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ВРАХУВАННЯ ІМОВІРНІСНОГО ХАРАКТЕРУ ГЕОМЕТРИЧНИХ НЕДОСКОНАЛОСТЕЙ ФОРМИ ПРОСТОРОВИХ ПОКРИТТІВ НАД ТРИБУНАМИ СТАДІОНІВ РАМНО-КОНСОЛЬНОГО ТИПУ

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Анотація. У статті розглянуті деякі види моніторингу стану геометрії стаціонарних рамно-консольних конструкцій покриттів над трибунами стадіонів з місткістю до 5 тисяч осіб. Наведені результати моніторингу геометрії конструкцій над трибунами СК «Олімпік». Запропоновано методику урахування можливих геометричних відхилень геометрії розглянутого типу конструкції, яка грунтується на методі кінцевих елементів у варіаційній постановці. Запропоновано метод урахування зміни розрахункової схеми геометрично нелінійно працюючих стаціонарних рамно-консольних конструкцій покриттів над трибунами стадіонів на різних етапах їх виготовлення, монтажу та експлуатації.

Ключові слова: моніторинг, геометричні недосконалості, металоконструкції, стаціонарні покриття над трибунами стадіонів, метод кінцевих елементів.

УЧЕТ ВЕРОЯТНОСТНОГО ХАРАКТЕРА ГЕОМЕТРИЧЕСКИХ НЕСОВЕРШЕНСТВ ФОРМЫ ПРОСТРАНСТВЕННЫХ ПОКРЫТИЙ НАД ТРИБУНАМИ СТАДИОНОВ РАМНО-КОНСОЛЬНОГО ТИПА

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Аннотация. В статье рассмотрены некоторые виды мониторинга состояния геометрии стационарных рамно-консольных конструкций покрытий над трибунами стадионов с вместимостью до 5 тысяч человек. Приведены результаты мониторинга геометрии конструкций над трибунами СК «Олимпик». Предложена методика учета возможных геометрических отклонений геометрии рассматриваемого типа конструкции, основывающаяся на методе конечных элементов в вариационной постановке. Предложен метод учета изменения расчетной схемы геометрически нелинейно работающих стационарных рамно-консольных конструкций покрытий над трибунами стадионов на различных этапах их изготовления, монтажа и эксплуатации.

Ключевые слова: мониторинг, геометрические несовершенства, металлоконструкции, стационарные покрытия над трибунами стадионов, метод конечных элементов.

ACCOUNTING FOR THE PROBABILISTIC NATURE OF GEOMETRIC IMPERFECTIONS FORM SPATIAL COATINGS ON THE STANDS BRACED-CANTILEVER TYPE

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Abstract. The article describes some types of monitoring the state of the geometry of the stationary frame-cantilever roof structure over the stadium with a capacity of up to 5 000 people. The results of monitoring the geometry of structures over the stands SC «Olympic» have been given. The methods take into account possible deviations of geometric in this type design, based on the finite element method in the variational formulation. We propose a method of accounting changes of design scheme of geometrically nonlinear operating stationary frame-cantilever structure covering over the stands at different stages of their manufacture, installation and operation.

Keywords: monitoring, geometric imperfections, metal construction, stationary cover over the stadium, the finite element method.

Introduction

Due to the considerable pace of development of modern technologies of construction, a very important aspect of ensuring the safety and reliability of constructions is to improve methods of monitoring the behavior of the main load-bearing parts of plants, both during construction and during operation. Particularly acute this problem occurs in areas with complex geological conditions of construction, when a significant impact on the construction site have external geodynamic factors such as underground mines, the movement of tectonic plates, high confining pressure, etc. So, at the moment carried out a considerable amount of research in the field of monitoring and deformation analysis of various types of engineering structures such as high-rise buildings, sports facilities, dams, bridges, industrial complexes, etc. These studies used measurement methods and systems that can be divided into geodetic and nongeodesic depending on the type of controlled deformations, the environmental conditions and the expected measurement accuracy. In this regard, the methods used for monitoring of equipment and accuracy strain measurement are different. Summing up the experience of domestic and foreign research methods for monitoring of buildings and structures can be classified into four groups: classical geodetic methods (surface leveling, measuring distances, measuring vertical and horizontal angles, etc.); photogrammetric methods (ground surveys, aerial photography and digital photogrammetry); satellite methods (global positioning system GPS, automated geodetic monitoring system, such as Leica GeoMos, GOCA, Trimble4DConrol, etc.); geotechnical methods (inclinometers, tilt meters, micrometers, treschinomery, plumb lines, etc.).

This article describes the study of some of these methods for monitoring of engineering structures, which, according to the author, the most important, and are mostly used by experts building surveying in during construction and operation of buildings and structures. Specifically, the use of modern satellite technology GPS in combination with classical methods of precision leveling gives the most tangible results both in the operational definition of deformations and precision measurements. The studies were conducted in July–September 2013 at the stadium «Olympic» in Donetsk.

Experimental stu3dies of geometrical deviations

During the research we have laid the 3 points of the geodetic network of the stadium and several control points on the carrier racks and farms tribune of the stadium (Fig. 1, 2). The experiment was performed three series of measurements of the

Cartesian coordinates X, Y, Z and elevation changes of control points GPS-shooting methods and leveling. Later, performed an independent analysis of deformation structures in time and space, using data from GPS and leveling data separately. The studies used Leica GPS System 1200 and digital level Leica Sprinter 50.

Geodetic network was built to control the geometric design parameters, as well as for further monitoring facilities in operation. The observations were carried out in three cycles at intervals of 1 month. In a zero cycle were recorded the initial coordinates of points network and coordinates of control points on the supporting structures of the stands. Deformation analysis of building structures was assessed by the following two cycles of observation, which defines the stable and unstable point shooting.

Analysis deformation circuit structures estimated in three stages. In the first phase, measurements, which were carried out in the first and second cycles of observation, equalized separately in accordance with the method of free adjustment. At this stage identified and eliminated errors and systematic measurement errors. At the second stage, a comprehensive assessment of the experiment on which checks the stability of the set of points in the network time intervals:

$$\Delta t_n = T_n - T_{n-1}. \quad (1)$$

After the definition of stable points as a result of a comprehensive assessment, the third step of the analysis is to determine the deformation of control points in height. For this purpose, the height deviation values calculated for each of the grid points other than the points stable, and they are compared with the critical values which are given in the table of Fisher distribution. Traditional method of deformation analysis was applied in all three schemes: leveling control points; GPS survey of heights and a combination of both methods. The result obtained

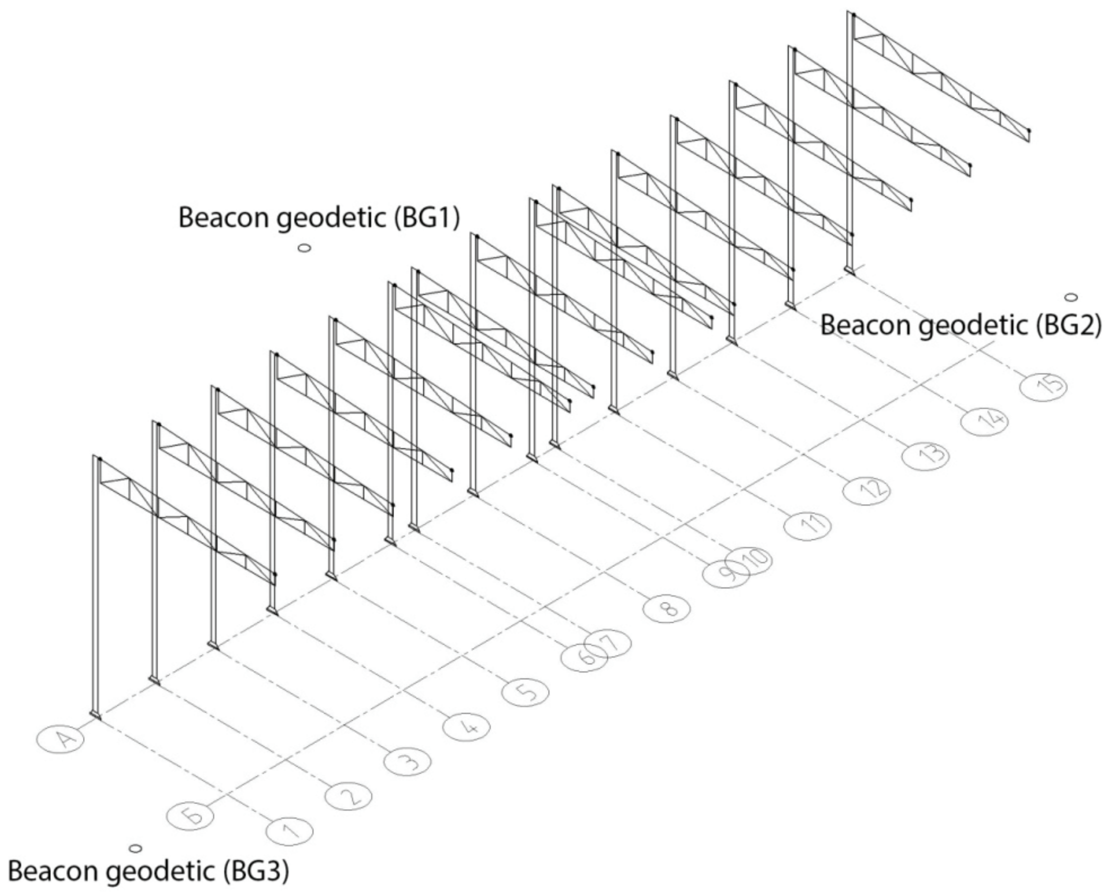

Figure 1. Schematic of a geodetic network for monitoring constructions of the stadium.

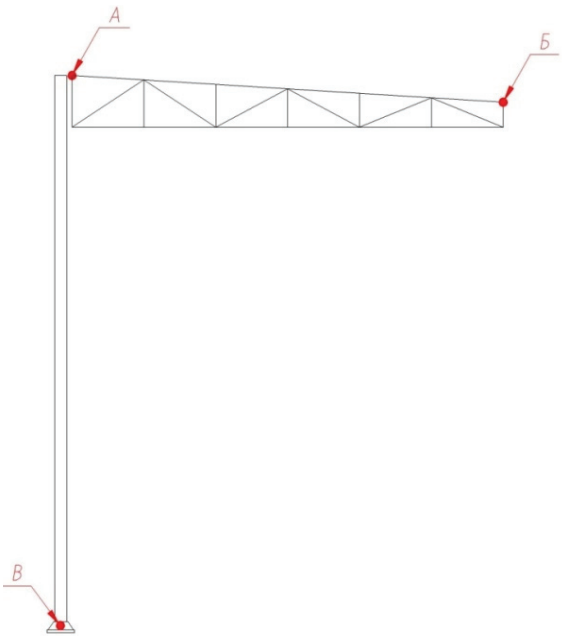

Figure 2. Schematic of the control points on structures of stadium tribunes.

from the evaluation of these three circuits are shown in the graphs (Fig. 3–5).

All of the above strain bearing skeleton frame-console cover over the stands of the stadium should be described as a geometric deviations from the initial design geometry of the structure [7, 8]. They are, of course, lead to an increase of additional load on the support elements due to inaccurate mounting structure. Among these deviations may be: deviation elements of metal structures of the design position in the installation, incorrect installation in the joint, died in transit and installation, foundation settlement... In the current regulations there are no requirements for accounting for these inaccuracies for unique designs, such as in most cases cover over the stands [6, 9]. To date, no systematic assessment was given to the value of this deviation arising during the actual installation, based on statistics obtained high-precision geodetic surveying methods geometry designs. Requirements for acceptance mounted constructions have been formulated for a long time and in full can not be applied to the unique structure with high reliability requirements.

The presence of initial geometric imperfections for many times statically indeterminate systems, which are the fixed metal frame-console cover over the stands, can reduce the load-bearing capacity, operational unfitness and accidents in many cases. In connection with this level of reliability and survivability rod structures decreases. Today has not been developed unique methods of calculating core metal structures subject geometry defects (inaccuracies of manufacturing...), which will ensure the reliability and survivability of structures during his term operation of the project [12–15]. There is a problem on the development of methods of calculation, which will be taken into account at least the basic defects arising in structural elements during their manufacture. The basis of this technique is advisable to apply «Finite Element Method» (FEM) is a numerical method is easily implemented in practice and is used in all modern settlement complexes.

The treatment of geometric imperfections in the framework of finite element analysis

Calculations rod designs with geometric imperfections necessitates solution of geometrically nonlinear problem in a probabilistic setting. The basic equation is:

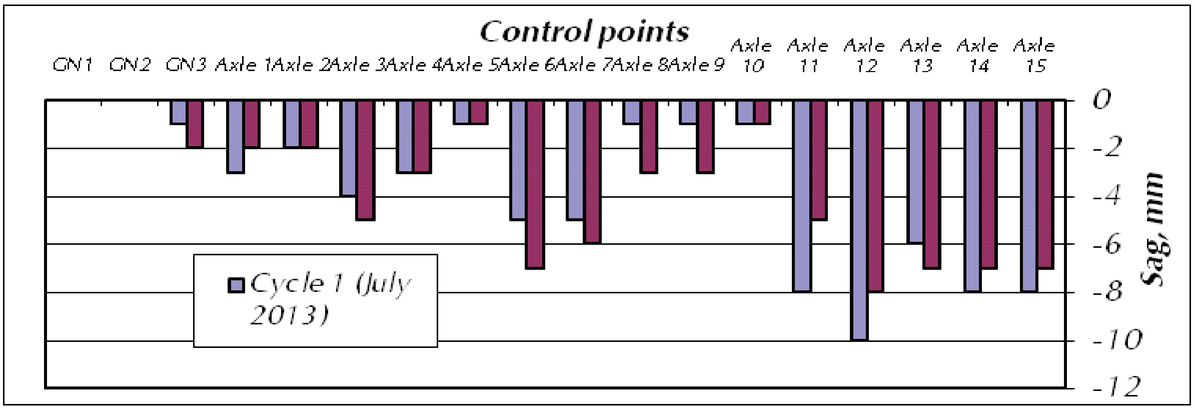

Figure 3. Schedule pellet designs the stands for the point «B».

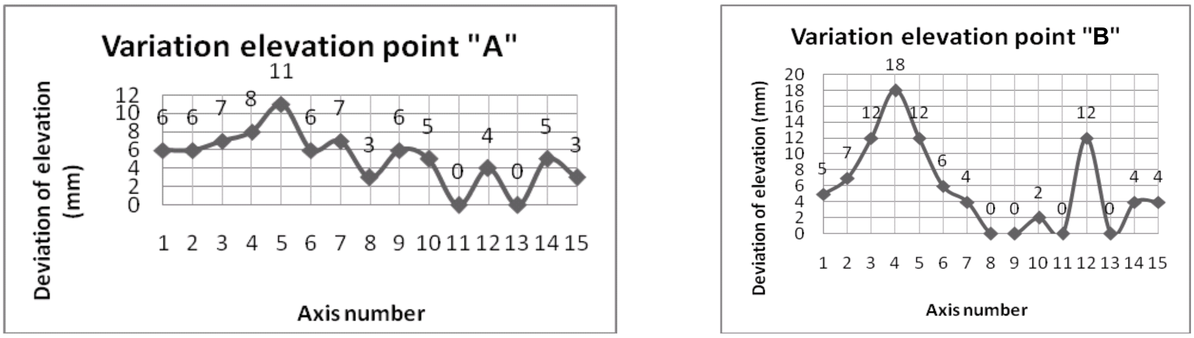

Figure 4. The scatter plot elevation point «A», «B».

$$([\bar{K}_0]+[\bar{K}_\sigma]+[\hat{K}_0^g])\times\{z\}=\{R\}, \qquad (2)$$

where $[\bar{K}_0]$ – stiffness matrix deformable finite element structure;

$[\hat{K}_0^g]$ – extra matrix defined on the basis of the variance matrix of the finite element stiffness $[\hat{K}_0^g]$, due to possible deviations from the desired geometry [7].

To account for the possible geometric imperfections expressed in random deviations from the project geometry, it is proposed along with the traditional: global (X, Y, Z) and local (x, y, z) – introduce the concept of the third «deformed» coordinate system ($\tilde{x}, \tilde{y}, \tilde{z}$), which takes into account possible deviations nodes of a finite element with respect to the local coordinate system (Fig. 6). As part of the proposed probabilistic method of calculation and design consideration deviations nodes of construction from design position carried out their generation in nodes finite element in accordance with the law of distribution. Most often possible to use the normal distribution.

The choice of the law of distribution should be based on the results of the processing of geodetic measurements geometry considered design. The advantage of the approach lies in the fact that the stiffness matrix of a finite element, counted in local coordinates already stores information about possible deviations from the element assemblies predetermined position, and further can be used in conventional finite element method operations:

$$[\bar{K}_0^g]_e=[C\tilde{L}]^T[\tilde{K}_0]_e[CL], \qquad (3)$$

where $[\bar{K}_0^g]_e$, $[\tilde{K}_0]_e$ – finite element stiffness matrix, expressed respectively in the deformed and the local coordinate system;

$[C\tilde{L}]$ – the matrix of direction cosines linking local and deformed coordinate system;

In this case, the probability supplement taking into account the probability of deviation and is the variance of the finite element stiffness matrix is given by:

$$[\hat{K}_0^g]_e \approx \left(\frac{\partial[\bar{K}_0^g]_e}{\partial\Delta\bar{z}_1}\right)^2\cdot\Delta\hat{z}_1+\left(\frac{\partial[\bar{K}_0^g]_e}{\partial\Delta\bar{z}_2}\right)^2\cdot\Delta\hat{z}_2+ +\left(\frac{\partial[\bar{K}_0^g]_e}{\partial\Delta\bar{z}_3}\right)^2\cdot\Delta\hat{z}_3. \qquad (4)$$

Thus, given the independence of the matrix $[\tilde{K}_0]_e$ on possible deviations element nodes $\Delta\tilde{z}_i$ with respect to the target position, the technical side of the problem is to find enough compact and convenient computing solution component $\left(\frac{\partial[C\tilde{L}]}{\partial\Delta\tilde{z}_i}\right)$.

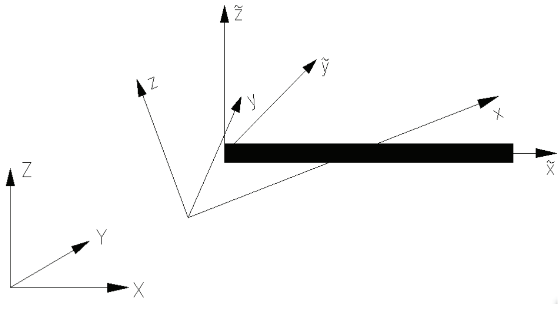

Figure 5. Coordinate systems.

Algorithm account the random nature of geometric imperfections in assessing the reliability of coating systems

On the basis of analysis of the sample geometry deviations of the points A, B obtained by surveying the geometry and construction subsidence stationary frame-console cover over the stands of the stadium «Olympic», the histogram distribution of deviations (Fig. 7). Introducing the geometry deviation points as a random variable, considered several distribution laws for the approximation (HI2, lognormal distribution and normal distribution). As approximating, adopted the normal distribution law. Additionally, the random variables were subjected to analysis by HI2-analysis by Pearson (used Microsoft Excel 2010). The analysis showed that the distribution of the random variations of magnitude point considered different from the normal by not more than 5 % (significance level was set to 0.05). Therefore, we can assume a normal distribution law acceptable.

The above use the finite element method in the stochastic and given geometric deviations as a random variable (which determines the reliability of the design) can calculate the reliability index structure (Fig. 8). In the first stage the initial input data relating to the MCE (coordinates of nodes, stiffness, ...) and data distribution of a random variable. Next generation of random variables is performed in accordance with a given law of distribution and elementwise form the basic and extra stiffness matrix.

Basic equation is solved FEM. Calculated stress in the structural elements, which are stored in a data file of realizations of the random variabl. To create the necessary data set forth the calculation process is repeated (generate new random variables, the cycle repeats itself, which ultimately suggests the use of the Monte Carlo method to solve this problem).

For samples generated stresses in structural elements $\{\tilde{\sigma}\}_i$ select appropriate laws of distribution. Based on the characteristics of the distribution of calculated upper (characterizes the reliability as a function of the probability of failure of the most loaded group elements) and lower (characterizes the reliability as a function of the probability of failure of the most responsible element the structure) reliability designed structure.

The considered algorithm can also be used as a separate unit of calculation in the calculation of reliability indices that depend on several random variables (strength characteristics of steel, geometric characteristics of sections).

Conclusions

1. The proposed some methods for monitoring of engineering structures, such as steel stationary frame-arm structures covering over the stadium with a capacity of up to five thousand people. The method was tested in the monitoring constructions SC «Olympic» (Donetsk).
2. For the considered spatial hinged-rod systems within the finite element analysis of VAT accounting methods proposed geometrical imperfections with – additional matrix due to possible deviations from the desired geometry defined on the basis of differentiation matrix of direction cosines. Experimental methods proved permissibility of the use of the normal distribution as a probability approximating geometric deviations of coordinates of nodes, as evidenced by means of HI2-test (distribution of each of the random variables differs from the normal no more than 5 %).
3. A method for the numerical determination of the upper and lower reliability indices stationary frame-console cover over the stands, taking into account the random nature of geometrical imperfections.

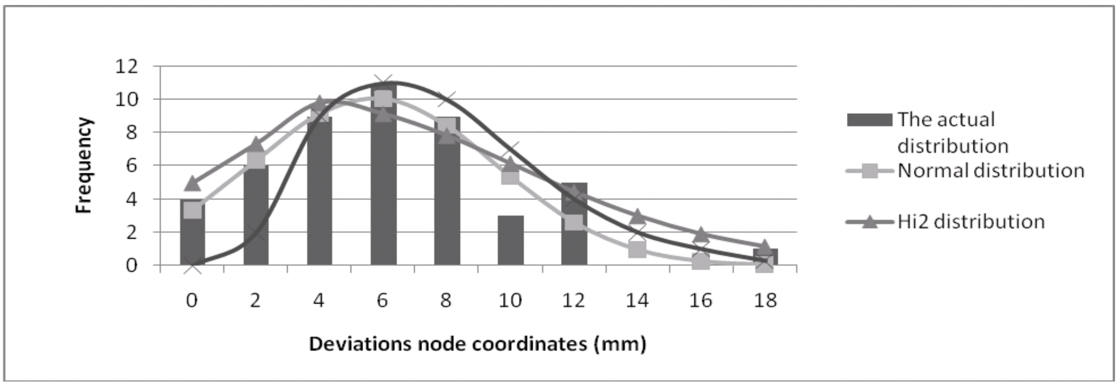

Figure 7. Histogram of distribution of deviations from the design coordinates of the nodes of the approximating curve.

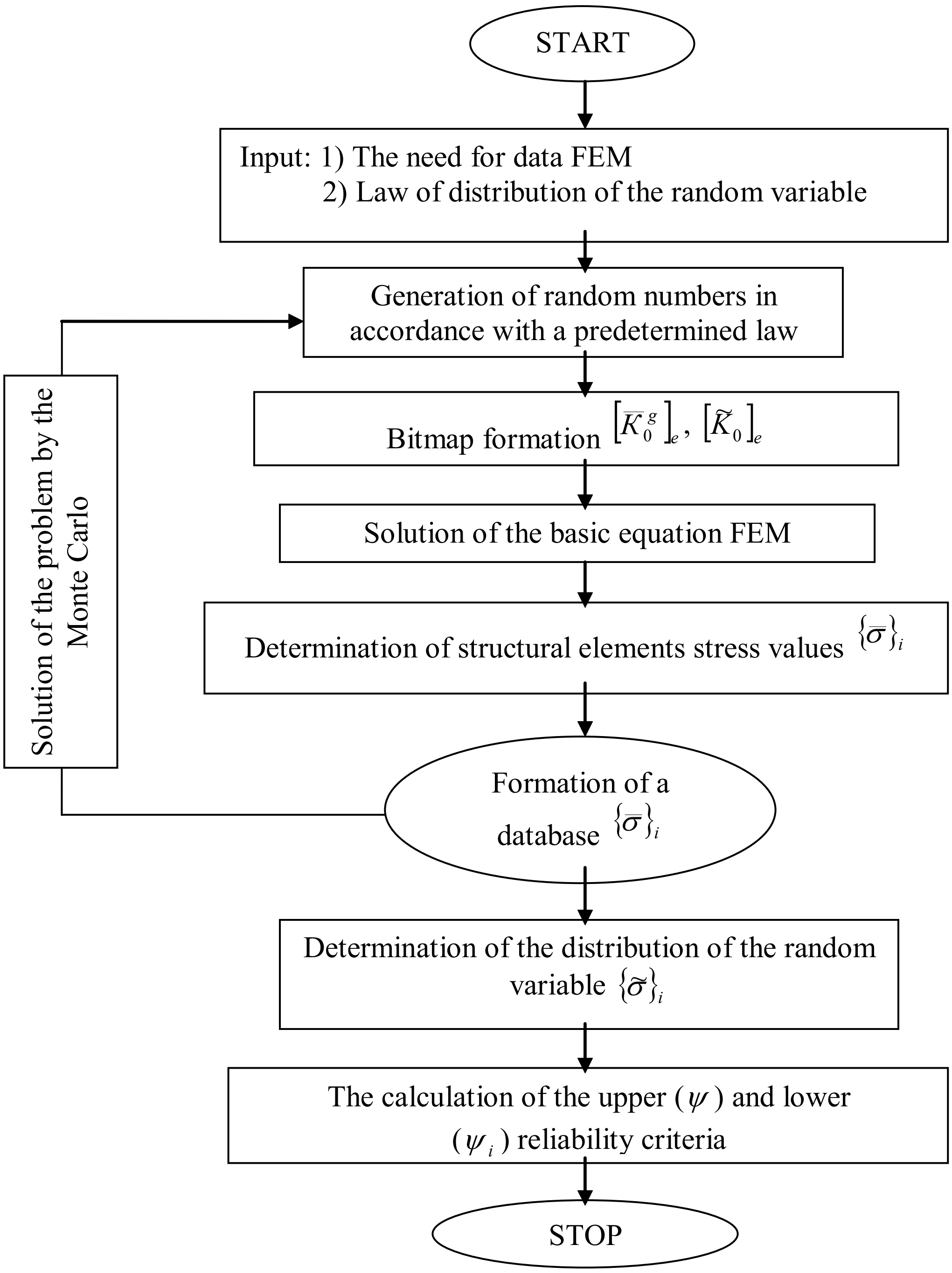

Figure 8. Block diagram defining the criteria of reliability stationary frame-console cover over the stands.

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