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EDITORIAL - Preface to Volume 13 Issue 1 of the Scientific Journal of Civil Engineering (SJCE)

Vladimir Vitanov EDITOR - IN - CHIEF

Dear Readers,

The **S**cientific **J**ournal of **C**ivil **E**ngineering (SJCE) is an international, peer-reviewed, open-access journal, initiated in December 2012, and distributed bi-annually. As of December 2021, SJCE has launched its dedicated website and transitioned to a fully digital platform for submission, review, and publication processes. For further details regarding the online edition of the Journal, kindly visit www.sjce.gf.ukim.edu.mk.

At SJCE, we are dedicated to publishing and disseminating high-quality, innovative scientific research across the broad field of engineering sciences. Our journal aims to advance technical knowledge and promote cutting-edge engineering solutions in civil engineering, geotechnics, surveying and geospatial engineering, environmental protection, construction management, and related areas. We strive to provide the best platform for researchers to publish their work transparently and comprehensively through our open-access model, offering a forum for original papers that address both theoretical and practical aspects of civil engineering and related sub-topics.

As the Editor-in-Chief of SJCE, I am delighted to present the first issue of Volume 13. This edition is entirely dedicated to our top graduates from the previous academic year. All the papers featured are authored by students and their mentors who received the best master thesis award across various study programs at the Faculty of Civil Engineering in Skopje. These award-winning students were invited to contribute a research paper for this issue of the journal.

The first paper highlights the importance of multicriteria analysis (MCA) in railway decision making, detailing its principles, challenges, practical applications, and future prospects for evaluating complex alternatives considering multiple criteria and stakeholder perspectives. The second paper investigates the potential of using wood biomass ash to partially replace cement in concrete, examining its effects on the mechanical properties of fresh and hardened concrete to reduce environmental impact and material costs. The third paper focuses on using terrestrial and UAV photogrammetry to create comprehensive spatial models for the digital documentation and long-term preservation of cultural heritage. The fourth paper examines how varying seismic hazards, defined by peak ground acceleration (PGA), impact the behavior and reinforcement requirements of reinforced concrete structural elements in North Macedonia, emphasizing the need for careful design in seismically active areas. The final paper in this issue conducts a hydrological analysis of the Crn Kamen river basin using GIS, SWAT, and HEC-HMS models to assess surface runoff and flow characteristics, supporting the planned construction of the “Lukovo Pole” reservoir.

We congratulate our students for the fine work they have done and we hope that they will contribute much more in their research field in the future.

I also express heartfelt thanks to all our contributors, reviewers, and readers for making this issue possible.

Sincerely,

Vladimir Vitanov, Editor-in-Chief

July 2024

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APPLICATION OF DIFFERENT CRITERIA FOR CHOOSING AN OPTIMAL RAILWAY LINE

Multicriteria analysis (MCA) has emerged as a valuable tool in railway decision making, enabling stakeholders to evaluate complex alternatives considering multiple conflicting criteria. Railway systems involve diverse and interrelated aspects, such as safety, efficiency, environmental impact, and cost – effectiveness.

This paper explores the application of MCA techniques in the context of railway decision making. First, it presents an overview of the key principles and methodologies of MCA, next, it explores the specific challenges and considerations when applying MCA in a real – world example of a railway decision-making, and lastly, the paper concludes with a discussion on the future prospects and emerging trends in MCA for decision making.

In summary, this paper emphases the significance of MCA in addressing the complexity of railway decision making by considering multiple criteria and stakeholder perspectives. It underscores the practical relevance of MCA methods, highlights challenges, provides examples, and explores future directions for the application of MCA in railway domain.

Keywords: designing, multicriteria analysis, Simple Additive Weighting (SAW), Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE), multicriteria optimization (VIKOR)

1. INTRODUCTION

The construction of infrastructure facilities begins with planning and design, an important process that anticipates needs and challenges that may arise during the construction and operation of the facility. Responsible planning and design helps to reduce investment costs and is a necessary part of the successful construction and operation of infrastructure facilities.

The design process focuses on solving problems in the urban environment by building new infrastructure, reconstructing the existing one or improving its management. Generating different variants, evaluating their advantages and limitations, and choosing the best solution are part of the process, the goal of which is to find an efficient solution to the problems in the environment.

Modern railways have many objectives to satisfy, including capacity, movement speed, transportation comfort, economic efficiency and protection of the environment. Some objectives require maximum values such as capacity, safety and transport quality, while others require minimum values such as construction investment, operating costs, travel time, construction time and environmental impact.

These goals are expressed in different ways – some quantitatively, others qualitatively, some in monetary values and others in time or evaluative parameters. This diversity of goals shows that the process of making a decision for the best solution is very complex.

In order to make the best solution, it is necessary to apply a complex and multi-step optimization process. First, a set of realistic variant solutions for the route is formed. Then, these solutions are evaluated according to the set criteria. The solutions are then ranked according to their value. Finally, they are analyzed and the most favorable solution for the route is selected.

Therefore, the purpose of multicriteria methods is to help in the decision making in choosing the best solution, or even to shorten the list of better solutions.

2. SUBJECT OF RESEARCH FOR THE APPLICATION OF MCA

The subject of research in this paper is the conceptual solutions for a railway line in Macedonia, between the city Strumica and the Border crossing to Bulgaria. Every solution will be analyzed by three different methods for MCA and a critical comparison of the obtained results will be made.

Methods of multicriteria analyzes that will be applied in the analyzes are the method SAW (Simple Additive Weighting), the method PROMETHEE II (Preference Ranking Organization Method for Enrichment Evaluations), and the method VIKOR (Multicriteria optimization).

2.1 SIMPLE ADDITIVE WEIGHTING METHOD (SAW)

The SAW method is a very commonly used method. The problem we analyze with this method is defined by setting different weight values for different criteria and evaluating them for each variant separately. The process of analyzing with the SAW method takes place in six steps:

Step I: Defining the criteria – in this step, the criteria according to which the variant solutions are evaluated will be defined.

Step II: Assigning weight coefficients – in this step, different weight coefficients are assigned for different criteria. This means that each criteria contributes differently in the final decision. In this case, the weight coefficients are determined with an anonymous survey of various experts in the considered areas.

Step III: Normalization of the values – in this step, we reduce the criteria to the same measurement unit as they would be comparable to each other.

Step IV: Evaluation of variants – in this step, we evaluate each variant according to each criteria.

Step V: Weighting sums – in this step, we multiply the normalized values of the criteria by the weight coefficients for each variant separately.

Step VI: Ranking – in this step, each of the variants is ranked according to the results obtained from the weighting of the sums.

The Simple Additive Weighting method offers a quick, direct and accurate way to rank multiple variant solutions. It is important to note that this method is very simple and that in itself gives some weakness. The weakness is that this method alone cannot determine whether the criteria being evaluated are dependent and related to each other. And if the user of the method does not establish it manually, the results with this method will lose their relevance.

2.2 PREFERENCE RANKING ORGANIZATION METHOD FOR ENRICHMENT EVALUATIONS (PROMETHEE)

PROMETHEE takes into account both positive and negative evaluation characteristics. It involves taking into account every advantage and every shortcoming of each of the variants that we analyze. In this variant of the method, the decision maker begins by identifying the relevant criteria for evaluating the variants. These criteria can be objective factors such as construction costs, construction duration, and subjective factors such as environmental impact and user satisfaction of the variant.

Once the criteria are determined, the decision maker defines preference functions to represent their preferences for each criterion. These preference functions can take different mathematical forms depending on the preferences of the decision maker and the nature of the criteria.

Next, the decision maker performs pairwise comparisons between each pair of alternatives on basis of each criterion. Comparisons are made using preference thresholds, which quantify the strength of preference. These preference thresholds are usually set by the decision maker.

By comparing the alternative pairs, the decision maker estimates the difference between them for each criterion. Positive flows indicate the superiority or benefit of the alternative over another, while negative flows indicate disadvantage.

After the currents are determined, the method calculates the advantages (in positive and negative sense) that measure the degree of dominance of one alternative over another. These calculated advantages take into account all criteria simultaneously and provide a comprehensive evaluation of the variants.

Then, based on the calculated advantages, this method generates a ranking of the variants. The ranking reflects the overall advantage or superiority of one alternative over another, taking into account positive and negative characteristics. The scorer can then interpret the ranking and make a decision based on the information provided.

2.3 MULTICRITERIA OPTIMIZATION (VIKOR)

VIKOR is a method for multicriteria optimization or multicriteria decision making. The method was developed by Serafim Opricovic for solving problems in decision making with conflicting and diverse criteria, assuming that the compromise is acceptable for resolving conflicts, that the decision maker wants a solution that is closest to the ideal and the alternatives are valued according to all the set criteria. VIKOR ranks the variants (alternatives) and determines the compromise solution that is closest to ideal.

This method focuses on variant ranking and selection in the presence of conflicting criteria, while using an ideal point as a reference point in the criterion function space. However, there is no variant that simultaneously satisfies all the criteria, so an admissible solution that is closest to the ideal in the space of criteria functions is sought. The solution that is closest to the ideal is called a compromise solution based on the adopted deviation measures.

3. DESCRIPTION OF VARIANTS

The route of a railway line in situation and longitudinal profile is subjected to strict design criteria of a safety and functional character. In order to connect Strumica with Bulgaria, through the “Novo Selo” border crossing, three variants have been created that are guided through fairly flat land with small height difference and they keep all the current standards for designing railways in Macedonia.

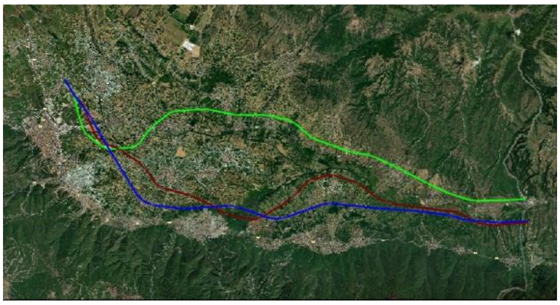

Figure 1. Situation of the three variant solutions Strumica – Border crossing

During the design of the three variants, all the design requirements are met including: maximum longitudinal slope 25‰, minimum radius of horizontal curve 300m, minimum radius of horizontal curve in station 500m, minimum intersection 150m, maximum longitudinal slope in station 1,5‰, interstation distance from 6 to 16km, minimum station plateau of 800m, maximum longitudinal slope in tunnel with lengths over 500m, 14‰.

It is important to note that when designing these three variants, the specified design conditions are oversized because the location conditions allow it, and they positively affect the comfort and long-term exploitation of the line. In fact, every designer aims to avoid the specified minimum parameters because the outcome is positive on a long-term level.

3.1 VARIANT 1 – RED

The starting point is the city of Strumica. Of course, a railway line to the city of Strumica has not yet been implemented, therefore, for all three variant solutions, a common initial railway station in the city of Strumica has been designed. The railway station is positioned 200 meters above the sea level. Specific to this variant is that the route follows the course of the Strumica river all the way to the border crossing itself. Starting from the thought that the flow of calm river naturally moves along the gentlest slope of the terrain, it is enough to follow the course of the river as a variant solution. The assumption is that the gentle slope of the terrain will have a positive effect on the longitudinal slopes of the route and most of the earthworks will be avoided. Of course, as can be concluded from the situation, the course of the river is not straight and with precise horizontal curves, so even during the design of the variant, the course of the river is taken as an orientation guide and it suffers major changes on the route. Along the route, two railway stations are planned apart from the starting and ending ones. The reason why only this variant has two stations unlike the others that have one station and one interchange is because this variant passes through several settlements. The variant solution ends with a train station in the immediate vicinity of the border crossing.

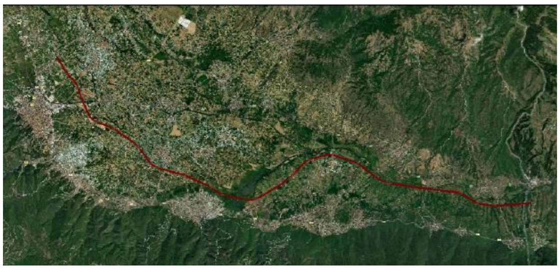

Figure 2. Variant route solution – Variant 1 – Red

3.2 VARIANT 2 – GREEN

The second variant solution is also specific in its own way. Unlike the first solution, where the direction of the route was the course of the river Strumica, in this case it is the main road A4 that leads to the border crossing “Novo Selo”. In terms of planning, the most efficient use of time is the application of already existing results. In this case, we know that the planners who designed the A4 highway did the same in order to take advantage of the most favorable conditions. If we follow that path, we know that most likely the route will go through the most favorable location. Starting from the common intended starting station in the city of Strumica, the route is in constant parallel movement with the main road, at a decent safety distance. The route, besides the starting station in the city of Strumica and the final station in the immediate vicinity of the border crossing “Novo Selo”, has one more station and one junction.

Table 1. Basic data for Variant 1 – Red

Route length	30,938.64m
Design speed	120km/h
Official slope	9.8‰
Minimum turning radius	800m
Number of stations	4
Number of interchanges	0
Number of culverts	61
Number of tunnels	0
Number of bridges	1
Bridge length	850.00m

Figure 3. Variant route solution – Variant 2 – Green

Table 2. Basic data for Variant 2 – Green

Route length	30,342.32m
Design speed	120km/h
Official slope	18.3‰
Minimum turning radius	800m
Number of stations	3
Number of interchanges	1
Number of culverts	55
Number of tunnels	3
Length of tunnel 1	337.21m
Length of tunnel 2	550.00m
Length of tunnel 2	800.00m
Number of bridges	1
Bridge length	150.00m

3.3 VARIANT 3 – BLUE

The third variant solution is formed to pass through the foot of the mountain Belasica. The purpose of this solution is to avoid the "Strumicko Pole" valley, and thus all possible intersections with roads, rivers and streams. This solution is different from the other two and the goal is to compare whether it is better to bypass the basin (and with it the costs for all overpasses and underpasses) and avoid potential pollution on nearby populated areas or is it more acceptable to avoid large slopes in the mountainous area and better economic picture of the route. This variant, like the other two, starts from the common starting railway station and the entire route moves through the boot of Belasica mountain. Apart from the starting and ending station, this route has one more railway station and one junction.

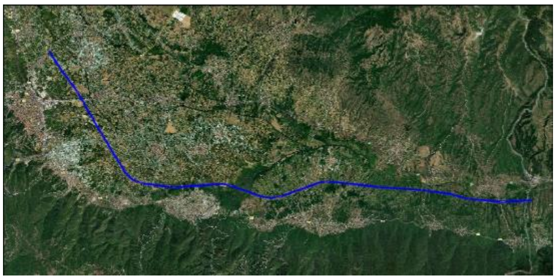

Figure 4. Variant route solution – Variant 3 – Blue

Table 3. Basic data for Variant 3 – Blue

Route length	30,222.48m
Design speed	120km/h
Official slope	17.2‰
Minimum turning radius	800m
Number of stations	3
Number of interchanges	1
Number of culverts	57
Number of tunnels	0
Number of bridges	2
Bridge 1 length	150.00m
Bridge 2 length	200.00m

4. APPLICATION OF MCA FOR CHOOSING THE MOST FAVORABLE OPTION

Before starting the analysis, it is necessary to determine the criteria by which the analysis will be performed. There is usually no limited number of criteria that can be applied to represent the characteristics of the studied phenomena. Applying a larger number of criteria does not necessarily mean that the analysis will be of higher quality. In order to choose a rational number of criteria, while not reducing the efficiency of the decision making process, it is necessary to apply the following principles when choosing criteria:

System principle – the selected criteria should represent the basic characteristics of the overall considered phenomenon;

Principle of consistency – one criterion should not include another criterion, i.e. the criteria should express the characteristics of the alternatives from a different point of view;

Principle of measurability – it is best if the criterion is measurable quantitatively, and if not, then it should be expressed qualitatively;

Principle of comparability – the decision maker will be able to make the decision more simply when the comparability of the criteria is obvious. In addition, the criteria must be normalized, so that they can be compared with each other because they are measured in different measurement units;

4.1 CRITERION 1 – ROUTE CONSTRUCTION INVESTMENTS

Investments for the construction of the route means all the financial investments of the investor for the performance of the construction works. This criterion is developed through pre-measurement and calculation. Estimates are made for all variants separately, the quantities for each position are taken, the cost prices of the positions are determined and the total cost of the route is formed. That actually represents an investment for the construction of the route. The final product of this criterion represents a quantitative value expressed in means of payment, usually millions of euros.

Table 4. Investment costs of all variant solutions

Variant 1 – Red	159,63 mil €
Variant 2 – Green	140,84 mil €
Variant 3 – Blue	86,10 mil €

4.2 CRITERION 2 – MANAGEMENT COSTS AND ROUTE MAINTENANCE AND TRAFFIC OPERATING COSTS

Companies that carry out transport should determine the prices of this type of transport service. The formation of costs and their analysis is usually done in two stages: first, the cost structure is defined, then each elemental cost is determined. The operating cost structure is usually grouped into the following segments:

Proportional costs that vary with kilometers traveled;

Fixed costs that are independent of the kilometers traveled in transport;

Direct costs that are related to newly offered services;

Table 5. Total costs for route management and maintenance

Variant 1 – Red	565.397,68 €
Variant 2 – Green	562.982,58 €
Variant 3 – Blue	562.497,23 €

4.3 CRITERION 3 – CONSTRUCTION – TECHNICAL CRITERION

Variant solutions of the route can also be evaluated based on construction – technical criteria such as lengths, heights to be overcome, slopes, number of stations and junctions, the percentage of the length of the route in objects, in curves, the size of the average radius etc.

For the technical comparison of the variant solutions for the route, in our case, one construction-technical criterion is used, because the road through which the route runs is quite flat, with a slight fall and a wide space for manipulation. In this case, if we were to apply criteria for overcoming heights, we would violate the integrity of the analysis because many unnecessary zeros would appear in the calculations. Therefore, in our case for this criterion we will use coefficient of the route in turns, because only that criterion is relevant.

Table 6. Coefficients from construction-technical criteria

Variant 1 – Red	0.3187
Variant 2 – Green	0.3062
Variant 3 – Blue	0.2278

4.4 CRITERION 4 – DURATION OF THE CONSTRUCTION WORKS

The criterion for the duration of the construction works is evaluated descriptively by ranking on a scale from 0 to 100, where a higher rating means a better ranking variant. The goal is to compare the construction works for the construction of the railway in the shortest possible period of time. The duration of construction works depends on several technical elements such as length of the railway track, number and total length of bridges and tunnels, amount of excavations and embankments, accessibility to the location.

Table 7. Ranking of variants according to criterion – duration of construction works

Variant 1 – Red	84.05 points
Variant 2 – Green	80.06 points
Variant 3 – Blue	85.27 points

4.5 CRITERION 5 – IMPACT OF THE ROUTE ON THE ENVIRONMENT

The basic information about the state of the environment and social conditions, in within the project environment, are based on data collected from direct communication with stakeholders, statistical data, project documentation, printed materials (strategic documents at national, regional and local level), visits to the project area, measurements of media quality and areas of environment (air quality, noise) etc. two types of data are most often used: directly collected data/measurements – refers to the sources of information collected directly in the project area, and indirectly collected data – refers to the data that has already been published/printed.

The use of this division in data collection serves to understand the concerns of local entities about environmental and social aspects, current social conditions and processes in the environment, cultural and social habits, as well as the socio-economic conditions of the residents in the project area, in terms of identifying potential impacts and how they can be avoided, minimized or mitigated.

In this paper, the criterion of the route's impact on the environment is considered by several key factors that contribute a different percentage to the final assessment, namely:

People factor (populated places and goods, noise and vibrations, emissions, recreational zones) which participates with 20% importance in the final assessment;

Flora and fauna factor (protected areas of international importance, protected areas of national importance, other important sensitive areas) which participates with 30% importance in the final assessment;

Soil and land use factor (agriculture, polluted areas, erosion) which participates with 5% importance in the final assessment;

Water factor (protected areas and use of water resources) which participates with 15% in the final assessment;

Air and climate factor which participates with 10% in the final assessment;

Landscape factor which participates with 5% in the final assessment;

Cultural and historical heritage factor which participates with 15% in the final assessment;

Table 8. Ranking of variants according to criterion – impact of the route on the environment

Variant 1 – Red	58.58 points
Variant 2 – Green	59.33 points
Variant 3 – Blue	55.67 points

4.6 DETERMINATION OF WEIGHTING COEFFICIENTS

After the selection of criteria that will be taken into account during the preparation of the MCA, a questionnaire is prepared regarding the weighting with weighting coefficients. The weighting of the coefficients was done using the Delphi method. This method is a systematic and interactive approach based of knowledge of independent experts. The method is based on the principle that the prediction of a group of experts is more accurate than the predictions of individual experts. The procedure consists in that, on two or more occasions, a group of well-chosen experts answers questions listed in a prepared questionnaire for selecting criteria. After each examination, the results of the selection of criteria with the reasons for their selection are submitted to all experts. In this way, it is suggested to the experts to create their previous selection of criteria taking into account the thoughts of the other experts from the group. This process stops when consensus or stable results are reached.

Table 9. Weighting coefficients table

C1	C2	C3	C4	C5
30%	26.15%	15%	16.54%	12.31%

4.7 MCA THROUGH SAW METHOD

In the very name of this method – Simple Additive Weighting, it is stated that this method is simple and we will not be wrong if we say that it is the simplest method for MCA. It is among the most frequently used methods and serves to make all kinds of decisions in everyday life, independent of construction.

Table 10. Ranking of variant solutions according to the SAW method

Variant	Points	Rank
Variant 1 – Red	0.811	3
Variant 2 – Green	0.831	2
Variant 3 – Blue	0.992	1

It can be seen from the table that the Variant 3 – Blue has the highest total and is ranked first, which means that when considering the given criteria and processing them with the obtained weight coefficients, it is recommended to choose the Variant 3 – blue in the process of further designing.

4.8 MCA THROUGH PROMETHEE II METHOD

The PROMETHEE method is much more serious method compared to SAW. This method exists for more than 40 years, and its reliability is evidenced by the constant improvement and creation of new versions of the method. The PROMETHEE method counts six versions covering different areas of learning and different approaches to valuations. In this paper, and as the most valid for our case, we will use the second method, PROMETHEE II, which represents a complete ranking of a given problem.

Table 11. Ranking of variant solutions according to the PROMETHEE II method

Variant	Sync index	Rank
Variant 1 – Red	-0.43	3
Variant 2 – Green	-0.11	2
Variant 3 – Blue	0.55	1

From the calculations made according to the PROMETHEE II method, the result was that the most favorable variant solution is the Variant 3 – Blue.

4.9 MCA THROUGH VIKOR METHOD

VIKOR is a method for multicriteria optimization or multicriteria decision making. The method was developed for solving problems when deciding with conflicting and diverse criteria, that the decision maker wants a solution that is closest to the ideal and that the alternatives are evaluated according to all the set criteria. VIKOR ranks the variants and determines a compromise solution that is closest to the ideal.

Table 12. Ranking of variant solutions according to the VIKOR method

Variant	Rank
Variant 1 – Red	3
Variant 2 – Green	2
Variant 3 – Blue	1

The results of the conducted multicriteria ranking using the VIKOR method show that the Variant 3 – Blue is the most favorable solution for all scenarios. Therefore Variant 3 – Blue is proposed as a compromise solution.

5. CONCLUSION

Analyzing the final results of all three multicriteria methods, it can be concluded that the Variant 3 – Blue is the best solution among the three offered solutions, according to all multicriteria analyses.

If a review is made of the practical application of the three methods for MCA, it can be concluded that they are a tool that is really of considerable help when the task is to make a decision to choose the most favorable variant solution in relation to several criteria. Regarding the applied methods, it is evident from the performed calculations that all methods give the same result, i.e. from the MCA carried out after all three considered methods, the result was obtained that the Variant 3 – Blue is the best variant compared to the other two depending on the different criteria which are taken into account.

Based on everything presented in this paper, it can be concluded that MCA, with proper definition and calibration, facilitate the process of designing and making a decision, a decision that benefits all parties concerned with the project.

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INFLUENCE OF THE WASTE ASH OF COMBUSTED WOOD BIOMASS ON THE PROPERTIES OF CEMENT MATERIALS

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The growing interest in saving materials and energy, in parallel with the growing concern for environmental issues and the uncertainty in the evolution of the economy, encourages the research for ways into full or partial replacement of the constituent elements of composite materials. Due to its many advantages, concrete is widely used composite, and in general, the most used material in construction. Being also the second most used substance (after water) in the world, it is inevitable that its impact on the environment is significant and unavoidable. Knowing that the production of cement clinker produces large amounts of carbon emissions worldwide, ways are sought to reduce the required amount of cement through the manipulation of other components of concrete. Thus, new materials can be added that would replace the cement and reduce the need for it. The focus is placed on materials that are usually leftovers from other industrial processes and have no other purpose, so they end up in a landfill. The ash obtained from the combustion of wood biomass is a material that is a good candidate for researching its potential to replace cement in cement composite materials. The ash obtained by burning wood biomass is a material that is often thrown away or used in small quantities for individual household needs.

The aim of this paper is to investigate the influence of the different percentages of ash in relation to cement, on some of the mechanical properties of fresh and hardened concrete: consistency, content of fresh concrete, compressive strength and density at the age of concrete of 3, 7 and 28 days. By increasing the amount of ash, and thus decreasing the consistency of the fresh concrete, insignificant differences are observed in the measured pore content and density of the samples. Compressive strength shows decrease with increasing amount of ash.

Keywords: cement, carbon emissions, consistency, bulk density, compressive strength

1. INTRODUCTION

The research activity nowadays is significantly directed towards preservation of the environment by way of finding alternatives to the current destructive industrial processes. Given that each year the produced waste increases, and that it requires handling, the idea of circular economy has become gradually more popular, even in the construction sector. Concrete production, and specifically cement production are one of the main carbon emission contributors, hence the growing interest of finding replacement materials whose sourcing, processing and production would be less environmentally destructive. Economic benefit provides an additional stimulation for exploring the reusability of waste materials.

There have been multiple studies examining composite concrete with waste materials such as: rice husk ash [2], ceramic ash from ceramic sanitary waste [15], eggshell powder [14], basalt powder from quarries [9], marble waste [10] etc.

This paper, however, strives to add value to the research of composite concrete with waste wood ash, including, but not limited to studies from Akhter, [1], Chowdhury, [4], Siddique, [11], Štirmer, [12]. The aim was to investigate the influence of the different percentages of ash in relation to cement, on some of the mechanical properties of fresh and hardened concrete. Consistency, content of fresh concrete, compressive strength and density at the age of concrete of 3, 7 and 28 days were analysed and conclusions were drawn.

2. MATERIALS AND METHODS

The aim of the experimental research was to vary only the ash/cement ratio (0.05 to 0.20) and measure the consistency, porosity, density and compressive strength of the samples. However, the mixture produced at the 0.1 mark proved to be barely workable, which implied that yielding mixtures by further increasing the ash/cement ratio would be unfeasible. This imposed altering the initial vision of the experiment by preparing new mixtures where water would be added to achieve a desirable consistency of the mixtures.

Consequently, the mixtures where the water/binder ratio is kept constant are referred to as first round of tests, while the mixtures where water is added are referred to as second round of tests. The interpretation of the mixture nomenclature is shown in the following example: P5-S2, where P denotes a mixture with ash replacement, 5 represents the percentage of replacement, and S2 signifies the consistency class the mixture belongs to. The control mixtures are denoted with E.

1.1 ASH OF WOODEN BIOMASS

Ash obtained by combusting plain wood and wood products (bark, shavings, pellets, briquettes, chips) is a powdery substance with highly variable chemical composition. Its properties depend on geographical location, type and age of the tree, part of the tree (roots, stem, branches, bark, leaves), the industrial process through which the ash is obtained (burning temperature and contamination) and the condition of the wood before combustion (painted and/or varnished). Nevertheless, the most common oxides present in wood ash are CaO, SiO_2, Al_2O_3, Fe_2O_3, MgO, K_2O and NaO, which are also important compound oxides of cement, thus suggesting that wood ash could potentially be used as (partial) substitution for cement.

The ash for this experiment is obtained from a local bakery which burns beech wood for heating up its ovens, Figure 1. The cement used has a grain size of up to 0.09 mm, so the ash was also sieved through sieves with aperture size of 0.09 mm.

Figure 1. Beech ash

The ash was acquired on two occasions, and despite the difference in colour, the difference of chemical composition between the two samples was insignificant. The chemical composition of the ash was determined according to MKS EN 196-2:2014, [16]. The average results of the two samples of ash are shown in Table 1.

Table 1. Average chemical composition of the two samples of beech ash

Measured	%
Loss on ignition	31.72
SO_3	0.49
Insoluble residue	1.82
SiO_2	14.35
Fe_2O_3	1.84
Al_2O_3	1.08
CaO	39.14
MgO	4.27
Cl^-	0.09

1.2 SAMPLE PREPARATION

In the first round, three different mixtures have been prepared: a control one, and two with 5% and 10% ash replacement, respectfully. As previously stated, the percentage replacement could not be further increased due to the very low consistency of the 10% mixture, and the subsequent failed attempt at preparing a 15% ash replacement mixture.

Figure 2. Preparation of samples

In the second round, water was added to the concrete mixtures with the objective of producing concrete that falls within the range of the S4 consistency class according to MKS EN 206:2013+A2:2022, [17]. In the process of experimentation, mixtures which can be classified in both S3 and S4 consistency class were obtained. Subsequently, the samples were divided into two groups: G-S3 (control, 5%, 10% and 15% ash replacement) and G-S4 (control, 5%, 10%, 15% and 20% ash replacement).

The materials used in the preparation of the mixtures are: cement type CEM I 52,5 R with maximal grain size of 0.09 mm, crushed limestone (calcite marble) with three fractions (0-4 mm, 4-8 mm, 8-16 mm), water from public water supply, and superplasticizer which enables water reduction from 15% to 20%. All materials used in the experimental research are in accordance with the current standard for concrete production and definition of concrete as a construction product - MKS EN 206:2013+A2:2022, [17].

Figure 3. Fresh concrete samples for testing compressive strength

The compressive strength of the hardened concrete was tested on samples with dimensions 150 mm x 150 mm x 150 mm, in accordance with MKS EN 12390-1:2021, [18]. After being cast in moulds (Figure 3), the samples were cured in standard laboratory conditions, in accordance with MKS EN 12390-2:2019, [19].

1.3 TESTING FRESH CONCRETE

Assessing the properties of fresh concrete is of crucial importance for the production process

Figure 4. Consistency (slump) test

Figure 5. Pore content testing

since it can be an indicator of the properties of hardened concrete, and it also discloses the casting aptness of the concrete.

This experimental research explored the consistency, density and pore content of all the prepared fresh samples, following the requirements and procedures of MKS EN 12350-2:2019, [20], MKS EN 12350-6:2019 [21] and MKS EN 12350-7:2019, [22]. Consistency and pore content tests are presented in Figures 4 and 5, respectively.

1.4 TESTING HARDENED CONCRETE

Testing and proving the mechanical properties of hardened concrete is imperative for ensuring that the finalized concrete product meets the material requirements and ensures the safety of the structure.

In this experimental research, two properties of hardened concrete have been examined: density and compressive strength, in agreement with MKS EN 12390-7:2019, [23] and MKS EN 12390-3:2019, [24], accordingly. Both properties were tested on three samples from each concrete mixture, at concrete age of 3, 7, and 28 days.

3. RESULTS

The slump, pore content and average density of the 3 mixtures of fresh concrete of the first round of concrete preparation (control, 5% and 10% ash replacement) are shown in Table 2.

The results of the properties of fresh concrete for group G-S3 (control, 5%, 10%, and 15% ash replacement) from the second round of concrete preparation are shown in Table 3.

Table 2. Results of testing fresh concrete of first round of tests

Mixture	Slump [mm]	Pores [%]	Avg. den. [kg/m^3]	w/b
E-S2	80	2.6	2430	0.56
P5-S2	80	2	2420	
P10-S1	30	1.5	2420	

Table 3. Results of testing fresh concrete of second round of tests (group G-S3)

Mixture	Slump [mm]	Pores [%]	Avg. den. [kg/m^3]	w/b
E-S3	130	2.4	2430	0.57
P5-S3	150	2.6	2370	0.59
P10-S3	130	2.1	2380	0.59
P15-S2	90	1.8	2340	0.67

Table 4. Results of testing fresh concrete of second round of tests (group G-S4)

Mixture	Slump [mm]	Pores [%]	Avg. den. [kg/m^3]	w/b
E-S4	190	2.2	2370	0.6
P5-S4	190	2.6	2340	0.64
P10-S4	190	2.5	2360	0.63
P15-S4	170	2.4	2380	0.64
P20-S4	190	2.2	2350	0.67

The results of the properties of fresh concrete for group G-S4 (control, 5%, 10%, 15% and 20% ash replacement) from the second round of concrete preparation are shown in Table 4.

The development of the average density of the 3 samples of hardened concrete during concrete aging (3, 7 and 28 days) for both rounds of concrete preparation are shown in Figures 6-8.

The development of the average compressive strength of hardened concrete for 3, 7 and 28 days for both rounds of concrete preparation are shown in Figures 9-11.

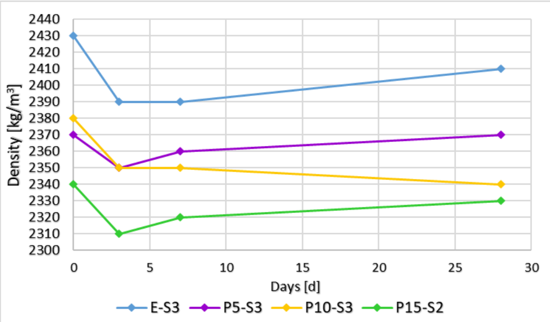

Figure 7. Average density of second round of tests (group G-S3)

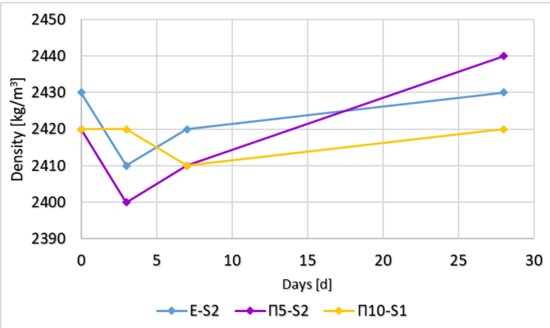

Figure 6. Average density of first round of tests

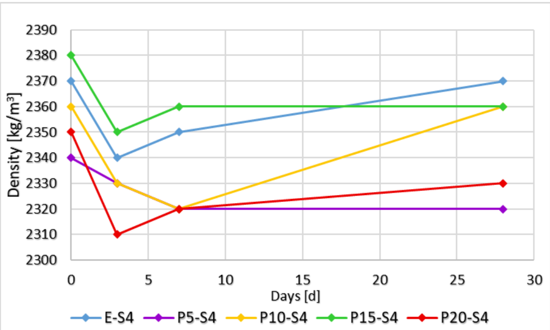

Figure 8. Average density of second round of tests (group G-S4)

4. ANALYSIS OF THE RESULTS

The chemical composition of the wood ash showed that the presence of CaO, SiO_2 and Al_2O_3 is lower than the usual content of these compounds in cement. Considering that these compounds are the forming blocks of the main minerals of the cement clinker, which influence the compressive strength, it could be suggested that this is a possible cause of the decrease in the concrete compressive strength. Also, the loss on ignition of the ash is 1/3 of its mass and 6 times higher than the limits for cement defined in MKS EN 197-1:2012, [25], which is caused by the higher content of water and CO_2.

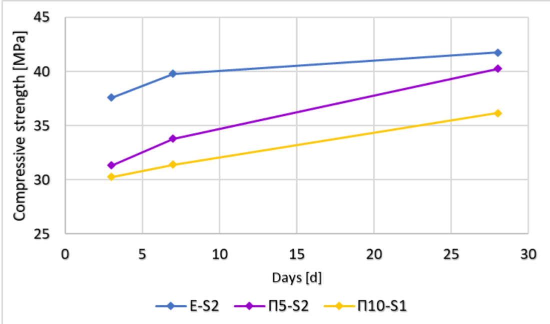

Figure 9. Average compressive strength of first round of tests

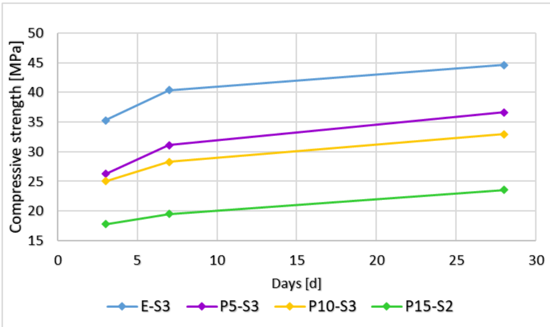

Figure 10. Average compressive strength of second round of tests (group G-S3)

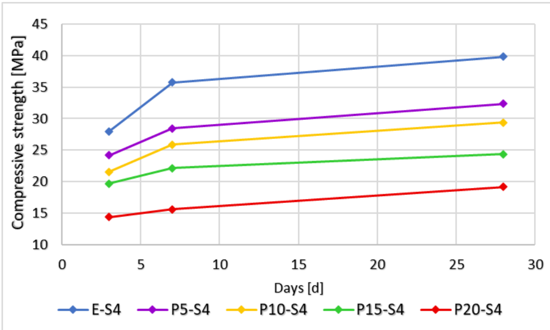

Figure 11. Average compressive strength of second round of tests (group G-S4)

From the first round of concrete mixtures, it can be noted that by increasing the ash content and keeping the water/binder ratio constant, the consistency decreases drastically after 5% ash replacement. The pore content of the concrete decreases steadily, with approximately 23-25% loss for each 5% ash content increase. The difference in density of fresh concrete is insignificant. The progression of density of the hardened concrete in time is characterised by a drop around the 3^{rd}-7^{th} day, after which there is a steady increase until the 28^{th} day. However, the density variations are trivial (up to 0.8% difference), and all the samples have normal density (around 2400 kg/m^3). The progression of compressive strength of the hardened concrete in time demonstrates decline with increase in ash content. However, the ash samples have a higher rate of strength increase compared to the control sample, which is most notable in the sample with 5% ash replacement.

From the second round of concrete mixtures, it can be discerned that in order to maintain the same consistency or the same class of consistency, an increase in the ash content also requires increase in the water content.

Furthermore, the timing of the addition of water is of crucial significance because the setting time of the concrete is sped up. This is the reason why sample P15 in group G-S3 has a lower consistency (i.e. lower consistency class) - the water was not added in a prompt manner. Concerning the pore content of the concrete, the results indicate that the pore content of the concrete increases at 5% ash replacement, otherwise it decreases up to 25% of the control sample. The density of concrete shows an inconclusive decreasing trend with increase of ash content; nevertheless, the density variations are negligible (up to 3.7% difference), and all the samples have normal density. The progression of compressive strength of the hardened concrete in time in this round of concrete mixtures complies with the progression in the first round, i.e. the compressive strength declines with the increase of ash content, and probably, to a large extent, this is due to the addition of water.

5. CONCLUSIONS

In this paper, the influence of partial replacement of cement with various quantities of wood ash has been examined. Properties of fresh and hardened concrete have been tested on mixtures with 5%, 10%, 15% and 20% replacement of cement with wood ash. The experimental tests have been conducted in compliance with the requirements of the current standards in the country.

From the obtained results, it can be concluded that partially replacing cement with wood ash causes decrease in consistency/increase in water demand and speeds up the setting time of the fresh concrete. The pore content and density of the concrete do not have significant variations, as all concrete mixtures have normal porosity and normal density, accordingly. In contrast, the compressive strength of the concrete decreases, and special attention should be paid to the amount of water added.

The application of this composite would be most acceptable in non-bearing structure elements. Nonetheless, more research is needed to establish the right interconnection between the ash and water content. Additionally, further research about tensile strength, creeping, water permeability, freeze and thaw resistance etc. should be conducted.

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EVALUATION OF TERRESTRIAL AND UAV PHOTOGRAMMETRY FOR CONSERVATION AND DOCUMENTATION OF HISTORICAL HERITAGE OBJECTS

In this paper, the emphasis is placed on the implementation and integration of terrestrial and UAV photogrammetry to obtain a complete spatial model. The protection of cultural heritage is always a serious challenge for all countries, a task that requires the mobilization and coordination of many different human and material resources from several sectors. The possibility of rematerializing the data as physical three-dimensional objects requires new research and in that direction the expected results are that the final product generated with a combined approach will be a plus step towards the digital documentation of the cultural heritage and its long-term preservation.

Keywords: UAV photogrammetry, terrestrial photogrammetry, LiDAR, photogrammetric software, cultural heritage, 3D models

1. INTRODUCTION

As a task for this paper, I chose to show the modernization, refinement and power of geodesy as a scientific discipline presented through increasingly advanced and powerful technology such as drones and the many new software applications that offer fast, accurate and efficient solutions. Today, there are numerous ways and technologies for transferring any object from the real world into the digital 3D space.

From day to day to see how technology continues to develop, one of the examples of this are such drones that are widespread and as such games significant in the process of planning, designing, performing, monitoring and reconstructing all the objects around us.

The use of digital photogrammetry for documenting cultural heritage creates a dynamic database and a valuable resource for a better understanding of the meaning of cultural heritage by end users who can access the information from a digital platform at any time.

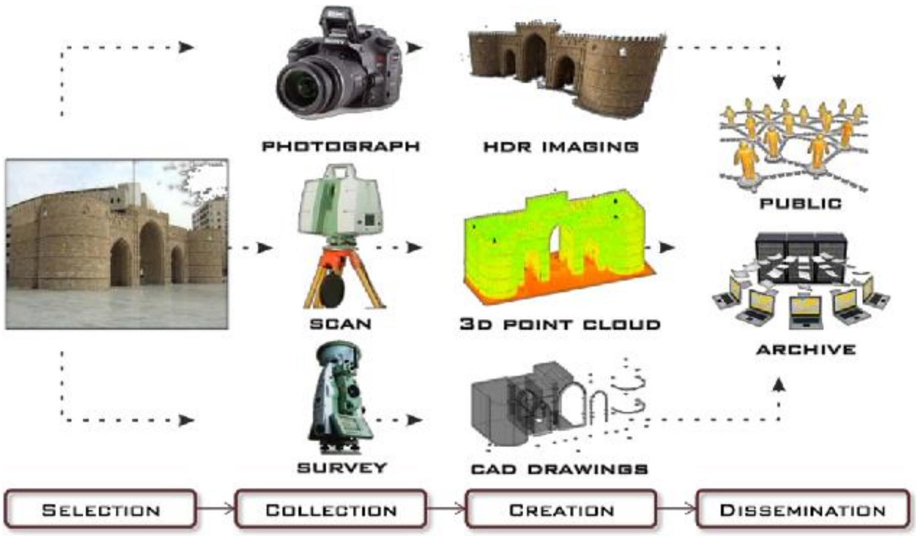

Figure 2. The process of digital reconstruction of cultural heritage objects using photogrammetry [1]

For this paper, the monitoring of a stone arch bridge from the Roman period was monitored in the village of Bogomila, Veles and it represents the cultural heritage of our country.

At the same time, a comparison and analysis of the obtained results will be made, which will be presented in this paper. The appropriate software that will be used to process the main task is of great importance, because it generates the results and data that we need to draw conclusions and opinions.

Several photo camera models with a combination of imaging and LiDAR sensors will also be implemented. In addition, more comparisons and analysis will be made of the obtained 3D models, which will also represent the final product.

1.1 STUDY AREA

The ancient Roman bridge (Figure 2) is located in the center of the village of Bogomila in the Azot region in the eastern part of the territory of the municipality of Čaška in the original catchment area of the Babuna river. It is placed in the northeast-southwest direction across the Babuna river, about 2 km from the railway station in Bogomila. The bridge belongs to the type of single-arch bridges and is classified as a significant cultural heritage site defined by the National Institution "Conservation Center" - Macedonia. The exact construction time of the bridge is not precisely determined. There is a belief among the people that the bridge dates back to the Roman period. It serves as a witness to the history of architectural development in our territory and as such is an important element for study in the context of scientific research on the development and peculiarities of construction in Macedonia. The bridge is a witness to the history of the development of architectural activity in our territory and as such is an important element for study in the context of scientific research on the development and peculiarities of construction in Macedonia. [8]

Figure 2. The oldest found image of the bridge [8]

1.2 PURPOSE OF RESEARCH

Of the numerous areas in which digital photogrammetry is used, I was most interested in architecture as a science that is close to geodesy in many aspects. So, the purpose of my research is to highlight the great importance of digital photogrammetry in architecture and the way it enables documentation for the needs of cultural heritage conservation. At the beginning of the research, I hypothesized that by applying digital photogrammetry, models of the objects that are categorized as cultural heritage, which are the subject of research can be obtained with satisfactory, high accuracy, and based on the models thus obtained, analyzes can be made for their possible displacements, damages and the possibility of their restoration, all in order to preserve them in

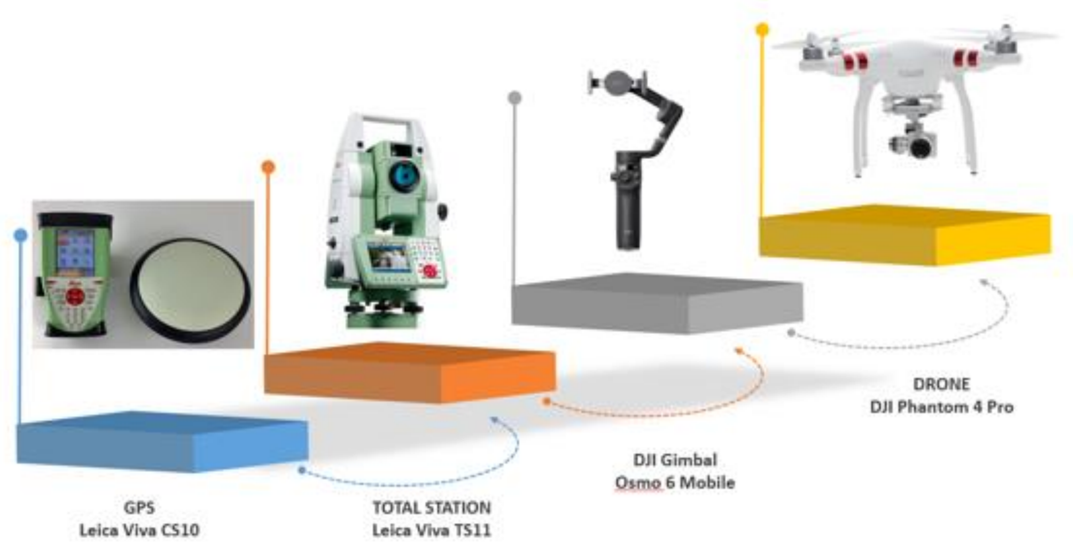

Figure 3. Geodetic measurement technology

their original state. During the creation of the practical example, several applications and software were used, such as Agisoft Metashape, Cloud Compare, Drone Deploy, etc.

2. GEODETIC MEASUREMENT TECHNOLOGY

The implementation of the practical part of the work includes field activities that include the use of various modern measurement technologies, such as the DJI Phantom 4 Pro drone with a 20 MP camera, the triple photo camera from the iPhone 14 Pro smartphone, the Leica Viva TS11 total station with a declared accuracy of 2 mm + 2 ppm and the Leica Viva CS10 GPS with a declared accuracy of 10 mm + 2 ppm for the static method and 20 mm + 2 ppm for the kinematic method. The drone is used to capture high-resolution aerial imagery of the bridge with flight paths strategically planned to achieve thorough coverage from various angles and elevations with support of Drone Deploy platform. Meanwhile, the smartphone camera is employed for capturing detailed close-up images of specific architectural features of the bridge, providing additional visual data for analysis. The GPS device and total station contribute to precise positioning and geo referencing of both the imagery and survey data, guaranteeing spatial accuracy throughout the reconstruction process.

3. GEODETIC MEASUREMENTS

Obtaining comprehensive and precise data, as well as creating a precise digital model with high-resolution detail, presents a challenge for every geodetic professional. It requires the use of a combination of terrestrial and aerial surveying methods, often utilizing advanced technologies like LiDAR or photogrammetry. [6] Given that it is a specific engineering object and an object where there is a greater height difference in the terrain around the object, a plan was made that included all significant changes in the terrain in terms of height in order to obtain a realistic model and a realistic representation of the field. The bridge was covered or recorded in such a way that a combination of terrestrial photogrammetry and unmanned photogrammetry was made. This method of combination gives quite accurate results as well as excellent visualization of all characteristic objects, especially objects that are under historical cultural heritage.

For geo referencing the 3D view from the photogrammetric recording, GNSS technology Leica CS10 was used in support of the MAKPOS permanent stations of the cadastre agency. After the acquisition of the data, it will be processed using different software: initially with Agisoft Metashape to obtain a cloud of points (Point Cloud), then the same cloud of points can be transferred to the software Cloud Compare, as well as to AutoCad Civil3D. It is practically shown how to get a complete 3D view of a specific object, in this case a bridge, and it is of historical and cultural importance. At the same time, to show that the same method is quite precise, accurate and economically viable, as well as to prove these claims through a series of analyzes and comparisons where data obtained by different methods will be used.

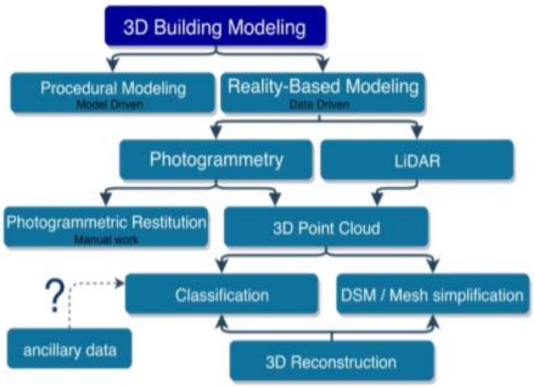

Figure 4. Process of obtaining 3D model [4]

3.1 3D MODEL FROM TERRESTRIAL AND UAV PHOTOGRAMMETRY

According to my analysis and knowledge of the terrain, I decided that the height of the flight should be 50 m, so I made a plan to place 13 markers for orientation points, namely 5 markers that are placed on the roadway of the bridge itself, that is, on the base of the bridge and around it, while the other 8 markers are placed laterally along the surface of the entire bridge and in its arc area in order to obtain better homogeneity and the most realistic display. The average longitudinal and transverse distance of the orientation points placed on the ground is about 10 m, while for the markers placed along the entire bridge it is 5 m. The markers that are placed on the ground have a square shape of 50 x 50 cm and were recorded using a GNSS Leica CS10, and the remaining 8 markers that are placed on the entire bridge were recorded using a Leica Viva TS11 total station, which will give the model coordinates in the state coordinate system.

Figure 1 Figure 5. Ground control points used in field measurements

Photogrammetry recording is supported by the Drone Deploy mobile app, which is designed and customized for the DJI Phantom 4 Pro.

First, the markers that are needed to perform the aerial photogrammetric recording are placed and they are later used as orientation points for geo referencing the model. Two markers were placed on the roadway, two before and after the bridge, and one marker was placed in the canal next to the bridge, that is, at the lowest point of the bridge, which made a correct layout and the average distance from marker to marker is about 10 meters. After the markers for the aerial photogrammetric survey are provided, the markers for the needs of the terrestrial surveys are placed next. Those markers can be said to have been placed laterally along the entire lateral surface of the bridge as well as inside the arch (arch) of the bridge. For that whole, 8 markers were placed and their average distance was about 5 meters. The coordinates of these markers were obtained by measurements using a Leica TS11 total station, thus the station and orientation points were obtained with a GNSS device. The dense network of markers placed on the surface of the bridge and around the bridge is all in order to get the best possible accuracy, that is, to be visible as many markers as possible from as many camera positions as possible. With that, the model gets more power and reliability. The coordinates of these markers were obtained using a GNSS device Leica Viva CS10 with the help of the permanent stations from the MAKPOS system, using a set of parameters for that area.

After recording the orientation points with the GNSS device and the total station, the same markers remain in their positions and the aerial photometric recording is started with the help of the drone. The flight is supported by the Drone Deploy mobile application (Figure 6), which is compatible with DJI drones, and the application itself offers many possibilities and recording methods. With the given parameters, the application gives the recorded pixel size of 1.1 cm/pix, which is sufficient for the required

Figure 6. Flight plan and parameters

research. The flight lasted about 6 minutes and 82 photos were collected. With these phases, the aerial photogrammetry recording is completed and the acquisition of terrestrial images is moving on. The terrestrial photos were provided using a triple camera with a fairly high resolution from the iPhone 14 Pro smartphone. At the same time, the smartphone was fixed to a DJI Gimble Osmo 6 hand-held movable tripod, which provides stability and fixation of the camera during photography. This gives better insight into the camera positions from which the recording is being made and care is taken to have a satisfactory overlap between all subsequent images. In this way, 100 photos were taken for which the geographical coordinates determined through the GPS of the smartphone itself are known.

3.2 3D MODEL FROM LIDAR SCANNING WITH SMARTPHONE

The other example of obtaining a 3D model of the bridge is by collecting scans that will serve to form a dense cloud of points. This was realized with the help of the LiDAR sensors that are present in the iPhone 14 Pro smartphone. The goal is to analyze what accuracy would be obtained in this type of data acquisition by using the orientation points placed on the bridge that were recorded with a total station for georeferencing this cloud of points. Collecting the scans was quite simple and was done from multiple positions. As we mentioned, for this example it was enough for us only the iPhone 14 Pro smartphone fixed to a DJI Gimble Osmo 6 handheld mobile tripod. The smartphone camera itself has built-in LiDAR sensors that can be used through the 3D Scanner application (Figure7) to collect scans and form on a cloud of dots. Two independent scans were made, that is, the entire bridge was covered but in two parts with two scans and they are in a local coordinate system. Interestingly, the app instantly generates a dense cloud of points based on the images at the moment. The same scans can be exported in .las format and processed in appropriate software.

Figure 7. Use of 3D Scanner App

4. RESULTS AND DISCUSSION

To start the process of obtaining a 3D model through the software, it is necessary to go through several stages that we have already mentioned. Each stage of production must take place in a certain order, step by step. Agisoft Metashape is an advanced image-based 3D modeling solution that aims to create professional and quality 3D content from photos. Based on the latest multi-view 3D reconstruction technology, it works with arbitrary images and is effective in both controlled and uncontrolled conditions. Photographs may be taken from any position, provided that the object to be reconstructed is visible in at least two photographs. Both image alignment and 3D model reconstruction are fully automated. [3] CloudCompare is a 3D point cloud editing and processing software. Originally the software was designed to perform direct comparison between dense 3D point clouds. It relies on a specific octree structure that allows excellent performance when performing such a task. In addition to the fact that most point clouds are obtained with terrestrial laser scanners, the software can handle huge point clouds - typically more than 10 million points. The software also allows comparison of a cloud of points with a network of triangles. [5]

4.1 PHOTOGRAMMETRIC PRODUCTS

The Agisoft Metashape software was used to process the data collected from the field, i.e. the images from the drone and the terrestrial photo camera, as this software provides a very clear and detailed view of the 3D model of the object.

Figure 8. 3D textured model

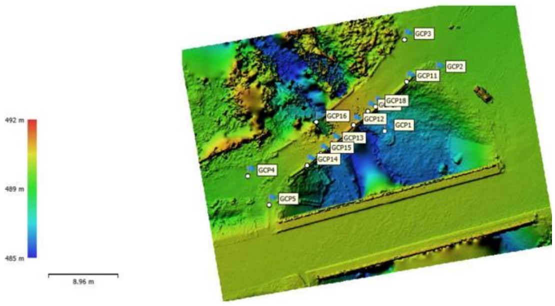

Figure 9. Digital elevation model of the site with all GCP

In general, the ultimate goal of photo processing with Metashape is to build a 3D model, orthomosaic and digital elevation model. (Figure 8)

A digital elevation model (DEM) is a 2.5D model of a surface represented in the form of a regular grid grid, with elevation values stored in each grid cell. (Figure 9) In Metashape, a DEM can be rasterized from a point cloud, anchor points, mesh, or generated directly from depth maps. Metashape also allows to create a digital surface model (DSM), i.e. a 2.5D model of the

Markers	East err (m)	North err (m)	Alt. err (m)
GCP13	0.000028	-0.000469	0.000888
GCP14	-0.000983	-0.004101	0.001290
GCP1	-0.011707	0.022760	-0.001920
GCP3	-0.012701	-0.010956	0.000895
GCP5	-0.018497	-0.003515	0.010458
Total Error			
Control points	0.008605	0.007257	0.003858

Figure 10. Results of geo referencing in Agisoft Metashape

Earth's surface with all objects on it, and a Digital Terrain Model (DTM) that represents the surface of the bare Earth without any objects such as plants and buildings. [2]

As we mentioned earlier, Agisoft Metashape is a software that can export a variety of file formats for its processed products. The software supports export of anchor points, point cloud, camera calibration parameters, camera orientation data as well as all models according to user requirements.

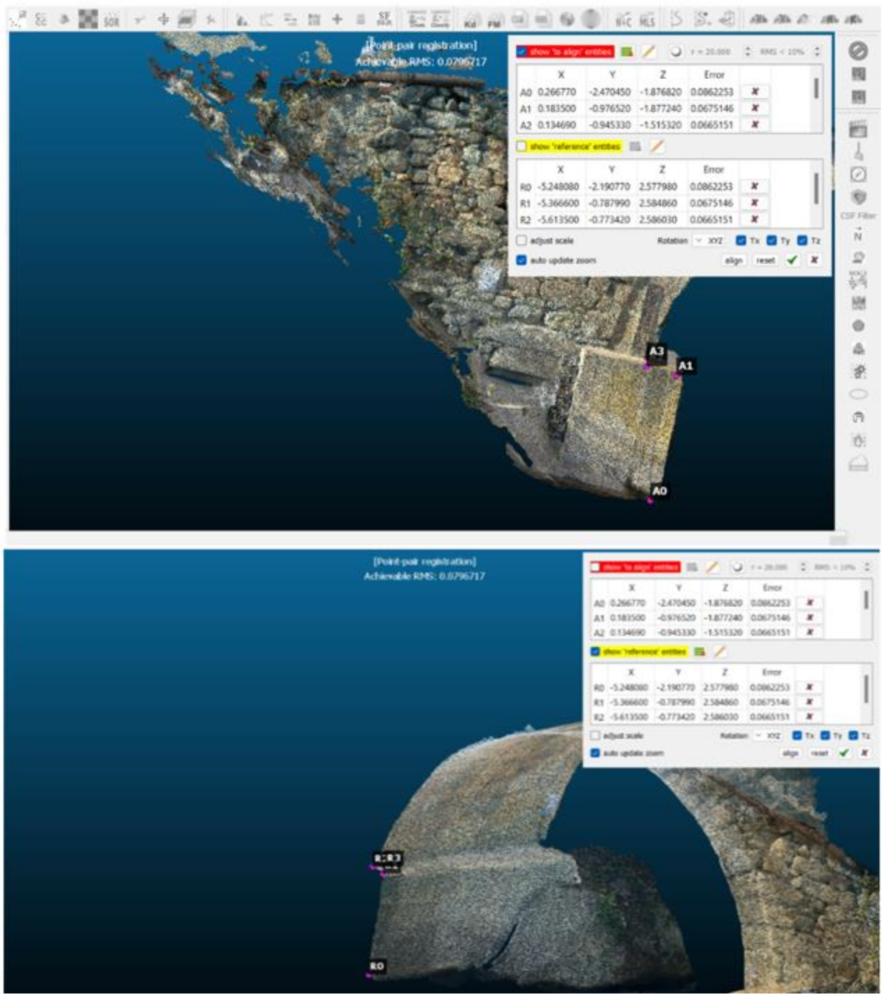

Figure 11. Process of scans alignment

4.2 LIDAR PRODUCTS (SCANS)

Cloud Compare software is software for better visualization and manipulation of models and point clouds with many additional functions such as comparing two models. A range of different tasks and analyzes such as scan alignment, geo referencing, classification and the like can also be performed. We exported the made field scans collected with LiDAR sensors through the 3D Scanner application in .las format and imported them into the Cloud Compare software. It is about two independent scans that are in a local coordinate system and each represents one part of the bridge. The goal is to merge the two scans, that is, to align them and to place them in a state coordinate system based on the previously recorded orientation points placed on the surface of the bridge. [9] Cloud Compare offers the possibility of aligning two clouds of points, i.e. fitting them by picking the same points that are on both shores and they represent natural "virtual" markers for alignment. In this case, 4 pairs of points were used, which turned out to be enough, and it is important to note that in order for this process to succeed and be precise, the same points from both clouds should be picked in parallel in order to have an insight into which point is picked exactly all in order to avoid mistakes as much as possible. [10] Because as we mentioned, the scans are in a local coordinate system and after their alignment they still remain so. The next step is to fit this model into the state coordinate system based on orientation points placed on the surface of the bridge. We'll do this by importing a portion of the points and repeating the same process with one entity being the points themselves while the other entity represents the entire new model.

That way the scans collected by LiDAR sensors are aligned properly and the point cloud is georeferenced and ready to perform any measurements, readings or analysis.

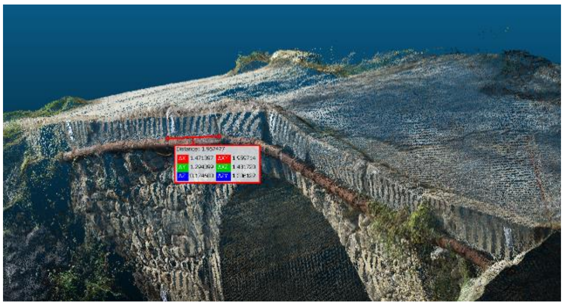

Figure 12. Geo referenced point cloud in Cloud Compare

4.3 ANALYSIS

The purpose of the analysis is to show what final product can be obtained at the end of processing, a product that has perfect visualization and satisfactory accuracy and a product that can be used in multiple areas for all kinds of cases. During the analysis of the obtained results, point clouds processed in Agisoft Metashape and Cloud Compare were taken. The goal was to see what the relationship is between the two models, one of which was obtained as a combination of terrestrial and unmanned photogrammetry, while the other only from smartphone LiDAR sensors, and both are georeferenced through the same orientation points. The analysis that I conducted consists of comparing the coordinates of two identical points from the two models in both software, lengths (Table 1), areas as well as a comparison of the complete clouds of points also known as C2C Distance in the Cloud Compare software. (Figure 13)

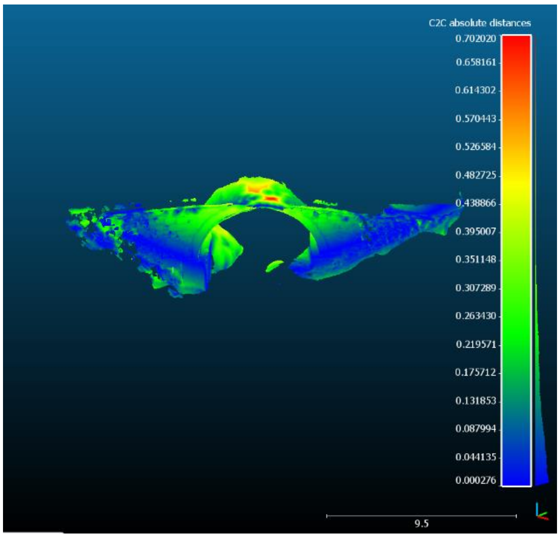

Figure 13. Graphic display of the final result of the comparison of two clouds of points with a scale of deviations from the two models expressed in meters

Table 1. Comparison of distances

Serial number	Agisoft Metashape	Cloud Compare	GCP
	Distance(m)	Distance(m)	Distance(m)
1	1.14	1.10	/
2	5.40	5.40	/
3	9.24	9.19	9.24

Cloud-cloud distances can be processed by selecting both point clouds and calling the appropriate command. The usual way to calculate the distance between two clouds is through the 'nearest neighbor distance' method: for each point of the compared cloud, the software searches for the nearest point of the reference cloud and calculates their distance. The two clouds are selected, and it is necessary to choose which of the two will be the reference model. It is recommended to take the larger or denser cloud of points as the reference cloud. [11]

5. CONCLUSION

At the very beginning of the research, a hypothesis was put forward that by applying exactly this method, which was developed throughout, it is possible to obtain models of the objects that are categorized as cultural heritage, and which are the subject of research with satisfactory, high accuracy and based on such the obtained models to be analyzed for their possible displacements, damages and the possibility of their restoration, with the aim of preserving them in their original state. However, the choice of measurement method depends a lot on the need for the measurements in terms of accuracy, precision, cost-effectiveness, etc. From what has been shown so far and according to the field measurements and their processing, it can be concluded that this method, which consists of a combination of unmanned and terrestrial photogrammetry with classic geodetic measurements, can give very good and precise results when it comes to the reconstruction of cultural and historical objects. Of course, classic measurements for this type of objects are irreplaceable and this is proven by their very inclusion in the field measurements in this paper, which are of great importance, their accuracy was and will be a benchmark for obtaining quality results. However, the method that was used in this paper also has many advantages, such as the visualization of the object, which is a very important item for objects of cultural heritage. At any moment, we can see which part of the object we want to analyze it, make different measurements, comparisons, and this is possible because we have a precise 3D model that is easily manipulated and that is integrated into a state coordinate system. We know that objects that are of historical and cultural importance are quite important and have great significance for a nation, society. They are under constant risk of collapse due to their age, weather effects, atmospheric effects, human factors and the like, and therefore I think that by establishing such projects, their soul would be preserved throughout their existence.

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INFLUENCE OF THE SEISMIC HAZARD ON THE BEHAVIOR OF REINFORCED CONCRETE STRUCTURAL ELEMENTS

At the core of every project designed by structural engineers, lies the requirement that the structure has to maintain its integrity under different actions, among which the most specific is the seismic action. The Republic of North Macedonia is situated in region which is seismically very active, so we need to pay special attention to the seismic action and its influence on the behavior of reinforced concrete structural elements.

In this paper, parameter study and numerical analysis are performed by varying the seismic hazard of certain reinforced concrete building. According to the seismic zone map for our country, its territory is divided into five seismic zones. The variable parameter for each zone is the peak ground acceleration a_{gR} (PGA), which according to EN 1998-1 is used to define the seismic hazard. This parameter takes the following values: a_{gR}={0,1g; 0,15g; 0,2g; 0,25g; 0,3g}. By implementing an analysis for each of the listed values, it is realized how and to what extent the seismic hazard affects the behavior of reinforced concrete structural elements.

It is expected that by increasing the value of PGA, the design values of the effects of actions in beams and columns will also increase. As a consequence to that, the geometric reinforcement ratio increases, too. When PGA varies, the design values of bending moment in beams, and thus the reinforcement ratio increase by 2-3 times. At the column sections, this ratio reaches an increase of 40% when PGA varies.

Overall, it may be said that the seismic hazard has a huge impact on the structural elements and the behavior of the structure at all. Therefore, it is necessary to pay special attention when designing buildings that are located in seismically active areas.

Keywords: seismic hazard, peak ground acceleration, geometric reinforcement ratio, type of failure, reinforced concrete structural elements

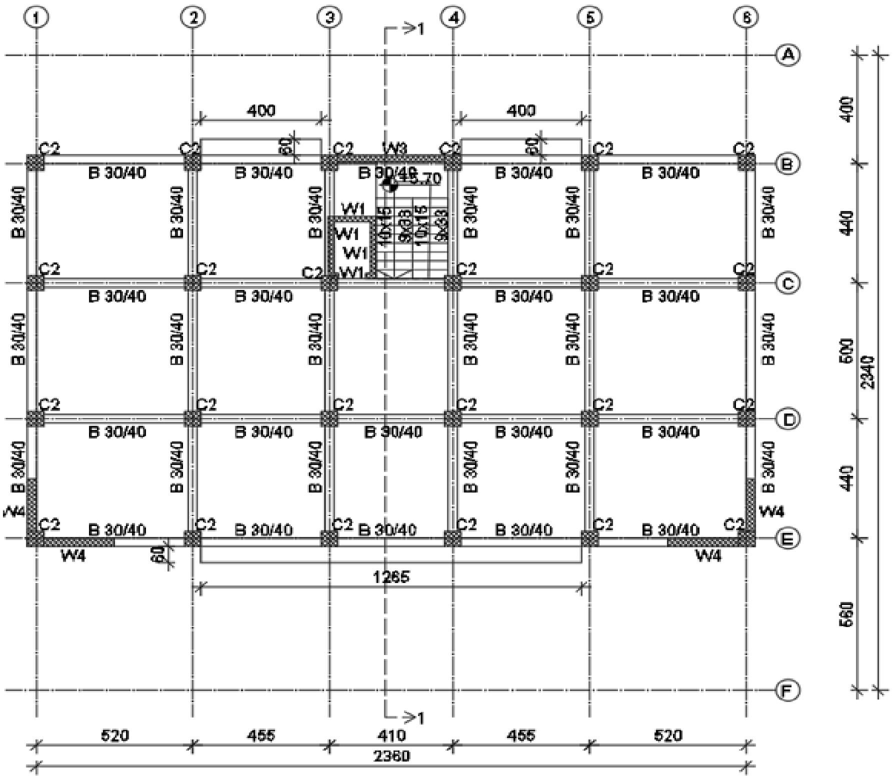

Figure 1. Typical floor plan of the building

1. INTRODUCTION

In this paper, the behaviour of reinforced concrete structure is analysed. The emphasis is on the seismic action, in a way that a parameter that defines this action, is varied. It is important to say that the entire design process of the building is in accordance with the European standards, so called Structural Eurocodes, which tend to become the only valid ones in our country.

Through the presented analyses, a representation of the impact of seismic action on a real structure is created. The outcome of all analyses are the design values of internal forces and the corresponding area of reinforcement in specific structural elements, as well as the type of failure in the analysed sections.

2. INITIAL MODEL

2.1 DESCRIPTION OF THE BUILDING

The analyzed building in this paper is a multi-story reinforced concrete structure, which has 4 stories above the ground level and 1 basement. The height of each story is 3 m, the ground floor is raised for 1,20m above the terrain, so that the

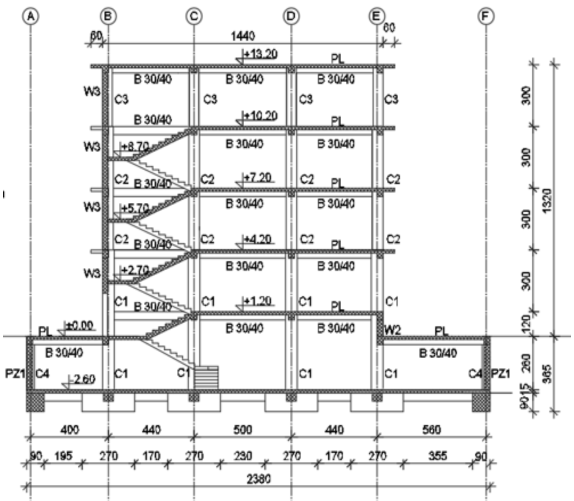

Figure 2. Cross section of the building

total height of the building above the terrain is 13,20m. The height of the basement is equal to 2,60m and the dimensions in plan of this level are 23,60 x 23,40m. The area of the other stories is smaller, and it is equal to 23,60 x 13,80m. The spans of the reinforced concrete frames in the direction of global axis X, are as follows: 5,60+4,40+5,0+4,40+4,00m. The spans of the frames in the direction of global axis Y are as follows: 5,20+4,55+4,10+4,55+5,20m. The typical floor plan and the cross section of the building are shown in Fig.1 and Fig.2.

The structural system consists of frames and walls. The columns are with square cross section with side lengths of 60cm in the basement and ground floor, 55cm on the first and second floor and 50cm on the third floor. The beams are with rectangular cross section 30x40 cm. The slab is 15cm thick. The vertical communication in the building is enabled through two-legged staircase with 15cm thick slab and lift core which includes 20cm thick walls. In the basement, there are peripheral walls, whose thickness is 30cm. There are also several additional walls, whose role is to prevent the appearance of short column effect in the building and to reduce the eccentricity between the center of mass and the center of stiffness.

2.2 STRUCTURAL MODEL

For the whole static and dynamic analysis, the program Radimpex Software (Tower 6), which is based on the finite element method, was used. During the analysis, the provisions of MKS EN Standards (MKS EN 1990 [3], MKS EN 1991 [4] [5] [6], MKS EN 1992 [7] and MKS EN 1998 [8]) were applied. Columns and beams are modelled as line elements. Slabs and walls are modelled as surface finite elements, which are four node quadrilateral elements with 50cm width. All elements are fully fixed at the foundation level -2,60 m. According to MKS EN 1998-1/4.3.1 [8], the stiffness of the load bearing elements is evaluated taking into

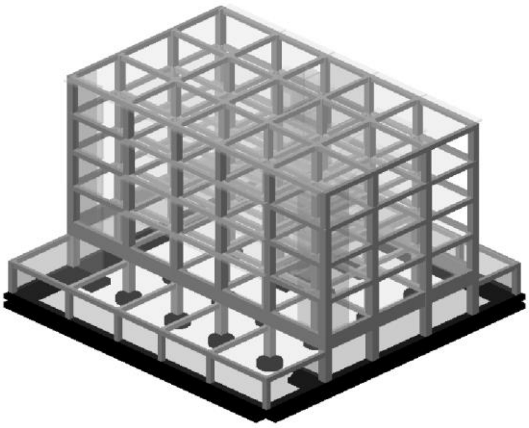

Figure 3. Structural model – 3D view

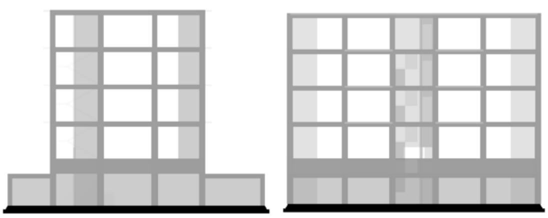

Figure 4. Structural model – Y and X direction

account the effect of cracking, in the way that the elastic flexural and shear stiffness properties are taken to be equal to one-half of the corresponding stiffness of the uncracked elements. For all load bearing elements, concrete C30/37 is used. The corresponding modulus of elasticity is E_{cm}=33 GPa (MKS EN 1992/Table 3.1[7]). Steel S500 Class B is used, so that the characteristic strain at maximum load is 5%. The structure is designed for ductility class DCM. 3D view and view in X and Y direction of the structural model is shown in Fig.3 and Fig.4.

2.3 ACTIONS

The permanent vertical loads G are represented by the self-weight of the structure, which is taken into account automatically by the software, and additional permanent load. The additional permanent loads are precisely calculated as 6,26 kN/m’ for facade walls, 6,21 kN/m’ for partition walls that separate the apartments, 3,40 kN/m^2 on all floor slabs, 0,70 kN/m^2 on roof slab, 4,20 kN/m^2 on stair slab and 2,00 kN/m^2 on the stair landings. The analyzed building is a residential building, so according to MKS EN 1991-1-1/Table 6.1 it belongs to category A. According to MKS EN 1991-1-1/Table 6.2 [4], the variable-live load Q, as uniformly distributed load is 2,00 kN/m^2 on floors, 2,50 kN/m^2 on balconies and 2,00 kN/m^2 on stairs. The roof slab according to MKS EN 1991-1-1/Table 6.9 belongs to category H, so the variable-live load is equal to 0,60 kN/m^2. The investigated building is located in Skopje, so the characteristic value of snow is equal to 0,83 kN/m^2 (MKS EN 1991-1-3:2012/NA:2020 [12]) and the snow load on the roof is 0,67 kN/m^2. The input parameters for the calculation of wind action are: fundamental value of the basic wind velocity $v_{b,0}$=24,47 m/s according to MKS EN 1991-1-4:2012/NA:2020 [13] for location Skopje, and terrain category IV (MKS EN 1991-1-4/Table 4.1). The calculated value of peak velocity pressure is equal to 0,507 kN/m^2.

2.4 STRUCTURAL REGULARITY

Criteria for regularity in plan

The criteria for regularity in plan are described in MKS EN 1998-1/4.2.3.2 [8], and it limits the slenderness of the building, the structural eccentricity and the torsional radius. After the calculation for the specified parameters such as lateral stiffness, torsional stiffness, torsional radius, center of mass, center of stiffness and structural eccentricity, positive results are

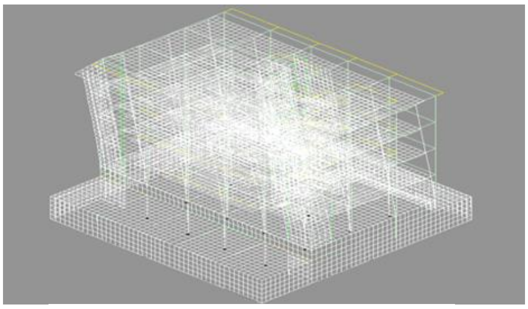

Figure 5. Mode 1 – translational in Y

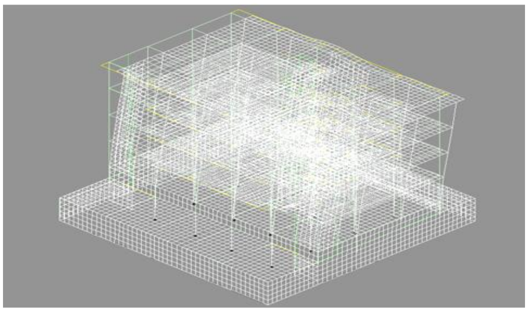

Figure 6. Mode 2 – translational in X

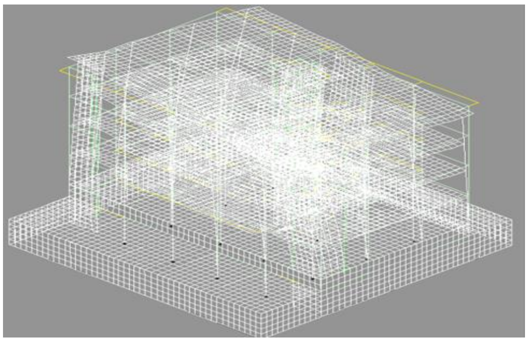

Figure 7. Mode 3 – torsional

obtained, i.e. the investigated building is regular in plan.

Criteria for regularity in elevation

After the conducted control for regularity in elevation, it is concluded that the structure fulfills all requirements stated in MKS EN 1998-1/4.2.3.3[8], provided that only the upper part of the structure (above basement) is considered.

2.5 MODAL RESPONSE SPECTRUM ANALYSIS

Seismic action is taken into account through the implementation of modal response spectrum analysis, whereby it was analyzed independently for the ground excitation in two horizontal directions X and Y. For this purpose, design spectrum according to MKS EN 1998-1/3.2.2.5 [8], is used. In doing so, spectrum Type 1 is chosen (MKS EN 1998-1/3.2.2.2). It is identified that the ground type, according to MKS EN 1998-1/Table 3.1, belongs to category B.

Periods, effective masses and modal shapes

In the modal response spectrum analysis 15 modes of vibration were taken into account and the sum of the effective modal masses is 91,67 % of the total mass of the structure in direction X and 91,74 % in direction Y. In this way, the provision defined in MKS EN 1998-1/4.3.3.3.1 [8], that this percentage has to be at least 90%, is fulfilled. The three fundamental periods of vibration of the building are 0,31s, 0,26s and 0,21s. The effective masses indicate that the first mode is predominantly translational in the Y direction, the second mode is translational in the X direction and the third mode is predominantly torsional. All three fundamental modes are shown in Fig. 5, Fig. 6 and Fig. 7.

Behaviour factor

Before calculating the behavior factor, it is necessary to determine the structural type of the building. After appropriate analysis it is concluded that this building belongs to a wall-equivalent dual system, where the shear resistance of the walls at the building base is greater than 50 % (51,63% in direction X and 57,83 % in direction Y). For this type of building the value of α_u/α_1 according to MKS EN 1998-1/5.2.2 [8] amounts to 1,2, so that the value for q_o according to MKS EN 1998-1/Table 5.1 [8] is equal to 3·1,2=3,6 for ductility class DCM. The factor k_w is equal to 1,0, therefore the behavior factor in both direction is equal to the basic value of the behavior factor $q=q_o=3,6$.

Peak ground acceleration and Design response spectrum

Design ground acceleration on type A ground a_g, which is one of the factors for defining the design response spectrum, is calculated as a product of reference peak ground acceleration on type A ground a_{gR} and importance factor γ_I. In the initial model the building is located in Skopje, so according to Seismic zones map (Fig. 8), peak ground acceleration a_{gR} = 0,25g. Since the analyzed building is a residential building, it belongs to importance class II – ordinary buildings (MKS EN 1998-1/Table 4.3[8]) and its value for importance factor γ_I=1,0. Finally, the value of design ground

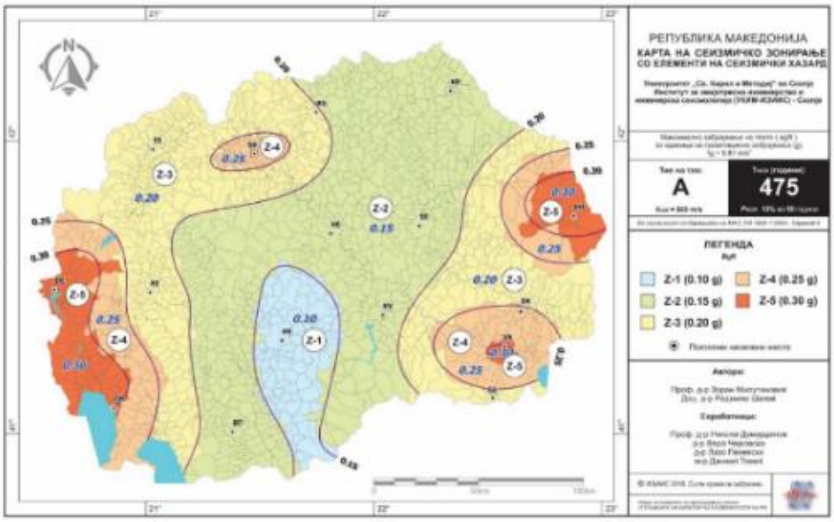

Figure 8. Seismic zones map

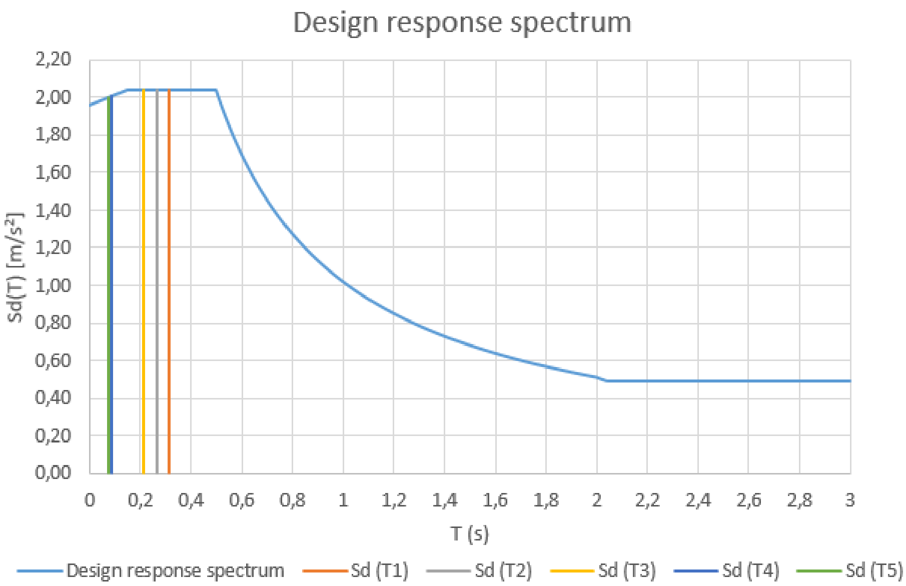

Figure 9. Design response spectrum – initial model

acceleration a_g=0,25g. The defined design response spectrum is shown in Fig. 9.

Design and detailing of reinforced concrete structural elements

After the implementation of static and seismic analysis and generation of combinations of actions according to MKS EN 1990/6.4.3[3], the design values of the effect of actions in load bearing elements were obtained. The columns and beams are fully designed in bending and in shear, after checking the provisions listed in MKS EN 1992 [7] and MKS EN 1998 [8].

For analysis and comparison of the results, three characteristic most loaded columns are selected, and the frames in X and Y direction that they are part of: column C-3 (frame C in direction X and frame 3 in direction Y), column C-5 (frame C in direction X and frame 5 in direction Y) and column E-6 (frame E in direction X and frame 6 in direction Y).

3. INFLUENCE OF THE SEISMIC HAZARD ON THE BEHAVIOR OF REINFORCED CONCRETE STRUCTURAL ELEMENTS

Seismic hazard according to MKS EN 1998 is defined by the value of reference peak ground acceleration on type A ground - a_{gR}. In compliance with Fig. 8, the territory of our country is divided into five seismic zones, where a_{gR}={0,10g; 0,15g; 0,20g; 0,25g; 0,30g}. The purpose of this part of the research is to vary this parameter, i.e. to conduct 4 more analyses, in the same way as it was shown in the chapter 2 of this paper. It means that the building will change its location in each analysis (Skopje, Prilep, Kavadarci, Tetovo, Debar). It is important to say that in all analyses the importance class does not change, i.e. the importance factor has a constant value equal to 1,0. All other parameters defined in section 1.5 do not vary, too. The list of conducted analyses is shown in Table 1.

Table 1. List of conducted analysis when varying the location, i.e. seismic hazard

Analysis	Seismic zone	Location	a_{gR}
1 (Initial model)	Z-4	Skopje	0,25g
2	Z-1	Prilep	0,10g
3	Z-2	Kavadarci	0,15g
4	Z-3	Tetovo	0,20g
5	Z-5	Debar	0,30g

3.1 INFLUENCE OF THE SEISMIC HAZARD ON THE BEHAVIOR OF REINFORCED CONCRETE BEAMS

By varying the location, i.e. seismic hazard, changes in the design values of bending moments are noticed in the beams of RX-E, RY-3 and RY-6 frames. In fact, in those beam sections, the relevant bending combination includes a seismic load case, which is a direct cause of the resulting changes. The reason why seismicity has a dominant influence in those sections is the existence of reinforced concrete walls in the mentioned frames. Namely, in frame RX-E there are two walls W4, in frame RY-3 there is a wall W1 and in frame RY-6 there is a wall W4 (Fig.1). All of them affect the increase of bending stiffness in the corresponding direction, and this results in the attraction of greater seismic forces, whereby their value becomes dominant. As a consequence, the increase in bending moments affects the increase in the area of longitudinal reinforcement.

Opposite conclusion follows in the direction of the RY-5 and RX-C frames, where there is no existence of reinforced concrete walls, that would increase the stiffness. In fact, in the frame RX-C there is the wall W1, but its elevator core door openings reduce the bending stiffness. In these beam sections the relevant bending combination does not include a seismic load case, so the change of seismic hazard does not affect the design values of bending moments. This means that the area of longitudinal reinforcement has an immutable value.

Frame RX-E: Positive bending moments in each analysis have a mutual increase of 15-30%, i.e. on average positive bending moments obtained at a_{gR}=0,3g are 2,3 times greater than those obtained at a_{gR}=0,1g. Negative bending moments in each analysis have a mutual increase of 20-40%, i.e. on average negative bending moments obtained at a_{gR}=0,3g are 2,8 times greater than those obtained at a_{gR}=0,1g. As a consequence, the area of reinforcement obtained in the analysis where a_{gR}=0,3g is on average 2,2 times greater than the area when a_{gR}=0,1 g.

Frame RY-3: Positive bending moments in each analysis have a mutual increase of 20-50%, i.e. on average positive bending moments obtained at a_{gR}=0,3 g are 3 times greater than those obtained at a_{gR}=0,1 g. As a result, the area of reinforcement obtained in the analysis where a_{gR}=0,3 g is on average 2 times greater than the area when a_{gR}=0,1 g.

Frame RY-6: Positive bending moments in each analysis have a mutual increase of 20-50%, i.e. on average positive bending moments obtained at a_{gR}=0,3 g are 3 times greater than those obtained at a_{gR}=0,1 g. For that cause, the area of reinforcement obtained in the analysis where a_{gR}=0,3g is on average 2,7 times greater than the area when a_{gR}=0,1 g.

Overall, the design values of bending moments in beams and the corresponding area of reinforcement, when varying the reference peak ground acceleration from 0,1 g to 0,3 g, increase by 2-3 times.

3.2 INFLUENCE OF THE SEISMIC HAZARD ON THE BEHAVIOR OF REINFORCED CONCRETE COLUMNS

The variation of the location, i.e. seismic hazard, does not affect the design values of bending moments in column C-5. This is a consequence of the second conclusion in 3.1, i.e. the area of reinforcement in the beams, which are part of RX-C and RY-5 frames, is constant.

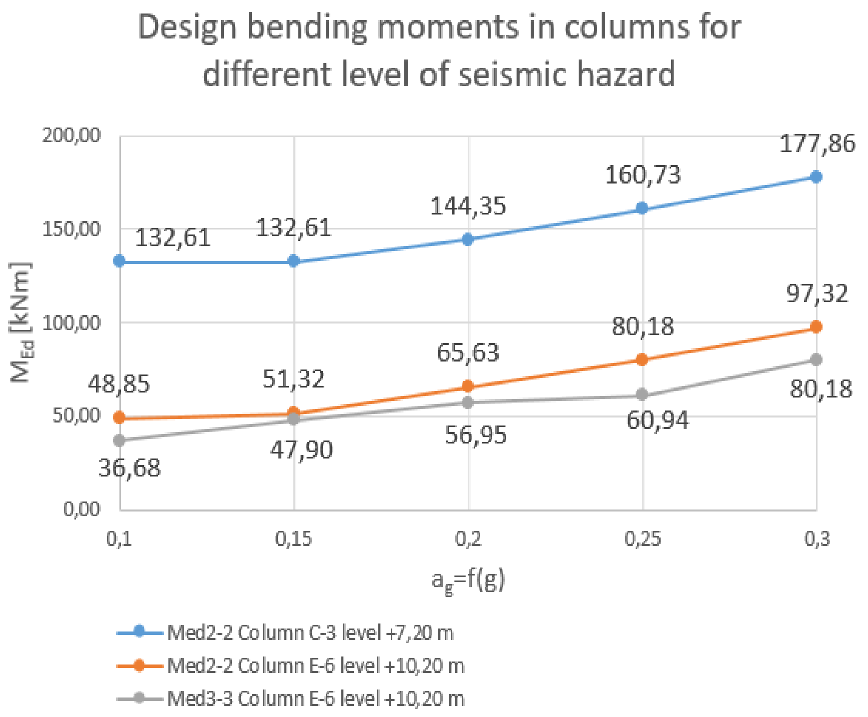

Figure 10. Design bending moments in specific sections in columns C-3 and E-6 for different level of seismic hazard

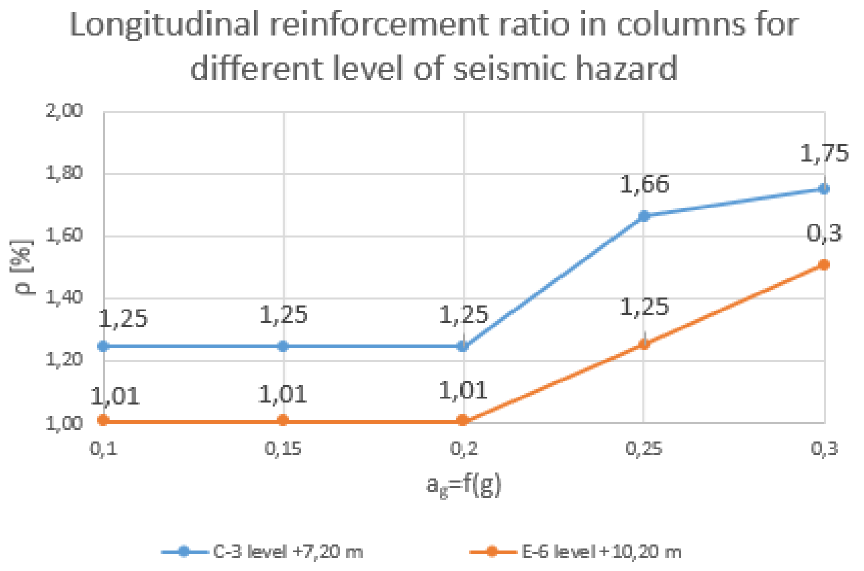

Figure 11. Geometric reinforced ratio in specific sections in columns C-3 and E-6 for different level of seismic hazard

The average 30% increase in bending moments in column C-3 results with 40% increase of geometric reinforcement ratio at the +7,20 m level, when comparing the values from the analyses a_{gR}=0,1 g (ρ_l=1,25%) and a_{gR}=0,3 g (ρ_l=1,75%). The greatest mutual increase of 33% occurs when changing from a_{gR}=0,2 g to a_{gR}=0,25 g.

Because of the increase of longitudinal reinforcement in beams in frames RX-E and RY-6, there are changes in the geometric reinforced ratio in the sections of column E-6. In fact, the greatest influence is at +10,2 m level, where the area of reinforcement increases for 50 %, comparing the results when a_{gR}=0,1 g (A_L=25,13 cm^2) and a_{gR}=0,3 g (A_L=37,70cm^2).

The results for design bending moments and geometric reinforced ratio, when varying seismic hazard, for both sections are shown in Fig. 10 and Fig. 11.

Common feature for all column sections is the ductile failure, so that the strain in steel decreases up to 24 % in the section where the ultimate strain in concrete is achieved. This happens at level +7,20 m in column C-3, where ε_b=3,5‰ and ε_a varies from 24,077‰ (a_{gR}=0,1 g) to 18,266‰ (a_{gR}=0,3 g). When the ultimate strain in steel is achieved, the strain in concrete increases up to 94%. This happens at level +4,20m in column E-6, where ε_a=50‰ and ε_b varies from 0,986‰ (a_{gR}=0,1 g) to 1,913‰ (a_{gR}=0,3 g). In some sections, for different level of seismic hazard, different material reaches the ultimate strain. A characteristic example is the section at level +1,20 in column E-6, where ε_b varies from 1,921‰ (a_{gR}=0,1 g) to 3,5‰ (a_{gR}=0,3 g), i.e. 82% increase, and ε_a changes from 50‰ (a_{gR}=0,1 g) to 40,107‰ (a_{gR}=0,3 g), i.e. 25% decrease.

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HYDROLOGICAL MODELING OF A RIVER BASIN: CASE STUDY ON THE BASIN OF RIVER CRN KAMEN

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Hydrological analysis of rivers and their basins is a basic task that is set in hydrology. When there is a lack of data on measured values of the surface runoff in a river basin, the so-called procedure of hydrologic modeling of the river basin is used. Hydrological modeling is applied in order to determine the surface runoff based on the meteorological parameters of the river basin (precipitation, air temperature) and the basic geometrical characteristics of the watershed (area of the river basin, length of the river, land use cover, etc.).

The subject of this paper is a hydrological analysis of the river Crn Kamen up to the outlet where the construction of a stone dam with central clay core is planned for the formation of the “Lukovo Pole” reservoir, using hydrological modeling of the river basin. The aim of the research in this paper is to study all of the parameters that affect the surface water in the river basin. For this purpose, a hydrological analysis of the river basin of the river Crn Kamen was made. The definition of the physical characteristics of the watershed was performed using the GIS platform, based on a Digital Terrain Model (DTM) and an appropriate model for hydrological modeling of the river basin (SWAT). A detailed map showing the land use of the river basin was also created (CORINE). Using the HEC-HMS software, a hydrological model of the river basin of Crn Kamen was developed in order to define the surface waters of the river Crn Kamen. The hydrological sequences of flow in the river were analyzed using the available measured data: historical sequences of characteristic flows (minimum, maximum and average monthly) from the hydrological station Lukovo Pole for the period 1974-2009.

A statistical analysis of data (array of 36 elements, formed from the maximum annual flows in the period from 1974 to 2009), was performed using the HEC-SSP software package. The maximum high waters with a given recurrence period of the analyzed basin were determined, using theoretical distribution functions.

Keywords: hydrological analysis, maximum high water, HEC-HMS, HEC-SSP

1. INTRODUCTION

The procedure of hydrological modeling (in some literature the terms mathematical modeling or simulation can be also found) refers to the establishment of a relationship between the real system (hydrological basin) and its mathematical (or physical) model. Simulation refers to the relationship between the model and the computer.

When modeling a river basin, all the techniques and procedures used can be divided into two basic groups:

- models that serve to assess the basin's characteristics, forecast and data generation, that is, models that operate the input-output relationship, in our case (precipitation-surface runoff);
- models dealing with water management systems for multi-purpose use of water, with the aim of finding an optimal solution based on physical characteristics, but at the same time respecting economic, social, environmental and political requirements.

The hydrological model is often associated with the term hydrological system. A hydrological system [Clark,1973] is defined as a set of physical, chemical and/or biological processes that influence input variables and transform them into output variables. The hydrological model represents simplified representation of the hydrological system and can be a physical model for a certain prototype and a mathematical model for representing the system through a set of equations.

In the development process of each model, it is constantly changing and upgrading. It begins as a rough empirical model, and with further study it is refined and changes its components with more plausible and sophisticated theoretical foundations.

The flow of surface water that falls in the form of precipitation in a basin can be non-stationary, uneven and three-dimensional. The basis of the hydrodynamic flow model is the physical laws of flow. The most accurate model would be obtained if equations were applied at the elementary volume level, observing the principle of conservation of mass (equation of continuity) and the principle of conservation of momentum (dynamic equation). Since the process is three-dimensional, non-stationary and spatially non-uniform, initial and boundary conditions must be defined at the boundary of the elemental mass, which would mean that such a model can function with spatially distributed parameters. It is about the numerical solution of the spatial (3D) models of flows under the influence of precipitation, which is not yet possible. If this model could be solved, a large number of input parameters, measured at the elementary volume level, are required, which make the model complicated and irrational. For these reasons, simpler (2D) models are considered, and for practical examples, linear (1D) flow models.

A thorough knowledge and understanding of the hydrological processes in the basin are of crucial importance for successful planning and management of water resources. To understand these processes, hydrological modeling has been widely applied in the last few decades. The models represent the processes in the river basin in a simplified way.

Thus, Ilias A. et al. (2006), presented a simulation of flood events from a single storm in the Ali Effendi basin, a sub-basin of the Pinios river basin, [1]. Flood risk assessment in this area is very important because the region suffers from frequent and dangerous floods, causing damage and operational problems to downstream multipurpose reservoirs and agricultural and residential areas. The simulation is performed using the NAM model, a core component of the DHI MIKE 11 package. The resulting mathematical model can be tuned to simulate a single storm. The model was applied in two phases (calibration and verification phase), giving good results.

Ibrahim-Bathis K., Ahmed S. A. (2016) applied the HEC-HMS 3.5 hydrological model to simulate precipitation-runoff in the Dodahala basin, [2]. The area is prone to drought and therefore, the failure of agriculture and/or other economic activities in this region can be minimized by conserving and rationally managing the available water. The simulated results of the Dodahala basin have been verified by the neighboring measured Huvinahole basin, with which they have similar characteristics. For run calibration and validation, a series of daily rainfall from October 20, 2009 to October 30, 2009, measured at the Hubinahol weather station, was used. The simulated result of this study can be useful for ungauged basins and water-scarce regions, and runoff estimation is mandatory for water resource maintenance.

Shimelis A.W. etc. (2017) conducted a study to assess the performance of the VHM and NAM models, by simulating precipitation-runoff in a small agricultural catchment area located southwest of the upper Blue Nile basin, [3]. Precipitation and evaporation were used as input to the models. The models are then calibrated for the period from January 1, 1990 to December 31, 2000. It is concluded that both models show good results in simulating the dominant hydrological processes.

Santillan J. R. et al. (2013), used the HEC-HMS model, to simulate the precipitation-runoff process, in order to assess the flood risk of the Marikina River located in Luzon Island, Philippines, [4]. This paper describes the model development as well as the calibration and validation of the flood model by comparing modeled and measured flow data. Based on the results, it is shown that the HEC-HMS model has more than satisfactory performance in simulating rainfall events. Therefore, this model can be used for forecasting and flood hazard assessment using hypothetical rainfall scenarios that could occur in the near future.

Fattah W. H., Yuce M. I. (2015), in order to determine the relationship between precipitation and runoff, performed a hydrological analysis of the Murat River Basin, the largest tributary of the Euphrates River, Turkey [5]. The hydrological characteristics of the wbasin were determined using the standard digital elevation model (DEM) and geographic information systems (GIS). Annual average runoff was obtained from seven streamflow measuring stations, while annual total precipitation data were obtained from nineteen precipitation measuring stations located near the basin.

Gjeshovska V. and Ivanoski D. (2016) performed a hydrological analysis of the upper basin of the Vardar river, [6]. The Ministry of Agriculture, Forestry and Water Management recently carried out the preparation of technical documentation for the regulation of rivers. The main objectives of the project are: to assess the overall condition of the flooded section of the riverbed, to assess the change in the hydrological regime and to propose protection measures. In order to achieve these goals, within the framework of the above technical documentation, the hydrological analysis was performed. The characteristics of the basin are defined by DTM (Digital Terrain Model). The study presents some of the output results of this analysis, as well as the results of the calibration of the hydraulic modeling of the flow in the natural river bed.

Rocha P. C., Santos A. A. (2018), performed a hydrological analysis of the Aguapei and Peix river basins, Brazil [7]. The purpose of this analysis is to give an account of the hydrological regime of the considered rivers.

The hydrological analysis for the basin of the river Crn Kamen done with the help of appropriate software packages (SWAT, HEC HMS, HEC SSP) provides the opportunity for a quick, precise and accurate definition of the necessary parameters for an appropriate hydrological analysis of a river basin [8].

2. HYDROLOGICAL MODELING OF THE BASIN OF R.CRN KAMEN

2.1 STUDY AREA

The river Crn Kamen is located in the northwest part of the Republic of N.Macedonia on the border of the Shara's and Korab's mountains massifs and is part of the basin of the river Radika. From its source to the confluence in Lake Debar, Radika river flows under different names. Thus, from the upper part to the confluence of Ajina River, it is known under the name r.Crn Kamen, from the confluence of Ajina River to the confluence of river Mavrovska, under the name r.Nichpurska, and from the confluence of the river Mavrovska to the confluence in the lake Debar flows under the name Radika. In its upper part, the construction of a rock dam with a central clay core is planned for the purpose of forming the reservoir "Lukovo Pole".

The reservoir Lukovo Pole is planned to be built in order to increase the capacity of the hydro system on the upper reaches of river Radika. The main purpose of the reservoir is to retain the water from the upper course of the river Crn Kamen, as well as the flow from the mountain Korab and their controlled use in the hydro system. By retaining and regulating these waters, floods will be avoided, and energy can be produced.

2.2 DATA SOURCES

The determination of the physical-geographical characteristics of the river basin of the river Crn Kamen was made on the basis of digital layers DTM (Digital Terrain Model) and DEM (Digital Elevation Model). The physical-geographic

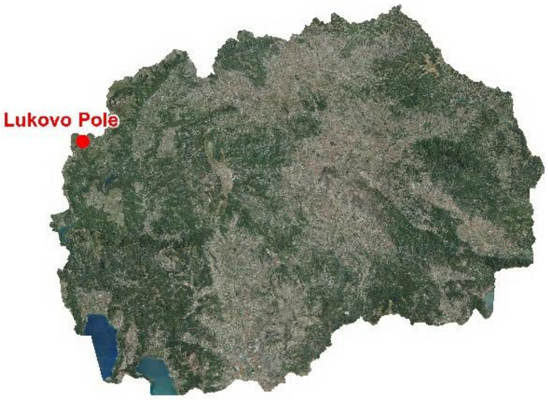

Figure 1. Location of the planned dam Lukovo Pole

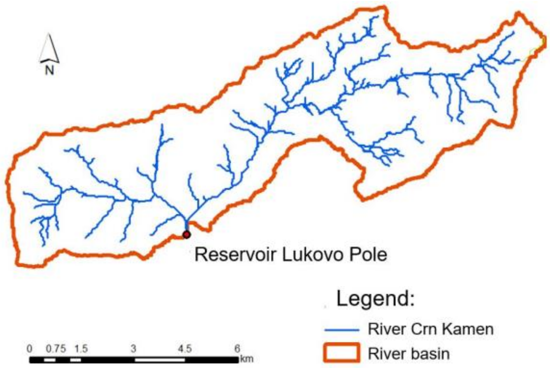

Figure 2. River basin of r.Crn Kamen at outlet Lukovo Pole

characteristics of the river basin of Crn Kamen are defined using a GIS software package. Information from the CORINE Layer Classification database from 2018 was used to define the land use. Precipitation has been analyzed through data on measured precipitation in the meteorological stations Lazaropole and Popova Shapka, in the period 1961-1990. Surface water has been analyzed with data on daily flow for the period 1974-2009, at the outlet of Lukovo Pole. In the HEC-HMS simulation daily data for the year 1975 is used.

2.3 METODOLOGY

The hydrological modeling of the river basin of r.Crn Kamen was made using the HEC-HMS software package. With the GIS processing (Spatial Analyst) and application of the SWAT module, the river basin of the r.Crn Kamen and its sub-basins is determined. The terrain data is transformed into a spatial database in an appropriate format (ArcGIS Shapefile), whis is used for input into the HEC-HMS model. Statistical analysis and application of probability distribution functions was done by using the HEC-SSP software package. Statistical Software Package - HEC-SSP was developed by the US Army Corps of Engineers as part of the research and development program of the Hydrological Engineering Center (Hydrologic Engineering Center-HEC).

2.4 HYDROLOGICAL ANALYSIS

2.4.1 Physical-geographic characteristics of the river basin of r.Crn Kamen

The river basin of the r.Crn Kamen and the physical-geographic characteristics of the river basin are defined based on the DEM, and with the application of SWAT, Figure 1. The geometric characteristics of the river basin are shown in Table 1 (A-area of the river basin in km^2, H_{max}-maximum elevation of the river basin in m asl., H_{min}-minimum elevation of the river basin in m asl., H_{avg}-average elevation of the river basin in m asl., L_t-length of the river in km, St-slope of the river in %, L_s-length of the river basin in km and S_s-slope of the river basin in %).

Table 1. Geometric characteristics of the river basin of river Crn Kamen from the source to the outlet at Lukovo Pole

A [km^2]	H_{min} [masl]	H_{max} [masl]	H_{avg} [masl]	L_t [km]	S_t [%]	L_s [km]	S_s [%]
52,8	1518	2519	1896,5	16,7	3,9	15,4	29

2.4.2 Land use

Within the boundaries of the basin of the river Crn Kamen, there are several classes of land use, characteristic for a given region, which were obtained by applying the CORINE Layer Classification, Figure 3. Land use classes in the river basin with their representation expressed in [km^2] are shown in Table 2.

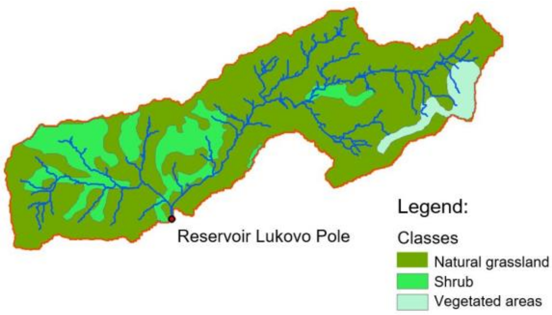

Figure 3. Land use classes in the river basin

Table 2. Land use classes according to the CORINE classification

No.	Code	Classes	Area [km^2]	CN
1	321	Natural grassland	39,5	79
2	324	Shrub	9,6	66
3	333	Vegetated areas	3,7	68

2.4.3 Hydrological characteristics

Within the basin of the river Crn Kamen as part of the hydrological network of R.N.Macedonia, data on daily flows for analysis are available for the time period from 1974 to 2009. With these data, a hydrological series of 36 years has been defined, which is sufficient for further statistical analyses.

Average monthly flows for the period from 1974 to 2009 measured on the Lukovo Pole profile are shown in Figure 4. The maximum and minimum average flows are shown graphically in Figure 5. The maximum average monthly flows are observed in the spring months, while the lowest average monthly flows are observed in the winter months. The highest amount of flow was recorded in 1974 in May, and the lowest was in February in 1981.

For the simulation in HEC-HMS daily data for one year was used, for the year 1975. The daily flows in the river Crn Kamen for the year 1975 are shown graphically in Figure 6.

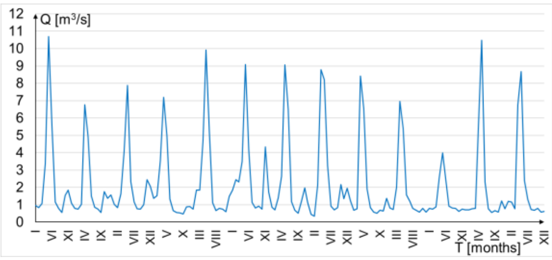

Figure 4. Hydrograph of average monthly flow for the river Crn Kamen for the period 1974-2009

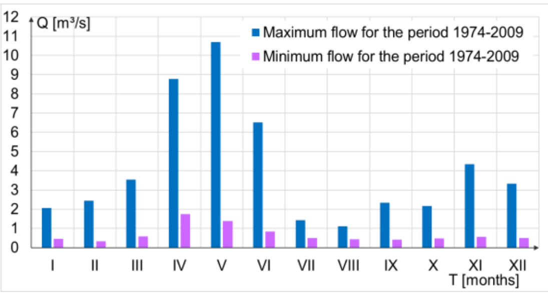

Figure 5. Maximum and minimum monthly flow for the period 1974-2009

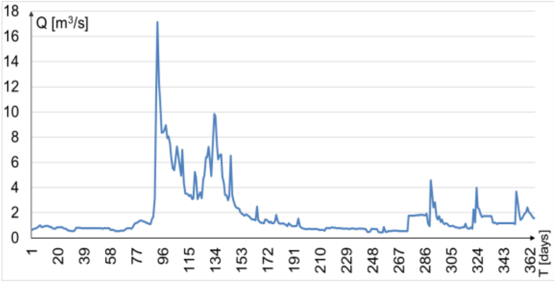

Figure 6. Hydrograph of daily flow in the r.Crn Kamen at the outlet of the dam Lukovo Pole in 1975

2.4.4 Climatic meteorological characteristics

Climatic characteristics of the basin are obtained from data recorded by the meteorological stations "Lazaropole" and "Popova Shapka" in the period 1981 - 2010 for air temperature and precipitation. In the area where the basin of the river Crn Kamen is located, climatic conditions prevail, which are characterized by mild and moderate winters and warm summer periods with pleasant evening temperatures. The climate is moderate-continental, and in certain areas it changes to Mediterranean. In Mavrovo National Park there is a continental climate with moderate influences of the Mediterranean currents along the valleys of Crn Drim and Radika, a colder mountain climate in the area of the Mavrovo Lake and its immediate surroundings, and an alpine climate in the highest mountain areas.

The average annual temperature measured in Lazaropole is about 7.3˚C, in Popova Shapka 4.9˚C. The average monthly temperature in the winter months was negative, in January it was -1.6˚C in Lazaropole and -4.6˚C in Popova Shapka. The highest average temperature was recorded in July with 16.9˚C in Lazaropole and 14.2˚C in Popova Shapka and August with 16.5˚C, ie 14.2˚C, respectively. The average annual temperature variation is about 18.8˚C.

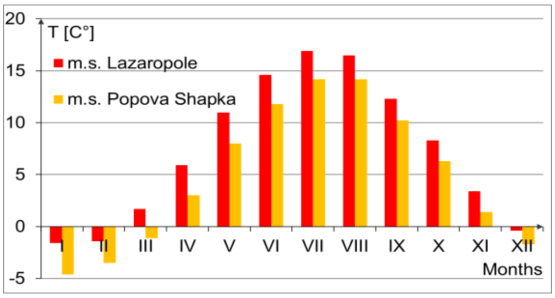

Figure 7. Average monthly air temperatures (m.s. Lukovo Pole and Popova Shapka, 1981-2010)

The average annual amount of precipitation for the period from 1961 to 1990 measured at the

Lazaropole meteorological station is 1059.09 mm. The highest average amount of precipitation was measured in November and was 145.60 mm, and the lowest average amount of precipitation was recorded in July with 48.86 mm and August with 50.43 mm.

The average annual amount of precipitation for the period from 1961 to 1990 measured at the Popova Shapka meteorological station is about 901.36 mm. The highest average amount of precipitation was measured in November and was 104.16 mm, and the lowest average amount of precipitation was recorded in February with 53.39 mm and August with 59.06 mm.

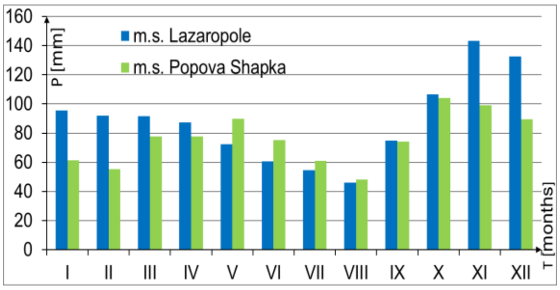

Figure 8. Average monthly precipitation (m.s. Lazaropole and Popova Shapka, 1961-1990)

2.5 HYDROLOGIC MODEL HEC-HMS

The river basin model is created based on a digital spatial model of the terrain. With the help of GIS processing (Spatial Analyst) it is determined the basin area of the river C. Kamen and its sub-basins. The terrain data is transformed into a spatial database in an appropriate format (ArcGIS Shapefile), which is used for input into the HEC-HMS model in the Background Maps section.

The base map added to the river basin model is a shapefile., obtained by processing the river basin in the Arcmap software package. The basin of the river Crn Kamen, up to the profile

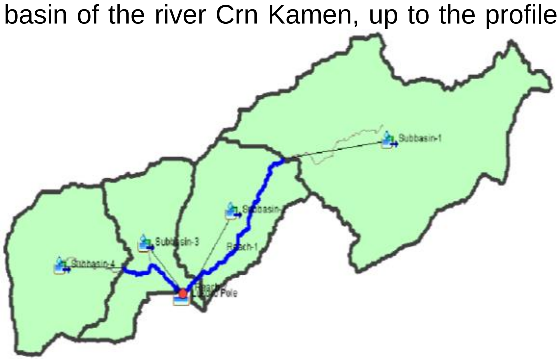

Figure 9. The basin with its sub-basins and their interconnections

of the planned Lukovo Pole dam, is divided into four sub-basins with different surfaces. Figure 9 shows the river basin of the river Crn Kamen with the subbasins Subbasin-1, Subbasin-2, Subbasin-3 and Subbasin-4, their interconnections (Reaches), as well as the outlet profile of the basin , marked with Lukovo Pole.

Input parameters in the model are as follows:

- the CN number for each of the sub-basins, defined according to Corine;
- concentration time Ts, calculated according to SCS: $Tc = (0.868 \cdot Lt^2/St)0.385$;
- precipitation, daily precipitation for 1975.

Table 3 Calculation of the number of concentration Ts for each of the sub-basins

	CN	Lt [km]	St [‰]	Tc [h]	Tc [min]
Sub-basin 1	77.51	7.69	46.1	1.042	62.535
Sub-basin 2	75.27	2.07	55.1	0.354	21.254
Sub-basin 3	75.69	4.88	27.9	0.891	53.457
Sub-basin 4	73.67	2.29	30.9	0.478	28.703

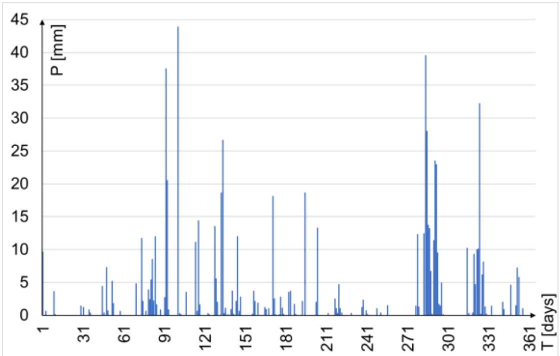

Figure 10. Daily measured precipitation for 1975, m.s. Lazaropole

During the hydrological modelling of the river basin of Crn Kamen, the SCS Unit Hydrograph Transform Method is used as a transformation method, or method for transforming precipitation into runoff according to SCS recommendations, which is parametric method and is based on the relationship between input (precipitation) and output (flow). The simulation was made for a time period of one year (start 12/31/1974, 00:00, end 12/31/1974). The daily runoff hydrograph calculated with HEC-HMS is shown in Figure 11, and the results for all the elements of the hydrological model in Table 4.

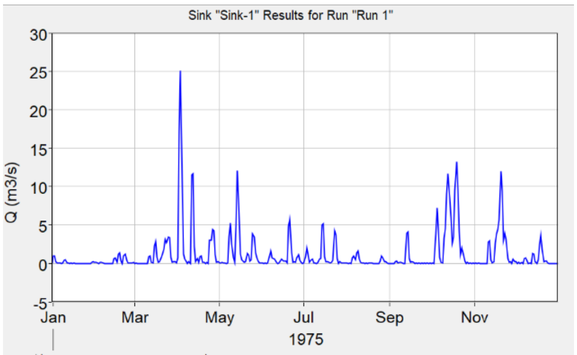

Figure 11. Hydrograph of daily flows in the r.Crn Kamen in 1975, obtained in HEC-HMS

Table 4. Summary table of results in HEC-HMS

Hydrological element	A $[km^2]$	Qmax $[m^3/s]$	T	V [mm]
Reach 1	25.23	7.7	03/04/75	666.93
Reach 11	51.63	14.6	03/04/75	668.68
Reach 2	33.98	10.1	03/04/75	669.56
Reach 3	10.20	3.5	11/04/75	668.95
Outlet 1	51.63	14.6	03/04/75	668.69
Sub-basin 1	25.23	8.9	11/04/75	659.14
Sub-basin 2	8.75	3.1	11/04/75	653.61
Sub-basin 3	7.46	2.6	11/04/75	654.66
Sub-basin 4	10.20	3.5	11/04/75	649.55

2.5.1 Calibration of the model

The adaptability of the simulated results with the measured values can be seen from the similarity between the runoff hydrographs, Fig.12. However, the quality and validity of the model can be assessed through the correlation coefficients: Nash Sutcliffe Efficiency (NSE) or Nash-Sutcliffe Efficiency, (0-1), and Root Mean Squared Error Ratio (RMSE) (<1).

In this case, it can be seen that RMSE has a value of 1.2, greater than 1, and Nash-Sutcliffe is -0.385, less than 0, which means that the model cannot be accepted as valid. Therefore, it is necessary to perform calibration and validation of the model, by changing certain input parameters, in order to obtain valid output results close to the measured values.

Calibration includes optimization of CN number values and control of correlation coefficients. With the following values for CN (83,586 for sub-basin 1, 79,458 for sub-basin 2, 79,161 for sub-basin 3 and 55,239 for sub-basin 4) RMSE after calibration has a value of 0.9, less than 1, and Nash-Sutcliffe is 0.195, within 0, Fig. 13. With these values, the model can be accepted as valid and used in further analyses.

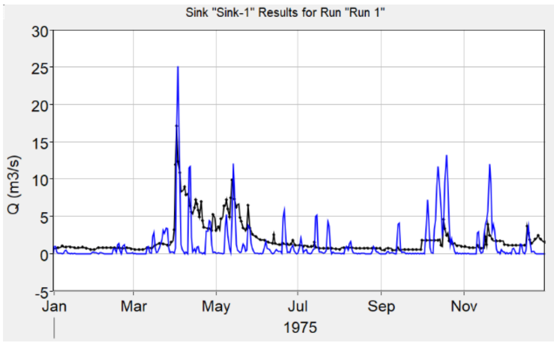

Figure 12. Runoff hydrograph of measured and simulated data

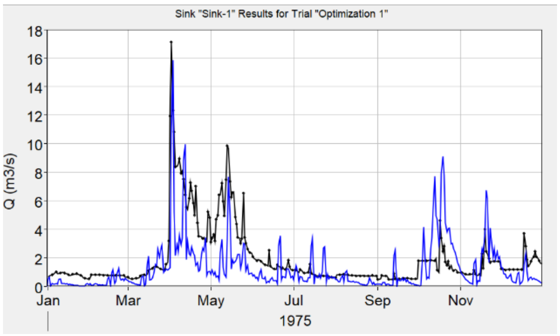

Figure 13. Runoff hydrograph of measured and simulated data after calibration

3 DEFINING HIGH WATERS

Statistical methods were used to determine the high waters of the river Crn Kamen up to the Lukovo Pole dam profile, that is, the maximum flows with a certain recurring period were determined by methods based on historical data of registered high waters. The analysis used the series of maximum registered annual flows of the river Crn Kamen to the Lukovo Pole dam profile for the period 1974-2009, Figure 14.

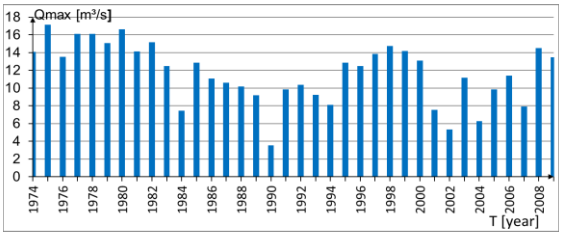

Figure 14. Maximum recorded annual flows of the river Crn Kamen

Determination of the statistical parameters of the sequence of maximum registered annual flows of the river Crn Kamen to the profile of the Lukovo Pole dam for the period 1974-2009, as well as the application of probability distribution functions was done using the HEC-SSP software package. Statistical Software Package - HEC-SSP was developed by the US

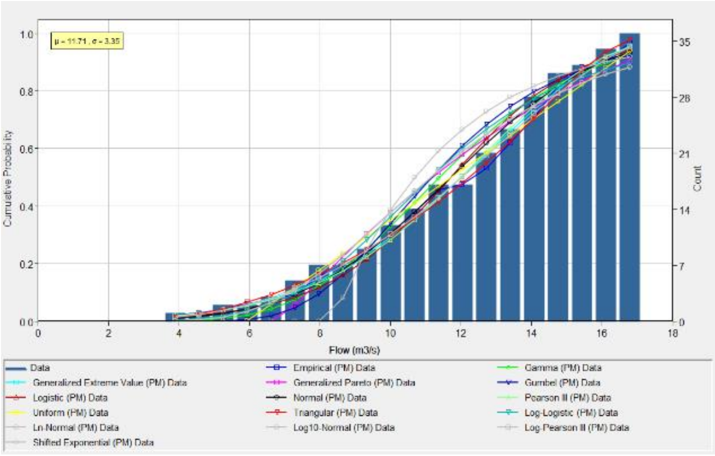

Figure 15. Theoretical distributions considered in HEC-SSP

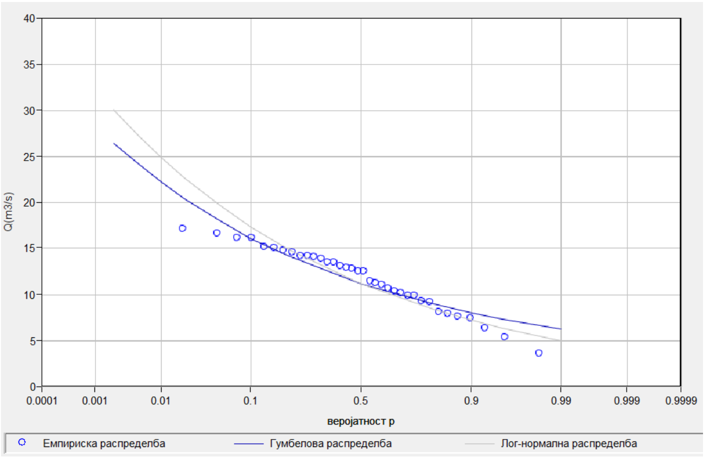

Figure 16. Most adequate distributions chosen

Army Corps of Engineers as part of the research and development program of the Hydrologic Engineering Center (HEC).

Table 5. Statistical parameters of the series of maximum annual flows in a period of 36 years calculated in HEC-SSP

Summary Statistics

Statistic	Original Data	Processed Data
Min	3.562	3.562
Max	17.123	17.123
Median	12.482	12.482
Mode	3.562	3.562
Sample Size	36	36
Mean	11.711	11.711
St Dev	3.346	3.346
Skew	-0.497	-0.497

In total 15 theoretical distributions were considered, Figure no. 15, and the adaptability was evaluated according to the Kolmogorov-Smirnov and Chi-Square tests. The following distributions are presented as the most adequate (Test statistics - Standard Product Moment): Gumbel's and Log-normal distribution, Figure 16. The Log-normal distribution was chosen for the analysis of the high flows in a specific recurrence period. According to this analysis, the determined values for the flows with different recurrence periods are shown in Table 6.

Table 6. Flows with defined recurrence periods according to Log-normal and Gumbel's distributions in HEC-SSP

p [%]	Log-normal	Gumbel's
	Q [m^3/s]	Q [m^3/s]
0.2	31.5	27.3
0.5	28	24.6
1	25.4	22.6
5	19.8	18
20	14.9	14.1
50	11.1	11.2
80	8.3	9
90	7.1	8
95	6.3	7.3
99	4.9	6

4. RESULTS ANALYSIS

The analysis of the results obtained by simulation of the hydrological model for the river basin of Crn Kamen, Figure 17, show that the maximum flow obtained from the simulated flow data is Q=14.6 m^3/s, which appears on 04/03/1975. The total runoff volume obtained from simulated data is V=668.69 mm.

If the measured data is analyzed, the maximum flow is Q=17.1 m^3/s and appears on April 2, 1975. Total runoff volume obtained from measured flow data, V=1153.17 mm.

The difference between simulated and measured data is also confirmed by model validation, Figure 17, where it can be seen that RMSE=1.2, and Nash-Sutcliffe is -0.385. After calibration of the model, these values are within the limits of acceptance, Figure 18, RMSE=0.9, and Nash-Sutcliffe is 0.195, and the validity of the model can be confirmed. With the calibration of the model, the maximum flow obtained from the simulated data is Q=15.8 m^3/s on 04/03/1975.

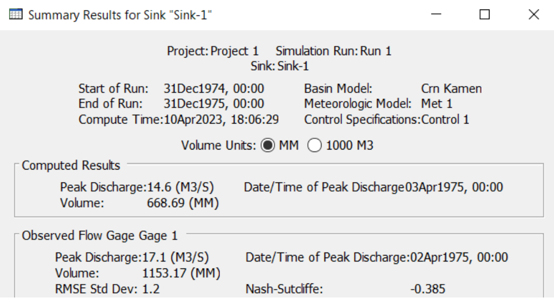

Figure 17. Results of measured and simulated data

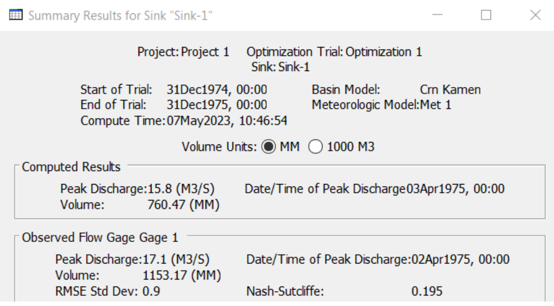

Figure 18. Results of measured and simulated data after model calibration

The definition of high waters of river Crn Kamen made with the HEC SSP software package, according to a larger number of theoretical distributions, shows that the Log-Normal distribution best adapts to the empirical distribution and it is recommended for use in further analyses.

5. CONCLUSION

From the analyzes made in this paper, it can be concluded that the hydrological modeling of a river basin with the help of appropriate software packages (SWAT, HEC HMS, HEC HSS, etc.) provides the opportunity for a quick, precise and accurate definition of the necessary parameters for an appropriate hydrological analysis of a river basin. In this particular case, for the river Crn Kamen, the average height above sea level of the river basin is 1896.5 m, the area of the river basin is A=70.6 km^2, of which 52.80 km^2 fall on the river basin area up to the profile of the future Lukovo Pole dam.

Most of the river basin, with an area of 39.5 km^2, is covered with natural grassland, and a part with shrub and vegetated areas, with an area of 9.6 km^2 and 3.7 km^2 respectively.

Determination of the hydrological sequences of flows in the river was made using the available measured data: historical sequences of characteristic flows (minimum, maximum and average monthly) from the Lukovo Pole hydrological station for the period 1974-2009.

The hydrological modeling of the river basin of Crn Kamen was done using the HEC-HMS software package. The model was made in order to define surface runoff based on measured precipitation data, that is, the transformation of precipitation into surface runoff was made. Precipitation data were used from Lazaropole station. Statistical analysis of hydrological data was done with the HEC-SSP software package.

The measured data for daily flows of the river Crn Kamen at the profile where the construction of the dam is foreseen for the period from 1974 to 2009 were used to define the high waters for different recurrence periods. The high waters of the river Crn Kamen with different recurrence periods have been analyzed by applying several theoretical distributions. The Log-Normal distribution best fits the empirical distribution and is recommended for use in further analyses.

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