the further part of this chapter, particular tests along with the procedures of their performance are described on the basis of the standard recommendation EN 12811-3:2003.

4.2 Tests on the part of scaffold system

The methodology for conducting research on the representative section of scaffolds and on which basis the validation of a numerical model is conducted, is described in the standard EN-12810-2:2010. It primarily concerns façade scaffolds, however, it happens that selected issues are also used for modular ones. The standard EN 12810-2:2010 distinguishes two types of research:

- type 1 – verification of system behavior under the influence of static load (Fig. 4.1),
- type 2 – determination of critical coefficient α_{cr}, at which buckling occurs (Fig. 4.2).

A sample test stand to type 1 test, used in Technical Research Institute in Sweden, is shown in Fig. 4.3.

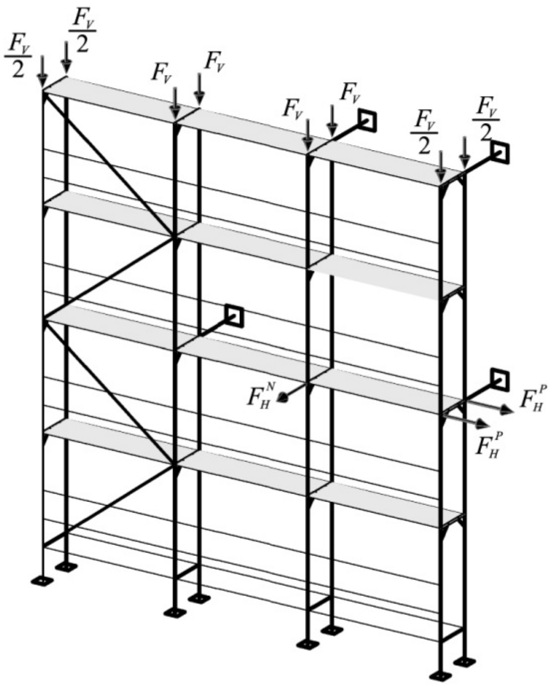


Fig. 4.1 The standard proposition of scheme of scaffold loading during type 1 test [EN 12810-2:2010]

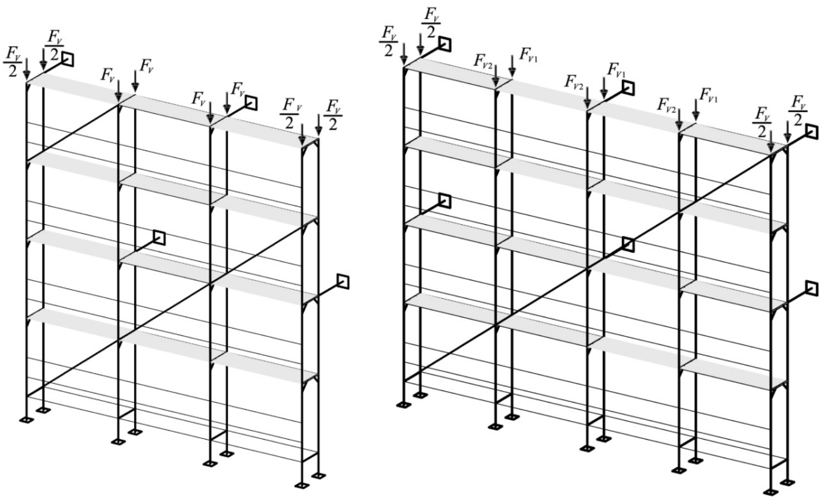


Fig. 4.2 The standard proposition of schemes of scaffold loading during type 2 test [EN 12810-2:2010]

In type 1 test, the first stage is to load a scaffold by the horizontal force F_H^n, normal to the elevation and acting in the node point, not anchored, as well as two horizontal forces F_H^p parallel to the elevation, acting in two neighboring node points, lying in a not anchored plane. The location of forces is shown in Fig. 4.1. The value of forces is determined from an equation:

$$F_H = F_d n_p \tag{4.1}$$

where: F_d is the calculation force of wind and n_p is the number of all points which lie on the same line in a horizontal plane. In the case of F_H^n force, the number of nodes is $n_p = 2$ and in the case F_H^p force, the value n_p depends on the number of frames. For the scaffold shown in Fig. 4.1, the number of nodes is $n_p = 4$ for parallel direction.

Forces F_H^p and F_H^n are applied from zero to final value, determined from the equation. Then the system is unloaded. This procedure aims at arranging scaffold elements and removing possible clearances. Subsequently, the scaffold is subjected to detailed inventory in order to define accurate geometrical inaccuracies and again loaded to previously established values of horizontal forces. After conducting the procedure of unloading and loading, the values of horizontal forces are treated as dead loads. Another loads, which are applied to upper nodes of scaffold, are vertical forces F_v, whereas force $0.5F_v$ is applied to the extreme posts. During tests, the value of these forces is increased until damage occurs.

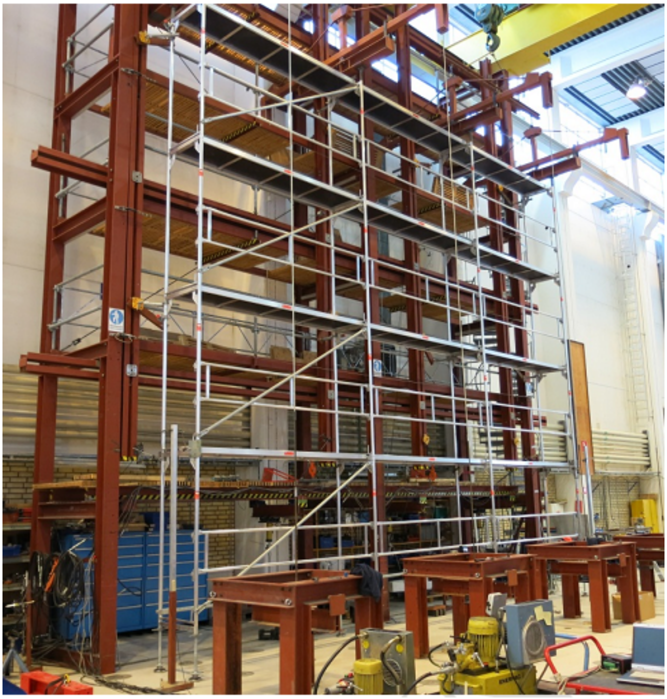


Fig. 4.3 The scaffolding used by the Swedish Technical Research Institute in the global test

While loading a scaffold, displacements shall be measured from time to time, in a continuous mode. Horizontal displacements shall primarily be measured in the places of horizontal forces application, e.g. as it is shown in Fig. 4.4.

The numerical model shall be developed for the same system which within a elastic range and outside a it shall generate similar diagrams of horizontal displacements depending on vertical forces F_v.

In the case of type 2 test, only vertical loads are applied to upper points of standards, as it is presented in Fig. 4.2. Obviously, forces at extreme standards shall take the half value of forces applied to central standards. As in the case of type 1 test, the structure shall initially be loaded so as not to exceed the elastic range. Then it shall be unloaded, geometry shall be inventoried, and a proper loading process shall be launched until damage occurs. During tests, the values of forces as well as horizontal forces shall be measured in vertical and horizontal directions to elevation.

On the basis of type 2 tests, the values of force F_v are determined, at which the loss of stability appears. Knowing the value of force which causes the buckling of system, the coefficient α_{cr} is ratio as a quotient of loading, at which the loss of stability occurs, and basic load, defined as e.g. usable load.

The calculation model of scaffold, developed for type 1 tests, shall be validated once again by determining the coefficient α_{cr}, which shall be close to the real value, yet simultaneously, it shall take safer value for the construction, thus lower one.

Two types of tests are described below. In practice, in the course of performing every test, damage can occur due to both the loss of structure load bearing capacity as well as the loss of stability. Thus the type 1 test needs to be conducted, and after its completion, the reason for damage needs to be defined. If the damage of scaffold is caused by the loss of load bearing capacity and not stability, then type 2 test can possibly be carried out.

Research of this type is required only in Sweden, France, and Germany due to the dimension of test standing.

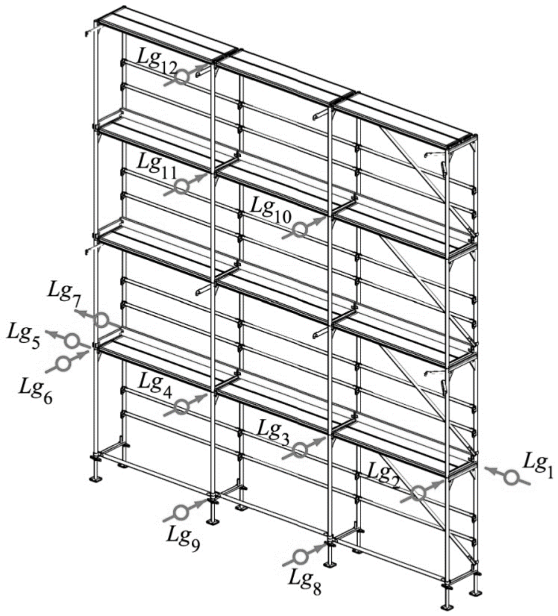


Fig. 4.4 The locations of displacement gauges

4.3 Low-cycle research

According to the standard EN 12811-3:2003, low-cycle research shall be performed on unused, new elements. Elements in which there are welds and thread pins are an exception. These elements of scaffolds shall be used in a scaffold before examination which was assembled for three times and disassembled also for three times. Every test shall consist of two stages:

- initial stage, in which initial load bearing capacity of the system shall be determined (the set of elements, element, coupling) – R_k,

- proper tests, in which load bearing capacity of the system is examined in at least three cycles in the case of full cyclic load at load changing within the scope of:

$$\left(+1.0\times\frac{R_k^+}{\gamma_M\gamma_F};-1.0\times\frac{R_k^-}{\gamma_M\gamma_F}\right) \tag{4.2}$$

or in the case of limited cyclic load within the scope of:

$$\left(+0.1\times\frac{R_k^+}{\gamma_M\gamma_F};-0.1\times\frac{R_k^-}{\gamma_M\gamma_F}\right) \tag{4.3}$$

Partial coefficients of safety, in compliance with the standard EN 12811-1:2007, are $\gamma_M = 1.1$ i $\gamma_F = 1.5$.

In the initial stage, tests shall be performed within the frame of which load is applied in one cycle and it alters from 0 to the value at which the loss of load bearing capacity of an element or tested set of elements is stated. Every type of tests in reference to one type of element shall be conducted at least five times.

During proper tests, apart from characteristic load bearing capacity R_k, the calculation value R, a partial coefficient of safety γ_{R2} , as well as in some cases, stiffness c and the value of clearances in the construction d_o are also determined.

Most frequently, research is conducted at full load. Research at limited load is performed when there are clearances in a system. Independently from the type of test, due to the scope of load, at least three cycles shall be carried out, in which load alters in terms of values listed above, and of the same direction, and in the last cycle, loading is increased until the system is destroyed or the system is stated to lose its load bearing capacity, on the basis of its behavior. If the element can act at load only of one turn, i.e. ledgers are bent in one direction from vertical loads, acting downwards, thus load in subsequent cycles can be applied not in the scope of negative to positive value of load, but from zero to the limit value. Such an examination shall be repeated at least five times. Loading shall be applied with such a velocity so that it can be assumed that it is a static load. The standard EN 12811-3:2003 recommends that load shall be applied in a continuous manner with the speed of $0.25R_k$ per minute or applied gradually so that in one stage the growth of load is $0.1R_k$.

The first step of the analysis of results consists in defining the function describing the load - displacement dependency (Fig. 4.5). In the case of the measurements of several cycles, a diagram, for which the function is chosen, is the envelope of results. The function, approximating the load-displacement dependency, shall be selected so that the correlation coefficient of diagram of measurement results and a chosen function, satisfies the condition $\rho^2 \geq 0.95$. If the whole diagram cannot be approximated by one function, i.e. the recommended correlation coefficient cannot be obtained, thus the diagram shall be divided into fragments. The division of load-displacement diagram shall be selected so that the value ρ^2 for all fragments exceeds 0.95. In practice, the procedures of test should be analyzed and its characteristic fragments, e.g. leaning a head against pipe while examining a node results in a change of a system work, and thus the change of diagram shape. In order to illustrate the rules for the selection of approximating functions, the results for diagrams, shown in Fig. 4.5 are listed in Table 4.1.

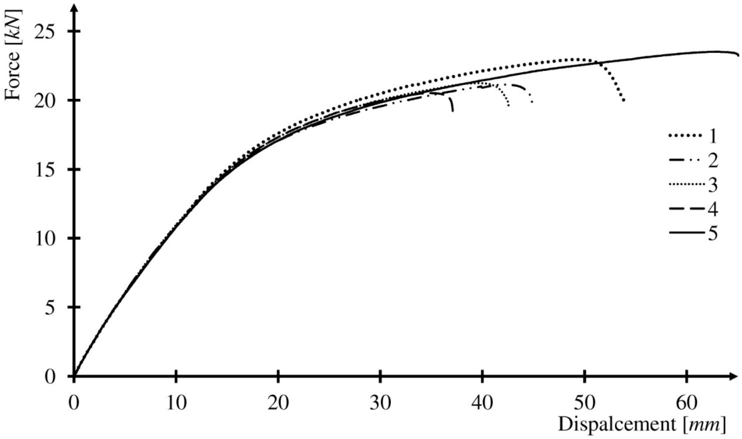


Fig. 4.5 Sample results of tests on load bearing capacity of ledger, loaded by the force concentrated in the mid-span

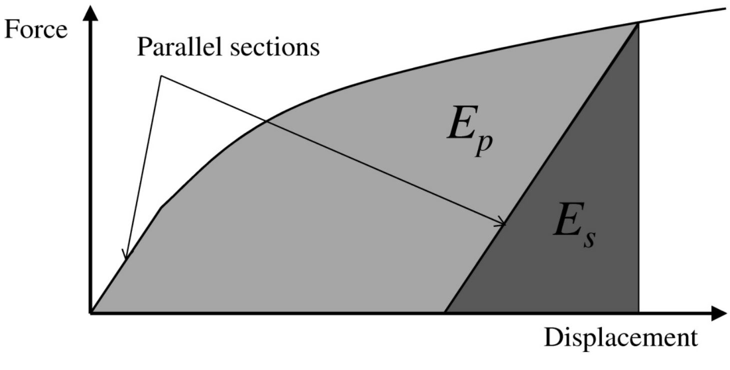


Fig. 4.6 Designations for calculation of coefficient q_e (an area from which E_p is determined contains an area from which E_s is determined)

Load bearing capacity of system, which can mean damage of tested elements, loss of stability, huge displacement and substantial plastic deformations, slippages, including other elements to work which shall be protected against damage etc., is most frequently determined parameter. In the standard EN 12811-3:2003, one more situation is given as load-bearing capacity limit. It is the value of loading at which the ratio of plastic energy E_p to elastic energy E_s is

q_e=E_p/E_s=11. The values of plastic energy E_p and elastic energy E_s are determined as areas under the load-displacement diagrams, as it is presented in Fig. 4.6. Basically, every test of new system requires not only static calculations but also the analysis of elements behaviour in order to check what can be treated as load-bearing capacity loss. Even while testing the same element, but e.g. of different length, various reasons can be expected, proving the end of correct work of element. The description of particular component's behaviour during research is also useful when the system is not stiff enough and structural changes to scaffold elements should be introduced. A manufacturer of scaffold having the information on the behaviour of element while loading, can design more accurately essential structural or technological changes.

Table 4.1 The approximation of force-displacement curves obtained in tests of concentrated force measurement applied to a legder

No.	Equation of a line	Crossover point of a line and curve described by a polynomial		Polynomial equation
		x [mm]	$r^a_{u,i}$ [kN]	
1	$r^a_{u,i}$ = 1.4836x ρ^2= 0.9992	1.31	1.95	$r^a_{u,i}$ = -0.12221+1.43486x+ -0.0326192x^2+0.000267427x^3; ρ^2= 0.9996
2	$r^a_{u,i}$ = 1.3686x ρ^2= 0.9998	2.53	3.46	$r^a_{u,i}$ = -0.307809+1.49234+ -0.0378136x^2+0.000347602x^3; ρ^2= 0.9996
3	$r^a_{u,i}$ = 1.3535x ρ^2= 0.9996	2.68	3.63	$r^a_{u,i}$ = -0.374135+1.50274x+ -0.0372194x^2+0.000333991x^3; ρ^2= 0.9998
4	$r^a_{u,i}$ = 1.3371x ρ^2= 0.9994	2.76	3.71	$r^a_{u,i}$ = -0.292929+1.44403+ -0.0327007x^2+0.000243647x^3; ρ^2= 0.9996
5	$r^a_{u,i}$ = 1.4540x ρ^2= 0.9994	1.45	2.12	$r^a_{u,i}$ = 0.453929+1.29043x+ -0.0267947x^2+0.000195664x^3; ρ^2= 0.9986

After the analysis of elements behaviour during tests, defining functions approximating the load-displacement diagram and making the decision on which points of the diagram can mean the end of safe system work, the static analysis of results can be performed. Subsequent steps of these calculations are:

1. Determination of the maximum value (the ultimate value) $r^a_{u,i}$ of the resistance for the i test, at which bearing capacity loss is defined as the smallest value among:

- the load value (force, torque, uniformly distributed load), at which q_e =11, where q_e is the ratio of the plastic energy to the elastic one,

$$q_e = \frac{E_p}{E_s} \tag{4.4}$$

- the value at which there is no resistance of the element to further load, so it is the first maximum in the graph of force versus displacement,
- the value at which the displacement causes damage which cannot be repaired.

2. Change of parameter value $r^a_{u,i}$ to $r^b_{u,i}$ due to inaccuracy in elements production, measured by standard deviation δ of geometric characteristics, affecting tested parameter; these changes need to be conducted according to the following principles:

   $\delta \leq 0.01 - r^b_{u,i} = r^a_{u,i}$

   $0.01 < \delta \leq 0.1 - r^b_{u,i} = (1-\delta) r^a_{u,i}$

   $0.1 < \delta$ – impermissible situation.

3. Determination of the parameter value after taking into account the slenderness of the element:

   $$r^c_{u,i} = \frac{r^b_{u,i}}{\xi_a},$$

   where:

   for the tests on nodes:

   $\xi_a = 1.0$

   for other elements:

   $\xi_a = 1.1$ for $0 \leq \bar{\lambda} \leq 0.2$,

   $$\xi_a = 1.1 - 0.1\frac{\bar{\lambda} - 0.2}{1.5} = \frac{3.26 - 0.2\bar{\lambda}}{3} \text{ for } 0.2 \leq \bar{\lambda} \leq 1.7,$$

   where $\bar{\lambda} = \sqrt{\frac{N_{pl}}{N_{cr}}}$ – the slenderness, $N_{pl} = f_y A$ – the normal force, at which the

yield point is reached, $N_{cr} = \frac{\pi^2 EJ}{L^2}$ – the critical force, J is lower value of J_2 and J_3. L – the elements length.

4. Static analysis is performed assuming that the values of logarithms of examined parameters have normal distribution, thus for every value $r^c_{u,i}$, $y_i = \ln\left(r^c_{u,i}\right)$ shall be calculated.
5. Characteristic value of parameter is defined as 5% quantile with the confidence level of 75%, thus next step is determination of bottom quantile of about 5% from a formula:
   $y_5 = \bar{y} - k\sigma$,
   where: $\bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i$ – average value,
   $\sigma^2 = \frac{1}{n}\sum_{i=1}^{n}\left(y_i - \bar{y}\right)^2$ – standard deviation,
   n –number of tests,
   k = 2.46 at n = 5.
6. Determination of the limited basic characteristic resistance:
   $R_{k,b} = e^{y_5}$.
7. Determination of the safety factor γ_{R2} from the equation
   $1.25 \geq \gamma_{R2} = -0.025\bar{q}_e + 1.275 \geq 1.00$,
   where:. $\bar{q}_e = \frac{1}{n}\sum_{i=1}^{n} q_{ei}$.
8. Determination of the nominal characteristic value of the resistance
   $R_{k,nom} = \frac{R_{k,b}}{\gamma_{R2}}$.
9. Determination of the maximum specified permissible value of examined parameter
   $R = \frac{R_{k,nom}}{\gamma_M \gamma_F}$.

Table 4.2 presents the results of static analysis in reference to the research on concentrated force applied to the mid-span of a ledger, on the basis of diagrams in Fig. 4.5 and the results of approximation, listed in Table 4.1. Presented analysis is performed for points where the extreme in the load-displacement diagram is obtained.

Permissible value of concentrated force e.g. R = 9.25 kN means that during operation, concentrated force 9.25 kN can be applied to a ledger at a mid-span. Nevertheless, while calculating the structure including a ledger, force shall be multiplied by partial safety coefficient γ_F = 1.5.

Table 4.2 Compilation of calculation results of concentrated force applied to a ledger for which a plastic deflection of element is L/300

No	Point for which a plastic deflection of element is L/300					$r^b_{u,i} = r^a_{u,i}$	$r^c_{u,i} = \frac{r^b_{u,i}}{\xi_a}$	$y_i = \ln(r^c_{u,i})$
	x [mm]	$r^a_{u,i}$ [kN]	E_p [kNmm]	E_s [kNmm]	q_e	[kN]	[kN] $\xi_a = 1.08$	
1	49.13	23.13	817.62	177.58	4.60	23.13	21.42	3.06
2	42.04	21.31	634.24	163.18	3.89	21.31	19.73	2.98
3	39.71	21.43	594.44	166.74	3.57	21.43	19.84	2.99
4	34.81	20.70	489.16	157.41	3.11	20.70	19.16	2.95
5	63.14	23.68	856.80	190.06	4.51	23.68	21.93	3.09
average value					$\overline{q}_e$ =3.94	average value		$\overline{y}$ =3.01
standard deviation								σ =0.0517
5% quantile with the level of confidence of 75%								y_5=2.89
safety coefficient								γ_{R2}=1.18
permissible basic characteristic value of concentrated force								$R_{k.b}$=17.95kN
permissible nominal characteristic value of concentrated force								$R_{k.nom}$=15.26kN
the specified permissible value of concentrated force								R=9.25kN

In the tests on nodes, their susceptibility shall be determined. In such a case, for all measurements, a relationship between load and displacement is determined within the spiral range. Subsequently, stiffness is determined according to the following procedure:

1. Determination of the average value of the stiffness (as the inverse of displacement) and the standard deviation according to formulas:

$\overline{c} = \frac{n}{\sum_{i=1}^{n} \frac{1}{c_i}}$ – the average value;

$\sigma_c^2 = \frac{1}{n} \sum_{i=1}^{n} (c_i - \overline{c})^2$ – the standard deviation;

$v_c = \frac{\sigma_c}{\overline{c}}$ – the variation coefficient.

2. Determination of the characteristic stiffness c_k depending on the standard deviation according to EN 12811-3:2003.

The set of low-cycle tests which shall be conducted depends on the type of scaffolds. In the case of frame scaffolds, the following research shall be performed in compliance with the standard EN 12810-2:2010:

- research on a representative section of system configuration,
- research on stiffness of platforms in horizontal planes of a set shown in Fig. 4.7,
- research on platforms at continuous loading,

- research on brace in the system of scaffold shown in Fig. 4.8,
- research of load bearing capacity of façade frame by the verification of load bearing capacity of frame post,
- research on railguard work while loading it in mid-span and connection with a post,
- research on load bearing capacity of supports at continuous loading and concentrated force loading,
- research on load bearing capacity of couplers according to EN 74-1:2006.

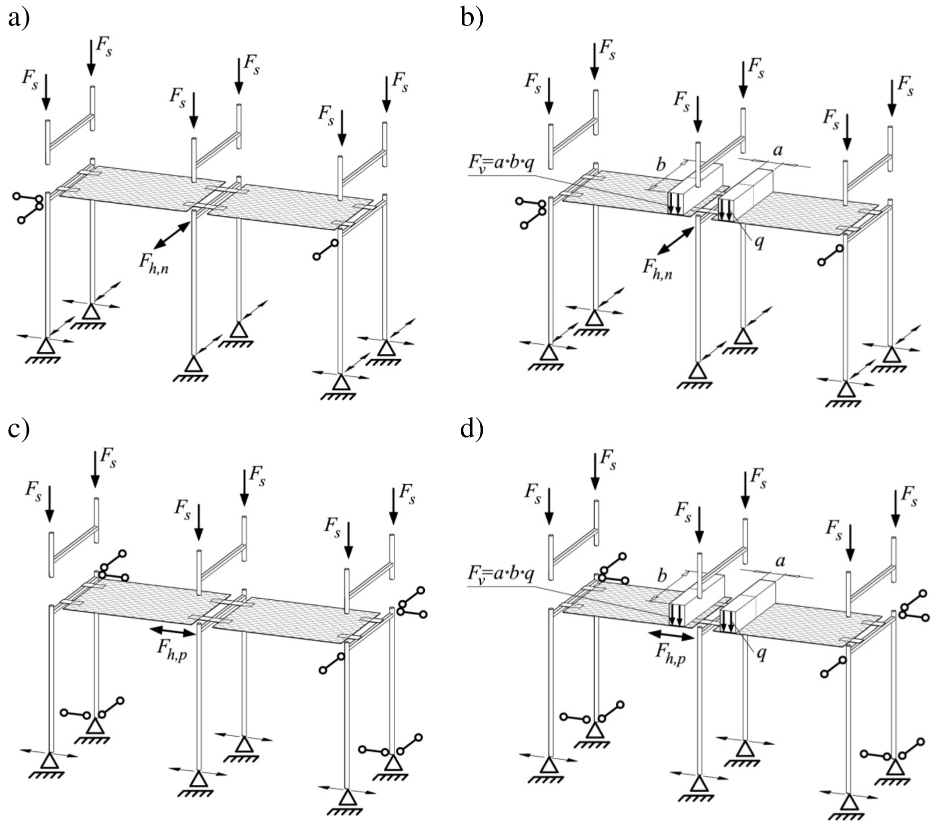


Fig. 4.7 Test set ups to determine: a) the stiffness and resistance normal to the façade by applying a horizontal force, b) the stiffness and resistance normal to the façade by applying a horizontal force with vertical loads on the platforms, c) the stiffness and resistance parallel to the façade by applying a horizontal force, d) the stiffness and resistance parallel to the façade by applying a horizontal force with vertical loads on the platforms. EN 12810-2:2010

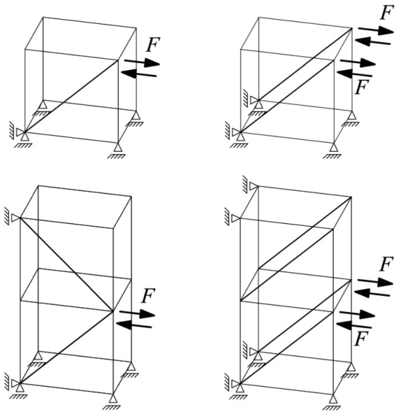


Fig. 4.8 The schemes of tests in configuration with bracings [EN 12810-2:2010]

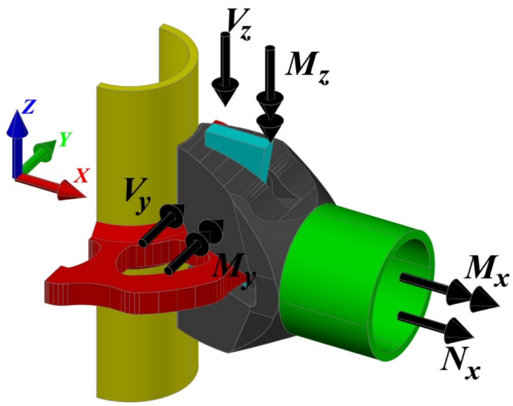


Fig. 4.9 The scheme of the node of modular scaffold with marked internal forces [Pieńko, 2014]

In the case of system modular scaffolds, according to the standard EN 12810-2:2010, the following low-cycle tests shall be conducted:

- research on load bearing capacity of nodes at six internal forces, shown in Fig. 4.9, (an example of test stand to measure load bearing capacity of a node during deflection of a ledger in a horizontal plane is presented in Fig. 4.10),
- research on load bearing capacity of a ledger at concentrated force load applied in mid-span Fig. 4.11),
- research on capacity bearing of ledgers at uniformly distributed loads,
- research on capacity bearing of standards (Fig. 4.12),
- research on load bearing capacity of bracings at compressive and tensile forces,
- research on load bearing capacity of platforms at continuous loading,
- research on horizontal stiffness of platforms.

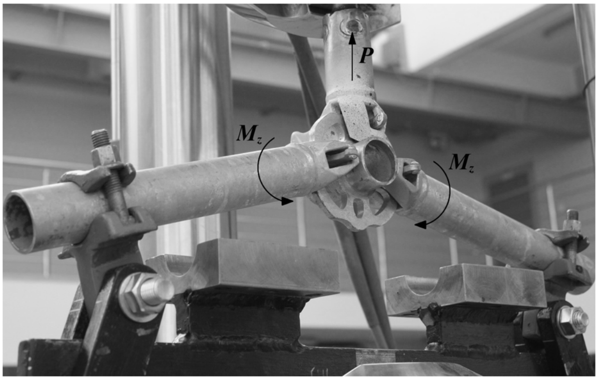


Fig. 4.10 The test stand to examine load bearing capacity of a node during deflection of a ledger in a horizontal plane [Pieńko, 2014]

The research on pulse loading of platforms, which is described in the standard EN 12810-2:2010 can be added to the set of tests. However, what the full research program on construction scaffolds shall cover in fact depends on a manufacturer, and in the case of scaffold certification on certifying authority. This is a scaffold manufacturer who shall decide which tests are necessary to verify applied construction solutions in a system, which information on load bearing capacity of particular elements is needed as well as which information is planned to be included into catalogues and made it available to designers. In the case of scaffold certification, in compliance with the standard EN 12810-2:2010, this is certifying authority that decides which laboratory tests and static-strength calculations are essential to assume whether a scaffold meets the requirements of a given certification.

Fig. 4.11 The view of the whole test stand with a ledger loaded by concentrated force applied in mid-span

Fig. 4.12 The test set-up to examine load bearing capacity of standards

4.4 Other tests

Selected elements of scaffold, depending on their application, can be subjected to different tests related to the specificity of usage. Hence, in the case of platforms in compliance with the standard EN 12810-2:2010, tests consisting of throwing a sphere in mass of 100 kg and in diameter of 0.5 m from the height of 2.5 m on a platform can be made. Such a test aims at verifying if a person falls down on a platform, it will protect him against further fall. A platform under the influence of such a load can deform, yet cannot damage so that it falls from a scaffold. Testing shall be performed for three times. The place of sphere impact to a platform can be the center of edge of a platform. The places of sphere impact to a platform during tests depending on the width of a platform are listed in Table 4.3 with markings shown in Fig. 4.13.

Table 4.3 Positions of impact to be tested [EN 12810-2:2010]

Width of the platform	Positions of impact in accordance with Fig. 4.13	
	Parameter	
	Maximum shear force	Maximum moment
$w \leq 0.7$m	*PS1*	*PM1*
$w > 0.7$m	*PS1* and *PS2*	*PM1* and *PM2*

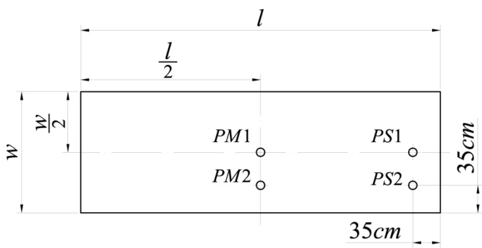


Fig. 4.13 Position of impact points [EN 12810-2:2010], *w* – platform width, *l* – platform length

Research on applying pulse force is also used for guardrails and toe boards. The task of a guardrail is to protect a person who will abruptly lean against it, whereas a toe board must prevent objects, which could strike it, from falling.

Treads should be subjected to fatigue tests. They should be loaded by 300000 cycles and the amplitude of this loading shall be equal to operating load, e.g. 1 kN, thus human weight who repeatedly climb the stairs. Elements, in which clearances can occur during operation, should be subjected to dynamic tests. Examination shall consist in loading an element by at least 3000 cycles with the force amplitude of a value $0.1\times\frac{R_k^+}{\gamma_M\gamma_F}$.

Research on scaffolds not only consists of laboratory tests. The inspection of scaffolds is also performed by computer-aided calculations. All types of tests for particular types of scaffolds are compiled in Table 4.4-4.7,. Types of tests, standard references, the number of essential tests, etc. are listed in tables.

4.5 Conclusion

Correct work of a scaffold depends on load bearing capacity of elements and their connections. They obviously depend on the material from which they are made and elements intersections. Nevertheless, bearing capacity of particular elements and whole scaffold primarily depends on the quality of execution, and this element is checked during laboratory tests. Thus the admission to the market of scaffolds shall always be proceeded by tests and then further quality of produced elements should also be controlled in such a manner.

Table 4.4 The compilation of lab tests on elements occurring in façade and modular scaffolds

No.	El.	Test type	Reference	Way to perform	Min_i	Min_p	Remarks
1.	Base jacks	Maximum normal force	EN 74-3 EN 12811-3 p.7.2	Lab tests	3	3	
2.		Maximum force shearing a screw	EN 12811-3 p.7.2				
3.		Determination of maximum axial force, shearing force and bending moment	EN 12811-1 Aneks B	Calculation			
4.	Toe boards	Test consisting in applying force to a toe board of a value 0,15kN	EN 12811-1 p.6.2.5.2 EN 12811-1 p.6.3.2 EN 12811-3 p.7.2	Lab tests	5	5	Tests can be performed for the longest toe board in a system
5.		Test consisting in striking a toe board by an element of 15 kg (impact test)	EN 12811-3 p.7.5			3	
6.	Platform	Measurement of platform deflection		Lab tests		3	Results of tests need to the verified of by computer models
7.		Maximum permissible load value of evenly assembled platform	EN 12811-1 p. 6.2.2.2 p.6.3.1 EN 12811-3 p.7.2	Calculation	5	5	Tests shall rather be conducted for the longest platforms, but this is also the decision of certifying authority
8.		Maximum load on the surface of of 0.5 m x 0.5 m in mid-span	EN 12811-1 p. 6.2.2.3 p.6.3.1 EN 12811-3 p.7.2				
9.		Maximum load on the surface of of 0.2 m x 0.2 m over support	EN 12811-1 p. 6.2.2.3 EN 12811-3				

10.		Fall of sphere of 100 kg from the height of 2.5 m on the center of a platform (impact test)	EN 12810-2 Aneks B EN 12811-3 p.7.5	Lab tests		3	
11.		Fall of sphere of 100 kg from the height of 2.5 m on the edge of platform (impact test)	EN 12810-2 Aneks B EN 12811-3 p.7.5				
12.	Stairs	Tests on load bearing capacity of a whole scaffold with stairs with continuous loading compatible with a loading class at 6 m^2 and 0.75 kN/m^2 at remaining surface	EN 12811-1 p.6.2.2.6	Computer calculations			
13.		Cyclic tests on load bearing capacity of a tread in stairs – force of a value 1.5 kN applied to the center of tread	EN 12810-1 p.8.5.1 EN 12811-3 p.7.3	Lab tests		1	Inspection is recommended for aluminum stairs
14.		Cyclic tests on load bearing capacity of a tread in stairs – force of a value 1.5 kN applied to stairs stringers	EN 12810-1 p.8.5.1 EN 12811-3 p.7.3				
15.		Tests on load bearing capacity of stairs – force value – 1.5 kN applied to the most unfavorable place on a surface 200 mm x 200 mm	EN 12811-1 p.6.2.4	Computer-aided calculations of whole stairs			
16.		Tests on load bearing capacity of stairs – load value – 1.0 kN/m^2 applied to all treads and platforms up to 10 m	EN 12811-1 p.6.2.4				
17.	Anc hor	Maximum tensile force	EN 12811-3 p.7.2	Lab tests	5	5	
18.	Angle braces	Maximum permissible value of normal force in a bracing N_x	EN 12810-2 Aneks A.4 EN 12811-3 p.7.2	Lab tests	5	5	For a modular scaffold, tests can be divided in shearing and tensile force.

Min_i – Minimum number of initial trials for lab tests; Min_p – Minimum number of proper trials for lab tests

Table 4.5 The compilation of lab tests common for façade and modular scaffolds

No.	El.	Test type	Reference	Way to perform	Min_i	Min_p	Remarks
1.	Horizontal stiffness of platforms	Measurement of horizontal displacements of a two-module system with platforms subjected to horizontal loading, perpendicular to platforms	EN 12810-2 Annex A EN 12811-3 p.7.2	Lab tests	5	5	Tests are conducted for the following purposes: – determining parameters for scaffolds calculations as planar arrangements, – determining horizontal stiffness of platforms in order to verify computer spatial models, tests on the strength of a platform-cross member or vertical elements coupling Tests shall be conducted separately for every length of platforms
2.		Measurement of horizontal displacements of a two-module system with platforms subjected to horizontal loading normal to platforms	EN 12810-2 Annex A EN 12811-3 p.7.2				
3.		Measurement of horizontal displacements of a two-module system with platforms subjected to horizontal loading parallel to platforms	EN 12810-2 Annex A EN 12811-3 p.7.2				
4.		Measurement of horizontal displacements of a two-module system with platforms subjected to horizontal loading, parallel to platforms	EN 12810-2 Annex A EN 12811-3 p.7.2				
5.	Element set (Global test)	Measurement of displacements of scaffold elements set (e.g. 3 modules in a horizontal plane and 4 modules upwards)	EN 12810-2 p. 4.4.2 EN 12811-3 p.8	Lab tests		1	Tests aim at verification of static calculations and data selection of a computer model which can indicate that the values safer for a construction are obtained in the calculations e.g. greater displacements and multiplier of ultimate load causing buckling
6.	Full standard sets of scaffolds	Verification of load bearing capacity of scaffold	EN 12810-1 p.7.2 – set description EN 12810-2 EN 12811-1 p. 6.2.9.2	Calcul ations			Configurations from 1 module to such a number of spans that the construction is repeated, a construction with three sets of repetitive modules, with extensions, scaffold height from 24m to 25.5m, with and without a protective net, span spacing – at least the longest two.

Min_i – Minimum number of initial trials for lab tests; Min_p – Minimum number of proper trials for lab tests

Table 4.6 The compilation of laboratory tests for façade scaffolds

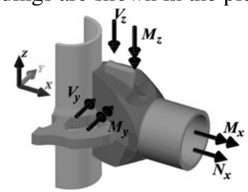
No.	El.	Test type	Reference	Way to perform	Min_i	Min_p	Remarks
1.	Façade frame	Maximum force acting on a frame post	EN 12811-3 p.7.2	Lab tests	5	5	
2.		Maximum loading transferred from platforms to bars	EN 12811-3 p.7.2				
3.	Guardrail	Maximum point force in mid-span	EN 12811-1 p.6.2.5.1 p.6.2.5.2 p.6.2.5.3 p.6.3.2 EN 12811-3 p.7.2	Lab tests	5	5	Tests shall be performed on at least one module of scaffold so as to check fixing of a guardrail Tests shall be performed for the longest system guardrail.
4.		Maximum point force at coupling with a standard	EN 12811-1 p.6.2.5.1 p.6.2.5.2 p.6.2.5.3 p.6.3.2				
5.	Truss girders	Maximum force concentrated in mid-span , modelling the transfer of force from façade frames	EN 12810-1 p.7.3.6.1	Lab tests			
6.		Maximum continuous loading modelling loading from platforms arranged on girders	EN 12810-1 p.7.3.6.1	Calculations			
7.	Supports	Maximum continuous loading	EN 12811-1 p.6.2.2.5 EN 12811-3 p.7.2	Lab tests or calculations	5	5	
8.		Maximum loading applied to a support end	EN 12811-1 p.6.2.2.5 EN 12811-3 p.7.2				

9.	Normal coupling	Maximum force evoking slippage of a tube in a coupling	EN-74-1 EN 12811-3 p.7.2	Lab tests	10	10	Test range depends on a coupling class. Given studies are valid for class A
10.		Maximum destructive force of a coupling parallel to the tube			5	5	
11.		Maximum tensile and destructive force of a coupling perpendicular to both tubes					
12.	Rotary couplin	Maximum force evoking slippage of tube in the coupling	EN-74-1 EN 12811-3 p.7.2	Lab tests	10	10	
13.		Maximum destructive force of coupling parallel to the tube			5	5	
14.	Parallel couplin	Maximum force evoking slippage of tube in the coupling	EN-74-1 EN 12811-3 p.7.2	Lab tests	10	10	
15.		Maximum destructive force of coupling parallel to the tube			5	5	
16.	Longitudinal coupling	Maximum force evoking slippage of tube in the coupling	EN-74-1 EN 12811-3 p.7.2	Lab tests	10	10	

Min_i – Minimum number of initial trials for lab tests; Min_p – Minimum number of proper trials for lab tests

Table 4.7 The compilation of laboratory tests for modular scaffolds

No.	El.	Test type	Reference	Way to perform	Min_i	Min_p	Remarks
1.	Standard	Maximum permissible value of standard loading of 2 m height with ledgers arranged within the distance of 2 m	EN 12811-3 p.7.2	Lab tests	5	5	Tests shall be performed with forces compressing a standard from zero to the value determined in initial tests. Tests of tensile force consist in shearing safety pins
2.		Maximum permissible value of standard loading of 2 m height with ledgers arranged within the distance of 1 m					
3.	Ledger	Maximum permissible value of force applied in the center of ledger length	EN 12811-3 p.7.2	Lab tests	5	5	Tests should be conducted for every type and length of ledger
4.		Maximum permissible value of continuous load					
5.	Supports	Maximum continuous load	EN 12811-1 p.6.2.2.5 EN 12811-3 p.7.2	Lab tests or calculations	5	5	
6.		Maximum force applied to the end of support					
7.	Node – a coupling standard-ledger	Maximum permissible value of tensile force of hole rozet N_x as well as susceptibility and possible clearances	EN 12810-2 Annex A.3 EN 12811-3 p.7.2	Lab tests	5	5	In every of these cases, the meaning of destruction can pose a problem, clearances can occur and a node can have various bearing capacity while changing loading. In some cases, the necessity of separate tests can appear, with loading which is assumed as positive, and separately with loading which is assumed as negative. The situation may also happen when a node works only in one turning of loading and here the question arises whether such a situation is permissible
8.		Maximum permissible value of shearing force of hole rozet in vertical direction to the plate plain T_z as well as susceptibility and possible clearances					
9.		Maximum permissible value of shearing force of hole rozet in vertical direction to the plate plain $T_y$as well as susceptibility and possible clearances					
10.		Maximum permissible value of bending moment of hole rozet M_x as well as susceptibility and possible clearances					
11.		Maximum permissible value of bending moment of hole rozet M_y	EN 12810-2 Annex A.3	Lab tests	5	5	

		as well as susceptibility and possible clearances	EN 12811-3 p.7.2				Loadings are shown in the picture: 
12.		Maximum permissible value of bending moment of hole rozet M_z as well as susceptibility and possible clearances					
13.	Wedge in the coupling standard-ledger	Node behavior under the influence of tensile force N_x vibration tests	EN 12811-3 p.7.4 EN 12810-1 p.8.6 EN12810-2 p.4.3.2	Lab tests		3	Tests shall be performed if there is a suspicion that an element at frequent load changes can fall out, or that a whole scaffold can be subjected to vibrations Complementary test to testing the coupling itself under static loading, thus only the proper study since the estimated value of destructive force is known. The system should be loaded by at least 3000 cycles, at frequency 5 Hz
14.		Node behavior under the influence of shearing force T_z vibration tests					
15.		Node behavior under the influence of shearing force T_y vibration tests					
16.		Node behavior under the influence of bending moment M_x vibration tests					
17.		Node behavior under the influence of bending moment M_y vibration tests					
18.		Node behavior under the influence of bending moment M_z vibration tests					
19.	Node – a coupling standard-bracing	Maximum permissible value of normal power in bracing N_x as well as susceptibility and possible clearances	EN 12810-2 Annex A.3 EN 12811-3 p.7.2	Lab tests	5	5	
20.	Node – random system	Possible tests on node bearing capacity at loads interaction	EN 12810-2 Annex A.3	Calculations	5	5	Other tests from single loadings are necessary in order to verify a model.

5 Designing non-typical construction scaffolds

5.1 Introduction

A scaffold, whose scheme is missing in DTR documentation, is called atypical scaffold and according to the regulation [J. Law 2003, 47], an individual design should be performed, called in this paper as a technical design. The technical design of scaffold should be made by a person with qualifications for designing without restrictions in the construction specialization. This design shall contain: technical description of scaffold, static-strength analysis, assembly and disassembly instruction, scope of activities covering scaffold examination, HSE information, as well as technical drawings of scaffold. Particular components of design are discussed in this section.

5.2 General information in the project

The scaffold project, as in the case of every construction design, has to meet the requirements enabling the verification of design correctness and its compliance with legal acts. The first element of a design is its cover, where there shall appear the information on the name and address of a facility at which scaffold will be assembled, investor and his address, purchaser and his address, title of design, table with information on design contractors (name and surname, industry sector, number of construction qualifications) along with their signs and date of design execution.

Another element of the scaffold project concerns legal documentation. In the case of scaffold design, this is only the statement of a designer in compliance with Art. 20 (4) of the Regulation on Construction Law of 7 July 1994 [J. Law 1994, 89], with further amendments in which the designer states that the design in terms of construction sector is prepared according to regulations and rules of technical knowledge in force, the copy of professional certificate on the membership to the Polish Chamber of Civil Engineers.

The scaffolds projects are developed on the basis of scaffold standards e.g.: [EN 12810-1:2010, EN 12810-2:2010, EN 12811-1:2007]. While developing the design, other standards can be used e.g.: EN 1990 Eurocode 0: Bases for design of structures [EN 1990:2010], EN 1991-1-4 Eurocode 1: Actions on structures – Part 1-4: General actions. Wind actions [EN 1991-1-4:2008], EN 1991-1-3 Eurocode 1. Actions on structures – Part 1-3: General actions. Snow load [EN 1991-1-3:2005], PN-B-02013 Loads on structures. Environmental variable loads. Ice loads [PN-B-02013:1987], EN 1993-1-1 Eurocode 3: Designing steel structures. Part 1-1: General rules and rules for buildings [EN 1993-1-1:2006], EN 1999-1-1 Designing of aluminum structures – Part 1-1: General rules [EN 1999-1-1:2011]. In order to shape a structure, the dimensions of facility around which a scaffold will be assembled, the layout of space for anchoring, information on the possibility of scaffold foundation and frequently also the information on the technical condition of a facility are necessary. This information can be obtained from the following sources: a construction or executive design of a facility, expertise of technical condition, inventory or on-site inspection. Obviously, the design is not possible without the information on the scaffold elements which can be used, and these pieces of information shall be contained in the documentation of scaffold system.

The list of documents which are the basis for a design shall be placed in a design under the heading “References”.

5.3 Technical description

After enclosing general information on the design, more detailed information shall be included, contained in the technical description. In this part of the design, information on where a scaffold will be placed, what its purpose is, what type of scaffold will be used and its dimensions shall be included. Here, also the type of scaffold foundation, its shape, the way of communication, as well as unusual solutions applied to a design shall be mentioned. The last piece of information which shall be placed in this part concerns the list of scaffold elements which are used in the construction.

The information on scaffold localization shall be supported by figures or drawings as possible. The example of providing a scaffold localization is given in Fig. 5.1. In the first part of a drawing, there is the scheme of scaffold with wall signatures so that these terms can unambiguously be used in the further description of a scaffold. Additionally in a Fig. 5.1 in the second part, the same walls are marked. The determination of scaffold localization and establishment of the nomenclature, used in a design, enable avoiding mistakes during scaffold assembly.

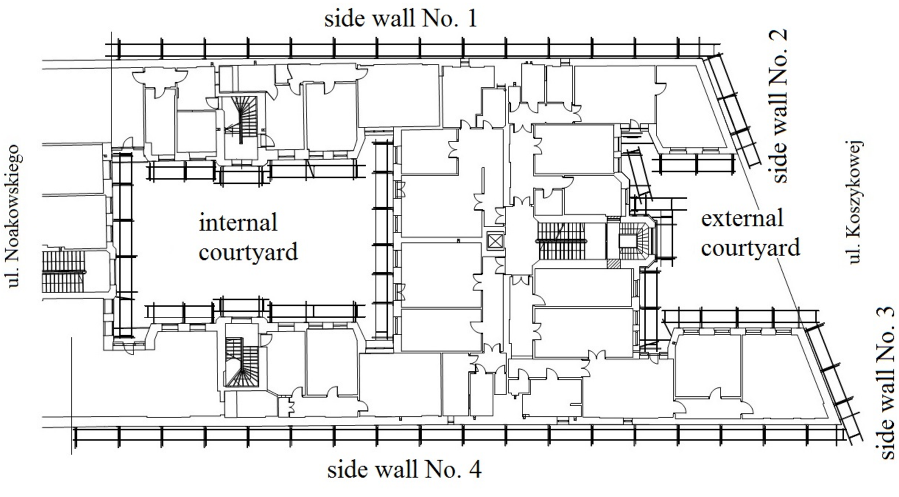


Fig. 5.1 The localization of scaffold around a building at Noakowskiego 16 St in Warsaw

5.4 Static-strength analysis

The static-strength analysis of scaffold is quite time-consuming and requires considerable experience. Thus it is described in several points below.

5.4.1 Static schemes of scaffolds

The basis for proper design of every structure is the determination of internal forces in a correctly assumed, thus most reflecting a reality, static scheme. In Fig. 5.2-5.4, three examples of scaffolds and their static schemes are shown. Unfortunately, the drawings of static schemes are performed with the use of FEM computer program and the symbols of supports and joints do not precisely correspond to the symbols used by civil engineers, e.g. in the drawings, the joints are not visible. Thus, in Fig. 5.5, the static scheme of typical frame scaffold fragment with correct markings is presented.

The first decision which has to be made by a designer is to choose whether the assumed scheme is a planar or spatial rod system. Both systems are authorized by the standard EN 12810-2:2010:2010 with a reservation that in the case of planar system. Nevertheless, considering the fact that scaffolds are quite complicated structures of possibly the smallest cross-sections, it is better to perform calculations for spatial systems which better reflect the reality. It is even more justified that currently designers possess tools which enable these calculations. Beam and truss elements are used in scaffolds. Bracings and guardrails can be modelled by truss elements. In a computer model, truss elements can be omitted since they can be replaced by beam elements ended by hinges, in which the vector of moments perpendicular to the beam axis equal to zero.

a) b)

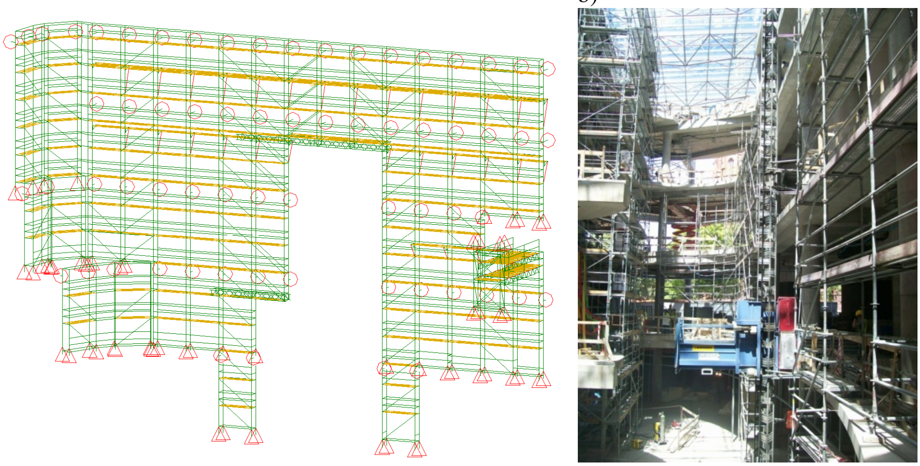


Fig. 5.2 A scaffold in the AGORA Shopping in Bytom Centre: a) static scheme; b) a scaffold during assembly conducted by Altrad Mostostal – Montaż

a) b)

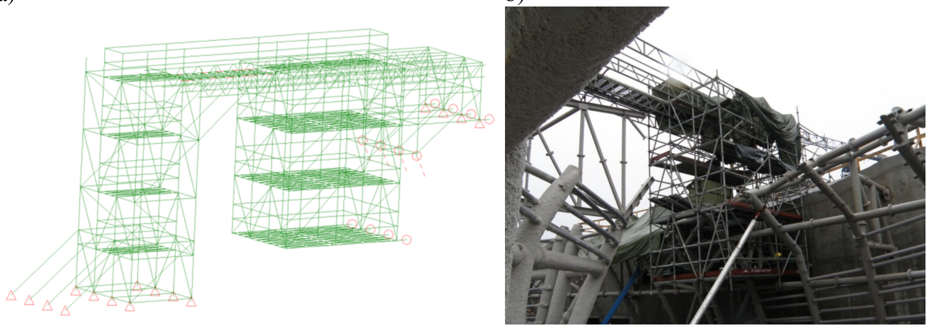


Fig. 5.3 A scaffold for painting works in the Museum of the History of Polish Jews in Warsaw: a) static scheme, b) a scaffold assembled by Altrad Mostostal – Montaż

a) b)

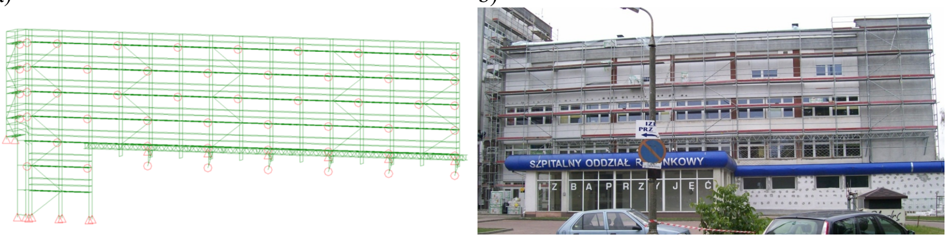


Fig. 5.4 A scaffold at the wall of Polish Railways Hospital in Lublin: a) static scheme, b) a scaffold assembled by the Pro-men Company

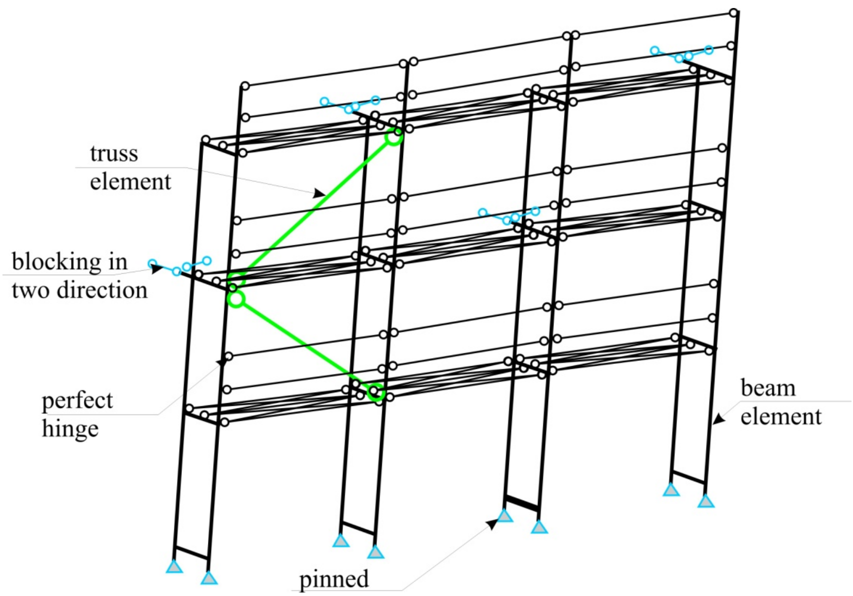


Fig. 5.5 The fragment of static scheme of frame scaffold

As it was previously mentioned, a scaffold structure can be formed as the system of beam, thus a spatial frame of the dimensions in compliance with the requirements included in the standards [EN 12810-1:2010, EN 12810-2:2010 and EN 12811-1:2007] and Health and Safety Regulations [J. Law 2003, 47].

According to the standards, both a load bearing scaffold structure and horizontal stiffness of working platforms shall be modelled with the use of beam elements. However, in the standard EN 12810-2:2010, the stiffness of platform is suggested to be replaced by one element, arranged diagonally in relation to a platform. This way of assuming the stiffness does not comply with the real work of a platform since at first, there is no load transfer from a platform to a crossbar which in fact is bent, and secondly, the properties of a platform, which behaves like a plate in a horizontal plane, are not modelled. Better solution seems to be placing two truss bars at two diagonals of one platform plate (comp. Fig. 5.5 and Fig. 5.6), so that these elements model the work of platform plates providing the stiffness in both horizontal directions, thus along a platform and in a perpendicular direction, and do not allow independent rotations of crossbars of neighboring frames. Moreover, replacing every platform plate with the set of bars enables e.g. transferring load to anchor point of platform plates. Fig. 5.6 shows a scaffold, used from October 2010 to February 2011 during elevation works at the Tax Chamber Building in Lublin and the part of static scheme of scaffold with a platform modelled in a previously mentioned way. The scaffold was made of modular system ROTAX with platforms ALTRAD Mostostal. Parameters for these elements are compiled in Table 5.1. It should be stated that geometric characteristics and material data depend on the type of platforms as well as the way of their anchorage. For this reason, they shall be determined for every system separately, on the basis of lab tests on horizontal stiffness as well as computer calculations, which were performed for decks ALTRAD Mostostal deck in the paper [Robak, 2014].

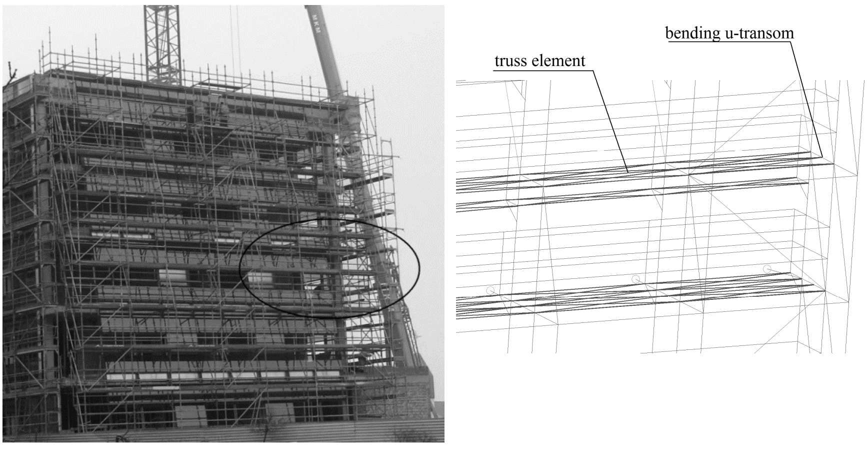


Fig. 5.6 The modular scaffold ROTAX by Altrad Mostostal at the Tax Chamber in Lublin

Table 5.1 Geometric and material characteristics of truss elements modelling decks [Robak, 2014]

Elements:	Cross-section characteristics		Material properties	
Parallel elements	A [m^2]	$5.65 \cdot 10^{-4}$	Volume density [kN/m^3]	7.85
Cross elements	A [m^2]	$3.10 \cdot 10^{-6}$	Young's modulus [kN/m^2]	$2.0 \cdot 10^8$
			Poisson's ratio	0.3

In relation to the fact that engineering structures never have perfect geometry, the impact of geometric imperfections shall be taken into account in the static-strength analysis. Construction scaffolds are of specific steel structures because they are repeatedly assembled from system elements. The joints of elements create the possibility of rotation of small elements, and thus introduce additional unfavorable changes to the geometry of structure. Recommendations, describing the way of taking imperfections for frame steel structures into consideration, are included in Eurocode 3 [EN 1993-1-1:2006], and in the scaffold standard EN 12811-1:2007. They are specified, e.g. by indicating the way of calculating the rotation of elements in the places where they are joined. In the case of scaffolds, their manufacturer decides on the possibility of imperfections occurrence and he places detailed information on permissible deviations during assembly as well as in some cases, information about the necessity of technical condition inspection. As regards the latter, it is not standardized and it is assumed that scaffold elements are systematically controlled and their geometry is almost perfect. Two ways of forming the geometry are proposed in the standards EN 12811-1:2007 and [EN 1993-1-1:2006, which consider imperfections:

- consideration of nodes displacements at the level of platforms, while the displacements of subsequent platforms shall be directed to the opposite side, and the direction of displacements shall comply with horizontal loading which is most frequently wind (Fig. 5.7),
- distribution of nodes displacements so that the obtained scaffold geometry created the form of buckling.

Consideration of global imperfections according to EN 12811-1:2007 at wind perpendicular to the scaffold plane consists in taking into account the rotation on base jacks and frames joints by the angle of Ψ. The least value of this angle, which should be used, is $\tan\Psi = 0.01$. The consideration of global imperfections at wind parallel to the scaffold plane consists in taking into account the rotation on base jacks and frames joints by the angle whose tangent equals to:

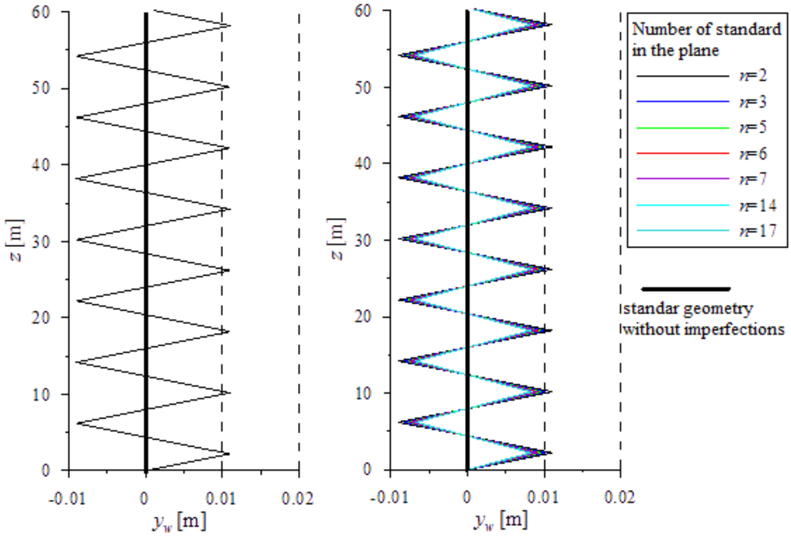
$$\tan\Psi_n = \sqrt{0.5 + \frac{1}{n}}\tan\Psi, \tag{5.1}$$

where n – the number of frame planes in a scaffold.

Geometry imperfections of values of 1 cm cause the rise of normal stress in bottom standards and bracings of about 10%. This results from the fact that normal stresses are increased by the stresses occurring as an effect of elements bending.

When scaffolds are higher or scaffold geometry is complicated, much larger growth of stresses shall be expected.

a)



b)

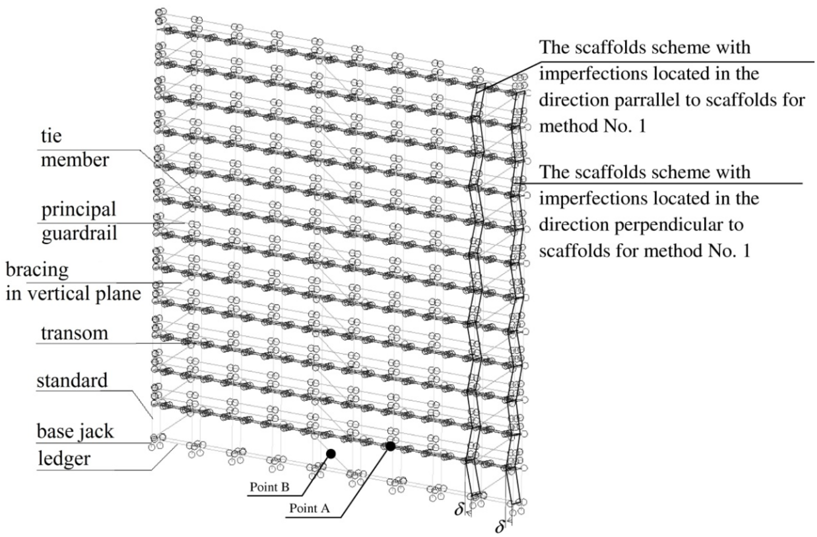


Fig. 5.7 Calculation model of scaffolds with a structure geometry after inserting imperfections: a) graph of imperfection value, b) distribution of imperfections on a scaffolds

In the static scheme, connections between particular components of scaffolds shall be appropriately modelled. The simplest connections are stiff or hinge ones modelling possibility of rotation. Nevertheless, there are no ideal stiff connections. Currently, standard recommendations, according to which susceptibility of connection between elements is considered, are a novelty not only in reference to scaffolds but in general to constructions. Developing the static scheme of construction, every coupling can be modelled by one of three types: stiff, flexible and hinge.

The standard EN 12811-1:2007 recommends to:

- treat couplings between tubular elements as stiff when length of pin is at least 150mm without a catch and 100mm with a catch, as well as when clearance between a tube and a pin is no more than 4mm,
- assume swivel coupler as hinge ones,
- treat right angle coupler as flexible ones, with the characteristics shown in Fig. 5.8,
- treat wedge node as flexible ones, not transferring torsion

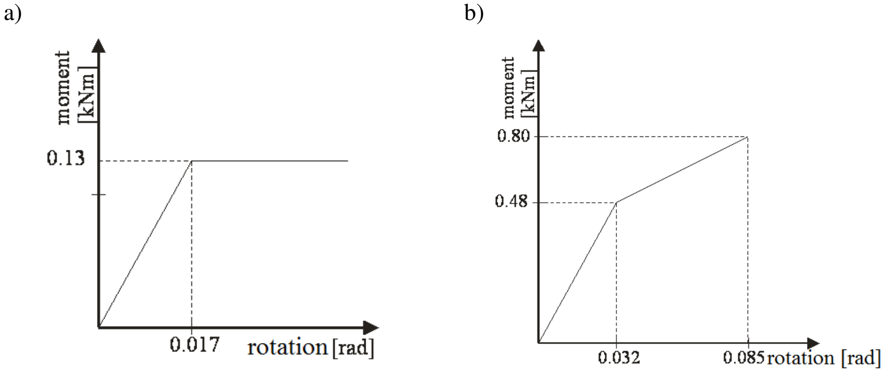


Fig. 5.8 Characteristics of susceptibility of cross couplings according to EN 12811-1:2007 at connecting steel tubes: a) susceptibility of coupling at torsion, b) susceptibility of coupling at bending

Moreover, it results from the analysis of elements cooperation that in reference to the majority of frame scaffold systems, the following rules can be applied (Fig. 5.9).

- connection of vertical and horizontal elements of frames shall be treated as fixed,
- connection of two frames can be treated as fixed,
- connection of platforms with frames shall be treated as a hinge one since platform handlers can rotate on the crossbars of frames,
- connection of guardrails with poles can be treated as a hinge one,
- connections of bracings with frames, both bottom and top ones, could be treated as a hinge.

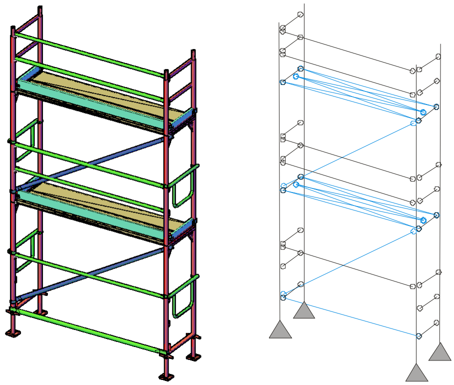


Fig. 5.9 The example of frame scaffold by Altrad Mostostal with its static scheme (elements which can be modelled by truss ones are marked in blue)

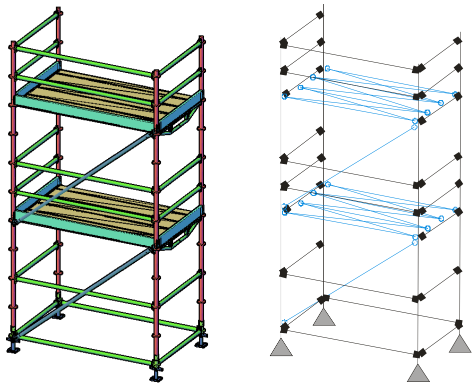


Fig. 5.10 The example of modular scaffold Rotax with its static scheme (elements which can be modelled as truss ones are marked in blue, ○ - hinge connection, ■ - flexible conection).

However, in reference to the majority of modular scaffold systems, the following rules can be applied (Fig. 5.10):

- wedge modular node in compliance with standard recommendations are described in the further part of the article,
- bracing-rossete coupling can be treated as a hinge one since tubular element is connected with a head by a pin,
- connection of platforms with ledgers can be treated as a hinge one since platform handlers can rotate on crossbars of frames.

While developing the computer model of structure, connections can be formed by the selection of appropriate elements or insertion of hinges. In the model of scaffold, one can use both truss and frame (beam)elements. Elements that are anchored by hinges on both sides and no loads are applied to them, can be treated as truss eones and other elements shall be treated as beam ones.

During calculations, it is important to be rather cautious about the recommendation that a wedge coupling does not transfer torsion. Obviously, it results from the fact that during torsion of element, the wedge can be removed and this fact should be borne in mind, however, on the other hand, a scaffold should be designed so that torsion of ledgers is not too big since this would mean instability of structure. Another problem to be taken into account is torsion at two ends of one element. A computer program treats the problem with an element, which does not have a blockade at both sides to turn around its own axis, as a geometrically variable problem, thus impossible to calculate. The problem is likely to be calculated only when one of node elements is blocked to torsion.

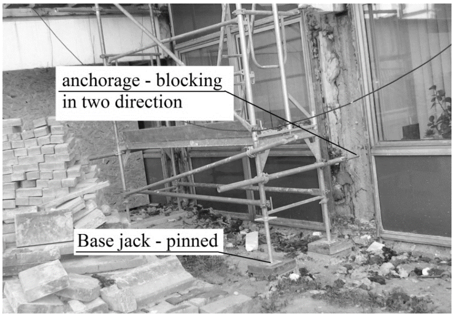


Fig. 5.11 The supports of a scaffold

Another important element of numerical model are boundary conditions. In the case of typical scaffold, supports usually model the arrangement on the ground and anchoring to walls (Fig. 5.11). According to EN 12811-1:2007, supports on base jacks shall be assumed as ideal hinges, thus three component displacements in vertical direction and two horizontal directions shall be blocked. Anchors block only horizontal displacement, thus they block a component in a perpendicular and parallel directions to a wall.

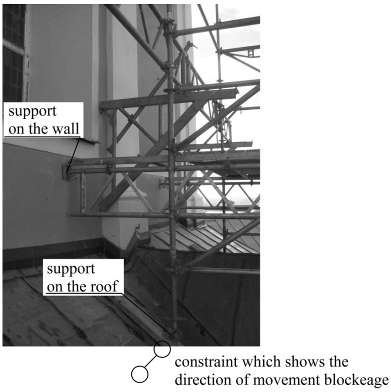


Fig. 5.12 The example of tilt support and supporting against the wall.

In practice, it is not so simple. Supporting on the surface with the use of base jacks (or without base jacks) cannot be modelled by hinge supports, since when a structure is light, its displacement can occur during high winds or at a car crash.

It is confirmed in the standard EN 12811-1 where in the last point there is a recommendation so as to check the scaffold in terms of the likelihood of slippage occurrence This verification can be performed by changing the support type in the calculations for the support that blocks only a vertical displacement, enabling movement on a surface, thus in a horizontal plane. The slippage can occur in the case of tilt supports arranged on the sloping surface (Fig. 5.12). In such a case, only the movement in the perpendicular direction to the surface shall be blocked. One cannot count on the fact that due to friction, the displacement along the ground surface will not occur. Unfortunately, this is not the last possible variant of supporting a scaffold on the ground. In the case of free-standing scaffold, it shall be checked if supports are not lifted, and thus do not work at all and the load is transferred by other supports (Fig. 5.13). Leaving the support in the static scheme in the place where the scaffold is lifted from the ground results in fewer reactions in other supports, and in relation to this, overloads of other elements or anchors fixing cannot be noticed.

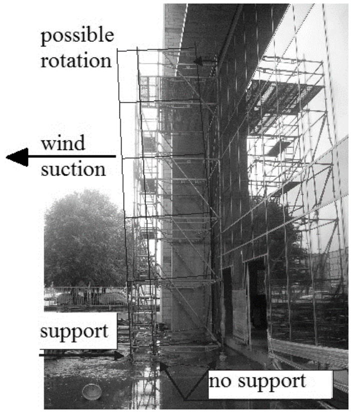


Fig. 5.13 The example of free-standing scaffold with the possibility of rotation

Anchor modelling with the use of horizontal movement blockage, including components perpendicular and parallel to the wall, is not always correct. Since the coupler is connected to the anchor in a ‘hole’, thus while detaching the scaffold from the wall, the full contact appears and the anchor fulfills its role. Nevertheless, in the case when e.g. a scaffold is arranged within quite a distance from a building and consoles are fixed to a scaffold on the elevation side, at winds pushing the scaffold to the wall, the rotation or displacement in this direction can occur. In such a case, anchoring does not work, and it can be stated that there is no blockage in the horizontal direction. During calculations, it shall always be checked if anchor couplings are compressed or tensed If they are tensed, the way of anchoring shall be changed in the construction of scaffold, e.g. to the one shown in Fig. 5.12. This way of fixing does not provide total blockage of displacement as well. If the scaffold moves away from the wall, then the base plate anchored to the wall will simply slide out, which should also be borne in mind during the analysis of static work of scaffold.

After assuming all supports and couplings, the geometric and material characteristics of particular elements shall be selected. In the case of truss elements, it is enough to determine the cross-section area, however, in the case of frame elements, the cross-section area, stiffness at torsion, moments of inertia as well as section modulus at bending should be also determined. Determination of cross-section characteristics takes place according to commonly known rules of mechanics, but to make it simpler one can use such programs as AUTOCAD, INTELICAD, RM-WIN which have the option of determining geometric characteristics of plane figures. Material characteristics, necessary to calculations, are following: density ρ, Poisson's ratio v and Young's modulus E. In the case of steel, these quantities are: $\rho = 7.85 \text{t/m}^3$, $v = 0.3$ and $E = 2.05 \cdot 10^8 \text{kPa}$ and in reference to aluminum, the following values can be assumed: $\rho = 2.72 \text{t/m}^3$, $v = 0.33$ and $E = 7 \cdot 10^7 \text{kPa}$. Geometric characteristics of selected systems are compiled in Table 5.2-5.7.

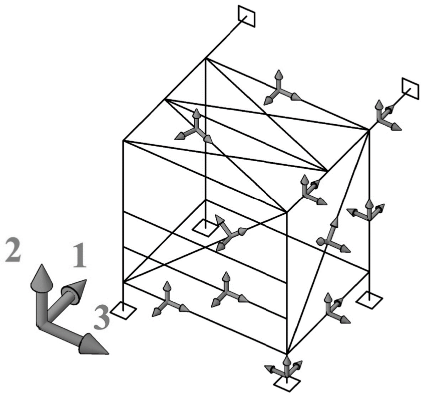


Fig. 5.14 The scheme of scaffold with the location the axes of local coordinate systems.

Subsequent parameters are: A –cross-section area, J_1 – stiffness at torsion, J_2 and J_3 – inertia moments in relation to the second and third axes of local coordinate system, W_1 – section modulus at torsion, W_2 and W_3 – section moduli at bending against to the second and third axes of local coordinate system. While determining characteristics, it is assumed that the second axis of horizontal elements assume perpendicular direction and the second axis of remaining elements are directed perpendicularly to the plane of the scaffold (Fig. 5.14).

Correctly developed static scheme with loads, properly describing real conditions in which a scaffold works, is a guarantee that internal forces and stresses in structure components, obtained as a result of static calculations, will be similar to real ones and a scaffold designed in such a way will be safe for its users.

Table 5.2 Geometric characteristics of main elements of façade system Mostostal Plus by Altrad Mostostal

No	Name	A [cm^2]	J_1 [cm^4]	J_2 [cm^4]	J_3 [cm^4]	W_1 [cm^3]	W_2 [cm^3]	W_3 [cm^3]
1.	Base jack ϕ38.0×4.0	4.27	12.52	6.26	6.26	6.59	3.29	3.29
2.	Standard ϕ48.3×2.7	3.87	20.18	10.09	10.09	8.36	4.18	4.18
3.	Bottom transom of a frame (rectangular pipe 20x48x2.5)	2.89	0.19	1.36	1.07	0.05	4.22	0.82
4.	Transom/ transom of bracket (u-profile 48×48×48×2.5)	4.76	0.08	19.85	18.88	18.82	8.27	5.97
5.	Bracing in vertical plane ϕ42x2.7	3.87	20.18	10.09	10.09	8.36	4.18	4.18
6.	Principal guardrail ϕ38x2.7	2.99	9.38	4.69	4.69	4.94	2.47	2.47
7.	Tie member ϕ48.3×3.2	4.53	23.17	11.59	11.59	9.59	4.80	4.80
8.	Support of a bracket (rectangular pipe 48x27x2.5)	2.34	51.56	8.19	1.67	16.96	3.41	0.90

Table 5.3 Geometric characteristics of main elements of modular system ROTAX by Altrad Mostostal

No	Name	A [cm^2]	J_1 [cm^4]	J_2 [cm^4]	J_3 [cm^4]	W_1 [cm^3]	W_2 [cm^3]	W_3 [cm^3]
1.	Base jack ϕ38.0×4.0	4.27	12.52	6.26	6.26	6.59	3.29	3.29
2.	Standard ϕ48.3×2.7	3.87	20.18	10.09	10.09	8.36	4.18	4.18
3.	Ledger ϕ48.3×2.7	3.87	20.18	10.09	10.09	8.36	4.18	4.18
4.	U-ledger (u-profile 48×48×48×2.5)	4.03	68.23	16.29	11.93	18.50	6.79	4.26
5.	Bracing in vertical plane ϕ48.3×2.7	3.87	20.18	10.09	10.09	8.36	4.18	4.18
6.	Principal guardrail ϕ48.3×2.7	3.87	20.18	10.09	10.09	8.36	4.18	4.18
7.	Tie member ϕ48.3×3.2	4.53	23.17	11.59	11.59	9.59	4.80	4.80
8.	Support of a bracket	2.34	51.56	8.19	1.67	16.96	3.41	0.90

Table 5.4 Geometric characteristics of main elements of façade system BAL by Pionart

No	Name	A [cm^2]	J_1 [cm^4]	J_2 [cm^4]	J_3 [cm^4]	W_1 [cm^3]	W_2 [cm^3]	W_3 [cm^3]
1.	Base jack ϕ38.0×4.0	3.27	7.54	3.77	3.77	4.43	2.22	2.22
2.	Standard ϕ48.3×2.7	3.87	20.18	10.09	10.09	8.36	4.18	4.18
3.	Bottom transom of a frame (rectangular pipe 40×20×2)	2.14	3.65	4.05	1.34	1.36	2.02	0.54
4.	Transom/ transom of bracket u-profile 48×53×48×2.5	4.22	0.57	16.83	14.49	0.28	7.01	4.90
5.	Bracing in vertical plane ϕ 42.4×2.0	2.54	10.38	5.19	5.19	4.90	2.45	2.45
6.	Principal guardrail ϕ33.7×2.3	2.27	5.62	2.81	2.81	3.34	1.67	1.67
7.	Tie member ϕ 48.3×3.2	4.53	23.17	11.59	11.59	9.59	4.80	4.80
8.	Support of a bracket, rectangular pipe 35×35×2	2.54	7.73	4.51	4.51	2.24	2.58	2.58

Table 5.5 Geometric characteristics of main elements of façade system PUM by Pionart

No	Name	A [cm^2]	J_1 [cm^4]	J_2 [cm^4]	J_3 [cm^4]	W_1 [cm^3]	W_2 [cm^3]	W_3 [cm^3]
1.	Base jack ϕ38.0×4.0	3.27	7.54	3.77	3.77	4.43	2.22	2.22
2.	Standard ϕ48.3×2.7	3.87	20.18	10.09	10.09	8.36	4.18	4.18
3.	Bottom transom of a frame ϕ33.7×2.6	2.54	6.19	3.09	3.09	3.67	1.84	1.84
4.	Transom/ transom of bracket (rectangular pipe 50×40×2)	3.34	16.57	8.39	11.84	3.83	4.19	4.74
5.	Bracing in vertical plane ϕ48.3×2.5	3.60	18.92	9.46	9.46	7.83	3.92	3.92
6.	Principal guardrail ϕ38.0×1.8	2.05	6.72	3.36	3.36	3.54	1.77	1.77
7.	Tie member, ϕ48.3×3.2	4.53	23.17	11.59	11.59	9.59	4.80	4.80
8.	Support of a bracket (rectangular pipe 35×35×2)	2.94	11.75	6.94	6.94	3.02	3.47	3.47

Table 5.6 Geometric characteristics of main elements of façade system RR-08 by Pionart.

No	Name	A [cm^2]	J_1 [cm^4]	J_2 [cm^4]	J_3 [cm^4]	W_1 [cm^3]	W_2 [cm^3]	W_3 [cm^3]
1.	Base jack ϕ38.0×4.0	3.27	7.54	3.77	3.77	4.43	2.22	2.22
2.	Standard ϕ48.3×2.7	3.27	7.54	3.77	3.77	4.43	2.22	2.22
3.	Bottom transom of a frame (rectangular pipe 25×20×2)	3.87	20.18	10.09	10.09	8.36	4.18	4.18
4.	Transom/ transom of bracket (rectangular pipe 50×40×2)	1.45	1.93	0.96	0.96	1.54	0.77	0.77
5.	Bracing in vertical plane ϕ 48.3×2.5	3.54	20.04	11.05	12.99	4.39	4.91	5.20
6.	Principal guardrail ϕ38.0×1.8	3.60	18.92	9.46	9.46	7.83	3.92	3.92
7.	Tie member, ϕ 48.3×3.2	2.05	6.72	3.36	3.36	3.54	1.77	1.77
8.	Support of a bracket (rectangular pipe 40×20×2)	4.53	23.17	11.59	11.59	9.59	4.80	4.80

Table 5.7 Geometric characteristics of main elements of façade system Plettac SL 70 by Plettac

No	Name	A [cm^2]	J_1 [cm^4]	J_2 [cm^4]	J_3 [cm^4]	W_1 [cm^3]	W_2 [cm^3]	W_3 [cm^3]
1.	Base jack ϕ38.0×4.0	4.27	12.52	6.26	6.26	6.59	3.29	3.29
2.	Standard ϕ48.3×2.7	3.87	20.18	10.09	10.09	8.36	4.18	4.18
3.	Bottom transom of a frame ϕ33.7.0×2.6	2.54	6.18	3.09	3.09	3.68	1.84	1.84
4.	Transom (rectangular pipe 50×35×2)	3.07	11.86	5.93	10.25	6.77	3.39	4.10
5.	Bracing in vertical plane ϕ48.3×2.6	3.73	19.56	9.78	9.78	8.10	4.05	4.05
6.	Principal guardrail ϕ33.7.0×2.6	2.05	6.72	3.36	3.36	3.54	1.77	1.77
7.	Tie member, ϕ48.3×3.2	4.53	23.17	11.59	11.59	9.59	4.80	4.80
8.	Support of a bracket, / transom of bracket (rectangular pipe 35x35x2)	2.34	51.56	8.19	1.67	16.96	3.41	0.90

5.4.2 Compilation of loads variants

Loads of scaffolds are subjected to quite thorough standard discipline. It results from the fact that correct determination of loads, which are frequently random phenomena (e.g. wind or snow), requires long-term studies and static analyses. The outcome of these studies are standard recommendations concerning particular technological situations, in the case of use load, or resulting from climatic conditions of particular areas of Europe, in the case of environmental impacts. Much of the information on determining loads of scaffolds are included in the standards EN 12810-1:2010 and EN 18211-1:2007, but depending on the scaffold application, information can also be found in other standards, e.g. in reference to scaffolds serving as support structures of boardings, such information can be found in EN 18212:2008 and while designing a load-bearing tower from prefabricated elements, the rules given in EN 12813:2005 shall also be applied. The descriptions of the ways of assuming loads are quite thorough, yet in standards there are also regulations recommending the use of proper Eurocodes in the case of environmental impacts, thus in reference to winds standard EN 1991-1-4:2008 and snow EN 1991-1-3:2005. As regards load with icing, currently the old standard is in force PN-B-02013:1987 which is not included in the standards of scaffolds. The last environmental impact, which is not mentioned in EN 12810-1:2010 and EN 18211-1:2007, is thermal load. Obviously, it is understandable since due to clearances in the scaffolds connections, elements can slightly move between themselves and hence, the material expansion does not cause stresses in a structure.

According to the standard EN 18211-:20071, the structure of scaffolding shall be subjected to the action of following loads types:

- dead load, to which dead weight of scaffold along with equipment shall be included,
- variable load, including operational load, wind action, snow and ice load,
- random load (in the standard EN 1990:2010 called accidental).

In static calculations, above mentioned loads shall be multiplied by partial safety coefficients, which in the case of scaffolds, in reference to all loads, equal to $\gamma_f = 1.5$ and shall be analyzed in combinations with other loads. The variants of loads are listed in Table 5.8. The first five variants correspond to loads which shall be analyzed in the case of scaffold operation outside the building in summer time, moreover the fifth variant should be analyzed only in situations when wind load is perpendicularly directed upwards (e.g. under domes). In winter time, a static analysis shall be additionally conducted, considering icing and snow load, thus variants from sixth to ninth. Nevertheless, every designed scaffold inside buildings shall be analyzed only in reference to the last two variants, i.e. the tenth and eleventh.

Table 5.8 The list of variants of scaffold loads

Scaffold: Within the period:	Outside a building									Inside a building	
	Summer time					Winter time					
Variant	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
Dead load	×	×	×	×	×[1)]	×	×	×	×	×	×
Full vertical operational load	×	×								×	×
Partial vertical operational load, depending on the loading class, acc. to Table 3.3.	×	×								×	×
Horizontal operational load in a parallel direction to a scaffold										×	
Horizontal operational load in a perpendicular direction to a scaffold											×
Wind action at wind speed 12m/s in a parallel direction to a scaffold	×					×[2)]		×			
Wind action at wind speed 12m/s in a perpendicular direction to a scaffold		×					×[2)]		×		
Full wind action in a parallel direction to a scaffold			×								
Full wind action in a perpendicular direction to a scaffold				×							
Snow load											
Ice load						×	×				
Full wind action directed perpendicularly upwards					×			×	×		

1) calculation dead load shall be determined at $\gamma_f = 1.0$.
2) increasing the area of wind load, related to the increase of area as a result of elements icing.

From the point of view of static scheme, dead load is a continuous load, directed perpendicularly downwards. In practice, if the calculations are performed with the use of a computer program, this calculation is not visible on a scheme since it is calculated automatically by software on the basis of cross-section area and volume declared by a user. Unfortunately, in the static scheme, only the elements which are significant to the static work of construction are taken into account, which causes that the load of such elements as couplings, toe boards, ladders, has to be included in other way, e.g. by increasing density of other elements or calculating the load of these elements and applying it in the form of concentrated forces in the location points of particular elements.

Operational loads can be divided into two groups: vertical ones from the load of users, materials, devices, etc., as well as horizontal ones, and the value of 2.5%

(yet not less than 0.3 kN per span), representing activities during operation and recommended when wind load is not applied. Vertical operational loads depend on the scaffold purpose. When it serves as support structure for working platforms, thus one from six load classes from the standard [EN 12811-1:2007] (comp. Table 3.3). In this case, usable load uniformly distributed is q_1 = 2.0 kN/m^2. It means arranging two persons or devices of maximum mass of 200 kg per every 1 m^2 of platform area. These loads shall be arranged in such a way to obtain the most favourable state of stresses in a construction. In practice it means applying the load to the highest working platform of scaffold. Moreover, EN 12811-1:2007 recommends that in the case when a scaffold has several working platforms, the platform below the loaded one shall be loaded by 50% of load applied to a proper platform.

In unusual situations, e.g. when a scaffolds is a support structure, a scaffold is not anchored, a scaffold is a suspended structure (weak points are usually couplers) or when a scaffold has got a usage which is unusual for this type of equipment (support structure for advertisements, a canopy for construction works, support structure for formwork), load has to be adjusted to reality on the basis of information from the future user as well as own analysis of possible situations.

Perpendicular loads of work zones in the form of uniformly distributed load, and in a separated variant, in the form of concentrated forces (comp. Table 3.3) has to be transferred by platforms to the load-bearing structure of scaffold. The structure of platform shall be made in such a way to transfer required types of loads to scaffolds and independently of scaffold location. It should be provided by a manufacturer. However, in a static scheme, while designing a scaffold, load shall be properly transferred to cross-ledgers. In relation to the fact that platforms are frequently supported on handles allowing free rotation, the platform itself can be treated as a freely supported beam, thus a beam supported from one side on a support blocking two displacements and form the other side, vertical displacement. The values of forces applied to ledgers are equal to the reactions in supports. In relation to this, load from platforms can be applied in the form of concentrated forces in the point of their support on ledgers. The values of these forces in reference to one platform can be determined from the following equations (Fig. 5.15):

$$F_A = F_B = \frac{k \cdot q_1}{2}, \; F_C = \frac{2a+b}{l} F_2, \; F_D = \frac{l-(2a+b)}{l} F_2 \tag{5.2}$$

Load can be modelled in less time-consuming way, i.e. adding shell elements of platform dimensions to the static scheme (comp. [Podgórski, 2001]) as it is shown in Fig. 5.16. These elements cannot have too large stiffness, which is achieved by introducing small Young's modulus, e.g. E = 1000 kPa and by giving small thickness of element. This last condition is also significant since these elements cannot add additional dead load, thus they need to have small thickness and volume density.

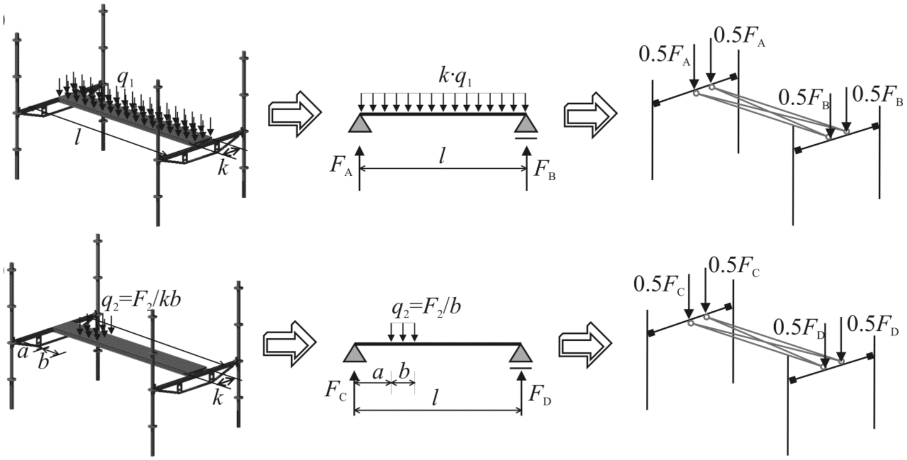


Fig. 5.15 The action of individual platforms

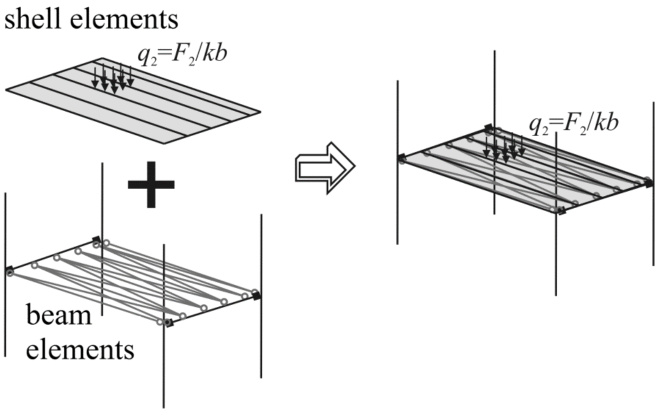


Fig. 5.16 Transfer of loads from platforms to cross-ledgers with the use of shell elements.

There is also other way of using these artificial elements. Their thickness and the volume density of material can be selected so that it equals the load from non-structural elements of scaffold which were previously mentioned. If shell elements are used, the same load can be applied as evenly distributed load or on the part of the surface in compliance with recommendations EN 18211-1:2007 a computer program determines itself node reactions which are the loads of ledgers.

Independently, if vertical load is applied as concentrated forces or as continuous load on shell elements, it is significant to consider that cross-ledgers are bent. The entire load from platforms shall not be applied as concentrated forces to standards since in this way internal forces can be wrongly estimated and the impact of ledgers bending can be omitted. In the case of scaffolds of complicated geometry, where cross-ledgers are frequently not only bent but also compressed, the load-bearing capacity may be exceeded.

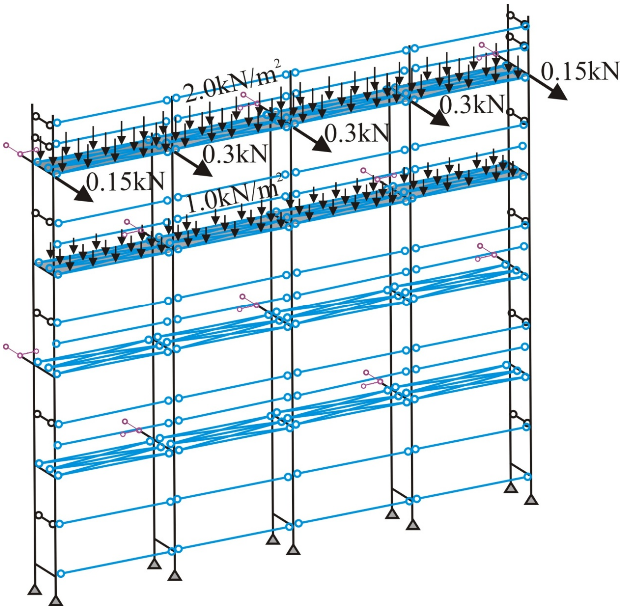


Fig. 5.17 The sample system of operational loads on a scaffold inside a building

Operational horizontal loads are transferred by such elements as: toe boards and guardrails to standards. As in the case of platforms, these elements have to be properly designed and produced by a manufacturer, whereas in designing the scaffolds, these loads can be applied to a model in the form of horizontal concentrated forces. As it was previously mentioned, if there is no wind action, e.g. inside a building, thus horizontal load shall equal to 2.5% of vertical operational load, but not less than 0.3 kN per span. Fig. 5.17 shows the example of static scheme with loads for class 3 of loading which shall be applied if a scaffold is used inside a building, thus with vertical and horizontal operational loads in the eleventh variant from Table 5.8.

The load of protective nets can also be included to operational loads. The easiest way to take net load into account is to model the net as shell elements of negligibly small stiffness, connected with a construction in the points of attachment.

Usually scaffolds are not commonly used in winter, at least until now. Currently due to economic reasons, every moment of warming during winter months is used to construction works, and it is connected with scaffold operation also in this period. The use of scaffold in winter is related to the possibility of icing the construction or covering it with snow. In both cases, scaffold should not be operated due to safety reasons, but it is worth considering how the stresses in the construction not used by workers but additionally loaded by icing or snow will increase. Icing is assumed according to the standard PN-B-02013:1987 as loading by evenly distributed mass on the surface of elements of the value:

$g_k = \gamma b \mu \xi$ (5.3)

where:

γ= 7 kN/m^3 – volume density of ice,

b – thickness of icing layer and, e.g. for Warsaw b = 0.012 m,

μ – shape factor which for pipe is 0.67 and for sections is 0.5,

$\xi = (z/10)^{0.3}$ – coefficient of the height above the ground

z – height.

Taking the example of pipe ϕ48.3x2.7 load per meter near Warsaw at the height of 10 m will be:

q_k=7 kN/m^3·0.012 m·0.67·π·0.0483 m=0.0085 kN/m,

which is 28% of load of pipe per meter ϕ48.3x2.7. Icing also refers to platforms and for the same conditions it is:

q_k = 7 kN/m^3·0.012 m·0.5=0.042 kN/m^2.

If load is taken from pipe and platforms, thus total load attributable to standards cannot be higher than (for spacing 3 m x 0.73 m between standards), which in comparison with operational load of platforms is about 2%. Operational load is applied only to the two highest platforms, and icing shall be included in the weight of the whole structure, in the case of low scaffolds, icing can be neglected because stresses in the scaffold are less than stresses caused by operational load. In the case of higher scaffolds, and in the climate zones with greater thickness of icing, unfortunately the load of icing causes greater stresses than operational loads and the icing itself increases the surface of wind laction. In such a case, detailed static calculations shall be performed, in which volume density shall be increased so that the load of elements icing is included into the weight of construction. For example, for pipe ϕ48.3 x 2.7 at q_k=0.0085 kN/m (additional icing load per 1 m) volume density considering icing is:

$\rho_z = (\rho_s A g+q_k)/(Ag)$ = (7850 kg/m^3·3.87·10^{-4} m^2·9.81 m/s^2+8.5 N/m)/(3.87·10^{-4}m^2·9.81 m/s^2) = 10089 kg/m^3

where:

ρ_s = 7850 kg/m^3 – volume density of steel,

A =·[(0.0483 m /2)^2-(0.0429 m /2)^2]·π = 3.87·10^{-4} m^2– cross-sectional area of pipe,

g = 9.81 m/s^2 – gravitational acceleration.

In the case of snow load, the standard EN 1991-1-3:2005, shall be used, but it should be clearly stated that the stipulations of this standard do not comply with such structures as open scaffolds or scaffolds with safety nets. If the scaffold is open, during snowfalls, snow will cover the highest platform. If snowfall is accompanied by wind, snow will also cover lower platforms. Unfortunately, in

EN 1991-1-3:2005 there is no data which can be extrapolated for scaffolds. In relation to this, potential snow load, corresponding to substantial snowfalls, shall be considered. Assuming that snowfalls are so big that e.g. 10 cm of fresh snow cover the scaffold. The density of fresh snow according to EN 1991-1-3:2005 is 1.0k N/m^3, thus a platform is loaded by additional uniformly distributed load of the value 0.1 kN/m^2, which is 5% of vertical operational load of class 3, thus as it was previously mentioned while describing the problem of icing, at the high scaffolds, snow load can substantially affects stresses in a structure and can have greater influence than operational load. Snow load can be applied as in the case of operational load, or as concentrated forces in the support points of platform on cross-ledgers or as continuous vertical load of shell elements.

The scaffold with safety net is subjected to completely different actions. Snow will rather not cover platforms, yet it can occur in the holes of net, and thus its load should be increased. At this point, a serious problem appears, since there are no studies or information on how much such snow should weigh.

Environmental load, quite thoroughly described in the standards EN 12810-1:2010 and EN 18211-1:2007 with an adaptation attempt in reference to scaffolds, is wind action. In both mentioned standards, it is assumed that wind load will be applied in the form of concentrated forces of the value:

$$F_k = c_s \cdot \sum_i \left(c_{fi} A_i q_i \right), \tag{5.4}$$

where:

c_{fi} – aerodynamic coefficient dependent on the cross-section shape of *i*-th element which shall be assumed on the basis of the standard or research in a tunnel,

A_i – projected surface area of *i*-th element on perpendicular plane to the direction of wind action,

q_i – dynamic wind speed pressure active of wind on *i*-th element,

c_s – position ratio.

It is an interesting fact that in the standard EN 18211-1:2007 there is a point describing the way of assuming aerodynamic coefficient c_f. The standard, on the one hand, recommends determining this coefficient on the basis of the respective standard or measurements in the aerodynamic tunnel (the first two paragraphs), and in the last, third paragraph, it is recommended to assume $c_f = 1.3$. After multiple reading of text, it can possibly be assumed that in the last paragraph of standard, elements with planar surface subjected to wind action are mentioned. However, it is only an implication since the text is imprecise. For the elements of circular cross-section which most commonly occur in scaffolds, it can be assumed according to the standard EN 1991-1-4:2008 that c_f is in the range from 0.4 to 1.2. Yet if it is assumed that scaffold elements are factory-made and their surface is very smooth, thus the relative roughness value is 10^{-4} and Reynolds number is about 10^6, it can result in the value of c_f=0.7 for circular cross-sections. Obviously, it shall be borne in mind that in the case of scaffolds bearing considerable signs of usage, it should be decided to increase c_f coefficient to the value of 1.2.

Position ratio c_s considers two aspects: the solidity ratio of the building facade, as well as the wind direction. In the case when wind action is parallel to elevation, thus c_s = 1.0. If wind action is perpendicular in reference to buildings with full walls, c_s = 0.25 and when there is a facility with no obstacles to flow, e.g. a reinforced concrete frame without elevation, thus c_s = 1.0 (comp. Fig. 5.18).

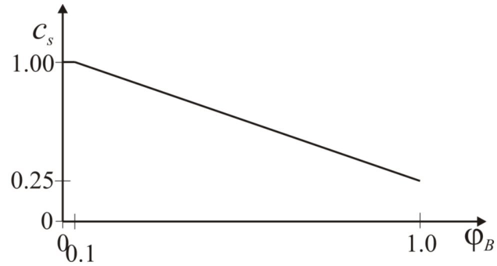


Fig. 5.18 The graph of position ratio c_s at loading perpendicular to elevation [EN 12811-1:2007]

Depending on calculation situation, dynamic wind pressure q_i is assumed on the basis of the wind standard EN 1991-1-4:2008 or by decreasing this value of 30%, or in the situation when a scaffold is used, it is assumed that q_i = 0.2 kN/m^2 (it corresponds to the wind speed about 12 m/s). Dynamic value of wind speed pressure according to the wind standard [EN 1991-1-4:2008] is determined by the formula:

$$q_i(z) = c_e(z) q_b \,, \tag{5.5}$$

where the base value of wind speed pressure is described by the formula:

$$q_b = (c_{dir} c_{season})^2 q_{b,0} \,, \tag{5.6}$$

and c_e is an exposure coefficient assumed on the basis of terrain category (Table 5.10).

In the above formulas, the following parameters were used:

$q_{b,0}$ – basic value of wind speed pressure. Every country has its own national annex to the standard [EN 1991-1-4:2008], whereas the values for Poland are listed in Table 5.9, for the division into zones shown in Fig. 5.19;

c_{dir} – coefficient defining the wind direction, if the wind rose in known for the location of scaffold, the value from the standard [EN 1991-1-4:2008] can be assumed which cannot be lower than one, but usually there is the lack of such information and this coefficient is assumed as c_{dir} = 1;

c_{season} – seasonal coefficient, the standard [EN 1991-1-4:2008] recommends assuming c_{season} = 1 or other value for seasonal facilities e.g. such as scaffolds, but in standards there is no information on how to assume a value other than 1.0.

Table 5.9 Basic values of pressure of speed wind $q_{b,0}$ [kN/m^2] for Poland [EN 1991-1-4:2008]

	Height above sea level	
zone	below 300 m	above 300m
1	0.30	$q_{b,0}(h) = 0.3[1+0.0006(h-300)]^2$
2	0.42	0.42
3	0.30	$q_{b,0}(h) = 0.3[1+0.0006(h-300)]^2 \dfrac{20000-h}{20000+h}$
where h – height above sea level in meters.		

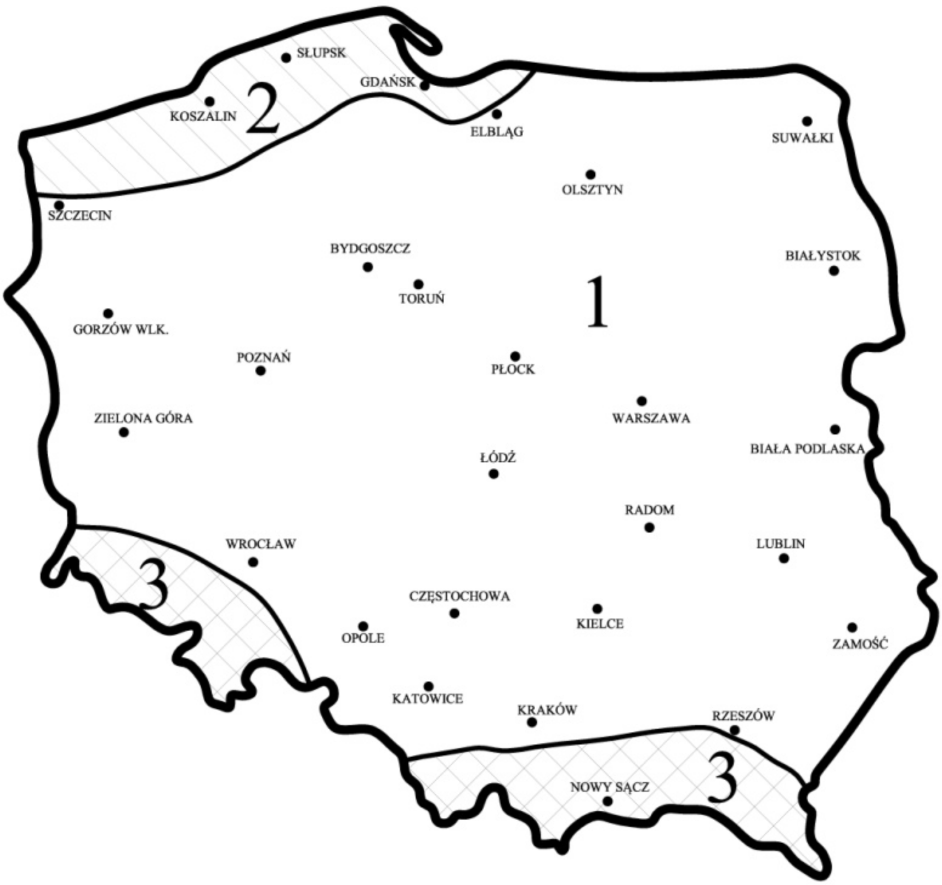


Fig. 5.19 The division of Poland into wind load zones [EN 1991-1-4:2008]

Table 5.10 Equations describing the exposure coefficient depending on the terrain category in Poland [EN 1991-1-4:2008]

Area category	Description of area category	z_{min} [m]	z_{max} [m]	$z < z_{min}$	$z_{min} \leq z < z_{max}$	$z_{max} \leq z$
0	Maritime and coastal area exposed to open sea	1	200	2.03	$c_e(z) = 3.0\left(\frac{z}{10}\right)^{0.17}$	4.99
I	Lakes and planar, horizontal areas of minor vegetation and without any area obstacles	1	200	1.81	$c_e(z) = 2.8\left(\frac{z}{10}\right)^{0.19}$	4.95
II	Areas of minor vegetation, such as grass, and of single obstacles (trees, buildings) distant from each other at a distance equal to at least 20 of their height	2	300	1.56	$c_e(z) = 2.3\left(\frac{z}{10}\right)^{0.24}$	5.20
III	Areas regularly covered by vegetation or buildings or of single obstacles distant from each other no more than the distance equal to 20 of their height (such as towns, suburban areas, forests)	5	400	1.59	$c_e(z) = 1.9\left(\frac{z}{10}\right)^{0.26}$	4.96
IV	Areas whose at least 15 % of surface is covered by buildings of average height exceeding 15 m	10	500	1.5	$c_e(z) = 1.5\left(\frac{z}{10}\right)^{0.29}$	4.66

In order to conclude the description of determining the dynamic pressure of wind, the procedure for determining the value of wind load, consisting of the following stages, will be presented:

- determining base value of pressure q_b,
- determining the function describing the exposure coefficient c_e depending on the terrain category,
- determining dynamic wind speed pressure q_i in the altitude function above the terrain level,
- determining of concentrated forces F_k according to the formula (5-4) in reference to particular levels of scaffolds, thus usually for the height z per 2 m.

Concentrated forces F_k, determined in this way, after multiplication by the partial safety coefficient $\gamma_f = 1.5$, shall be applied to a scaffold as horizontal forces parallel or perpendicular to elevation. In Fig. 5.20, a sample static scheme is shown in which there is, among others, wind load.

If there is a protective net or clad on the structure of scaffold, thus surface area A_i shall be assumed as cover area and aerodynamic coefficients are:

- in reference to the net in perpendicular direction to elevation $c_{f\perp} = 1.3$ and in parallel direction $c_{f\text{II}} = 0.3$,
- in reference to the clad $c_{f\perp} = 1.3$ and $c_{f\text{II}} = 0.1$, respectively.

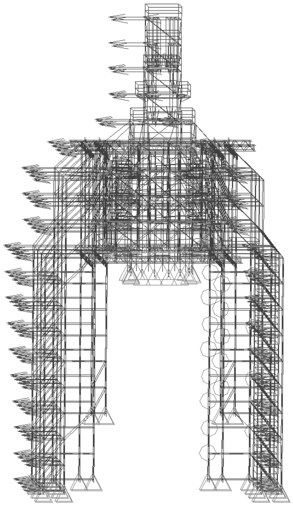


Fig. 5.20 The static scheme of scaffold around Scheibler's Chapel in Lodz with wind load

The cases of wind action in perpendicular and parallel directions to the construction according to the standard EN 18211-1:2007 shall be examined separately. The standard recommends determining concentrated forces which shall be applied to the nodes of model. Nevertheless, it can be done with lower workload. As it was previously mentioned, nets and clad can be modelled by shell elements. The majority of programs enables their loading by continuous load. Thus, it is enough to calculate the pressure of wind from the formula:

$$Q_k = c_s c_f q_i \tag{5.7}$$

and it can be applied as continuous load to shell elements, modelling the cover of scaffold. The model with load applied in such a way is shown in Fig. 5.21.

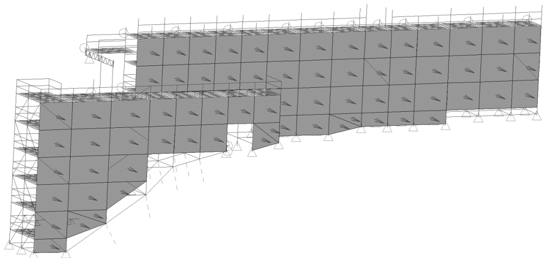


Fig. 5.21 The static scheme of scaffold part at the elevation of Archcathedral in Lublin with wind load applied to shell elements

In this place, another problem related to wind action shall be mentioned. In many situations, e.g. above domes, wind speed can have perpendicular direction with upward turn. Such wind causes the lifting of platforms. The surface of this action is quite big, and when the platforms are not blocked, they can be lifted. The loss of stiffness in horizontal planes by a construction is consequent upon this and it can result in the failure of scaffold. This aspect shall be taken into account both by designers and assemblers. In calculations, vertical wind action directed upwards unloads the construction, thus designers do not consider such a variant in calculations. However, in a design, there must be a recommendation for assemblers on the necessity to protect platforms against the possibility of pulling out due to wind action.

To conclude the problem of wind load on scaffolds, it can be stated that standard recommendations do not reflect real wind action. Unfortunately, in many cases, standard wind action is too big and a lot of design cases are not even mentioned. For this reason, designers while performing static calculations of scaffolds, as in the case of snow load, can count on own knowledge and intuition.

5.4.3 The analysis of construction effort

After preparing the static scheme which models particular elements of construction, their couplings, construction support, loads and geometric imperfections, the construction stability analysis and static calculations can be performed. In Fig. 5.22, calculation paths depending on critical coefficient α_{cr} are shown, thus the multiple load values at which the loss of stability can occur caused by the buckling of construction. It means that static calculations need to be proceeded by stability calculations of construction without inserting imperfections to its geometry. If the coefficient $\alpha_{cr} > 10$ is obtained, the strain-stress state of construction can be checked on the basis of internal forces, determined in the system of perfect geometry, yet according to the standard [EN 1993-1-1:2006], taking into account imperfections by considering buckling coefficients χ_1, coefficient of lateral torsional buckling χ_{LT} as well as moment value growth $\Delta M_{2,Ed} = a_2 N_{Ed}$ and $\Delta M_{3,Ed} = a_3 N_{Ed}$ due to local deformation of elements in the shape of arch. The quantities a_2 and a_3 are maximum values of the distance from the points of initially bent bar to its perfect axis.

In practice, this calculation path is not used because coefficients a_{cr} are close to the value of 2. It means that in the case of scaffolds, the two remaining paths can be used, and primarily, in static calculations of scaffolds, imperfections shall be taken into account by the change of construction geometry, which was previously mentioned.

If coefficients a_{cr} assume values above 2, the static calculations can be performed by the middle path, shown in Fig. 5.22. Moreover, the majority of controls of static façade scaffolds shall be conducted using this path since façade scaffolds usually have critical coefficients above 2. It is also confirmed by the standard EN 12810-1:2010 in which even with larger critical coefficients, it is recommended to perform calculations using the middle path. For the construction with geometry considering imperfections, loads shall be applied and static calculations shall be performed at least by the theory of the second order, taking the effects *P-Δ* into account. The static calculations of this type are a simplified version of nonlinear calculations with geometric nonlinearity and consist in determining internal forces which are the effect of load action on displaced nodes (Fig. 5.23 for iteration 2). They can be conducted by selecting appropriate options of computer program, when one gives such possibilities.

However, e.g. program Algor Autodesk Simulation 2011, in a cheaper version, does not provide such a possibility, hence the results presented below are obtained in a way which contains the following calculation stages:

- linear (traditional) calculations and determination of nodes displacements,
- change of construction geometry by inserting the displacements of nodes, calculated in the first static calculations,
- application of loads to changed geometry and performance of subsequent static calculations, as it is shown in Fig. 5.23 for iteration 2,
- determination of internal forces for the configuration in iteration 2.

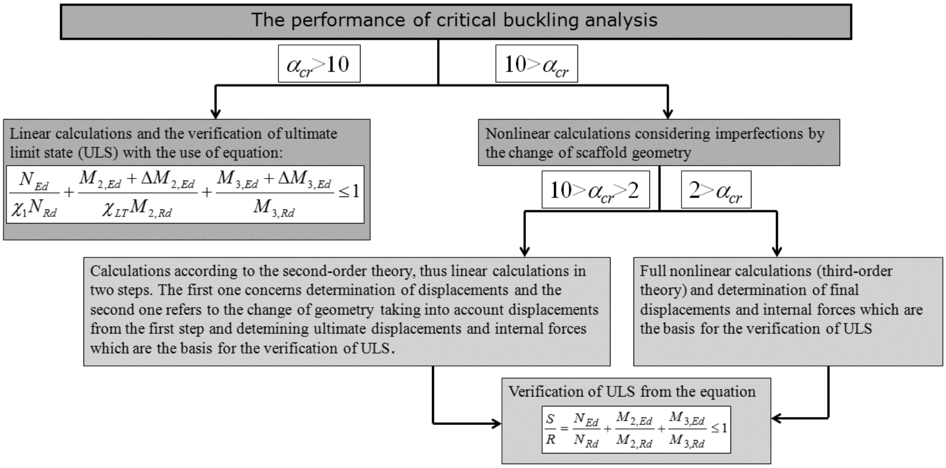


Fig. 5.22 Paths of calculations according to standards EN 12810-2:2010, EN 12811-1:2007 and EN 1993-1-1:2006, markings: N_{Ed}, $M_{2,Ed}$, $M_{3,Ed}$ – calculated values of normal forces and bending moments relative to two axes of local coordinates system of element, N_{Rd}, $M_{2,Rd}$, $M_{3,Rd}$ – maximum permissible values of normal forces and bending moments relative to two axes of local coordinates system of element, χ_1 – buckling coefficient [EN 1993-1-1:2006], χ_{LT} – lateral torsional buckling coefficient [EN 1993-1-1:2006], $\Delta M_{2,Ed}=a_2 N_{Ed}$ and $\Delta M_{3,Ed}=a_3 N_{Ed}$ – growth of moments caused by local imperfections of elements [EN 1993-1-1:2006]

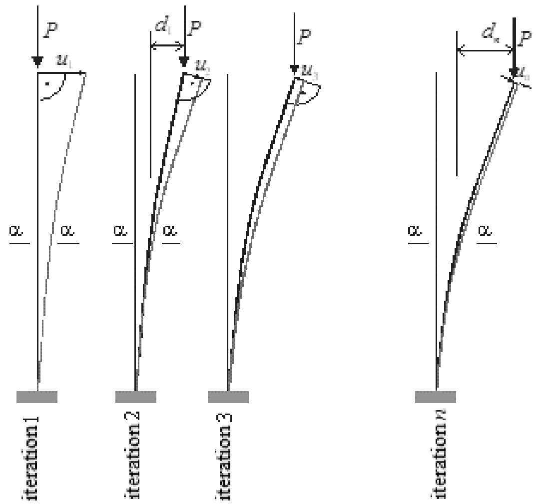


Fig. 5.23 The scheme of searching for the solution in static calculations with geometric nonlinearity

The last path of calculations yields the most precise results. Nonlinear calculations with geometric nonlinearity take real displacements into account since no simplifications are inserted, such as exclusion of the impact of additional bending moments caused by the displacements of nodes. Searching for the solution consists in finding such a geometry of system at which external loads, acting on the system with a geometry considering loads, are in balance (e.g. the shape of support from the last iteration in Fig. 5.23).

In the standards EN 12810-2:2010 and EN 12811-1:2007, there are also recommendations to apply the susceptibilities of elements couplings whose graphs are shown for example in Fig. 5.8. Nonlinear character of these graphs causes that static calculations are even more complicated. If the linear range of susceptibility graph is exceeded, thus the second type of nonlinearity must be taken into account which is material nonlinearity described by the curves: internal force-displacement, such as in Fig. 5.8, or the stresses-deformations curves. Inserting material nonlinearity significantly complicates calculations and in many cases makes it difficult to find the solution or even impossible to find one. It results from the fact that at first, strength hypotheses shall be determined which will define the state of stresses, and secondly, partial plasticity of cross-sections shall be taken into account. The issue remained in such a way becomes a scientific, not an engineering problem which can be solved in reasonable time frames defined by investment process.

In paths when $\alpha_{cr} < 10$, the final effect is the verification of ultimate limit state, thus the condition described by the formula:

$$\frac{S}{R} = \frac{N_{Ed}}{N_{Rd}} + \frac{M_{2,Ed}}{M_{2,Rd}} + \frac{M_{3,Ed}}{M_{3,Rd}} \leq 1, \tag{5.8}$$

where load bearing capacities of cross-sections at particular internal forces are:

$$N_{Rd} = \frac{Af_y}{\gamma_M}, \tag{5.9}$$

$$M_{2,Rd} = \frac{W_2 f_y}{\gamma_M}, \tag{5.10}$$

$$M_{3,Rd} = \frac{W_3 f_y}{\gamma_M}. \tag{5.11}$$

As it results from these formulae, normal forces N_{Ed} and bending moments relative to two axes of local coordinates system of element $M_{2,Ed}$ and $M_{3,Ed}$ are necessary to verify the construction. In Fig. 5.25 there are sample internal forces for the problem shown in Fig. 5.24. These results are obtained with the use of Algor Autodesk Simulation Program 2011.

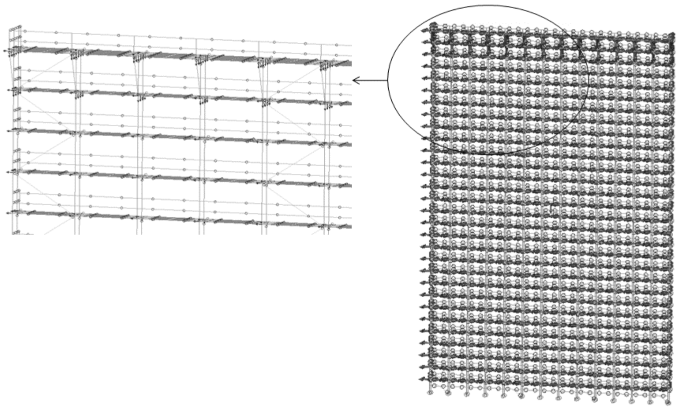


Fig. 5.24 A sample static scheme of scaffold prepared for calculations in Autodesk Algor Simulation Program

Every computer program, based on the finite element method, makes the results of calculations available, among others, in such a form. The possibility of direct verification of load bearing capacity of elements cross-sections depends on the used software. In Fig. 5.26, there are normal stresses determined from the formula:

$$\sigma = \frac{N_{Ed}}{A} + \frac{M_{2,Ed}}{W_2} + \frac{M_{3,Ed}}{W_3} \tag{5.12}$$

as well as capacity strain of elements S/R according to the formula (5.8). The values of stain-stress directly show the use of cross-section. Whereas, normal stresses σ shall be compared with permissible values of stresses which are f_y/γ_M, where f_y – characteristic yield strength, and $\gamma_M = 1.1$ according to EN 12811-1. The condition is fulfilled if $\sigma < f_y/\gamma_M$.

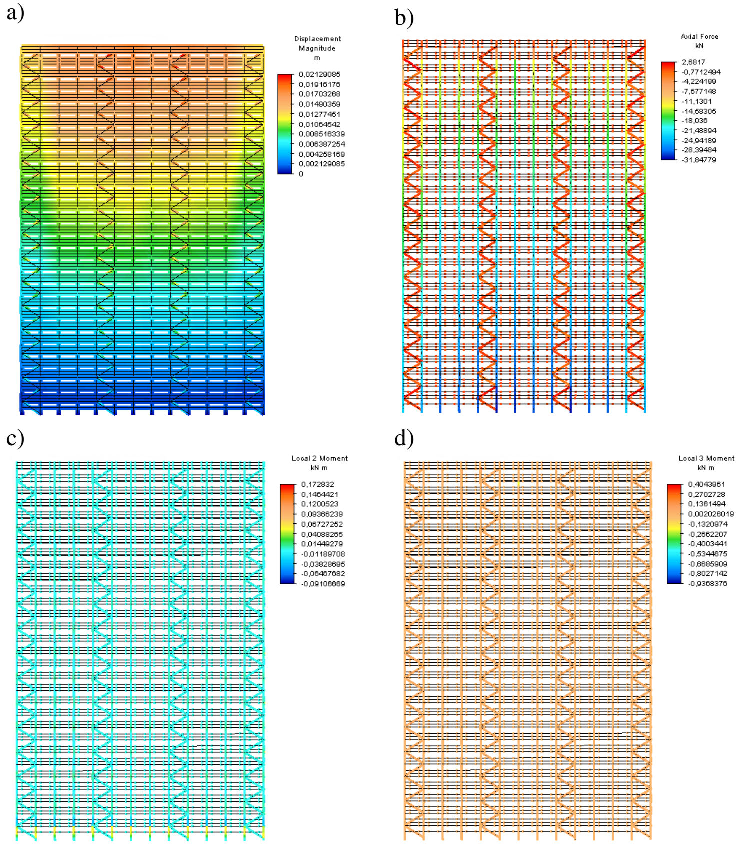


Fig. 5.25 The results of calculations for the problem shown in Fig. 5.24: a) resultant displacements, b) normal forces N_{Ed}, c) bending moments relative to the second axis of the local system of coordinates $M_{2,Ed}$, d) bending moments relative to the third axis of local system of coordinates $M_{3,Ed}$

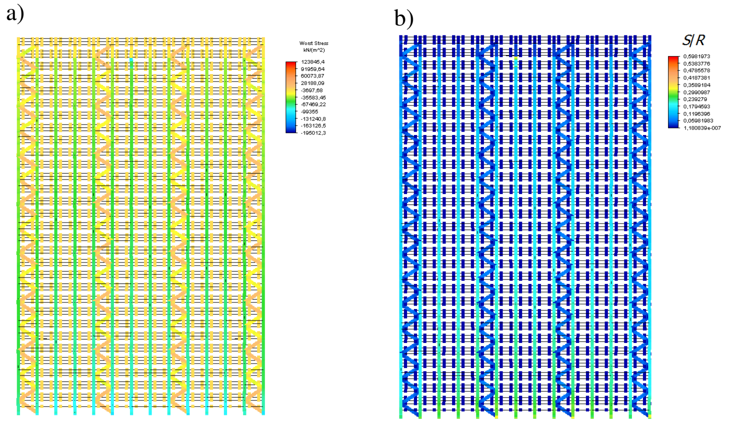


Fig. 5.26 The results of static-strength analysis for the problem shown in Fig. 5.24: a) normal stresses, b) strain-stresses of cross-sections S/R

A scaffold needs to satisfy the conditions of ultimate limit state of usage, thus primarily large displacements due to characteristic loads cannot occur, which threatens on one hand the comfort of use, and above all, the proper work of construction.

The condition for ultimate limit state of scaffolds operation is not strictly defined. The recommendations of steel standards EN 1993-1-1:2006 can possibly be used for rad structures, and the following permissible deflection of construction can be assumed:

- vertical bends for secondary beams: u_{dop} = l/250, where l – the width of scaffold,
- horizontal bends in multi-storey systems: $u_{dop} = h/500$, where h – the height of scaffold.

Concluding, it should be pointed out that one of the most important, and in the same time, not the easiest stage of scaffolds designing, are static calculations, even despite the use of computer programs. Every of these programs has its own specificity of preparing the data, making the specialist numerical methods available and presenting the results. Hence, it is very difficult to give universal information on calculations which all designers can benefit from.

5.5 Other components of a scaffolding project

5.5.1 Information on Health and Safety at work on scaffolds

The information relating to Health and Safety of workers has to be included in every construction design. In the case of scaffolds designs, this information particularly refers to hazards which can occur during assembly and disassembly. Nevertheless, in the case of scaffolds of untypical purpose or operation mode, also the information on the way of operation shall be included in this part.

Information HSE in the first part shall include the following information: at which facility a scaffold will be assembled, the list of existing facilities in the neighborhood of scaffold, the scope of works and anticipated hazards. Within the framework of assembly and disassembly of scaffold, the scope of works covers such activities as: assembly of scaffold structure, assembly of platforms, implementation of scaffold anchors, vertical transport of elements, and transport of elements by cranes. However, the main threats that occur while performing construction-assembly works include: the fall of workers from heights, fall of tools and scaffold components, impact of motor vehicles into a scaffold, impact of elements transported by a crane into a scaffold, impact or pushing off workers by transported elements.

Information HSE should serve to increase safety at construction site, thus subsequent components of this part include the description of technical and organizational measures preventing hazards. At this point, given recommendations shall describe the on-the-job training primarily related to assembly works with a particular consideration of the works at heights, medical certificate that enables performing works at heights, the way to protect the area in compliance with the regulation [J. Law 1997, 169].

Among the recommendations related to the performed works, there should be:

- locating the first-aid-kit at the construction site,
- locating the information on emergency calls in a visible place,
- works at heights shall be performed using individual or collective protection, according to health and safety regulations,
- assembly of scaffold shall be performed in compliance with binding health and safety regulations as well as the assembly and operation instruction for a scaffold of a given system,
- acceptance of scaffold is conducted by the entry in the construction log book or in the protocol of technical acceptance,
- inspections should be conducted on daily basis by the worker of company operating the scaffold,
- steel scaffold should be appropriately grounded and equipped with lightning protection system,
- inspection of scaffold should also be performed after occurring adverse weather conditions, such as storm, high winds above 10 m/s as well as in the case of fall of heavy devices or materials on a scaffold; special attention should be paid to technical condition of anchoring as well as platforms attachment.

Among recommendations, related to performed works, the following detailed restrictions shall be listed:

- working platforms should have protective guardrails at the height of 0,5 m and 1.0 m from internal and external side,
- clearances cannot occur in working platforms of scaffolds,
- platforms have to be secured by toe boards of the height of 15 cm,
- protective canopies have to be placed over passages,
- it is not permitted to load platforms over their established load bearing capacity and to collect materials in one place on the platform,
- test on load bearing capacity of anchoring to pulling out shall be performed before proceeding to assembly,
- it is not allowed to climb standards, transoms, and scaffold guardrails,
- it is not allowed to throw the components of disassembled scaffolds,
- it is not allowed to leave tools at the edges of platforms,
- it is not allowed to make rapid movements, lean over the guardrails, collect materials and tools at one side of scaffold, lean against the wall of building, etc., by the persons on the platform.

A certain standard range of recommendations is given above, however, in specific cases other recommendations can appear, e.g. that during snowfalls, remaining snow shall be removed on an ongoing basis, at welding works, there is a recommendation that a welder needs to be isolated from a scaffold, and in the case of mobile scaffolds, the recommendation that all the workers should leave working platforms for the travel time. Atypical application of scaffold always requires detailed analysis of circumstances which can lead to a disaster, and the information of such possible hazards as well as the way of their avoidance shall be included into HSE information.

5.5.2 Technical drawings of scaffolds

In fact, technical drawings of scaffolds shall fulfill all the requirements of manufacturing drawings. During the preparation of drawings, it should be borne in mind that assemblers must assemble and properly anchor the structure on their basis. Thus, the shape of scaffold with its dimensions and markings of elements shall be included into a drawing, where the details of typical couplings can be neglected, yet such information shall also be placed in the technical documentation of scaffold.

In the drawings, the following components should also be included: scaffold draft, the dimensions of elements mesh, the distances from the facility at which a scaffold is located, markings of elements, the position of anchors, textual comments, as well as a table with data. The drawings, depending on the degree of complexity and collected data, can assume the following forms:

- three-dimensional visualization (Fig. 5.27),
- the views of scaffold and cross-sections in a horizontal plane and two vertical planes at which scaffold elements are marked only by the segments of straight lines (Fig. 5.28),
- the views of scaffold and cross-sections in a horizontal plane and two vertical planes at which scaffold elements are drawn with details (Fig. 5.29).

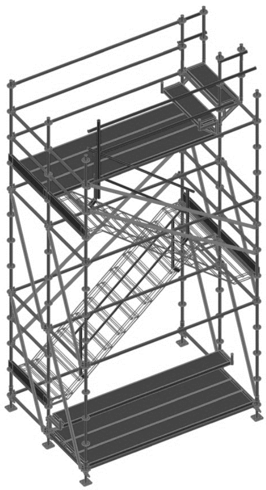


Fig. 5.27 The example of 3D visualization

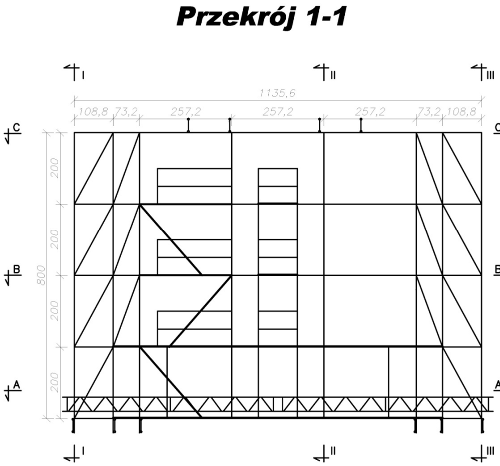


Fig. 5.28 The example of simplified drawing of scaffolds

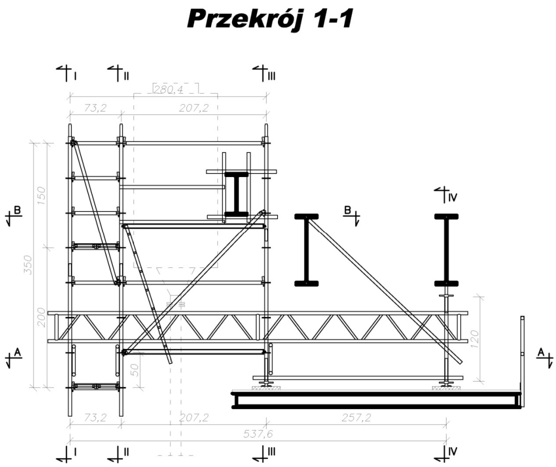


Fig. 5.29 The example of detailed drawing of scaffolds

The three-dimensional visualization can be applied if a building is small. In such a drawing, it is difficult to insert dimensions, and for this reason, it has to be accompanied by the selected projections which enable determining scaffold dimensions.

In the case of larger constructions, the 3D visualization is blurred and the views of scaffold are essential, as well as the cross-sections in horizontal plane and two vertical planes. Depending on the collected information on a scaffold (e.g. if a designer has the drawings of particular components) as well as the time for the preparation of a design, drawings can contain either scaffold schemes where scaffold elements are marked only by the segments of straight lines, or precise technical drawings with elements containing all their details.

Every drawing shall be annotated as well as shall contain the table with data on the design and designer. The following data shall be found in the table: an investor and his address, an investment and its address, a contractor of a design, designers, a name of drawing and design, scale, date of preparation, and a number of drawing. A sample table is shown in Fig. 5.30.

INVESTOR			
PROJECT NAME			
ORDERED BY			
DESIGNERS			
	TITLE, FIRS NAME LAST NAME	LICENSE	SIGNATURE
DESIGNED BY			
DRAWN BY			
VERIFIED BY			
	DRAWING TITLE		
PHASE			
SCALE		DRAWING NO	
DATA			

Fig. 5.30 The example of the table with data on scaffolding project

5.5.3 Point at the end of a scaffold project

The last point of design gives recommendations and conclusions. In the case of scaffolds, the information on how long and in which seasons the scaffold can be operated shall be placed in this part. It is significant to include the information on permissible load of construction. Moreover, the recommendations related to basic principles of Health and Safety at work, as well as acceptance and inspections of scaffold shall also be repeated in this part. The aspect of safety at work on a scaffold is very important, thus even if there are double entries in the study, it should be repeated also in this part so as to reach all the concerned people.

5.6 Conclusion

Designing of scaffolds is a responsible and difficult task. Designing atypical scaffold means that new technical solutions shall be applied, and in consequence, the unusual way of its operation can be expected. Hence, it is essential to conduct static calculations and the analysis of hazards which can occur during the operation of scaffold. All these aspects are discussed in this chapter.

6 General conclusion

Construction scaffold are used at every construction site. Every civil engineer has to deal with them every day. Thus it is so important to familiarize with legal acts which define the principles of scaffold use, to know the rules of developing scaffolds as well as to know what can be expected from a technical documentation of scaffold. And finally every civil engineer has to be aware of the fact that scaffolds are of great importance for the safety of work at the construction site. Unfortunately, the majority of disasters at construction sites are related to the use of scaffolds. It results from the fact that scaffolds are used for the protection of works at heights and places with limited access, and hence from the performing such works, there exists a danger for workers. The knowledge contained in this study shall help in solving the issues related to the operation of scaffold and anticipation of hazards posed by the work on them, and in the same time their prevention.

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