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Article

Toe drain size and slope stability of homogeneous embankment dam under rapid drawdown

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Abstract. The slope stability of an embankment dam has always been a serious issue of concern for any design team. Unfortunately, the information on the potential influence of a toe drain size on the slope stability of an embankment dam under rapid drawdown conditions is still scarce. This study investigated the potential effect of a toe drain size on the slope stability of a homogeneous embankment dam under rapid drawdown conditions. Three different sizes (5m, 10m, and 15m) of the toe drain were investigated under instantaneous (worst scenario) and 5 days (more realistic) drawdown rates with the help of numerical modeling in GeoStudio. From the results, it was observed that the pore-water pressures at the upstream face of the embankment decreased with the increase in the toe drain size, while the pore-water pressures at the downstream toe were increasing with the increase in the toe drain size. The factor of safety values were also observed to be affected by the changes in the toe drain size. The 5m drain size had a minimum size of 0.961, the 10m drain size had a minimum factor of safety of 0.970, while the 15m drain size had a minimum factor of safety of 0.978.

Keywords: slope stability, embankment dam, seepage, toe drain, rapid drawdown, factor of safety.

1. Introduction

Slope stability is among the serious issues of concern when designing embankment dams. This is due to the fact that the inappropriate design of embankment dams increases the risk of failure leading to catastrophic consequences [1]. A toe drain is among the features of embankment dams that have to be properly investigated during the design and operation phases under different loading conditions [2].

Among many other factors, seepage remains to be a very important factor that has to be carefully investigated and controlled when designing embankment dams [3]. The significance of controlling seepage is brought by the fact that excessive seepage through the embankment can pose a significant threat to the stability of the dam and eventually leading to its failure. Piping and sloughing are regarded to be the most prominent types of seepage failures along the downstream face of the embankment. In history, there are many cases of dam failure reported due to a lack of proper seepage management, including the Teton Dam in Idaho and Tunbridge Dam in Australia [4].

The application of drains and filters in embankment dams becomes handy as they tend to reduce seepage and loss of soil particles, which in turn improves the slope stability [5]. It has to be noted that, in the case where seepage through the embankment is blocked, then it will find a new route or build-up, leading to slope instability. Therefore, to avoid the aforementioned issues the embankment should include a well-designed internal drainage system. However, the effectiveness of the toe drain can be significantly affected by its shape, location, and most importantly the size of the toe drain. Unfortunately, the information regarding the potential effect of a toe drain size on the slope stability of an embankment dam under rapid drawdown conditions is still scarce. A rapid drawdown condition occurs when the water elevation that has reached the peak suddenly drops within a relatively pore water pressure in the embankment. In this matter, estimation of velocity of flow through the embankment is also important. To achieve that, Darcy derived an equation that calculates the velocity of flow of water through porous media as illustrated in Eq. 1 [7].

$$V = Ki \tag{1}$$

Where: V stands for Darcy's velocity, K is the hydraulic conductivity of the porous medium, and *i* is the hydraulic gradient.

The combination of numerical modeling and finite element method is among the prominent approaches in investigating the nature of seepage through the embankments and the slope stability. GeoStudio is a widely used computer program for seepage and slope stability modeling [8].

In this study, the potential effect of a toe drain size on the slope stability of a homogeneous embankment dam under rapid drawdown conditions is investigated using numerical modeling. In the modeling process, three different sizes (5m, 10m, and 15m) of the toe drain are investigated. Also, two transient flow cases; instantaneous (worst scenario) and 5 days (more realistic) drawdown rates are investigated in GeoStudio.

2. Methods

2.1 General description of the numerical simulation

Finite element method analyses were performed to investigate the influence of the toe drain size and rapid drawdown rates on the slope stability of the embankment. Three different cases as determined by the toe drain size were taken into consideration. The numerical modeling process was achieved using the GeoStudio software (GeoStudio 2018 R2 v9.1.1.16749). Mainly SEEP/W and SLOPE/W sub-units of the GeoStudio were used for the seepage analysis and slope stability analysis respectively.

2.1.2 Embankment geometry

The geometry of the embankment was kept constant in all three main investigations while changing the toe drain size. The width of the embankment is approximately 59m at the base as well as 7m at the top, while the height of the embankment is 13m as shown in Fig. 1. The toe drain located at the downstream toe of the embankment varied from 5m, 10m to 15m. The maximum water level in the reservoir is 10m. Table 1 provides a summary of the embankment geometry parameters.

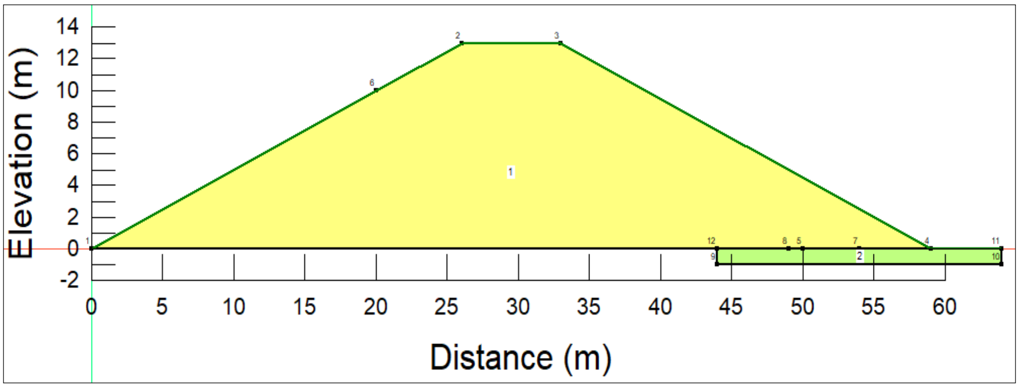


Figure 1 – General embankment geometry

Table 1 – Summary of the embankment geometry parameters

Parameter	Unit	Value
Bottom width	m	59
Top width	m	7
Embankment height	m	13
Maximum water level	m	10
Slope, H:V	-	2:1
Toe drain	m	5, 10, 15

2.2 Seepage and slope stability analyses

In general, the SEEP/W water transfer-based analyses were used to assess changing pore-water pressure conditions. The instantaneous drawdown case was taken as the worst drawdown scenario and then the rate was increased to 5 days (Fig. 2). To simulate the drawdown behavior of the slope in this study, initially, the transient seepage analysis was performed to obtain seepage-induced pore pressures and free groundwater-surface for different drawdown rates.

On the other hand, the slope stability analyses were performed using the SLOPE/W sub-unit of the GeoStudio based on the Spencer method. Generally, the Spencer method allows for unconstrained slip plains which in turn can determine the factor of safety along any slip surface [9].

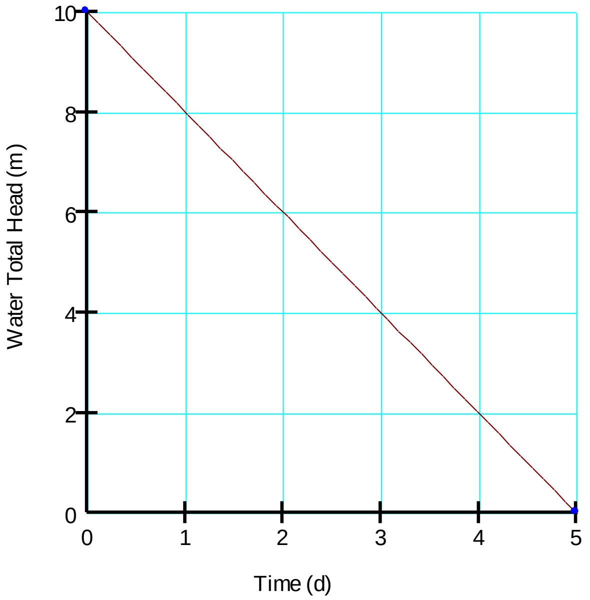


Figure 2 – Water total head function for 5 days drawdown rate

2.3 Soil material characteristics

The soil material properties for the embankment were kept constant for all the cases investigated to avoid any variability and capture the effect of the changes in the toe drain sizes. Table 2 provides a summary of the soil material properties used in the seepage and slope stability analyses. The saturated water content, coefficient of compressibility, saturated conductivity, residual water content, soil unit weight, cohesion, internal friction angle, young's modulus as well as Poisson's ratio were the main soil parameters to the model.

Table 2 – Soil properties

Soil material properties	Symbol	Unit	Value
Saturated water content	θ_s	%	43
Coefficient of volume compressibility	M_v	$\mathrm{m^2/kN}$	2×10^{-4}
Saturated conductivity	K_{sat}	$\mathrm{m/s}$	1×10^{-6}
Residual water content	θ_r	%	5.5
Soil unit weight	γ	$\mathrm{kN/m^3}$	20
Cohesion	c'	$\mathrm{kN/m^2}$	5
Internal friction angle	$\emptyset'$	degrees	25

3. Results and Discussion

The seepage and slope stability analyses were successfully executed using the combination of the finite element method and numerical modeling. From the seepage analysis, the water pressure at the downstream toe of the embankment was observed to increase with the increase in the toe-drain size. From Fig. 3, it can be observed that the 15m length drain size has higher pore-pressures than the 10m and 5m. In general, in the literature drains have been observed to be important features in the stability of embankments [10–12].

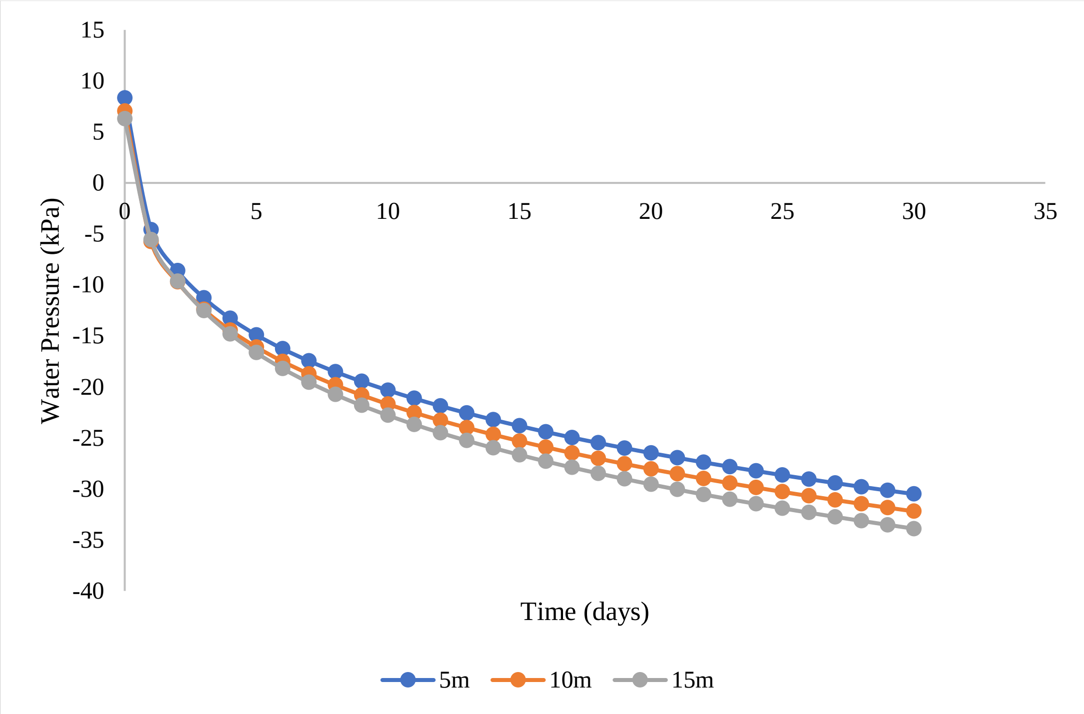


Figure 3 – Pore-water pressure at the upstream face

Contrary to the downstream toe, the pore water pressures at the upstream face of the embankment were observed to be decreasing with the increase in the toe-drain size. From Fig. 4, it can be observed that the pore-water pressures from the 15m length drain size were slightly higher than those from the 10m and 5m. The phenomenon suggests that, as the size of the toe drain increases, the seepage is more conveniently carried through the embankment allowing easy dissipation of pore-water pressures in the embankment after the drawdown.

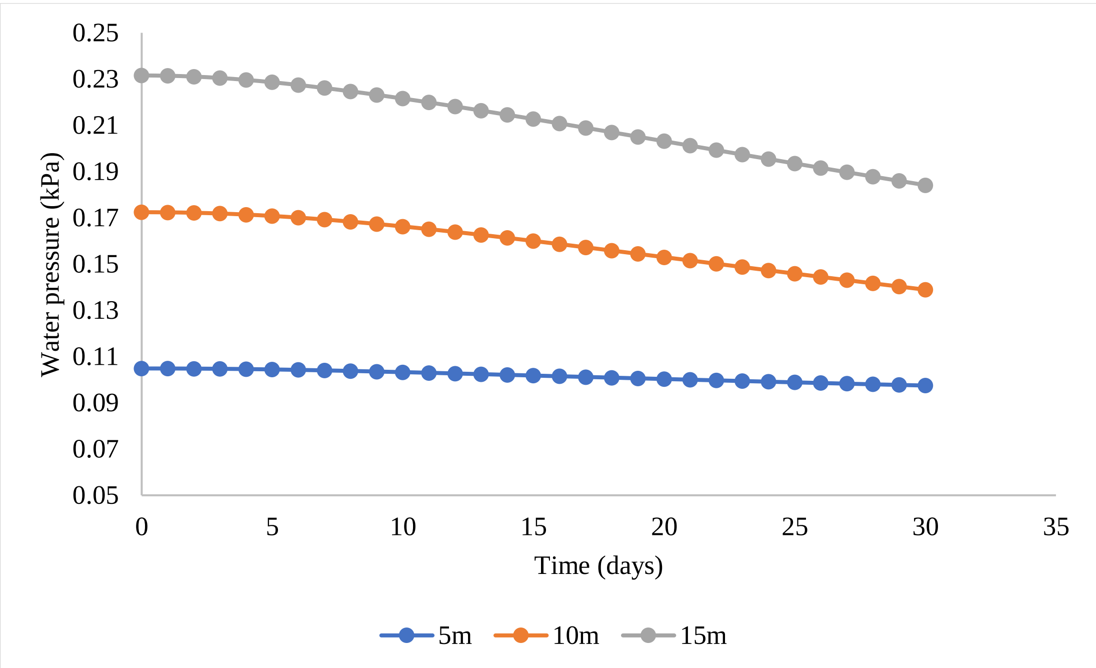
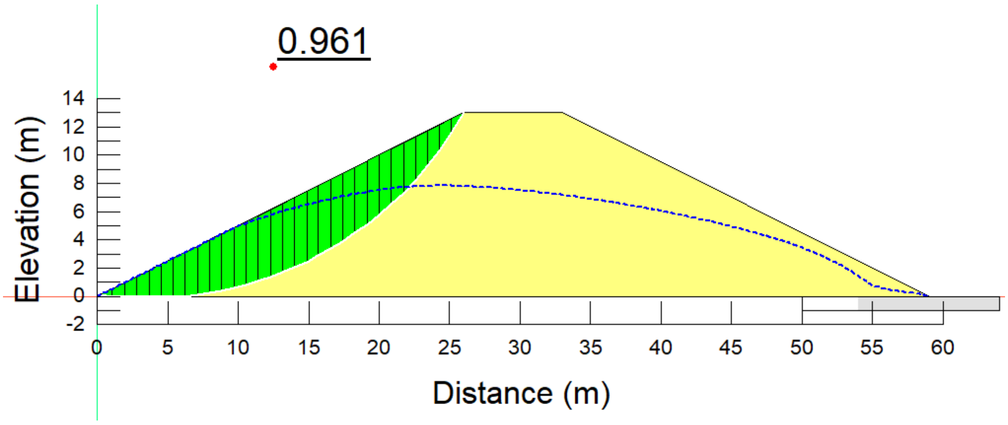
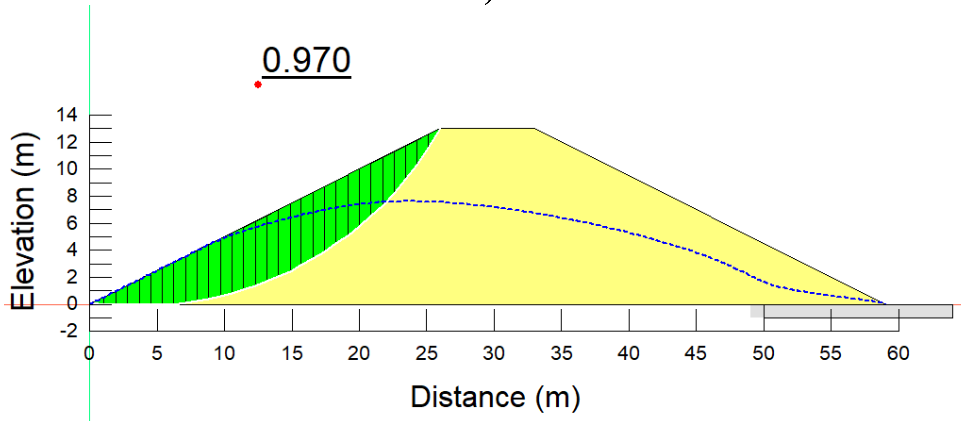


Figure 4 – Pore-water pressure at the downstream toe

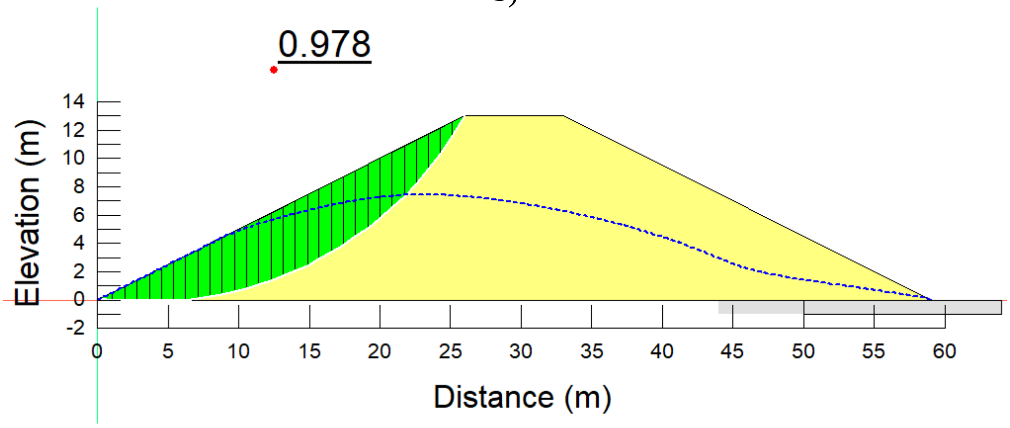
Similarly, from the slope stability analysis, it was observed that the change in the toe drain size affected the factor of safety. From Fig. 5 it can be observed that the 15m length toe drain size showed to have a bit higher factor of safety in comparison to the 10m and 5m toe drain sizes. The 5m drain size had a minimum size of 0.961, the 10m drain size had a minimum factor of safety of 0.970, while the 15m drain size had a minimum factor of safety of 0.978.



a)



b)



c)

Figure 5 – The factor of safety with slip surfaces from 5 days drawdown rate: a) 5m drain size; b) 10m drain size; c) 15m drain size

From Fig. 6, it can be observed that the lowest factor of safety values was obtained somewhere close to the last day of the drawdown. The factor of safety values dropped rapidly during the drawdown period with a gradual increase after the drawdown.

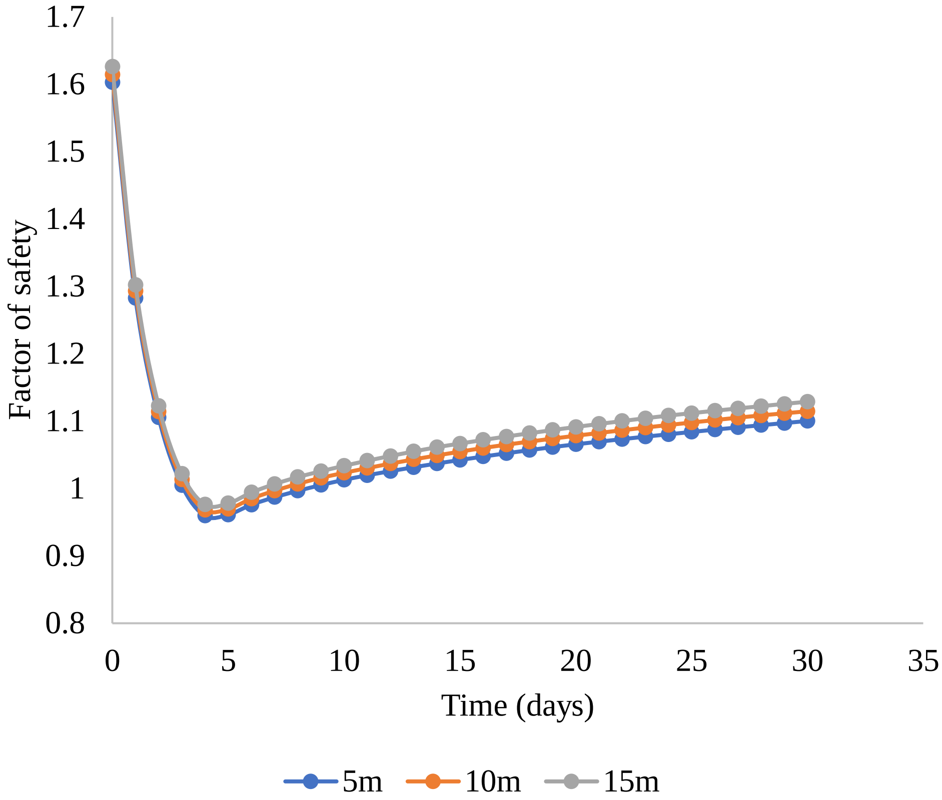


Figure 6 – The trend of the factor of safety values with time

Table 3 provides a summary of the maximum and minimum values of the factor of safety from the instantaneous and 5 days drawdown rates. From both drawdown cases, it can be observed that the factor of safety values was increasing with the increase in the toe drain size.

Table 3 – A maximum and a minimum factor of safety values from the instantaneous and 5 days drawdown rates

Drawdown rate	Toe drain size	Factor of safety	
		Maximum	Minimum
Instantaneous	5m	1.603	0.799
	10m	1.614	0.805
	15m	1.626	0.811
5 days	5m	1.603	0.959
	10m	1.614	0.968
	15m	1.626	0.976

4. Conclusions

The potential influence of a toe drain size on the slope stability of an embankment dam under rapid drawdown conditions has been investigated. From the results, it was observed that the pore-water pressures at the upstream face of the embankment were decreasing with the increase in the toe drain size, while the pore-water pressures at the downstream toe were increasing with the increase in the toe drain size. The factor of safety values were also observed to be affected by the changes in the toe drain size. Therefore, the results from this study revealed further that, there is a significant potential relationship between toe drain size and factor of safety when an embankment is subjected to a rapid drawdown condition.

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Timoth Mkilima – concept, methodology, resources, data collection, testing, modeling, analysis, visualization, interpretation, drafting, editing, funding acquisition.

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Article

Non-destructive testing of bored piles

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Abstract. Quality control of bored piles is a complex operation aimed at determining possible defects in the pile shaft and the strength of the pile material made by different technologies. The presence of pile shaft defects and a decrease in the strength characteristics of the pile shaft material lead to the development of negative processes at the stage of subsequent operation of the building and structure. It is known that the bearing capacity of the pile material should not be less than the bearing capacity of the ground. Consequently, it is necessary to strictly observe the quality of the concrete of the design strength values to ensure the reliability of the designed building concerning the service life. Nowadays different methods of nondestructive testing such as pile integrity test, cross-hole sonic logging. The paper presents a discussion of the advantages and disadvantages of each of them, experimental data also are given.
Keywords: pile, test, soil, integrity, method.

1. Introduction

1.1 General provisions

Due to the multistage and complexity of the bored pile manufacturing process, as well as the dependence of the result on the human factor, various defects can appear in the piles: zones of complete absence of concrete, porosity, decreased concrete strength, inclusions of natural soil. Deviation in manufacturing from the design characteristics of the pile in length, continuity, shape, diameter, the strength of the concrete, size of the armature leads to a loss of bearing capacity of the pile and settlement of bridges and foundations, up to the destruction of buildings and structures. The term "continuity of concrete" is understood as "an indicator of the quality of paving, characterizing the continuity of the material and the absence of abnormal zones (sludge, voids)" [1–3]. Traditional tests of piles with static and dynamic loads, being the most representative tests, can only determine the carrying capacity of piles, but in no way can guarantee the quality of the pile as a reinforced concrete structure, that is why the international standards provide for the bored pile bore integrity control. Because direct methods of control, including testing of piles by traditional methods, sampling with subsequent testing in the laboratory, and some others, are time-consuming and costly. Therefore, there is a need for investigation for inexpensive and non-destructive control methods that allow for quick observations.

1.2 Testing methods for pile foundations in different stages of investigations

Engineering geological investigations considered three stages which are shown in Table 1. Testing methods for pile foundations in different stages of investigations include the follows weight sounding test (WST); cone penetration test (CPT); dynamic probing tests (DP); standard penetration test (SPT); field vane test (FVT); pressuremeter test (PMT); static axially loaded compression; pile integrity tests and determination of a pile length. In pile integrity tests, the highest quality signals are achieved by observing the following:

–Blow zones of concrete foundation construction should be trimmed back to sound material, free of loose surfaces and debris;

–The surface should be free of water;

–Any structures or elements attached to the concrete foundation construction, e.g., long projecting reinforcement or cages, may return signals generated by these elements which may make the signal impossible to interpret. Often, interference from these elements may be electronically filtered out;

–Access to the side of the pile should permit delivery of several hammer blows and provide sufficient room for movement of the transducers on the side;

–Concrete foundation construction normally requires a curing time of 28 days to being ready for testing;

–Several blows should be delivered to each test place to ensure repeatability and hence consistency of results.

Table 1 – Testing methods for pile foundations in different stages of investigations

Preliminary survey		Geological investigations on design stage		Control investigations	
Investigation of the topographical and hydrogeological maps, archival material, geological investigations	Clay soil (CPT, SS, DP, SPT, GW, PMT)	pre-selection of the type of foundation	PILE FOUNDATION WST, CPT, DP, SPT, FVT, PMT, PIL SHALLOW FOUNDATION WST, CPT, DP, FVT, DMT, PMT, GW, BJT	the final choice of the type of foundation	PILE FOUNDATION PILE; sonic pile test; GWC measurement; measurement of settlement SHALLOW FOUNDATION control of the type of soil; CPT, control of the settlement
	Sandy soil (CPT, SS, DP, SPT, GW, PMT, DMT, GW)	pre-selection of the type of foundation	PILE FOUNDATION CPT, DP, SPT, FVT, DMT, GWO SHALLOW FOUNDATION CPT+DP, SPT, PMT, BJT, GWO	the final choice of the type of foundation	PILE FOUNDATION PILE; sonic pile test; GWC measurement; measurement of settlement SHALLOW FOUNDATION control of the type of soil; CPT, control of the settlement

The test procedure associated with a pile integrity test consists of the following steps [5]:

–Clearing of the concrete pile from the soil, snow, ice to the sound surface. Preparation of three zones (if possible) of flat, dry concrete on the pile; the size of such zones should be approximately 100×100 mm to attach the sensor (accelerometer) and to blow by a special hammer on the concrete surface.

–The following parameters are introduced in memory of the device: Site, symbol of concrete foundation, length, stress wave velocity in concrete.

–The sensor, registering reflected signals is fixed on a prepared zone on the pile through special paste for best registration of the signals. Three light blows are produced by a special hammer on the foundation site of the prepared place. The graph (reflectogram) of blow amplitude to the length of concrete foundation dependence is represented on the display of the device. If the operator determines graphs to be acceptable for interpretation, these results are written into the memory of the device for additional processing. If the blows were either very strong or very weak, the device does not register any signal and it is required to repeat the blow. The blows are produced until the operator can interpret the reiterative graphs (reflectograms).

All integrity tests data are processed by special software after testing, and output is represented by a graph "signal amplitude" – "crack location". According to the graphs the operators classify the depth of crack penetration. A technical report will be given to the client after all tests with detailed analysis.

The pile side is struck with a hand-held hammer that sends sound waves directly through the concrete foundation. Pile side movements affected by a series of hammer blows and subsequent rebounds are then received by a very sensitive acceleration meter positioned on the side of the foundation. The acceleration signal is converted into velocity and is represented on the screen as a function of time. All results are easily saved into the computer, to be used in the processing thereof.

The interpretation of reflectograms consists of the following actions [4-5]:

–If the graph has clear fluctuations with a further reflection of the signal, it means the pile has experienced necking, cracking, incursions, geological influence, etc.

–If such fluctuations are not significant, it means that the pile is without defects.

–has necking, the influence of geological conditions (e.g., soils filled by water), change of density of soil or concrete, etc.

–If the graph has sharp fluctuations, it means that the pile has serious cracking/necking in the place of the beginning of fluctuation.

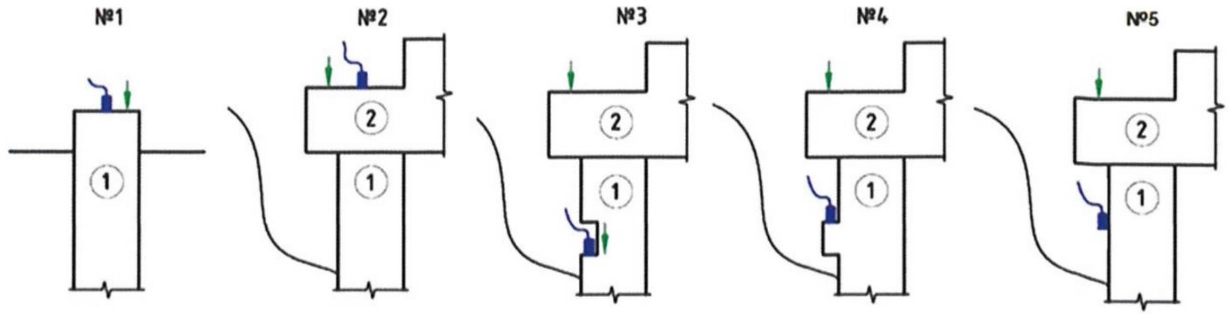
2. Methods

2.1 Pile Integrity Testing in Object 1

Work on continuity diagnostics and length control of 18 bored piles at the Bridge site [6] (Figure 1). The bored piles were erected using rotary drilling technology with inventory casing. Equipment used during the test: pile diagnostic unit Spektr, seismic receiver, hammer with nozzles of different stiffness, software Spektr [7].

Figure 1 – Constriction site of 18 bored piles

The number of sensors to be installed and their location and impact locations are set for each pile separately. To increase reliability, the sensors are installed on several control points (at least 3 per pile). To press and fix sensors on the pile a special viscous composition is used, which provides tight contact of sensors with the pile. To excite the pulses passing through the pile for each method of control, at least 10 impacts were made. The measurement technique was carried out according to ASTM requirements. The sensor-accelerometer depending on the design features of the object of the conditions of access to the pile was installed in accordance with the diagrams shown in Figure 2.



1 – pile, 2 – strut

Figure 2 – Principle schemes of tests: №1 – on the pile head; №2 – overhead; № 3, 4 – to the site prepared above the pile; №5 – on the side surface of the pile

In the course of the study, preference was given to Scheme 1. The first stage included applying a series of blows, the second stage involved determining the speed of propagation of the acoustic wave rod in the pile concrete. The average velocity is taken in the range of 3600-4100 m/s, and the third stage - the cameral processing. The results of testing 9 piles are shown in Table 2 and Figures 3-6.

Table 2 – Results of measured pile length

Number of pile	Measured pile length, m	Result of testing
1	25.3	satisfactory
2	25.7	satisfactory
3	26.8	satisfactory
4	26.2	satisfactory
5	26.4	satisfactory
6	25.6	satisfactory
7	25.9	satisfactory
8	26.3	satisfactory
9	25.5	satisfactory

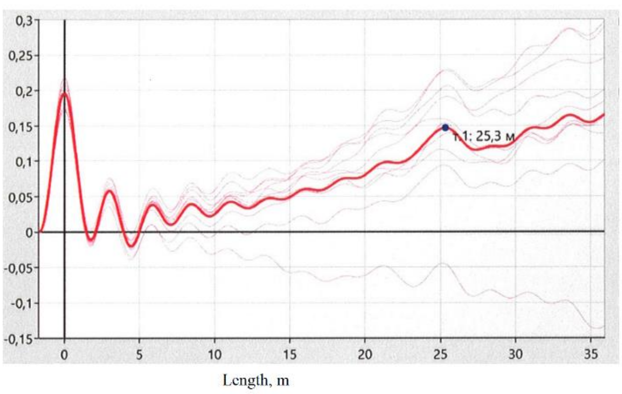


Figure 3 – Analysis of the wave passage through the body of the pile 1

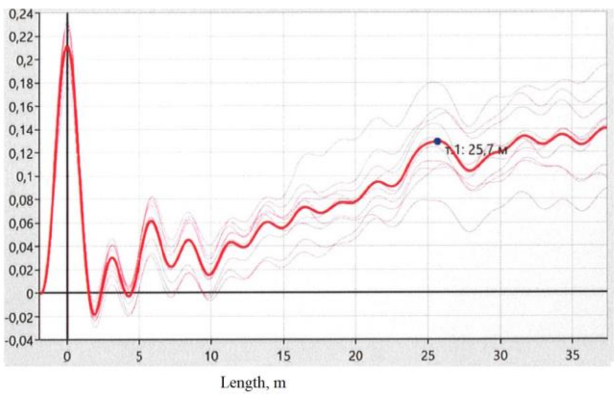


Figure 4 – Analysis of the wave passage through the body of the pile 2

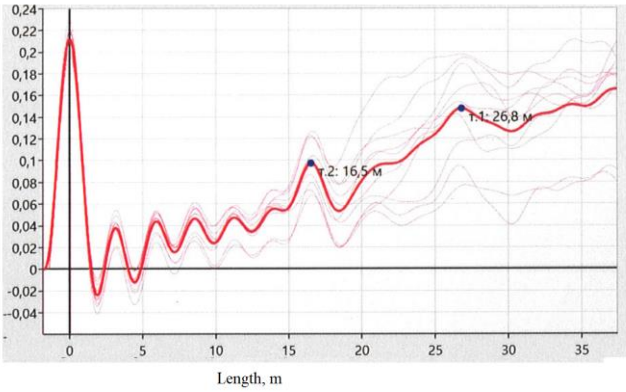


Figure 5 – Analysis of the wave passage through the body of the pile 3

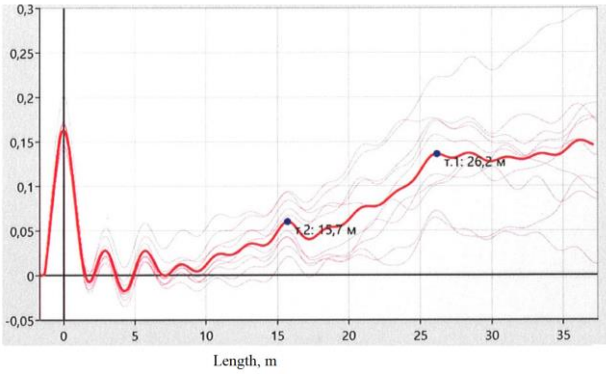


Figure 6 – Analysis of the wave passage through the body of the pile 4

2.2 Cross hole sonic logging test

Also in practice, the cross-hole sonic logging (CSL) method is used. Inspection of piles by the CSL method [8] is based on determining the properties of the inspected object by changing one of the parameters of the ultrasonic wave passed through the inspected area of the pile [7-8]. The ultrasonic wave is transmitted from the transmitter to the receiver in the form of pulses with a set. The transducers are pulled through water-filled tubes installed in the frame of the pile under study. The amplitude of the ultrasonic wave passing through the monitored area and the time of its passage are used as the registered parameter [9-10]. The measured transit time and energy of ultrasonic waves correlate unambiguously with the quality of concrete. The signals coming from the measuring instruments during the ultrasonic wave transit are recorded and processed on the PC, and then provided as the sought information about the integrity and homogeneity of the pile shaft. The CSL were conducted at the construction site of Nur-Sultan (Figure 7). The data of testing bored pile is presented in Table 3 and results in Table 4 and Figure 8-9 [11].

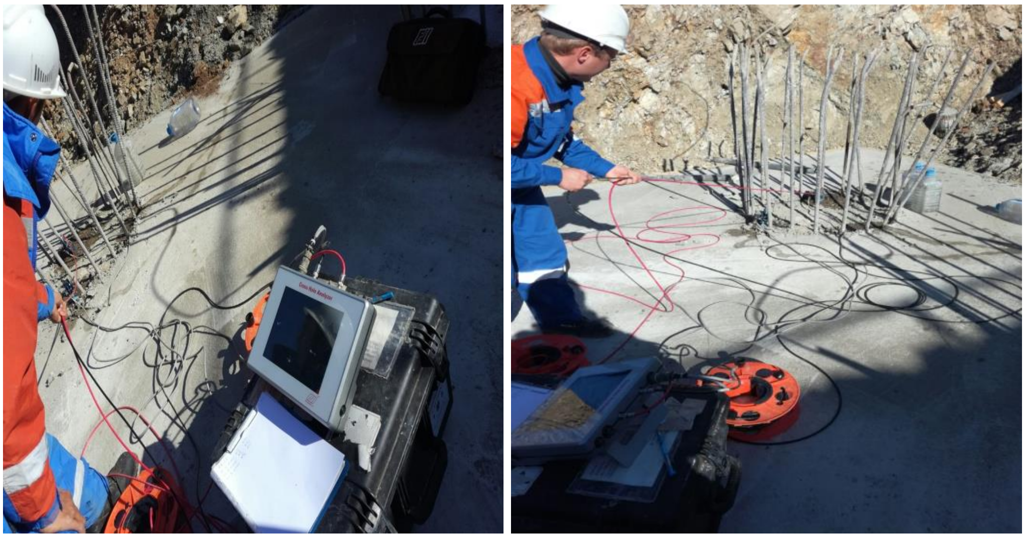


Figure 7 – Testing in construction site

Table 3 – Data of testing pile

Number of piles	Pile length, m	Diameter of the pile,m	Number of test tubes / their diameter,m	Height of test tubes above the pile concrete, cm
Entry and exit line, YCR13 support, pile 1	53.1	1.5	3/42	5

Table 4 – Results of a testing pile

Number of piles	Test tube pair numbers	Distance between the test tubes, m	Available length of test tubes, m	Results of test
Entry and exit line, YCR13 support, pile 1	1-2	1.000	53.10/53.10	The defect was detected at a depth of 22.64-24.59 m
	1-3	0.930	53.10/53.10	
	2-3	1.010	53.10/53.10	

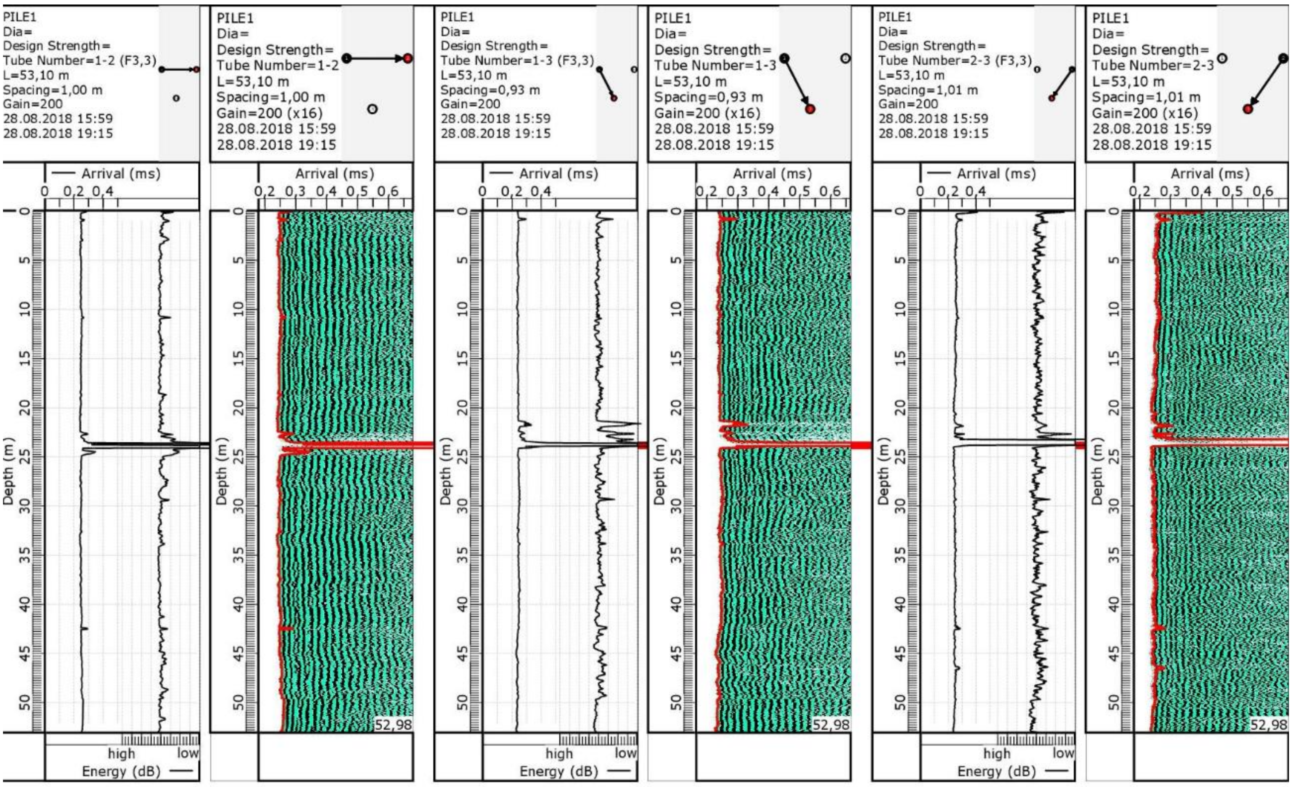


Figure 8 – Results of measurement

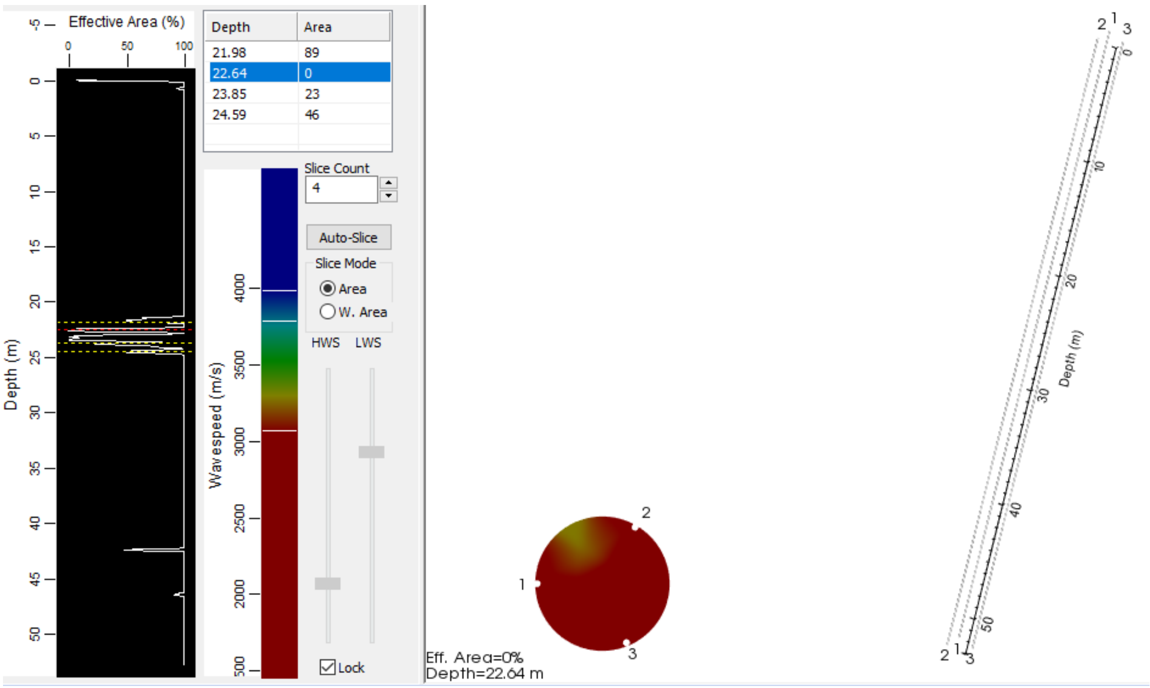


Figure 9 – PDI-TOMO measurement results

3. Results and Discussion

The PIT method and the CSL method provide data on the quality of piles with a significant degree of reliability in a relatively short time. However, in the course of the study, it is possible to highlight such features as presented in Table 5.

Table 5 – Advantages of PIT and CSL

Indicators	PIT	CSL
Number of tests per day	✓	
Measures to prepare for the test	✓	
Pile length variations		✓
Detection of defects of different nature		✓
Interpretation of results	✓	

Thus, the advantages of the PIT are a very quick data acquisition on any pile on the construction site and the ability to check up to 100 piles per day; pile length within 100 m; identification of defects of different nature in the barrel of the reinforced concrete pile; the possibility of diagnosing any pile by one operator independently; maintaining the integrity of the pile; relatively low cost of the test.

Advantages of CSL is no pile length limitation; can determine the depth of an anomaly with reasonable accuracy; can estimate horizontal extent of a defect if enough access tubes are present.

4. Conclusions

The PIT method allows an expert assessment of the actual condition of the pile, determines its length, and analyzes the integrity of the structure. This method is an expression control and does not destroy the concrete of the pile. The PIT method makes it possible to obtain, with a high degree of certainty and in a relatively short time, data on the load-bearing capacity of the pile. The CSL method of concrete structure continuity control is based on the difference of velocities of ultrasonic waves in environments with different structures, mechanical and physical properties.

However, as the study showed, there are disadvantages of each of them, among which we can highlight: access tubes must be cast during shaft construction; evaluation often requires experience and engineering judgment when results are complicated or not outwardly conclusive; inconclusive results or complicated signals can be caused by several factors. In this regard, it is necessary to use a comprehensive approach using these two methods.

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Article

Modern trends in the development of the construction industry in the production of building materials

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Abstract. The paper describes the technology of manufacturing a construction product by vibrocompression using ash and slag waste from thermal power plants in the Pavlodar region. The task of the experimental research was to obtain a hollow wall stone based on ash and slag waste with a strength grade that is not inferior to products made according to the traditional recipe. A study was carried out with selected samples of bauxite sludge from the sludge dumps of the Pavlodar Aluminum Plant, as fillers was used metallurgical slag of fractions 0-5 and 20-30 according to 6 recipes made in forms 100x100x100 mm. The obtained samples with different ratios of components in the mixture were investigated for compressive strength, moisture absorption, frost resistance. It has been established that when ash and slag waste are added to the composition of the concrete mixture in an amount of up to 35 % of the mass of dry components, the strength characteristics of the hollow wall stone correspond to the selected brand.
Keywords: slag, ash, waste, development of the construction, industry, building materials, concrete mix.

1. Introduction

Currently, in the Republic of Kazakhstan in dumps, according to reports of independent assessments [1-2], more than 400 million tons of ash and slag waste from thermal power plants and metallurgical waste have been accumulated, which is an aggravation of the environmental situation in industrial regions and requires the development of technical solutions to improve it [3].

One of the scientific and technical solutions to this problem, which is also essential for the construction industry, is the production of construction products using industrial waste in the concrete mixture. Utilization of large-tonnage industrial waste confirms the relevance of the development of this issue and, in parallel, is strengthened by the implementation of large-scale State programs to increase the affordability of housing, mortgage lending, which ensures a stable growth in demand for construction products and, as a result, raw materials for their manufacture [4].

A promising raw material for the production of building products is ash and slag waste from thermal power plants and waste from the metallurgical industry [5-6]. In addition, today the scaling of the technology for the production of heavy concrete using ash and slag waste from thermal power plants and waste from metallurgy of the Republic of Kazakhstan is widely used [1-7].

LLP «EcostroyNII-PV», organized under the grant program «Stimulating productive innovations» from the Ministry of Education and Science of the Republic of Kazakhstan and the World Bank (Subproject № APP-SSG-17/0290F), uses ash and slag and metallurgical waste as a basis for the manufacture of building products: ash from the TPP of Pavlodar and Aksu TPP of JSC «Eurasian

Energy Corporation» (EEC, ERG) based on Ekibastuz coal, slimes of the Pavlodar aluminum plant of JSC «Aluminum of Kazakhstan», steel-making slags of Pavlodar steel-making factories PF LLP «Casting», PF LLP «KSP Steel».

2. Methods and Materials

The development of new compositions of concrete mixtures with improved performance characteristics using ash and slag waste from thermal stations and metallurgical enterprises of Pavlodar region as aggregates and binder requires a large number of experiments with varying the percentage of all components that make up concrete mixtures, establishing the regularity of the effect of various additives on physical and mechanical characteristics of mixtures [8].

Expansion of the raw material base of ash and slag waste allowed us to make samples using recipes, which include ashes of the above-mentioned TPP.

Table 1- Chemical composition of fly ash from Pavlodar TPP-1 in %.

SiO_2	Al_2O_3	TiO_2	Fe_2O_3	CaO	MgO	K_2O	Na_2O	P_2O_5	MnO
60.6	28.6	1.4	5.4	2.0	0.5	0.5	0.2	0.7	0.1

The fly ash used in our technological process (Figure 1) is characterized by a fine granular fraction [9-10]. According to GOST 25818-91 and 25592-91, the content of calcium oxide CaO in the ash component of the ash and slag mixture and in the fine-grained mixture should be no more than 10 % by weight. The content of magnesium oxide MgO in the ash component of the ash and slag mixture and in the fine-grained mixture should be no more than 5 % by weight [11-12]. The content of sulfurous and sulfuric acid compounds in terms of SO3 in the ash and slag components of the ash-and-slag mixture should be no more than 3 % by mass, including sulfide sulfur – no more than 1 % by mass. The content of alkaline sodium and potassium oxides in terms of Na2O in the ash component of the ash and slag mixture and in the fine-grained mixture should be no more than 3 % by weight [13].

Figure 1 – Fly ash of Pavlodar TPP-1

Bauxite sludge from the Pavlodar Aluminum Plant is a by-product of the production of alumina A2O3. The currently known methods for the production of alumina can be divided into electrothermal, acidic and alkaline. It is possible to convert the alumina contained in the raw material into sodium aluminate in various ways, one of which is the «Dry» process (Bayer sintering process) or simply «Sintering» (the so-called Mueller-Jakovin process). Ore with alkali metal salts is sintered in rotary kilns, then the aluminate is leached, and the resulting aqueous solution is subjected to decomposition. The composition of the concrete mixes included bauxite sludge from the Pavlodar Aluminum Plant (Figure 2a, 2b, 2c), of various fractions, sifted into a sieve with cells from 0.05 to 2 mm [14].

Table 2 – Chemical composition of bauxite sludge from Pavlodar Aluminum Plant, obtained by Bayer sintering

Fe_2O_3	Al_2O_3	CaO	SiO_2	TiO	CO_2	Na_2O	MgO
27-33	4.0-5.0	39-44	19-21	2.0	0.8-1.0	0.9-1.5	0.3-1.2

In appearance, bauxite sludge (Figure 2a) is medium-grained beige-brown sand with inclusions of easily crumbling lumps of various sizes. The moisture content of bauxite sludge samples should be within 20-30 %, density – 2.6 - 2.86 g/cm^3, bulk density in a loosened state - from 1.1 to 1.3 g/cm^3.

Figure 2 – Bauxite sludge: a) from the Pavlodar Aluminum Plant; b) fraction 0.63; c) fraction 0.4

For the research, representative samples of bauxite sludge were taken from the sludge dumps of the Pavlodar Aluminum Plant. Sludge samples were taken in accordance with the requirements GOST 12071-2014. Statistical processing of the research results was carried out in accordance with the «Recommendations for the use of bauxite slimes of alumina production in concrete and mortars» NIIZhB Gosstroy USSR 1990.

Metallurgical slag of fraction 0-5 (Figure 3a) and coarse fractions 20-30 (Figure 3b) were used as fillers.

Figure 3 - Metallurgical slag: a) fraction 0-5; b) fraction 20-30

The slag is gray, a porous microstructure is observed, the presence of a crystallized glassy component is noted [15–17]. Brown inclusions indicate the presence of iron oxide. The chemical composition of the slag PF LLP «Casting» (Table. 3). Depending on the formulation, the above-described technogenic raw materials were included in the composition of the concrete mixture as aggregates and binder [18]. For each recipe, 6 samples were made (Figure 4), which were placed in molds (Figure 5) 100x100x100 mm in accordance with GOST 25781-81, the samples (without steaming) were stored at room temperature for 28 days, after which strength tests were carried out with them (Figure 6-7).

Table 3 – Average chemical composition of slag in EAF ESPC PF «Casting» LLP and PF «KSP steel» LLP for 2019, %

Fe	SiO_2	Al_2O_3	CaO	MgO	MnO	S	imp.	Σ
28-35.9	12.1-18.9	1.9-4.8	21.1-24.6	6.9-20.2	5.1-8.2	0.03-0.04	1.2-1.7	90.0-98.3

Figure 4 – Test pieces

Figure 5 – Forms 100x100x100 mm in accordance with GOST 25781-81

Figure 6 – Test for the strength of the sample

Figure 7 – Destruction of the sample

Figure 8 – Indication of strength values for sample № 17-5

Figure 9 - Compression of a hollow wall stone

As a result of experiments, it was revealed that:

- Ashes of Pavlodar TPP, used as a filler, do not affect the decrease in the strength of the concrete mixture. Due to its low activity (when grinding ash to a size of 0,0005), it can be used as a replacement for clinker, which is not practical on an industrial scale. The use of ash up to 15 % of the amount of cement does not affect the decrease in strength indicators and can be used as an aggregate to replace sand.
- The use of bauxite sludge with the addition of milk of lime made it possible to increase the strength of concrete specimens up to the M50 grade, class B3, 5, taking into account the absence of vibropressing. Formulation development using bauxite sludge continues.
- The use of metallurgical slag of fraction 0-5 as a filler did not affect the strength of the samples due to the absence of vibrocompression and a steaming chamber, due to which the cement adhesion process was low. At the same time, hollow stones made with metallurgical slag on the Rifey-Udar-SDA production line showed class B7.5 (M100), but the stones turned out to be heavy (27 kg).

To date, 33 recipes for concrete mixtures have been developed using various fillers, additives and binders. It should be noted that the process of vibrocompression on the Rifey-Udar-SDA line makes it possible to obtain the strength of products in a short time. For example, a sample made according to recipe № 17 received a strength almost similar to the prototype after 7 days (Figure 8 and 9).

Based on the results of the tests, the compositions of concrete were selected using ash and slag waste (Table 4).

Table 4 – Results of testing concrete samples using ash and slag waste

Sample brand	Mass fraction of cement, (%)	Strength, kg/cm^2	Strength, MPa	Concrete strength class	Concrete strength grade	Density, g/cm^3
Z0040-vt	40	243.8	23.9	B23	M300	2.09
Z1035-vt	35	175.0	17.2	B17	M200	1.90
Z2030-vt	30	163.3	16.0	B16	M200	1.76
Z3025-vt	25	88.3	8.7	B8	M100	1.64
Z4020-vt	20	36.1	3.5	B3.5	M50	1.59
Z0040-vt	40	386.0	37.9	B30	M400	2.59
Z1035-vt	35	329.0	32.3	B25	M350	2.37
Z2030-vt	30	309.0	30.3	B25	M350	2.17
Z3025-vt	25	236.6	23.3	B20	M250	1.98
Z4020-vt	20	212.2	20.8	B15	M200	1.88

Note: vt – vibrating table (sample obtained on a vibrating table); vp – vibropressing (industrial design)

Based on the tests of samples using ash and slag waste from Pavlodar TPP-1, it was found that there are reserves for saving cement when using ash in the case of preparing industrial samples by vibrocompression; to adjust the composition of concrete, it is required to conduct pilot tests of products under the combined action of vibration and pressing.

On the technological line «Rifey-Udar-PU-SDA» were made industrial samples of stone wall hollow composition Z4020 (table 4). Tests have shown concrete class B15. After reducing the amount of cement, tests showed the concrete class – B3, 5 (M50), which is sufficient for the construction of low-rise buildings. The same composition was used to make «Partition stone 390x120x188 mm». The strength of the stones was also obtained B3, 5 (M50). Since this strength is not required for the material of the baffles, it is possible to reduce the consumption of cement. After laboratory tests, it was decided to investigate the use of ash and slag waste from Pavlodar TPP in industrial and field tests.

2. Industrial and full-scale tests of the construction product

Industrial and full-scale tests of the construction product «Four-hollow wall stone, type SKT-1, using ash-and-slag waste»:

- Product «Wall stone four-hollow four-hollow SKSH-1 with ash» – product size: 390×188×190 mm.
- *Test object:* one-story extension to the office building of the workshop on the territory of the production site of EcostroyNII-PV LLP (Figure 10).

Parameters of the object of full-scale tests: length – 3 m, width – 2.7 m, height – 2.5 m, wall thickness – 190 mm.

The object of full-scale tests was made on a strip prefabricated concrete foundation; the laying of four-hollow wall stones was carried out with a cement-sand mortar of a ratio of 1:3.

The number of products for the construction of a full-scale object: Wall stone four-hollow hollow with the use of ash-and-slag waste – 300 suitable artificial stones. The building is covered with plates PK 3x1,5 – 2 pcs.

Location of the object of full-scale tests: Pavlodar, central industrial region.

*The purpose of carrying out full-scale tests***:** Research of the behavior of four-hollow wall stones based on ash and slag waste in natural operation (weight, wind, rain and snow load) in a moderately aggressive environment in order to assess the suitability of EcostroyNII-PV products for further use by consumers while ensuring safety conditions and functional load on products.

Figure 10 – Full-scale tests of the manufactured pilot-industrial batch of products «Hollow wall stone with ash-and-slag waste» in the form of construction of an extension to the production workshop of EcostroyNII-PV LLP

The composition of the raw mixes used for the manufacture of products is shown in Table 5 [19]

Table 5 – Composition of raw mixes for the manufacture of hollow wall stones

Component name and characteristics (granulometry)	Quantity
Natural sand for construction work of Pavlodar River Port JSC, size group - medium, GOST 8736-2014.	15-20 %
Ash and slag waste from TPP-1 of JSC Aluminum of Kazakhstan, GOST 25592-91. Ash and slag mixtures of thermal power plants for concrete. Technical conditions.	30-35 %
Screening crushing of dense rocks for construction work, LLP «Asphalt concrete», deposit «Maikinskoe» GOST 31424-2010.	35-40 %
Portland cement Premium 450 CEM II/A-Sh 32.5N (Semey cement plant production company LLP) GOST 31108-2016.	9-13 %
Water-cement ratio (GOST 23732-2011 Water for concrete and mortars. Specifications).	0.16-0.2
Additive Solitard S3, TU 20.59.59-001-16918243-2018 LLC «Bentax», Novosibirsk – 0,4-0,6 % by weight of cement.	0.4-0.6 % by weight of cement

3. Results and Discussion

The mechanical characteristics of the products were preliminarily determined by the destructive method using a PMG 1000MG4 hydraulic press in an amount of 5 % of each batch of products. Water absorption of stones was determined according to GOST 12730.3-78 «Concrete. Method for determining water absorption». 5 selected product samples were tested. The test results are shown in Table 6.

Table 6 – Test results

Indicator name	Sample № and marking				
	1	2	3	4	5
Weight, kg	18,5	18,7	19,4	19,0	19,8
Ultimate strength, MPa/concrete class	3.6/B2.5	3.3/B2.5	3.8/B2.5	3.2/B2.5	3.8/B2.5
Water absorption, %	5,.0	4.8	4.7	4.2	3.8

4. Conclusions

Based on the results of industrial tests, the following conclusion was obtained:

1. The produced artificial stones in their mechanical characteristics correspond to the class of concrete B2.5.
2. During the period of observation the object of full-scale tests within one year, the object was subjected to weight, wind, rain and snow loads.
3. The water absorption of products did not exceed 5 %, which corresponds to the standard indicators. Destruction of the object, cracks on the surface, delamination, chips were not observed, the object corresponds to its functional characteristics.
4. It is recommended to apply the recipe for the composition and production technology of hollow wall stones using ash and slag waste for the use of these products in low-rise construction.

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Article

BIM for Construction Clash Detection Process after Design stage

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Abstract. The construction industry is one of the most unpredictable and human-dependent sectors of production. This is due to the large flow of information during construction, which requires clear organizational activities. Traditionally established methods of communication on construction sites require modernization. That is why the concept for practitioners "Building Description System and Construction Product Modeling" was developed in 1970. The building society supported this concept and called it "Building Information Modeling" - BIM. The new wave of digital design required a strong material and technical base, the analysis of existing documentation and the creation of design tools began. The authors of the article use the highly specialized NavisWorks software to analyze possible losses as a result of combining the existing design documentation into BIM models on the example of one of the Nur-Sultan projects. The residential complex located in Nur-Sultan was chosen as case study. The residential apartment building was chosen because of the scale of the project and its full implementation in the BIM system. The article makes a comparative analysis on finding the intersections on the principle of combinatorics. The section of structural and space-planning solutions is checked for intersections with the sections of heating and ventilation, water supply and sewerage, then the logic is repeated. Exceptional combinations are selected to check for conflicts (collisions).
Keywords: BIM, NavisWorks, 3D, Management, Clash Detection, Collision.

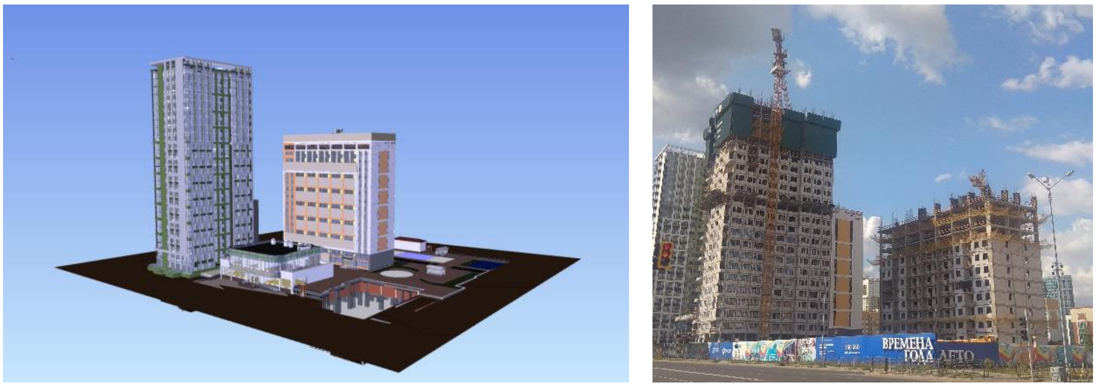
1. Introduction

The construction industry is one of the most unpredictable and human-dependent sectors of production. This is due to the large flow of information during construction, which requires clear organizational activities. Traditionally established methods of communication on construction sites require modernization. Because maintaining a paper-based document flow can lead to errors, which can result in unforeseen costs for the project, which will affect the quality of construction, as well as the overall profit of the company [1]. For this purpose, various digitalization tools are being implemented. One of the latest innovations in this direction is BIM technology. The advantage of the introduction and use of BIM technology is an increase in productivity from the development and design stage to the operation and complete destruction of the building [2].

The first practical guide in this direction is [3], where Charles M. Eastman conducts his early research in the field of information design. This led to the development of a concept for practitioners "Building Description System and Building Product Modeling" in 1970. The building society supported this vision of the author, which contributed to the renaming of the concept into the generally accepted term "Building Information Modeling" - BIM [3]. The new wave of digital design required a strong material and technical base, the analysis of existing documentation and the creation of design tools began. All this leads to the creation of the first two- and three-dimensional computer-aided design and drafting systems. So, the first version of AutoCAD software by Autodesk is released 12 years after the publication of the early studies described in [3]. Further review of the effectiveness of BIM technology is comprehensively considered in [4]. Much attention is paid to the existing literature in order to determine the current status of the development and implementation of BIM. The interviews with key experts in this area are noted separately. The points related to future opportunities, resource needs, existing barriers and general potential of user interest are touched upon [4]. It is worth noting that the development of the functionality of the tools allowed some of them to become separate software, thereby determining the specifics of the work. For example, the emergence of highly specialized software, such as NavisWorks, 3ds Max Design, Civil 3D and others, are widely used in the architectural and construction industry, both in combination and separately. The use of BIM technology in, speaks not only about the technical possibilities but also about the methodology of their use, as another positive side is the interaction with generally accepted standards, which should be adhered to [5]. The virtual model reconstructed in this way in BIM, correlates well with the construction documents in terms of determining the preliminary and final scope of work, as evidenced by two case studies [6]. Based on the above, it can be assumed that the relevance of the implementation of project analysis is significant not only for developed countries, but also for developing countries [7,8]. Thus, the authors of this article made a comparative analysis of possible losses received as a result of combining the finished design documentation in BIM models on the example of one of the projects released in Nur-Sultan.

2. Methods

The residential complex located in the city of Nur-Sultan was chosen as the object under study. The residential multi-storey building was chosen because of the scale of the project and its full implementation in the BIM system (Figure 1).



a) BIM model b) Construction area

Figure 1 – Residential complex in Nur-Sultan

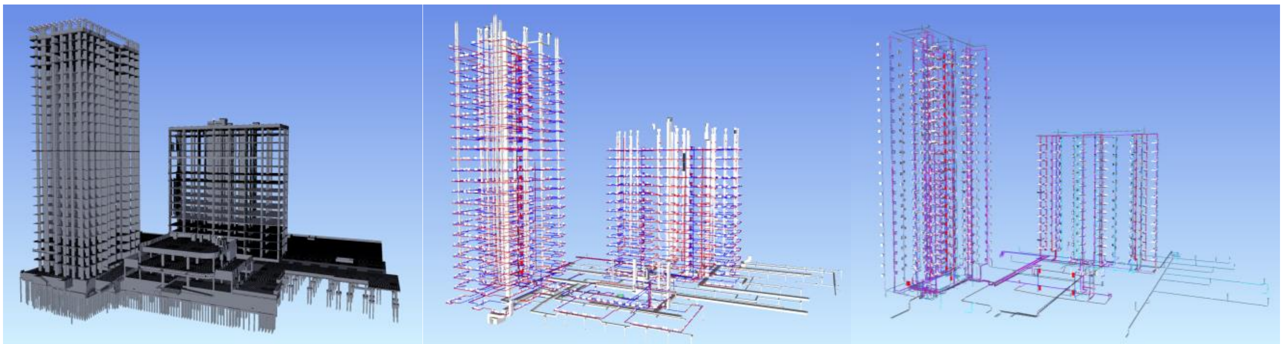
Digital analysis requires powerful software and when choosing a personal computer, it is worth paying attention to the system requirements (Table 1), because the speed of data processing directly affects the speed of decision-making, which is an important factor for the successful completion of the project [9,10].

Table 1 – Single Installation Requirements for NavisWorks

№	Requirements	Descriptions
1	Operating System	Microsoft® Windows® 10 (64-bit) on the Semi-Annual Channel servicing option. See Autodesk's Product Support Lifecycle for support information.
2	CPU	3.0 GHz or faster processor
3	RAM	2 GB RAM or more
4	Disk Space	15 GB free disk space or more
5	Graphics	Direct3D 9® and OpenGL® capable graphics card with Shader Model 2 (minimum)
6	Display	1280 x 800 VGA display with true color (1920 x 1080 monitor and 32-bit video display adapter recommended)
7	Pointing Device	Microsoft Mouse-compliant pointing device
8	Browser	Microsoft Internet Explorer 11, Google Chrom etc.

A key analysis tool is NavisWorks Manage software from the company's AutoCAD family of assembly investigation and verification software. The built-in tools for publishing reports make it possible to open collision objects in the source application.

It is generally accepted to analyze the conflicts that appeared when the 3 main sections of the design documentation were combined (Figure 2 a, b, c).



a) CS b) HVAC c) WSS

Figure 2 – Sections of the design documentation

For this purpose, a comparative analysis for finding intersections on the principle of combinatorics. That is, one section is compared with others and vice versa, for example, the section of structural and space-planning solutions (CS) is tested for intersections with the sections of heating and ventilation (HVAC), water supply and sewerage (WSS). Such sections as low-current networks (LPN) or electricity supply (ES) are not taken into account in the analysis of conflicts for the reason that the flexibility of installation allows to avoid moments associated with them. It is also possible to compare the sections with each other, if necessary. Exceptional combinations are selected to perform a conflict (collision) check (Table 2).

Table 2 – Combinations of sections of the project documentation to find a collision

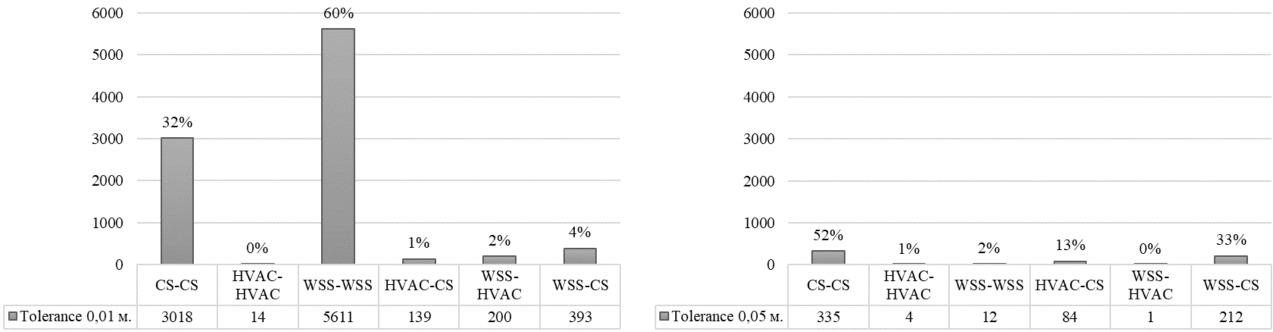
Sections of project documentation	**CS**	**HVAC**	**WSS**
CS	CS-CS	CS-HVAC	CS-WSS
HVAC	HVAC-CS	HVAC-HVAC	HVAC-WSS
WSS	WSS-CS	WSS-HVAC	WSS-WSS

Combinatorial configurations are based on the simplest technique of combining and categorizing the detected collisions: geometric collisions, technological collisions, empty objects and substrates.

In the case of geometrical collisions identify 2 types: detected by a simple visual inspection of the three-dimensional model and based on the rules in the presence of an informative three-dimensional model. Technological collisions relate to system malfunctions that are often encountered in the design of piping systems. The last category of blanks and substrates are of an auxiliary nature and are not used in the analysis. Two values of 0.01 and 0.05 m were used for tolerance, respectively, to check for conflicts in contact surfaces, faces and angles. In general practice, a value of 0.05 m is often accepted [11].

3. Results and Discussion

The analysis of the virtual model revealed the number of conflicts that occurred after merging the three sections of the design documentation into the BIM model. The figures below show the number and percentage of conflicts at different tolerances. A 0.01m tolerance revealed a total of 9,375 and a 0.05m tolerance of 648 conflicts (Figure 3).



a b

Figure 3 – Combinations of the main sections of the design documentation to find conflicts: a) number of conflicts with a tolerance of 0.01 m; b) number of conflicts with a tolerance of 0.05 m

Most of the identified conflicts fit the description in [10], if we take into account a tolerance of 0.01 m. This is justified by the increased requirements for BIM model, which do not take into account the possible changes made in the project on the fact of work, as often the sections are developed and approved by design organizations in parallel, which leads to future deviations.

The conflicts detected when comparing the CS-CS sections relate to intersections due to joints and adjacencies of monolithic concrete structures and do not pose a threat (Figure 4). In such cases, it is often common to ignore conflicts that lie on the same layer. This is done by assigning them a status type, such as active or accepted.

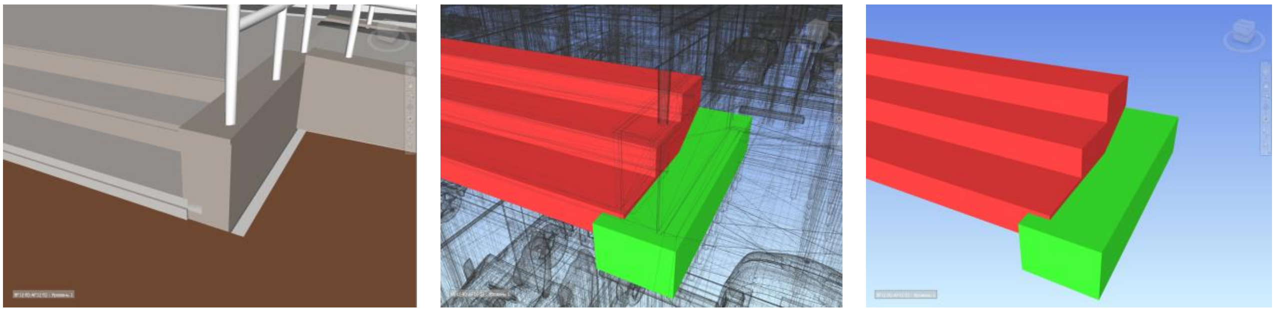


Figure 4 – Example of a conflict when comparing sections of the CS-CS

The HVAC-HVAC section has the fewest conflicts in the two tolerances. This is due to the different heights at which ventilation ducts and heating pipes are installed. Most often, difficulties are encountered with the installation of equipment at the ventilation outlets. This arrangement of several baffles occurs when saving space allocated for the ventilation ducts (Figure 5).

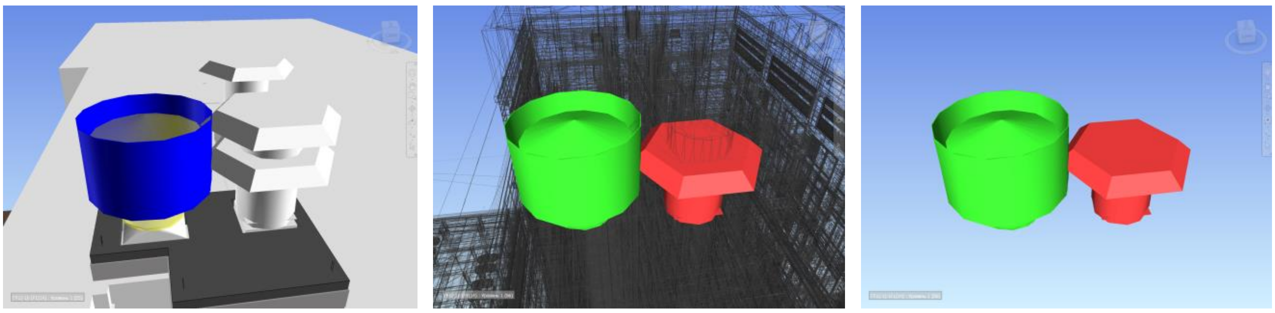


Figure 5 – Conflict when comparing HVAC-HVAC sections

In the section WSS-WSS predominantly conflicts related to the equipment of the toilet, bathroom or other sanitary equipment. The solution of these conflicts is individual in nature, since the use of standard solutions contained in the library, do not take into account the peculiarities of the structure of the equipment and their components (Figure 6).

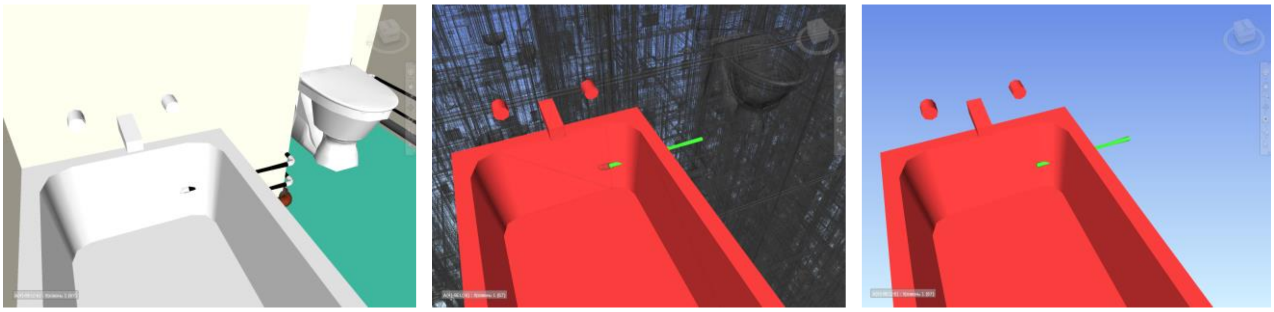


Figure 6 – Conflict when comparing WSS-WSS sections

Conflicts found in the sections HVAC-CS and WSS-CS are associated with the location of technological openings. Due to the use of materials with different dimensions, the difficulty of their marking at an early stage of design is reflected in the fact of construction (Figure 7, 8). As a rule, conflicts of this kind are the most labor-intensive and costly.

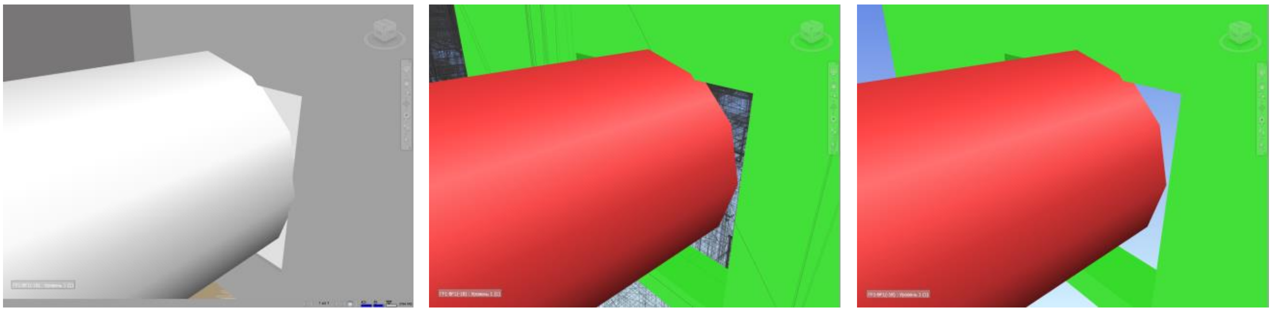


Figure 7 – Conflict when comparing sections of the HVAC-CS

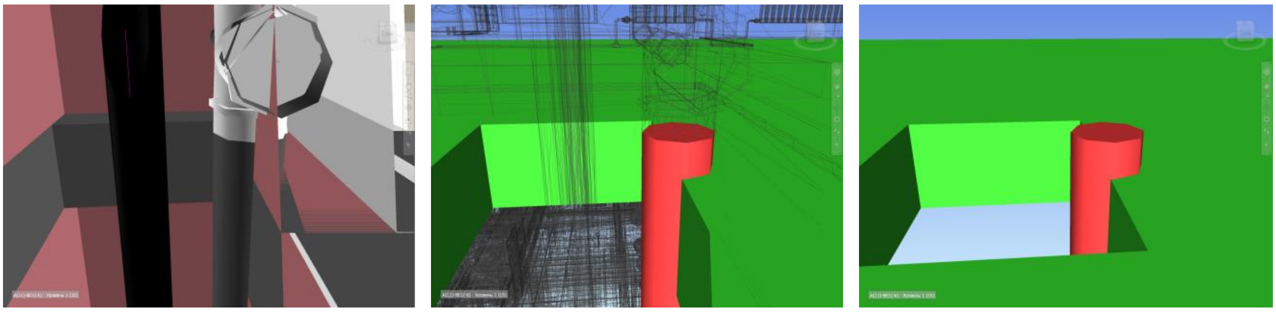


Figure 8 – Conflict when comparing the sections of the WSS-CS

The smallest risks are conflicts related to the WSS-HVAC, because of the ease and convenience of installation of ventilation ducts (Figure 9). In practice, the conflicts of comparison of sections of the WSS-WSS, which were described above, prevail (Figure 6)

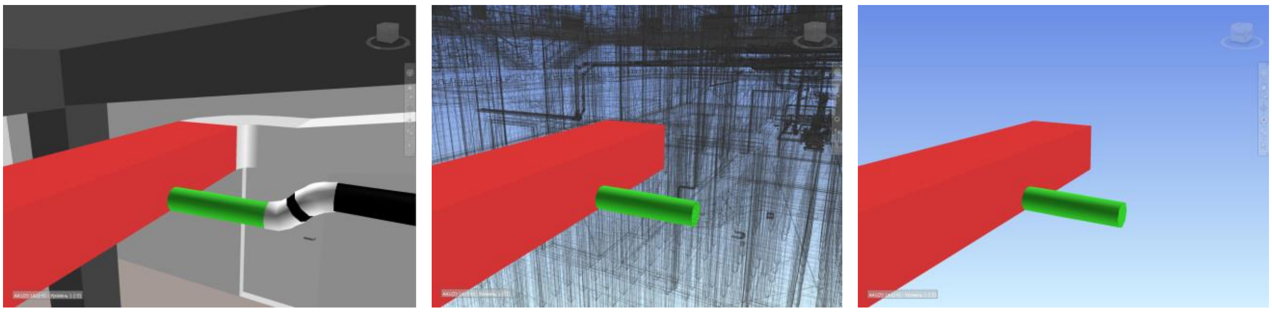


Figure 9 – Conflict when comparing WSS-HVAC sections

4. Conclusions

BIM technologies are part of the digitalization of the construction process. This is confirmed by the growth rate of construction, which requires versatile tools for the control of project documentation. The introduction of such tools helps to detect deviations in the design phase.

The analysis of the residential complex using AutoCAD NavisWorks showed the number of conflicts detected after the design documentation was merged into the virtual model. During the conflict analysis, attention was paid to the tolerance of deviations with respect to various combinations of the main sections of the design documentation. A review was made of some of them. It was noted that the process of finding conflicts is not yet so independent and requires improvement. To avoid possible errors, the virtual model should not be developed in parallel, but one at a time, to warn the designer of the inconsistency in the development of the subsequent section of the design documentation. This methodology will avoid disputes, reduce rework costs and save labor costs.

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Article

Influence of architectural and planning solutions on fire risk in public buildings

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Abstract. This article is devoted to the study of the influence of architectural and planning solutions on fire risk in public buildings. The calculation and assessment of fire risk was carried out on the example of one floor of a conditional office building with a free layout, where the tenant himself can change it at will. The input data for the calculation were two different layouts of the same floor, while the total square footage remained unchanged. As a calculation tool used the software package FireCat, which includes the programs Pyrosim, Pathfinder and FireRisk. The calculation took into account parameters such as the degree of fire resistance of the building, the number of rooms, the width and direction of door opening, the number of people on one floor of the building, including various mobility groups. Simulation modeling allowed to compare architectural and planning solutions for the same building and choose the best layout in terms of individual fire risk.
Keywords: fire safety, evacuation, architectural and planning solution, evacuation simulation, individual fire risk, FireCat.

1. Introduction

Nowadays, the rate of construction increases every year. For example, in spite of the COVID-19 pandemic, in 2020 in Kazakhstan the construction of residential buildings was allocated 1968 billion tenge, which is 33% more than in 2019 [1]. Such growth is caused by the increasing level of urbanization in the country, which inevitably entails the construction of buildings of higher storeys. In this regard, architectural and planning solutions in the construction of high-rise buildings become more complex, which makes the issue of fire safety relevant. One of the most important parameters, taken into account in the design of reliable and safe buildings, is the calculation of fire risk. According to the standard [2], fire risk - a quantitative characteristic of the possibility of realization of fire hazards and their consequences for people and property.

Timely evacuation from the building is one of the most important tasks for ensuring the safety of people in case of fire [3–6]. Preventing fire hazards in a building is accomplished by evaluating the individual fire risk, which is an indicator of the fire risk to human life. Individual fire risk (risk of death in a fire) is a quantitative characteristic of the possibility of death of an individual as a result of the effects of fire hazards [2-7]. Today there are many techniques to estimate this indicator, one of which is the use of specialized software that allows to quickly make the necessary calculations and provide a visual representation of the evacuation process [8–11].

As a rule, smoke and carbon monoxide poisoning, rather than flames, are the most common cause of death. This is about 70% of all fire deaths [12]. The cause of death in such situations is almost always improper operation of the facility in terms of fire safety, which leads to the inability to evacuate in a timely manner. Extreme conditions for evacuation, unpreparedness of people for a fire, ignorance of the evacuation plan, and often complex architectural and planning solutions of the building - all this negatively affects the time it takes to get out of the building when a fire risk occurs

[13–16]. Thus, more than half of the smoke victims die on the spot. About 42% of the victims are severely poisoned, of whom one in three subsequently dies [12-17].

The above statistics show that the problem of evacuating people in a fire is extremely urgent and must be solved at the design stage of the building. It is possible to evaluate the effectiveness of architectural and planning solutions for evacuating a large number of people by calculating the individual fire risk. This article is devoted to the research of influence of architectural-planning decisions on fire risks in public buildings by calculation of an individual fire risk on the example of an office building and comparison of the received results.

2. Methods

As noted earlier, in addition to the extreme conditions during evacuation, the choice of the wrong architectural and planning solution can be a negative factor. For this experiment, two building layouts were used: corridor and mixed.

2.1 Corridor planning scheme

Typically, public buildings such as hospitals, schools, and offices use a corridor layout (Figure 1). In this layout, the main element is the corridor, from which all rooms on the floor, as well as the elevator (if any) and the stairwell, can be accessed. Rooms are located on both sides of the corridor, which maximizes the use of usable floor space [18-19]. However, this layout is considered the least efficient in terms of evacuation due to the narrow corridor and lack of sufficient natural lighting. In this case, when there is a lot of smoke, people in the building may have problems with orientation. Another significant problem with this layout is the possibility of blocking one of the evacuation exits.

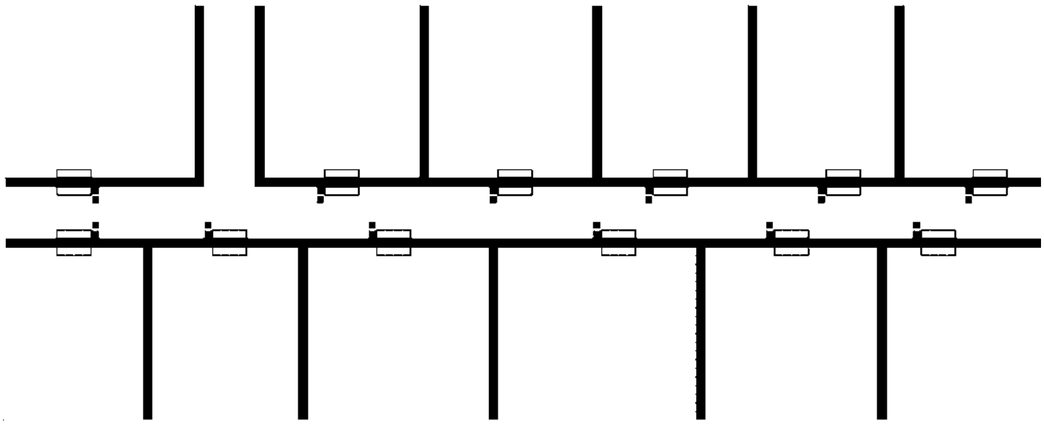

Figure 1 – Corridor architectural and planning scheme

This type of layout and its subsequent calculation of individual risk are chosen as a reference point for comparison with an alternative architectural and planning scheme.

2.2 Mixed-type architectural and planning scheme

Theoretically, the proposed architectural and planning scheme of mixed type, which is based on the corridor layout scheme, could be an alternative solution.

It is assumed that such a layout scheme makes it possible to avoid the disadvantages of the corridor layout with a relatively small reduction in the space used on the floor. For example, in the gallery layout, which is a variation of the corridor layout, the proportion of usable space that can be used is significantly reduced because the rooms are located on one side of the corridor axis.

In the proposed scheme, the rooms will also be located on both sides of the corridor opposite each other, but a large central space is provided in the middle of that corridor, with staircases and elevators at both ends of that hall (Figure 2). The presence of a central space is a feature of the centric layout [20], so the proposed layout can be called a mixed-type layout.

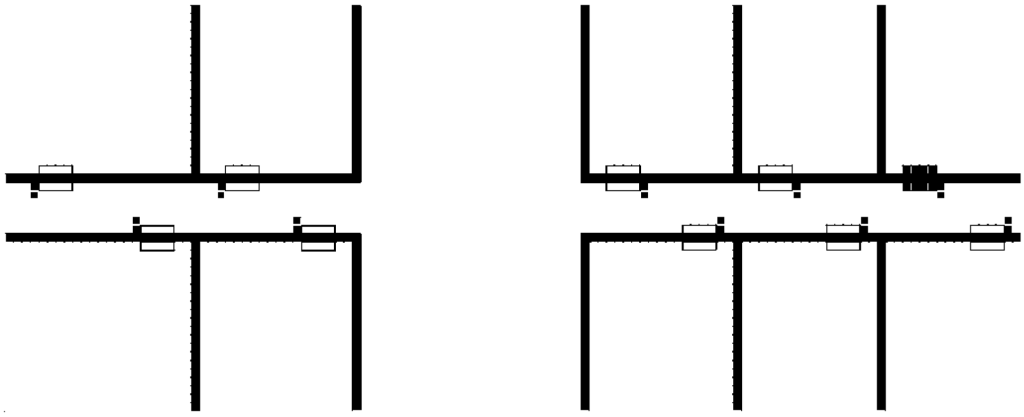

Figure 2 – Mixed-type architectural and planning scheme

Thus, in the case of evacuation, people will have the same access to the exits, which will be located in the central hall. Even if one of the evacuation exits is blocked, the distance to the other will be significantly less than in the case of the corridor layout. It is also assumed that the problem of lack of natural light in the corridors can be solved by the fact that windows can be installed in the central hall.

All of these factors indicate that a mixed-architecture layout can be effective from a fire safety standpoint and should be compared to the corridor layout type.

2.3 Description of the calculation object

The object for the calculation was a conditional office building with a free layout, located on the first floor of the building. These types of buildings are most often rented as open space, where the tenant has the right to choose their preferred layout of space. In this case, the total area of the space and the number of exits (two) remained unchanged (Figure 3). The width of each egress is one meter.

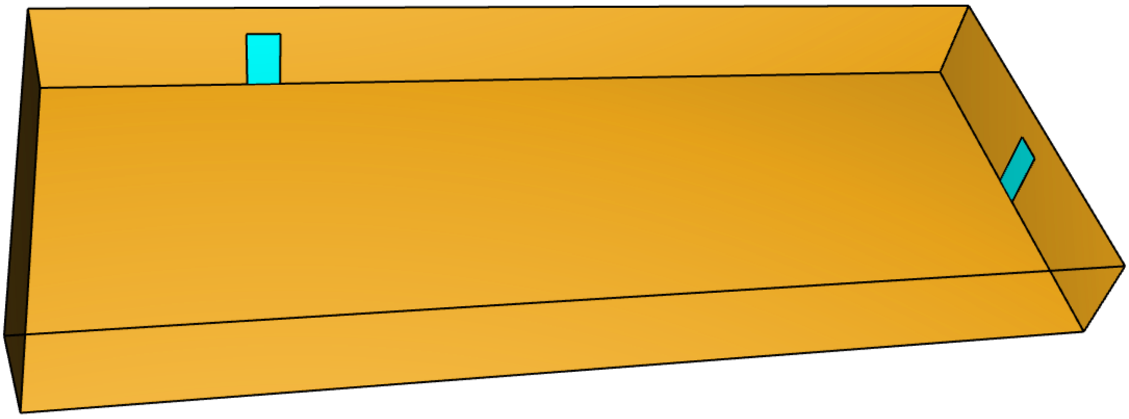

Figure 3 – General view of the room

General information about the building is shown in Table 1.

Table 1 – General information

Degree of fire resistance	II
Number of floors	5
Height of floors/premises	3 m
Distance to the nearest fire station	2 km
Facility operating time	12 h.

The building is equipped with a fire detection system, as well as a type 3 warning and evacuation control system. The building is not equipped with smoke ventilation system. There are no safety zones in the building. There is an automatic fire extinguishing system and it meets the regulatory requirements. There are people in the rooms at the rate of 6 m^2/person. The mobility group of all people in the building is healthy (mobility group M1). The building is not intended to be used by people with low mobility.

2.4 Description of calculation scenarios

Scenario of fire was chosen according to Methodical Recommendations on Estimation of Individual Fire Risk of Public Buildings, approved by the Minutes of Session of Scientific and Technical Council of MES RK from October 26, 2011 № 12, and also on the basis of data on volume-planning decisions, about the location of combustible load and people on the object. The calculation considers fire scenarios in which the worst-case conditions for the safety of people are realized. As scenarios with the worst fire conditions should be considered scenarios characterized by the most difficult conditions of evacuation of people and (or) the highest dynamics of growth of dangerous factors of fire (hereinafter - DFF).

In the case of a corridor-type layout, the fire occurs in the room near Exit 1 (Figure 4), the size of the fire source is 1·2.5 meters.

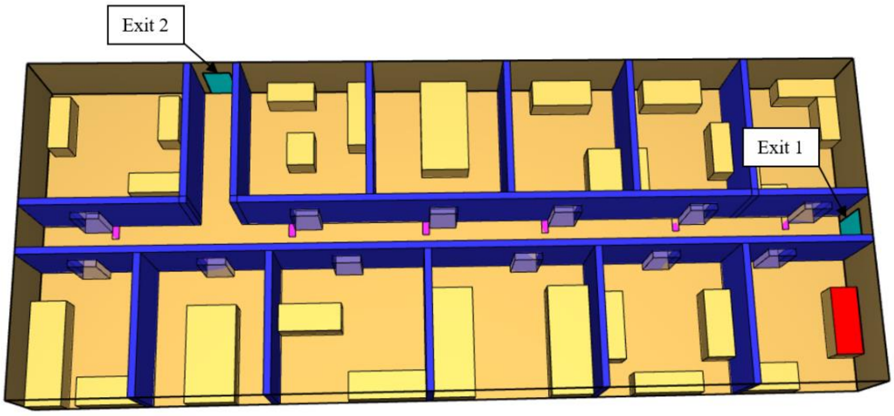

Figure 4 – Fire source emergence diagram for corridor planning scheme

The fire in the mixed scheme calculation occurs in the same area, but the location of the exits is different due to the use of the related of layout (Figure 5).

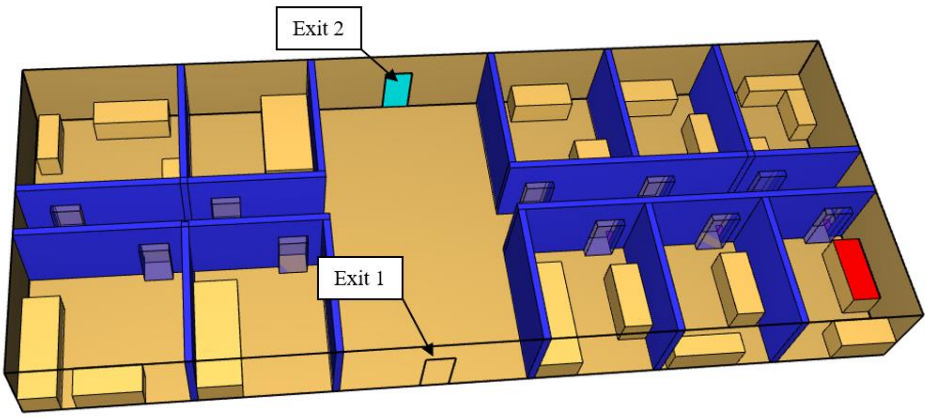

Figure 5 – Fire source emergence diagram for a mixed planning scheme

In both cases, when a fire occurs, smoke and other hazards enter the corridor and spread under the ceiling, forming a smoke layer, and descend, blocking the evacuation exits.

People from the fire room leave the room 6 seconds after the start of the fire and go to Exit 2, since the nearest Exit 1 is blocked by the fire hazards. People from other rooms start evacuating 90 seconds after the start of the fire, after receiving the signal of the alarm system, and move to Exit 2.

Calculation of the fire scenario is performed in the software package FireCat, which includes the following programs:

- PyroSim program for calculating the spread of hazards in a fire ;
- Pathfinder program for calculating the evacuation of people in a fire;
- FireRisk program to calculate the individual fire risk.

PyroSim program is a graphical interface for the program NIST: FDS 6, which implements a field model for calculating the propagation of DFF. This model is adopted for the calculation based on the following factors:

- The size of the fire source in the early stages of a fire is much smaller than the size of the room;
- Complex geometry of the object.

The Pathfinder program implements an individual-flow model for evacuating people. This model is adopted for calculation based on the following factors:

- People individually determine the path of travel;
- People flexibly choose which exit to evacuate through.

3. Results and Discussion

3.1 Dissemination of hazards

According to the results of fire hazard propagation calculations for the two layout models (Figure 6, 7), there are no significant differences in CO_2 emissions. This is not surprising, since the characteristics of the fire and its location remained identical. It is also worth noting that in the case of the corridor layout, the poisonous gas spreads further down the corridor, whereas in the mixed planning scheme, CO_2 accumulation is observed mainly near the fire location.

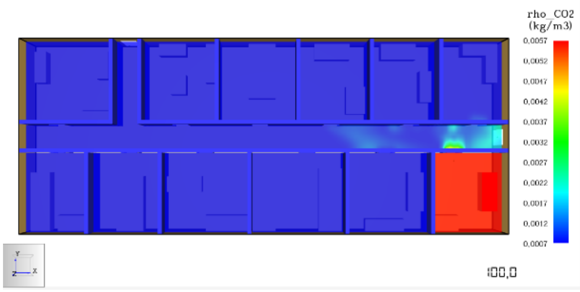

Figure 6 – CO_2 propagation pattern in a corridor layout scheme

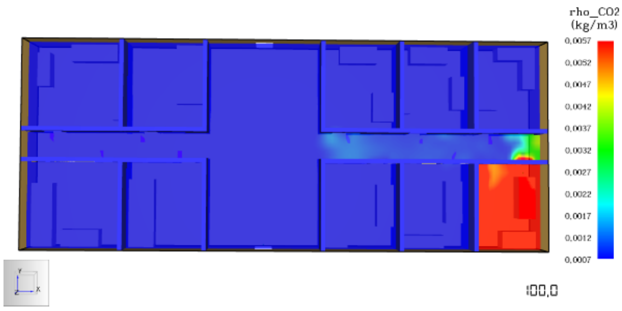

Figure 7 – CO_2 propagation pattern in a mixed layout scheme

A similar pattern is observed in the distribution of heat across the floor. In both cases, the heat release rates are comparable (Figure 8, 9).

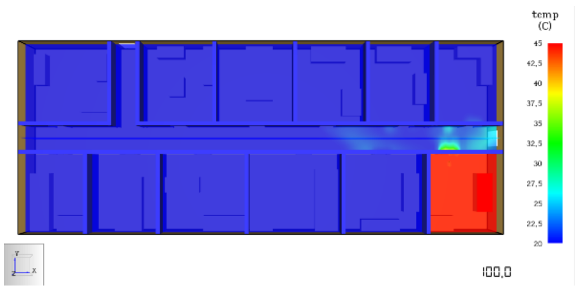

Figure 8 – Temperature propagation pattern in a corridor layout scheme

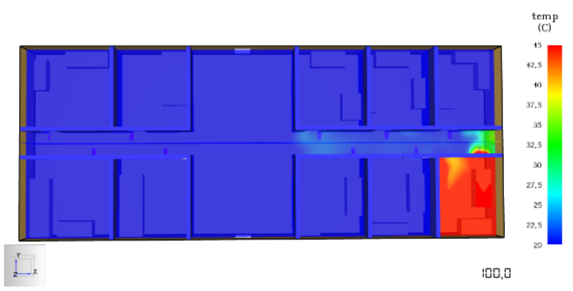

Figure 9 – Temperature propagation pattern in a mixed layout scheme

As the results of calculations of the allocation of fire hazards show, specifically in this comparison of the two layouts there are no serious differences.

3.2 Individual fire risk

According to Methodical Recommendations on an estimation of individual fire risk of public buildings, confirmed by the report of session of Scientific and Technical Advice of MES RK from October, 26th, 2011 № 12, individual fire risk for an object of calculation should not exceed an admissible value ($1 \cdot 10^{-6}$). Both calculation models do not exceed this value, and therefore the level of safety of people in case of fire meets the required one.

For the corridor layout, this figure was $0.75 \cdot 10^{-6}$, and for the mixed layout, it was $0.72 \cdot 10^{-6}$. The comparable figures indicate that the conditions of fire initiation and spread are similar. Theoretically, the results could be different if one of the models had a fire origin in a different location.

3.3 Evacuation simulation

Despite the similar results of the previous calculations, the main indicator of the effectiveness of the architectural and planning solution in this comparative analysis is the calculation of the evacuation of people (agents) on the floor.

Figure 10 shows a graph of the number of people remaining at each design point for the corridor layout – at the first moment in time, the graph shows the number of people that will pass through the design point during the simulation time, and at the following moments in time, the number of people not yet passed. At the moment when the number of people becomes zero, the evacuation through the design point is complete.

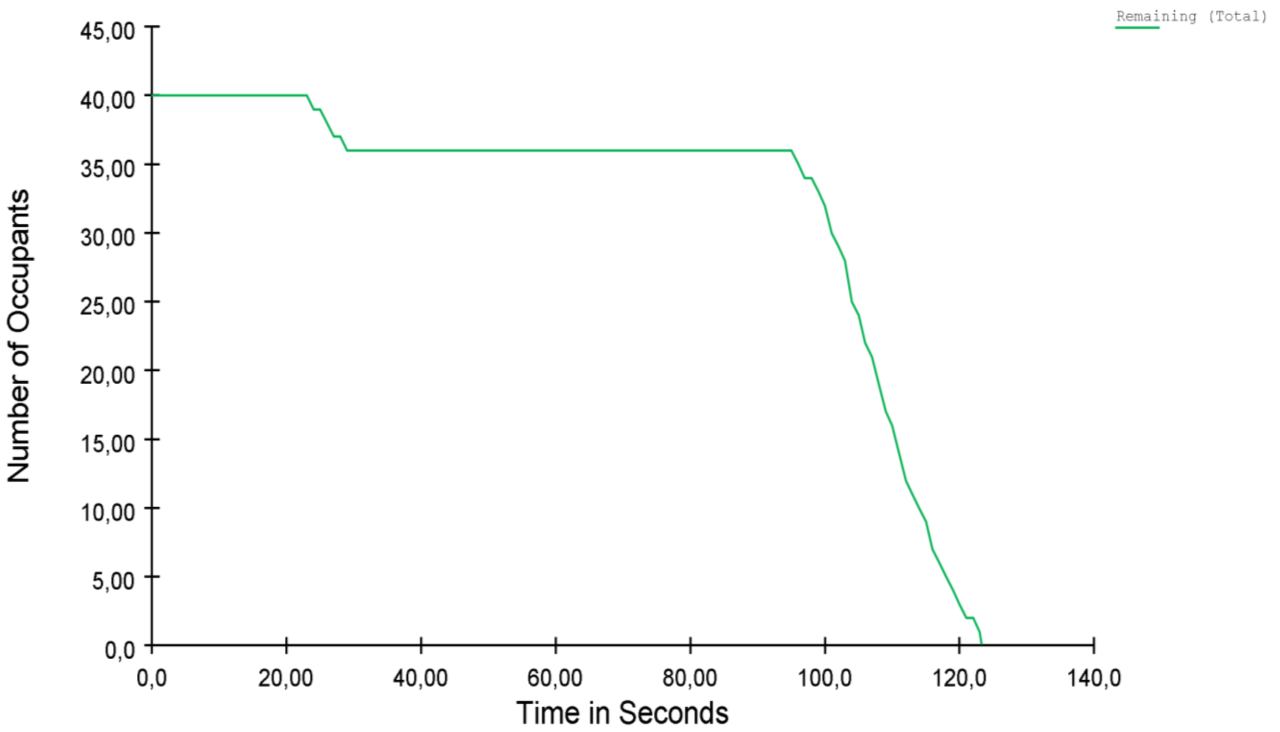

Figure 10 – Number of agents in selected rooms for the corridor layout

A total of 40 people participated in the evacuation, no non-evacuees. The total time taken for a complete evacuation was 123 seconds.

In the evacuation simulation case with the mixed plan layout, the results are noticeably better compared to the previous calculation. As in the first case, all 40 evacuees successfully left the building, but the evacuation time was 121 seconds, which can play a decisive role in a critical situation (Figure 11).

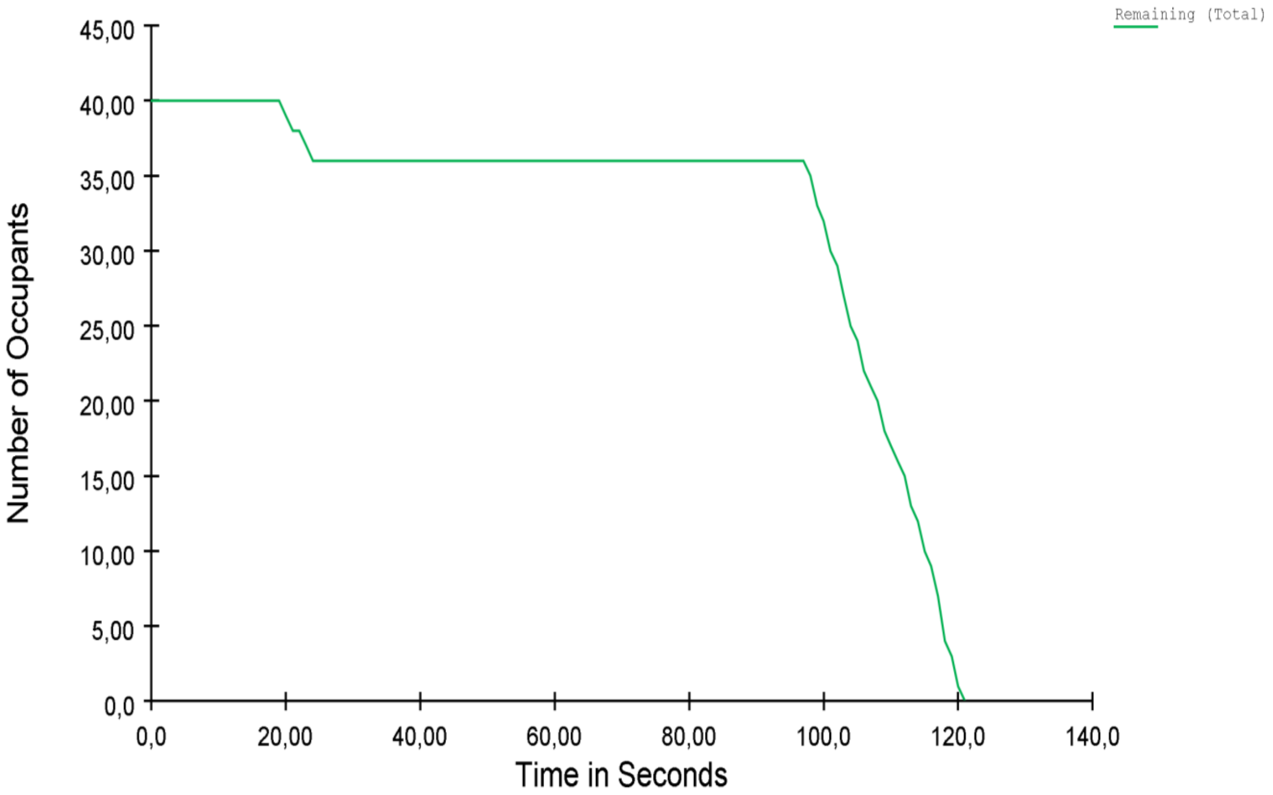

Figure 11 – Number of agents in selected rooms for the mixed-type architectural and planning scheme

During the simulation for the corridor layout, there was a large accumulation of agents in the corridor (Figure 12). This fact is due to the peculiarity of this type of layout. If one of the exits was blocked, agents would move from both sides of the corridor toward the nearest exit, which could cause difficulties for evacuation and crush. In the simulation it was avoided, but in practice it is likely that people evacuating will panic and the evacuation time will inevitably increase.

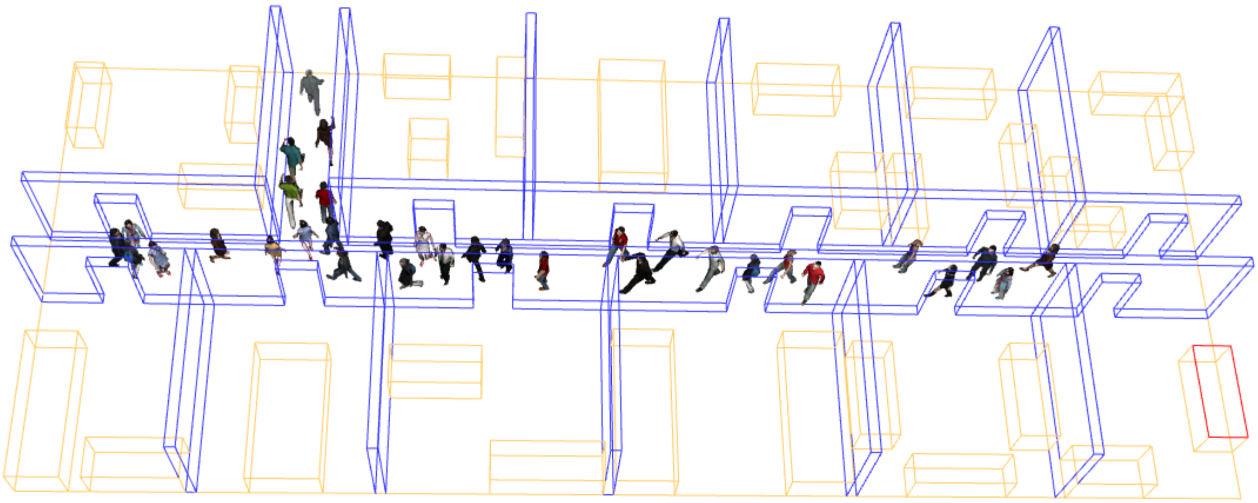

Figure 12 – Agent evacuation in corridor layout

In the agent evacuation simulation with the mixed layout there was no pandemonium, due to the presence of a central room. As in the first case, one of the exits was blocked, but it is more likely that panic will be avoided. The positive point is that the evacuation exits are located in the middle of the floor, which means that evacuation conditions will be equal for agents on both sides of the building.

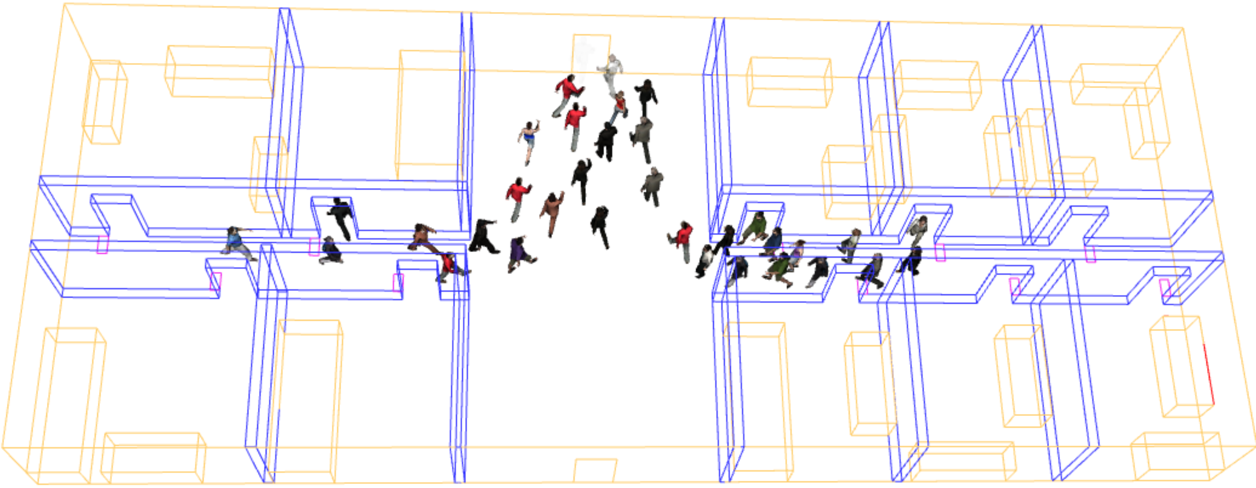

Figure 13 – Agent evacuation in a mixed layout scheme

4. Conclusions

In this article the influence of architectural and planning decisions on the fire risk of public buildings was investigated. On the example of an office building with a free layout were compared corridor and mixed layout schemes based on calculations in the software package FireCat. As a result, the following conclusions can be made:

1. The corridor layout makes the best use of the floor area of the building, but from a fire safety point of view, this solution is the least suitable;

2. The proposed mixed layout scheme has an insignificant loss of usable area at relatively high rates of fire safety;

3. The number of hazards in both cases is comparable due to the fact that the fire location and combustible materials are the same;

4. The individual risk score for the corridor layout type was 0.75-10-6, and 0.72-10-6 for the mixed layout type, indicating a preference for the latter.

5. In both cases, all agents were evacuated. The evacuation times for the corridor and mixed layouts were 123 and 121 seconds, respectively.

6. The mixed layout solves the problem of pandemonium in the corridor by having a central hall on the floor.

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