SAFETY ENGINEERING OF ANTHROPOGENIC OBJECTS

SELECTED ASPECTS OF CONSTRUCTION PRODUCTION ENGINEERING IN THE DESIGN OF TECHNOLOGY AND ORGANIZATION OF THE EXECUTION OF COMPLEX MONOLITHIC BUILDING STRUCTURES

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Abstract

Construction objects are anthropogenic objects that meet human needs in the area of housing. They should be designed, made and used in a way ensuring the safety of people and property at every stage of its life cycle. To achieve this effect, the cooperation of designers, contractors and users of the facility is required. It is especially important for building contracting. Safe construction implementation requires the design of technology and organization of works. The article characterizes selected aspects of construction production engineering that should be taken into account when designing the technology and organization of monolithic works.

Key words: construction production engineering, organization technology, monolithic works

INTRODUCTION

Construction objects are anthropogenic objects [1] that meet the needs of people from the area of historically broadly understood construction and nowadays - from the area of the developing new discipline of engineering and technical sciences called civil engineering.

Civil engineering is a science that deals with many aspects of the life cycle of a building object. Civil engineers work at all its stages: designing, erecting and operating the facility [10,11].

At the erection stage, it is construction production engineering, which focuses on the precise planning of the construction site and all necessary arrangements related to the construction of the designed building object together with the surrounding infrastructure.

Pursuant to the definition contained in the Construction Law [25], a construction object may be a building, structure or small architecture object, together with installations ensuring the possibility of using the object in accordance with its intended purpose, erected with the use of construction products. This concept introduces a preliminary division of buildings into: building, structure and small architecture object, which have their strictly defined legal definitions. When talking about a building, it should be treated as a construction object that is permanently connected with the ground, separated from the space by building partitions, and has foundations and a roof. Small objects are called the small architecture object. The Act does not provide a direct definition of them, but does contain specific examples showing what the legislator meant when introducing such a term. Small architecture buildings are in particular:

- objects of religious worship (small chapels, roadside crosses, or figures),
- architectural objects such as: fountains, water jets, statues, including garden architecture objects,
- utility objects for everyday recreation and keeping order, such as sandboxes, garbage cans, or equipment for playgrounds for children.

The above definitions answer the question of what a building is. By way of elimination - a building is any construction object that is not a building or a small architecture object. The term is very broad, it includes anthropogenic objects which seem to be in no way related to each other. Namely, a building can be called both facilities related to communication and media transmission (bridges, airports, tunnels, technical networks, linear facilities (roads, railways, pipelines, power lines), all earth and hydrotechnical facilities, defensive fortifications, free-standing advertising boards , sports facilities, but also foundations for machines and devices, which, despite the fact that they are usually located within, for example, an industrial building, constitute its separate part [25].

The regulation on the **P**olish **C**lassification of **C**onstruction **O**bjects (PCCO) [23] introduces the Polish Classification of Construction Objects - PKOB. It has been developed in such a way as to ensure the compliance of symbolism and nomenclature with the European Classification of Building Objects (CC). It constitutes a specific, systematized, four-level division of buildings into: 2 sections, 6 divisions, 20 groups and 46 classes. This classification focuses on the purpose of a given anthropogenic object and therefore introduces its definitions. According to PCCO, the construction object is a structure permanently connected to the ground, made of building materials and components, as a result of construction works [23]. Further definitions result from the division of construction works into two sections: buildings and civil engineering structures. Contrary to the Construction Law Act, PCCO does not introduce the concept of a small architecture object - such structures are not classified here. According to the PCCO the building is a roofed structure, with built-in installations and technical devices, used for permanent purposes, which basically corresponds to the definition contained in the construction law.

All other objects belong to the second section - civil engineering structures, this is also their definition given in the construction law, which includes these anthropogenic objects defined as structures.

A more detailed division (into departments, groups and classes) is based on a tabular list of data for objects, the main criterion of which is the way of using a given object, depending on the percentage of usable space allocated to a specific project purpose. A good example explaining this dependence can be a multi-family residential building (apartment block), on the ground floor of which there is a commercial and service part. Despite the fact that such an object de facto fulfills two functions, due to the fact that its usable area is predominantly intended for permanent human habitation, it is also classified as such.

It should also be explained how building works are classified according to this method. In this method, the analysis of the destination of a given object, adjusting it to the aforementioned partitioning frames, leads to a four-digit PKOB symbol. For example, when considering a building whose main usable part is an airport terminal, it receives the following series of numbers: 1 - because it is a building, 2 - non-residential building, 4 - communication, station and terminal buildings, and again 1 - buildings of airports, train stations and bus terminals, etc. Finally, according to PKOB, the airport terminal has the symbol 1241. It should be noted that it is the terminal itself, and not the airport as a whole, because in this case it should be treated as a complex structure / complex of facilities. All buildings at the airport will have the symbol 1241 derived earlier, but the runway is treated as a civil engineering structure with the number: 2130 (2 - civil engineering structure, 1 - highways, transport infrastructure, 3 - airport roads, 0 - airport roads). To sum up, the airport as a whole should be defined with two PCCO symbols - for buildings 1241, and for runway 2130.

The **P**olish **C**lassification of **C**onstruction **O**bjects has basically one goal: to facilitate the exchange of information between individual participants of the investment process, as well as between people holding individual positions in them. This is of measurable importance when it comes to calculating prices and costs of a given project. Moreover, it introduces a specific nomenclature, thanks to which it is possible to avoid many linguistic misunderstandings, which may even have legal consequences. For example, in official documents, a youth hostel can be referred to as a hotel for which legal requirements can vary widely, causing unnecessary confusion as the law (PCCO) defines these facilities as two separate classes.

Construction objects - buildings can be classified according to the type of construction materials used for their construction. From this point of view, they can be divided into brick, wooden, reinforced concrete and metal buildings. It is rare that only one material is used, usually different load-bearing elements are made of different materials. In order to be precise, it is hard to say about the steel hall that it was made only of a material consisting of an alloy of iron and carbon and additives, because it also (usually) has reinforced concrete foundations. Therefore, attention should be paid to the technology of their production, and not directly to the material from which their bearing parts are made.

In construction, there are four main technologies for the execution of building objects:

1) traditional (craft) technology, which is characterized by the performance of all works directly on the construction site. The foundations are most often in the form of monolithic footings or footings, load-bearing walls made of small-size materials (various types of bricks, blocks), wooden (less often) or reinforced concrete ceilings, roof structure in the form of a wooden truss. In its improved form at the moment, it is the most popular technology for erecting residential buildings, both single and multi-family. Its main advantage is simplicity - it does not require the use of highly technically advanced equipment or specially qualified staff and does not generate production costs and transport to the construction site of structural elements.

2) traditional technology improved, which is very close to traditional technology. The difference is that it allows the use of some prefabricated elements, for example lintels, columns or staircase elements.

3) industrialized technology (prefabrication), in which mainly only the assembly of previously manufactured structural elements, e.g. foundations, walls, ceilings, takes place on the construction site. It is popular primarily in the construction of various types of halls, both industrial, commercial and sports. Recently, the use of this technology in housing construction, both single-family (wooden and steel modular houses) and multi-family houses, has been increasing significantly. The advantage of prefabrication is a significant reduction in the time of erecting objects. This form, however, generates additional costs related to the transport and assembly of elements of the object, which makes this technology generally more expensive than the traditional one.

4) monolithic technology, in which the objects are mainly made of ready-mixed concrete, delivered or produced on the construction site. Various types of formwork play a very important role in this technology, enabling the desired shaping of walls, ceilings and other structural elements. It is mainly used in the case of non-standard-shaped structures, or possibly massive engineering structures, such as dams or dams.

Research on the technology of building structures has shown the significant popularity of monolithic technologies [3,4,13]. The basic advantages include: the possibility of giving any shape and layout of a building, long service life of the structure, lower thickness of structural elements, or resistance to seismic shocks.

Designing technologies, organization of of monolithic construction

Designing the technology, organization as well as safety and health protection for the execution of monolithic structures is based on a construction design, which should include:

- *plot or area development plan*, drawn up on a current map, including: definition of the plot or area boundaries, location, outline and layouts of existing and planned buildings, utilities network, sewage disposal or treatment, communication system and greenery, indicating characteristic elements, dimensions, ordinates and mutual distances of objects in relation to the existing and planned development of the neighboring areas;
- *architectural and construction design*, specifying the function, form and structure of the building, its energy and ecological characteristics as well as the proposed necessary technical and material solutions, showing the principles of relating to the environment;
- in the case of a national or provincial road, *a declaration of the competent road administrator* about the possibility of connecting the plot with the road, in accordance with the provisions on public roads;
- depending on the needs, *the results of geological and engineering research and geotechnical conditions for the foundation of buildings*;
- *information about the area of influence of the object* [3,4,11].

The information contained in the construction design mainly focuses on the physical, mechanical and chemical properties of concrete (reinforced concrete). The material described is a composite consisting of concrete reinforced with a steel element or elements. Most often these are reinforcing bars of different diameters. The so-called dispersed reinforcement (steel or made of various types of plastics), improving the overall quality of the described material, is becoming more and more popular. In some situations, steel inserts in the form of ready-made profiles are used as concrete reinforcement. Pre-stressed concrete is a separate construction material. While in traditional reinforced concrete structures, the cooperation of the concrete mix with steel is mainly based on the adhesion of one material to another, in the case of prestressed elements, there is also a prestressing force applied to the concrete through a special type of steel, which increases the strength of such a structure many times over.

When designing a reinforced concrete structure, attention should be paid to three main issues: its durability, static analysis and the influence of imperfections and second-order effects [7, 14, 24]. The durability of a structure is its ability to meet the requirements of the ultimate limit states and use throughout the service life [14]. In other words, this problem describes the relationship between the technical condition of an object or its individual parts and the environment in which it is located. In the case of reinforced concrete structures, the issue of durability is somehow defined mainly by exposure classes. They result from the standard [18] and are selected on the basis of the expected environmental conditions in which the designed structure will operate [6,8].

The threats listed in the standard [18] apply to both concrete and reinforcing steel. It should be remembered that a given structure or its element may qualify for several classes at the same time. The facility located in the seaside area is not only exposed to the harmful effects of salt water, but also to other factors. The described exposure classes play a very important role in determining the minimum cover of the reinforcement [16,17]. They also determine to which class of structure (determines the relationship between the durability and the designed service life of a given structure) a given object or part of it will qualify. These dependencies are described in the standard [17].

Another important aspect of designing reinforced concrete structures is the static analysis of their models. It leads to obtaining the value of internal forces acting in given elements and caused by various types of loads. The standard [16] lists the following loads acting on buildings:

- permanent loads - for example self-weight and payloads;
- variable loads - for example snow, wind or thermal loads;
- exceptional loads - for example the impact of earthquakes, explosions or fire.

Their correct definition is very important as it leads to the values of internal forces as close to those that may occur in reality. These forces can be obtained by various methods of analysis, including linear-elastic, plastic or non-linear analysis. However, in no case is it possible to obtain their exact values as they actually occur. This is due to the fact that when designing, the idealized model of the structure is analyzed, and not the structure itself [7,8,15].

The last issue to consider when designing reinforced concrete structures is the analysis of imperfection and second order effects, which is particularly important in the case of monolithic structures. This is due to the fact that, as previously mentioned, an idealized model of the structure is analyzed during the design. This analysis aims to reduce the resulting discrepancies.

The design assumptions result from the investor's requirements for a given facility. The architect is responsible for the architectural and functional design. The remaining activities are in practice carried out by a building constructor. It can be said that the previously described issues related to durability, static analysis and the influence of imperfections and second-order effects fall within the scope of the constructor's work. The data obtained in this way make it possible to dimension the structure and make construction drawings. It should be emphasized that it is often necessary to change them when they lead to a significant oversizing of a given element (or the entire system), or on the contrary: designing for such data results in failure to meet the standard conditions regarding the load capacity of the structure or its performance properties. The whole process ends with determining the value of a given investment (costing) and leads to obtaining full architectural and construction documentation.

The construction of an object in monolithic technology can be presented in the form of a system for transforming input data into output data, which is mainly made of concrete works.

The main concepts of transformation are *input data* that is transformed into *output data* as a result of a processing process consisting of a manufacturing and logistics process.

The input data are:

- technical means of production (for example, construction site and its technological equipment);
- work items (building materials);
- energy factors;
- human factor (employees: management and workers);
- information, also understood as employee experience;
- capital (also that "frozen", for example in building materials or machines).

As a result of the processing process, these factors produce output data, such as:

- a building structure constructed in the assumed stage of completion;
- possible production services (for example, a concrete mix for an adjacent construction site);
- waste polluting the environment generated during construction (dust, sewage, but also noise related to technological processes);
- information about the erected building - its technical condition at the time of completion, the actual costs of its construction, but also experience gained by employees [11, 12].

The technology and organization of construction works require prior planning, because the erection of monolithic building structures is a complex process, consisting of basic and auxiliary processes [3,4,5,11,19]. The former, including the assembly of formwork and reinforcement, laying of the concrete mix and the care of fresh concrete obtained from it as a result of the hydration of cement, are closely dependent on the latter. In order to assemble the formwork, it is first necessary to complete it, taking into account possible non-standard parts, which must be specially manufactured. Reinforcement of a given element is also not possible without prior preparation of reinforcing meshes or skeletons, and a concrete mix with a properly selected composition must first be produced. These activities are just auxiliary processes. The place of performance of individual works is a separate issue. While activities related to the basic processes must undoubtedly be performed on the construction site, in the case of auxiliary processes, this issue is not so obvious. Nowadays, formwork is most often completed through specialized production plants, and then borrowed without contractors. Reinforcement meshes, in turn, are usually prepared in reinforcement plants located on the construction site by qualified employees. The issue of producing a concrete mix is related to two factors: the size of the construction site, and thus the amount of material needed, and the distance from concrete plants not located on the construction site. In the case of small construction sites, which require relatively small amounts of concrete mix, it is usually produced in external production plants and transported to the construction site using concrete trucks or, in the case of longer distances - truck mixers, which allow the process of mixing concrete components to start at the right time. This issue looks different when a large investment is considered, for example, the construction of an entire estate consisting of several dozen multi- or single-family buildings, or in the case of the implementation of special facilities, for example a dam on a river, requiring the consumption of large amounts of concrete mix. Then, a common practice is to organize field concrete plants, located directly on the construction site or in its close vicinity. This procedure is also used during the construction of roads with a concrete surface - in this case, the delivery of material from which the surface will be made from external plants, in addition to being long-lasting, may also turn out to be very troublesome or even impossible.

Designing technology and organization of works is closely related - without a technology design it is not possible to prepare a works organization design [3,4,9].

Designing the technology of construction works includes the following activities:

- identification of construction works that occur in the process;
- calculating the number of works that will occur during the construction of the facility, mainly on the basis of an architectural and construction design and catalogs of material inputs);
- selection of machines and devices (technical objects) needed to perform the assumed works;
- calculation of the efficiency and working time of machines and devices along with the development of their work patterns on the construction site.

The diagram of the works technology design procedure is presented in Fig. 1

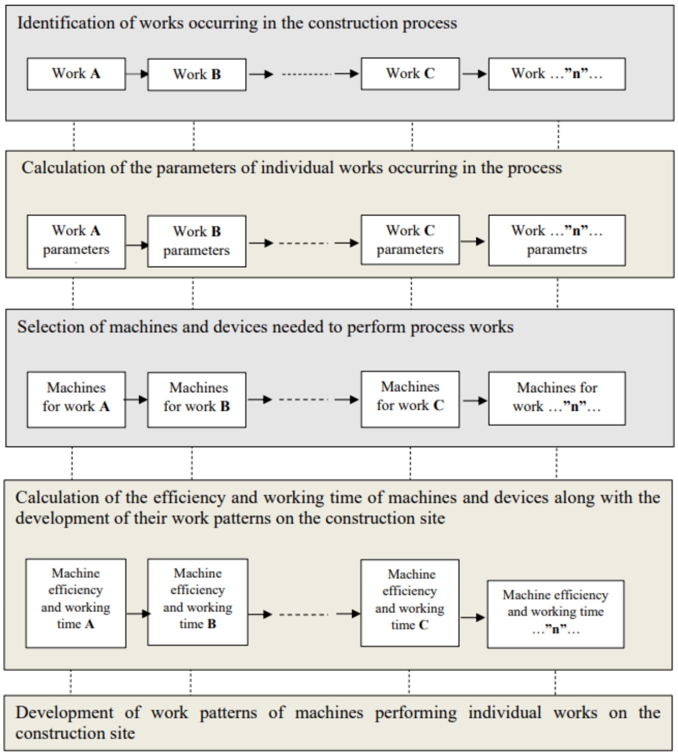

Figure 1. *Diagram of the procedure for designing the technology of construction works*

After the technological design is completed, you can start designing a safe organization of works [2, 10, 20, 21, 22]. The procedure for designing the organization of construction works includes the following steps:

- pre-selection of the work organization method;
- calculation of the duration of individual works in the process and the number of working teams;
- development of a network of dependencies between the robots in the process;
- execution of schedules: construction and / or individual works;
- development of the development of the construction site development: on the basis of the calculated amounts of individual resources: construction workers, construction materials and equipment for carrying out works.

A diagram of the work organization design procedure is shown in Figure 2.

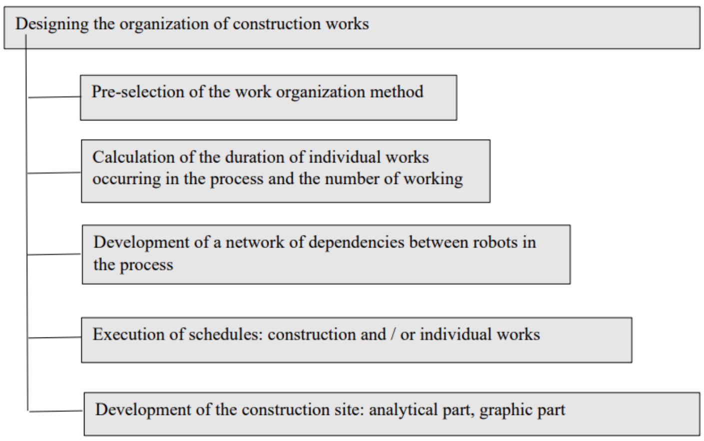

Figure. 2. *Diagram of the work organization design procedure*

In organizing construction works, three main methods of organizing works on a construction site can be distinguished [3,4,9,11]:

- *the method of successive execution* - it consists in the successive performance of works one after the other on individual plots of land - for example: the investment involves the construction of three multi-family residential buildings - according to this method they will be carried out one by one, the construction of the second one will start only after the first one is completed, and so on,

- *parallel execution method* - is the complete opposite of the sequential execution method. Referring to the previous example, all three facilities are being constructed at the same time by three independent construction teams,
- *uniform work method* - the works carried out during the construction of the building object are divided according to technological criteria into individual stages, performed one by one by specialized brigades on working plots. Referring to the considered example: the brigade performing earthworks carries out them on the first facility. After their completion, it moves to the second one, and at the same time foundation works are carried out on the first structure.

Each of the above-described methods has both advantages and disadvantages (Table 1).

Method	Disadvantages	Advantages
Successive execution method	- long construction time of the facility; - lack of continuity of work of individual working teams.	- a small number of simultaneously needed workers and machines.
Parallel execution method	- very high demand for both employees and equipment and construction machinery, and thus very high costs.	- definitely the shortest completion time of the facility.
Smooth work methods	- the need to skillfully divide the erected object into individual plots of land - so that they are characterized by a similar labor consumption; - the need to complete specialized brigades for individual works.	- the structures are erected evenly and continuously; - after some time, "you get" specialized brigades.

Tab. 1. *Advantages and disadvantages of methods of organizing work in construction*

The activities of the design procedure for the organization of construction works (Tab.1) allow for proper management of the resources necessary for the execution of a building object.

Development of the construction site is performed at least in the scope of:

- fencing the site and designating danger zones,
- construction of roads, exits and pedestrian crossings,
- supply of electricity and water, hereinafter referred to as "media", and discharge or disposal of sewage,
- equipment for hygiene and sanitary facilities and social facilities,
- provide natural and artificial lighting,
- ensuring proper ventilation,
- ensuring telephone communication,
- equipment for storage of materials and products. [3,4.,9,11].

The issue of engineering construction production in the design, technology and organization of monolithic works is very important. It would be a big mistake to treat these processes as completely separate parts of the building's life cycle. While technology and organization are naturally complementary areas, the design and operation of a building are often treated as a completely independent process. This state of affairs leads to negative consequences for the implementation of the entire construction project implementation process, resulting mainly from disputes and misunderstandings between project participants: designers, contractors and users of the facility. A very beneficial practice is the cooperation of all participants in the process. Thanks to the combination of their knowledge and experience, optimal solutions for the implementation of a specific construction and further operation can be obtained already at the design stage. The detailed design becomes more understandable for contractors, the implementation is less complicated, and the operation more meets the users' requirements.

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