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OPTIMIZATION OF MODELLING OF SUPPORT SCAFFOLDING

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Abstract. Recently, there has been a shortage of manpower, especially in the construction sector; therefore, innovative solutions and technologies are being looked at in this area in order to alleviate and reduce the issues related to the shortage of manpower during the construction work. In case of the construction of bridges and/or industrial buildings, the main structures are high, and scaffolding is required to support them, the erection of which is labour-intensive and is very time-consuming. Until recently, scaffolding supporting loads in construction work have been selected according to the manufacturer's recommendations and are installed on site with great reserve.

3D modelling applications can provide a better understanding of the "behaviour" of scaffolding when exposed to external influences. In this work, a 3D model is created using the LayPLAN software package for AutoCAD. Calculations performed by the structural calculation computer program Dlubal Rstab to determine the first member that loses stability (stumbling) and the initial compressible part of the frame system are presented. The article demonstrates that changing the design of a scaffold structure while maintaining stability can significantly reduce labour costs and time.

Keywords: scaffolding, efficiency, impact, rod, labor cost.

INTRODUCTION

Construction is a strategically important industry that ensures the existence of buildings and infrastructure on which all other industries depend. According to the Department of Statistics, construction is one of the fastest growing sectors of the Lithuanian economy with great potential for development. The construction sector is one of the most important in the European Union, generating around 10% of GDP and has a positive impact on employment growth in other related economic activities. Construction production processes and operation of buildings consume about 50% of Lithuania's energy needs, and buildings and engineering structures consume about 50% of the country's material investments (Lithuanian statistics).

Buildings, structures with their surroundings, as well as engineering communications are important elements in cities. In addition, buildings and infrastructure indirectly affect the social, economic and natural areas of the city. When construction or repair work needs to be carried out at higher heights, it is necessary to choose the equipment that will allow you to work both safely and comfortably. Probably, the most common choice is construction scaffolding, with the help of which it is possible to reach the required heights and perform all the desired work.

The objective of the paper is to perform modeling of scaffolding installation technologies. Tasks of the paper: to provide structural stability calculations, to determine the amount of labor, time, cost and amount of structural elements for the installation of bridge scaffolding.

SCAFFOLDING MODELING

Scaffolding structures are temporary and often used in construction work to support structures and withstand various loads. Vertical loads on scaffolding may include workers, equipment, formwork and building materials. In addition, scaffolding usually has to withstand horizontal loads: wind loads, shock loads and even earthquakes.

The installation, use and calculation of scaffolding is regulated by the European standard LST EN 12811-1 “Temporary construction equipment. Part 1. Scaffolding. Technical requirements and general design“, LST EN 12811-2 Temporary construction equipment. Part 2, LST EN 12811-3 Temporary construction equipment. Part 3. Test load.

Scaffolding is a temporary structure commonly used in construction to support various types of loads. Recently, their collapse has become more frequent, as shown by the number of accidents and injuries (Reynolds et al., 2017, Candrangsu et al., 2010, Peng et al., 2014). Cimellaro et al. (2017) analyzes the major flaws and imperfections that can cause scaffolding to collapse. The results show that the compounds and multidirectional scaffolding are similar because their geometry and dimensions are similar. Multi-storey scaffolding does not affect the critical load, which is affected by the eccentricity of the applied vertical load and the type of external boundary conditions (Cimellaro et al., 2017). The vertical bending stiffness is much

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higher than the horizontal bending stiffness. Four-way connectors have greater rigidity than other joint configurations (Chandrangsu et al., 2011).

"Allround" systems by the German scaffolding manufacturer LAYHER, which are used for our calculations are the most common among Lithuanian construction companies. The system analyses in order to identify the first member which has lost stability (stumbling), as well as the initial compressible part of the frame system. The scaffolding material is steel S460.

Data from the technical work project of the 83-meter-long pedestrian and two-way bicycle path bridge construction in Finland were selected for the calculations (Fig. 1).

The scaffolding structure is 13.80 m long, 1.57 m wide and 12 m high was designed.

The concrete slab (18.6 t) with the following dimensions was used for the load: 13.84 m wide, 1.57 m long, 0.5 m (at the thickest point).

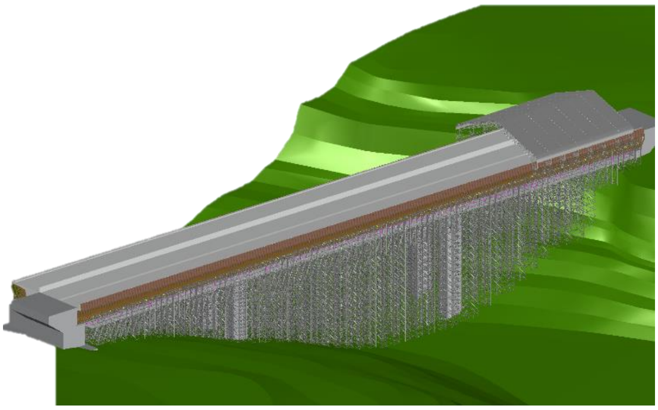


Figure 1. **Spatial view of the design bridge** (Compiled by the authors)

Figure 2. **Layher Allround scaffolding** (Compiled by the authors)

The load-bearing scaffolding Layher Allround (Fig. 2) is made of S460 steel pipes with a diameter of 48.3 mm. The lifting power of each vertical base can be up to 6 tons. The ends of the crossbars and diagonals are flat, so Allround sockets can be connected to each hole in the ring (Fig.3). These scaffolding can be mounted on the ground in parts by connecting each frame with pins. Once the entire structure has been installed, it can be moved to the work site with the help of a crane. The load-bearing scaffolding Layher Allround is symmetrical. For this reason, there is no need to worry about the direction of the diagonal installation (Chandrangsu et al., 2011, Zhang et al., 2013, Peng et al., 2017).

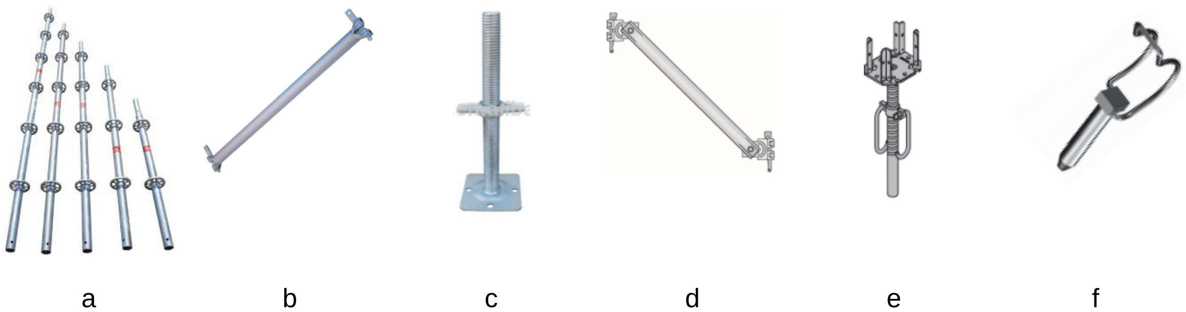
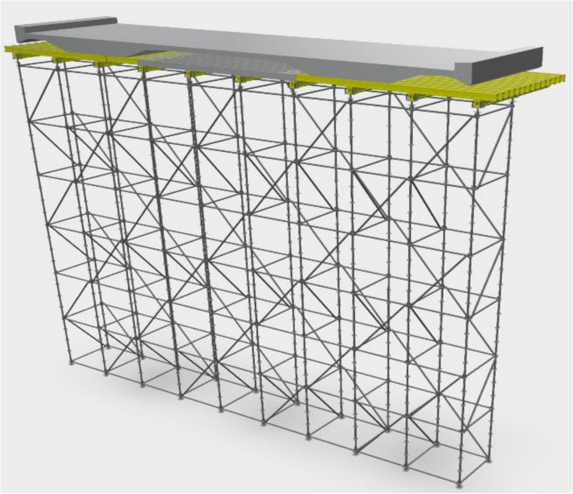
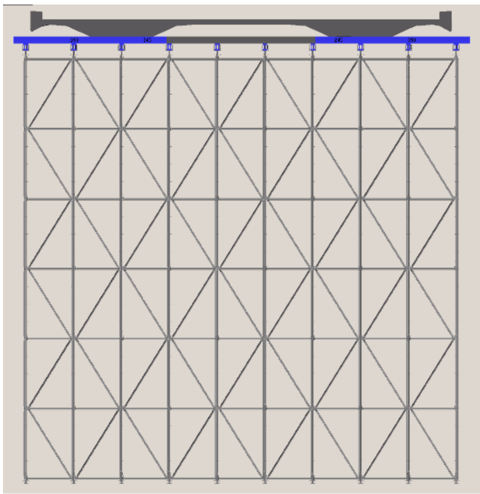


Figure 3. **Parts of Layher Allround modular scaffolding: (**a) **stand (standard); (**b) **transverse; (**c) **adjustable support (foot); (**d) **diagonal; (**e) **adjustable upper support (head); (**f) **connecting pin (**Allround Katalog**)**

The 3D model is created using the LayPLAN software package for AutoCAD. This package is adapted for the design of scaffolding elements. Strength calculations were performed with the Dlubal Rstab program. In this program, calculations are caried out in two-dimensional space, summing the loads that act on each support according to the Eurocode standard. Only the load on the structure and the material of the structure are indicated. It is important that the reserve is included in the calculation formulas, so that the resulting stresses can be 100% of the material strength limit.



a



b

Figure 4. **3D model** (a) **and calculation scheme** (b) **of the reinforced concrete cross-section of the bridge with the load-bearing scaffolding structure variant 1** (Compiled by the authors)

The loads on the supports were calculated in a simplified way, breaking down the 18.6 t weight of the reinforced concrete bridge cross-section into the segments of 1.57 x 1.57 m which rely on each support. Initially, the scaffolding structure, which is designed using the manufacturer's instructions, is calculated (Fig. 4).

THE RESULTS

In the obtained calculation scheme, we see the most loaded support of 48.92 kN (marked with a red rectangle), and the least loaded one of 16.07 kN, (marked with a green rectangle).

The magnitude of the stresses in the most loaded element is about 47% of the strength limit of the element material (Steel S460) (the reserve to the strength limit is 1/0.47 = 2.13), and the reserve until the onset of plastic deformation is 1/0.82 = 1.22 (Fig. 5). The maximum displacement of the structural elements is 32 mm (Fig. 6).

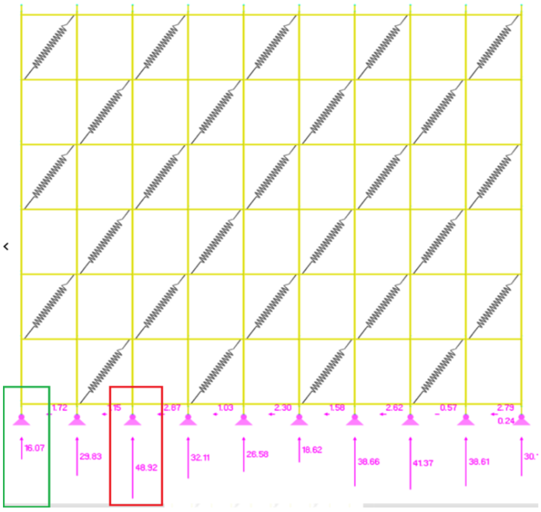


Figure 5. **Loads to the substrate (Option 1)** (Compiled by the authors)

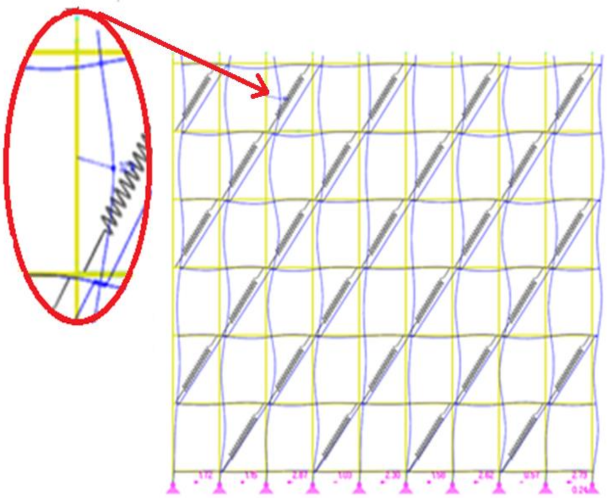


Figure 6. **Structural displacement of deformation (scale 15:1)** (Compiled by the authors)

Since the reserve to the strength limit is about 2.13 (1 / 0.47) times. Therefore, in a scaffolding design proposed by the scaffolding manufacturer, the number of elements can be reduced, thus increasing the "utilization" of the elements (bring the value of the reserve factor to plastic deformation closer to 1). To "exploit" the scaffolding elements more in the scaffolding system, 15% of the least-loaded structural elements are removed. Following that, a new 3D calculation model is created.

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In the obtained calculation scheme, we see the most loaded support of 63.13 kN (marked with a red rectangle), and the least loaded one of 15.40 kN, (marked with a green rectangle).

The magnitude of the stresses in the most loaded element is about 75% of the strength limit of the element material (the reserve to the strength limit is 1/0.75 = 1.33), and the reserve until the onset of plastic deformation is 1/1.24 = 0.8 (Fig.7). The maximum displacement of the structural elements is 46.8 mm (Fig. 8).

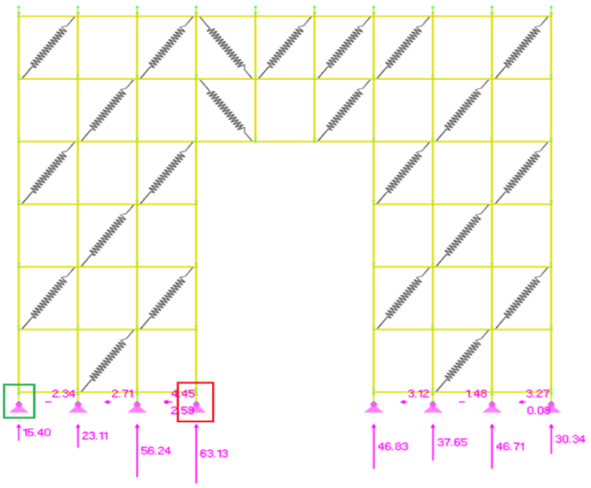

Figure 7. **Loads to the substrate (Option 2)** (Compiled by the authors)

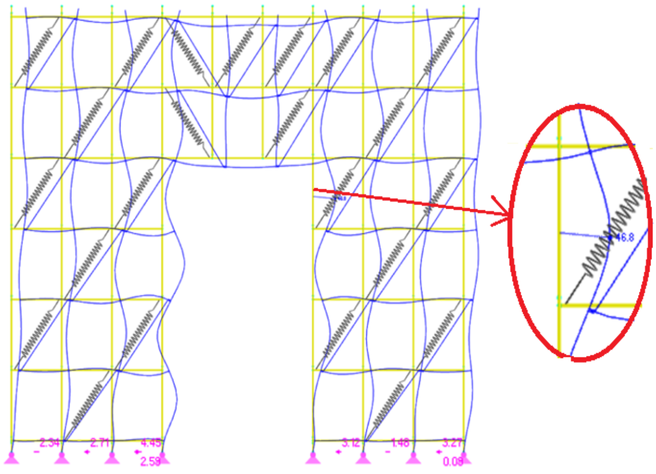

Figure 8. **Structural displacement of deformation (scale 15:1)** (Compiled by the authors)

The stresses of the most loaded scaffolding element are 75% limits of the strenght stress. The margin of resistance of the most loaded element before the onset of plastic deformation is about 1.33 (1/0.75) times. Therefore, in a scaffolding design that is reduced by 15% of the number of elements than recommended by the scaffolding manufacturer, it is also possible to increase the "utilization" of the elements (bring the value of the reserve factor to plastic deformation closer to 1). Following that, a new 3D calculation model is created.

In this scaffolding version we saw that the leg of the structural element marked with a black circle does not support the lateral wind loads. In order to continue the rationalization, it is necessary to install a support that would withstand up to 1.2 t of lateral load (Fig. 9).

The program installs a support that moves in a vertical direction, which restricts the movement of the structure in the direction of the wind load.

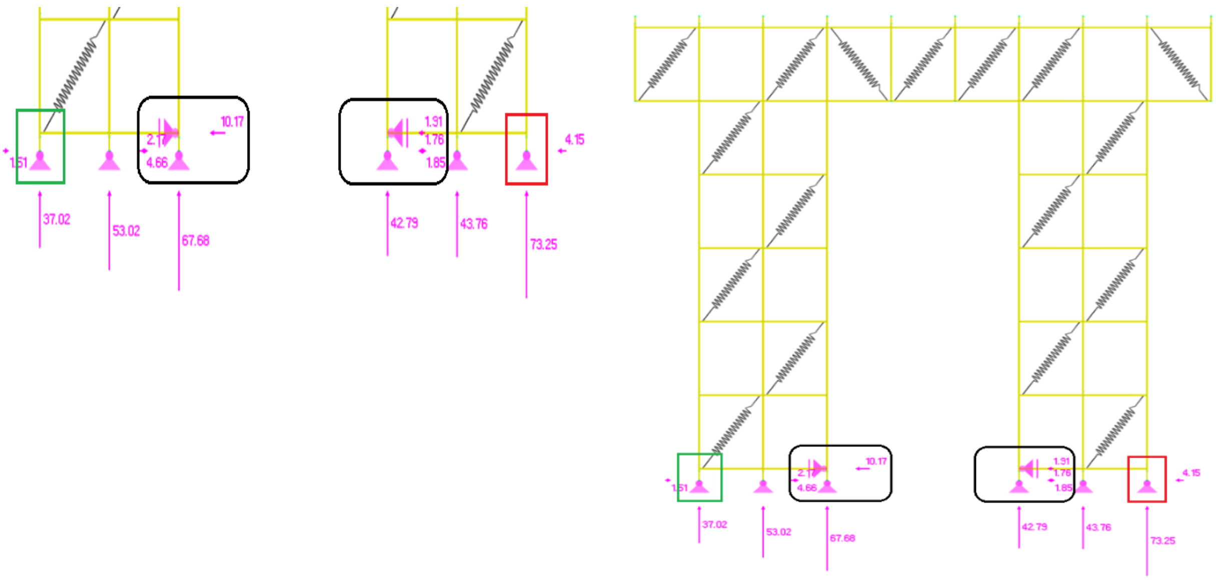

Figure 9. **Loads to the substrate (Option 3)** (Compiled by the authors)

In the obtained calculation scheme, we see the most loaded support of 73.15 kN (marked with a red rectangle), and the least loaded one of 37.02 kN, (marked with a green rectangle).

The magnitude of the stresses in the most loaded element is about 86% of the strength limit of the element material (the reserve to the strength limit is 1/86 = 1.16), and the reserve until the onset of plastic deformation is 1/1.34 = 0.75. The maximum displacement of the structural elements is 47.6 mm.

By further reducing the number of elements, the system loses stability, eventually we complete the calculation.

In this work, the salary is accepted according to the average payment of the dominant companies performing scaffolding installation in Lithuania (on the day of the research work): 1 h / 17 € per person (this is the cost of hiring a professional installer). The price includes all additional work related to the installation of the scaffolding: loading, unloading, bringing, lifting to the installation site.

Installation time is taken from the practice of scaffolding installation companies in Lithuania. Professional installer in 6.5 hours installs 1 ton of scaffolding elements of this type.

Table 1 presents the calculation results for different scaffolding structures.

Table 1

Layher Allround calculation data for load-bearing scaffolding

Properties	Scaffolding design version		
	1	2	3
Exploitation of strength, %	47	75	86
Number of supports, units.	20	16	12
Amount of equipment, t	3,77	3,24	2,53
Price of equipment, €	18280	15855	12495
Max. load to one support, kN	48,92	63,13	73,25
Min. load to one support, kN	16,07	15,4	37,02
Displacement, mm	32,0	46,8	47,6
Installation time, hrs.	24,5	21,00	16,44
Wages for installation, € (€17/hrs)	416,5	357,1	279,5

The ratio of the stresses of the most loaded scaffolding element to the strength stress, expressed in percentage, is considered to be the utilization of resistance.

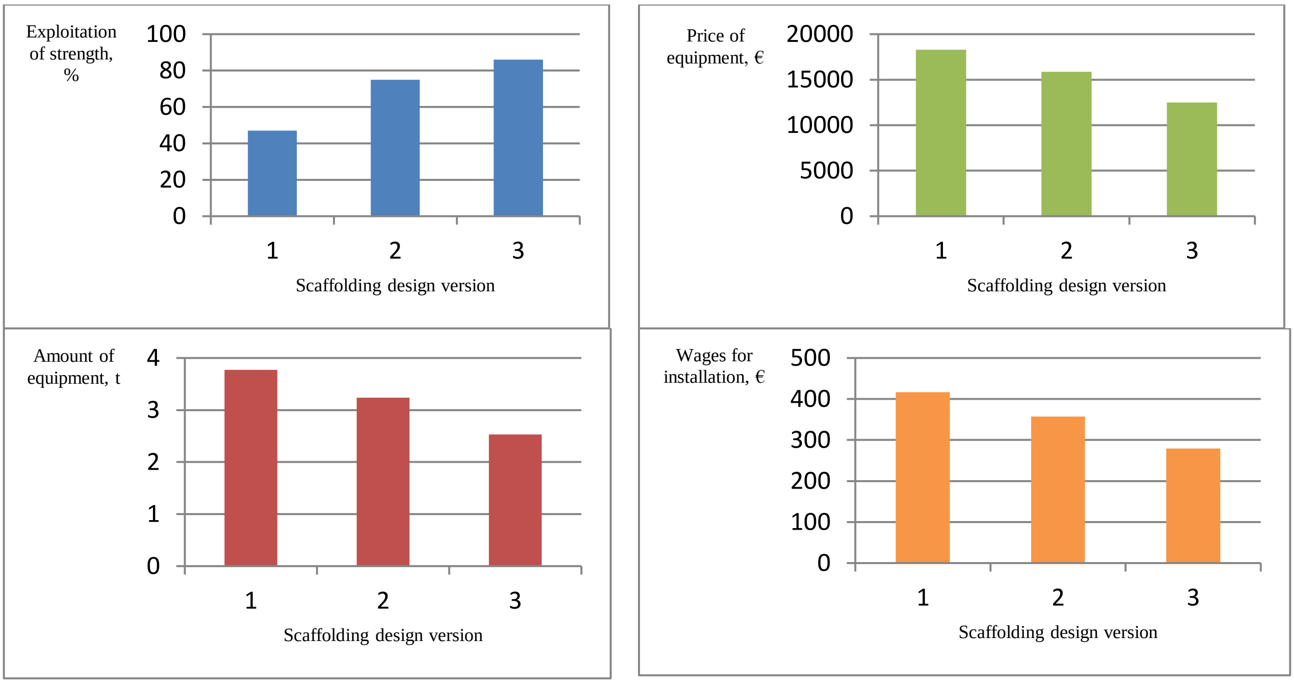

Figure 10. **Dependence of exploitation of strength, equipment price, amount of equipment and installation wage according to the scaffolding design version** (Compiled by the authors)

This increase, decrease tendencies well visible in these bar charts (Fig. 10). Decrease trend is similar for price and amount of equipment, wages for installation.

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CONCLUSIONS

1.In the scaffolding construction offered by the manufacturer, the reserve of the most loaded element to the strength limit is about 2.13 (1/0.47) times. By changing the design of the scaffolding (removing the least loaded elements), it is possible to achieve that the reserve of the most loaded element is close to 1 until strength limit.

2.Reducing the number of scaffolding elements will reduce the scaffolding installation time and wages by about the same amount of times.

3.For individual calculations of supporting structures, the loads are assessed using the technical documentation of the building design, and the manufacturer recommends that the loads specified in EN 12811 be the same for all cases.

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