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OPTIMISING LOAD TRANSFER USING TEMPORARY SUPPORTS IN MONOLITHIC CONSTRUCTION

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Abstract. When constructing a ceiling slab, it is essential that the load is effectively transferred to the lower floors. However, challenges arise when the lower ceiling slabs do not meet the specified design strengths, potentially indicating inadequate load bearing capacity. This article explores a novel approach to solving this problem by using supports that are not traditionally used for slab formwork, but rather as backpropping mechanisms. These supports serve as static reinforcements for the ceiling slabs, optimising the load distribution. This article delves into the distinctive features of these supports and evaluates their potential impact on the overall structural integrity of the implemented design.

Keywords: Optimisation, monolithic construction, backpropping.

1. Introduction

Supports are a temporary structure used to support a building structure. Reinforcement of successive floors is the most common method used in the construction of reinforced concrete structures. This method consists of supporting the newly cast slab with some lower decks that are fully or partially supported. The weight of the newly cast panel, plus any possible construction load, is thus distributed among one or more lower decks [1]. Structural support may be required not only for new structures, but at any stage of construction, including maintenance/repair or demolition. A support is used to hold or support an object until the permanent structure is complete and able to support the design load, or to support another temporary object during the construction work. Within the supports for the construction of a reinforced concrete slab, we can work with two concepts. The first one is "Slab Propping", which is a classic support for the ceiling structure. The layout and number of these supports are indicated by the formwork manufacturer. The second one is "Back Propping", which are supports that are used to support lower floors in order to transfer the load from the constructed structure, and therefore, instead of loading one slab, these supports help us transfer the load across several floors [2]. In the past, however, construction sites have experienced structural failures of these systems due to improper design, poor installation, and overloading, which have caused not only construction delays but also serious injuries to construction workers [3].

Slab-support systems in tall buildings result in very high design loads that are greater than the actual weight of the slabs [4]. These design loads are also higher than the structural loads, almost every building is designed for a payload that is only a small fraction of the total structure load [5]. Therefore, the self-weight of the newly cast concrete slab cannot be supported by the recently completed slab below. The structural load has to be distributed to the lower floors. According to the analysis, supporting concrete slab structures during construction is still a taboo in Slovakia [6]. Abroad, especially in the UK, this issue is called "backpropping". Currently, on many construction sites, developers rely on subcontracts that carry out a given construction work to solve this problem. However, the support of lower structures must be taken into account during the project preparation, as it is possible to identify deficiencies in the project and anticipate areas of risk of overstressing the structure. The calculation of the loads acting on these supports, as well as on the structure, must be carried out sufficiently in advance in order to determine the cycle time for the erection of the structure and for the spatial design of the support. The literature does not recommend a single procedure for supporting multi-storey buildings [7].

The problem may also be that in different regions of the world, other methods of support and other types of supports are used. It is also important to note that not all construction sites emphasise the importance of structural safety of the structure during construction, and even when they do, it is only according to the experience of the workers, which may not reflect the real need for the placement of supports, and certainly does not take into account all the additional loads induced, for example, by the fixing of the supports [6].

2. Backpropping

Backpropping can be defined as a support placed on the lower floors under the slab that supports the newly constructed ceiling slab. Backpropping is carried out in order to distribute the load acting on the highest supporting plate of the object on which the formwork is supported [8]. Supports distribute the load to the supporting system of the object, such as walls, columns, or ceiling slabs, reaching the necessary strength to support the load. Backpropping can also be used to stabilise a structure when renovating, modifying or demolishing a building.

Use of backpropping in a newly constructed building In this case, it provides support for the safe distribution of the load on the formwork and structure through the supports. These loads typically exceed the permanent design capacity of the floor, which typically ranges from 2–3 kPa [9]. Thus, the load will have to be transferred through a number of newly built floors below to avoid overload, excessive deformations, or, in the worst case, a collapse of the structure. The number of supports is determined primarily by the function of the magnitude of the payload, the strength and type of the floor systems in relative age, and the stiffness of the ceiling slabs. They are usually located on the two or three lower floors above the ceiling slab [9]. The use of backpropping in newly constructed buildings is also possible as a support for the ceiling slab when storing materials or placing other objects necessary for the construction using a certain technology [10].

Use of backpropping in older objects The second common application is in buildings where building modifications or demolition work are to be carried out. These projects require the movement of heavy equipment and machinery to transverse suspended ceiling systems or require the removal or modification of permanent elements. In these applications, backpropping can help distribute the load when the load exceeds the designed capacity of the ceiling slab. It may also allow alternative loading paths to reinforce broken links of pre-existing permanent structural elements in their temporary state. This can often lead to a safer and more flexible construction process, as there are fewer restrictions on the extent of the demolition after the design [9].

2.1. Props

Supports are auxiliary elements that support the horizontal formwork system. As load-bearing elements, they are responsible for transferring the load that generated during the concreting of the structure, they act as a support on several floors until the structure gains the required strength. Despite the importance of supports, there is no known procedure for accurate sizing and an experimental study is needed to verify the specific supports used, as supports are not uniform in the construction industry. The steel support consists of a set of pieces of different strength. They consist of four parts: an inner tube with one top plate, an outer tube with a bottom plate and an external thread, an adjustment handle, and a fuser pin [11]. Supports are often used for various other purposes, mainly due to their high strength However, it should be noted that it is not only strength that is important, but also their correct placement and installation. In addition, excessive overloading of supports can complicate or delay the implementation of the project.

2.1.1. Types of props

According to the material, we can divide supports into:

- Steel Metal supports are the most common and can include a variety of finishes. The supports are further distributed according to the possibility of loading and according to the possibility of extending. Mostly, in a span of 2 to 6 metres. The steel supports increase worker productivity, reduce construction time, and are versatile, but we can also consider recyclability and sustainability as advantages [11].
- Aluminium supports are lighter and stronger than steel ones, but their high cost discourages many contractors from using them. Aluminium supports are also more susceptible to damage during handling. However, compared to steel supports, aluminium supports (e.g. MULTIPROP-PERI) can carry up to 90 kN and can handle considerably higher loads with their low weight [12].
- Wooden supports are the forerunner of steel ones and are no longer widely used today. The disadvantages were high labour intensity, low range of reuse, and high material consumption [11].

We can divide supports into several other categories, such as according to the type of thread that can be admitted or not declared, it is also called a Spanish type support. Another division may be, for example, the type of extension of the support. The support can be extended either from the top or from the bottom. The choice of the type of support used in the construction of individual structures is up to the designer, unless otherwise specified in the project documentation. The most commonly used are types of supports are those with which workers already have experience or which the contractor has in his inventory. The choice of supports and the condition of the supports used can play a significant role in the size of the preloading supports.

2.1.2. Elasticity of props

Supports provide the ideal and most economical way of support for all kinds of boards, beams, formwork, walls, and columns. For supports, high elasticity is proven under heavy loads, where, after the subsequent release of the load, the support will return to its original state if it does not exceed such a degree of deformation from which it will not be able to return. This elasticity also depends on the level of ejection of the support. A higher extended support has a greater deflection under load than a shorter extended support. This elasticity depends, in particular, on the type of the support, the material of which it is made of, and the role it is intended to play in a given structure [13].

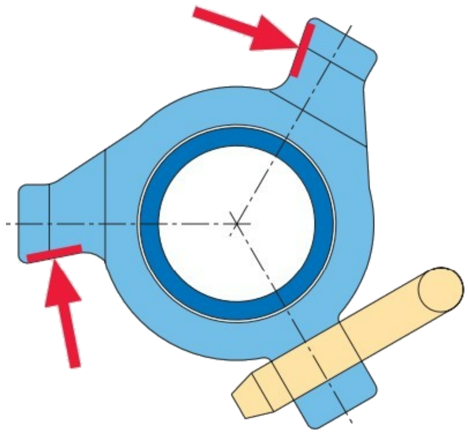

FIGURE 1. Support thread with marked places for hammer strikes [12].

2.1.3. Preloading of props

Preloading of supports occurs when the supports are mounted between two ceiling plates by fixing the supports with hammer blows to the threaded screws on the supports. The locations for the hammer blow are shown in Figure 1. Preloading is a highly variable and subjective matter. It depends on how many times and with what force the worker strikes the thread with the hammer, on the rigidity of the board, but also on the distribution of supports between the individual floors. Measurements and theories about the preloading of supports vary among researchers. Sources state that the preloading of the supports can range from 1 kN to 14 kN [14, 15]. For support systems using lifting mechanisms, expansion can cause tensions of up to 15 kN [16].

These values cannot be determined in general terms as these values are influenced by a number of factors, such as: the type of supports available on the construction market, the technical condition of the supports, the diversity of workers working with them, and, last but not least, the flexibility of the structure. These values need to be defined more precisely for further investigation, at least for the most widely used supports on the construction market. In construction, workers rarely, if ever, fix a support to a stop with zero preload. Workers know from experience that it takes a few blows with their hammer to fix the support between the boards [16]. So, it can be assumed that workers will install individual supports with greater preload due to perfect fixation between floors and to prevent them from tipping over. Since the boards are flexible, one support can release adjacent supports so that the supports will not be pre-stressed in the same way [16].

The magnitude of the difference between individual measurements may also be that it is not realistic on the construction site for all supports to be carried out by one person. And thus, each person fixes the supports with a different force and a different style. It also depends on the type of supports used. There is a risk with older supports that a part of the thread may be corroded or dirty, creating more resistance to twisting, and therefore the support will be less fixed for the same force than, for example, new supports. Most static calculations do not take into account the preloading of supports, which can have a major impact on the structure [17].

2.2. Reinforcement activation

Some formwork support systems allow the formwork board to be removed, leaving the newly cast board still supported by supports. If the construction progress is fast, the next new ceiling slab can be cast without removing the supports from the lower floor. Therefore, this ceiling slab cannot acquire its deflected shape due to its own weight and does not activate its reinforcement, which would help to transfer the load to the load-bearing system of the structure [16]. This procedure significantly changes not only the distribution of the load between floors, but also means that the total load on the lower floors will not only be from the new ceiling slab, but also from the slabs on which the reinforcement has not been activated, and therefore these loads will be significantly higher than with the usual consideration of transferring the load only with the new ceiling slab. An example of such a construction system could be the PERI ALPHADECK formwork, or construction where the formwork is not removed on several floors, i.e. it is left in place during the construction of the upper floors. Therefore, an important rule of thumb for ceiling slab support calculations is that the formwork on the recently cast slab is completely removed and the new slab can immediately deflect under its own weight, and only then can the designer be sure that the actual weight of the floor is now transferred directly to the permanent support system of columns/walls, etc. and not to the formwork supports. Any load transmitted through this floor from the structure of the upper floors will be additional to the load already on the slab [16, 18].

2.3. Slab load by the type of supports

In general, we can say that the support is elastic, and when it is fixed, a tension is created that acts on the structure. However, there are also supports that are not elastic or are not designed with preload [16]. It is possible that even with clearly defined properties of the support, in reality but also in calculations, the simplest version of the support is used, i.e. a fixed support, whose properties, however, do not reflect the reality that occurs on construction sites.

2.3.1. Rigid props

Load transfer through ceiling slabs is basic physics within the limits of flexibility. The deflection of the slab is proportional to the total load on the slab. In order to carry the load, it has to deflect, in our case it has to bend over by some part. So if there are two identical floor slabs separated by rigid (inelastic) supports, the load on the top slab would cause both slabs to deflect equally [16] as you can see in Figure 2.

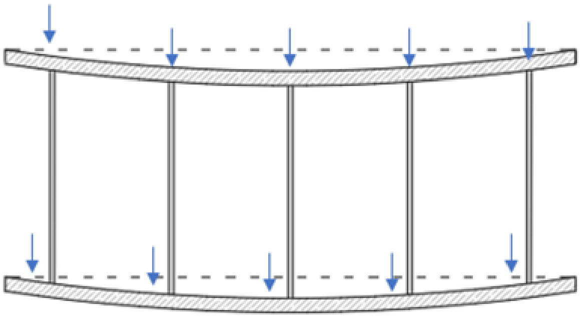

Figure 2. Fixed supports – the slabs will deflect the same way.

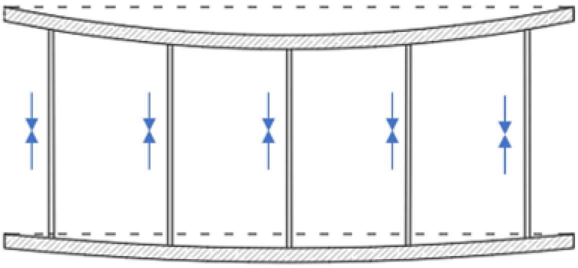

Figure 3. Elastic supports – a larger deflection will occur in the top slab than in the bottom slab.

2.3.2. Elastic supports

Since the load/deformation is proportional, each slab would actually take up 50 % of this load. In theory, however, this is not correct, because the slabs themselves will be somewhat elastic and will develop a slight deflection in order to activate the reinforcement in the ceiling slab. So let us have two identical floor slabs, but now separated by flexible supports, see Figure 3. As the load acts on the top slab, the supports are physically shortened to transfer the load to the bottom slab. The top slab now has to be deflected more than the bottom slab because the distance from each other decreases, and therefore it carries more load [16].

2.3.3. Pre-tensioned elastic supports

Of course, the magnitude of the load transfer depends on the relative rigidity of the entire system. In Figure 4, we can see the case when elastic supports are preloaded. The top slab is pushed up and the corresponding force increases the load on the bottom slab, so when additional load is added to the top slab, the load distribution changes. This can also be affected by whether the slabs have been preloaded or not. This theory is the most relevant in our case, since it takes into account all aspects that affect the support and takes into account the most likely behaviour of the supports and the structure [8].

2.4. Removal of props

In no case can the supports be removed until the formwork for the new slab is removed and the load with it begins to be transferred to the supporting system. Supports on lower floors should be removed

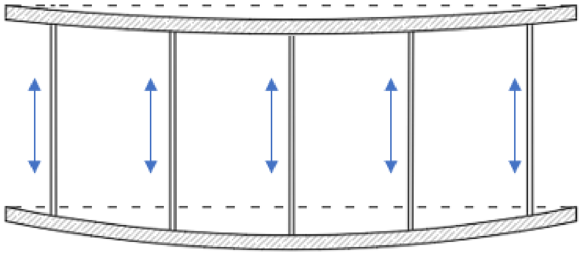

Figure 4. Preloaded elastic supports – a larger deflection will occur in the bottom slab than in the top slab.

from bottom to top, i.e. the supports on the lowest supported floor where the least load is transferred are removed first [8]. If the new slab reaches the necessary strength for the formwork, it is possible that no load is transferred to the lowest floor. On higher floors, we remove the supports from the centre towards the building's structural system.

After removing the formwork of the new slab, the placement of supports should be carried out as soon as possible, preferably immediately after the removal of the formwork in order to avoid damage caused by additional loads on the new slab.

2.5. Distribution of supports between floors

The distribution of supports between floors can have a major impact on load transfer. The most famous 3 options for supporting a monolithic structure are: the possibility of leaving the supports in place, placing the props one under the other, placing the supports on the axis of a higher raster. At the moment, there are no standards or detailed instructions for the placement of supports on the lower floors. Formwork manufacturers such as Doka or Peri recommend that calculations and project documentation should be prepared by a specialist, or determine only the percentage removal of supports, but it is not clear from which places and in what proportions these supports can be removed.

2.5.1. Supports left in place

Structure support style "Leaving supports in place means that the formwork or supports remain in place on one or more floors. This method has a number of disadvantages, but it is still quite widely used" [16]. One of the disadvantages is the large amount of formwork material used, which is used on several floors, which increases the amount of material needed to rent and therefore the overall construction budget. The second significant disadvantage is that when the formwork and supports are left in place, the structure does not have room for deflection under its own weight, and therefore cannot activate the designed reinforcement. As a result, the load from the new slabs is only partially transferred to the load-bearing parts of the structure, but the entire load is transferred to the last formwork panel in the sequence. This can lead to excessive overloading of this panel.

2.5.2. Supports located underneath each other

With this type of support, the supports are placed in a specific raster below each other. The advantage of these supports is that the load passes directly through the recently cast slab to the supports and does not cause deformation or excessive bending of the support slab. This form of support is much safer during construction. It distributes the load to several points on the slabs. The supports are arranged in a raster, which determines the distribution of supports for the formwork of the new ceiling slab [8]. The advantage is that in the case of excessive preloading of the support, the return load is transferred to the support above it and there is no lifting of the slab. The disadvantages of this method of slab support include the increased use of supports and the occupation of a large area of the slab that could be used for the benefit of the construction.

2.5.3. Supports placed on the axis of the grid of the higher floor

These supports are centred on the axis of the higher supports. This arrangement of supports results in much greater loads being transferred to the ceiling slab than in the previous variant, as the slab acts as a beam transferring the load from the support to the lower support [8]. The disadvantage is that the increased spacing of the supports makes it more difficult to stabilise the supports. If the support becomes more pre-stressed and there is no other support above it, the slab may rise, causing it to deform or the formation of unwanted cracks.

Pre-concreting requirements For casting a new slab, the support slab immediately below it should have sufficient capacity to withstand the load exerted on it during the construction. The loads on the support slab are:

- own weight of the slab,
- structural load of the slab,
- the total load of the construction of the new slab, such as: the weight of fresh concrete, reinforcement, formwork, workers and machinery required to construct the new slab.

If the supporting slab complies with these conditions, no additional measures are necessary. If not, measures must be taken to ensure that the structure of the supporting slab is not damaged in any way by the arrangement of supports on the lower floors [8].

3. Load transfer theory

In an extensive 2018 research on load transfer, we can see a number of experimental, numerical, and computational studies that deal with load transfer between slabs in the construction of reinforced concrete structures and explain the importance of knowing the size and distribution of the load created during the construction [1]. However, these calculations and experimental tests cannot apply universally to every building, in particular, because of the use of different support systems in the world, the variety of building structures, and the method of fixation of supports. Most of these calculations and theories do not take into account the additional load caused by the fixing of the supports, which can fundamentally change the view of the areas of load transfer between the plates. A theory was put forward by Peter Pallett in his publications [16], where he describes the theory of load transfer between slabs in a ratio of 65:23:12 %.

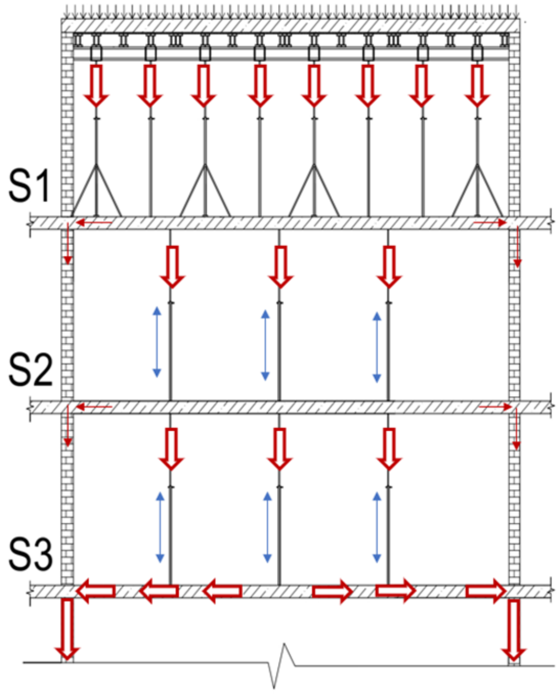

Figure 5. Load transfer scheme in the structure.

However, these examples also fail to take into account many other physical aspects, such as the different stiffness of constructed floors (newer floors are less rigid than older floors, and therefore have different deformation properties), the different stiffness of the rear supports (steel supports carry a greater part of the total load compared to aluminium ones), the magnitude of the switching force in the supports and, finally, any influences related to shrinkage, creep, and temperature change. The expected load transfer can be seen in Figure 5.

4. Discussion

Within the available scientific publications and the data obtained, it can be stated that the static securing of ceiling slabs during a construction is a very complex issue and cannot be generalised. We can determine with clarity that many experimental and computational findings do not reflect all the properties of supports, which in fact is not even possible, as different methods of supports are used in, for example, Central Europe and the rest of the world. It is equally difficult to determine the technical condition of individual supports and, last but not least, no structure is the same, either technically or architecturally. However, when using formwork supports to transfer loads between floors, we can precisely define their properties and the additional stresses that occur when they are fixed between floors. However, the magnitude of the stresses induced is influenced by many factors, from the technical condition of the supports, the type and material of the supports to the workers who carry out these operations. However, if the condition of using only one type of support is respected, we can get closer to the value of preloading the supports on a given structure. One of the possibilities is to make a general overview of the available supports in the given area and by preloading measurements using strain gauges to determine the average preloading for a given support or directly on the construction site to measure the average preloading of supports directly by workers who will fix the supports between floors. The fact that the measurement will take place on real supports that will subsequently be used on the construction site and by real workers who will handle these supports, allows us to obtain the most accurate value of the pretensioning rate of the support on the given structure. The disadvantage of this proposed method is that these measurements must be made well in advance of the implementation in order to calculate the distribution of supports without negative impacts on the structure. To calculate the load distribution, it is possible to work with already available methods and calculations, but already with the fact that another influence on the structure is taken into account, namely the pressure on the slab caused by the preloading of the supports.

5. Conclusion

The static securing of ceiling slabs during construction is a very extensive and complex topic, especially because of its great diversity in terms of structures, types of use and placement of supports, quality of supports, and, last but not least, workers who will fix the supports between slabs. Therefore, it is impossible to generalise one correct procedure for construction. In this article, we tried to explain the various properties of supports and possible additional loads that can be applied to the structure when fixing the supports, especially since the switching of supports is ignored in the calculations, and during implementation the size of the preloading is not addressed at all. This can have a negative effect on the structure and affect the transfer of the load to the lower floors, can have a negative effect on the edge and cantilever structures, with a young age of the structure and a large preload on the support, serious deformation of these parts can occur. However, it is enough to let construction workers know that even such a simple act as fixing supports between floors has an impact on the structure. The article describes the shortcomings of the solution directly on the construction site and serves only for an overview of the issues that arise in the static securing of ceiling slabs. It is very important to focus on this topic, as it is not sufficiently explored. The optimisation of the design and its appropriate solution should ensure the improvement of not only the properties of the construction, they should also help in the possible prevention of failures in these structures, which is a significant benefit, especially from the point of view of the financial monitoring of the construction. The next step in the research should be to determine the actual preload of individual supports and the ideal state of preload of individual supports and then adjust the use of various methods to achieve the ideal preload of the supports, such as torque wrenches.

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