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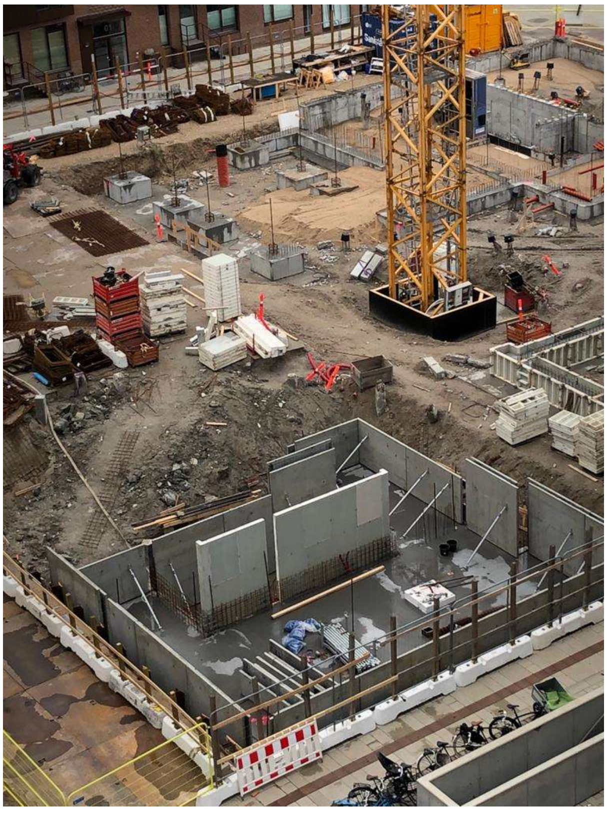
JOURNAL FOR RESEARCH OF MATERIALS AND STRUCTURES



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SOCIETY FOR MATERIALS AND STRUCTURES TESTING OF SERBIA

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БЕОГРАД,

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др Игор Марић

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FATIGUE OF STEEL SPECIMENS AT LOW TEMPERATURES

ZAMOR ČELIČNIH UZORAKA PRI NISKIM TEMPERATURAMA

ORIGINALNI NAUČNI RAD
ORIGINAL SCIENTIFIC PAPER
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Alexander TESAR

1 INTRODUCTION

Fatigue behaviour of steel specimens at low temperatures has recently become the focus of intense efforts in structural engineering. This is because of pressing problems of fatigue disaster prevention in long-termed exploitation of steel specimens appearing in slender structures, such as space and offshore facilities, guyed masts, cable roofs, bridges or lines of high voltage air conductors located in northern territories and subjected to heavy dynamic loads under low temperatures. Sophisticated analysis is required in order to answer the questions associated with fatigue behaviour and reliability of such specimens.

Simulation models adopting the wave analysis on the micro-mechanical level was used for fatigue research considering the behaviour of multi-string elements configurated in backpropagation neural network. Such models have been developed and treated by Tesar, A. ([1], [2], [7], [11]), Simo, J.C. ([3]), Huston, R.I. and Passerello, C.E. ([4]), Adeli, H. and Yeh, C. ([5]), Lu, W. and Mäkeläinen, P. ([6]), Budiansky, B. ([8], [9]) and others.

This paper deals with:

1. mathematical formulation of governing wave equations for fatigue analysis of steel specimens at low temperatures,
2. brief description of ultimate fatigue analysis at low temperatures adopting the parallel processing FETM-wave approach with backpropagation neural network,
3. numerical and experimental analyses.

2 FATIGUE BEHAVIOUR AT LOW TEMPERATURES

If a steel specimen consists of densely packed inclusions, the interaction effects of inclusions play a dominant role in fatigue behaviour of resulting continuum at low temperatures. The concept of transformation strain can be used when an elastic medium contains periodically distributed inclusions or voids in the material. Because of periodicity, the transformation strains as well as other field quantities entering into estimate of elastic moduli are periodic functions of space, time and temperature. The periodicity is exploited in an effort to obtain accurate estimates for transformation strains used to approximate mechanical properties of steel specimens at low temperatures.

The Washizu´s variation principle is adopted below in order to include initial stress and strain components due to isothermal deformations in time. The stress in microelements of the model adopted at the beginning of time increment studied is considered as initial stress and thermal strain increment ([8], [9]). The variation principle under consideration is written in terms of time rate quantities given by

$$I = \{\int_V [S_{ij}\, \varepsilon_{ij} + 0.5\, W_{ij}\, u_{ki}\, u_{kj} - (\varepsilon^o_{ij} + 0.5\, \varepsilon'_{ij})\, S_{ij}]\, dV - \int_{A1} r_i^{(.)}\, u_i\, dA1 - \int_{A2} s_i\, (u_i - w_i)\, dA2\}(dt)^2$$
$$+ \{\int_V W_{ij}\, \varepsilon_{ij}\, dV - \int_{A1} r_i\, u_i\, dA1 - \int_{A2} p_i\, (u_i - w_i)\, dA2\}dt \qquad (1)$$

where W_{ij} and S_{ij} are the Piola-Kirchhoff stress tensors for initial stress and strain rate states, respectively, p_i and s_i are the Lagrange surface traction and its time rate quantity, respectively, r_i and $r_i^{(.)}$ are prescribed on surface

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area A1, w_i on area A2 and V is the volume bounded by area A=A1+A2. The total strain rate ε_{ij} is composed of initial strain rates $\varepsilon^o ij$ and ε'_{ij}, corresponding to instantaneous stress rate S_{ij}. To evaluate the strain rate, thermal expansion coefficient at temperature T be $\alpha(T)$ and at temperature T+dT be $\alpha(T+dT)$ is adopted. By expanding $\alpha(T+dT)$ into Taylor series, the average thermal strain rate is obtained.

Governing wave equation for treatment of ultimate fatigue behaviour of elastic continuum at low temperatures ([10]) is given by

$$\mu\ \eta(u_t) + (\lambda+\mu)\ grad(div\ u_t) + f = \rho\ \partial^2 u_t/\partial t^2, \qquad (2)$$

where λ and μ are Lame constants, mass density is ρ, corresponding Laplace operator is η, the body force vector is f and the vector of displacements is u_t.

In terms of derivatives of displacement components u_t, the governing wave equation is modified as

$$c_2\ u_t + (c_1^2 - c_2^2)\ u_t + f/\rho = a_t\ , \qquad (3)$$

with propagation velocities for dilatational waves

$$c_1 = \sqrt{[(\lambda + 2\mu)/\rho]}\ , \qquad (4)$$

and shear waves

$$c_2 = \sqrt{(\mu/\rho)}\ . \qquad (5)$$

Strain and stress components are defined by

$$\varepsilon_{ij} = (u_{i,j}+u_{j,i})/2\ , \qquad (6)$$

$$\sigma_{ij} = \lambda\ \varepsilon_{kk}\ \delta_{ij} + 2\ \mu\ \varepsilon_{ij}\ ,\quad i,j = 1, 2, 3,\ , \qquad (7)$$

with Kronecker delta function δ_{ij}.

3 PARALLEL PROCESSING

Mathematical and physical backgrounds of micromechanical simulation, based on the idea of parallel processing as part of backpropagation neural network approach ([11]), are described below.

The Euclidean n-dimensional space B^n is assumed. An open interval (a,b) is stated in B^1, assuming a<b, $a,b\in B^1$ and <a,b> being contained in B^1. The symbol $G^{(k)}(a,b)$, with $k\in N$, is a set of real functions with continuous derivatives of the order $s(0\leq s\leq k)$ in (a,b). $C^{(k)}(<a,b>)$ is the set of functions from $C^{(k)}(a,b)$, with derivatives continuously expanded into <a,b>. $L(B^n)$ is the set of real matrices n x n.

Let in <a,b> be assumed the system of n-linear differential equations of first order, given by

$$u_i'(t) = \Sigma\, a_{ij}(t)\ u_j\quad ,\quad i = 1, 2, ...\ n\ , \qquad (8)$$

where $a_{ij}(t)\in C^{(o)}(<a,b>)$ holds for all i and j.

In vector notation the system (8) is given by

$$u' = A\ u\ . \qquad (9)$$

Definition 1. An n-dimensional column vector u(t) = $[(u_j(t))^n{}_{j=1}]^T$ is solution of system (9) if

$$\forall j:\quad u_j(t) \in G^{(1)}(<a,b>)\ , \qquad (10)$$

$$\forall t \in <a,b>:\quad u' = A\ u\ . \qquad (11)$$

Theorem 1. The treatment of system (9) creates the n-dimensional vector space in the field of real numbers. The matrix having n-columns and containing all fundamental solutions of sys-tem (9) is denoted by $\Phi(t)$.

Theorem 2. Necessary and sufficient condition for the validity of the matrix $\Phi(t)$ for solution $(\{\Phi_i(t)\}_1{}^n$ of system (9) is det $\Phi(t)$ G, where G is constant regular matrix of the same type.

Definition 2. An n x n square matrix of type

$$U_A(a,t) = \Phi(t)\ \Phi^{-1}(a)\quad ,\quad \forall t \in <a,b>\quad , \qquad (12)$$

holds in the interval <a,t>.

The simulation model for fatigue behaviour is established by micromechanical string made of spring elements as shown in Fig. 1.

For physical interpretation of above definitions the internal and left-hand external wave displacements of the spring element are denoted by u_a and u_b. The u_a will match the u_b when the microelement is moved one bay to the right, so that u_a and u_b share the same dimension.

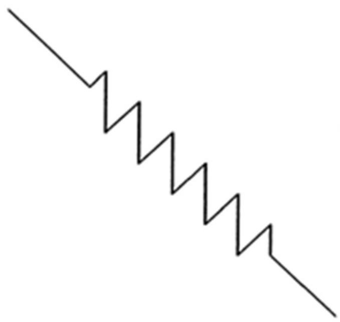

Fig. 1. Single spring microelement adopted

The internal wave displacement vector u_i is eliminated beforehand, giving the stiffness matrix

$$K(\omega) = \begin{bmatrix} K_{aa} & K_{ab} \\ K_{ba} & K_{bb} \end{bmatrix} \qquad (13)$$

and displacement wave vector by

$$u = \begin{bmatrix} u_a \\ u_b \end{bmatrix}\ . \qquad (14)$$

Corresponding force wave vectors are given by

$$n_a = K_{aa}\ u_a + K_{ab}\ u_b\quad , \qquad (15)$$

$$n_b = -K_{ba}\ u_a - K_{bb}\ u_b\quad . \qquad (16)$$

State wave vector v is defined as combination of wave displacements and forces given by

$$v = [u, n]^T\ . \qquad (17)$$

Wave state vector at boundaries a and b is given by

$$v_b = S\ v_a\ , \qquad (18)$$

adopting corresponding wave transfer matrix S. It holds

$$S = \begin{bmatrix} S_{aa} & S_{ab} \\ S_{ba} & S_{bb} \end{bmatrix}, \qquad (19)$$

with

$$S_{aa} = -K_{ab}^{-1} K_{aa} \quad , \quad S_{ab} = K_{ab}^{-1} \quad ,$$
$$S_{ba} = -K_{ba} + K_{bb} K_{ab}^{-1} K_{aa} \quad , S_{bb} = -K_{bb} K_{ab}^{-1} . \qquad (20)$$

The damping parameters are contained in the complex elasticity moduli appearing in the stiffness terms of corresponding transfer matrix S.

The calculation run of the FETM-wave approach which is adopted below with updated variability of the mesh size in space, time and temperature. The details of parallel processing FETM-wave approach are summed up, for example, in [1], [2], [3] or [4].

4 NEURAL NETWORK

Neural network has been developed for solution of some sophisticated problems in structural engineering. Compared to conventional digital computing techniques, neural networks are advantageous because of their special features, such as parallel processing, distributed storing information, low sensitivity of error, robustness in operation after training and adaptability to new information.

The idea for application of the neural network in structural engineering appeared in [5]. Neural networks have been used in structural analysis and design, material behaviour and damage identification.

Among such applications the neural network trained by backpropagation algorithm appears as most utilized neural network today, primarily due to its simplicity.

The topology of backpropagation neural network and training algorithm adopted [6] are described briefly below. It is a multilayered feed forward neural network trained by backpropagation algorithm.

The topology of neural network is plotted in Fig. 2, including the input layer, one or several hidden layers and the output layer. The fundamental building block of neural network called artificial node is shown in Fig. 3.

The node is composed of connecting springs, an adder using to sum the weighted input, an activation function used to decrease the magnitude of the output and a threshold for activation function.

The backpropagation algorithm starts with randomly initialised weights. Using the calculation rule for one node, the input vector is feed-forwarded from layer to layer until the output is produced.

5 FATIGUE ANALYSIS

It is in nature of things that fatigue cracks are initiated as a result of cumulative ultimate damage process in structure.

As with any other ultimate state, the assessment of fatigue is carried out in demonstrating that strength function is higher compared with relevant ultimate fatigue resistance of the steel specimen studied at low temperatures.

The calculation rule for one basic node of the backpropagation neural network is given by

$$y = f\,(net) = f\,(\sum w_i\, x_i - \Theta) \, , \qquad (21)$$

where x_i is i-th component of input vector, w_i is i-th component of weight vector, Θ is threshold adopted, f is activation function, y is output of the node and t_i is i-th component of target vector, which is the desired output of neural network corresponding to input vector.

The backpropagation algorithm starts with randomly initialised values. Using the calculation rule for one node the input vector is feed-forwarded from layer to layer until the output is produced. The output vector is compared with target vector and the error in the output layer is calculated using

$$\delta_{pk} = (t_{pk} - o_{pk})\, f_k\, (1 - f_k) \, , \qquad (22)$$

where t_{pk} and o_{pk} represent target and output values of the k-th node in the output layer corresponding to the p-th training pattern and f_k is the activation function for the k-th node.

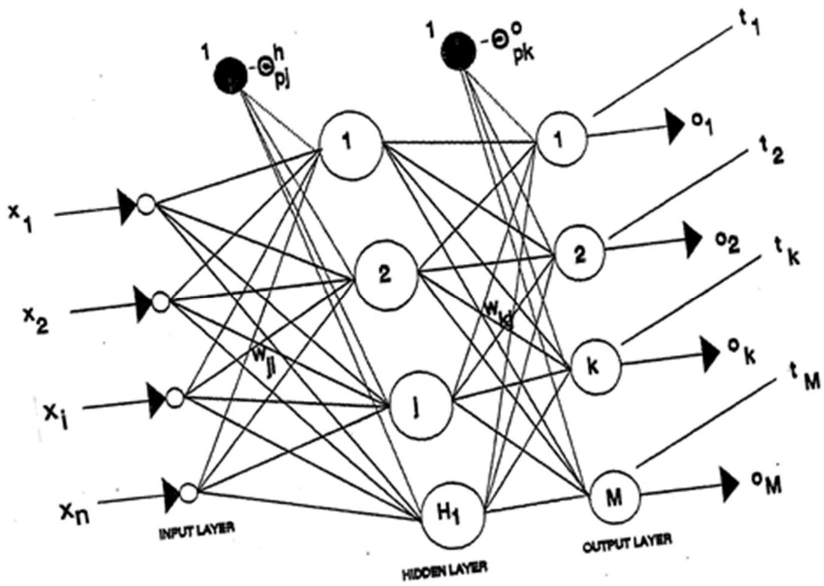

Fig. 2. Topology of the backpropagation neural network adopted

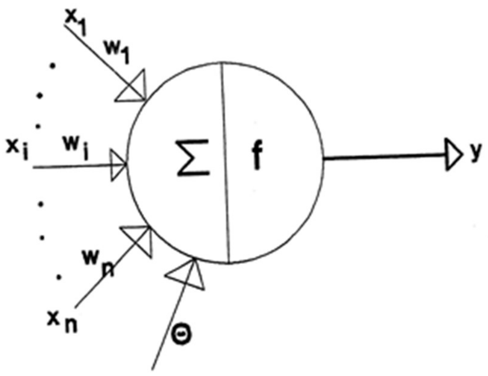

Fig. 3. Artificial node

Adopting the approach, calculation of ultimate fatigue analysis ([1], [10]) is given by:

Micromechanical modelling of material and structural configurations of specimen in space, time and temperature.

Updated calculation of wave stress and strain states in space, time and temperature as well as low and high cyclic structural response in each step of forcing and deformation process being stated in all microelements of the model adopted.

Comparison with ultimate fatigue strength stated in the Wöhler curve for the steel material used.

Initiation of cracks in micro-mechanical elements trespassing the ultimate fatigue strength in corresponding Wöhler curve,

Updated calculation of fatigue crack growth with the development of cracks in space, time and temperature, until fatigue destruction of the specimen is studied.

The regime of crack initiation and growth is rather complex. One or several cracks develop and propagate slowly along critical regions of the specimen studied. In the case of shear loading the cracks turn inside the body in a direction that is quasi-perpendicular to the tension ([3], [4], [5], [6] or [7]).

6 APPLICATION

Above approaches were adopted for numerical and experimental research of fatigue behaviour of steel specimen as shown in Fig. 4, subjected to static and dynamic loads at low temperatures.

Calculation mesh was adopted as well as stress-strain curve of specimen which is plotted in Figs. 5 and 6, respectively.

In numerical/experimental assessment static and dynamic tests at low temperatures were made. The pulsator with loading capacity of 6000 kN was adopted for experimental research, and it was established at the Institute of Construction and Architecture of Slovak Academy of Sciences in Bratislava, Slovak Republic (Fig. 7).

Fig. 4. Steel specimen studied

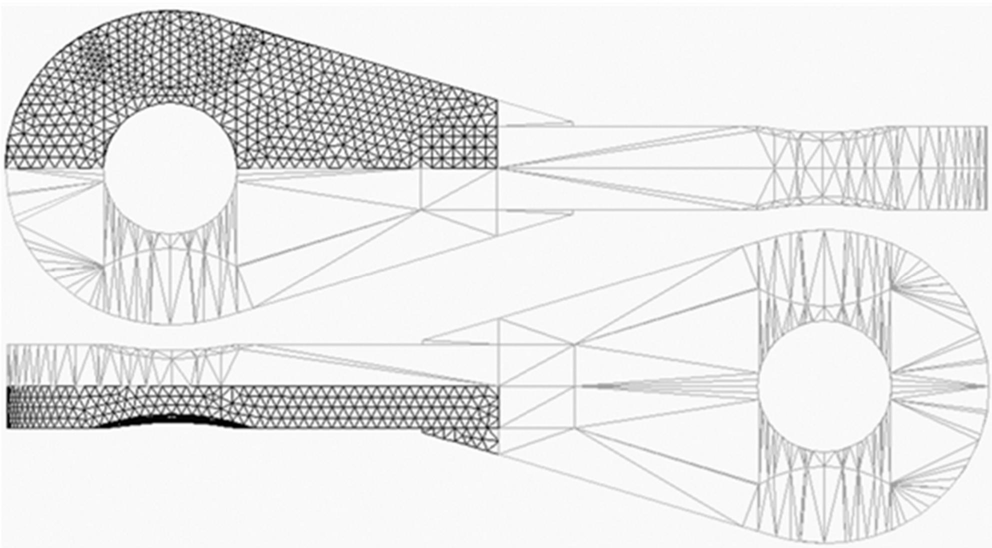

Fig. 5. Calculation mesh adopted

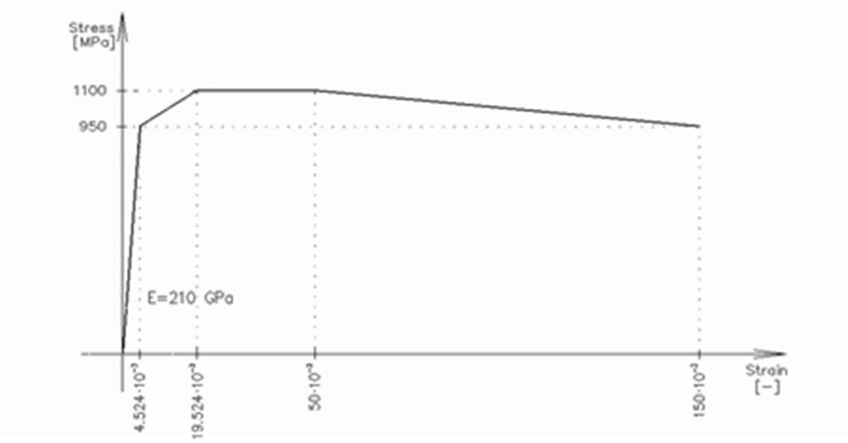

Fig. 6. Stress-strain curve of the specimen studied

The low temperatures were obtained in special insulated tube filled with dry ice where seven specimens were located in scope of exerimental research (Fig. 8). Specimens were tested at temperature values in scope from -60º C until +25º and simultaneously were subjected to axial loads being updated until fatigue collapse.

The flow-chart of static testing:

Updated increase of axial static loading until the level 450 kN, with following decrease on the level 79 kN (the laboratory weight of testing platform).

Updated increase of axial static loading until the collapse of the studied specimen.

Fig. 7. Pulsator with loading capacity of 6000 kN adopted

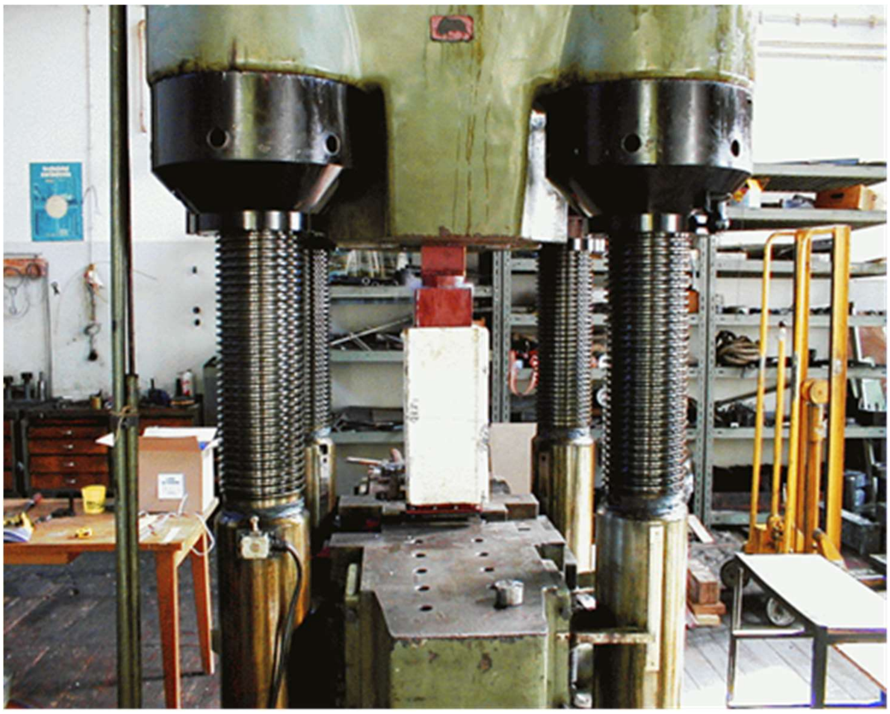

Fig. 8. Insulated tube filled with dry ice

The flow-chart of dynamic (fatigue) testing:

1. Updated increase of static loading until the level of 400 kN with the following decrease on the level 100 kN.
2. Updated increase of static loading on the level 400 kN.
3. Fatigue part of testing with specification of frequency as well as lower and upper amplitude levels of vibrating axial forces and the start of fatigue testing.
4. After obtaining required amplitude level the start of numbering of cycles.

Some numerical and experimental results obtained are summed up in Tables 1 and 2.

Table 1. Some results of static testing

Specimen Nr.	Temperature	Ultimate axial force in kN	
		calculated	tested
4	-60º C	642	640
5	-60º C	628	625
8	-30º	614	610
9	-30º C	639	635

Table 2. Some results of the fatigue testing

Specimen Nr.	Temperature [ºC]	Upper & lower load amplitudes [kN]		Upper & lower force amplitudes [kN]		Frequency [Hz]	Number of cycles Calculated	tested
3	25	450	100	400	200	3.7	5276	5300
6	-60	400	200	-	-	2.8	4157	4180
7	-30	400	200	-	-	2.8	2364	2400

3D-plotting of the simulation model which used is shown in Fig. 9. The stress developments at some levels of axial load adopted are given in Figs. 10, 11 and 12.

The comparison of numerical and experimental results submits the surmise about the adaptability of above theoretical approaches for analysis of ultimate fatigue behaviour of slender steel specimens at low temperatures. Besides, theoretical, numerical and experimental results presented provide some image dealing with complicated ultimate behaviour of steel specimens dependent of temperature.

7 CONCLUSIONS

Theoretical, numerical and experimental activities presented were made in scope of expertise for industrial facility ELBA, Kremnica, Slovakia, in order to explain some problems of steel specimens adopted in electric air conductors of high voltage lines being located in northern territories with cool temperatures. The results obtained were immediately adopted in scope of new developments of such conductor lines.

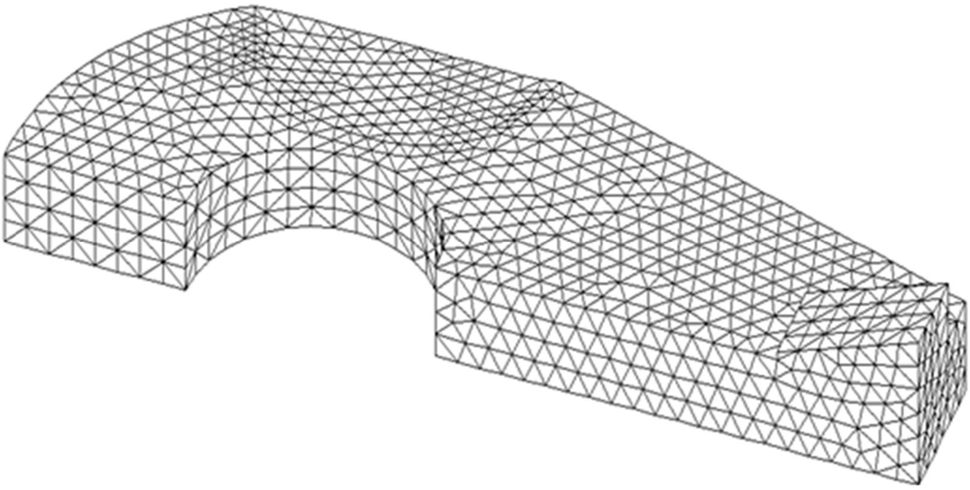

Fig. 9. 3D-model used for calculation (4944 Solid Elements, 1889 Nodes)

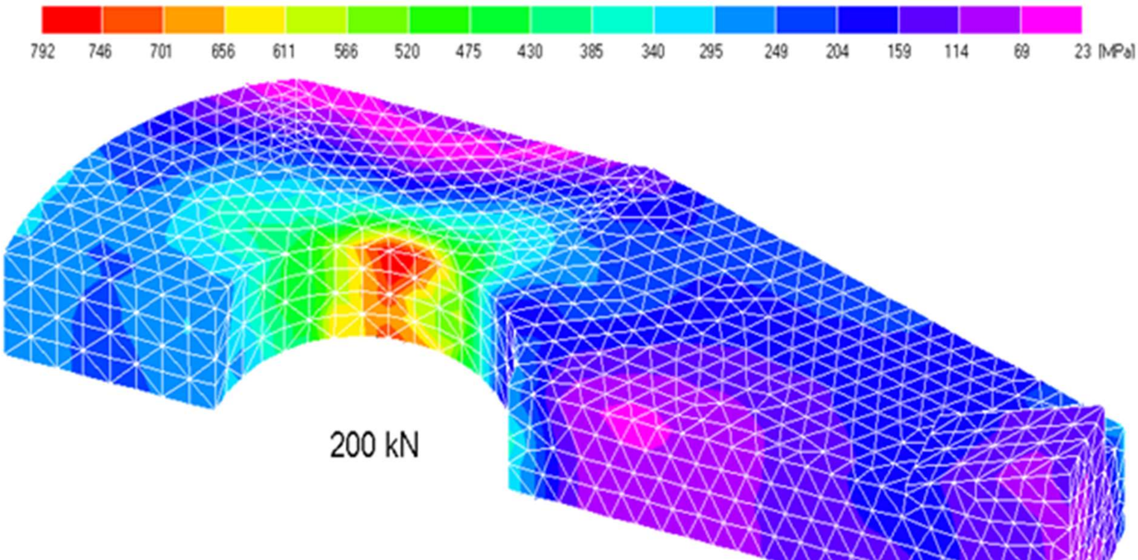

Fig.10. Stress configuration at axial load level 200 kN

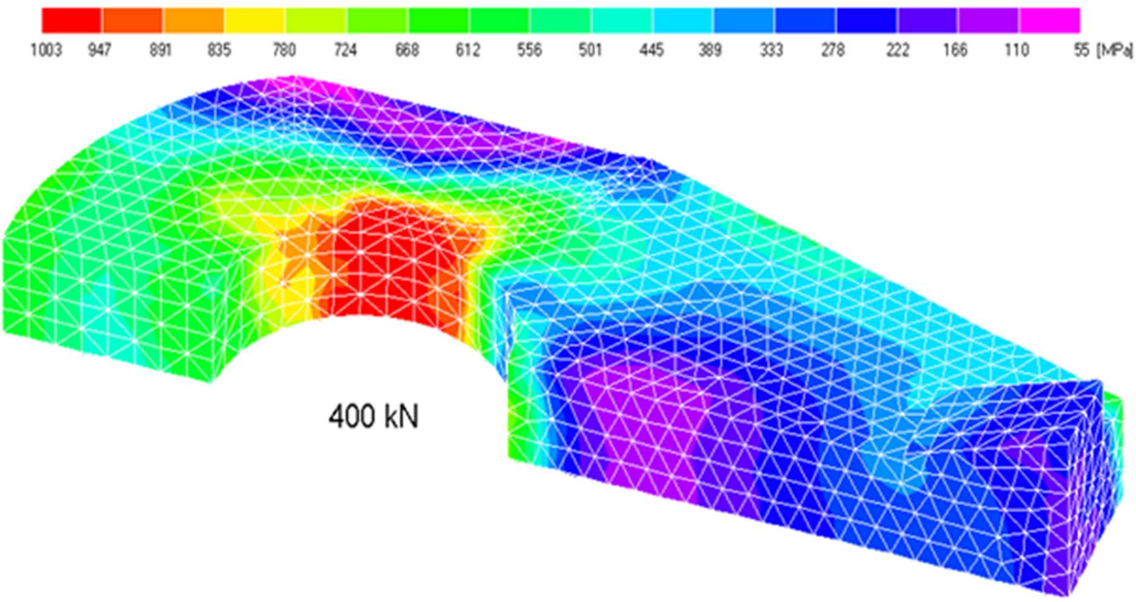

Fig.11. Stress configuration at axial load level 400 kN

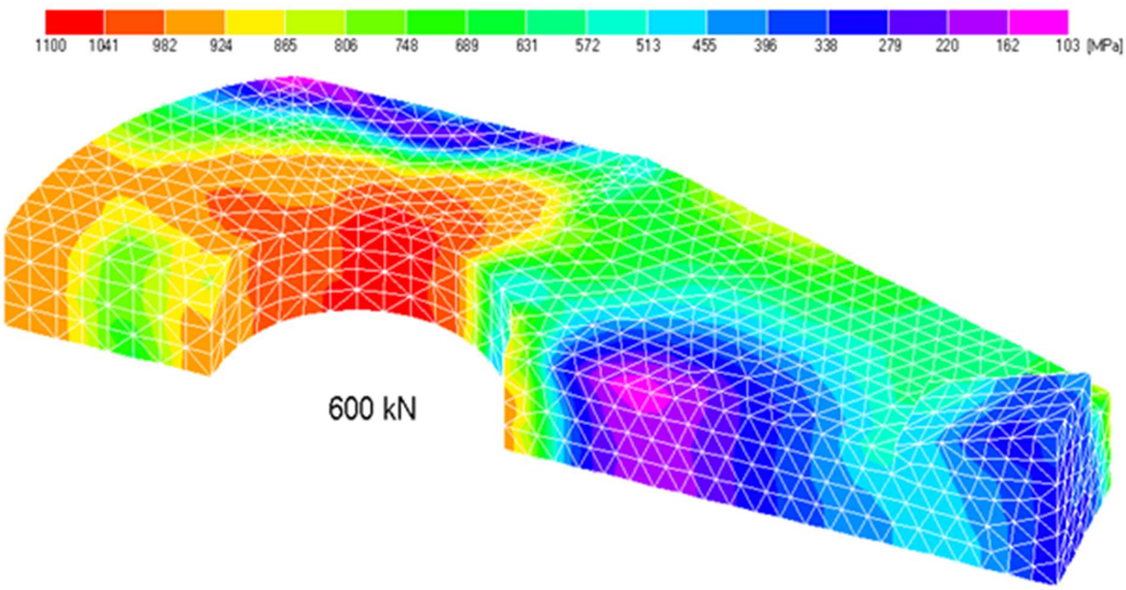

Fig.12. Stress configuration at axial load level 600 kN

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8 REFERENCES

[1] Tesar, A.: Transfer Matrix Method, KLUWER Academic Publishers, Dordrecht/Boston/London, 1988.

[2] Tesar, A. and Svolik, J,: Wave distribution in fibre members subjected to kinematic forcing. Int. Journal for Communication in Numerical Mechanics, 9, 1993

[3] Simo, J.C.: On a fully three-dimensional finite strain viscoelastic damage model – formulation and computational aspects. Comput. Meth. Engng. 29, 1990

[4] Huston, R.L. and Passerello, C.E.: Multibody structural dynamics including translation be-tween the bodies. Computers and Structures, 11, 1980

[5] Adeli, H. And Yeh, C.: Perception Learning in Engineering Design. Microcomputers in Civil Engineering, 4, 1989

[6] Lu, W. and Mäkeläinen, P.: A neural network model for local and distortional buckling behaviour of cold-formed steel compression members. Proceedings of 9-th Nordic Steel Con-struction Conference, Helsinki, 2001

[7] Tesar, A.: Mémoires of Engineer. EDIS, Žilina, 2019

[8] Budiansky, B.: Micromechanics. Computers and Structures, Vol. 16, Issues 1-4, 1983, pp. 3-12

[9] Budiansky, B.: Micromechanics II. Proceedings of the 10-th US National Congress of Applied Mechanics, Austin, Texas, 1986, pp. 1-8.

[10] Tesar, A.: Nonlinear Structural Dynamics. EDIS, Žilina, 2016

[11] Tesar, A.: Transfer Matrix Method - new developments and applications. Lambert Academic Publishing, 2015

ABSTRACT

FATIGUE OF STEEL SPECIMENS AT LOW TEMPERATURES

Alexander TESAR

Fatigue behaviour of 3-D steel structural specimens at low temperatures was investigated in this paper. Simulation model adopting backpropagation neural network approach is used for the analysis. The updated Lagrange formulation of motion combined with pseudo-force technique in the FETM-wave approach was used for the treatment of non-linear problems. Each step of iteration approaches the solution of linear problem and the feasibility of parallel processsing combined with backpropagation neural network is established. Numerical and experimental analysis is submitted in order to demonstrate the efficiency of the procedures suggested.

Key words: fatigue, FETM-wave approach, low temperature, neural network, parallel processing, pseudo-force technique, ultimate behaviour

APSTRAKT

ZAMOR ČELIČNIH UZORAKA PRI NISKIM TEMPERATURAMA

Alexander TESAR

U radu je analizirano ponašanje čeličnih uzoraka pod dejstvom zamornog opterećenja pri niskim temperaturama. Za analizu su primenjene neuronske mreže i pristup propagacija unazada (bakcpropagation). Nelinearni problem je tretiran pomoću modifikovane Lagranžeove formulacije kretanja, kombinovane sa metodom pseudo-sile u FETM pristupu. Svaki korak iteracije se približava rešenju linearnog problema, pri čemu je ilustrovana primenljivost paralelnog procesuiranja u kombinaciji sa neuronskim mrežama. Poređenjem numeričkih i eksperimentalnih rezultata demonstrirana je efikasnost predloženog postupka.

Ključne reči: zamor, FETM pristup, niska temperatura, neuronske mreže, paralelno procesuiranje, metoda pseudo-sile, granično ponašanje

VALORISATION OF EGG SHELL ASH AS A POTENTIAL REPLACEMENT FOR LIME IN STABILIZATION OF EXPANSIVE SOILS

VREDENOVANJE PEPELA OD LJUSKE JAJETA KAO POTENCIJALNA ZAMENA KREČA U STABILIZACIJI EKSPANZIVNIH TLA

Jijo JAMES
K. JOTHI PRIYA
P. KARTHIKA
S. KOKILA
V. VIDYASAGAR

ORIGINALNI NAUČNI RAD
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1 INTRODUCTION

Lime stabilization of expansive soils has been one of the oldest and most effective methods for improvement of poorly performing swelling soils. Addition of lime to expansive soils result in reduction in plasticity and swell-shrink characteristics and improves strength of the stabilized soil [22]. However, a sift through literature reveals that lime stabilization has been found wanting under certain soil conditions like sulphate rich environments, conditions of alternate wetting and drying, freezing and thawing to name a few. In the recent years, a lot of focus has been put on the reuse of solid wastes in various streams of Civil Engineering for their effective management. Soil stabilization is one such avenue for effective reuse of solid wastes [16]. There have been a lot of investigations on the utilization of different types of solid wastes in soil stabilization. However, an effective replacement for lime is yet to be found despite its limitations. One pragmatic way of finding an effective replacement for lime is to adopt solid wastes similar to lime in chemical composition. Lime is an umbrella term adopted for quick lime (CaO), hydrated lime ($Ca(OH)_2$) and carbonate lime ($CaCO_3$). Egg shell waste is one such waste material whose chemical composition is very similar to lime. The targeted egg production in India for the year 2020 is 106 billion [14]. Based on the calculation done by James et al. [19], considering 5.5 grams of shell weight per egg, it is estimated that the annual generation of egg shell waste in India, by the end of 2020 will be 583,000 tonnes. This huge quantity can put a strain on the waste collection and management systems unless an effective reutilization method is not adopted. A lot of investigations have been carried out in the reutilization of egg shell waste in its powdered form in concrete as well as in soil engineering. Egg shells are primarily composed of calcium carbonate. Carbonate lime is not commonly adopted in soil stabilization as it is a chemically inert material and does not readily react with water [15]. One modified form of egg shell waste is egg shell ash (ESA). The chemical composition of ESA is very similar to quick lime [25] and can be potentially more reactive than egg shell powder. Very few investigations were found for the valorisation of this waste in soil stabilization despite its close similarity to quick lime in composition. Okonkwo et al. [25] researched the use of ESA along with cement in the stabilization of a lateritic soil. James and Pandian [17] studied the influence of ESA in improving the early strength of a lime stabilized expansive soil. Later, James et al.[19] investigated the effect of ESA as an auxiliary additive to lime in the stabilization of an expansive soil. Bensaifi et al.[4] delved into the mechanical properties of marl stabilized using combinations of Portland cement, blast furnace slag and ESA. Thus, it can be seen that very little work has been done in the use of a waste material that can be a potential replacement for lime in soil stabilization. This work attempted to investigate the capability of ESA as a replacement for lime for the stabilization of an expansive soil under normal as well conditions of alternate wetting and drying.

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2 MATERIALS

The various materials adopted in this investigation are the virgin swelling soil, industrial grade lime and ESA prepared from egg shell powder. The virgin swelling soil was investigated in the laboratory for its various geotechnical properties. The various properties of the soil that were investigated include liquid limit [11], plastic limit [11], shrinkage limit [7], grain size distribution [10], specific gravity [8], compaction characteristics [28], unconfined compression strength (UCS)[12], and classification [6]. All the tests were done in accordance with various codes of Bureau of Indian Standards (BIS). The geotechnical properties of the soil as determined through laboratory tests are given in Table 1. The chemical composition of the soil as well as the other materials, determined as a part of an earlier investigation [19] are shown in Table 2a. The industrial grade lime was sourced from M/s. Shiyal Chemicals, Chennai, India. The ESA was prepared by calcining egg shell powder obtained from M/s. SKM egg products, Erode, Tamil Nadu, India.

3 METHODS

The experimental investigation began with the preparation and characterization of the materials used in the investigation. It was followed by determination of initial consumption of lime (ICL), fixing of mix proportions, casting of UCS samples, simulation of wetting and drying, testing of specimens and determination of plasticity. Each stage of the experimental investigation has been explained in detail in the following subsections.

3.1 Preparation and Characterization of Materials

The investigation began with the preparation and characterization of materials. The soil was crushed and pulverized in the laboratory and sieved through the requisite sieves for the various tests based on BIS code [9]. Lime used in the investigation was used as obtained from the manufacturer without any preparation. The ESA was prepared from egg shell powder obtained from SKM egg products. The ESA was obtained by decomposition of the calcium carbonate in egg shells into calcium oxide by calcining the egg shell powder at a temperature of 500°C for a period of 3 hours [19]. After that, the ash was sieved through BIS 75-micron sieve for removal of any coarse unburnt particles that may have remained in the ash.

3.2 Determination of ICL

The initial consumption of lime may be defined as the minimum lime content required to raise the pH of the soil to 12.4 [2]. This value was obtained from the Eades and Grim pH test [13] done based on ASTM D6276 [2]. This is the minimum lime content required for the modification of soil properties. It is also referred to as lime modification optimum.

3.3 Fixing of Mix Proportions

After the determination of the ICL, the various proportions by which the lime content was to be substituted using ESA was fixed based on trial and error method. The ICL for the soil under investigation was 3%. Table 2b shows the various proportions selected for use in this investigation.

Table 1 Geotechnical Properties of Soil

Property	Value
Liquid limit (w_l)	66.9 %
Plastic limit (w_p)	27.1%
Plasticity index (I_p)	49.8%
Shrinkage limit (w_s)	9.2%
Specific gravity (G_s)	2.75
Maximum dry density of the soil	15.1 kN/m^3
Optimum moisture content of the soil (w_{opt})	23.1%
Unconfined compressive strength of soil (q_u)	82.4 kPa
Sand Content	2.6%
Silt Content	65.2%
Clay Content	32.2%
Classification	CH

Table 2a Chemical Composition of Soil, Lime and ESA

Oxide (%)	Al_2O_3	CaO	Fe_2O_3	K_2O	MgO	Na_2O	P_2O_5	SiO_2	TiO_2	SO_3
Soil	18.8	2.3	7.5	2.3	1.7	1.4	0.0	63.6	0.9	0.2
Lime	0.4	81.1	0.1	0.0	3.2	8.0	0.2	4.7	0.0	2.3
ESA	0.1	88.5	0.0	0.0	0.6	9.0	1.0	0.7	0.0	0.2

Table 2b Replacement Combinations of ESA for Lime

Lime Content (%)	ESA Content (%)	% Replacement	Designation
3	0	0	LE30
2	1	33.33	LE21
1.5	1.5	50	LE1.5
1	2	66.67	LE12
0	3	100	LE03

3.4 Casting of Specimens

Cylindrical specimens of dimensions 38 mm x 76 mm were cast using a split mould using static compaction. The specimens were prepared at the maximum dry density and optimum moisture content of the soil determined from the compaction test. Three samples were cast for each of the combinations. The samples were demoulded and placed in sealed polythene covers until the specified curing period to prevent loss of moisture.

3.5 Simulation of Wetting and Drying

The samples prepared for wetting and drying were removed from the polythene bags after 28 days of curing and were subjected to cycles of wetting and drying. The samples were completely soaked in a bed of wet cotton for a period of 24 hours followed by air drying for a period of 24 hours. This constituted one cycle of wetting and drying. Different researchers have adopted different number of cycles in their investigations varying from three going up to twelve cycles ([26],[21],[1],[30],[23],[20]). The samples were subjected to one, three and five cycles of wetting and drying to determine the resistance of the sample to the loss in strength due to the extreme conditions.

3.6 Sample Testing

After the end of the designated curing period, the samples were removed from their covers and strained axially in a uniaxial loading frame of 40 kN capacity. They were strained at a rate of 0.625 mm/minute until the samples failed. In the case of samples subjected to wetting and drying, the same procedure was followed on the samples, after the wetting and drying cycles.

3.7 Determination of Plasticity

The 28 days cured samples after failure were crushed and pulverized and sieved through the BIS 425 micron sieve and subjected to liquid limit and plastic limit tests to determine the effect of lime and ESA on the plasticity nature of the soil.

4 RESULTS AND DISCUSSION

The effect of lime and its replacement by ESA on the uniaxial strength, plasticity and resistance to wetting and drying has been discussed in detail in the following subsections.

4.1 The Effect of Lime and ESA on the UCS

Figure 1 shows the effect of lime and ESA on the UCS of the stabilized soil after 28 days of curing. The 3% lime stabilized soil specimen was considered as the control combination to compare the strengths of the modified specimens. It can be seen that the addition of lime has resulted in a very good improvement in strength. However, the replacement of lime with ESA in any proportion did not yield any improvement in strength of the soil. In fact, the addition of ESA in the stabilization process has resulted in the strength of the stabilized soil dropping by more than half of the control specimen. The strength of the lime stabilized soil was 309.8 kPa whereas the strength of the other combinations are in the range of 95.6 to 128.7 kPa.

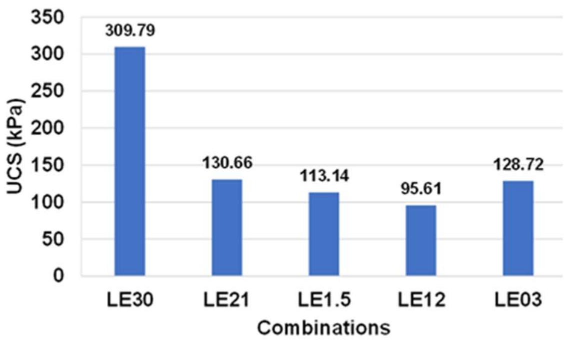

Figure 1 The Effect of Lime and ESA on the UCS of the Stabilized Soil

A comparison of the present study with similar earlier investigations was performed to check the beneficial effect of ESA addition. The investigations considered for comparison include the works done by James et al. [19] and James and Pandian [17]. The investigations were selected based on the similarity with the present study viz. use of combinations of lime and ESA in soil stabilization. To bring in the effect of the combination of lime and ESA, the two additives were reduced to a ratio as done in some earlier investigations ([18],[27]). However, pure lime and pure ESA combinations have not been included in the comparison. The UCS values of the ESA and lime stabilized soil specimens after 7 days of curing were compared. Figure 2 shows the comparison of the present study with earlier investigations. Therefore, it is clear that the strength gain in the present study was the lowest of all the three studies. However, it was very close to those obtained by James et al. [19]. The strength gain in the work reported by James and Pandian [17] was the highest. This may be due to the fact that high quality laboratory grade lime was used for the study. Moreover, when carefully considering these studies, only the present one adopted ESA as a replacement for lime whereas the other two studies adopted ESA as an auxiliary additive to lime. The minimum quantity of lime determined from the Eades and Grim pH test was present in the soil for stabilization in the other two studies. Investigations dealing with ESA as a partial replacement higher than ICL content could not be found in literature. Thus, based on the strength test results from figures 1 and 2, it can be stated that ESA as a replacement for lime is not a functional combination when minimum lime content required for stabilization is not present. Nasrizar et al. [24] state that there are three phases in the relation between strength and lime content viz. less than ICL (Phase 1), between ICL and optimum lime content (OLC) (Phase 2) and greater than OLC (Phase 3). The current investigation deals with lime content less than ICL when ESA replaces lime in the mix i.e. phase 1. Future investigations on whether ESA will be an effective replacement for lime should be investigated for phases two and three as well. The second major conclusion, that can be derived from the comparison is that lower ESA/lime ratios perform better in terms of strength gain when compared to higher ESA/lime ratio with the exception of one anomalous data point. It can be seen that ESA/lime ratio less than one gives higher strength results. Even comparing the present work with the work done by James et al. [19] which produced comparable strength results, it can be seen that lower ESA/lime ratios produced better strength.

Figure 3 shows the effect of curing period on the development of the strength of the stabilized soil. It can be seen that for the lime stabilized soil, there is a steady increase in the strength of the stabilized soil with increase in the curing period of the specimens. This is very much in agreement with earlier published works in lime stabilization ([22],[3]). However, in the case of the ESA modified specimens, with the exception of LE21, all the other specimens show a different trend of strength gain. All the combinations with the exception of LE21, show a dip in strength at 7 days of curing when compared to 3 days of curing. However, at 28 days of curing, there is a further increase in the strength. In the case of LE21, there is a very marginal but steady increase in strength of the stabilized soil from 3 days to 28 days of curing. This was in contrast with the results obtained by James et al. [19] as well as James and Pandian [17]. It is interesting to note that this happens in ESA modified combinations with ESA content either equal to or higher than lime content in the

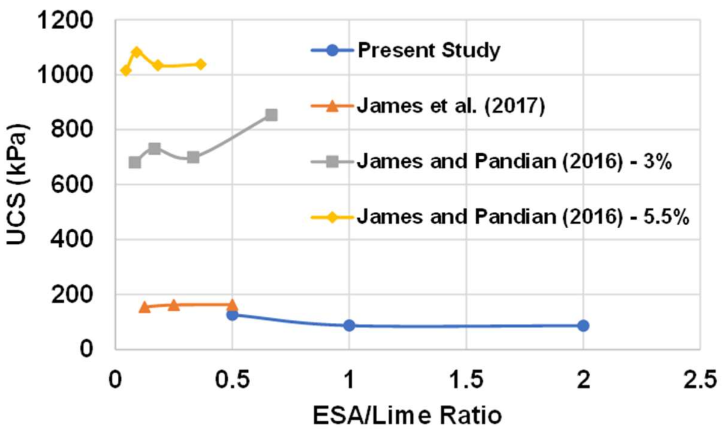

Figure 2 Comparison of the Present Study with Earlier Works

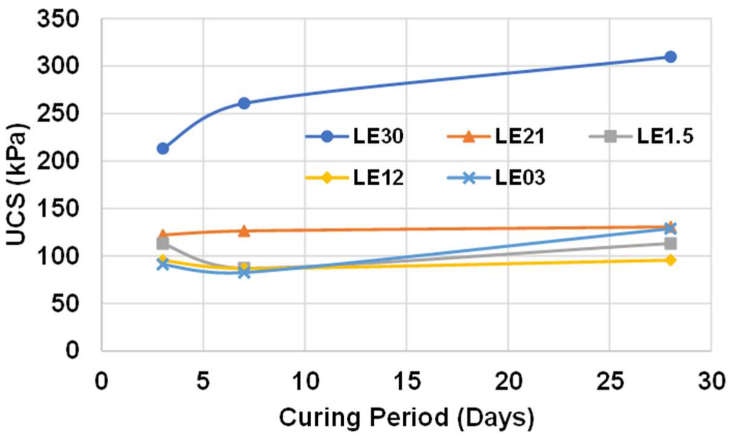

Figure 3 Development of UCS with Curing Periods

stabilization admixture. It is possible that the presence of other chemical compounds in the ESA may have interfered with the hydration process of the lime thereby slowing down the formation of the reaction products. Moreover, this happens only when ESA content is dominant in the combination. Thus, the effect of curing period on the development of ESA modified lime as well as ESA stabilized soil needs to be investigated further to clearly understand the strength gain trend.

4.2 The Effect of ESA and Lime on the Plasticity of the Stabilized Soil

Figure 4 shows the effect of the stabilization on the Atterberg limits of the stabilized soil. It can be seen that the replacement of lime with ESA resulted in a marginal increase in the liquid limit of the soil whereas pure ESA was able to reduce the liquid limit to a value much lower than that of pure lime stabilized soil. Coming to the plasticity limit, it can be seen that with an increase in the ESA content in the mix, there is an increase in the plastic limit of the soil. However, pure ESA stabilized soil resulted in a slightly lower plastic limit values. Based on the combined results of liquid and plastic limit, it can be seen that the increase in ESA content in the mix reduced the plasticity of the pure lime stabilized soil from 24.3% to 18.9% for pure ESA stabilized soil. It is well known that the lime results in reduction in plasticity due to ion exchange ([22],[5]), reduction in diffused double layer with increase in electrolyte concentration and viscosity of the pore fluid [29]. ESA having a similar composition of lime may have resulted in a similar behaviour. It is clear that though the ESA replacement of lime failed to produce a favourable result in terms of strength, ESA did contribute to a favourable improvement in the plasticity characteristics of the soil. Thus, it can be stated that ESA replacement can be considered where the workability of the soil needs to be improved.

4.3 The Effect of Wetting and Drying on the UCS of Lime and ESA Stabilized Soil

The durability performance of the stabilized soil against cycles of wetting and drying was evaluated by subjecting the specimens to one, three and five cycles of wetting and drying. Figure 5 shows the durability resistance of the various combinations to wetting and drying cycles. From the figure, it can be seen that pure lime stabilized soil, LE30, shows a drastic loss in strength after the first cycle of wetting and drying. The strength drops from 309.8 kPa to 174.5 kPa. However, the loss in strength is more or less stabilized after 3 cycles of wetting and drying. The strength stabilizes close 161 kPa for 3 and 5 cycles of wetting and drying. As the lime content is replaced with ESA, at low replacement levels i.e., LE21, the wetting and drying resistance is very similar to that of lime stabilized soil wherein there is a reduction in the strength of the specimens after the first cycle of wetting and drying. The strength drops from 130.7 kPa to 69.6 kPa. The loss in strength also stabilizes after 3 cycles of wetting and drying similar to pure lime stabilized soil LE30. The strength ranges between 34-40 kPa between 3-5 cycles. But, as the ESA replacement increases in the mixture, there is a change in the wet-dry resistance of the specimens. For LE1.5, there is a slight increase in strength after an initial loss in strength at cycle 1. The strength drops from 113.1 kPa to 43.1 kPa after the first cycle. The strength of the specimens after 3 and 5 cycles are marginally higher. The strength lies between 54.7 to 69.1 kPa after three cycles. Combinations LE12 and LE03 show a much more cleared increase in strength after 3 cycles of wetting and drying after a marginal reduction in strength after the first cycle. Combination LE12 increases in strength from 95.6 kPa for no cycles of wetting and drying to 133.5 kPa for 5 cycles. Combination LE03 performs extremely well in extreme conditions to such an extent that it gains strength higher than pure lime stabilized soil after 3 cycles of wetting and drying. The

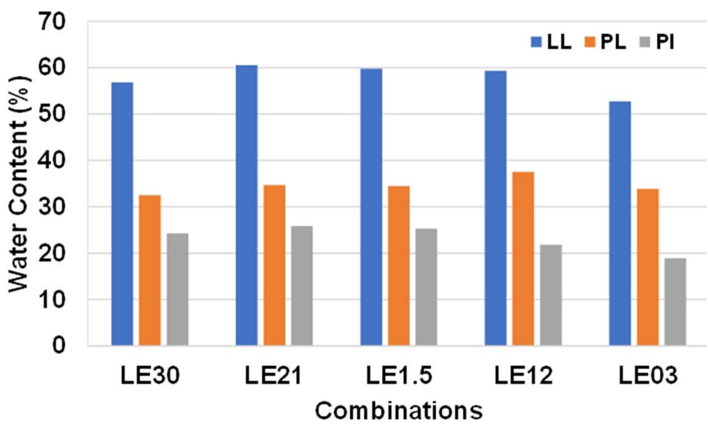

Figure 4 Effect of Lime and ESA on the Atterberg Limits

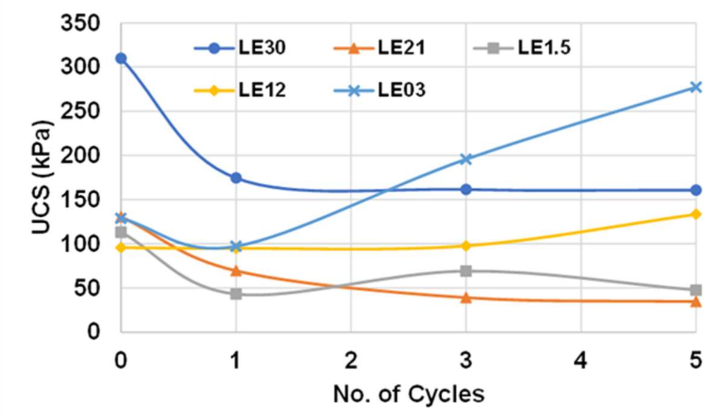

Figure 5 Wetting and Drying Resistance of ESA and Lime Stabilized Soil

trend even continues till 5 cycles of wetting and drying wherein the strength of the specimens are significantly higher than pure lime stabilized soil, LE30. The strength of LE03 increases from 128.7 kPa for no cycles to 195.8 kPa and 277.4 kPa for 3 and 5 cycles respectively. The increase in strength of the specimens may be attributed to the deficiency in water content during moulding of the specimens. The wetting and drying cycles may have supplied sufficient moisture for the specimens for hydration and progress of pozzolanic reactions to proceed further. Similar results of increase in strength with increase in number of wetting and drying cycles have been reported by other researchers as well ([1],[23]). Muntohar and Khasanah [23] attribute the increase in strength with wetting and drying cycles to two reasons. First, the increase in the duration of chemical reactions during wetting and drying cycles and second, the increase in the quantum of cementitious compounds during wetting and drying cycles. Thus, it can be stated that ESA replacement of lime in soil stabilization can be considered under extreme conditions like wetting and drying where they can perform better than pure lime stabilized soil. However, the optimum quantity of replacement cannot be concluded based on the present investigation and more studies need to be conducted to comment on the same. The variations in microstructure due to ESA replacement of lime should be studied to better understand the mechanism of strength enhancement after wetting and drying cycles.

5 CONCLUSIONS AND RECOMMENDATIONS

The present investigation dealt the possibility of valorization of ESA as a potential replacement for lime in stabilization of expansive soils. Based on the results of the investigations the following points can be concluded.

I. With increase in ESA replacement of lime from zero to hundred percent, the strength dropped from 309.8 kPa to 128.7 kPa. The replacement of ICL content with increasing proportion of ESA also results in reduction of lime content below the minimum required value. Thus, it can be concluded that under normal conditions, replacement of lime with ESA leading to less than ICL content, is not a viable option.

II. From the results of the present and earlier works, it was found that ESA/lime ratio of less than one performed better when compared to higher ratios of ESA/lime. Thus, lower ESA/lime ratios are recommended when using ESA along with lime in soil stabilization.

III. ESA replacement of lime resulted in a reduction in strength after 7 days of curing, followed by further increase in strength for 28 days of curing for all combinations with ESA. This trend of strength gain with curing was unlike lime stabilization and needs to be investigated further.

IV. Increasing proportion of ESA in the stabilization mix reduced the plasticity from 24.3% to 18.9%. Thus, it can be concluded that ESA under normal conditions, though not capable of strength improvement, can be considered as a soil conditioner, to improve the workability of the soil by modifying its plasticity characteristics.

V. With increasing, proportion of ESA, the durability performance of the combinations improved when subjected to multiple cycles of wetting and drying. However, an optimal replacement content cannot be recommended based on the present investigation and more research is needed in this area. Thus, it can be concluded that the ESA replacement of lime can be considered a viable option in soil stabilization in areas prone to alternating wet and dry subsoil conditions.

The investigation only dealt with replacement of lime content below ICL. However, there are other phases of lime stabilization based on OLC which need to be investigated for its performance when replaced with ESA. Other proportions/replacements can be attempted with different curing periods to better understand the strength development and optimization of ESA content.

6 REFERENCES

[1] Anggraini, V, Asadi, A, Farzadnia, N, Jahangirian, H & Huat, BBK 2016, 'Reinforcement benefits of nanomodified coir fiber in lime-treated marine clay', Journal of Materials in Civil Engineering, vol. 28, no. 6, pp. 1–8.

[2] ASTM 2006, D6276 Standard Test Method for Using pH to Estimate the Soil-Lime Proportion Requirement, vol. 14, United States, pp. 1–4.

[3] Bell, FG 1996, 'Lime stabilization of clay minerals and soils', Engineering Geology, vol. 42, no. 4, pp. 223–237.

[4] Bensaifi, E, Bouteldja, F, Nouaouria, MS & Breul, P 2019, 'Influence of crushed granulated blast furnace slag and calcined eggshell waste on mechanical properties of a compacted marl', Transportation Geotechnics, vol. 20, no. 100244, pp. 1-9.

[5] Bhuvaneshwari, S, Robinson, RG & Gandhi, SR 2013, 'Behaviour of Lime Treated Cured Expansive Soil Composites', Indian Geotechnical Journal, vol. 44, no. 3, pp. 278–293.

[6] BIS 1970, IS 1498 Classification and Identification of Soils for General Engineering Purposes, India, pp. 4–24.

[7] BIS 1972, IS 2720 Methods of Test for Soils:Part 6 Determination of Shrinkage Factors, India, pp. 1–12.

[8] BIS 1980, IS 2720 Methods of Test for Soils Part 3:Determination of Specific Gravity/Section 1 Fine Grained Soils, India, pp. 1–8.

[9] BIS 1983, IS 2720 Methods of Test For Soils:Part 1 - Preparation of Dry Soil Sample for Various Tests, India, pp. 1–10.

[10] BIS 1985a, IS 2720 Methods of Test for Soils:Part 4 Grain Size Analysis, India, pp. 1–38.

[11] BIS 1985b, IS 2720 Methods of Test for Soils:Part 5 Determination of Liquid and Plastic Limit, India, pp. 1–16.

[12] BIS 1991, IS 2720 Methods of Test for Soils:Part 10 - Determination of Unconfined Compressive Strength, India, pp. 1–4.

[13] Eades, JL & Grim, RE 1966, 'A Quick Test to Determine Lime Requirements for Lime Stabilization', Highway Research Record, vol. 139, pp. 61–72.

[14] Government of India 2018, National Action Plan for Egg & Poultry-2022.

[15] James, J & Pandian, PK 2013, 'Performance Study on Soil Stabilisation using Natural Materials', International Journal of Earth Sciences and Engineering, vol. 6, no. 1, pp. 194–203.

[16] James, J & Pandian, PK 2015, 'Soil Stabilization as an Avenue for Reuse of Solid Wastes : A Review', Acta Technica Napocensis: Civil Engineering and Architechture, vol. 58, no. 1, pp. 50–76.

[17] James, J & Pandian, PK 2016, 'Development of Early Strength of Lime Stabilized Expansive Soil: Effect of Red Mud and Egg Shell Ash', Acta Technica Corviniensis - Bulletin of Engineering, vol. 9, no. 1, pp. 93–100.

[18] James, J, Pandian, PK, Deepika, K, Venkatesh, JM, Manikandan, V & Manikumaran, P 2016, 'Cement Stabilized Soil Blocks Admixed with Sugarcane Bagasse Ash', Journal of Engineering, vol. 2016, no. Article ID 7940239, pp. 1–9.

[19] James, J, Pandian, PK & Switzer, AS 2017, 'Egg Shell Ash as Auxiliary Addendum to Lime Stabilization of an Expansive Soil', Journal of Solid Waste Technology and Management, vol. 43, no. 1, pp. 15–25.

[20] James, J & Saraswathy, R 2020, 'Performance of Fly Ash - Lime Stabilized Lateritic Soil Blocks Subjected to Alternate Cycles of Wetting and Drying', Civil and Environmental Engineering, vol. 16, no. 1, pp. 30–38.

[21] Kampala, A, Horpibulsuk, S, Prongmanee, N & Chinkulkijniwat, A 2014, 'Influence of wet-dry cycles on compressive strength of calcium carbide residue-fly ash stabilized clay', Journal of Materials in Civil Engineering, vol. 26, no. 4, pp. 633–643.

[22] Little, DN 1995, Handbook for Stabilization of Pavement Subgrades and Base Courses with Lime, Austin, Texas.

[23] Muntohar, AS & Khasanah, IA 2019, 'Effect of moisture on the strength of stabilized clay with lime-rice husk ash and fibre against wetting-drying cycle', International Journal of Integrated Engineering, vol. 11, no. 9 Special Issue, pp. 100–109.

[24] Nasrizar, AA, Ilamparuthi, K & Muttharam, M 2012, 'Quantitative Models for Strength of Lime Treated Expansive Soil', in GeoCongress 2012, March 25-29, American Society of Civil Engineers, Oakland, California, US, pp. 978–987.

[25] Okonkwo, UN, Odiong, IC & Akpabio, EE 2012, 'The Effects of Eggshell Ash on the Strength Properties of Cement Stabilized Lateritic', International Journal of Sustainable Construction Engineering & Technology, vol. 3, no. 1, pp. 18–25.

[26] Phanikumar, BR, Manvita, C & Patnaik, R 2011, 'Influence of Wetting-Drying Cycles on Heave Behaviour of Fiber-Reinforced Expansive Soil Specimens', in Proceedings of the Indian Geotechnical Conference 2011, December 15-17, Kochi, India, pp. 505–507.

[27] Saraswathy, R, James, J, Pandian, PK, Sriram, G, Sundar, JK, Kumar, GS & Kumar, AS 2019, 'Valorization of Crushed Glass as a Potential Replacement for Sand in Cement Stabilized Fly Ash Bricks', Civil and Environmental Engineering, vol. 15, no. 1, pp. 48–57.

[28] Singh, A & Punmia, BC 1965, 'A New Laboratory Compaction Device and its Comparison with the Proctor Test', Highway Research News, vol. 17, pp. 37–41.

[29] Sivapullaiah, P V. & Jha, AK 2014, 'Gypsum Induced Strength Behaviour of Fly Ash-Lime Stabilized Expansive Soil', Geotechnical and Geological Engineering, vol. 32, no. 5, pp. 1261–1273.

[30] Yilmaz, F & Fidan, D 2017, 'Effect of Wetting-Drying on the Volumetric Stability of Clayey Soil Stabilized with Lime and Perlite', European Journal of Technique, vol. 7, no. 2, pp. 207–218.

ABSTRACT

VALORISATION OF EGG SHELL ASH AS A POTENTIAL REPLACEMENT FOR LIME IN STABILIZATION OF EXPANSIVE SOILS

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The investigation focussed on the possibility of replacing lime in soil stabilization using Egg Shell Ash (ESA), a waste derived from poultry industry. An expansive soil was characterized for its properties in the lab. The minimum lime content required for modification of soil properties was determined from the Eades and Grim pH test. This lime content came out to be 3%. The lime content was replaced using ESA in the proportions of 33%, 50%, 67% and 100%. Unconfined compression test specimens of dimension 38 mm x 76 mm were cast for different combinations and were cured for periods of 3, 7 and 28 days. Samples were also subjected to 1, 3 and 5 cycles of wetting and drying to understand its durability. After the designated curing periods and cycles of wetting and drying, they were strained axially till failure. Atterberg limits tests were done to determine the plasticity of the stabilized soil. The strength results indicated that ESA cannot be used under normal conditions as a replacement for lime, however, ESA replacement resulted in good durability of the specimens under conditions of wetting and drying. It was concluded that ESA replacement of lime can be adopted in conditions of wetting and drying.

Key words: Expansive soil, lime, egg shell ash, stabilization, strength, durability.

APSTRAKT

VREDENOVANJE PEPELA OD LJUSKE JAJETA KAO POTENCIJALNA ZAMENA KREČA U STABILIZACIJI EKSPANZIVNIH TLA

Jijo JAMES
K. JOTHI PRIYA
P. KARTHIKA
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Predmet ovog istraživanja odnosi se na mogućnost zamene kreča pri stabilizaciji tla korišćenjem pepela ljuske jaja (ESA), otpadnog nusproizvoda koji se dobija iz živinarstva. U tu svrhu laboratorijski su ispitana svojstva ekspanzivnog tla. Minimalni sadržaj kreča koji je neophodan za modifikaciju svojstava tla određen je na osnovu Eades-Grimovog pH testa. Test je pokazao da je količina neophodnog kreča 3%. Sadržaj kreča je zamenjen pepelom ljuske jaja (ESA) u proporcijama od 33%, 50%, 67% i 100%. Odliveni su neutegnuti uzorci dimenzija 38 mm x 76 mm, namenjeni za testiranje čvrstoće pri različitim kombinacijama, koji su ostavljeni da se suše 3, 7 odnosno 28 dana. Da bi se odredila njihova trajnost, uzorci su podvrgnuti 1, 3 i 5 ciklusa vlaženja i sušenja. Nakon odgovarajućih perioda stvrdnjavanja i ciklusa vlaženja i sušenja, uzorci su podvrgnuti delovanju aksijalne sile do loma. Plastičnost stabilizovanog tla određena je primenom testa Aterbergovih granica. Rezultati ispitivanja čvrstoće pokazali su da se u normalnim uslovima ESA ne može koristiti kao zamena za kreč, međutim, zamena kreča ESA-om rezultirala je dobrom izdržljivošću uzoraka u uslovima vlaženja i sušenja. Zaključeno je da se kreč može zameniti ESA-om u uslovima vlaženja i sušenja.

Ključne reči: ekspanzivno tlo, kreč, pepeo od ljuske jaja, stabilizacija, čvrstoća, trajnost

UPOREDNE ANALIZE NEKIH SISTEMA ZA UPRAVLJANJE MOSTOVIMA

COMPARATIVE ANALYSIS OF SOME BRIDGE MANAGEMENT SYSTEMS

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1 UVOD

Mostovi su najznačajnija komponenta saobraćajnica. Oni imaju suštinsku ulogu u transportnim sistemima i u ekonomskom proizvodnom procesu. Prema EN 1990: 2002, procenjeni vek trajanja mostova jeste 100 godina, pa je potrebno osigurati ekonomičan rad mostova adekvatnim projektovanjem i građenjem, ali i upravlja-njem. U svetu i regionu, najzastupljeniji su betonski mostovi (BM) čija trajnost često nije zadovoljavajuća. Stoga, razmatranja u ovom radu usmerena su upravo na njih. Njihova nosivost i njihove eksploatacione karakte-ristike opadaju tokom vremena, pa je i njihov eksploa-tacioni (životni) vek često kraći od očekivanog. Na to utiču i porast funkcionalnih zahteva i izloženost mostova agresivnom dejstvu okoline (vlaga, temperatura i aero-zagađenje), a zimi – i soli za odmrzavanje. Poslednjih godina povećavaju se i težine i broj vozila na saobraćajnicama. To uslovljava stalno praćenje stanja mostova, te izvođenje manjih ili većih radova, da bi se omogućio nesmetan saobraćaj. Cilj upravljanja građevinskim objektima (GO) jeste očuvanje određenog stepena pouzdanosti funkcionisanja u toku životnog veka, uz optimizaciju troškova održavanja.

Transportne agencije (institucije) trebalo bi da održavaju mostove u prihvatljivim uslovima kako bi obez-bedile poželjan nivo usluge korisnicima u okolnostima ograničenih budžeta, a neki od mostova brzo stare [1]. U mnogim zemljama razvijeni su sveobuhvatni sistem upravljanja mostovima i praksa inspekcije mostova. Ciljevi menadžera mostova jesu da osiguraju to da mostovi postignu svoj životni vek, da ostanu otvoreni za

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1 INTRODUCTION

Bridges are the most important component of transportation systems and they play an essential role in the economy. According to EN 1990:2002 the desired service life of bridges is 100 years so it is necessary to secure the cost-effective service of bridges through an adequate design and construction, as well as management. Globally and in the region, concrete bridges (CB) are most common, but their durability is often unsatisfactory. Therefore, the considerations in this paper are focused on them. Their load-bearing capacity and service characteristics degrade over time, so their service life is shorter than expected. They are also influenced by increasing functional requirements and the exposure to the aggressive action of the environment (humidity, temperature and air pollution), and in winter also to de-icing salts. In recent years, the weight and number of vehicles on the roads have been increasing. This necessitates constant monitoring of the condition of bridges, and performing light or intensive maintenance works, in order to enable unhindered traffic flow. The goal of structural management (SM) is to maintain a certain degree of reliability during service life, while optimizing maintenance costs.

Transportation agencies should maintain bridges, a number of which are aging rapidly [1] in acceptable conditions to provide a desirable level of service to the users/public within limited budgets. In many countries comprehensive bridge management systems (BMS) and bridge inspection practices have been developed. The objectives of a bridge manager are to ensure that bridges

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saobraćaj i da rizik od većih oštećenja i/ili rušenja uvek bude vrlo nizak. Sve to treba postići na održiv način i uz minimalne troškove. Neki aspekti upravljanja mostovima uglavnom su u vezi s pojedinačnim mostovima (nivo projekta), dok se drugi aspekti odnose na upravljanje grupom mostova (BM na nivou mreže [2]).

Uloga BMS-a od posebnog je značaja u optimizaciji troškova održavanja, za šta je neophodno koristiti sistematski i planirani pristup, zasnovan na tehničkim, ekonomskim i sociološkim aspektima. Prvenstveno, imaju se u vidu prioriteti, vrste i obim intervencionih mera, kao i odgovarajući troškovi. Ovakvi problemi uspešno se rešavaju razvojem i primenom informacionih sistema za upravljanje objektima. Opisane su različite vrste inspekcija/pregleda zbog znakova deterioracije (slabljenja svojstava), zbog curenja, prslina, deformacija, itd. Inspekcija se može obaviti da bi se naznačio način održavanja mostova. Cilj inspekcijskog održavanja (IO) jeste otkriti bilo koji kvar koji može prouzrokovati neprihvatljiv rizik sigurnosti ili upotrebljivosti. Svrha inspekcije sigurnosti jeste da identifikuje očigledne nedostatke koji predstavljaju opštu opasnost ili koji mogu da dovedu do nje, te stoga zahtevaju posebnu pažnju i/ili hitnu intervenciju.

Poslednjih godina, u svetu se pojavljuje sve više radova [3], [4], [5–7] u kojima se uporedno analiziraju iskustva više zemalja, naročito kada je reč o načinu inspekcije, ali i o ostalim elementima BMS-a, s ciljem unapređivanja sopstvenih metodologija, na osnovu iskustva drugih. Među njima je i [8], u kojem se upoređuju inostrana iskustva sa onima iz SAD, iako su oni znatno napredovali – i u pojedinim državama i na nivou Federacije. To nas je motivisalo da napišemo ovaj rad da bi se i u Srbiji i Bugarskoj radilo na unapređivanju BMS-a – po ugledu na druge zemlje, a osnova za to jesu uporedne analize. Međunarodna udruženja IABSE, RILEM, *fib*-međunarodno udruženje za beton (ranije CEB i FIP), ACI (Američki institut za beton), AASHTO (Američka asocijacija za puteve), kao i drugi, bave se aktivno upravljanjem mostovima putem preporuka za projektovanje trajnih konstrukcija, praćenje i procene stanja, kao i za obim i vreme radova na održavanju. To rade i pojedine države putem ministarstava za saobraćaj i/ili putem saobraćajnih agencija [11], i drugi. Mnogi od njih rade na tome i propisuju mere za adekvatno održavanje mosta već u fazi projektovanja kako bi se obezbedili pouzdanost i upotrebljivost mosta uz što manja ulaganja. Važni elementi, pored trajnosti mosta, takođe su pristupačnost inspekciji i pogodnost za održavanje konstrukcije mosta i okruženja.

U ovom radu prikazane su neke smernice za pregled mostova, utvrđivanje i vrednovanje stanja, što je osnova redosleda prioriteta aktivnosti (rejtinga) na održavanju ili rehabilitaciji. Komentarisan je razvoj BMS-a u Srbiji, kao i sistemi koji se primenjuju u nekim drugim državama, uz uporednu analizu. U radu su prezentovane neke analize dokumenata koji se odnose na BMS u Srbiji, Južnoj Africi, Kini, J. Koreji, Japanu, SAD, te u nekim zemljama Zapadne Evrope (npr. Engleska, Danska, Švedska, Nemačka).

achieve their design life, remain open to traffic continuously and keep the risk of failure always very low, achieving this sustainably at a minimum lifecycle cost (BM). Some aspects of bridge management are concerned primarily with the individual bridges (project – level B-M) whereas other aspects are concerned with the management of a stock of Bridges (network-level BM) [2].

The role of BMS is of a particular importance in the maintenance cost optimization, for which it is necessary to use a systematic and planned approach based on technical, economic and sociological aspects. They primarily concern the priority, type and scope of intervention measures, as well as the associated costs. Such problems are successfully resolved by the development and application of information systems for managing the structures. Inspections describe different signs of distress in CB, such as leakage, deflection, etc. An inspection can be carried out to indicate the way to maintain a bridge. The objective of maintenance inspection (MI) is to detect any defect which may cause an unacceptable safety or serviceability risk. The purpose of a safety inspection is to identify obvious deficiencies which represent, or might lead to, a danger to the public and therefore require special attention and/or immediate or urgent measure.

In recent years, an increasing number of papers have appeared in the world [3], [4], [5-7] in which the experiences of multiple countries are analyzed, especially regarding the method of inspection, and other elements of BMS with the aim of improving their own methodologies based on the experience of others. Among them is [8] which compares foreign experiences with those from the United States, at the state and at the Federal level. This motivated us to write this paper in order to encourage the work on the improvement of BMS in Serbia and Bulgaria, following the example of other countries, and the basis for that are comparative analyses. International associations IABSE, RILEM, *fib*-international concrete association (formerly CEB and FIP), ACI (American concrete institute), AASHTO (American Roads Association) [11], and others are actively involved in bridge management through recommendations for the design of durable structures, monitoring and condition assessments, scope and timing of maintenance work. This is also provided by the individual States through the Ministry of Transport and/or Transportation agencies. Many of them also develop and prescribe measures for adequate maintenance for bridges in the stage of design to secure their reliability and usability with minimum investment. Important elements also include requirements for durability, accessibility for inspection and suitability for maintenance.

This paper presents some guidelines for inspecting bridges, determining and evaluating their condition, enabling the prioritization and rating of maintenance or rehabilitation activities. The development of BMS in Serbia and Bulgaria and the systems applied in some other countries are commented on with a comparative analysis. This paper presents some analyses of the documents related to BMS in Serbia, Bulgaria; South Africa, China, S. Korea, Japan USA, and some Western Countries (UK, Denmark, Sweden, Germany, et al.).

2 ISTORIJSKI RAZVOJ BMS

U radu [9] navodi se da je u SAD 2009. godine postojalo više od 603.000 evidentiranih mostova. Razvoj BMS-a povezuje se sa izveštajima o katastrofalnim rušenjima (na primer, čuveni Silver most, 19. decembra 1967. godine, gde je poginulo 46 osoba). To je izazvalo Federalnu agenciju FHWA da ustanovi Nacionalni program pregleda mostova 1970. godine. Program je propisao da se mostovi pregledaju najmanje jednom u dve godine i da se formira inventarska baza mostova. Devedesetih godina XX veka, razvijeni su poznati softverski paketi PONTIS i BRIDGIT u SAD i DANBRO u Danskoj.

Najduže iskustvo sa upravljanjem ima Švedska (od 1940. godine), što je doprinelo kasnijem smanjenu procenta izdvajanja za održavanje, u odnosu na vrednost građenja. U Srbiji je Javno preduzeće za puteve 2009. godine publikovalo prevod njihovog priručnika za pregled mostova, ali on još uvek nije uklopljen u ukupni BMS.

Određivanje nosivosti mostova važno je i za formiranje prioriteta (ranga), a još uvek preovlađuje i može se preporučiti korišćenje determinističkog pristupa po ugledu na onaj koji se koristi u SAD (prikazano u radu [4]). Uporedni pregled BMS-a nekoliko država Evrope, među kojima su Srbija i Bugarska, prikazan je u Tabli 1, prema [10]

U tabeli su upisani podaci početka uvođenja BMS-a i vidi se da je to u Srbiji bilo 1985. godine, a u Bugarskoj – 2004/2005. U Srbiji je uveden sistem prioriteta (rejting), dok u Bugarskoj nije do 2009. godine. Broj mostova, obuhvaćenih BMS-om, u Srbiji jeste 3.500, a u Bugarskoj

2 HISTORY OF BMS

In [9] it is stated that in the USA in 2009, there were more than 603,000 bridges recorded. The development of BMS is related to reports of catastrophic collapses such as the famous Silver Bridge on December 15th, 1967 with 46 fatalities. This prompted the Federal Agency FHWA to establish the National Bridge Inspection Program in 1970. The program mandated that bridges be inspected at least once every two years and that an Inventory of Bridges be formed. In the 1990s, the well-known software packages PONTIS and BRIDGIT in the USA and DANBRO in Denmark were developed.

Sweden has the longest experience with management (since 1940), contributing to reduced allocations for maintenance, as a fraction of the value of construction. In Serbia, the Public Road Company published a translation of their Sweden Bridge Inspection Manual in 2009, but it was not incorporated into the overall BMS.

Determining the load - bearing capacity of bridges is also important for forming priorities (range). A deterministic approach, modelled on the one used in the United States [4] is recommended. A comparative overview of the BMS of several European countries, including Serbia and Bulgaria, is presented in Table 1 according to [10]. The table contains data on the beginning of the introduction of BMS. This occurred in Serbia in 1985 and in Bulgaria in 2004/2005. A system of prioritization was introduced in Serbia, while in Bulgaria it was not, until 2009. The number of bridges included in BMS in Serbia is 3.500, and in Bulgaria it is 1312. Scan point-Freissinet

Tabela 1. BMS u zemljama Evrope, prema [10]
Table 1. BMS in European country, after [10]

Država *Country*	God. uvođenja BMS *Year of BMS starting*	Prioretizacija BMS *Prioritization in BMS*	Broj mostova u sistemu *Numb. of bridge managed in BMS*	Korišćeni sistem/softver *Used system/software*
Bugarska *Bulgaria*	od 2004/05 *From 2004/05.*	Ne *No;*	1.312	*Scan print-Freissinet*
Hrvatska *Croatia*	u razvoju *Developed now*	Da *Yes;*	800 na auto-putevima *800 on motorways*	*Oracie 10.G*
R. Češka *Czech Republic*	*2002.*	Da *Yes;*	18.740	*IIS database+MS SQL Server*
Engleska *England*	*2001.*	Da *Yes;*	8.600	*Oracle*
Estonija *Estonia*	*2001.*	Da *Yes;*	922	*Pontis*
Francuska *France*	*1999.*	Ne *Not yet;*	9.000	*Own system*
Nemačka *Germany*	*2000/2001.*	Da *Yes;*	38.000	*SIB-Bauwerke; BMS-Optimisation-tools*
Mađarska *Hungary*	*1996.*	Da *Yes;*	6.000	Sopstveni sistem *Own system*
Italija *Italy*	*1986.*	Da *Yes;*	3.626	*Oracle, SQL server*
Litvanija *Latvia*	*2002.*	Da *Yes;*	1.775	*LatBruts*
Srbija *Serbia*	*1985.*	Da *Yes;*	3.500	*BPM*

– 1.312. *Softver Scan point-Fressinet* koristi se u Bugarskoj, a BPM – u Srbiji. Iako je u Srbiji otpočela primena BMS-a relativno rano, još uvek nije konstituisan jedinstven sistem. Priručnik za pregled mostova, koji se koristi u Švedskoj, 2009. godine je preveden na naš jezik, ali nije zvanično usvojen za primenu. Pregovarano je i s Francuskom, ali bez rezultata. Bugarska koristi francuski softver. I ostale evropske zemlje su na putu razvoja sistema i zaostaju u poređenju sa SAD.

Jedno poglavlje u [12] posvećeno je BMS-u i vrednovanju mostova u Srbiji. Propisi (1992) pokrivaju tehničke standarde za korišćenje i redovno održavanje mostova. Oni uključuju sledeće: sadržaj podataka koji se registruju (banka podataka); vrste inspekcija, kao i njihov sadržaj u vezi sa elementima mostova i specifikacije radova na redovnom održavanju. Održavanje razmatra inspekciju, uočavanje i registrovanje promena njihovog stanja, aktivnosti održavanja i mere za otklanjanje svih defekata i oštećenja. Sledeće vrste inspekcija obavljaju se u skladu s Jugoslovenskom pravilnikom (1992), citiranim u [12]: kontrolne inspekcije; redovne inspekcije; detaljne inspekcije; posebne inspekcije i vanredne inspekcije.

U Srbiji se aktivno radilo na uvođenju BMS-a, uz informatički (IT) aspekt baze podataka od 2001. godine, ali još uvek nije konstituisan jedinstveni BMS u Srbiji. Informacioni sistem o putevima (ISP) sadržao je bazu podataka (BP) o mostovima i BP o saobraćaju. U GIS-u, s podacima o prostoru, skladište se, edituju i svrsishodno koriste podaci o lokaciji objekata sa okolinom. U okviru Integrisanog sistema za puteve, struktura je bila: inventarski podaci o mostu; podaci o pregledima mostova (stanje mosta, rejting mosta, kategorija stanja elemenata, podaci o nosivosti); podaci o vanrednim prevozima; kao i planirani i izvedeni radovi. Autor BMS-a, rađenog na Institutu za puteve, po ugledu na sistema upravljanja mostovima u SAD i Organizaciju za ekonomsku saradnju i razvoj (OECD), bio je pok. D. Bebić. Počelo se s bazom podataka o mostovima, da bi postupno napredovao do procene nosivosti mostova [4]. Naglašen je multidisciplinarni karakter.

Opisani BMS zahteva dalju razradu uvođenjem finansijskih pokazatelja, koji bi vlasniku omogućili planiranje sredstava za održavanje, sistem procene stanja mostova u vezi sa sanacionim radovima, kriterijume za procenu, koji se koriste za utvrđivanje konstruktivne i funkcionalne adekvatnosti mosta. Tehnički propisi za održavanje konstrukcije mosta postojali su od 1992. godine. U slučaju kada je potrebno sprovesti mere revitalizacije mostova, optimalno rešenje se iznalazilo na osnovu istraživačkih radova, u skladu s posebnom procedurom.

Novija uporedna analiza prakse inspekcije mostova Kine, SAD, Japana i J. Koreje prikazana je u [1]. Standardi, priručnici i smernice, koji se koriste u navedene četiri zemlje, predstavljeni su i upoređeni. Predstavljeni su tipovi inspekcija i njihovi intervali, sistem izveštavanja o inspekciji, ocene stanja mosta, uz uporednu analizu. Na osnovu te analize, autori su zaključili da ove četiri zemlje pokazuju sličnosti u ukupnom procesu prakse inspekcije mosta i u programima upravljanja mostovima, poput upotrebe BMS-a u programu kontrole kvaliteta.

Međutim, razlike su iskazane iz aspekata detalja. Model narušavanja i funkcija ažuriranja, zasnovan na

software is used in Bulgaria, and BPM in Serbia. Although the implementation of BMS started relatively early in Serbia, a unified system has not yet been constituted. The Bridge Inspection Manual used in Sweden was translated in 2009 but has not been officially adopted for implementation. There were also negotiations with France but without results. Bulgaria uses French software. Other European countries are also developing the system and lag behind the United States.

One chapter in [12] is dedicated to BMS and bridge evaluation in Serbia. Regulations (1992) cover technical standards for utilization and regular maintenance of bridges. They include the following: contents of the data to be registered (data bank); kinds of inspections (control, regular, main and extraordinary), as well as their content regarding the elements of bridges; specification of works on regular maintenance. Maintenance considers inspection, observation and recording of changes and their condition, maintenance activities and measures for eliminating all defects and damage. The following types of inspections are performed according to the Yugoslav Regulation 1992, cited in [12]: Control inspections; regular inspections; detailed inspections; special inspections, and extraordinary inspections.

In Serbia, there has been active work on the introduction of BMS, with IT aspects of the database since 2001, and a single BMS in Serbia has not yet been constituted. The Road Information System (ISP) contained a database (BP) on bridges and a BP on traffic. In GIS, along with data on space and location of structures with their environment are stored, edited and purposefully used. The Integrated Road System had the following structure: inventory data on the bridge; data on inspections of bridges (bridge condition, bridge rating, and element condition category, bearing capacity data); data on emergency transport; and planned and performed works. The BMS was created at the Roads Institute, after the model of the bridge management system in the USA and the Organization of Economics Cooperation and Development (OECD) by the late D. Bebić. A bridge database started to gradually progress towards assessing the load-bearing capacity of bridges [4]. Its multidisciplinary character was prominent.

The described BMS requires its further elaboration by introducing financial indices which would enable the owner to plan the funds for maintenance, a system of evaluating the condition of bridges in connection with rehabilitation works, evaluation criteria used for the determination of structural and functional bridge adequacy. Technical regulations for the bridge structure maintenance existed until 1992. In cases requiring revitalization measures of bridges, optimum solutions are obtained on the basis of research works, in line with a special procedure.

A recent comparative analysis of the practice of inspection of bridges in China, USA, Japan and S. Korea was presented in [1]. Standards, manuals and guides used in the four countries are presented and compared. Inspection types, intervals, reporting systems, bridge condition ratings are also presented and compared. Based on this analysis the authors conclude that the four countries show similarities in the overall process of bridge inspection practices and bridge management programs such as the use of a BMS in quality control.

However, differences are shown in terms of detailed skladištenju podataka, ali i BMS-i nekih zemalja još se nisu pripremili i nisu uveli sve funkcije. Koreja, kao i mnoge druge zemlje, ne uključuje informacije o sigurnosti mosta ili model optimizacije rizika za održavanje troškova [4]. Sistem se može koristiti za procenu upotrebljivosti postojećih mostova. U tom smislu, razmatra se model za predviđanje procesa deterioracije elemenata postojećih mostova i povezuje se s planom održavanja ili rehabilitacije.

3 ZAHTEVI BMS

U mnogim zemljama, a i našem regionu, postavljaju se sledeća pitanja:

- kakvo je stvarno stanje mostova i da li je BMS koji se koristi adekvatan ili ga treba unaprediti?
- koliko košta da postojeće stare mostove dovedemo u stanje prihvatljivih performansi?
- da li su obezbeđene odgovarajuće podloge za adekvatne i optimalne intervencije na mostovima?

Upravljanje i održavanje uslovljavaju sistematsko praćenje – sisteme za upravljanje mostovima, što treba da omogući organizovano prikupljanje podataka za analize i procene u svim fazama životnog ciklusa, zavisno od značaja saobraćajnice i kompleksnosti objekta. U ovoj oblasti prednjače SAD. BMS je usmeren na postojeće mostove, da bi obezbedio ostvarenje njihovog projektovanog eksploatacionog veka, tj. to da u kontinuitetu budu otvoreni za saobraćaj i da se minimizira rizik od „otkaza" [2]. Termin upravljanje mostovima obuhvata široki opseg aktivnosti, prvenstveno inspekcije – nadgledanje, procene budućeg stanja putem modela deterioracije tokom vremena za određivanje prioriteta za izvođenje radove na održavanju. Potrebno je određivanje nosivosti mosta, naročito kada je potrebno prevesti vangabaritne terete, kao i različita ispitivanja. Rezultat tih aktivnosti jeste racionalnije održavanje mosta i okoline.

U SAD na realizaciji BMS radi se u pojedinim državama, ali i na nivou Federacije [11]. Upravljanjem se najčešće obuhvata skup mostova na saobraćajnoj mreži, a ređe pojedinačnih mostova; jedan od primarnih zadataka jeste vrednovanje njihovog stanja i brzina propadanja (deterioracije). Značajno je obezbediti kvalitetne projekte i njihovu realizaciju, da bi se dostigao proračunski eksploatacioni vek, odnosno bitno je realno ga predviđati [4] i [9]. Zbog ograničenih sredstava, moraju se odrediti i uvažavati pomenuti prioriteti za realizaciju radova. Da bi se to ostvarilo, potrebno je odrediti stvarno stanje konstrukcije setom pregleda koji se redovno obavljaju, u pravilnim vremenskim razmacima. Uvek se u BMS-u postavlja uslov da postupci pregleda budu standardizovani, da bi bili ujednačeni i objektivni, jer ih obavljaju stručnjaci različitog nivoa znanja i različitih kriterijuma. Adekvatni upitnici – ni suviše opširni, niti nepotpuni – obezbeđuju brži, jeftiniji i realniji pregled. Sve više se uvodi planiranje životnog ciklusa mosta, kojim sa obuhvata koštanje – od projektovanja, građenja, upravljanja, do uklanjanja objekta. Upravljanje životnim ciklusom zasniva se na ekonomičnosti, uz istraživanje mogućnosti optimizacije faktora, kao što su troškovi, profit, rizik i kvalitet, trajnost, održivost, itd. [4]. Upravljanje kvalitetom (QM) jeste sveobuhvatan pristup za sve faze stvaranja do zamene objekta [9] i [15]. U radu [16], preporučuje se i u

aspects. Deterioration model, and updating function, based on data storage but the BMSs of some countries have not yet prepared for all features. Korea does, as well as many other countries, not include information on bridge safety or a risk optimisation model for cost maintenance. In addition, many papers also compare some components of BMS of individual States and recommendations of the associations, and this can be commented upon in the further presentation with tabular reviews. Development of BMS in Japan, for individual bridges, which is integrated into the Miyamoto concrete bridge expert rating system, is cited in [4]. The system can be used to assess the serviceability of existing bridges. In that sense, a model for predicting the process of deterioration model of the elements of existing bridges is considered and linked with the plan of maintenance or rehabilitation.

3 REQUIREMENTS FOR BMS'S

In many countries, as well as in our region, questions are being asked:

- What is the real condition of bridges and is the BMS being used adequate or should it be improved?
- How much does it cost to bring the existing old bridges to the state of acceptable performance?
- Are adequate datasets provided for adequate and optimal interventions on the bridges?

Management and maintenance require systematic monitoring – the monitoring of Bridge Management System (BMS) should enable organized data collection for analysis and assessment at all stages of the life cycle depending on the importance of the road and the complexity of the structure. The United States are the leaders in this area. BMS should be focused on the existing bridges with a goal to ensure the realization of their designed service life, i.e. to keep them continuously open for traffic, and minimize the risk of "failure" [2]. The term bridge management comprises a wide range of activities, primarily monitoring-inspections, assessments of future condition through models of deterioration over time to determine priorities for performing maintenance work. The load-bearing capacity of the bridge, especially under oversized loads should be determined, and various tests should be performed. These activities should result in a more cost-effective maintenance of the bridges and the environment.

In the USA, the realization of BMS is being worked on both in individual states and at the Federal level [11]. Management usually includes a set of bridges in the traffic network, and less often individual bridges, and one of the primary tasks is to evaluate their condition and rate of deterioration. It is important to provide quality designs and their realization of service life and provide its realistic prediction [4] and [9]. Due to limited funds, the mentioned priorities for the realization of works should be determined and observed. In order to achieve that, it is necessary to determine the actual condition of the construction by a set of inspections that are regularly performed at regular intervals. BMSs always set the condition that the review procedures be standardized, in order to be uniform and objective, because they are performed by experts with different levels of knowledge and criteria. Adequate questionnaires, neither too extensive nor incomplete, provide a faster, cheaper and more realistic overview.

BMS-u primena savremene informacione BIM tehnologije (tehnologija za modeliranje građevinskih informacija).

Razmatranje BMS-a nerazdvojivo je od trajnosti konstrukcije mostova čija je izloženost nepovoljnim dejstvima okoline izražena [11]. Održavanje mostova predstavlja skup svih mera i postupaka, koji se preduzimaju tokom eksploatacionog veka da bi se postigla potrebna trajnost, uz ostvareni nivo sigurnosti i upotrebljivosti [4]. Pri tome se koriste priručnici/smernice za pregled mostova, često zvanični dokumenti pojedinih država. U njima se pored tekstualnog dela grafički prilozi prikazuju karakteristične delove konstrukcije mosta, opreme i neposrednog okruženja mosta [17]. U nekim radovima se upoređuje deterministički i probabilistički pristup upravljanju [18]. Od značaja je i predviđanje budućeg stanja mosta, modelom deterioracije, radi optimizacije troškova. Većina naših stručnjaka oslanja se samo na Evrokodove (EN), iako su dokumenti [15] savremeniji.

Procene koje se obavljaju primenom metodologije koju je razvila Evropska komisija istraživanja transporta (EKIT) i Sistem za monitoring i informacije (EKIT) i informacije monitoringa i informacionih sistema (TRIMIS) [6]. Izveštaj je kritička analiza s preporukama i istovremeno osvetljava nove tehnološke razvoje i buduće orijentisane pristupe. Te metodologije su primenjene u Italiji, Švajcarskoj, Austriji, Nemačkoj, Francuskoj, Portugaliji i Grčkoj [5]. O strategiji upravljanja pouzdanošću mostova, zasnovanoj na pouzdanom semi-markovljevom i determinističkom modelu, dato je [17]; u Sabahu [3]; u Iranu [5]; i u Italiji [19]. Evropska iskustva i BRIME prikazani su u [20]. Za države u SAD, Federalna agencija za autoputeve (FHA) prikazala je komparativnu analizu u [11]. Pregled probabilističkog projektovanja eksploatacionog veka i održavanja šire je razmatran u [18]. Polazi se od toga da je eksploatacioni vek konstrukcije određen projektovanjem i građenjem, ali i njenim upravljanjem. Matematički model performansi uključuje proces starenja, slično modeliranju pri projektovanju konstrukcije.

4 INSPEKCIJA U REGULATIVI I PRAKSI

Zbog značaja pregleda (inspekcija) objekata i njihovog okruženja, sve države publikovale su smernice s mnoštvom ilustracija. Neke smernice su veoma obimne (npr. Ontario [4]), a neke su manje. Potrebno je sažeto objašnjenje pojmova i delova mostova, sa smernicama za aktivnosti [4] i [2], kao i federalni priručnik [11]. U [11], uvršteno je nekoliko dokumenata, među njima smernice za ocenu stanja u eksploataciji i o rutinskom održavanju mostova. Osnovni cilj pregleda mosta i njegovih komponenata jeste registrovanje defekata i oštećenja, koji utiču na sigurnost i upotrebljivost, i/ili povećanje stepena propadanja koje redukuje njihov životni vek. U Velikoj Britaniji postoje opšti, glavni i specijalni pregledi. Opšti pregledi se obavljaju svake druge godine i zasnivaju se na vizuelnom pregledu iz pristupačnih pozicija, pomoću durbina i veštačkog osvetljenja [17].

Increasingly, bridge life cycle planning is being introduced, which includes costs from design, construction, and management to demolition of the structure. Life cycle management is based on cost-effectiveness while exploring the possibilities of optimizing factors such as cost, profit, risk and quality, durability, sustainability, etc. [4]. Quality management (QM) is a comprehensive approach to all phases since the creation of a structure to its replacement [9] and [15]. In the paper [16], the application of modern information BIM technology in BMS (Building Information Modeling Technology) is also recommended.

The consideration of BMS is inseparable from the durability of bridge structures whose exposure to adverse environmental impacts is pronounced [11]. Bridge maintenance is a set of all measures and procedures that are taken during the service life in order to achieve the required durability with the achieved level of safety and serviceability [4]. In doing so, bridge inspection manuals/guidelines are used to inspect bridges, often official documents of individual countries. In addition to the textual part, the graphic illustrations show the characteristic parts of the bridge structure, equipment and the immediate surroundings of the bridge [17]. Some papers compare the deterministic and probabilistic approach to management [18]. It is also important to predict the future condition of the bridge, using a deterioration model, in order to optimize costs. Most of our professionals rely only on Eurocodes (EN), although the documents [15] are more up-to-date.

Assessments are performed using the methodology developed by the European Commission for Transport Research and Information Monitoring and Information Systems (TRIMIS) [6]. The report performs a critical analysis with recommendations and techniques while highlighting new technological developments and future-oriented approaches. They have been used in Italy, Switzerland, Austria, Germany, France, Portugal and Greece [5]. On the reliability management strategy of bridges based on reliability Semi-Markov deterministic model [17]; in Sabah [3]; in Iran [5]; in Italy [19]. European experiences and BRIME are presented in [20]. For the states in the United States, the Federal Highway Agency (FHA) presented a comparative analysis in [11]. An overview of probabilistic design of service life and maintenance is discussed in more detail in [18]. It is assumed that the service life of the structure is determined by design and construction, but also by its management. The mathematical performance model involves an aging process similar to modelling in structural design.

4 INSPECTIONS IN CODES AND PRACTICE

Due to the importance of inspecting structures and their surroundings, all the states have published guidelines with many illustrations. Some guidelines are very extensive, such as Ontario [4], and some smaller ones are concisely explained terms and parts of bridges with guidelines for activities [4] and [2] as a federal handbook [11]. In [11], several documents were included, including guidelines for assessing the condition in operation and routine maintenance of bridges. The main goal of the inspection of the bridge and its components is to register defects and damages that affect safety and usability and/or reduce their service life by increasing the

Opšti pregledi (inspekcija) mora pružiti informacije o fizičkom stanju svih vidljivih elemenata i mora sadržati vizuelni pregled svih delova bez posebne opreme za pristup ili posebno upravljanje saobraćajem. Glavni pregledi moraju pružiti sveobuhvatne i detaljne informacije o fizičkom stanju svih pregledanih delova konstrukcije objektu na putu. Tehnike inspekcije uključuju kucanje čekićem radi otkrivanja i uklanjanja betonskog zaštitnog sloja betona; obavljaju se najmanje jednom u šest godina. Posebni/specijalni pregledi konstrukcija sa ograničenjima težine, pre i posle prevođenja nenormalnih/teških tereta preko mosta, ukoliko je sleganje veće od dozvoljenog ili građevina izloženih incidentnim oštećenjima (npr. rečni mostovi nakon poplave onda je nužan i podvodni pregled). Inspekcija za procenu uključuje parametre potrebne za utvrđivanje nosivosti elemenata, uključujući moguće nedostatke (npr. naprsline, korozija, sleganje, neadekvatan materijal, sistem za odvodnjavanje). Raspored pregleda/inspekcija, priprema za to, evidencija (lokacija, ozbiljnost, obim i vrsta defekata i oštećenja) potrebni su da bi se obavila procena konstrukcije. Pristup za pregled može biti merdevinama, skelama, pokretnim podiznim radnim platformama, vozilima sa hidrauličnim platformom. Znakovi preopterećenja/slabljenja svojstava u armiranobetonskim (AB) konstrukcijama (defekti i oštećenja), AB greda i ploča (naprsline i pukotine) moraju se registrovati. Profil kolovozne ploče mosta treba proveriti zbog prekomernih ugiba ili nagiba [2].

U Srbiji je propisano nadgledanje betonskih mostova 1992. godine, a zatim i u Zakonu o putevima (1993). U njima su propisane aktivnosti bitne za BMS. Cilj redovnih pregleda jeste direktno kontrolisanje stanja građevine i održavanje bezbednosti u saobraćaju na zadovoljavajućem nivou. Kontrolne preglede obavlja inspektor puta, najmanje jednom mesečno. Zbog toga, pored praćenja nedostataka u dogledno vreme, potrebno je proučiti svu dostupnu dokumentaciju kako bi se utvrdili, pre svega, uzroci nastanka oštećenja. Započinje inicijalnim vizuelnim pregledom, s ciljem da se dobiju potrebni podaci o obimu i načinu detaljne inspekcije. Pre svega, potrebno je obezbediti siguran pristup oštećenoj konstrukciji. Na osnovu vizuelnog pregleda, utvrđuje se obim detaljnih metoda ispitivanja i ispitivanja [12].

Cilj detaljnog pregleda jeste dobijanje informacija o optimalnom obimu kako bi se procenilo stanje konstrukcije, kao i mogućnost dalje upotrebe, uz neophodne intervencije. Detaljni pregledi mostova trebalo bi da se rade najmanje jednom u dve godine. Tokom pregleda, uključuju se svi elementi mosta. Tokom specijalnih/posebnih pregleda, koriste se posebna oprema i posebni merni instrumenti, radi provere stvarnog stepena oštećenja utvrđenih redovnim ili povremenim pregledom, naročito na građevinama za koje je ustanovljeno da su sklone padu ili intenzivnoj deterioraciji, što iziskuje hitne popravke. Specijalni pregledi obavljaju se prema ranije planiranom programu. Vanredni pregledi obavljaju se prema pravilima redovnog pregleda, nakon neočekivanog događaja, kao i pre i posle prevoza vanrednih tereta koji mogu ugroziti kapacitet nosivosti ili funkciju konstrukcije. U slučaju oštećenja, oprema za inspekciju je ista kao i tokom specijalnog pregleda [12].

degree of deterioration. There are general, main and special examinations in the UK. General ones are performed every other year, and are based on visual inspection from accessible positions using binoculars and artificial lighting [17].

General inspection must provide information on the physical condition of all visible elements and comprise a visual inspection of all parts without special access equipment or traffic management arrangements. Principal inspection must provide comprehensive and detailed information on the physical condition of all inspectable parts of a highway structure. Inspection techniques include hammer tapping to detect elimination of concrete cover (six-year intervals). Special inspections for structures with weight restrictions, before and after having to carry abnormal heavy load, if settlement is greater than allowed for or structures subjected to accidental damage, river bridge after flooding (underwater inspection). Inspection for assessment includes parameters needed to determine the strength of members including possible deficiencies (cracks, corrosion, settlement, defective material, drainage system, etc.). Scheduling of inspection, preparation for it, records (location, severity, extent and type of defects and damage) needed to carry out a structural assessment. Access for inspection may be by ladder, scaffolds, mobile elevating work platform, vehicles with a hydraulic operated walkway. Signs of distress in RC S (defects and damage) of RC beams and slabs, cracks) must be registered. Profile of bridge deck may need to be checked for sagging or unusual deflection [2].

In Serbia monitoring of concrete bridges was prescribed in 1992, and afterwards the Regulation on the roads of 1993. The activities important for BMS are prescribed in them. The aim of regular inspections is to control the state of a structure directly and keep the traffic safety on a satisfactory level. Control inspections are done by a road inspector, at least once a month. Due to that, in addition to monitoring of deficiencies in due time, it is necessary to study all available documentation in order to define, in the first place, the causes of occurrence of the damage. It begins with an initial visual inspection which is meant to obtain data concerning scope and way of detailed inspection. Primarily, it is necessary to provide a safe access to the damaged structure. On the basis of the visual inspection the scope of detailed inspection and testing methods are determined [12].

A detailed inspection is aimed to obtain information on an optimal scope in order to assess the condition of structure and possibility of further use with necessary interventions. Detailed inspections of bridges should be done at last once in two years. During the inspection all elements of the bridge are included. During special inspections, special equipment and measuring instruments are used in order to check the actual degree of damage, especially at structures for which it has been established, by the regular or occasional inspection, to be in at risk of falling down or ruining, which requires urgent repairs. A special inspection is conducted according to a previously planned program. Extraordinary inspections are conducted according to the regular inspection rules after an unexpected event, as well as before and after the transportation of an extraordinary load which might endanger the capacity or function of the structure. In the case of damage, equipment for the inspection is the same as during the special inspection [12].

5 UPOREĐIVANJE NEKIH ELEMENATA BMS-A

Najčešće se mostovi i nadvožnjaci klasifikuju prema njihovim rasponima i statičkom sistemu. Međutim, već na rasponu od 2,0 m uvodi se obaveza pregleda, jer se to tretira kao most. Britanci uvode najmanju vrednost raspona od 1,80 m, a Južna Afrika – 6,0 m. Sistem ocenjivanja mosta u Velikoj Britaniji prikazan je u tabeli 2, sa određenim normama i opisima, prema [8]. Takođe, prikazno je nekoliko detaljnih opisa oštećenja, s njihovim uticajem na funkciju mosta, kao i definicije komponenti mosta.

5 COMPARISON OF SOME ELEMENT OF BMS

Most frequently bridges and overpasses are classified according to their span and statical system. At a span of 2.0 m the inspection mandate applies, as this is treated as a bridge. The British introduce the least value of the span of 1.80 m and the South Africa of 6.0 m. The bridge status assessment system in Great Britain is presented in table 2, with certain norms and descriptions, after [8]. Several detailed descriptions of defects with their impact on the bridge function, and definition of bridge components are presented, also.

Tabela 2. Vrste inspekcije mosta – Ujedinjeno Kraljevstvo [17]
Table 2. Types of bridge inspection – United Kingdom [17]

Vrsta inspekcije *Inspection Type*	Interval *Interval*	Realizuje *Performed by*	Opis *Description*
Prihvatanje *Acceptance*	Nije primenljivo *Not applicable (N/A)*		Kada se promeni vlasnik ili po završetku sklopi ugovor o održavanju objekta *When responsibility for the structure changes hands; i.e., on completion of construction of construction, when contracts for maintenance change*
Površno *Superficial*	Zahteva *Requent*	Izvođač *Contractor*	Osoblje izvođača radova treba da prati i u svakom trenutku prijavi sve što zahteva hitnu pažnju, kao što su oštećenja na gornjoj konstrukciji, nosačima mosta, oštećenja od poplave, dilatacione sprave, itd. *The contractor staff is encouraged to be vigilant at all times and report anything needing urgent attention, such as impact damage to superstructure, bridge supports, flood damage, expansion joints, etc.*
Opšti *General*	Na 2 godine *2 years*	Izvođač *Contractor*	Vizuelni pregled svih delova konstrukcije, koji ne zahtevaju posebnu opremu. *A visual inspection of all parts of the structure that can be inspected without special access equipment*
Glavni *Principal*	na 6 godina *6 years*	Izvođač *Contractor*	Vizuelni pregled na dodir pomoću posebne opreme za pristup *Touching-distance visual inspection using any necessary access equipment.*
Specijalni *Special*	Po potrebi *As necessary*	Izvođač *Contractor*	Istražiti neke utvrđene nedostatke. *To investigate some identified defect*

Tabela 3. Inspekcije i nadzor na programu pregleda, prema [8]
Table 3. Inspections and supervision by inspection program, after [8]

Program pregleda *Inspect. Program*	SAD *USA*	Danska *Denmark*	Finska *Finland*	Francuska *France*	Nemačka *Germany*	Norveška *Norway*	Južna Afrika *South Africa*	Švedska *Sweden*	Velika Britanija *United Kingdom*
Površno *Superficial* Opšte *General* Glavno *Principal* Posebni *Special*	Rutinski *Routine* Rutinski 48 meseci *Routine 48-manth* Dugotrajno 120 meseci *In depth 120 manth*	Dnevno *Daily* Rutinski *Routine* Glavno *Principal* Ekonomski *Economic* Posebni *Special*	Godišnje *Annual* Opšte na 5 godina *General 5 years* Opšte na 8 godina *General 8 years* Posebni *Special*	Rutinski *Routine* Godišnje *Annual* Predstava kvaliteta umetničkog dela *IQOA**	Površno *Superficial* Manji *Minor* Ozbiljni *Major*	Opšti *General* Ozbiljni *Major* Posebni *Special*	Praćenje *Monitoring* Glavni *Principal* Na nivou projekta *Project-Level*	Površni *Superficial* Opšte *General* Ozbiljni *Major* Posebni *Special*	Površno *Superficial* Opšte *General* Glavni *Principal* Posebni *Special*

*IQOA = Image de la Qualite des Ouvrajes d'Art

Uporedni podaci pregleda/inspekcija i nadzora po inspekcijskom programu u SAD, J. Africi, Velikoj Britaniji i šest evropskih zemalja sažeti su u tabeli 3. Za iste zemlje, u tabeli 4 sumirani su podaci pregleda i preporuka za održavanje i popravku.

Pored Velike Britanije i pomenutog priručnika [17], inspekcija mostova je najčešće propisana na nivou država, uključujući i SAD. Kao primer, pominje se priručnik Departmana za transport (DOT) Masačusetsa [21], gde je – pored uputstava za pregled na terenu i beleženja podataka – navedeno uputstvo za pisanje izveštaja. Slične priručnike koriste i Njujork, Džordžija, Florida i druge države, a federalna agencija je to sintetizovala i publikovala priručnik [8]. Inspekcija za održavanje i ocenjivanje/rejting analizirani su u priručniku [22], a pored inspekcije, jedno poglavlje posvećeno je jednom od novijih metoda praćenja stanja/„zdravlja" mostova (BHM) [23].

Najšire su problemi u vezi s BMS-om razmatrani u Priručniku [2], i u poglavljima posvećenim deterioraciji, istraživanjima, nadgledanju i proceni. Od značaja je predviđanje stanja postojećih mostova, kao i formiranje modela deterioracije mosta, što je predmet radova [10], [24] i [25]; razvoj BMS-a, zasnovanog na modeliranju informacija o građevini, analiziran je u [26].

Pored programskih paketa sistema/softvera koji su korišćeni u nekim državama Evrope i navedeni u tabeli 1, u tabeli 5 prikazan je 21 BM Sistem, koji se koriste širom sveta. Neke države koriste i više sistema (npr. Kanada i SAD).

Comparative data of inspections and supervision by inspection program in USA, S. Africa, U.K. and six European countries are summarized in table 3. For the same countries data of inspection and maintenance and repair recommendation are summarised in table 4.

In addition to the U.K. and the mentioned manual [17], bridge inspection is most often regulated at the state level, including the USA. An example is the Massachusetts Department of Transportation (DOT) manual [21], which provides instructions for writing reports in addition to field inspection and data recording instructions. Similar manuals are used in New York, Georgia, Florida, and other states, and the federal agency has synthesized and published the manual. Maintenance inspection and rating were analyzed in the BE Handbook [8]. Inspection for maintenance and rating system in BE Handbook [22] are analysed. Supplementing inspections, one chapter is dedicated to one of the newer methods of Bridge Health Monitoring (BHM) [23].

The problems related to BMS are most extensively considered in the Manual [2], with chapters devoted to deterioration, investigation, monitoring and assessment. In addition, the condition prediction of existing bridges is important, as well as forming the bridge deterioration model, which is the subject matter of 13], [24] and [25]. The development of BMS based on Building Information Modelling is analyzed in [26].

In addition to the systems / software used in some European countries and listed in Table 1, Table 5 shows the 21 BM Systems used worldwide. Some countries use more systems such as Canada and the United States.

Tabela 4. Preporuke za preglede, održavanje i sanacije, prema [8]
Table 4. Inspections and maintenance and repair recommendations, after [8]

Akcije *Actions*	SAD *USA*	Danska *Denmark*	Finska *Finland*	Francuska *France*	Nemačka *Germany*	Norveška *Norway*	Južna Afrika *South Africa*	Švedska *Sweden*	Velika Britanija *United Kingdom*
Čišćenje *Cleaning* Sve akcije *All Actions* Troškovi i količine *Costs nd Quantities*	Rutinski *Routin* Posebni *Special*	Rutinski *Routine* Glavni *Principal* Ekonomski *Economic* Posebni *Special*	Godišnji *Annual* Opšti na 5 godina *General 5 years* Opšti na 8 godina *General 8 years*	Godišnji *Annual* Predstava kvaliteta umetničkog dela *IQOA**	Manje *Minor* Ozbiljni *Major* Posebni *Special*	Opšti *General* Ozbiljni *Major* Posebni *Special*	Praćenje *Monitoring* Glavni *Principal* Na nivou projekta *Project-Level*	Površno *Superficial* Opšte *General* Ozbiljni *Major* Posebni *Special*	Površno *Superficial* Opšte *General* Glavno *Principal*

*IQOA = Image de la Qualite des Ouvrajes d'Art

Tabela 5. Dvadest jedan BMS korišćen u svetu, prema [26]
Table 5. Twenty one BMS used worldwide, after [26]

Br. *No.*	Država / *Country*	Ime sistema / *System name*	Skraćenica *Abbreviation*	Prva verzija *First version*
1	Kanada / *Canada*	*Ontario BMS*	OBMS	2002
2	Kanada / *Canada*	*Quebec BMS*	QBMS	2008
3	Kanada / *Canada*	*EBMS*	EBMS	2006
4	Kanada / *Canada*	*PEIBMS*	PEIBMS	2006
5	Danska / *Denmark*	*DANBRO BMS*	DANBRO	1975
6	Finska / *Finland*	*The Finish BMS*	FBMS	1990
7	Nemačka / *Germany*	*Bauwerk Management System*	GBMS	N/A
8	Island / *Ireland*	*Eirspan*	Eirspan	2001

9	Italija / *Italy*	Autonomna pokrajina Trento BMS *Autonomous Province of Trento BMS*	APTBMS	2004
10	Japan / *Japan*	Institut za regionalno planiranje Osake BMS *Regional Planning Institute of Osaka BMS*	RPIBMS	2006
11	Koreja / *Korea*	Korejski posl. sistem za održavanje puteva *Korea Road Maintenance Business System*	KRBMS	2003
12	Litvanija / *Latvia*	*Lat Brutus*	*Lat Brutus*	2002
13	Holandija / *Netherland*	*DISK*	DISK	1985
14	Poljska / *Poland*	*SMOK*	SMOK	1997
15	Poljska / *Poland*	*SZOK*	SZOK	2001
16	Španija / *Spain*	*SGP*	SGP	2005
17	Švedska / *Sweden*	Sistem upravljanja mostom i tunelima *Bridge and Tunnel Management System*	*BaTMan*	1987
18	Švajcarska / *Switzerland*	*KUBA*	*KUBA*	1991
19	SAD / *USA*	*Bridgit*	*Bridgit*	1993
20	SAD / *USA*	*Pontis*	*Pontis*	1992
21	Vijetnam / *Vietnam*	*Bridgemann*	*Bridgemann*	2001

Najznačajnija primena savremenih BMS-a može se uočiti u SAD. Glavni BMS koji se koristi u SAD jeste Pontis, razvijen početkom devedesetih za FHVA, a postao je AASHTO „proizvod” 1994. godine. On beleži, čuva i usmerava podatke o popisu i inspekcijama mosta, simulirajući stanje i predlažući akcije, razvijajući politiku zaštite/očuvanja i razvijajući ukupni program upravljanja mostom. Sistem omogućuje predstavljanje mosta kao skupa konstruktivnih elemenata, pri čemu se za svaki element izveštava na osnovu njegovog stanja. Sistem Bridget, razvijen 1985. godine Nacionalnim kooperativnim istraživačkim programom za auto-puteve (NCHRP), sličnih je katakteristika kao Points.

Nedavno evropsko iskustvo predstavljeno je u TISBO sistemu za održavanje infrastrukture, razvijenom u Holandiji. To je sistem koji integriše registraciju nakon inspekcije i upravljanje održavanjem. Evropska komisija uspostavila je brojne istraživačke projekte, a objavljene su i neke smernice koje se bave procenom postojećih mostova u Evropi, BRIME (2001), COST345 (2004), SAMARAS (2005) i održivim mostovima (2006). Sistem inspekcije, koji obuhvata vizuelni pregled, propisan je standardom BRIME i italijanskim normama/kodom. Ovu inspekciju može obaviti osoblje za održavanje puteva kako bi utvrdilo njihovo stanje, bez posebne opreme, samo vizuelnim pregledima [19].

Procena stanja na osnovu iskustva u Velikoj Britaniji uvela je vrednovanje stanja koja varira od 1 do 5 i odgovara preciznoj grupi oštećenja elementa koja je vezana za stanje (tabela 6). Konstrukcija mosta može se podeliti na njegove osnovne komponente (za konstrukcijski kapacitet i bezbednost od urušavanja) i nekonstrukcijske elemente (relevantno za funkcionalnost i dugotrajnost konstrukcije). Svakom elementu dodeljuje se različita težina W, koja varira od 10 (maksimalna važnost) do 5 (minimalna važnost). Lokacijski faktor (LF) odgovara svakoj težini, kao što je prikazano u tabeli 7.

Danska direkcija za puteve prikuplja ocene stanja za 13 komponenti mosta: celokupna konstrukcija; zidovi krila; kosine i kegle; oporci; međuoslonci; ležišta; nosiva gornja konstrukcija; hidroizolacija; krajnje grede; zaštitna barijera; površine; dilatacione spojnice, i druge komponente. Ukupna rejting skala je 0 do 5, a „0” znači nema oštećenja i „5” komponente više ne mogu da funkcionišu. Delovi mosta identifikovani su u

The most significant application of contemporary BMS’s can be found in the USA. The principal BMS used in US is Pontis, developed in the early 1990s for the FHWA and it became an AASHTO product in 1994. It records, stores and directs data on the inventory and inspections of the bridge, simulating the situation and proposing actions, developing a preservation policy and developing an overall bridge management program. The system allows representation of bridge as a set of structural elements, where each element is reported based on its condition. The Bridget system, developed in 1985 by the National Cooperative Highway Research Program (NCHRP), has a capability similar to the Points.

A recent European experience is the TISBO Infrastructure Maintenance Management System, developed in Netherland. It is a system that integrates inspection registration and maintenance management. A number of research projects have been established by the European Commission and some published guidelines dealt with the assessment of existing bridges in Europe, BRIME (2001), COST345 (2004), SAMARAS (2005) and sustainable bridges (2006).

The inspection system, which includes a visual inspection, is prescribed by the BRIME standard and the Italian code. This inspection can be undertaken by the road maintenance staff to ascertain their condition, without special equipment, only by visual inspections [19]. The Evaluation of the condition based on the UK experience introduced a condition value which varies from 1 to 5, and corresponds to the condition of the related precise group of defect of the element (table 6). The bridge structure can be divided into its fundamental components (for the structural capacity and safety against collapse) and non-structural elements relevant for functionality and durability of the structure. A different weight W assigned to each elements varies from 10 (maximum importance) to 5 (minimum importance). A location factor (LF) corresponds to each weight, as shown in (table 7). The Road Directorate of Denmark collects condition ratings for 13 bridge components: entire structure; wing walls; slopes; abutments; intermediate supports; bearings; load-carrying superstructure; water-proofing; end beams; safety barrier; surfacing; expansion joints; and other components. The overall rating scale is 0 to 5, with “0” meaning no damage and “5” that the hijerarhijskom sistemu numerisanja, koji inspektorima omogućava da dodele/vrednuju stanje i zapišu zapažanja o delovima mostova (kolovozna ploča, gornja konstrukcija, donja konstrukcija). U Norveškoj praksi izveštava se o oceni stanja elementa mosta i identifikuju se određene vrste oštećenja koja su registrovana. Ocene stanja (CR) dodeljuju se na skali od 1 do 4, a 1 označava dobro stanje. Ocena stanja daje se za sve četiri posledice stanja elemenata: nosivost, bezbednost u saobraćaju, troškovi održavanja i estetika.

Francuska praksa u oceni stanja koristi skalu od 1 do 3. Područja 2 i 3 podeljena su prema hitnosti održavanja/intervencije. U Nemačkoj, ocena stanja CR-a kreće se od 0 (dobro) do 4 (veoma loše). Svakoj komponenti mosta dodeljene su tri ocene: jedna za oštećenja građevine, sigurnost u saobraćaju i trajnost mosta [8]. U mnogim dokumetima se ističe da trajnije konstrukcije imaju duži eksploatacioni vek i da se znatno lakše i jeftinije održavaju [13].

components can no longer function. Bridge components are identified in a hierarchical numbering system that allows inspectors to assign conditions and record observations about general regions of the bridges (deck, superstructure, and substructure). Norwegian practice reports condition ratings for bridge element and identifies specific types of damage that are observed. Condition ratings (CR) are reported on a 1 to 4 scale, with 1 indicating good condition. CR are provided for each four consequences of element condition: strength, traffic safety, maintenance cost and aesthetics. French practice reports CR on a 1 to 3 scale. Range 2 and 3 are subdivided according to the urgency of maintenance/intervention. In Germany CR scales run from 0 (good) to 4 (very poor). Each bridge component is assigned three ratings: one each for structural damage, traffic safety, and bridge durability [8]. Many documents point out that more durable structures have a longer service life and are much easier and cheaper to maintain [13].

Tabela 6. Vrednost stanja (CV), prema [20]
Table 6. Condition value (CV), after [20]

Defekti / *Defects*	CV
Bez procene / *No judgement*	0
Bez suštinske mane / *No meaningful defect*	1
Manji defekti koji ne izazivaju štete / *Minor defects that do not cause damage*	2
Srednji defekti koji izazvaju štete / *Moderate defects that could cause damage*	3
Ozbiljni defekti koji izazvaju štete / *Severe defects that cause damage*	4
Nefunkcionalni ili nepostojeći element / *Non-functional or non-existent element*	5

Konverzija iz vrednosti stanja (CV) u faktor stanja (CF) / *Conversion from the condition value (CV) to the condition factor (CF)*

CV	0	1	2	3	4	5
CF	0	10	7	4	2	1

Tabela 7. Faktor lokacije (LF) i težina (W), [19]
Table 7. Location factor (LF) and weight (W), [19]

Konstruktivni element / *Structural elements*	LF	W
Glavni elementi (grede, lukovi, stubovi)/ *Principal elements (beams, arches, piers)*	5	10
Poprečni elementi (ležišta, neseizmički uređaji, ploče) / *Transversal elements (bearing, non-seismic devices, slabs)*	6	9
Oporci, pritupni nasip, krilni zidovi / *Abutments, approach embankment, wing-walls*	7	8
Oporci i temelji stubova / *Abutment and pier foundations*	8	7
Nekonstruktivni elementi / *Non-structural elements*	LF	W
Hidroizolacija, kolovoz puta, dilatacione razdelnice / *Waterproofing, road pavement, expansion joints*	9	6
Kolovoz, parapeti, drenažni sistem, pristupi / *Pavements, parapets, drainage systems, accessories*	10	5

Tabela 8. „Zdravlje" mosta (MLIT, 2014) Japan, [1]
Table 8. Bridge soundness (MLIT, 2014) Japan [1]

Stanje / *Condition*	Opis / *Description*
1. Dobro / *Good*	Bez problema u funkcionisanju / *No problems in bridges functions*
2. Preventivno održavanje / *Preventive maintenance*	Bez problema u funkciji mosta, ali zahteva se preventivno održavanje / *No problems in bridges functions but preventive maintenance required*.
3. Rane aktivnosti / *Early action*	Mogući problemi u funkciji, potrebne rane akcije / *Possibility of problems in bridges functions, need for early actions*.
4. Hitne akcije / *Emergency actions*	Mogući problemi u funkciji, potrebna hitna intervencija *Possibility of problems or existing problems in bridges functions, need for emergency action* .

Table 9. NBI Rejting stanja (FHWA, 2012), [11]
Table 9. NBI Condition ratings (FHWA, 2012), [11]

Rating	Opis stanja / *Description*
9	Odlično stanje / *Excellent conditions*
8	Vrlo dobro stanje. Nisu zapaženi problemi / *Very good conditions. No problems noted*
7	Dobro stanje. Zabeležni manji problemi / *Good conditions problems noted. Some minor problems*
6	Zadovoljavajuće stanje.Elementi pokazuju manje znake deterioracije / *Satisfactory conditions. Structural elements show some minor deterioration*
5	U osnovi, povoljno. Svi primarni elementi su „zdravi", s manjim gubitkom preseka, naprslinama, odljuskavanjima ili podlokavanjima / *Fair foundation. All primary structural elements are sound but may have minor section loss, cracking, spalling, or scour*
4	Kritično stanje. Gubitak dela preseka, deterioracija sa odljuskavanjem ili podlokavanje / *Critical conditions. Loos of sections, deterioration spalling, or scour*
3	Ozbiljno stanje.Gubitak preseka ili deterioracija primarnih elemenata. Naprsline od zamora čelika ili smičuće naprsline u betonu / *Serious conditions. Loos of sections andor deterioration of primary structural elements. Fatigue cracks in steel or shear cracks in concrete may be present*
2	Kritično stanje. Uznapredovala deterioracija primarnih elementa. Naprsline od zamora čelika ili smičuće naprsline u betonu ili podlokavanje izaziva pomeranje oslonaca, može iziskivati zatvaranje mosta do sanacije / *Critical conditions. Advanced deterioration of primary structural elements. Fatigue cracks in steel shear cracks in concrete may be present or scour may have removed substructure support. Unless monitored, it may be necessary to close the bridge until corrective action is taken*
1	Stanje „otkaza". Veća deterioracija ili gubitak preseka u kritičnim elementima ili jasna pomeranja. Most se zatvara za saobraćaj do sanacije / *„Imminent" failure Failed conditions. Major deterioration or section loss present in critical structural components or obvious vertical or horizontal movement affecting structural stability. Bridge is closed to traffic but corrective action may put it back in light service*
0	Stanje „otkaza". Van upotrebe / *Failed conditions. Out of service and beyond corrective action*.

Od osobite važnosti je način ocene stanja mostova i njihovih komponenti iako procena mosta započinje vizuelnim pregledom. U tabeli 8. prikazana je metodologija ocene stanja u Japanu, povezivanjem stanja i opisom akcija/interventnih mera. Da bi se obavio početni pregled i ustanovilo i vrednovalo svako stanje mosta, stvara se set izveštaja o pregledu mosta, korišćenjem tabele sa opisom stanja prema tabeli 9 koju je utvrdila FHVA [11]. Pokazatelji performansi za kontrolu i upravljanje kvalitetom mostova prikazani su u [27].

U COST Action TU 1406 definišu se pokazatelji performansi mosta: pouzdanost, dostupnost, održivost, sigurnost, bezbednost, zdravlje, okruženje, ekonomija i politika [28]. Terminološki kriterijumi bi trebalo da budu povezani sa aspektom performansi i podkriterijumima s ciljem [21] – bezbednost od neprihvatljivog rizika, u smislu povreda ljudi. Sigurnost sistema u vezi s vandalizmom i nerazumnim ljudskim ponašanjem. Ovaj problem se može rešiti analizom robusnosti mosta. Ekonomija razmatra odnos između troškova i vrednosti, a politika se odnosi na političko-administrativne i društvene potrebe.

Savremeni BMS-i uključuju bazu podataka mostova, sistem pregleda, procenu stanja, predviđanje budućeg stanja u eksploatacionom veku i planiranje održavanja objekta. Savremeni BMS-i imaju sledeće module: 1) baza podataka / inventar; 2) pregledi/inspekcija; 3) održavanje; 4) trošak životnog ciklusa; 5) model predviđanja oštećenja

The method of assessing the condition of bridges and their components is important. Table 8 shows the methodology for assessing the condition in Japan, by connection the condition and describing the actions. The bridge inspection report forum is created for initial inspection of determination of the baseline of every bridge condition by using general condition rating table 9 which was established by FHWA [11]. Performance indicators for bridge quality control and management is shown in [27].

In COST Action TU 1406 defining bridge performance indicators: reliability, availability, maintainability, safety, security, health, environment, economics, and politics [28]. The terminology criteria should be related to the performance aspect and sub-criteria [21]. Safety related from unacceptable risk in terms of injure to people. Security related to the safety of a system regarding to vandalism and destructive human behaviour. This problem can be solved by analysis of bridge robustness. Economics addresses the relationship between cost and value, and politics concerning political-administrative and social requirements.

Modern BMS includes a bridge database, an inspection system, a condition evaluation, a lifetime prediction of the future conditions of the structure and maintenance system planning. Modern BMSs have the following modules: 1) Database/Inventory; 2) Inspection;

– slabljenja svojstava za preostali vek trajanja postojećih mostova [24] i [29]. Većina poteškoća je povezana s definisanjem modela deterioracije, jer agencije za transport (u Srbiji Direkcija za puteve) nemaju pouzdane podatke o oštećenjima i brzini starenja i oštećenja (slično je i u svim ostalim državama).

U više radova može se pronaći uporedna analiza BMS-a u različitim zemljama, kao što su [2–6], kao i za metodologije pregleda i kriterijume za procenu [7]. Najšira razmatranja o sadržaju i primeni BMS u SAD i u svetu obuhvaćena su u knjizi Yaneva [30], koja može poslužiti za dublje razumevanje složenih problema u vezi s BMS-om.

6 ZAVRŠNE NAPOMENE I ZAKLJUČCI

Na osnovu svih ovih upoređivanja, mogu se uočiti razlike i sličnosti između odredaba pojedinih zemalja, što može koristiti pri inoviranju BMS-a u Srbiji, Bugarskoj i državama našeg regiona. Pri tome, treba imati u vidu sledeće:

- Napredak nauke s razvijenim determinističkim i probabilističkim pristupom upravljanju mostovima mora u potpunosti iskoristiti i jedno i drugo, u ravnoteži pogodnoj za specifične potrebe svake lokacije.
- Redovni monitoring stanja komponenti mosta u BMS-u omogućuje blagovremene intervencije, čime se obezbeđuju veća trajnost i upotrebljivost mostova. To se postiže optimizacijom troškova održavanja.
- Predloženi BMS treba da obuhvati modele celokupnog životnog ciklusa i alate za upravljanje kvalitetom i optimizacijske modele troškova/koristi povezanih s mostovima, što bi pomoglo u donošenju odluka institucijama koje upravljaju saobraćajem i mostovima. BMS je postao lako dostupan inspektorima i donosiocima odluka zahvaljujući napretku informacionih tehnologija [1].

Za smanjenje troškova održavanja, preporučuje se projektovanje integralnih mostova (bez dilatacija), a i sa integralnim pristupom tretirajući kompletan životni ciklus (od početka projektovanja do uklanjanja objekta), jer se time obuhvata i upravljanje objektima [4] i [6].

Procedura u BMS-u uključuje dva nivoa analize: nivo projekta (uzima u obzir svaki pojedinačni most) i nivo mreže (s obzirom na to što je most deo globalne putne mreže). Cilj je utvrditi prioritet intervencije, prema oceni stanja mosta na osnovu pregleda i kvantitativne ocene (rejtinga). Održavanje mreže mostova moglo bi se poboljšati definisanjem trendova deterioracije, pomoću modela životnog ciklusa, zasnovanih na performansama. Neophodna je adekvatna metodologija upravljanja mostovima, koja uključuje planiranje troškova održavanja ili rehabilitacije objekata.

Cilj redovnih inspekcija jeste direktno kontrolisanje stanja građevine i održavanje bezbednosti saobraćaja na zadovoljavajućem nivou. Ipak, upravljanje se zasniva na ekonomskim analizama i rangiranju po prioritetima, jer se neophodno raspoloživa sredstva koriste na najefikasniji način, budući da je budžet u svim državama ograničen. Koncept upravljanja objektima zahteva da minimalnim ulaganjima u praćenje ponašanja i popravke obezbedimo nesmetano korišćenje objekta u nekom vremenskom intervalu. Imajući u vidu strategije održavanja, dve krajnje pozicije jesu: sprovođenje održavanja čim se pregledima

3) Maintenance; 4) Life Cycle Cost; 5) Prediction model (Deterioration prediction in remain service life for existing bridges [24] and [29]. Most difficulties occur while developing deterioration models because transportation agencies have no reliable data about defects and rates of aging and damage. They are specific to every state.

In another paper we can find comparative analysis of BMSs in different country as in [2-6], and for inspection methodologies and evaluation criteria [7]. The widest considerations on the content and application of BMS in the United States and in the world are given in Yaneva book [30], which can serve for a deeper understanding of the complex problems related to BMS.

6 FINAL REMARKS AND CONCLUSIONS

The presented comparisons reveal differences and similarities between the provisions of individual countries, which can be used in the further development of BMS in Serbia, Bulgaria and the countries of our region. It should be borne in mind that:

- Science advances by deterministic and probabilistic reasoning and bridge management should take full advantage of both, in a balance suitable for the specific needs of every location;
- Regular monitoring of the condition of bridge components in the BMS enables timely interventions, which ensures greater durability and service-ability of bridges. This is achieved by optimizing maintenance costs; and that
- The proposed BMS should include life-cycle models, tools for quality management, and cost-benefit optimization models related to bridges, which would help decision-making institutions that manage traffic and bridges. BMS has become easily accessible to inspectors and decision makers thanks to advances in information technology [1].

It is recommended to design integral bridges, without expansion joints, and using an integral approach, comprising the complete life cycle (from the beginning of designing to the removal of the structure) because this includes the structural management [4] and [6].

The procedure includes two levels of analysis: the project level (considers every single bridge), and the network level (considering inserted in a global road network). The aim is to establish priority of intervention, according to the evaluation of bridge condition based on inspection and quantitative rating. Bridge evaluation starts with visual inspection. For bridge network maintenance could be improved by defining deterioration trends with performance-based life cycle models. An adequate bridge management methodology is needed, which includes planning the costs of maintenance or rehabilitation of structures.

The goal of regular inspections is to directly control the condition of the building and maintain traffic safety at satisfactory level. However, management is based on economic analysis and ranking by priorities because it is necessary to use the available funds in the most efficient way, since the budget in all countries is limited. The concept of structural management requires that minimal investments in behaviour monitoring and repair ensure an uninterrupted use of the structure in a certain time interval. When considering maintenance strategies there utvrdi potreba; održavanje ostvariti samo iz sigurnosnih razloga. Prva uslovljava češće popravke i zastoje u saobraćaju, a druga zahteva uravnoteženje troškova zbog kraćeg trajanja mosta, kako bi se izbegli veći troškovi održavanja [2].

U SAD, pored sinteze dokumenata iz njenih pojedinih država, sačinili su uporednu analizu evropskih i nekih drugih država u [8]. Ocenjujemo da bi Srbija i Bugarska, s ponekim modifikacijama postojećih BMS i po ugledu na neku od evropskih zemalja, mogle doprineti ekonomičnijem upravljanju mostovima. Takođe, preporučuje se uvođenje savremene metode praćenja stanja elemenata i mostova – nadgledanje „zdravlja" konstrukcije (SHM).

are two extreme positions: to carry out maintenance as soon as inspections identify the need, and to carry out maintenance only on safety grounds. The first requires more frequent repairs and traffic congestion, and the second requires balancing costs due to the shorter bridge life in order to avoid higher maintenance costs [2].

In the USA, in addition to the synthesis of documents from the states, a comparative analysis of European and some other countries [8] was conducted. We estimate that Serbia and Bulgaria, with certain modifications of the existing BMS and following the example of some of the European countries, would contribute to more economical management of bridges. Also, it is recommended to introduce a contemporary method of monitoring the condition of the elements and bridges - Structural Health Monitoring (SHM).

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7 LITERATURA
REFERENCES

[1] Jeang, Y. et al. (2018): Bridge inspection practices and bridge management programs in China, Japan, Korea and U.S., J. of Integrity and Maintenance, Vol. 3, No. 2, 126-135.

[2] ICE Manual Bridge Engineering (2008): Bridge management (P.R. Vassie and C. Arya) 691-613; Deterioration, investigation, monitoring and assessment (C. Abdunur) 615-657; Inspection and assessment (I. Kennedy Reid) 659-693, Ed. by G. Parke, N. Hewson, T. Telford, London

[3] Dullah, C. Et al. (2014): Bridge management system i Sabah, Int. J. of Engineering Research & Technology (IJERT), Vol. 3 Isuse 8, August, pp. 976-980.

[4] Folić, R. (2019): Comparative analysis of BMS, J. Izgradnja, Belgrade, 73, No. 11-12. pp. 455-488. (in Serbian)

[5] Gholami, M. et al. (2013): Assessment of Bridge Management System in Iran, Procedia Engineernig, 54, pp. 573 – 583. Italija do Grčke

[6] Gkoumas, K. Et al. (2019): Publications Office of the European Union: A European perspective based on the Transport Research and Innovation Monitoring and Information System (TRIMIS)

[7] Hsien-Ke, L. et al. (2017): Comparison of bridge inspection methodologies and evaluation criteria in Taiwan and foreign practices, 34th Int. Symp. on Aut. and Robotics in Constr. (ISARC), 1- 8.

[8] National Cooperative Highway Research Program (NCHRP) Synthesis 375 (2007): Bridge inspection practices-A synthesis of highway practice, Transportation research board

[9] Figueiredo, E. et al. (2013) Condition assessment of bridges: Past, present and future, A complementary approach, Univers. Catolica Editiora,

[10] Stryk, J. Prezntation on CERTAIN Workshop, 21.5.2009. Czeh Repablic (10)

[11] a) AASHTO (2011): Bridge element inspection; Ch. 4. Bridge inspection reporting; Manual bridge evaluation, 2018; b) ACI Committee 201: Guide for making a condition survey of concrete in service (2019); 345.1R-92 Routine Maintenance of Concrete Bridge; c) FHWA (2012): Bridge inspector's manual, Section 2.2-BM (Concrete), Instr. M. Rossow, PDH Center; Reference manual, 2012;

[12] Folić, R. (2014): Bridges in Serbia, Handbook Bridge Engineering, Ed. Wai-Fah C. and L. Duan, CRC Press, Taylor&Francis, Boca Raton, pp. 587-647.

[13] ACI Committee 365. 1R-42 (2017): *Service-Life Prediction-State of the Art report*. ACI 201.12R-08 (2016): Guide to durable concrete, ACI.

[14] CIRCULAR (2008): Transportation research, Number E-C 1218, International Bridge and Structure management, 10th Int. Conf. October 20-22, Bufalo New York

[15] *fib* *B*ulletin44 (2008): Concrete structures Management: Guide to ownership and good practice, Lausanne. *fib* Model Code 2010, *fib*, Lausanne 2013.
[16] Van, C. (2019): Development of a Bridge Management System Based on the Building Information Modeling Technology, MDPI Sustainability, 11, 4583; doi:10.3390/su11174583
[17] Bridge inspector's handbook (2008): Overseas road note, Vol. 2, Crowthorne, England.
[18] Yanev, B. (2019): Probability and determinism in bridge management, Bridges, Building Materials and Structures–GM i K. No. 2. pp. 3-13.
[19] Pellegrini, C., et al. (2011): A simplified management procedure for bridge network maintenance, Structure and Infrastructure Engineering, Vol. 7, No. 5, May, pp. 341-251
[20] Woodwaard, R.J. et al. (2001): BRIME, Project, March.
[21] Bridge inspection handbook (2018): Ch. 4: Field inspection, data collecting, report writing and report review. Mass, DOT, 14.05.
[22] Bridge Engineering Handbook (2002): Ch. 49: Maintenance inspection and rating (M. Vinayagamoorthy) Ed. by Wai-Fah Chen and L. Duan, CCR Press, Boca Raton.
[23] Bridge Engineering Handbook – Construction and maintenance (2014): Ed. by Wai-Fah Chen and L. Duan, (Ch. 10:Bridge health monitoring, D. Frangopol&S.kim; Ch.13: Bridge inspection, J. E. Copelan)
[24] Maheswaran, T. et al. (2005): Deterioration modelling and prioritising of reinforced concrete bridges for maintenance, Australian Journal of Civil Eng., No 1. pp. 1-11.
[25] Zambon, I. et al. (2019): Condition Prediction of Existing Concrete Bridges as a Combination of Visual Inspection and Analytical Models of deterioration, Applied Sciences, 9, 148; p. 26
[26] Kenshei, O. et al. Proposal for Libia's BMS, J. of Engin. Research, September, 2014; pp. 77-94.
[27] Angelo Zanini, M. et al. (2019): State –of research on performance indicators for bridge quality control and management, Frontiers in Build Engineering, doi: 10.3389/fbuil.2019.00022
[28] Matos, J.C. et al. COST Action TU 1406: Quality specifications for roadway bridges, standardization a European level (BRIDGESPEC)-Performance indicators, Conference paper, November 2016.
[29] Folić, R., Zenunović, D., Stojković, N. (2019): Durability and service life prediction of concrete structures, Macedonian Association of Structural Engineers, 18th International Symposium, Ohrid, 2-5 October 2019, Proc. MT – 14, pp 280-291
[30] Yanev, B.: Bridge management (2007) John Wiley & Son, New Jersey, p. 651.

APSTRAKT

UPOREDNE ANALIZE NEKIH SISTEMA ZA UPRAVLJANJE MOSTOVIMA

Radomir FOLIĆ
Doncho PARTOV

Sigurnost i funkcionalnost betonskih putnih mostova od posebnog su značaja za kontinuitet saobraćaja u različitim okolnostima, uključujući zemljotrese, poplave, kao i nakon udara broda ili vozila u njihove stubove. To je razlog što skoro sve države koriste Sistem za upravljanje mostovima (BMS). Ovi sistemi uključuju priručnike za inspekciju mosta, smernice za pisanje izveštaja, procenu stanja mosta i određivanje prioriteta za radove na održavanju ili sanaciji radi postizanja proračunskog eksploatacionog veka mostova. U ovom radu predstavljena je uporedna analiza nekih dokumenata iz određenih zemalja i udruženja, koji se odnose na BMS i njihove glavne komponente.

Ključne reči: betonski mostovi, sistem za upravljanje mostovima, pregledi, procena stanja, rejting mosta, deterioracija, modeli za prognozu, performanse, eksploatacioni vek

ABSTRACT

COMPARATIVE ANALYSIS OF SOME BRIDGE MANAGEMENT SYSTEMS

Radomir FOLIC
Doncho PARTOV

Safety and functionality of concrete road bridges are of a special importance for the traffic flow continuity in different circumstances including after earthquakes, floods, as well as after vessel or vehicle impact on piers. This is why almost all countries use Bridge Management Systems (BMS). They include the bridge inspection manuals, guidelines, report writing, bridge condition evaluation and determination of priorities (rating) for maintenance work or rehabilitation to achieve the design service life of bridges. This paper presents a comparative analysis of some documents of certain countries and associations, related to BMSs and their main components.

Key words: Concrete bridges, bridge management system (BMS), inspections, condition assessment, bridge rating, deterioration, performance, forecast models, service life

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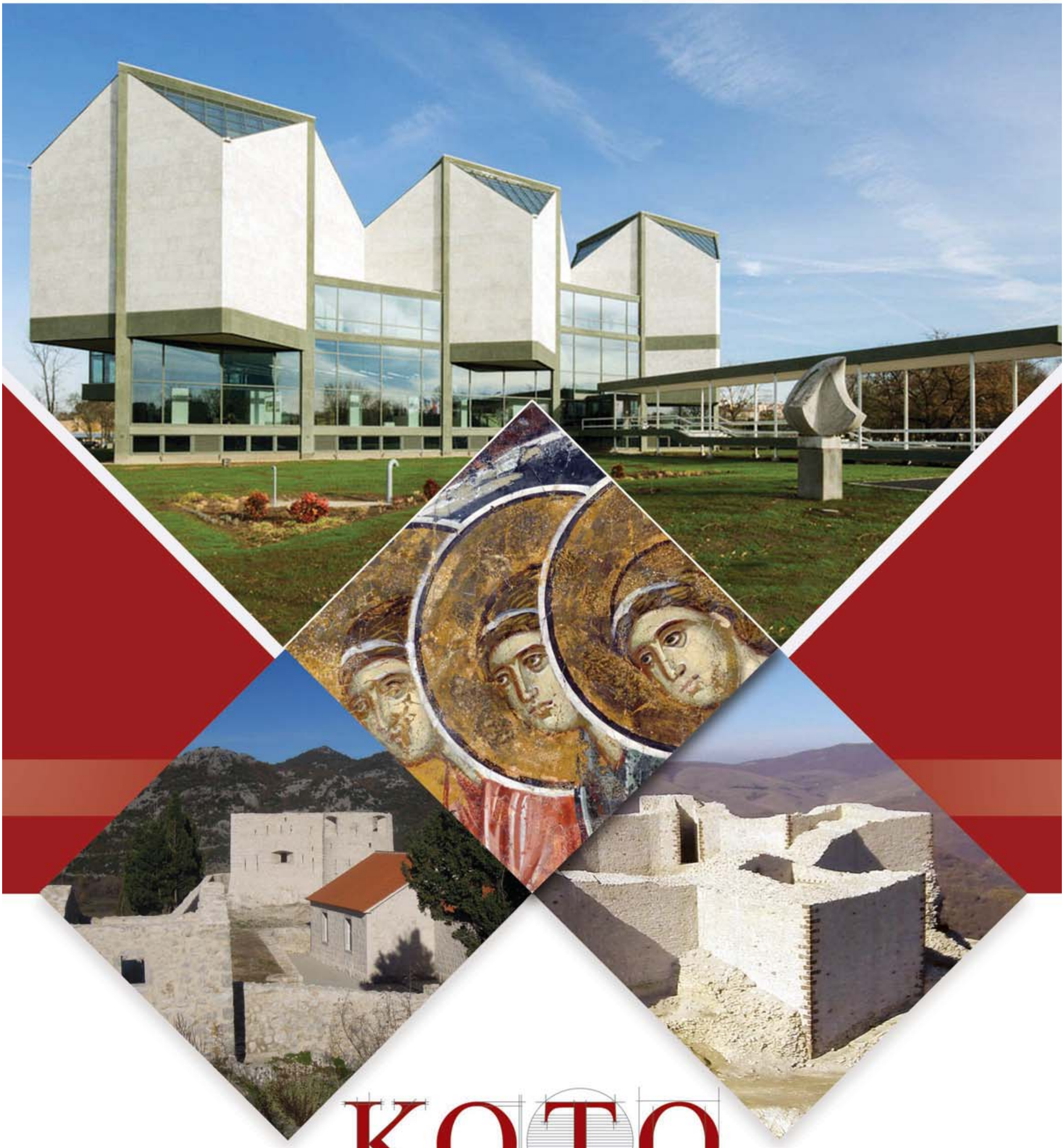

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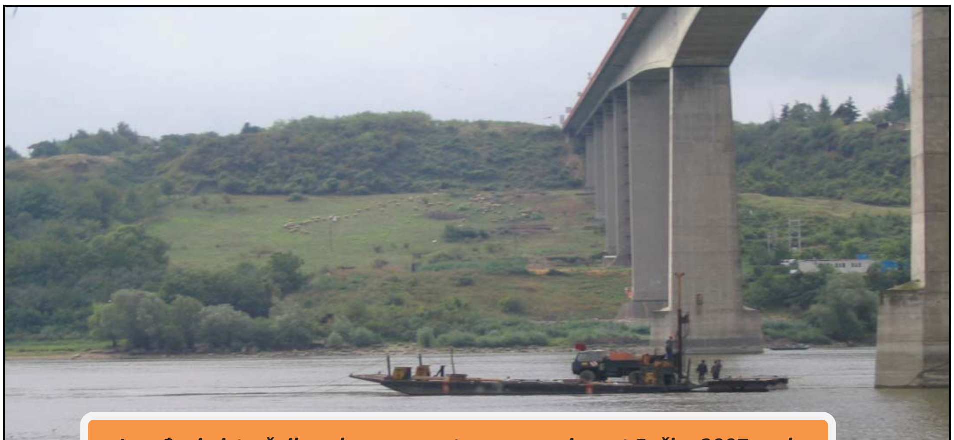


Izvođenje istražnih radova sa pontona za novi most Beška,2007.god.

Geotehnička istraživanja i ispitivanja – in situ

Od terenskih istražnih radova izdvajamo izvođenje istražnih bušotina (IB), standardnih penetracionih opita (SPT), statičkih penetracionih opita (CPT i CPTU), opita dilatometarskom sondom (DMT i SDMT), ispitivanja vodopropustljivosti tla različitim terenskim metodama (VDP), ugradnja pijezometara i dr.
Terenske metode ispitivanja šipova zauzimaju značajno mesto u našoj delatnosti, a na tržištu se izdvajamo kao lideri u toj oblasti u protekloj deceniji.

DLT-dinamičko ispitivanje šipova

Ispitivanje šipova

SLT metoda (Static load test) ispitivanje nosivosti šipova statičkim opterećenjem;
DLT metoda (Dynamic load test) ispitivanje nosivosti šipova dinamičkim opterećenjem;
PDA metoda (Pile driving analysis) omogućava praćenje i optimizaciju procesa pobijanja prefabrikovanih betonskih i čeličnih šipova u tlo;
PIT (SIT) metoda (Pile(Sonic) integrity testing) koristi se za ispitivanje integriteta izvedenih šipova (dužine, prekida, suženja ili proširenja).

CPT/CPTU opiti

Aktivno klizište

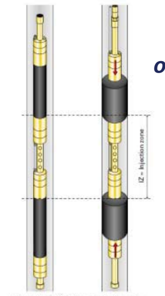


Fig. 9. IPAC GD Regular double packer

oprema za ispitivanje vodopropusnosti stena pod pritiskom do 10 bar-a metodom LIŽONA

Laboratorija za puteve i geotehniku

Laboratorija za puteve i geotehniku akreditovana je kod Akreditacionog tela Srbije – ATS prema SRPS ISO/IEC 17025:2006. U njoj se vrše ispitivanja tla (identifikaciono–klasifikaciona ispitivanja, fizičko–mehanička modelska ispitivanja), kamenog agregata i brašna, bitumena i bitumenskih emulzija, asfaltnih mešavina. U okviru laboratorijskih ispitivanja na terenu vrši se kontrola kvaliteta ugrađenog materijala i izvedenih radova (prethodna, tekuća, kontrolna ispitivanja i izvođenja opita in situ).

Projektovanje puteva i sanacija klizišta

U okviru projektovanja značajno mesto u radu zauzimaju geotehnička istraživanja terena i projekti sanacije klizišta - nestabilnih kosina useka i nasipa puteva i prirodno nestabilnih padina . Značajna su i projekovanja svih vrsta fundiranja specijalnih geotehničkih konstrukcija. Ističe se i iskustvo u oblasti putarstva, na projektovanju novih, rehabilitacija i rekonstrukcija postojećih puteva svih rangova sa pratećim objektima i dimenzionisanjem kolovoznih konstrukcija.

Nadzor

Naši inženjeri imaju veliko iskustvo u kontroli i proveri kvaliteta izvođenja svih vrsta radova, kontroli građevinske dokumentacije i praćenju radova u skladu sa njom, kao i rešavanju novonastalih situacija tokom izvođenja radova.

BUILDING TRUST

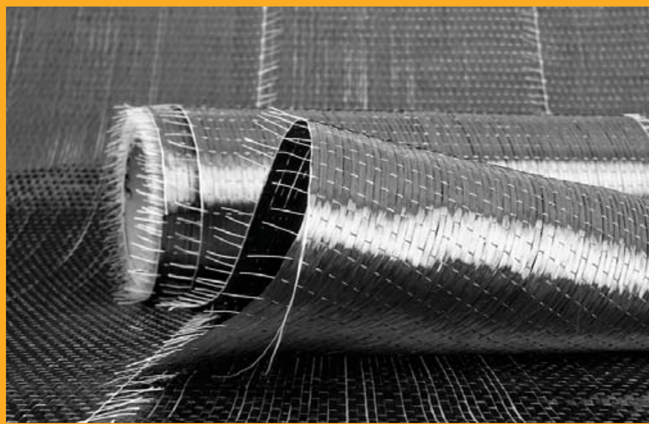
NAPREDNA SIKA REŠENJA U OBLASTI STRUKTURALNIH OJAČANJA

Kompanija Sika pruža trajnu dodatnu vrednost vlasnicima građevinskih objekata, njihovim konsultantima i izvođačima, kao i tehničku podršku tokom svih faza projekta, od ispitivanja uslova i razvoja inicijalnog koncepta ojačanja pa sve do uspešnog završetka i primopredaje projekta

SIKA – VAŠ PARTNER NA GRADILIŠTU

- Globalni lider na tržištu građevine i građevinske hemije
- Najbolja tehnička ekspertiza i praksa za sanaciju betona i strukturalna ojačanja
- Odlična reputacija kod vodećih izvođača i ugovarača posla

SIKA VREDNOSTI I INOVACIJE U GRAĐEVINI



- Integrisani proizvodi i sistemi visokih performansi koji mogu da povećaju i poboljšaju kapacitet, efikasnost, trajnost i estetiku zgrada i drugih objekata – u korist naših klijenata i boljeg održivog razvoja
- Sika mreža obučenih i iskusnih građevinskih stručnjaka

JEDINSTVENA SIKA REŠENJA U ZAHTEVNIM USLOVIMA

- Rešenja za gotovo sve uslove apliciranja
- Kontrolisano vreme rada, vreme sazrevanja i očvršćavanja za različite vremenske uslove
- Posebna rešenja završnih ojačanja za korišćenje kod betona slabije jačine i drugih podloga

POTVRĐENI SIKA SISTEMI I TEHNIKE APLICIRANJA

- Preko 40 godina iskustva u strukturalnim ojačanjima, sistemima i tehnikama
- Proizvodi i sistemi sa brojnim testovima i procenama kako internim tako i eksternim
- Najviši međunarodni standardi proizvodnje i kontrole kvaliteta

PUT INŽENJERING

Put inženjering d.o.o punih 25 godina radi kao specijalizovano preduzeće za izgradnju infrastrukture u niskogradnji i visokogradnji, kao i proizvodnjom kamenog agregata i betona. Preduzeće se bavi i transportom, uslugama građevinske mehanizacije i specijalne opreme.

Za spravljanje betona koristimo drobljeni krečnjački agregat sa našeg kamenoloma, deklarisanih frakcija, kontrolisane vlažnosti. Kompletan proces proizvodnje i kontrole kvaliteta vršimo prema važećim standardima.

Kao generalni izvođač radova, vršimo koordinaciju svih učesnika na projektu, planiranje, praćenje i nabavku materijala, kontrolu kvaliteta izvedenih radova, poštujući zadate vremenske rokove i finansijski okvir investitora.

Obradu armature vršimo brzo, stručno i kvalitetno, sa kompjuterskom preciznošću i dimenzijama po projektu.

Osnovi princip našeg poslovanja zasniva se na individualnom pristupu svakom klijentu i pronalaženje najoptimalnijeg rešenja za njegove transportne i logističke potrebe.

Koristeći inovativne tehnike i kvalitetan građevinski materijal iz sopstvenih resursa, spremni smo da odgovorimo na mnoge zahteve naših klijenata iz oblasti niskogradnje.

Naša kompanija u oblasti visokogradnje primenjuje sistem prefabrikovnih betonskih elemenata koji u odnosu na klasičnu gradnju ima brojne prednosti.

Usluge građevinskom mehanizacijom vršimo tehnički ispravnim mašinama, sa potrebnim sertifikatima kako za rukovaoce građevinskim mašinama tako i za same mašine.

Osnovna prednost prefabrikovane konstrukcije jeste brzina kojom konstrukcija može biti projektovana, proizvedena, transportovana i namontirana.

Prednapregnute šuplje ploče su konstruktivni elementi visokog kvaliteta, proizvedeni u fabrički kontrolisanim uslovima.

Raspolažemo opremom i mašinama za sve zemljane radove, kipere i dampere za rad u teškim terenskim uslovima, automiksere i pumpe za beton, autodizalice, podizne platforme.

Izvodimo hidrograđevinske radove u izgradnji kanalizacionih mreža za odvođenje atmosferskih, otpadnih i upotrebljenih voda, izvođenjem hidrograđevinskih radova u okviru regulacije rečnih tokova, kao i izvođenjem hidrotehničkih objekata.

Izrađujemo betonske "New Jersey profile" koji se u svetu koriste za preusmeravanje saobraćaja i zaštitu pešaka u toku izgradnje puta, kao i Betonblock sistem betonskih blokova.

Sakupljanje i privremeno skladištenje otpada vršimo našim specijalizovanim vozilima i deponujemo na našu lokaciju sa odgovarajućom dozvolom. Kapacitet mašine je 250 t/h građevinskog neopasnog otpada.

Površinski kop udaljen je 35 km od Niša. Savremene drobilice, postrojenje za separaciju i sejalica efikasno usitnjavaju i razdvajaju kamene agregate po veličinama. Tehnički kapacitet trenutne primarne drobilice je 300 t/h.

Uslugu transporta vršimo automikserima, kapaciteta bubnja od 7 m³ do 10 m³ betonske mase. Za ugradnju betona posedujemo auto-pumpu za beton, radnog učinka 150 m³/h, sa dužinom strele od 36 m.

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