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GLOBAL ELASTIC MODULUS USAGE FOR DIAGNOSING THE MRATINJE DAM BEHAVIOR

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Abstract. *Having in mind the attention given to the safety of large dams and the estimation of their future behavior in the last few decades, a concept of global module is developed whose aim is to evaluate the current state of dam in a relativly simple way. Global modules are defined on the mathematical model of a dam, based on the Finite Element Method. It has to cover all assumtions from which we started while working on the model, so that it loses its initial meaning of material property and becomes a structural parameter which has its meaning only in connection with the mathematical model calibrated in terms of field measurements. The aim of the authors was to find the possibilities for the application of this method in monitoring the behavior of arch dams. The global module of elasticity is defined on the mathematical model which used the sofware ANSYS, while the measurements of radial movements on the dam carried out as a part of regular dam monitoring are taken as the results of monitoing.*

INTRODUCTION

The arch dam represents a space construction in the form of a shell, which is primarily loaded with water pressure, drift, earthquake and some other loads.

Having in mind the attention given to the safety of large dams and the estimation of their future behavior in the last few decades, a concept of global module is developed whose aim is to evaluate the current state of dam in a relativl simple way.

Global modules are defined on the mathematical model of a dam, based on the Finite Element Method. It has to cover all assumptions from which we started while working on the model, so that it loses its initial meaning of material property and becomes a structural parameter which has its meaning only in connection with the mathematical model calibrated in terms of field measurements.

The mathematical model bounded to *in situ* measurement program is called a "hybrid"

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model. The major part of the process of global module identification is the model calibration and the procedure of collecting data on site. Model calibrations are conducted with several non-linear back analysis of the state of stress and deformations on the finite element model of dam, where every analysis starts with a certain presumed value of concrete elasticity module.

Global module for an existing dam may be successfully applied for diagnosing its security during the time. We can use new data, obtained during the measurement process on site, for recalibrations of the same mathematical model. In that way, we can define a new value of the global dam module. If the new value of global module is not much different from the previous value, it can be concluded that the dam retains its attributes and its security. If this is not the case, this may indicate the degradation of the structure or the appearance of a crack in the dam or in its fundamentals, so that it is required to undertake further investigations.

The aim of the author was to find the possibilities for the application of this method in monitoring the behavior of arch dams. If the value of global module for the dam is defined, we must have some knowledge of geometrical attributes of the dam and rock mass in its fundamentals, the way in which the state of stress in the dam is evaluated, and type and locations of monitoring equipment. Because of that, these things are given special attention in this paper.

THE GLOBAL ELASTICITY MODULUS AS A MEASURE OF INTERPRETATION OF DAM BEHAVIOR

The global modules are defined upon the mathematical model of the dam with finite elements.

The prediction of dam behavior by using mathematical model includes several assumptions: elastic behavior of the dam, structural continuity, the quality of dam monitoring system, etc. Furthermore, the calculation of the state of stress and deformations is usually performed by using the theory of elasticity, so that the effect of plastic deformations, and the influence of time (ageing of construction), is not considered. The mathematical model itself, however, always has some differences when regarding the actual dam. The global module has to cover all these assumptions, as well as some other ones, so it loses its initial meaning of the attribute of dam material and becomes a structural parameter, which has its meaning only in connection with the mathematical model, calibrated in terms of field measurements.

The mathematical model bounded to a certain *in situ* measurement program is called a "hybrid" model. The mine tools of the calibration technique are the procedures for recording data and their processing in order to identify the characteristic displacement of the dam body. The calibration technique is performed by several back analyses using the model with finite elements, where each of these starts with a certain presumed value of elasticity module for dam. As the construction model consists of the dam and rock mass in its foundations, it is necessary to adopt actual values obtained through on site investigations as rock mass deformation module. Thus, it is possible to establish a graphic correlation between the elasticity module and mathematically calculated values of particular dimensions. Having for information the measured values of the same dimensions on the dam, it is possible to define the global module, which is significant for the whole construction in a particular moment of its life.

The global module of an existing dam can be successfully used for safety assessment of the dam during its life. The new acquired field measurements are used for recalibration of the same mathematical model and the global module is consequently updated. If the new value does not differ significantly from the previous value it can be concluded that the dam preserved its structural properties. If this is not the case, further investigations are required in order to evaluate the causes and the significance of the change which can be due to either ageing or fatigue or structural local degradations.

IDENTIFICATION OF GLOBAL ELASTICITY MODULES OF MRATINJE DAM

The concept of hybrid model, which is defined in order to obtain the global elastic modules, is applied for the identification of the behavior of Mratinje dam in Montenegro.

Having in mind that the aim of the calibration process is obtaining a sort of "identity card" of the structure; the mathematical model has to handle as accurately as possible all the geometrical details and foundation particularities.

The finite model of the dam – foundation system was developed using the computer program ANSYS (S.A.S.I.).

The deformation module of rock mass is obtained *in situ* investigations and their value is from 7 to 15 GPa.

Besides, data on radial displacements from six measurement series at different times are used. Those data are a part of usual monitoring of Mratinje dam. Radial displacements on this dam are measured by using geodetic survey and by using certain instruments.

THE MRATINJE DAM

Because of necessary information for the mathematical dam model, and for understanding the dam behavior, it is necessary to briefly describe the dam itself (geometry and its foundations) and tell something about the way in which it is calculated and describe monitoring instruments installed in it.

The dam Mratinje is an arch dam with a double curvature and variable thickness in horizontal and vertical direction. Upstream and downstream face in horizontal intersection of the dam are defined with curved lines, composed from circular arches circumscribed from a five-center point.

Geometric characteristics of the dam:

– height	220.00 m
– length of cantiviler arch	268.56 m
– thickness in center of the crown arch	4.51 m
– Max. thickness in the foundations	45.00 m
– central angle of arch in crown	84.78^o
– central angle of arch in foundations	55.50^o
– volume of concrete	732 940.0 m^3

Volume of reservoir is $880 \times 10^6 m^3$.

STATE OF STRESS ANALYSIS

The state of stress analysis in the dam was performed by using the methods of finite differences and by using the method of finite elements. For a detailed static calculation of the dam, and in order to obtain better accuracy for the state of stress, Dr Nikola Hajdin's method was used, based on the numerical integration of fundamental partial differential equation for thin shell. The solution of these equations was obtained by equalizing radial and tangential displacements and rotation in intersection point of horizontal and vertical system lines (arches and consoles) and by establishing the basic condition equilibrium for each point. Calculation was performed on computer Elliot 803. The computation adopted the elasticity module for concrete of 18 GPa and real deformation modules of rock mass were obtained in field investigations. Deformations in foundations were calculated by using Dr Frederic Foct's and V. Mlađenovica's equations.

The highest obtained value of pressure is 10400 KN/m^2 and the lowest is 1700 KN/m^2. These pressures occured in points of upstream and downstream faces of the dam near the foundation on the level of 558.00 m. The greatest obtained radial displacement is 9.06 cm and it occurs in the middle of the dam on the level of 638.00 m.

MONITORING OF MRATINJE DAM

On Mratinje dam, horizontal and vertical displacements and rotations are measured by using geodetic survey, as well as by using electromagnet strainmeters and dilatometers. The temperature and the state of stress in construction and in its fundamentals and water level in reservoir are monitored too. The dam is equipped with instruments for seismic measurement, too.

The absolute horizontal and vertical displacements in certain points on the dam are obtained with geodetic survey.

Disposition of geodetic points is shown in figure 1.

Numerical processing of obtained measurements is performed on the computer.

Measurements of water and air temperature are performed in the central console on the each gauge point on level 518.00, 558.00, 598.00 and 638.00 (figure 2).

For these measurement thermometers with vibrating wire "Telemac" are used, whose measuring range is from -20°C to +60°C and response 0.2°C.

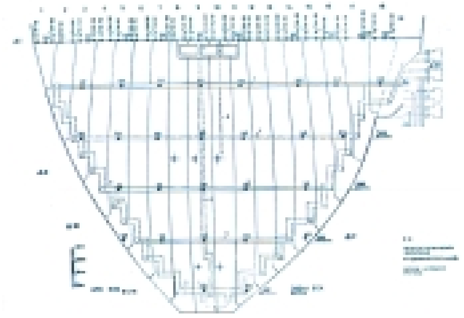


Fig. 1.

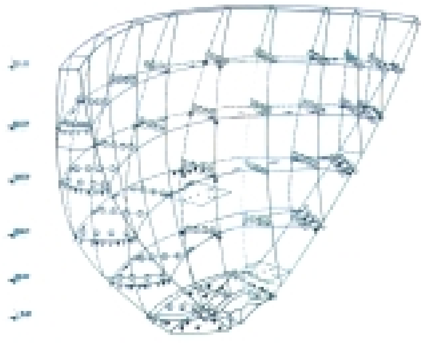


Fig. 2

MATHEMATICAL MODEL OF MRATINJE DAM

A finite element model of the dam – foundation system was developed using the ANSYS computer program. The discretizations comprise 3D linear finite elements (SOLID 73) both in the foundation ground and in the dam structure.

The model has 8045 elements, 3241 of them being in the dam body.

The finite element model of dam is shown on figure 3.

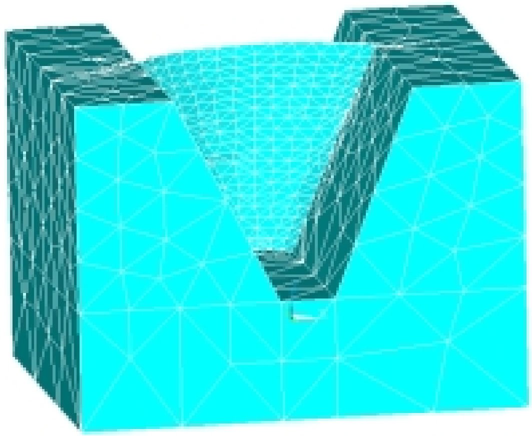


Fig. 3

LOADING

The loading of the dam and its foundations consists of three loading categories: self-weight of the dam, hydrostatic pressure acting up on the dam and the temperature changes and differences.

Dam self-weight is applied as the weight of material in the dam body.

Loading combinations discussed in this paper correspond to the real measuring series in different moments of dam's life.

These combinations are shown in the next table.

Table 1. – Loads and obtained radial displacements

Date	Water level (m)	Air temperature (^oC)	Water temperature (^oC)	Radial displacement* (mm)
20. 09. 87.	214.0	15	7	67.2
01. 09. 91.	212.0	11	7	72.4
15. 10. 94.	199.0	4	5	61.8
15. 06. 96.	215.0	15	5	64.2

* Radial displacements correspond to the point 11/2, where they are the greatest.

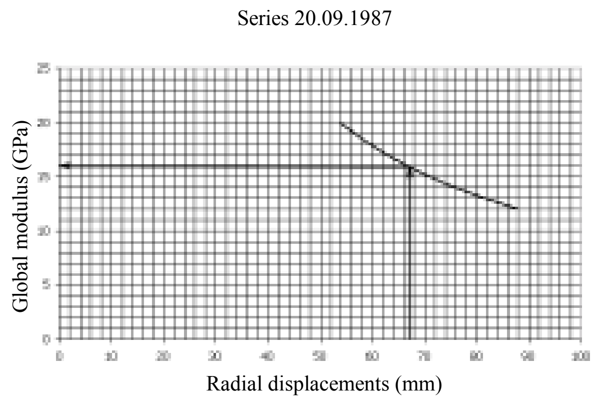
THE OBTAINED RESULTS

Having in mind that radial displacements of downstream dam face are taken as the results of real measurement, the results of calculation (table 2) are given as displacements in the direction of Y axis, for selected combinations of loading and corresponding elasticity modules of concrete.

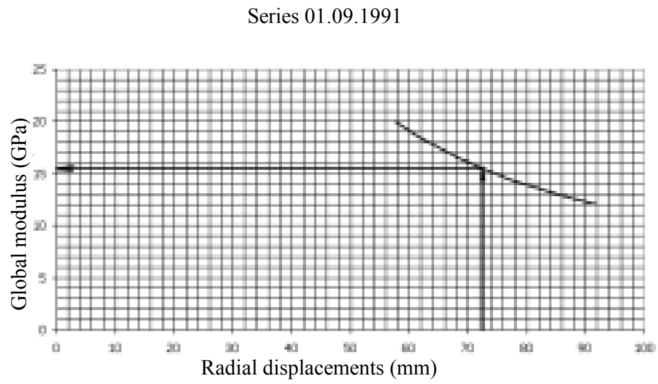
Table 2. Radial displacements of construction

Date	Radial displacements for point 11/2 (mm)					Measured value (mm)
	E=20GPa	E=18GPa	E=16GPa	E=14Gpa	E=12GPa	
20.09. 87.	53.71	59.45	66.60	75.76	87.93	67.2
01.09. 91.	57.52	63.27	70.44	79.62	91.80	72.4
15.10. 94.	52.05	56.23	61.44	68.08	76.89	61.8
16.06. 96.	52.28	57.30	63.56	71.56	82.19	64.2

It is possible to establish a graphic correlation from which the global modulus of elasticity for each of the measuring series can be obtained.

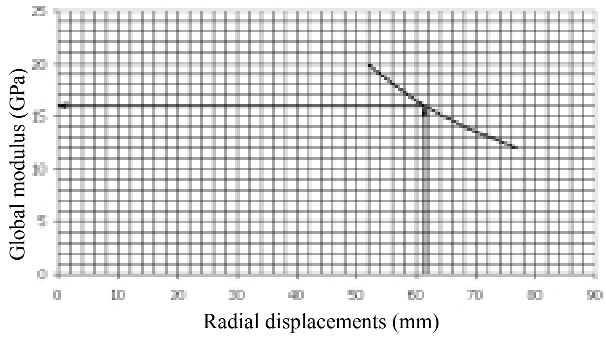


Radial displacements for series 20. 09.1987



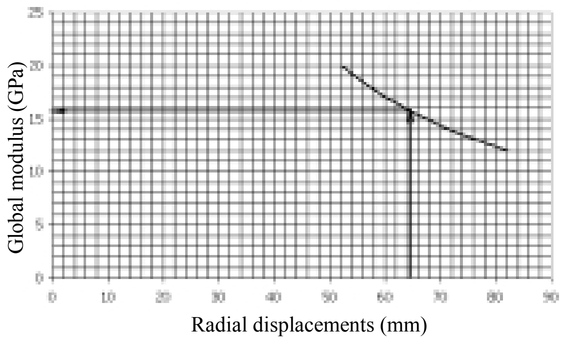
Radial displacements for series 01. 09.1991

Series 15.10.1994



Radial displacements for series 15. 10.1994

Series 15.06.1996



Radial displacements for series 15. 06.1996

The obtained values for global elasticity modulus are shown in the next table.

Table 3. Values for global elasticity modulus

Date	20.09.87.	01.09.91.	15.10.94.	15.06.96.
Global modulus	15.9	15.6	16.0	15.8

FINAL REMARKS

The aim of calculations global modules in different periods of dam's life is the assessment of construction security. The values of global modules at differrent times are compared to each other.

It is possible to see from the previous table that the values of dam global module are similar. Its value is about 16 GPa. This means that the Mratinje dam is safe and that its behavior is normal, even after 30 years of work.

The difference between the values of global modulus in the period from 1987. to

1996. is negligible and it can be explained with the imperfect model of the dam. In order to decrease computer-working time, a finite element mesh with elements whose length is 20 m is adopted. Because of such a length it is not possible to enter completely correct values for some loads (value of water temperature on different levels, for example). This problem can be eliminated if the length of element is decreased, but then the period of computer working time

In order to compare the obtained value, the finite element model of dam with element length of 8 m is created. This model has a total of 20428 elements, while computer working time is 1657 sec per iteration (the program commonly works with 4 iterations in one analysis). Memory needed for one analysis is 466 MB, which presents a great amount of memory if it is considered that at least five back analyses need to be performed. On the other hand, the adopted model has 8045 elements, while the required working time of computer is 316 sec per iteration. An analysis using this model required 139 MB of memory.

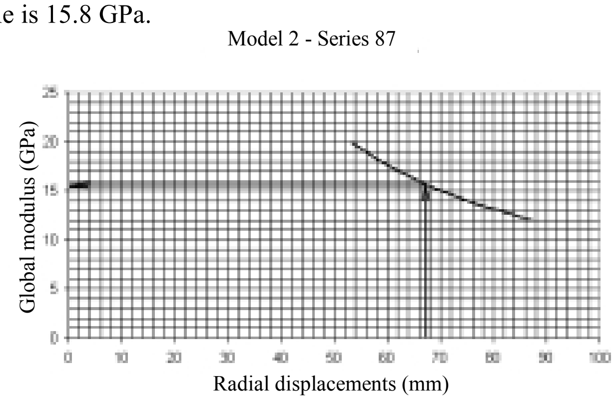
Furthermore, we must have in mind that the obtained results are very similar (the accuracy is not much better). This was the main reason for adopting the model with element length of 20 m.

In the next table the obtained results for adopted model and for model with element length of 8 m for measurement series 20.09.1987 are shown.

Table 5. Radial displacements – Comparisons of the obtained results

Date	Radial displacement in point 11/2 (mm)					Measurement (mm)
	E=20GPa	E=18GPa	E=16GPa	E=14GPa	E=12GPa	
20.09.87. 20m	53.71	59.45	66.60	75.76	87.93	67.2
20.09.87. 8m	53.09	58.82	65.99	75.09	87.31	67.2

The next chart shows radial displacements in point 11-2 for measurement series from 1987. for model with element length of 8 m. It is possible to see that in this case the value of global module is 15.8 GPa.



Radial displacement for series of 1987 - Model 2.

The advantage of this manner of predicting the dam behavior is that the interpretations of measured values can be obtained very fast. Also, we can use the same dam model to perform a new back analysis with updated measuring value for all the following measurements.

REFERENCES

1. Sipozijum o izgradnji HE Mratinje, 23. – 25. maj 1974. Nikšić
2. *Arch dams design*, DEPARTMENT OF THE ARMY, U.S. Army Corps of Engineers, Washington, D.C. 1994
3. A. Abdulamit, D. Stematiu, I. Toma - *Identification of dynamic elastic material properties using hybrid models*, Balkema, Rotterdam, 1997

KORIŠĆENJE GLOBALNOG MODULA ELASTIČNOSTI ZA DIJAGNOSTIKU PONAŠANJA BRANE MRATINJE

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Koncept globalnog modula elastičnosti je razvijen u poslednjih nekoliko decenija sa namerom da se usavrši i pojednostavi praćenje i prognoza budućeg ponašanja viskokih brana.

Globalni modul se definiše na matematičkom modelu brane za čije numeričko određivanje je korišćen metod konačnih elemenata. On pokriva polazne pretpostavke modela tako da gubi svoje osnovno značenje mehaničke karakteristike materijala i postaje strukturni parametar, koji ima smisla samo u sadejstvu sa matematičkim modelom koji se kalibrira uz pomoć izmerenih podataka.

Cilj autora je bio da se pronađu mogućnosti primene ovog metoda u oblasti osmatranja viskokih lučnih brana. Globalni modul elastičnosti je definisan uz pomoć programskog paketa ANSYS, dok su merenja radijalnih pomeranja deo redovnog godišnjeg osmatranja brane Mratinje.