Védelem Tudomány 9. évfolyam 1. szám, 2024 január DOI: 10.61790/vt.2024.15245

Korszerű zsaluzórendszerek jellemzése és alkalmazása ipari baleset-elhárítási szempontok vizsgálata során

Characterization and application of modern formwork systems during analysis of the aspect of industrial accident prevention

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Absztrakt:

Az építőipar területén számos ipari balesetvédelmi szempontot kell figyelembe venni a rendkívüli események megelőzése érdekében. Ezen túl a beruházásoknál elhangzó leggyakoribb három kérdéstípus a mit, mikorra és mennyiért. Nincs ez másként az építőiparon belül a szerkezetépítésében sem. Különösképp érdekes ez a kérdéskör, amikor ideiglenes szerkezetekről beszélünk, mint például a födémzsaluzat. A kész terméknél, mint például egy lakóépület, egy középület, vagy egy ipari csarnokszerkezet már nem találkozunk a zsaluzattal, és mégis a monolit vasbetonszerkezet építés egyik legköltségesebb és legidőigényesebb folyamata. Az utókalkulációk azt mutatják, hogy a teljes vasbeton szerkezetépítés költségének mintegy 35-40% teszi ki zsaluzási munka. Így érthető, hogy mind a tervezőket, mind a kivitelezőket mindig is foglalkoztatta, hogy hogyan lehetne a leghatékonyabban optimalizálni a felhasználandó zsaluk mennyiségét, és azok időbeni felhasználását. Ennek okán fejlesztették ki a födémzsalukat részben helyettesítő, bent maradó zsaluzó kéregpaneleket. A cikk bemutatja, hogy az idő és költségtényező befolyással lehet a rendkívüli események bekövetkezésére is.

Kulcsszavak: födémzsaluzat, zsaluzó kéregpanel, idő, költség, balesetvédelem

Abstract:

In the field of the construction industry, many aspects of industrial accident protection must be taken into account in order to prevent extraordinary events. Furthermore the three most common types of questions asked in investments are what, when and for how much. This is no different in structural engineering within the construction industry. This issue is particularly interesting when we talk about temporary structures, such as slab formwork. With the finished product, such as a residential building, a public building or an industrial hall structure, formwork is no longer encountered, and yet it is one of the most costly and time-consuming processes of monolithic reinforced concrete structure construction. Post-calculations show that formwork accounts for about 35-40% of the total cost of reinforced concrete structural construction. Thus, it is understandable that both designers and contractors have always been concerned about how best to optimize the amount of formwork to be used and their timely use. For this reason, the remaining formwork bark panels, which partially replace the floor formwork, were developed. The article shows that time and cost factors can also influence the occurrence of extraordinary events.

Keywords: slab formwork, formwork bark panel, time, cost, accident protection

1. INTRODUCTION

Reinforced concrete structural construction can basically be divided into two types of construction technology: monolithic, reinforced concrete construction made on-site, and prefabricated reinforced concrete structure construction, which is manufactured at a plant. It is possible to analyze and evaluate which method is the most effective according to many aspects, which can of course be considered both from a technical and economic point of view and separately. Between the two technical solutions, there is a well-known third solution, prefabrication at the construction site, but this actually follows the method of factory prefabrication in terms of technology, obviously with its advantages and disadvantages. Recently, however, a new segment of factory prefabrication has also appeared, namely the production of formwork bark panels, which in the first step will be treated as a prefabricated structure as a construction technology but will already operate as a monolithic structural construction auxiliary element at the construction site.

The question of how much the formwork bark panel takes over the role of slab formwork, where and how they can be applied, and whether we can speak of competition at all, depends on which segment of the market is affected. However, to decide this, let's familiarize ourselves with both systems in a little more detail and then attempt a comparative analysis.

2. MODERN FLOOR FORMWORK

Formwork has been a well-known tool for making vault belts and supporting them since ancient times. The real great progress of formwork work began in the middle of the last century with the invention of reinforced concrete. [2] With the development of reinforced concrete, formwork played an important role in surface formation in addition to the earlier shaping and supporting tasks. Around the turn of the century, the conscious development of formwork had already begun, because it became clear that formwork requires the most manpower among the processes of making reinforced concrete, surpassing iron installation and concreting. The next major development started with the end of World War II, primarily driven by the increased demand for formwork in prefabricated reinforced concrete structures. Sliding formwork, spatial formwork and creeping formwork are born, and at the end of the 1960s the large-panel formwork system spreads, and in the late 1970s and early 1980s modern framed formwork systems as we know them today, enter the market. In this study, only the formwork of slab structures is examined, contrasted with prefabricated bark panels.

2.1 About slab formwork in general

The following modern formwork systems are used in industry for the formwork of horizontal or inclined sheets: Framed formwork systems and their variants with drop heads, wood-supported floor formwork, and in the last 10-12 years, the well-tried table formwork has come to the fore again, but with a modern design.[1] The fundamental difference between framed slabs and formwork is that slabs are always made with aluminium frames, whereas this is very rare for wall structures, as aluminium has a higher modulus of elasticity, so larger deformations can occur under high concrete pressure. Of course, the boards are much smaller than the large dimensions used for formwork, as they have to be lifted manually. The largest slab panel ever marketed is the size a180x180 cm, which weighs almost 40 kg. The floor panels are either suspended directly on special heads on the supports or mounted on beams made of system components located between the panels.

The supports are modern, nowadays usually external, trapezoidal hot-dipped galvanized lofts, which are equipped by developers with various drop pins for easy and quick formwork.

Obviously, systems are more practical the fewer parts they can be assembled from, which of course can have a decisive influence on the time of formwork and its setup.

2.1.1 Wooden slab formwork systems

Perhaps the most common slab formwork system in the Hungarian construction industry is the so-called timber support system, which consists of the support, i.e. the loft, the fork head, the three-legged bollard, the wooden support and the covering, i.e. the shell. The supports are the same, the above-mentioned frame slab formwork supports, compatible in each other's system. The main supports of the formwork are inserted into the fork head on the supports, then the drawer holders are placed perpendicular and naturally thickened to it, and finally the formwork shells are placed on it as a cover. The drawer and main supports are made of one and the same material, so the formwork designer decides what size elements to build the system with. Wooden supports are generally glued I supports 16 or 20 cm high, regardless of manufacturing companies, with a belt width of 8 cm, or wooden supports featuring high truss ridges. Previously, the ridge design was only conceivable from glued pine, but nowadays it is not uncommon to have a wooden support with a pressed wood pier or a double-ridged design for telescopic splicing. The three-legged supports, which are attached to the main supports, can only be used as auxiliary structures until the formwork is completed, i.e. they only serve a function during formwork installation. In terms of shelling, two types are usually the most common, one is the three-layer glued pine shell, which satisfies all options from 1 meter to 3 m in 50 cm raster, and the eternal "competitor" is plywood. Three-layer pine boards are cheaper than plywood, but their lifespan is also shorter, even despite the often-visible metal edge protectors. Their surface is damaged sooner, they can't really be repaired, and after 15-20 uses, the adhesive status peak during a lot of water absorption, i.e. swelling and drying out, and they no longer give a truly plaster-free surface. In contrast, plywood boards receive a phenol-coated, hard Bakelite layer on both sides, which has a high resistance to mechanical stress, protects the sheet from strong sunlight and frost, prevents water from entering the wood layers, and in case of damage, forms a well-plastered and smooth concrete surface that can be painted or wallpapered without any special preparation. The disadvantage is that they are expensive, heavy, and are available on the market only in relatively large sizes, usually 125x250 cm.

From the point of view of industrial safety, the most serious source of accidents is when the entire structure collapses. One of the reasons is improper absorption of horizontal loads. In this case, in the absence of wedges or Andrew's Crosses, the formwork moves horizontally sideways and collapses. Another reason may be sudden overloading, in such cases most often the load capacity of the wooden supports is exhausted and simply breaks, dragging the formwork boards along with the reinforcing steel and concrete. A similar accident can happen if the formwork is not installed on site, the supports are distributed according to the static plans, overload is created, and the slab breaks off. The main tools for preventing accidents are organized work, highly qualified on-site management and scheduled on-site inspections. [7]

In the case of timber durable formwork, the combined time required for construction and formwork cannot compete with prefabricated bark panel systems, in this respect it is certainly not competitive.

2.1.2 Drop head formwork systems

Today, almost all large formwork distributors produce drop head systems, the essence of which is that the structure can be formwork in such a way that in certain raster the supports or, in some cases, the beams on the supports remain inside after formwork, thus enabling the so-called early formwork.

We can distinguish two basic types; one is the panel (framed) drop head system and the other is the aluminium beam durable drop head system. The basic elements of the panel, or as many calls it the framed drop head system, are the traditional floor support, the special drop head resting on the support and the slab formwork panel. Aluminium frame formwork usually has phenol-coated plywood covering, but recently plastic formwork shells can also achieve good indicators in formwork rotation.

They are most suitable for rectangular formwork fields with clear geometry, where the large continuous surface is dominant. The other drop head system is the so-called beam system, which is most comparable to the timber slab system. Its frame structure is the well-known support system, the aluminium main and drawer holders, on which the traditional formwork boards rest. While the construction and demolition time is longer compared to the framed system mentioned earlier, its layout offers more flexibility. Curved slab fields with irregular geometry can be solved with much less constraints. Of course, early formwork is also ensured here by the special drop head.

But what is early formwork, how can it be interpreted, and to what extent does it influence the decision maker in deciding on formwork or bark panel slab system. A wide variety of opinions, arguments and counterarguments have already been expressed about the concept of early formwork and the drop-head slab formwork technique, but these are usually not objective statements, but rather opinions adapted to market needs, heated by emotions and often emotions. Today, most experts agree that at normal temperatures (>15 C°), reinforced concrete slabs can be formwork after days 3-4 without any special quality damage. This does not depend on the type of formwork system, but on the quality of the concrete, the useful load of the slab, the thickness of the slab, and the post-treatment of the concrete. By this time, the slab usually reaches 50 % of its compressive strength and 70 % of its tensile strength.

Many people ask whether it is worth formwork earlier than this, for which, of course, only a drop head solution can be used. Given the possibility of reducing construction time, it is of course worth using drop head formwork systems. The primary concern is identifying potential defects and damage to concrete quality beyond the benefits of drop head systems, and, most importantly, how to prevent them.. In the case of a drop head system, the slab loads above each other add up, albeit showing a decreasing trend. This effect can occur in the power play of the reinforced concrete slab, when negative torque is generated in the reinforced concrete slab above the supports, [3], which causes tensile stresses to occur on the upper section of the slab. In the absence of sufficient ironing, they can cause cracks on the upper surface of the plate. The cumulative floor loads can also damage the support system if the support force exhausts the load capacity of the system. In addition, the most common accidents are falls from the edge of the slab, due to unprofessional barriers or their complete absence. One of the best solutions for this is to use bracket platform (Figure 1). Controlled protection not only prevents falls, but also allows you to work safely.

Figure 1: Bracket platform [10]

3. THE PREFABRICATED FORMWORK BARK PANEL

Formwork panels are not new either, as their predecessors began to be produced in Germany after World War II. Sometime in the 1940s, István Keller, who was of Szekler origin, set off from Banat to the West to try his luck, fleeing from the war. In post-war Germany, there was a great shortage of materials. From that time emerged the saying of Filigran, which is still highly respected today, "to replace mass with structural solutions". This is how István Keller - who became known as Stephan Keller - founded Filigran in 1949, after developing lightweight steel truss supports. The product of that time was most similar to the Fert slab beams we know today. Between 1960 and 1965 the "Filigran-Elementdecke" was sold in Germany and, of course, in other Western countries. Slabs formed by working together with larger prefabricated slab elements and monolithic concrete later became known as Kaiser, Omnia, etc. In France, already in the 70s, planks 5 cm thick were made with stretched iron.

There were several attempts to popularize formwork panels in Hungary, but it really appeared on the market after the change of regime, in the 1990s, and since then they have been producing in several plants, also for foreign markets. It is interesting to note that formwork floor panels were first imported from Slovenia in the nineties during the construction of Hotel Kempinski. In Hungary, the most common formwork panel type is the surface grid rib-reinforced bark panel and the top-ribbed stretched formwork panel.

3.1 Surface grid rib-reinforced bark panel

A reinforced concrete slab can be made from the bark panel reinforced with the rib of the space grid (Figure 2) with monolithic upper concrete. The cooperation between the two layers is due to the roughening of the upper surface of the slab element and the space grid cemented at intervals of 60 cm or less. The rigidity of the floor element during transport and lifting is also ensured by the built-in space grid. Typical raw materials used in the manufacture of the slab element: according to MSZ EC: concrete: C20-16/KK20/25; C25-16/KK25/30; reinforcing steel: B60.50 B 500.

In individual cases, raw materials of a different quality may be used. Characteristic element thickness of the slab element: 5.0 cm; 6.0 cm and 8.0 cm. Maximum element width 2.50 m, while length is 8 – 12.00 m [4]

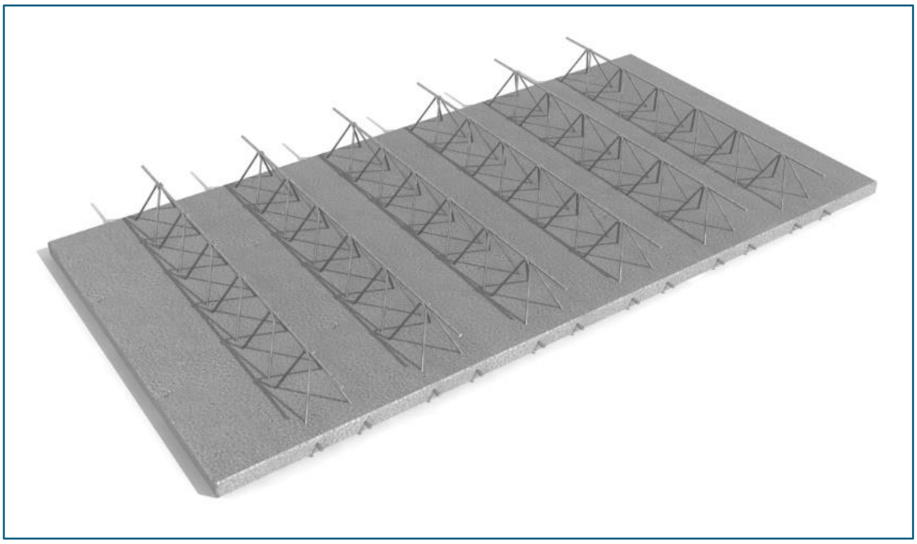

Figure 2: Bark panel reinforced with a spatial grid rib [4]

Areas of application of the slab system: the slab system is designed individually for new or existing buildings, regardless of all architectural functions and static loads. It can be applied to single-family houses, multi-apartment buildings, office buildings, educational, communal buildings, underground garages, industrial facilities, etc. It is especially recommended for spaces with low ceilings, e.g. cable ducts, where costly and time-consuming formwork removal can be saved, or for spaces with high ceilings, where the number of supports can be reduced or sometimes omitted by compressing the space grid. It can be used as formwork remaining in bridge construction, taking into account the relevant regulations. It can also be used for renovation work, where the load bearing capacity of the old load-bearing structure is of reduced value, e.g. to replace vaulted slabs and wooden slabs.

Application benefits:

- The floor plan of the building can be of any geometry.
- The individual slab element is always designed for the given building.
- It does not imply architectural or static constraints!
- The slab made with a panel must be treated like a monolithic reinforced concrete slab.
- With the slab system, balconies and interior consoles can also be created.
- It is possible to place thermal insulation elements, eliminate thermal bridges, form a water nose, create a free plate edge (e.g. gallery).
- The slab system can be multi-support, and it can also be load-bearing in several directions.

The disadvantage is that it is not possible to make safe protection of the slab plate from the system element against falls in terms of work and accident protection. Of course, with careful and far-sighted planning, these accidents can also be prevented, for example, by building a façade safety shield, or safescreen (Figure 3).

Figure 3: Safescreen [9]

3.2 Top-ribbed formwork bark panel

In line with European practice, a ribbed formwork element working together with concrete made on site has also been developed in Hungary.[5] Based on the new and at the same time very strict manufacturing technology, the developed product family allows the production of elements with higher load capacity and span than conventional ones. It differs from the bark panel with a surface lattice rib in that it is made with a prestressed process, so it has a higher load capacity. Elements manufactured with different types of ironing are suitable for creating slab structures of different thickness. Together with the dimensioned concrete made on site, the slab designer can move freely over a very wide range of load capacity. The element is manufactured using extruder technology that takes into account the strict requirements of today. Due to the technological requirement system of the production line, the final strength value of the concrete of the slab elements reaches the min C50 concrete quality. The elements can be used when using both two-support and multi-support static models. (Figure 4) The reinforcement required for multi-support must be included in the concrete on site. The reinforcement of concrete on site also includes the grout net to be built between the elements, as well as the amount of torque reinforcement resulting from possible clamping near the wall. Planks can only be laid on an even surface. A neoprene strip with a thickness of 5 mm is recommended. The reinforcement placed in the slab element takes into account the load-bearing structural element and the corresponding static model in one direction. The transverse distribution within the element is ensured by a welded mesh of 4.2 diameter located above the strands.

Figure 4: Top-ribbed formwork bark panel [5]

The transverse co-operation of the finished slab structure is ensured by the means of semi-concrete and additional reinforcement. Transverse coexistence can be determined by precise static calculation for concrete slab structures. The coexistence between the prefabricated slab element and the monolithic concrete is ensured partly by the roughness of the rib and partly by the roughness of the surface of the element. For slabs with higher bearing capacity high shear force), the possibility of slipping between two concretes of different qualities must be examined separately. In case of a breakthrough formed during production, the element must be supported during construction. The rigidity of the openwork element can be significantly reduced, so support during construction is necessary. Between supported and adjacent non supported elements, it must be ensured that adjacent elements are placed on the same plane. The breakthrough environment and the load capacity of the final slab shall be examined by separate static calculations in each case. If the load capacity of the element cannot be verified in this way, it is necessary to pull the elements apart and install a monolithic slab field. Slab planks must always be tied into the wreaths. At the end of the element, it is necessary to put a tie iron. The prefabricated ribbed formwork element has a tension fold upon delivery. The amount depends on both the type and length of the element. On the weight of monolithic upper concrete, the element suffers additional deflection.

The condition during construction can easily be the most unfavourable load case in the load history of the element, as the rigidity of the structure increases dramatically after the concrete solidifies. Limiting the stooping to the weight of fresh concrete is therefore a very important design issue. The elements are supported along a line at the midpoint of the span during concreting. During supporting, a transverse beam should be placed under the slab elements, supported by posts with adjustable height. Height-adjustable pillars are used to clamp the beam to the slab element. During support with columns, there may be a possibility of a small cant.

4.1 Structure, time, cost

Of course, a comparative analysis of modern slab formwork and prefabricated formwork bark panels is only possible under identical construction conditions. Both construction technologies have areas where only one or only the other structural solution can be applied, but this is not the subject of our analysis. Such a case example would be a monolithic, pillar-framed office building or residential park, where the support spacing is no more than 6-8 m. During the preliminary study, alternatives to both floor systems should be considered, since both systems are technically suitable for the task.

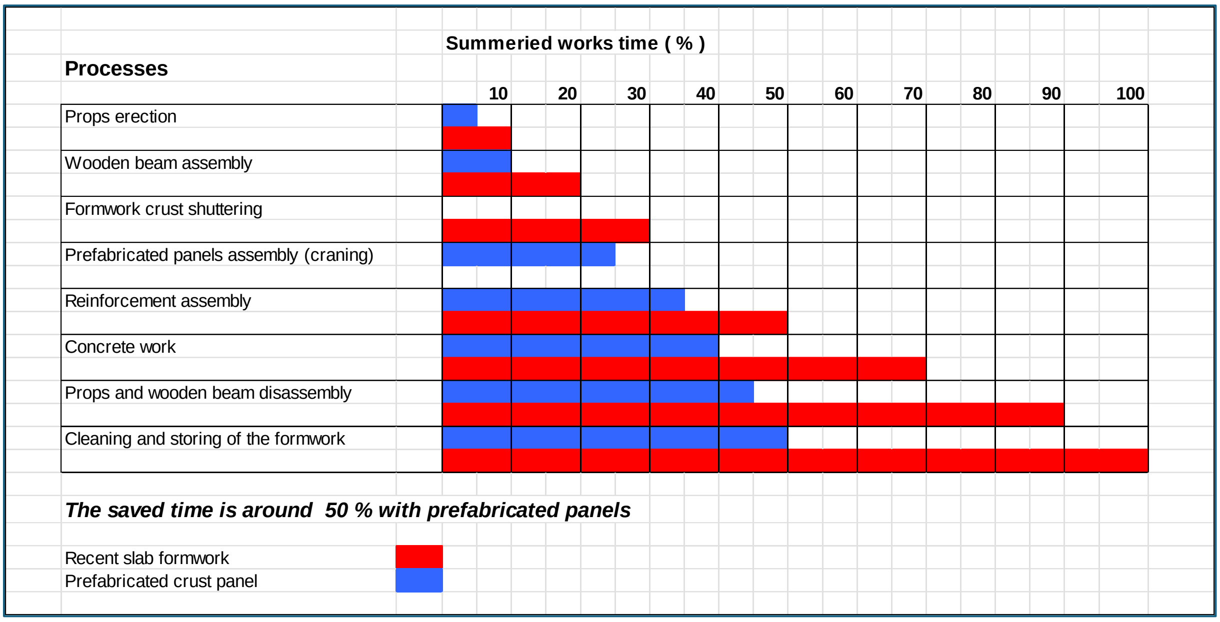

Figure 5: Comparison of total formwork time (own resource)

If we take the construction time as the main measure, we can clearly state that with the bark panel construction process we can save about 45-50% of the time required for slab construction. (Figure 5) In terms of on-site organization, the tower crane, but as a minimum requirement, the mobile crane is indispensable for prefabricated technology, while in the case of a monolithic slab system, the formwork phase itself can be solved without the help of a crane. Modification during construction is only possible with the monolithic slab formwork system, the technology manufactured in the finished plant cannot be modified on site.

However, looking at the most important factor, costs, it should be said that currently the prefabricated bark system is in a more difficult situation on the domestic market, namely due to the following. In housing construction and the construction of public buildings, the spread of prefabricated technology is greatly hindered by the well-known "black work", which further depresses the already low wage level. Housing construction is particularly characterized by work without VAT and wage contributions, income tax and social security contributions, making it more difficult to implement than construction with elemental slab elements. As a result, industrialized methods have always spread more slowly in low-wage countries. Thus, truly pure competition will only be possible if the construction industry is completely whitened.

4.2 Work and accident protection aspects

The construction sector is one of the most dangerous sectors, with the highest number of fatal or serious accidents at work. Construction works must also take into account significant health hazards and risks arising from the activity and the working environment. Work culture in the construction sector is often below desirable standards, and the combined effect of tight deadlines, fast-paced work and unskilled workers causes a further deterioration of the OSH situation. One of the greatest hazards for formwork work is activities carried out at height. Since formwork is a construction aid, its safety technology must be constantly adapted to an ever-changing condition. The most common accident when building formwork occurs due to ignoring horizontal loads during construction. Both timber-durable and framed formwork systems can only absorb horizontal loads by wedging them to the vertical structures that have been built. These horizontal loads are usually caused by the combined movement of workers, pumping concrete or wind load. If it is not possible to wedge the formwork with sufficient density, the supports must be stiffened with Andrew's Crosses. Slab collapse accidents during rebar installation are typical for timber formwork systems.

The reason for this is that the supports transferring the load of the slab to the subsoil or to the lower slab level are installed only sparsely in the first phase of construction. Most slab accidents occur during the concreting of the structure. One of the reasons is the inadequate absorption of horizontal loads, which have already been mentioned several times. In this case, in the absence of wedges or St. Andrew's Crosses, the formwork moves out horizontally sideways and collapses. Another reason may be sudden overloading, which can occur with concrete of dense consistency, if, for some reason, the concrete pump is not in continuous motion. In such cases it can squeeze out in one place, even half a meter or a cubic meter of concrete, which can cause an overload of the slab by 3-4 times. The most common cause of formwork accidents is the use of incorrect demolition sequence, which can result in the collapse of the entire formwork. As a result, workers working under formwork can be buried under the entire formwork system.

In the case of prefabricated bark panels, the greatest source of accident is the crane of batteries. As a rule, in no case should the angle between the slab elements and hanging chains be less than 60 degrees. At a lower angle, the panels produce a damaging bending moment of such magnitude that the structure is not dimensioned, and the thin bark panel collapses. Another frequently occurring case is when the ideal supports under the panels are not built on solid structures. In case of subsidence of the supports, the panels crack, and under the weight of fresh concrete, the entire slab structure can break off. The third most common source of accidents is the lack of protection of the slab edges against falls. [6] While in the case of monolithic reinforced concrete slabs, the module railing system developed by the manufacturers can be applied to the formwork, in the case of bark panel slabs, only a unique suspended railing system mounted on the load-bearing wall is a good solution. However, this is often missed to save cost and time, and the slab is made without safety barrier.

4.3 The relationship between dangerous plants and modern formwork systems

In everyday life, we can clearly state that daily developments and innovations result in more and more chemicals being marketed and used in production. Thanks to this, the number of hazardous plants increases year by year in Hungary as well as in the world. Existing or newly established hazardous plants work with materials with many different hazard factors.

Plants dealing with hazardous substances can be identified as follows [11] [12]:

- a plant dealing with hazardous substances with an upper threshold value,
- plant dealing with hazardous substances with a lower threshold value,
- operation below the threshold value,
- priority facility,
- the plant does not fall under the scope of the law.

For plants, depending on their classification, the legislation and SEVESO III directive requires a security analysis, a security report, the creation of an internal or external protection plan, which is controlled by the authorities [13].

As part of the storage, production, or use process, chemicals are mixed in plants, and their basic properties can also be combined, becoming more and more toxic, flammable and explosive. The bigger a plant and the more dangerous substances are present on a site, the more it becomes necessary to create a higher level of protection for the workers and the security personnel who can initiate any protection processes. This is one of the important, primary tasks of those who run the plant, as it guarantees that initial, small incidents can be handled without injury and without the involvement of external help, even within the plant.

In the event of an emergency, one of the most important tasks of the security management system is to initiate the alarm and then the evacuation and rescue processes. This can mostly only be achieved if the specialists who initiate these processes are successfully protected from danger within the room from which they manage the defense. Therefore, knowing the existing hazardous materials and their hazardous effects (e.g. explosion hazard, poisoning, fire hazard), it is advisable to examine the installation of formwork systems in the case of hazardous plants under construction or already existing. It is conceivable that in some cases the goal will be to seal the hazardous material in the building, but it may be especially justified even near an explosive area, thus separately examining the type of the appropriate formwork system and its suitability installation.

5. SUMMARY

Typically, when comparing load-bearing structures, the two most important aspects are construction time and cost. I have already analysed the construction time, and it is clear that with the bark panel slab structure, time savings of about 50% can be achieved. The cost part is not that simple anymore. In previous years, it was relatively clearly demonstrated that the total cost of the formwork bark panel is more than the cost of the slab formwork. This was also possible because 6-8 years ago the ratio of material to labour was 2:1, which meant that on average the cost of materials was twice the cost of labour. In recent years, however, this ratio has almost reversed, given the very high hourly rates for labour. Of course, in addition to time and cost factors, the location of construction, the type of building, geometry, the preparedness of the construction team also influence the decision, and industrial safety risk assessment. The issue of industrial safety risk is not negligible, for example in the case of renovation or expansion of an operating nuclear power plant. In this case, monolithic reinforced concrete structures must be built in working condition, with the lowest possible risk of accidents. [8] An equally important issue may be the case of battery factories under construction in the future, when during scheduled construction the formwork of a new reinforced concrete structure must be safely made with the above technologies.

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