50| Претходно саопштење
Preliminary report
doi 10.7251/STP1813679N ISSN 2566-4484

МОГУЋНОСТ ОТКРИВАЊА ПРОМЕНЕ ГЕОМЕТРИЈЕ НА ВЕЛИКИМ БРАНАМА ПРИМЕНОМ ГЕОДЕТСКИХ МЕТОДА

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Резиме:

Велике бране изложене су утицају различитих сила које током времена изазивају промену њиховог положаја и геометрије. Познавање промене положаја и геометрије великих брана је од критичног значаја за одређивање њихове стабилности и сигурности. Бране се у процесу деформационе анализе апроксимирају скупом дискретних тачака а затим се на основу промене положаја ових тачака у простору и времену доносе закључци о промени положаја и геометрије брана. За сигурност великих брана је од изузетног зачаја да се одреде промене положаја и геометрије док су оне малих величина како би се открили негативни трендови и благовремено предузеле мере за спречавање последица од угрожене сигурности бране. У овом раду се истражују могућност откривања промене геометрије великих брана на основу резултата добијених геодеским методама.

Кључне речи:Деформациона анализа, тестирање статистичких хипотеза.

ON THE POSSIBILITY OF GEOMETRIC CHANGES OF LARGE DAMS DETERMINATION BY GEODETIC METHODS

Abstract:

Large dams are exposed to the influence of various forces which in time cause changes in their position and geometry. Knowledge about changes in position and geometry of large dams is of crucial importance for their stability and security determination. Dams, in process of deformation analysis, are approximated by set of discrete points and on the base of the changes in position and through time of those points the conclusions of changes of dam position and geometry are made. For large dams' security of highest importance is to detect changes of position and geometry where they are small in order to discover the negative trends and to take measures for prevent consequences of jeopardized dams' security in time. This paper investigates the possibilities of dams' geometry changes detection on the base of geodetic measurements.

Keywords: Deformation analysis, statistical hypotheses testing.

1. INTRODUCTION

Large dams are objects of high value and they are being built with the purpose create a new values i.e. to satisfy elementary human needs mainly for water providing and needs for electric power. The other utilization of water accumulations such as providing irrigation systems in agricultural production are not of smaller importance as this increases the food safety of the population. In that sense large dams are significant component of social wealth and the base for civilizational development. Bearing in mind previous facts large dams need necessary attention in order to keep their functionality in as long period as possible and to extend the period of their exploitation.

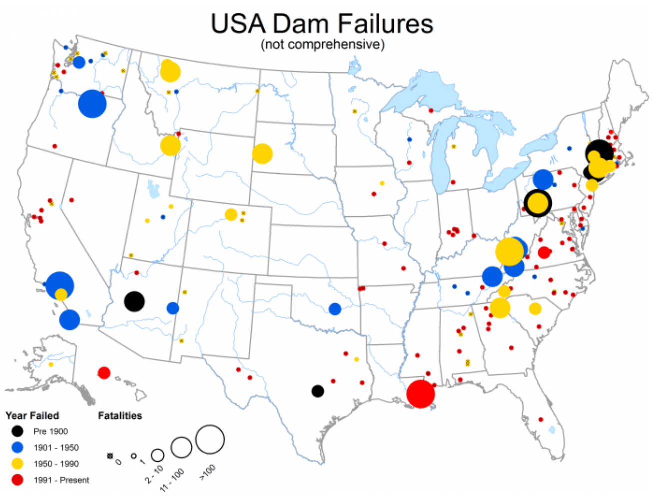
Large dams along with accumulation are also a risk for downstream area. In case of their failure different damages could occur including possibilities of human lives loss and big material damages.

Material losses are multiple:

- Damage of large dam itself,
- Material loss which ocurs in downstream area and
- Losses which occur because of termination or decrease of functionality of large dam at the level of value which could be sreated if large dam was not damaged.

Large dams are complex systems. Their complexity originates from their complexity itself, influence of accumulation, influence of external conditions as well as from complex interactions between large dam and the soil on which it was being built. If those influences are represented by forces it could be said that the large dam will keep its shape (geometry) and position until the forces are in balance. The change of balance between forces inevitably leads to the changes of geometry or the position of large dam or both. Determination changes of geometry and position of large dam (when those changes are monitored in enough large period of time) could point out the trends which lead to its vulnerability. In order to decompose the problem on the elementary factors the concepts of risk and hazard were developed which are the base for large dams risk management [1]. Development of risk and hazard concept as well as risk management is the utility for unwanted events prevention but they cannot eliminate all of them. The map of dam failure in USA [2] is shown on figure 1.

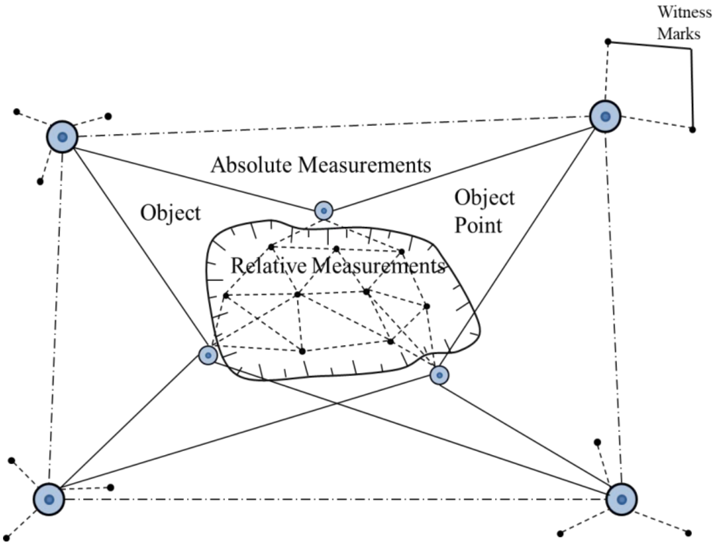
Determination of geometrical changes of large dams is of crucial importance for making conclusion about their state as well as for decision making about timely undertaking measures and activities for prevention failures. The change of geometry of large dams in geodetic sense means changes of certain or all dimension of large dam parts related to other parts of it or change of shape of their parts (or complete large dam). In order to determine or monitor those changes large dam is approximated (or discretized) with finite set of points and after that, by measuring in certain time intervals, the coordinates and heights changes of these points could be determined in space. Mutual changes of these points position are defined as relative movements while the changes related to stable reference (control) points which are defined as absolute movements. In this paper research will be limited to the relative movements of points.



Слика 1. Мапа оштећења брана у САД

Figure 1. Map of dam failures in the USA

Concept of absolute and relative movements is shown on figure 2 [3].



Слика 2. Концепт апсолутних и релативних померања

Figure 2. Concept of relative and absolute meaurements

Specificity of geodetic networks for large dam monitoring are before all related to the high level of accuracy and determination of small movements of points and limited possibilities for their design with maximal level of quality parameters. The limitations for geodetic network design are mainly related by position for control point's stabilization as well as for obstacles for visibility between control points and marks situated on large dam. The optimization of geodetic networks for large dam monitoring design could mitigate the problem but it could not completely eliminate it [4]. The pillar (reference points) stabilization is limited to the positions which are not influenced by large dam and/or accumulation and provide long term stability in geological sense. Another limitation factor is the position of the river and impossibility to choose the optimal position for control points. As a result of research efforts for determination of absolute and relative movements of points the numerous methods for deformation analysis of geodetic networks were developed [5]. In literature and in practice dominates the opinion that this problem is not solved yet.

2. METHODOLOGY

For dimension changes between points which approximate large dam it is necessary:

- To choose dimension which will be analysed,
- To formulate null and alternative statistical hypothesis,
- To adopt the level of significance for decision making about adoption or rejection null hypothesis,
- To form test staistics based on adjustment of measurements,
- To compare value of test statistics and determine if it follows the theoretical distribution and
- If test statsistcs follows the theoretical distribution on the adopted level of significance conclusion is that results are harmonized with null hypothesis and the reasons for its' rejection do not exists while, in opposite case the reasons for its adoption do not exists.

Because of importance of data about the changes of large dams dimensions the authors suggests local tests of each dimension.

The test statistics is [6]:

$$t = \frac{d}{m_d} = \frac{|X_n - X_0|}{\sqrt{m_{X_n}^2 + m_{X_0}^2}} \sim t_{1-\alpha}(f) \quad (1)$$

where:

- t – Students' statistics,
- d – the difference of certain dimension in two series of measurements (for example: null and n),
- m_d – mean root square error of researched dimension,
- X_0, X_n – dimension in two different series of measurements null and n respectively,
- $m_{X_0}^2, m_{X_n}^2$ – mean square error of dimension X in null and n respectively and
- $t_{1-\alpha}(f)$ – quantile of Students' distribution for significancy level α and number of freedom f.

The difference of researched dimension is obtained on the base of coordinates in two series of measurements while the mean square errors are obtained as a function of adjusted values by following formula:

$$m_X = m_0\sqrt{g^T Q_x g} \quad (2)$$

where:

- m_X – root mean square error of researched dimension as a function of adjusted values,
- m_0 - root mean square error of unit wight obtained from adjustment,
- g^T - linearized function of researched dimension and
- Q_x - cofactor matrix from adjustment.

Statistical hypotheses could be formulated in this case in the following way:

- H_0: dimension X is equal in two series of measurements and
- H_a: dimension X is not equal in two series of measurements.

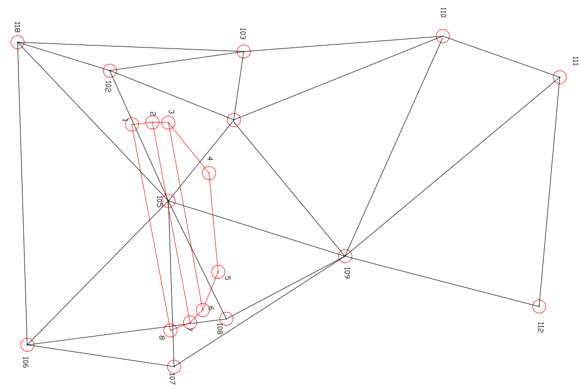
If dimension X is tested related to designed value then test statsistics (1) reads:

$$t = \frac{d}{m_d} = \frac{|X_n - X_P|}{m_{X_n}} \sim t_{1-\alpha}(f) \quad (3)$$

where X_P – is designed value while the rest symbols have the same meaning as in formula (1). Along with mentioned individual tests the tests of equality of sets of points as well as the tests of equality of positions [7].

3. RESULTS AND DISCUSSIONS

In order to illustrate possibility for change in geometry determination which represents the state and of geometry of large dam in time and space the analysis is realized on the one real example. The shape of geodetic network and position of points which represents earth filled large dam is given on figure 3.



Слика 3. Пример геодетске положајне мреже за осматрање велике бране

Figure 3. the example of geodetic network for earth filled large dam monitoring

The change of directions and distances between null and actual series were analyzed and results are shown as follows. Table 1 contains data about changes of directions while the data about changes of distances are given in table 2.

Табела 1. Промене дирекционих углова

Table 1. Change of directions

Pravci ["]							
Станица	Визура	Дирекциони текући	Дирекциони нулти	Δ ["]	m_p	t	Ho
8	1	258.45589	258.45573	1.6	1.5	0.7676	Да
7	2	258.39583	258.39568	1.5	2.2	0.4761	Да
6	3	258.53574	258.53545	2.9	3.0	0.6830	Да
5	4	84.03314	84.03344	-3.0	3.7	0.5705	Да
1	2	353.39202	353.40195	-59.3	19.5	2.1554	Не
2	3	0.10200	0.09504	29.6	13.8	1.5150	Да
3	4	70.49466	70.49473	-0.7	1.9	0.2596	Да
8	7	337.19310	337.20328	-61.8	33.1	1.3201	Да
7	6	315.07374	315.09343	-116.9	24.9	3.3245	Не
6	5	264.03314	264.03344	3.0	3.7	0.5705	Да

Табела 2. Промене дужина

Table 2. Changes of distances

Duzine [mm]							
Станица	Визура	Дужина текућа [m]	Дужина нулта [m]	Δ [m]	m_d	t	Ho
8	1	220.9451	220.9482	-3.1	3.5	0.6089	Да
7	2	214.6740	214.6789	-4.8	3.2	1.0650	Да
6	3	200.9266	200.9446	-18.0	2.7	4.6608	Не
5	4	104.4496	104.4536	-4.0	3.0	0.9451	Да
1	2	21.5965	21.5930	3.5	1.8	1.3957	Да
2	3	16.8323	16.8333	-1.0	1.7	0.4167	Да
3	4	165.8576	165.8583	-0.7	1.9	0.2620	Да
8	7	22.3370	22.3314	5.6	2.6	1.5135	Да
7	6	18.8081	18.8042	3.9	4.3	0.6304	Да
6	5	144.4735	144.5012	-27.7	3.0	6.5975	Не

Criteria for adoption of null hypotheses is as follows:

$$t = \frac{d}{m_d} < t_{1-\alpha}(f) = t_{0.95}(161) \cong \mathcal{N}(0,1) = 1.9600$$

where $\mathcal{N}(0,1)$ is normal distribution for significance level $\alpha = 0.05$.

A criterion for normal distribution is more stringent than criteria for Students' distribution and for the case of large number of freedom it is possible to use it. When the analysis of geometry of large dams is provided it is needed to use more stringent criteria for changes determination because of immanent risk and hazard.

According to obtained results it is possible do conclude that there is consent with majority of null hypothesis about equality of directions and distances between points which represents the behaviour of the dam and that only in two cases the alternative hypotheses for directions (ϑ_1^2, ϑ_6^5) as well as for two distances (d_6^3, d_6^5) were adopted.

The value of changes which could be determined by utilization of formula (1) for significance level $\alpha = 0.05$ and for criterion for normal distribution is:

$$\frac{d}{m_d} < 1.9600 \qquad (4)$$

For all changes of geometric elements of large dam for which the difference is bigger than $1.9600 m_d$ the alternative hypothesis could be adopted i.e. it is possible to conclude that analyzed element of geometry has changed its value between two series of measurements.

On the base of obtained results there are no reasons to conclude that geometry of large dam is not changed but only that obtained results do not prove the changes for analyzed elements of geometry between two series of measurements. The elements of geometry of large dam which have been changed between two series of measurements need additional and careful analysis in order to determinate causes.

4. CONCLUSION

The determination of geometry changes of large dams is of crucial importance for reliable conclusions about their state and behaviour. Limitations in the process of geodetic networks for large dams monitoring design are caused by topography and conditions for mutual visibility of reference points as well as the visibility of points which represents the dam. Those limitations could decrease the accuracy and reliability of coordinates of points which represent large dam as well as the dimension which is analyzed.

Shown example shows that changes of geometry of points which represents large dam (changes of directions and distances between points) could be detected while they are relatively small and that it is possible to monitor their development in time.

Detection of trends in geometry of large dams change makes possible to undertaking activities for prevention or elimination unwanted events, as dam failures, timely.

For the sake of caution it is needed to use more stringent criterion for null hypotheses adoption about geometry of large dam equality between two series of measurements. Also it is needed to check equality between measured and designed values for some dimension of the dam. Utilization of more stringent criteria is justified especially when the number of freedom is big and in that case it is posible to use normal distribution instead of Students' distribution.

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