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Euro-CASE CAETS

EDITOR-IN-CHIEF'S WORD

Dear readers,

It has become a tradition that in its Bulletin the Croatian Academy of Engineering presents scientific achievements of its members and associates to the wider world.

The printed and electronic edition of this issue has been edited by our guest editor Meho Saša Kovačević, a prominent member of the Academy as well as the Secretary of the Department of Civil Engineering and Geodesy.

I believe that you will be interested in reading the presented contributions.

Editor-in-Chief
Vladimir Andročec, President of the Croatian Academy of Engineering

EDITOR'S WORD

Dear readers,

In this edition of HATZ Bulletin Engineering Power we continue to present excellent research groups of the University of Zagreb that – in their professional activities – adopt a multidisciplinary approach, combining best practice of the 'traditional' engineering methodologies with new and emerging technologies.

The Guest-Editor of this issue is Meho Saša Kovačević, Ph.D., Professor of the University of Zagreb, Faculty of Civil Engineering, Associate Member and Secretary of the Department of Civil Engineering and Geodesy of the Croatian Academy of Engineering.

Editor
Zdravko Terze, Vice-President of the Croatian Academy of Engineering

FOREWORD

Civil engineering is one of the oldest and broadest engineering fields, dealing with the design and construction, but also with the maintenance of the naturally and physically built environment. It includes a vast spectrum of works such as buildings, roads, railways, bridges, canals, dams, sewage systems etc. It is a fact that civil engineering does not develop at the same progressive rate as some other engineering disciplines (i.e. mechanical, electrical or computing engineering) where new discoveries are introduced practically on a daily-basis. The objective reasons for this are to be found in the nature of civil engineering which has been developing gradually not for centuries, but for millenniums. However, the implementation of numerical codes, modernization of investigation and testing equipment, much more powerful construction machines have all led to the implementation of innovative techniques and technologies in civil engineering over the last few last decades. At the same time, cities worldwide rapidly developed and the rate of urbanization is so high that by 2050 two-thirds of the world's population will live in urban areas. Safe and quality civil engineering works are therefore not desirable but crucial. At the same time, while our cities grow, our existing infrastructure continuously age and deteriorate and there is a strong need to maintain and even to improve its level of safety and functionality. Geotechnical engineering, as one of the branches within civil engineering, is somewhat specific. Since that all civil engineering works are in some way connected to soil and rock, challenges which geotechnical engineers need to face are numerous, mainly due to the fact that they deal with materials of characteristics which need to be investigated, unlike concrete, steel or wood, whose characteristics are well known to the designer.

The papers listed below represent a part of the scientific and professional work of experts of the Department of Geotechnics, Faculty of Civil Engineering, University of Zagreb. The Department of Geotechnics is one of nine departments of the Faculty of Civil Engineering and it is organised in two chairs, the Chair for Soil and Rock Mechanics and the Chair for Geotechnical Engineering. Through investigation works, design, quality control, consultancy services and scientific-research work the Department has a strong influence on current and future trends in geotechnical engineering both at the national and international level. The first paper presents several innovative technologies and techniques in geotechnical engineering such as non-destructive testing methods, utilization of industrial waste in sustainable soil improvement, use of geotechnical structures for the utilization of geothermal energy and risk management which is more often implemented in geotechnical engineering, especially when there is a need for a rational decision-making process conducted by the infrastructure managers/owners. All these technologies and techniques emerged in the last several decades and clearly represent the trends in geotechnical engineering. The second paper presents the efforts in safety enhancement of the existing railway infrastructure through the demonstration of activities conducted within the three ongoing H2020 research projects. In these projects, experts of the Department of Geotechnics actively collaborate with researchers (and some of them are co-authors of the paper) and infrastructure managers all around Europe in order to implement and to develop state-of-the-art techniques further and tools in the field of railway infrastructure safety. The last paper presents the possibilities of Unmanned Aerial System (UAS) application in Engineering Practice including the development of 3D models to determine volumes, areas and cross sections in a very short time, which is in most cases the basic information in practical engineering.

Guest-Editor
Meho Saša Kovačević, University of Zagreb Faculty of Civil Engineering

CONTENT

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Some Innovative Technologies and Techniques in Geotechnical Engineering

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Abstract

Several emerging technologies and techniques have been in focus of geotechnical community during the past few decades. This paper presents some of them, such as non-destructive testing methods and utilization of industrial waste in sustainable soil improvement. These elements represent a step forward from the classical concept of geotechnical engineering which is mostly based on destructive investigation works and application of standard engineering cement-based materials. Further, perspectives faced by geotechnical engineering in the use of the shallow geothermal energy will also be presented due to more and more prominent needs for the utilization of this valuable renewable energy source. Finally, during the last few years risk management has been implemented in geotechnical engineering, especially when there is a need for a rational decision-making process conducted by the infrastructure managers/owners.

1. Introduction

Geotechnical engineering connects civil engineering and geo – sciences and as such it comprises a wide range of activities which are necessary in order to secure a safe, functional and economical structure. Investigation works in geotechnical engineering, including the ones for the assessment of the condition of existing structures, are still predominantly conducted using destructive methods. Classical soil and rock investigations primarily include borehole drilling, which is the basic geotechnical test that provides an insight into the geological structure of the foundation soil. By carrying out the SPT tests during the drilling, as well as taking samples and their testing in the laboratory, an insight into physical and mechanical properties of the foundation soil is obtained. However, this traditional method has certain limitations in terms of time and finances, and these limitations were the main motive for the development of the non-destructive methods that would, besides saving these resources, encompass larger volumes being investigated. Of course, these non-destructive methods are still burdened with certain disadvantages, which partially restrict their use, but an increasing trend of their application is evident. Advantages of non-destructive testing come to the fore in the assessment of the condition of strategic infrastructure line structures such as railway lines, road and motorway network, embankments for flood protection, etc. In order to evaluate a method as acceptable and successful, there must be a change in the physical properties of soil and rock to which the method is sensitive. Therefore, the choice of geophysical methods suitable for the observed problem is of crucial importance. The type of physical properties clearly determines the scope of application of non-destructive methods [1]. Knowledge and experience is needed to interpret the data collected through non-destructive methods, because the set of data obtained from tests does not have to indicate a specific condition in the soil or rock, which may result in unsatisfactory results. The paper will demonstrate several applications of non-destructive testing examples in the field of geotechnical engineering.

The urbanization process has several negative effects on the environment and on social life [2]. One of the most prominent negative effects is the production of industrial waste materials, where huge amounts of thermal power plant byproducts, as well as steelworks byproducts, need to be disposed in a proper manner. In the same time, rapid urbanization leads to lack of suitable construction surfaces for further development activities caused by progressive city development. Two solutions are possible to overcome the problem of construction site deficiency. The first one is expansion of cities in underground where an increasing number of underground structures gives rise to the complexity of underground building systems. The second solution is to 'stay on surface' and to utilize the ground which is, from the geotechnical aspect, originally unsuitable for construction.

The later one is still more often applied. These mentioned problems of non-satisfactory ground characteristics and accumulation of industrial waste materials on deposits can be simultaneously dealt with a ground improvement as one of the disciplines which tend to reuse waste materials. In second part of 20th century, a series of techniques for engineering treatment of ground were developed in order to enhance its geotechnical characteristics and this paper also discusses potential of using industrial byproducts for different ground treatment technologies.

Geothermal energy is thermal energy generated and stored within the Earth. The exploitation of geothermal resources is divided into deep and shallow resources, where the 'separation line' is roughly determined by a depth of 400 m [3]. Geothermal energy is a very attractive energy source that has many advantages over conventional energy sources (coal, natural gas and oil). The most significant advantage is in the fact that it is a renewable and clean energy source with no negative environmental impact. Croatian experience in the exploitation of geothermal energy was historically mainly based on the possibilities of exploitation of deep geothermal resources. In particular, this form of exploitation is attractive in the Pannonian basin where the geothermal gradient exceeds the world average. However, during the last few years systems for exploiting shallow geothermal resources have been developed at a high rate. Based on the principle that soil/rock and groundwater temperatures at a specific depth are constant throughout the year, numerous scientific studies and subsequent implementation in practice are based on applying underground structural elements in the process of exploitation of shallow geothermal energy, as presented in the paper.

The importance of risk management in geotechnical engineering was recognised in the second half of the 20th century. In Croatia, systematic research on the identification, analysis and response to risks in geotechnical interventions has been conducted during the past 15 years. The primary objective of managing each project, including those of a geotechnical nature, is to implement a project for a predetermined period of time with planned costs and with satisfactory quality. Contrary to this is the fact that due to insufficient knowledge of soil and rock conditions, the implementation of a geotechnical project takes place in conditions of uncertainty, meaning that the outcomes of all envisaged events cannot be predicted with certainty. Every geotechnical project goes through several phases in its evolution and in each phase, the number of potential risks or adverse events with an unfavourable outcome that may negatively impact the success of the project can be determined. Virtually every activity carried out in implementing a project is burdened by the possibility that something might go wrong, so the implementation of the risk-based management plays an important role in geotechnical engineering.

2. Application of non-destructive testing tools

One of the first major applications of non-destructive testing in Croatian geotechnical practice was the dynamic testing of pile capacity and testing of the pile columns integrity. Dynamic testing of the capacity is based on the measurement of deformation and acceleration of the pile induced by a shock impact using relatively heavy loads. The weight of the load is 1-2% of the expected static capacity of the pile [4]. The height from which the load falls is 0.5-3 m. At a depth of at least two pile diameters, two or four deformation gauges or two or four accelerometers are placed at the shaft area of the pile. Based on measurements of deformation and the presumed elastic modulus, the dynamic force in the pile is calculated. Integrating the acceleration provides the velocity. Using numerical analysis based on a one-dimensional wave equation, the capacity of the pile is determined from the measured force and velocity. The dynamic process is much faster with a considerable lower cost compared to the static test. Testing of the pile column integrity is based on measuring acceleration or velocity of the column head caused by mechanical impact shocks. A low-deformation impact generates a pressure wave that travels toward the bottom of the column. Due to changes in its cross-section or in the quality of concrete, the wave is reflected and the tension wave travels toward the top of the column. By making an assumption of the wave propagation velocity in the column, defects in the columns can be located, as well as changes in the cross-section or cracks. The test is quick, cost-effective and allows testing of tens of pilots in a single day.

Figure 1 shows examples of dynamic testing of pile capacity and the integrity of a column for the requirements of foundations at the Drežnik viaduct on the Zagreb-Split-Dubrovnik motorway. A total of 69 dynamic tests and 358 integrity tests were performed.

One of the most widely used non-destructive geophysical method in Croatian geotechnical engineering is the Spectral Analyses of Surface Waves (SASW). It is used

Fig. 1. Dynamic testing of the pile capacity and integrity of pile columns

to determine the stiffness of soil at various depths, the compaction quality of road fills and fills made of reinforced soil, the thickness of transportation structures, the thickness of the concrete lining in road and hydropower tunnels and the quality control of soil improvement.

The measuring process is reliable since it avoids disturbances in the soil due to drilling, extracting samples and inserting samples in laboratory equipment. The method solves some of the fundamental problems of surface refraction, since it can reveal a softer layer that lies beneath a stiffer layer. The SASW method measures the layer stiffness and thickness with an expected accuracy of 5% and it is based on the dispersion characteristics of Rayleigh waves. It takes into account the fact that Rayleigh surface waves of different wavelengths or frequencies disperse to different depths [5]. Surface waves are generated mechanically by vertical impact at the ground surface. Vertical sensors, geophones and accelerometers are placed at predefined intervals and measure the velocity and acceleration of a passing wave. Fourier analysis transforms the received signal from the time to frequency domain and the transformed signal is subjected to further spectral analysis. Spectral functions of the phase (cross power spectrum, coherence) assist in determining dispersion characteristics of the wave. Back-analysis utilises the dispersion characteristics of the surface wave and result in stiffness values of horizontally layered soil.

Figure 2 shows an example of the test implementation and its results for the quality control of soil improvement with stone columns technique at seven sections of the Zagreb-Macelj motorway. A total of 13,090 stone columns were constructed (approximately 104,780 m'). A total of 856 tests were conducted before and after the improvements.

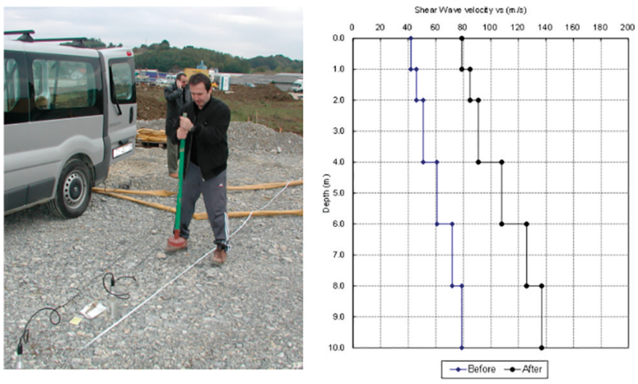


Fig. 2. The SASW method on the Zagreb-Macelj motorway

Further, very common is the use of seismic non-destructive geophysical methods, which are based on the determination of longitudinal wave velocities. Methods of seismic refraction and reflection, and their combination called the hybrid method, have important application in Croatian geotechnical engineering practice. The refraction and reflection methods define the velocity profile of longitudinal waves based on depth. The propagation velocities of the waves depend on the stiffness properties of the material through which they pass after generation of impulse or controlled vibrations at the ground surface. At the boundaries between the layers the waves are reflected or refracted, and then travel back to the surface. The arrival of a wave at the surface is detected by measuring sensors – geophones, which are placed at predefined positions. The time it takes for the waves to reach the geophones is measured. The seismic refraction method which analyses the refracted waves and reflection method which analyses reflected waves, have their advantages and disadvantages. The zone of weathering, typical for karst, is successfully registered using refraction, and provides significantly better results at lower depths. However, reflection has an advantage of being a test for identification of faults, fissures, cracks or caverns at greater depths. The hybrid seismic method combines independently obtained results of refraction and reflection into a single profile, providing geologists and geotechnicians a better insight into the engineering-geological profile being investigated [6].

Figure 3 shows implementation and test results of hybrid seismic method conducted for the requirements of the foundation project for column S17 at Pelješac Bridge [7]. Testing was conducted along two profiles, 09PELJ-1 with a length of 60 m and 09PELJ-2 with a length 80 m. Testing conducted on profile 09PELJ-1 gave possible positions of faults in a north-east direction, which is associated with a mass of debris and loose material, clearly recognisable. Profile 09PELJ-2 runs along the fault, which is seen as a zone of non-compacted material. Zones containing this kind of material are registered due to a reduction in the velocity of seismic waves in that particular area.

When appropriate, the refraction method is used in combination with Ground penetrating radar (GPR) as an electromagnetic geophysical method which provides a high-resolution image of dielectric characteristics of investigated media. The depth of testing varies considerably, and generally depends on the frequency of the antenna used [8]. Ground penetrating radar surveying is based on the principle of transmitting electromagnetic signals of different frequencies into the ground, rock or structure by using an appropriate antenna. The emitted

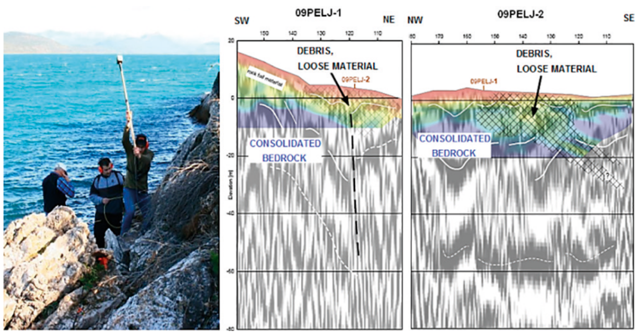


Fig. 3. The hybrid seismic method applied at the Pelješac Bridge

waves may attenuate, reflect or refract. When a wave encounters an obstacle, part of the energy is reflected back to the receiver, and the reflection is processed by forming a continuous profile of the material's electrical properties. The frequency of the antenna determines two key test parameters – the test depth and the resolution. At higher frequencies, a lower investigation depth can be achieved, but image has higher resolution. The use of lower frequencies results in lower resolution images, but a greater investigation depth can be achieved.

An example for the combined use of seismic refraction and GPR method is the location of an opening with a depth of approximately 3 m and aperture area of 10 m^2, appeared between the two lanes on Croatian highway. Figure 4. Detailed geological mapping indicated that the reason for this is due to the so-called 'reverse' karstification where the rock mass dissolves from bottom layers to top layers [9].

Fig. 4. The opening between two highway lanes

In order to determine the size and dispersion of the cavernous system, geological and geophysical investigations were carried out. Geophysical surveys included ground penetrating radar (GPR) profiling whose main task was to identify potentially 'karstification – caused' anomalies beneath the highway which could endanger its functionality and safety, while seismic refraction geophysical surveys were carried out in the area between the lanes and it was used to determine the volume and position of the cavern.

One of GPR profiles, Figure 5, located in the vicinity of surface opening, suggests that karst-linked features are presented. Therefore, GPR investigation has fulfilled its main task and also provided a useful information on where the optimal position to conduct seismic refraction investigations is.

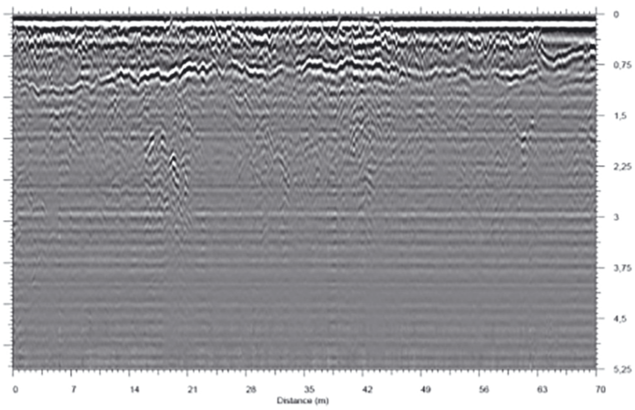


Fig. 5. One of the investigated GPR profiles on the location of an opening between two highway lanes

After the interpretation of refraction data, a longitudinal velocity profile was obtained and it is shown in Figure 6. A feature which can be easily seen is an area of the reduced velocity of seismic waves assigned to cavern which caused material collapse on the surface.

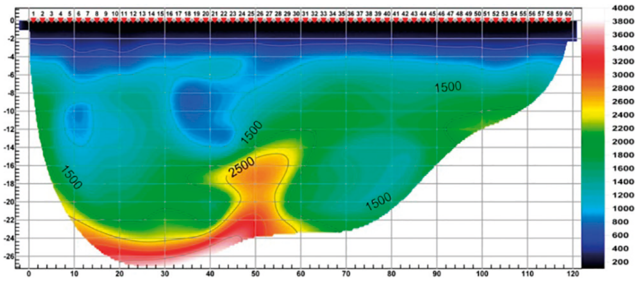


Fig. 6. A refraction profile with evident position and extent of zone with lower velocities [16]

Another example of the combined application of geophysical methods is the condition assessment of the 70 years old tramway embankment in Zagreb, located on line 2.7 km long line between Mihaljevac and Dolje stations [10]. In order to assess the condition of embankment, which will serve as a basis for remediation works, a non-destructive geophysical methods of Continuous Generation of Surface Waves (CSWS) and Ground Penetrating Radar (GPR) were implemented. The Continuous Generation of Surface Waves (CSWS) is a seismic geophysical method which represents a modification of Spectral Analysis of Surface Waves (SASW) method which uses a vibrator as an energy generator. This provides generation of controlled frequencies, overcoming the issues of the lack of certain frequencies from the source spectrum evident from SASW method. The GPR method, Figure 7, was used for the detection of geometrical features such as layer bound-

Fig. 7. Conduction of GPR investigations for the tram embankment condition assessment [10]

aries and man-made or natural anomalies, while the seismic CSWS method was used for the determination of small strain stiffness of the embankment.

Figure 7 shows a section of the investigated line, where the GPR profile is the upper one, and CSWS results are shown through the developed classification system based on obtained stiffness values. A cca 85 m zone of extremely small values of small strain stiffness to greater depths (lowest stiffness near the surface) can be seen. The GPR results also point to certain anomalies in this section. In this part of section, anomalies of tram tracks along with tilting of tram poles was noticed through the visual inspection. This demonstrates the advantages of using non-destructive methods for the condition assessment, since the destructive methods would yield much larger time and financial resources to obtain an insight into embankment condition.

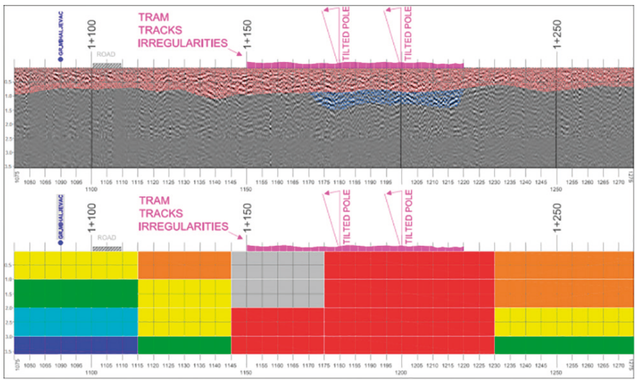


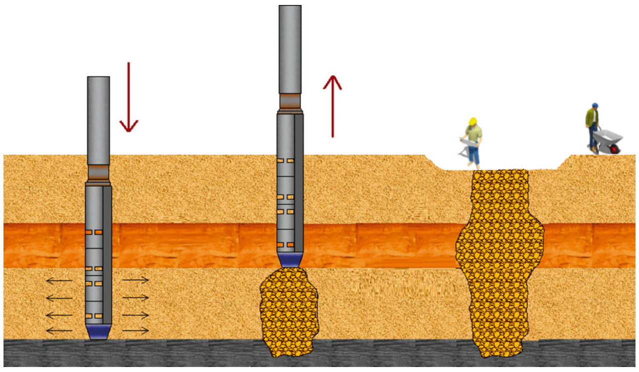
Fig. 8.. GPR and CSWS results for one section of tram line [10]

3. Use of industrial waste materials in sustainable ground improvement

In today's construction industry, there is an increasing need for the foundation of residential, commercial and infrastructure structures on ground possessing low stiffness characteristic or insufficient load-bearing capacity. Improving soil mechanics is a technological process that increases the load-bearing capacity of soil, reduces or maintains under control total and differential settlements, reduces the time for deformations to occur, reduces soil permeability, completely removes water from the ground by creating internal drainage systems, increases erosion stability of the soil and reduces the danger of liquefaction. This involves a controlled change in state, nature and behaviour of the soil in order to achieve planned and satisfactory results for existing or future engineering activities. The use of various technological processes transforms natural soil into a new material that provides better physical and mechanical characteristics. A great potential in using industrial waste materials for sustainable soil improvement have applications of the slag in stone columns technique and use of fly ash in deep soil mixing technique, Figure 9.

Fig. 9. Industrial waste materials: fly ash (left) and slag (right) [2]

The technology used in stone columns is based on the implementation of columns of gravel or crushed stone into the ground by pressing in or through vibration. In combination with the surrounding soil, this kind of granular material inserted using a vibrator has a higher stiffness and provides greater resistance to shear forces. It increases the load-bearing capacity of the foundation, while reducing settlement. Due to the high permeability of stone columns, the consolidation time is significantly decreased, consequently leading to a successive increase in the shear strength of natural soils [11]. The danger of the onset of liquefaction is also reduced (Figure 10).



Fig, 10. Stone columns technology [2]

Slag is a waste product generated from the purification and alloying of metals. Large amounts of the material can be found on the territory of the Republic of Croatia, totalling about 1.8 million tonnes. The material is easily accessible from steelworks in Sisak and Split. Results acquired from slag samples at the Faculty of Civil Engineering in Zagreb [12], where they were for tested for the usability of slag as an aggregate in concrete, includes particular tests implemented to evaluate the quality of the slag used in stone columns all in compliance to British standards. These results showed that the available slag in Croatia does meet the criteria for use in stone columns. The impact of slag on the environment has also been confirmed as non-hazardous and easily controllable. Although the idea of using slag in stone columns is not new, it has not been accompanied by adequate research or construction techniques. In Croatia, not a single stone column has been constructed using slag as substitute for gravel or pulverised stone.

By using mechanisation, deep mixing technology breaks down the soil structure and afterwards a binder is mixed

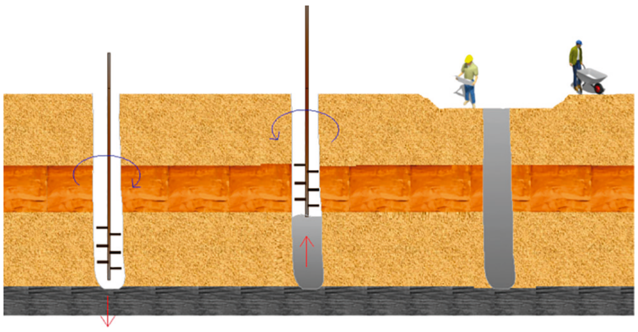


Fig. 11. Deep mixing technology [2]

into the soil resulting in elements of various shapes and configurations [11]. Ground columns, when distributed in a dense grid, improve strength and stiffness of otherwise soft soils (Figure 11).

The concentration of cement and lime in a soil improvement process is usually 2-5 %. A reduction in the quantity of used cement and lime reduces consumption of natural raw materials and fossil fuels as well as CO_2 emissions. For instance, to improve one ton of soil, at least 20 kg of cement and 30 kg of natural raw materials are required including 96 MJ of fossil fuel energy. Furthermore, 18 kg of CO_2 [13] are emitted into the atmosphere. The introduction of synthetic binders such as fly ash reduces the concentration of cement and lime in the soil improvement process.

In Croatia, the only coal combustion thermal power plant, Plomin, is located on the east coast of the Istrian peninsula. It is the only thermal power plant due to the fact that energy sources in Croatia are mostly focused on hydropower. At present, there is no deposited fly ash in Croatia due to a small generated amount which is mostly used in concrete industry. The same as in Croatia, where deposition of fly ash is managed properly due to small deposits, neighbouring Slovenia has also 'settled problem' with fly ash. With total three thermal power plants in operation, Slovenia annually produces around 970,000 tons of fly ash of which most is used as fill material in construction and mining operations, while only a small portion is deposited. On the other hand, neighbouring countries as Bosnia and Herzegovina and Serbia still have huge deposits of fly ash due to large quantities of fly ash produced on the annual basis (Bosnia and Herzegovina produces annually around 2 million tons of industrial ashes, while in Serbia, five thermal power plants produce close to 7 million tons of industrial by-products annually).

4. The prospects of utilising geothermal energy in geotechnical engineering

Foundation structures, retaining structures, tunnel support systems, anchors and geosynthetics are used as parts of geothermal system for transferring heat from soil and rocks to the surface or vice-versa during the summer [14].

Referring to the above mentioned items, foundation structures are the most frequently encountered underground energy structures. Even though their primary role is to fulfil all safety and functional requirements of a particular structure, the piles can be a part of the geothermal system (they are referred to as energy piles). In case of prefabricated driven piles, the geothermal pipes are installed in the factory, while in case of piles constructed on construction site, the pipes are attached to reinforcement cages. The piles are installed to the depth defined by the design and, at the bottom of they are rotated for 180°, so that they assume the shape of the letter U. In this way a pile is used as the vertical heat exchanger, Figure 12.

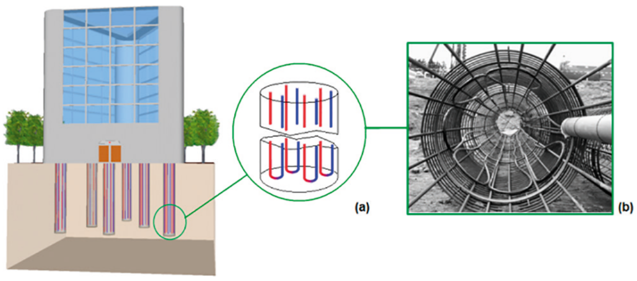


Fig. 12. Column used in energy facilities: a) pipe-positioning scheme in a column: b) geothermal pipes attached to a column reinforcement [14]

Retaining structures such as RC diaphragms, column retaining walls and even basement walls can be used effectively as part of a geothermal system, with the tubes tied to the rebars of supporting elements (Figure 13). In this case they are referred to as energy support structures.

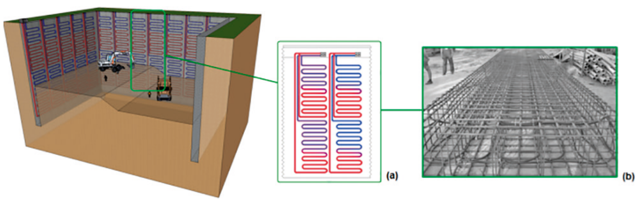


Fig. 13.. Retaining structure used in energy facilities: a) pipe-positioning scheme in a structure: b) geothermal pipes attached to a reinforcement [14]

Further, the use of TBM tunnels as parts of geothermal systems is based on utilization of prefabricated rings. After the excavation of tunnel segment, prefabricated concrete ring-shape segments are installed, containing geothermal pipes connected with the ring reinforcement, filled with working fluid and put into operation. In this way it becomes possible to use the heat of soil, or the heat generated by tunnel traffic, to heat buildings situated on the ground surface. Due to the fact that tunnels are linear structures that can measure several tens of kilometres in length, large volumes of soil or rock can be utilized in the geothermal energy exploitation process.

In Croatia, not a single underground structure has been constructed containing elements that have been used as heat exchangers in a geothermal system. Global knowledge and experience in the possibilities of using underground structures for exploiting geothermal potential has still not been implemented in Croatia. The first pilot project for the exploitation of geothermal energy using underground structures was stopped after the conceptual design phase [14]. The plans for the reconstruction of the Ksaver Sandor Gjalski Elementary School in Zagreb included a supporting structure approx. 150 m long which was designed as 20-metre high RC column wall, additionally secured using geotechnical anchors. In certain columns a heat exchangers would be located. The resulting energy would be used for heating the sports hall and associated locker rooms by using a conventional floor system.

5. Risk management in geotechnical engineering

The risk management process begins with the identification of the risk, and the objective is to form a list of key risks for each phase of a geotechnical project. In order to draw up such a list, the potential sources of risk, adverse events carrying such risks and adverse effects that occur if an expected adverse scenario occurs should be investigated. Each activity within a project can be identified as a risk or as a source of other risks, which then enters the list. A good example of this is geotechnical monitoring. Cerić et al. [15] identified the key risks involved in sustainable soil improvement, where unsatisfactory monitoring and quality control of soil improvement represented a risk on the ranked list of risks. Other identified risk factors are inadequate investigation works, selection of unsuitable soil improvement technologies, insufficiently worked out details in a soil improvement design and unsatisfactory performance of soil improvement works. Mihalinec et al. [16] characterised monitoring as a risk. They considered measurement purpose, measurement parameters, measurement equipment and measurement results as potential sources of risk in monitoring of landslides.

Risk assessment is carried out for each identified risk. The risk contains two independent components: the likelihood of risk (risk probability) and the impact of risk on the project (risk impact). Both of these components must be quantified in some way so as to analyse various risks, their mutual comparison and prioritisation. This is done by introducing the notion of risk exposure that represents the product of the risk probabilities and risk impact on the project: risk exposure risk = risk probability * impact risk [17]. Risk probability and risk impact for each identified risk can be determined using a quantitative or qualitative approach.

The quantitative approach implies that the probability of a certain risk can be calculated if there is a statistically relevant database of experiences related to similar events in the past. This creates the basis for forming the distribution function, for which the probability of occurrence, expectation, dispersion, confidence intervals and all other statistically significant parameters are calculated using statistical methods. The qualitative approach is applied when an appropriate database of previously implemented projects is unavailable. A qualitative approach to risk assessment for sustainable soil improvement by applying an analytic network process (ANP) was presented by Cerić et al. [15]. Based on the acquired risk exposure, a risk priority list is formed according to which responses to the risks are prepared as well as allocation of resources to respond to risks.

Each identified risk, depending on risk exposure value, is classified as unacceptable, undesirable, acceptable or negligible. Depending on this classification, a decision on response to each individual risk is made. If risk is classified as unacceptable, a response can be risk avoidance or risk transfer. If t risk is classified as undesirable, response can be risk avoidance, risk transfer, risk reduction or risk sharing accompanied by appropriate risk monitoring. If risk is classified as acceptable, response to risk can be risk retention accompanied by the appropriate risk monitoring. If risk is classified as negligible, it requires no response. Action taken as response to a risk may produce new risks that should be identified, analysed and, depending on risk acceptability, a response should be formulated. Thus, the risk management process becomes a cyclic process (Figure 14).

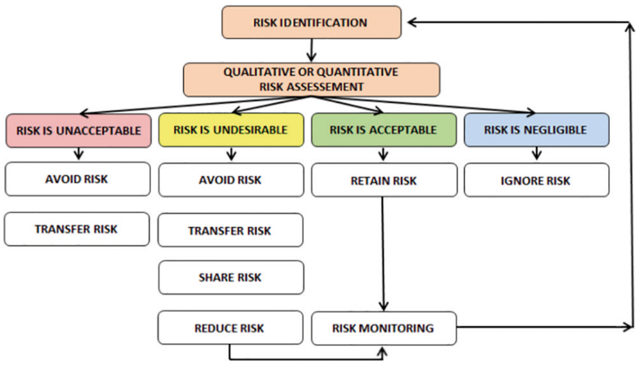


Fig. 14.. Cyclical risk management process [17]

In order to effectively manage risks in geotechnical projects, information systems for decision support should be developed. Holsapple and Whinston [18] define a decision support system as a computer system that supports the decision-making process by assisting the decision-maker in the organisation, identification, retrieval, analysis and transformation of information, selection and implementation of appropriate decision-making methods and assists also in the analysis of the acquired modelling results.

Cerić at al. [17] have developed a risk management methodology in tunnel construction using the PP-risk computer program that represents an independent and integrated information system satisfying all elements in a cyclic risk management process. PP-risk provides a basis for improving communication amongst all project participants and by using information technology it integrates all information relevant to project implementation. It was developed in a MS Visual Basic environment on the Microsoft Windows platform and consists of four mutually integrated modules: User interface, Database Management System, Method Management System and Document Management System. Data, methods and documents are accessed using the appropriate management systems, where a single user interface provides access to the entire system. From the main menu, the project list, user lists for a specific project and key risk (lists or the risks analysed at each stage) can be updated. Furthermore, risk probability and risk impact can be determined, which in turn identifies risk exposure. Finally, risk acceptability can also be directly determined once all necessary decisions are made and entered into the database (Figure 15).

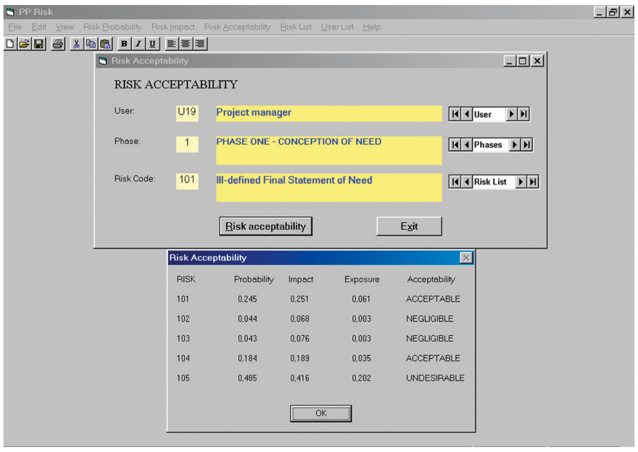


Fig. 15. The PP -Risk user interface [17]

Conclusion

The technologies and techniques presented in paper are increasingly used in the field of geotechnical engineering. Their innovative aspects represent a step forward from the classical concept of geotechnical engineering. Non-destructive methods are used whenever it is appropriate since they provide savings in comparison to destructive of both time and financial resources, while at the same time offering possibility of much larger investigated soil and rock volume. The potential application of industrial by-products in ground improvement technologies could make a contribution to the reduction of their significant deposited amounts, while at the same time some amounts of standard (cement, lime) materials, usually used for ground improvement, could be reduced, leading to positive environmental footprint. Using geotechnical structures for the purpose of utilization of shallow geothermal energy is also an emerging field with numerous examples of the installed system throughout the world. However, Croatia is still waiting for its first implementation of structures as an integral part of geothermal systems. The techniques linked with risk management help effectively manage risks in geotechnical projects and for this purpose information systems for decision support should be developed. This has become more and more evident over the past years, especially when there is a need for a rational decision-making process conducted by the infrastructure managers/owners.

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Trends in Enhancement of Safety Aspects of Existing Railway Infrastructure

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Abstract

Since more than 95% of the existing European railway network is older than 100 years, the ageing has unavoidably caused its gradual degradation and there is currently a strong need for risk assessment associated with this type of infrastructure. To increase the safety aspects, as well as to reduce the cost of remediation, railway infrastructure managers need to have more advanced tools on their disposal, since they currently make safety critical investment decisions based on poor data and an over-reliance on visual assessment. As a consequence their estimates of risk are therefore highly questionable and large-scale failures happen with increasing regularity. The paper presents the efforts conducted within the framework of some relevant scientific-research projects funded by the Horizon 2020 programme, whose overall goal is to implement and to further develop state-of-the-art techniques and tools in field of railway infrastructure safety.

1. Introduction

The first railway line in Europe was constructed over 200 years ago and by the time of World War 1, more than 95% of the existing European railway network was in operation [1]. Approximately 215,400 km of rail lines in the EU represent a significant asset for the transportation of people and goods. At the same time, considering the data as fatalities per person kilometre travelled, it can be seen that the safety performance of the rail (as well as air) is by far the safest sector, in comparison to the road and highway sector, Table 1.

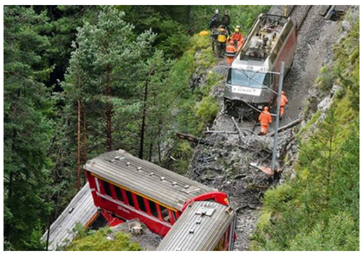
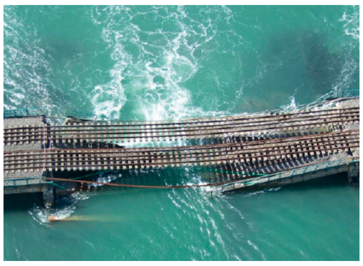
Table 1. Fatality risk on passenger transport across the EU-27 (2008-2010) [2]

Transport Mode	Fatalities (per billion passenger km's)
Airline	0.10
Rail	0.16
Car	4.45
Bus/Coach	0.43
Motorised two-wheel	52.59

This is additionally pronounced considering that the safety level of much of the EU rail network is significantly lower than modern highway infrastructure, not just in transit states, but also in the developed ones. The lack of clear strategies and non-investment atmosphere that are further fuelled by the economic crisis, have led to a situation where railways in EU are currently not at an enviable level [3]. For example, in Croatia the railway sector has been neglected for the past 30 years which can be seen through the *'Strategy of transportation development in Republic of Croatia'* [4] since 1999, where it was planned that 5% of GDP will be invested in transportation, and 25% was foreseen for the railway sector. However, only 28% of the foreseen budget was actually invested. At the same time, most of the budget was used for the development of the road and highway network.

The age of the railway infrastructure has unavoidably caused its gradual degradation and there is currently a strong need for risk assessment associated with this obsolete infrastructure, all with the aim of increasing safety and reducing the cost of rehabilitation. Even though the EU Rail Industry employs 800,000 people and generates a turnover of €73bn, there are still significant challenges in regard to prioritising the rail investments in both construction of new and remediation of existing networks. Replacement costs for civil engineering infrastructure items such as rail track, bridges and tunnels are prohibitive. The failure of a single asset results in potential fatalities, large replacement costs, the loss of service for sometimes extended periods and reputational damage. Is not only the ageing of the infrastructure that causes a failure, but other factors also, such as more and more evident climate changes, Table 2.

Table 2. Examples of climate change impact on railway infrastructure

Location of the event	Cause / consequence
 Croatia, east Slavonija, section Drenovci – state border, R105 line, May, 2014. / taken from [5]	floods / significant damage of superstructure and substructure
 Switzerland, ski resort St. Moritz near Tiefencastel, August 2014. / taken from [6]	rain / formation of landslides with impact on railway line (derailment)
 Ireland, Malahide viaduct near Dublin August 2009. / taken from [7]	bridge scour due to river flow / railway bridge collapse

The establishment of a Single European Railway Area (SERA) was seen in the 2011 Transport White Paper [8] as being critical to ensuring long-term competitiveness, dealing with growth, fuel security and decarbonisation in the EU. However, given current economic constraints and the challenges of climate change and population growth it is vital that we maintain safety level and develop optimal ways to manage our rail network and maximise the use of all resources. In past several years, EU has recognized the need for more advanced tools and techniques for increasing the safety of existing railway infrastructure. Therefore, current trends in enhancement of safety aspects will be demonstrated through several ongoing EU innovation and research projects from Horizon 2020 programme.

2. DestinationRAIL project – Decision Support Tool for Rail Infrastructure Managers

The DestinationRAIL project [9] provides solutions for common infrastructure problems encountered in diverse regions of Europe, e.g. deterioration and scour damage to bridges, slope instability, damage to switches and crossings and track performance [10]. Whilst similar failure modes are seen around the EU, the triggers (precipitation, earthquake loading etc.) are regional.

Fig. 1. Different types of failure on railway infrastructure [10]

To obtain solutions, 15 institutions from 9 European countries (Ireland, Croatia, Norway, Netherlands, Austria, Germany Slovenia, Switzerland and United Kingdom) are working closely together in development of management tools based on scientific principles for risk assessment using real performance measurements and other vital data stored in an Information Management System. The objectives are achieved through a holistic management tool based on the FACT (Find, Analyse, Classify, Treat) principle. These four phases follow the project workflow.

2.1. FIND module

The question which first arises when discussing the safety of railway infrastructure is *'how do we locate and identify risky assets before they fail?'*. The idea offered by the project is to use a combination of remote monitoring, advanced visual assessment, structural health monitoring (SHM) as well as expert judgement to determine the real-time condition of infrastructure assets. These activities are focused towards the development of algorithms to help find so-called 'hot-spots' (critical sections of the rail infrastructure) rather than classifying these after an event. Therefore, the first task includes a review of key problems faced by infrastructure manager's case histories (e.g. slope instability, bridge scour, switches and tracks and structures) followed by the identification of hot-spots. Here, a Ground Penetrating Radar (GPR), Figure 2, is used consisting of antennas measuring at different frequencies in conjunction with complementary seismic and electric tomography (ERT) measurements [11]. This enables a complete three dimensional image of the investigated section and allows detection of anomalies such as ballast pockets due to depression, animal burrows and the distribution of water content.

Fig. 2. Conduction of multi-channel GPR investigations within DestinationRAIL project

Furthermore, the project aims to develop a methodology to continuously monitor critical track infrastructures, such as switches and crossings, using inbuilt sensor technologies. The sensor communicates with passing trains / monitoring trains to inform the status and condition of the switch. A data analysis and storage system was developed and installed, as well the communication system to transfer data in real time. The project thus develops efficient screening methods to determine dynamic properties of railway tracks, locate hot-spots for adverse track deterioration, sources of annoying environmental vibration emission and areas where adverse track response at increased train speed can be expected.

Besides the railway superstructure, the project deals with monitoring of earthworks and other engineering structures along the line. Within these activities, a drone with a digital camera is used, which can perform the rapid assessment of slopes. In particular, using a special software, the digital data can be transformed into a 3D orthographic image of the slope which can be used directly in the stability analysis, Figure 3.

Fig. 3. Drone application for the determination of railway slope cross-sections

To increase the insight into the structure's health and to improve maintenance decision making in regard to engineering structures along the line, advanced structural health monitoring (SHM) concept is developed.

2.2. ANALYZE module

In order to deal with *'how do we determine the real-time safety of existing infrastructure?'* issue, the project introduces an idea of using advanced models updated using monitoring data from FIND module. The advanced probabilistic models are used to assess the current condition and the effect of maintenance intervention on the remaining lifecycle.

Tasks within the activity include the development of a probabilistic framework to facilitate multi-criteria performance optimization of railway infrastructures (i.e. structures, earthworks and tracks). Also, tailored algorithms are developed to perform the statistical information updating provided on the condition of structures, earthworks and tracks. Developed frameworks are used for the assessment of structures, earthworks and tracks.

2.3. CLASSIFY module

To determine safety level and to assign scarce resources, as the next step in the project implementation, a consortium implements an interdisciplinary infrastructure management tool, based on a risk assessment framework. The framework was developed, where the critical aspect, i.e. the Hazard Assessment, was based on the real scientific data included, rather than on a subjective rating system derived from visual assessment.

A key aspect in performing efficient risk assessment is the management of the volume of data generated, so the project develops an information management system (IMS) based on smart objects. The IMS holds all the data relating to an individual asset and the network. Risk assessment methodology takes into consideration the probability of occurrence of the events to which the infrastructure objects will be subjected and the probability of the infrastructure objects providing different levels of service following an event. Risk ranking methodology is based on risk assessment methodology. It was developed to provide infrastructure managers with the decision support required to help them optimally allocate limited resources.

As the final step within ANALYZE module, Decision Support Tool (DST) was developed, which will help infrastructure managers in the decision making process in the context of dealing with a number of previously identified and ranked risks. The DST forms the basis for the development of 'pre-standard' or benchmark guidelines which can be used by infrastructure managers and stakeholders to support robust development measures which ultimately mitigate multiple risks that are associated with aging railway networks, increased traffic and climate change impacts, along with decreasing maintenance budgets.

2.4. TREAT module

Having established risk rating through CLASSIFY module, Life Cycle Analysis (LCA) is performed to prioritise investment decisions. The answer to relevant question *'how do we choose the optimal rehabilitation technique?'* is given through the set of construction techniques assessed through Probabilistic Whole Life Cycle Model. The DESTination RAIL project considers methods for the rehabilitation and construction of major elements of infrastructure including bridge abutments, transition zones, embankments and open-track.

This is achievable through two areas:

1. Development of modelling tools to optimise and prioritise maintenance based on a range of possible maintenance regimes, with the ability to constrain the model by cost, risk and operational impacts.
2. Development of novel and innovative maintenance and construction techniques for rail infrastructure including tracks, earthworks and structures. Transferring experience from other sectors and regions, e.g. highways, to the rail domain.

By implementing a holistic DST for infrastructure managers, DestinationRAIL project will (i) reduce the cost of investment by using the IMS to manage the network; (ii) contribute to monitoring and real-times analyses which will prevent unnecessary line restrictions and closures; (iii) lower maintenance costs by optimising interventions in the life cycle of the asset and (iv) optimise traffic flow in the network.

3. GOSafe project – A Global Safety Framework for RAIL Operations

The GoSAFE RAIL project [12] is another ongoing research and innovation project from Horizon 2020 programme and it gathers 10 institutions from 6 European countries (Ireland, Croatia, Norway, Netherlands, Austria and United Kingdom). The consortium consists of experts for risk-based assessment of infrastructure, artificial intelligence, object detection and data management sectors, as well the experts in network micro-simulation modelling [13].

The overall aim of the project is the development of a Network Decision Support Tool which will serve as the basis for the Global Safety Framework which provides integrated solutions to different issues related to infrastructure safety and planning. To achieve this objective, the involvement of railway Infrastructure Managers as full partners in the project is of great importance, since they currently make safety critical investment decisions based on poor data and an over-reliance on visual assessment. As a consequence their estimates of risk are therefore highly questionable and large-scale failures happen with increasingly regularity.

The Global Safety Framework aims to assist infrastructure managers [14] by:

– providing the central data repository of asset registers (geometry, location, etc.;
– integrating key performance indexes (KPIs) related to the current condition, maintenance records, failure history, processed sensor data as well as storing the dynamic data, generated as a result of different analysis, for later use;
– implementing the reliability-based assessment models and life cycle cost models on the object level;
– integrating risk assessment model based on the hazard scenarios and network effects;
– establishing a link between traffic flow model outputs, which makes estimations of traffic disruption impacts based on the planned and unplanned maintenance activities;
– assisting in maintenance decision making by recommending maintenance treatments and maintenance plans as a result of following the procedural flow of defining the scope, objective(s)

The information flow of all components of the Global Safety Framework is given in Figure 4. Other than developing a GSF, the project focuses on other objectives as well. These include (i) developing a range of obstruction detection

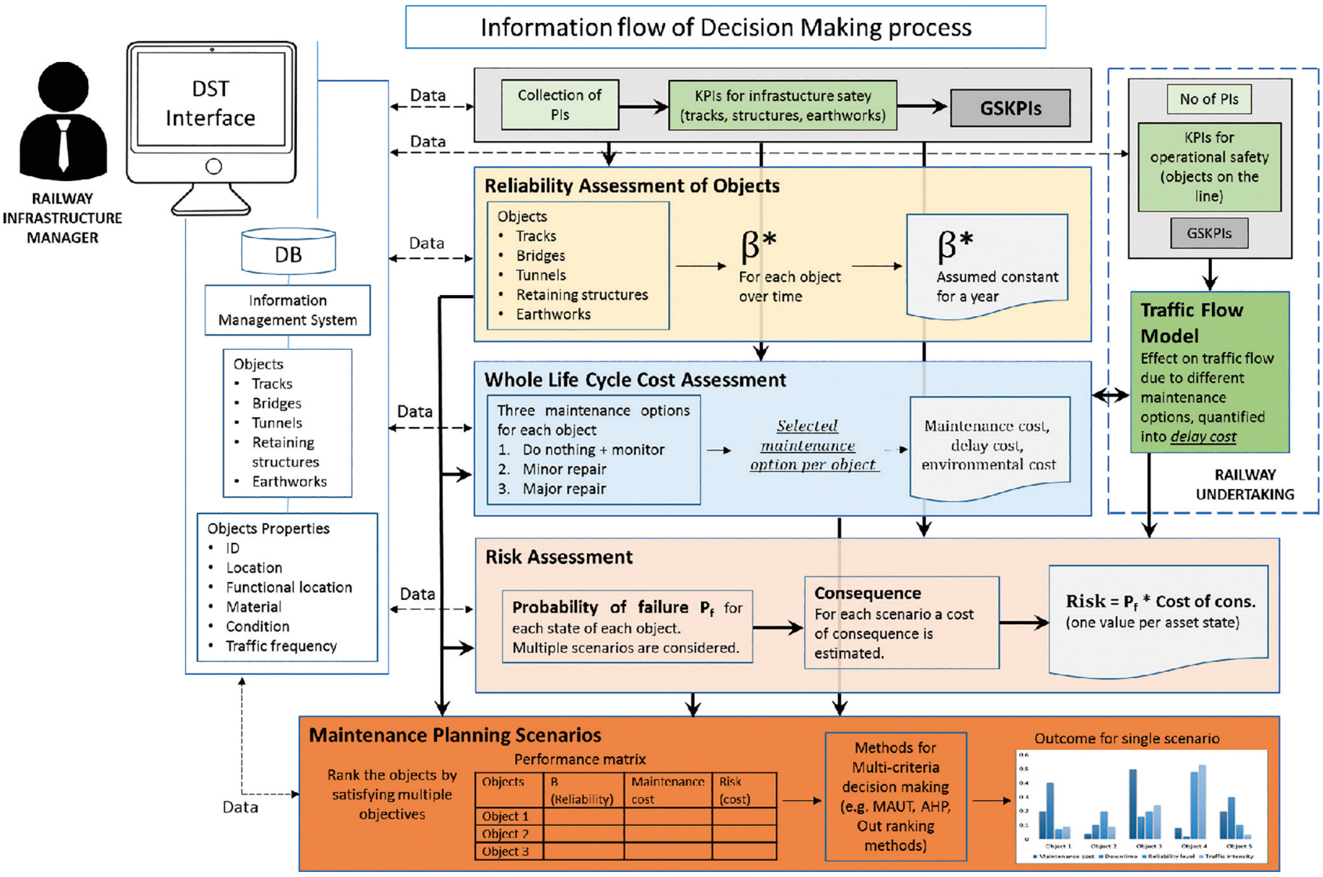


Fig. 4. Global Safety Management Framework developed through the GOSafe project [14] and budget, selecting the assets on network, analysing the assets and budget, selecting the assets on network, analysing the assets.

methods using a combination of vibration based sensor networks, train mounted cameras and lasers in order to identify a range of hazards; (ii) implementation of the machine learning algorithms developed based on the near-miss concept where the usage of low-consequence events to train models will provide statistically significant data for model training and (iii) development of the new safety indicators based on existing concepts and knowledge gained (and validated) from the live safety framework.

The implementation of project activities was conducted through several activities, described above.

3.1. Risk Assessment Methodology

Using a combination of remote monitoring, case histories and expert judgement, the key safety performance indicators associated with railway infrastructure are identified. The focus is on the infrastructure including, switches, crossings, tracks, earthworks, tunnels and bridges. Using results from real time monitoring of a case study railway bridge, a probabilistic risk assessment framework was developed. The framework incorporates a unified risk ranking hierarchy to provide infrastructure managers with the decision support required to help them optimally allocate limited resources in a manner which optimises safety. Consequently, rather than just focusing on risk, the framework takes into consideration the availability of resources to reduce risk, the ability to accept or tolerate risks (i.e. the consequences), the effectiveness or availability of interventions to reduce risk and the residual risks following an intervention. The methodology allows different interventions to be compared, taking into consideration their relative costs (both direct and indirect). The tasks within this activity include:

(1) Identification of Global Safety KPIs where consideration is given to how changes in use (increased speed and or loading), climate change etc. might affect the safety performance of infrastructure and cause increased incidence of existing or new heretofore unseen problems;

(2) Monitoring Systems which consider monitoring system for obstruction detection, monitoring system for landslides as well as monitoring system for infrastructure objects. The monitoring system for obstruction detection is particularly interesting since a new system involves multiple sensors mounted on the train, consisting of high-resolution cameras which are in focus of investigation methodology and which are used for acquisition of series of 2D images, large-range LIDAR scanners and near distance and far distance radar, Figure 5;

(3) Assessment and ranking of risks where a probabilistic framework is developed, providing infrastructu-

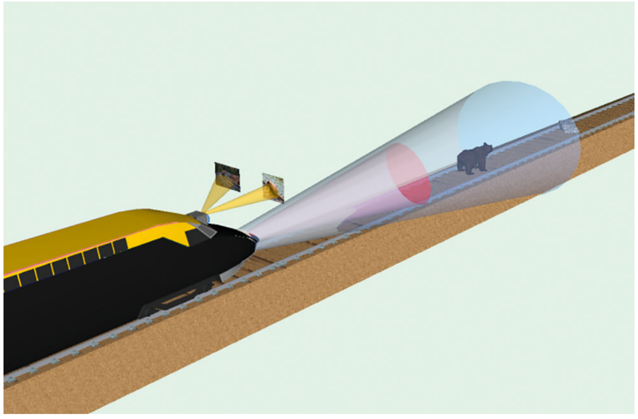


Fig. 5. Train mounted camera system for detecting obstacles [13]

re managers with the facility to optimise budgets/ resources for maximum safety

3.2. Mobility

By application of a suitable algorithm for online optimization of traffic flow, the capacity of bottleneck sections will be increased in comparison to today´s operational practice. This will lead to an increase in punctuality and by the way saving of energy. Today´s production aims to drive as fast as possible in case of receiving the signal aspect track speed. Unfortunately, this leads directly to a conflict when the block in front is not available when passing the closed distant signal. Hence, time and energy are wasted, which is especially critical at bottlenecks. Having an integrated real-time rescheduling algorithm verified by micro-level simulation offers the advantage of reducing track speed to a calculated value when needed; the driver does this and then again accelerate while passing the bottleneck section. This allows an efficient usage of existing capacity, which is not the case at the moment.

The tasks within this activity include:

(1) Micro-planning Simulation where the existing API is used to integrate an algorithm based upon Kronecker Algebra for rescheduling into micro-planning simulation:

(2) System testing in terms of punctuality where the algorithm based upon Kronecker Algebra is tested in terms of punctuality to verify the expected improvements:

(3) Big data integration by establishing an inventory of data sources describing the physical status of a railway network that are available to the railway management authorities that form part of the project consortium.

3.3. Decision Support Tool

The development of a decision support tool to support infrastructure and operations managers to plan railway network assets and operations in an integrated manner (or to take the good decisions to manage the safety of the railway system at a global level in each situation) is the main objective of this activity. The decision support tool will be based upon a safety management process that can guide collaborative decision making activities between operations and infrastructure managers. Additionally, the decision support system will be based upon an integrated mobility systematic that allows for quick micro-simulation based experiments to understand different network conditions and to intervene appropriately and timely.

The tasks within this activity include:

(1) Development of mentioned Framework for Global Safety Management

(2) Validation and training of the model where the artificial intelligence algorithms will be implemented to compare the outputs from the risk models (in terms of infrastructure performance) and the network model (in terms of travel times/disruptions etc.) and use the performance as a means of model improvement

(3) Information management and visualization through the development of four java script based Open Source modules that can be used for the development of web based decision support systems

(4) Decision Support Tool which will help infrastructure managers and railway undertakings make robust, cost-effective decisions that increase safety and maximize the network capacity – the decision making process in the context of dealing with a number of previously identified and ranked risks. The tool will be developed to ensure that outputs of previously conducted project activities are practically integrated and used under specific process workflows and modules.

The demonstration projects ensure that the outputs from the project are implemented in the practice of the infrastructure management within and beyond the life cycle of the project. To ensure this, several demonstration sites are chosen: (i) Case Study 1 – The Safety Framework will be tested on a long distance corridor on the TEN-T Network. (ii) Case Study 2 – The Safety Framework will be tested on a complex partial section of the TEN-T Network. (iii) New techniques for object detection will be demonstrated in Norway, Ireland and Croatia.

The project implementation will yield several impacts. Taking into consideration that maintenance of the network and coordination between the infrastructure managers and operators is a determining factor in ensuring safety, the implementation will enable decisions regarding the management of safety for the railway at a global level. Further, the global approach will help evaluate the impact of the new equipment integrated into the existing railway system. It is also assumed that smart planning will significantly reduce delays in long-distance traffic (e.g. from planning, operations and secondary sources such as train connections and reducing the widespread use of speed limits to control risk).

4. SAFE-10-T project – Safety of Transport Infrastructure on the TEN-T Network

In order to ensure high safety performance while allowing longer life-cycles for critical infrastructure across the railway, but also road and inland waterway modes, the SAFE-10-T project [15] takes a step forward from considering critical infrastructure such as bridges, tunnels and earthworks as inert objects to being intelligent (self-learning objects). Consortium of 15 partners from 8 European countries (Ireland, Croatia, Netherlands, Switzerland, Germany, Italy, Belgium and United Kingdom) gathers experts from risk based assessment of infrastructure, artificial intelligence (AI), wireless sensor networks and data management sectors with sociologists and industry groups to deliver a next generation, cross-modal safety model that will be transformative for infrastructure safety [16].

The project considers a number of common problems faced by EU infrastructure managers, leading to the realisation of a number of key policy objectives namely; increased safety and capacity of networks, reduced environmental impact and improved competiveness of the transport networks. It both accurately quantifies the resilience of infrastructure at a node and interchange level on transport networks and allows for investment in rational adaptation strategies, so as to maintain high levels of safety.

The Safety Framework developed in the project, Figure 6, delivers the following:

- Embedded monitoring techniques and data analytics which guide the development of improved probabilistic analyses tools for major infrastructure objects (bridges, tunnels and earthworks) resulting in a much safer infrastructure leading to the near eradication of sudden failures.
- A cross-modal probabilistic network traffic model is developed to assess the effect of maintenance, adaptation and structural interventions and natural hazards on the capacity of the network and the safety of users.
- Life cycle assessments are performed to allow for strategic investment decisions that maximise safety, minimise disruption and allow for the best use of limited resources.
- The end-product is an off the shelf, online safety management tool that will be commercialised by the project partners. A unique feature is the ability to allow infrastructure owners to make informed decisions and to communicate risks to users (road operators, railway undertakings, waterways managers, public transport operators) using modern communication tools. To accomplish this, risk experts work closely with project partners including sociologists, representative bodies and owners.

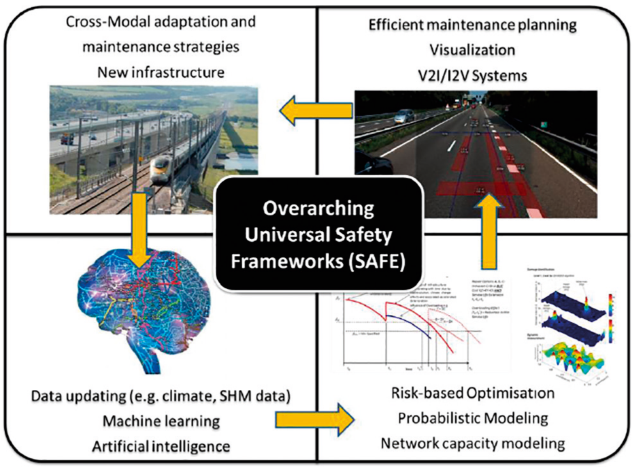


Fig. 6. Information flow in the SAFE-10-T project [16]

The implementation of project activities is conducted through several activities, described above.

4.1. MAP (modelling and monitoring)

The objective of this activity is to develop protocols for advanced real-time assessments of the condition of transport infrastructure assets (bridges, tunnels and earthworks). Probabilistic methods are developed to incorporate results from monitoring to facilitate safety assessments so as to evaluate infrastructure resilience. Under this activity, a Resilience Assessment guideline is developed for resilience ranking of transport infrastructure. Advanced assessment techniques are combined with the machine learning algorithm as well as the network analysis of subsequent activities to demonstrate the probabilistic consideration of infrastructure resilience. Advanced safety analysis of bridges, tunnels and earthworks develops a probabilistic basis for assessment of bridge structures for various travel modes, a probabilistic based displacement model for tunnel safety which estimate the probability of failure (considering a serviceability limit state) of the structure and probabilistic framework which evaluates the stability of earth slopes (cuttings, embankments and dykes). Embedded Monitoring Systems develops a series of methods for self-monitoring of critical infrastructure objects in order to optimise the structural safety of models.

4.2. FLOW (multi-modal traffic flow model)

This activity focuses on smart planning and mobility of multi-modal networks, where existing macro-simulation models are applied for planning and testing in cooperation with railway and road operators in order to identify safety conflicts. The first step is to identify users and to determine their demands for different modes of transport (road, rail waterway) followed by the development of a macroscopic traffic model for a multi-modal transport network, using the existing traffic flow model for railways and extending this to other modes of transport

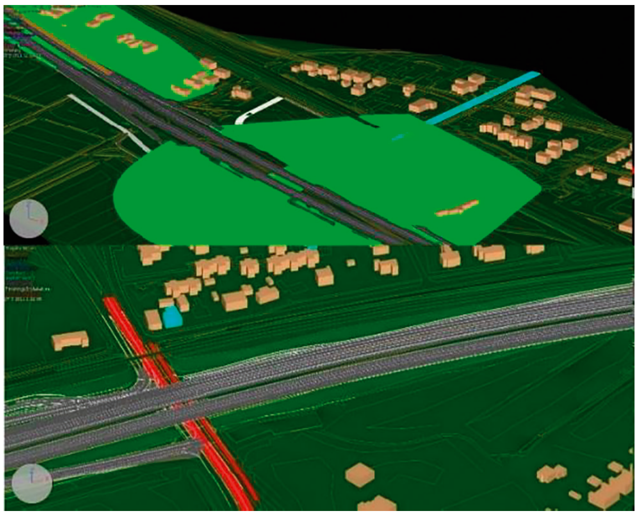


Fig. 7. Visualization of conflicts on nodes and interchanges of different networks [16]

(roads and waterways). Next, a map-based visualization of conflicts caused by insufficient capacity or critical infrastructure failures is developed where users will be able to identify conflicts (e.g. hot spots, maintenance overlaps, and capacity gaps) and develop safety management plans accordingly, Figure 7.

As the final step within this activity, an economy and environmental impact analysis is performed. Here, a whole life cycle model (WLCM) is developed with the aim of integrating owners, users and societal costs related to transport infrastructure. The purpose of the model is to determine economic and environmental impacts (cost benefits) of planned developments and unplanned (e.g. hazards, failures) disruptions followed by the cost benefit of structural and maintenance interventions.

4.3. SAFE (Global Safety Framework)

The focus of the project is in the development of a multi-hazard, risk-based safety framework to manage multi-modal transport networks. The framework enables infrastructure managers, state and private funding agencies and policy makers to make decisions related to infrastructure objects that maximise safety and investment and consider network performance. Big Data Management activity provides the core BIM platform to collect, correlate, and make available data from multiple sources for the entire project and specifically for integration with the work undertaken in Machine Learning and the Decision Support Tool tasks.

Through the development of a Machine Learning Algorithm an improvement of risk assessment at the object and network levels will result. At the object level, the approach combines SHM information with climate and traffic predictions in order to assess structural health. At the network level, machine learning will allow users to forecast infrastructure demand at a higher precision than previous solutions, hence enabling risk-based optimization at the level of the network planner. As a final step, a Decision Support Tool (DST) is developed, which will help infrastructure managers make robust, cost-effective decisions that increase safety and maximize the network capacity.

4.4. DEMO (demonstration case studies)

Through this activity the R&D providers will demonstrate the project outputs on real demonstration case studies on road, railway and waterway networks operated by the three agencies (partners on project). These demonstration projects ensure that the outputs from the project are implemented in the practice of infrastructure management within and beyond the life of the project. The chosen demonstration sites are; (i) Case Study 1 – North Sea – Baltic Corridor, as an example of the long distance corridor on the TEN-T Network. (ii) Case Study 2 – Mediterranean Corridor – focusing on the Rijeka harbour, Figure 8, as an example of a complex partial section of the TEN-T Network. (iii) Case Study 3 – Urban interchange and node where different modes meet and where the failure of critical infrastructure components (e.g. bridges, tunnels) would cause multiple hazards.

Fig. 8. The Rijeka port as one of demonstration sites within SAFE-10-T project

In regard to the project impact, the implementation will contribute to near eradication of infrastructure-caused accidents. It will also increase readability and forgiveness of the transport infrastructure by providing warnings to user when risk levels exceed certain levels (KPI's), prove the effectiveness of long-term, predictive maintenance systems and it will deliver a number of how-to guideline documents for different stakeholders. An increase in infrastructure safety performance will also contribute to the achievement of sustainable development in the sector and will minimise effects on climate changes via the improvement of traffic smoothness.

Conclusion

The paper presents several ongoing H2020 projects which have a similar overall objective – enhancement of safety aspects of railway infrastructure. Additionally, these projects offer the railway infrastructure more advanced tools for their critical investment decisions. The DestinationRAIL project, GOSafe project SAFE-10-T project provide solutions for common infrastructure problems encountered in diverse regions of Europe. The tools and techniques such as embedded monitoring, advanced modelling and simulations, transition to intelligent (self-learning) infrastructure objects, risk assessment based on probabilistic models, big data information management systems, safety management framework and decision support tools are in focus of these ongoing projects recognized by the European Commission for their innovation aspects. The performed activities clearly demonstrate current, but also future trends in increasing the safety aspects of the railway infrastructure as one of most important modes for transportation of people and goods.

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Application of Unmanned Aerial Vehicles in Engineering Practice

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Abstract

Unmanned Aerial System (UAS), also known as 'drone', is an aircraft without a human pilot aboard which has found many applications in various sectors of human activity. Drones were shown useful since they can be used for remote investigations in a very simple manner. They can be navigated by the operator from the ground or conduct an investigation by themselves in a programmed flight path. Recently drones have been effectively used for all purposes in practical engineering, giving them an advantage over some traditional methods for data acquisition. The most usual type of data that is collected by the drone are high resolution digital images of a specific object or area. With certain overlapping of these images it is possible in post processing to recreate 3D models of specific areas and objects in the form of point cloud, Digital Terrain Model (DTM), or Digital Surface Model (DSM). By using such data and models, it is possible to generate volumes, areas, cross sections and contour lines in a very short time, which are in most cases the basic information in practical engineering.

1. Introduction

Use of UAS in practical engineering delivers a highly privileged aerial point of view. Through this kind of assessment and observation, provided data can be viewed in real time or used later for detailed analysis. The most usual type of data provided by UAS is high resolution photography and video, which makes them ideal for surveying structural objects and areas of interest, especially in hard to approach terrain [1]. Classical technics of surveying (Figure 1) in these types of areas can easily lead to an oversight of critical information. With the development of technologies, software and materials UAS is becoming a tool which can provide owners and engineers with a much bigger perspective for assessing and surveying respecting accuracy and time, which are one of the most important parameters in modern time. Luxury of being able to make fast and correct decisions based on precise and reliable data puts engineers and other interested users in these kind of structures into a really comfortable position. In recent times UAS has been used in a lot of applications regarding surveying, monitoring and mapping of remote objects (indoors or outdoors), although they are hard to reach, hazardous or just more profitable than any other classical method. Various types of final products delivered from UAS data like point clouds, digital terrain models (DTM), digital surface models (DSM) and other types of formats can be used with various software types for planning and designing.

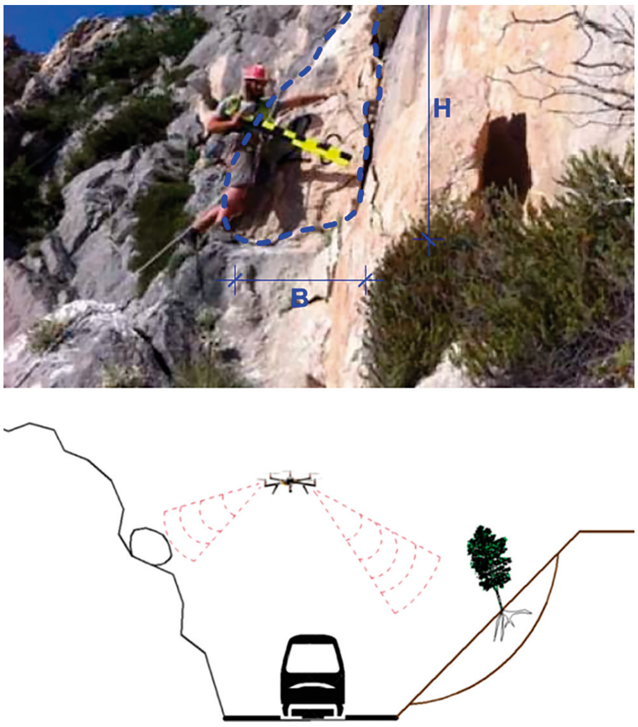

Fig. 1. Replacement of traditional determination of rock block volume by remote sensing via unmanned aerial vehicles

2. UAS

Unmanned Aerial System (UAS) or Unmanned Aerial Vehicle (UAV), commonly and popularly known as "drone" is a flying device or aircraft without the crew and can be operated by remote controller, or fly independently using a prescheduled flight plan [2]. UAS can take different forms, with different levels of controls and the capacity to carry a very wide range of sensors (Figure 2).There are many types supporting different uses, but they are also subject to different regulations. They are built with intelligent stabilization systems to keep them flying and carry sensors to perform dedicated functions. One of the most common devices is a camera mounted on gimbals to obtain high-quality video and still photography [3]. They can be divided into two major groups by constructions which are "rotary wing", Figure 3a and "fixed wing" shown in Figure 3b.

Fig. 2. Various sensors that can be mounted on UAS

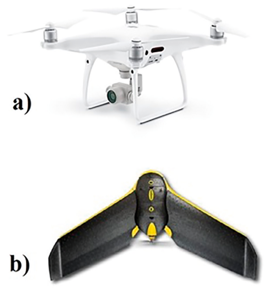

Fig. 3. a) Rotary wing UAS & b) Fixed wing UAS

Each of these types is capable of performing missions for practical engineering, but still each one has advantages and disadvantages shown in Table 1.

Table 1. Comparison of fixed and rotary wing UAS

	Fix wing	Rotary wing
Projects	Larger are mapping	Smaller area mapping, inspection
Applications	Land surveying, agriculture, GIS, environmental, construction	Urban surveying, real estate, construction surveying and mapping
Cruising speed	High	Low
Coverage	Large	Small
Object resolution	Cm/inch per pixel	Mm per pixel
Take-off/landing area	Large	Very small
Flight time & wind resistance	High	Low

One of the most typical types of UAS used for practical engineering is rotary wing DJI Phantom 4 Pro [4]. It is a quadcopter drone that can be also called "ready to fly", meaning all of its components are already built in. In order to use this type of UAS for data collection its most important specifications are camera resolution, flight time, shutter type, built in GPS antenna (Global Positioning System), camera stabilization system and ability to perform autonomous flight operation. It is operated by the remote controller who has attached a tablet computer on it, which is used to set up all the drone's functions and also has live preview from the camera (Figure 4).

Fig. 4. UAS DJI Phantom 4 Pro with corresponding remote controller and tablet computer

One of its very useful functions is to remotely transfer real time preview (live stream) to another place through a mobile data connection. This kind of interactive approach can offer the evaluation of on-site condition to the persons who are at other locations (offices, cabinets, laboratories). They can focus more on receiving live fed and navigate the on-site operator to take more detailed pictures or videos of the specific area of interest [2]. A schematic view of how it works can be seen in Figure 5.

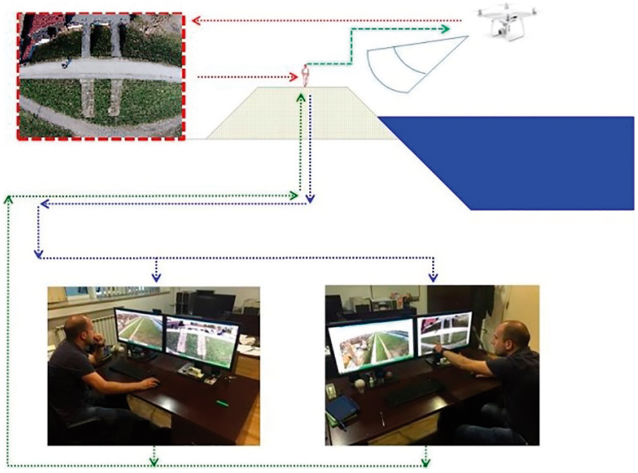

Fig. 5. Interactive scheme for engineering prospection

3. Creating 3D model

In order to create a three-dimensional model of a terrain or structure, a considerable number of photographs of the area must be taken with longitudinal and transverse overlapping between the photographs. The principal objective of the computer program is to link these photographs into a single whole, and to generate a point cloud using the following steps [5, 6, 7]:

1. identify similarities between the digital photos,
2. derive the SfM (Structure from Motion) algorithm,
3. make geo-references,
4. finalise the process and make image changes as needed.

The final result of the above procedure is the point cloud (Figure 6) that consists of a set of points in a given coordinate system. In the three-dimensional coordinate system, these points are defined by X, Y and Z coordinates, and they most represent the external surface of an object. In addition to coordinates, the point cloud also contains the data about the lighting, time of survey, and colour of every point within the cloud.

One of the softwares that uses this kind of procedure for creating 3D models is Pix4Dmapper [8]. It processes the images that were taken from the air using unmanned aircraft, or from the ground with digital camera. To do so, it uses SFM (Structure From Motion) algorithm that works on the principle of recognizing the image content (pixels) in order to make a complete 3D model of the subject in the form of creating a point cloud. The software is completely adaptable to all types of cameras and image processing results can be converted and used by any GIS or CAD applications. Pix4Dmapper can be used in many different branches of industry and science, such as mining, agriculture, geodesy, civil engineering, management of natural resources and emergency services, and allows the following:

- line and polyline measurement (break lines), making longitudinal and cross sections, contour drawing, measuring areas and volumes directly in the model and their export to other different formats
- generating 3D point cloud, true orthomosaic and orthophoto maps, 3D textured models, DSM (Digital Surface Model), DTM (Digital Terrain Model) from vertical and oblique aerial or terrestrial photos
- it uses a fully automated flow of data processing and calibration of each photo in order to achieve a satisfactory level of accuracy, but also the "Rapid Check mode" for checking the quality of recording directly on the field

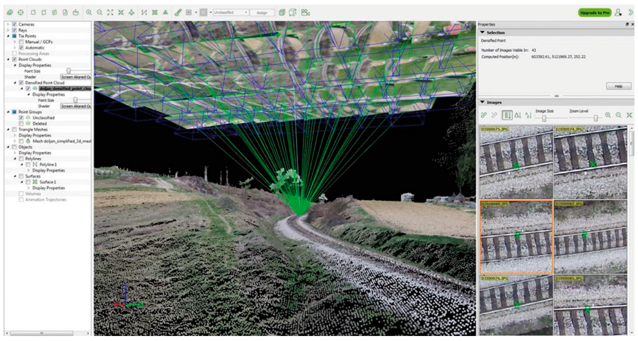

Fig. 6. Interactive scheme for engineering prospection

4. Data acquisition

Upon the arrival at the location the first step is to prepare an autonomous flight mission for UAS by defining the area of interest [9]. Through that procedure it is necessary to set up parameters for flight which include the height of the flight, angle of the camera view, longitudinal and side overlapping of the images and UAS speed. All these parameters are important for determining GSD (Ground Sample Distance) of the future model. GSD is the distance between two consecutive pixel centres measured on the ground. The bigger the value of the image GSD, the lower the spatial resolution of the image and the less visible details. The GSD is related to the flight height: the higher the altitude of the flight, the bigger is GSD value [10]. The whole procedure is done in interactive application installed on the tablet computer, and the one used in this case is “Pix4Dcapture” [11], (Figure 7).

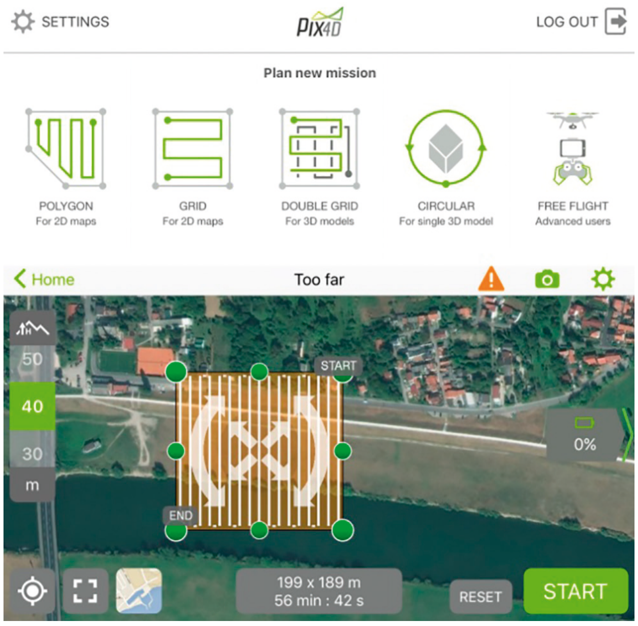

Fig. 7. Application screen for setting up flight mission

Depending on the area of interest, various types of missions can be selected and performed. The most usual mission types are “grid” and “double grid” which are suitable for flat areas and terrains. More complex missions like “circular” and “free flight” are performed when the object, or area of survey is placed in vertical position, urban areas or areas with a lot of obstacles that can endanger the flight. These types of missions directly depend on the experience and competence of the pilot navigating UAS.

5. UAS survey for practical engineering

5.1 Sava embankment

At the location a total of 117 images were taken. All images were geo-located at the time of exposure (Figure 8) and the overall area covered by flight was 3.69 hectare, which was enough to make the quality analysis of embankment. Images taken from UAS were imported into “Pix4D mapper” and processed.

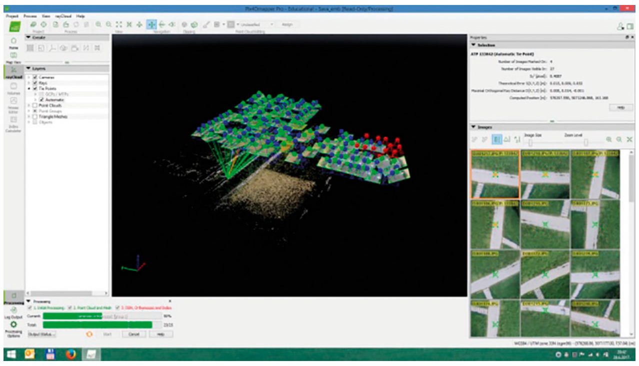

Fig. 8. Visible point cloud and aerial positions of images

One of the first noticeable things after processing the images was so called “Uncalibrated Cameras”. The reason why did it happen is the impossibility of the software to find enough matches on neighbouring images to create a stereoscopic effect and by that not able to crate 3D points. These 14 images were created above water, (Figure 9.) and as water was moving it changed its surface making it impossible to create points.

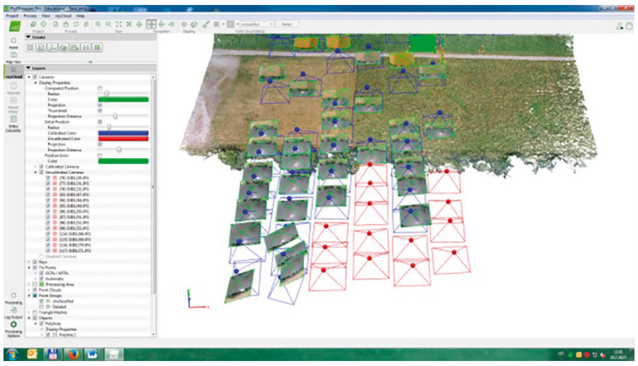

Fig. 9. Uncalibrated Cameras visible in red colour

The overall processing time was 1.5 hours, which combined with flight preparation and flight time, taking 30 minutes, which altogether amounted to around 2 hours. The achieved GSD was 2.26 cm creating a number of 7.304.850 3D points shown in Figure 10.

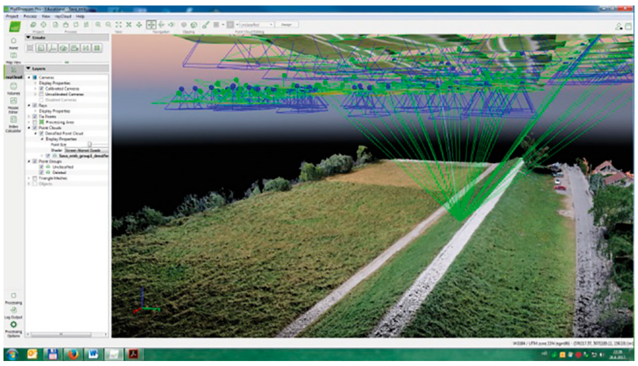

Fig. 10. Point cloud containing 7.304.850 3D points

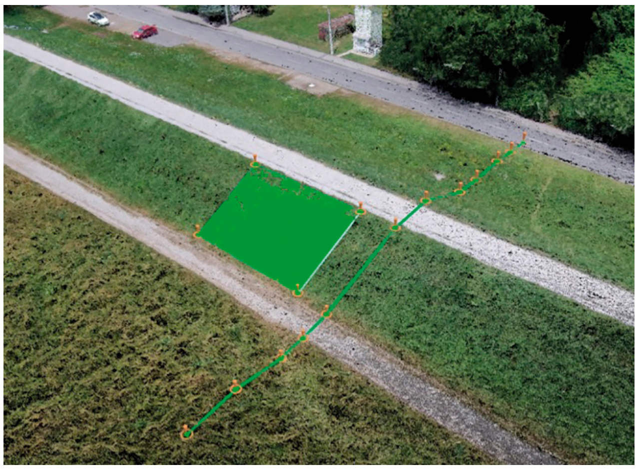

Fig. 11. 3D polyline and surface

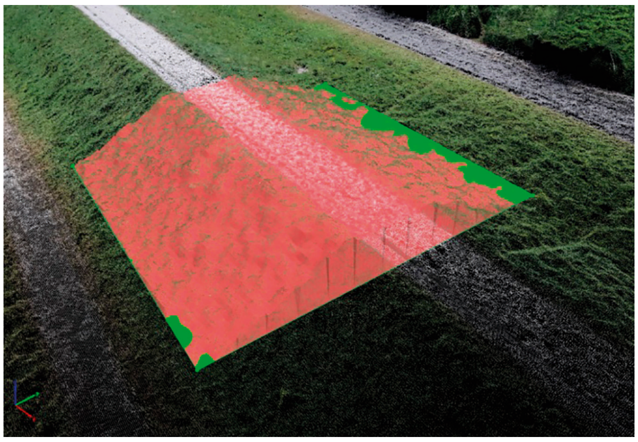

Fig. 12. Volume calculation

Inside of the software it is possible to create 3D polylines, surfaces, (Figure 11), volume calculations, (Figure 12) and orthoplanes, which all can be exported into other types of formats such are *.dxf, *.shp, *.dgn and *.kml.

Through application called "Mosaic editor" the generation of DSM and DTM is possible. The difference between these two is in filtering out the surface data and leaving only terrain "DTM" (Figure 13), or leaving all the surface data creating "DSM" (Figure 14).

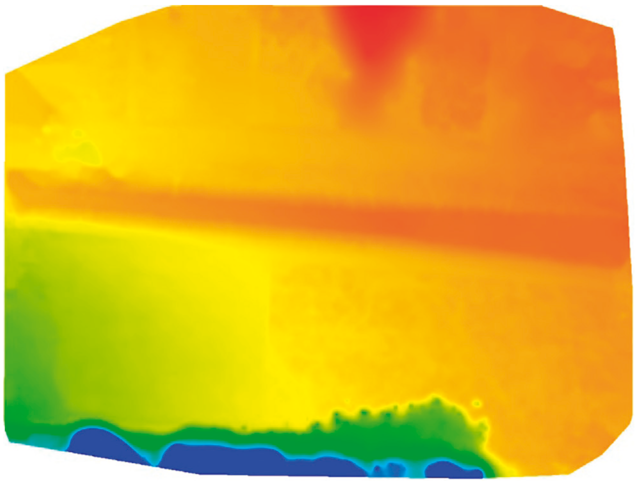

Fig. 13. Digital Terrain Model „DTM"

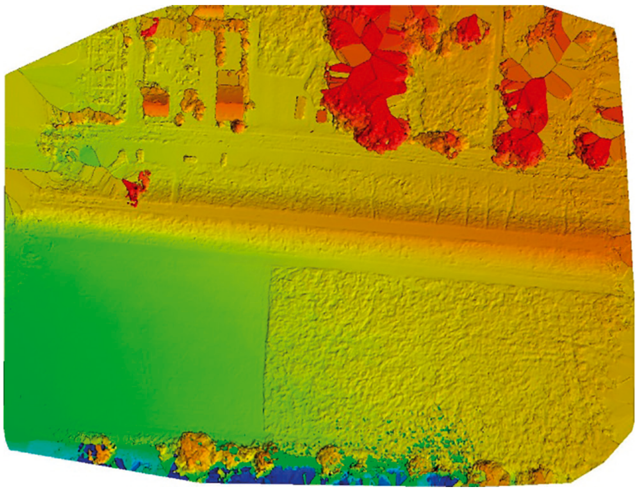

Fig. 14. Digital Surface Model „DSM"

Fig. 15. Digital Surface Model „DSM"

Also, a digital orthophoto map is created using all taken pictures combining it into one big high resolution map (Figure 15).

5.2 Doljan cutting landslide

Doljan cuttings is situated in km 80+830, railway track R201 Zaprešić – Čakovec between the railway stations Novi Marof – Turčin. The instability in the form of the landslide occurred on the right side of the Cutting (Figure 16).

Fig. 16. Picture of landslide taken from UAS

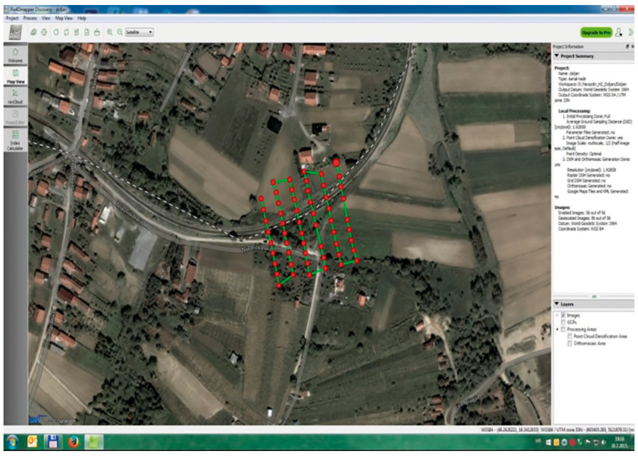

Fig. 17. Images taken on „Doljan cutting“

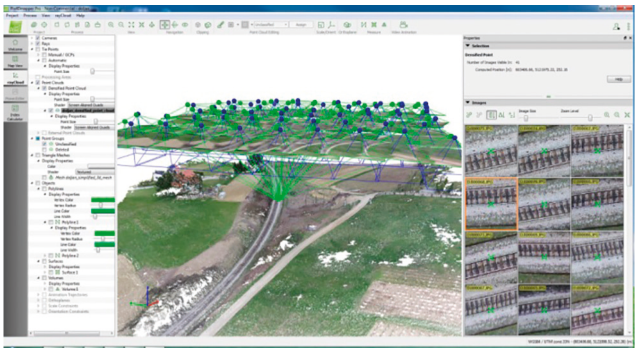

Fig. 18. Point cloud of „Doljan cutting“

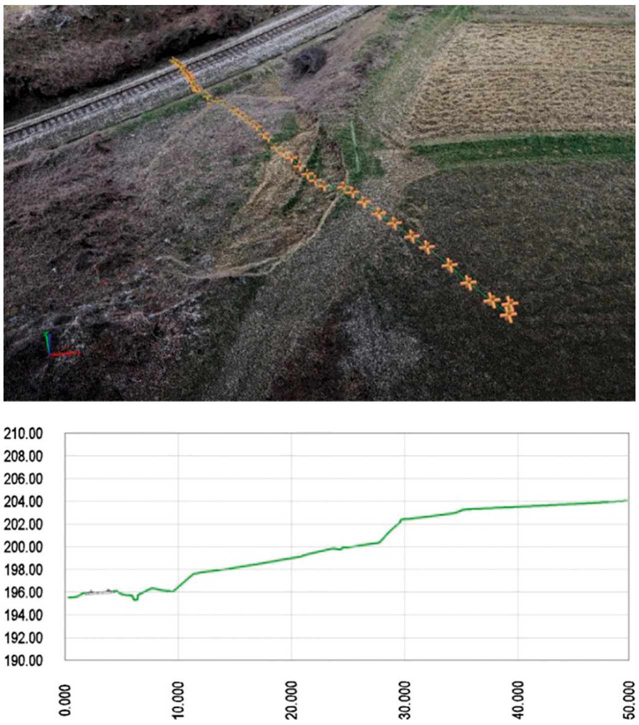

Fig. 19. Cross section extraction

The purpose of the project was to develop a remediation and reparation design in this location that would ensure the permanent stability of the cuttings. Collection of 3D data by conventional surveying methods in these cases can be quite time-consuming, and even dangerous for the field operator. Steep locations like embankments, vertical cuttings and locations

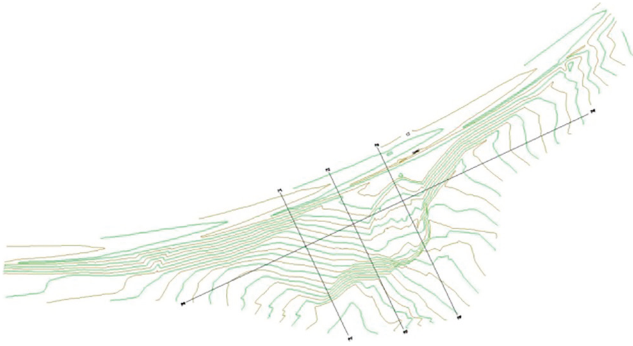

Fig. 20. Generated contour lines from the point cloud

with potential landslides or mudslides, could be given as an example. In such locations, the visual inspection of the terrain as geodetic data collection by classical methods, can result in an incomplete and insufficiently detailed display of the terrain. The use of UAS in these locations can greatly complement, enhance and even completely replace the classical methods of mapping. Upon the arrival at the field it is not required to approach the hazardous location, but come to a safe proximity and send UAS (with a pre-programmed flight or manually guided) to collect the data needed for quality and correct visualization and interpretation. All together 56 images were taken at the field with foot prints and can be seen in Figure 17.

For the purpose of the remediation design, a 3D point cloud was created containing approximately 5 million points (Figure 18).

An extraction from the point cloud was made and given to the designers at specific locations that represent geometry of the landslide in the form of cross sections (Figure 19) and contours (Figure 20).

5.3 Irija – Jelični Vrh, Slovenia rockfall protection

For the purpose of the Ministry of transportation of the Slovenian Republic a survey was carried out to make a calculation of embedded materials in the form of rock fall protection nets and barriers. As the location is situated in a mountainous region right next to regional road number 102, the usage of UAS was a reasonable choice to carry out this task. The slope dimensions were approximately 200 meters in horizontal and 100 meters vertical direction. A free flight mission was performed, and 451 images were taken (Figure 21).

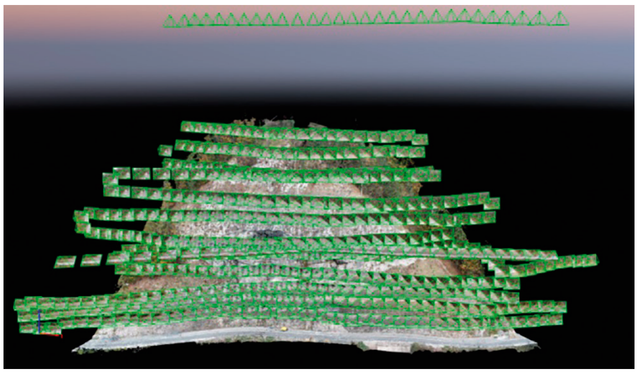

Fig. 21. Positions of 451 images taken from UAS

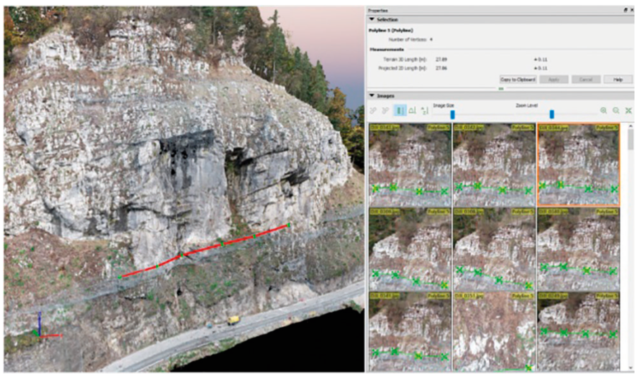

Fig. 22. Calculation of barrier length from point cloud

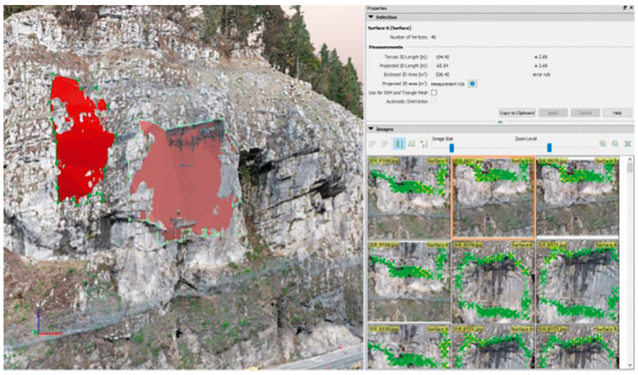

Fig. 23. Calculation of 3D areas built in protection nets

The Average Ground Sampling Distance (GSD) was achieved at 1.24 cm per pixel. The calculation of the length built in barriers was done through a point cloud (Figure 22) visible in red colour (on the left) and all images from where this particular barrier is visible, and also the calculation of 3D surfaces in square meters for protection nets (Figure 23).

Conclusion

The use of unmanned aerial systems can greatly broaden, improve, and even fully replace traditional methods for mapping and for determining volumes, cross sections, contour lines and other parameters that are needed for practical engineering analyses. Their use is especially appropriate in case of steep and high cuttings and other hardly accessible sites where the implementation of traditional survey procedures can sometimes prove hazardous. Despite evident advantages of unmanned aerial system, some limitations do exist with regard to deficiencies of the method itself, and the regulatory framework. One of the major deficiencies is weather. It is impossible to fly in the rain, snow, fog or wind.

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