Probability-Based Research on Sensitivity of Saddle-Shaped Cables Suspended

Zhansheng Liu and Aiwu Luo

***Abstract*—Performance-based structural analysis is the main trend of the future development of engineering design; probability-based sensitivity can reflect the importance of different parameters in the structural performance-based design. Therefore based on the response surface method, the reliability analysis program has been established, within which the sensitivity analysis of different parameters, such as the prestress, cable sectional area, cable strength and elastic modulus of saddle-shaped cable suspended, was conducted. And the corresponding sensitivity coefficient has been given, which can not only be used as a reference to the design of structure, but also can check the rationality of the structure design.**

***Index Terms*—Saddle-shaped cables suspended, main parameters, sensitivity, response surface method**

I. Introduction

The saddle-shaped cable suspended(as shown in Fig. 1), which belongs to the whole tensioning flexible structure, can not only overcome the deficiency of current technology, but also can realize larger span and cantilever, and it is light. The probability-based design thought, based on performance, is the development trend of today's codes [1], [2], so in the analysis and design process, how to accurately judge the key parameters of the structure performance is especially important. The sensitivity coefficient can provide a reference for the structure design, as well as check the rationality of the structure design, finally giving out the amendment opinions before construction to save money.

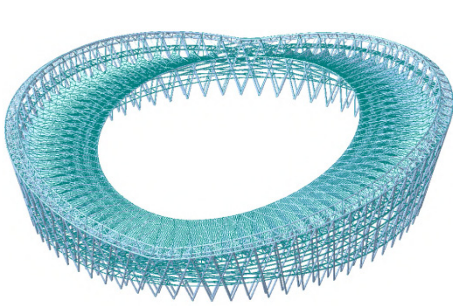

Fig. 1. Saddle-shaped cable suspended

II. Reliability-based Sensitivity Analysis Methods

A. Sensitivity

Sensitivity analysis is the method to evaluate the structural response rate caused by the change of the design variables or parameters. It plays an important role in the reliability evaluation of system performance and the research on structural redundancy [3]. Generally the analysis on all kinds of uncertainty factors can be carried through the sensitivity analysis method that is based on Spearman rank correlation coefficient [4].

B. Calculation Steps

The response surface technology is to use a hyper surface to approximately substitute the relationship between the input and output of the actual complicated structure [5], [6]. The specific steps of method in this paper:

1) Deterministic finite element analysis, create analysis file;

2) Define the random input variables and random output variables;

3) Invoke finite element program and solve the equations, getting the fitting expression of failure function and solving the undetermined coefficient;

4) Through the response surface test design, conduct the regression analysis to determine the composition item and coefficient of response surface equation;

5) Use the response surface equation to instead the finite element model, based on the Spearman rank correlation coefficient, then carry out the sensitivity analysis.

III. Engineering Examples

A. Calculation Model

The cover system of the stadium of PanJin belongs to the large-span saddle-shaped cable structure; its building plane has a shape of elliptic ring, with maximum size of about 267 meters in the long axis direction, and 234 meters in the short. The main cable system consists of one inner ring cable and several radial cables, including 144 lifting cables, 72 notochord cables and 72 rope valley cables. The overall ANSYS finite element calculation model is shown in Fig. 2.

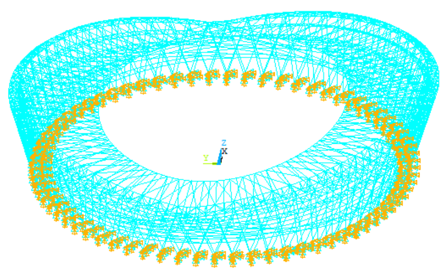

Fig. 2. Panjin stadium integral finite element calculation model

B. Statistical Parameter Selection

To ensure certain reliability of the structure design, the parameters, such as the load value, material strength value,

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component size and so on, are all standard value that meets a certain standard of reliability. In order to conduct the reliability analysis, it is necessary to know the real distribution of these parameters, or according to statistics experience, work out their relationship. The statistical parameters [7] of random variables used in this example, such as the material properties and section size and so on are shown in table I.

TABLE I: THE STATISTICAL PARAMETERS OF RANDOM VARIABLES

Number	*Random variables*	*Distribution pattern*	*Average value*	Coefficient of variability
E1	Radial cable elastic modulus	Normal distribution	1.56e11N/m^2	0.06
E11	Ring cable elastic modulus	Normal distribution	1.65e11N/m^2	0.06
Dens11	Cable density	Normal distribution	9000kg/m^3	0.05
FYN	Ultimate tensile strength of ring cable	Lognormal distribution	1670Mpa	0.07
FYD	Ultimate tensile strength of radial cable	Lognormal distribution	1670Mpa	0.08
uhuo	Live load	Extreme I type	0.45kN/m^2	0.288
ANS	Inner ring cable sectional area	Lognormal distribution	0.00830m^2	0.05
AJS1	Ridge cable sectional area	Lognormal distribution	0.00249m^2	0.05
AGS1	Valley cable sectional area	Lognormal distribution	0.00332m^2	0.05
ADS1	Lifting cable sectional area	Lognormal distribution	0.00634m^2	0.05
Pre	Inner ring cable prestress	Normal distribution	277.27Mpa	0.288
Prej	Ridge cable prestress	Normal distribution	277.27Mpa	0.288
Preg	Valley cable prestress	Normal distribution	277.27Mpa	0.288
Pred	Lifting cable prestress	Normal distribution	277.27Mpa	0.288

IV. SENSITIVITY ANALYSIS RESEARCH

According to the above method and the sensitivity analysis methods that based on Sperman rank correlation coefficient, use the secondary development platform provided by ANSYS, formulate corresponding APDL calculation procedure, and conduct relative calculation. Carry out the response surface fitting and the sensitivity analysis of related parameters of the string support network shell, choosing the load condition as 1.2DL + 1.4LL + PRL.

A. *Response Surface Fitting*

According to the response surface method, the sample value of maximum displacement (DMAX) and inner ring line intensity (NSQ) of the string support network shell was shown in Fig. 3 and Fig. 4, the column graph of output parameters DMAX and NSQ was shown in Fig. 5 and Fig. 6, the response surface of the maximum displacement (DMAX) and inner ring cable stress (SAXL) was shown in Fig. 7 and Fig. 8.

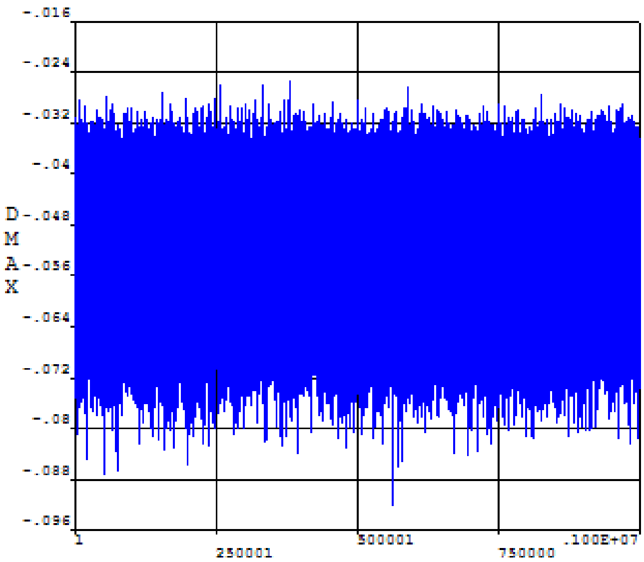

Fig. 3. Sampled Values for DMAX

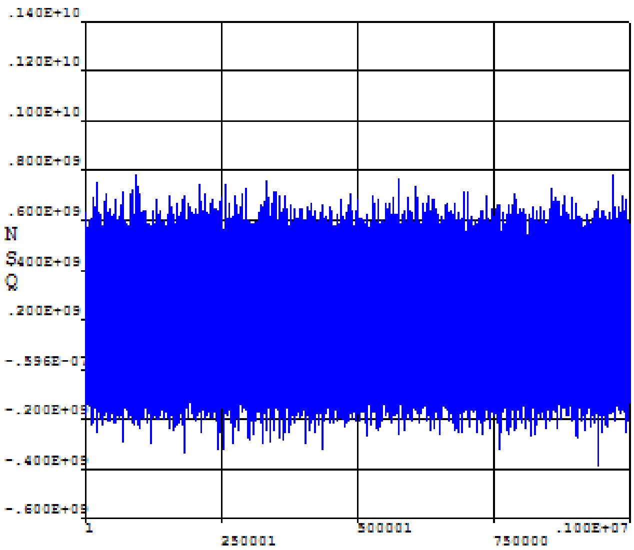

Fig. 4. Sampled Values for NSQ

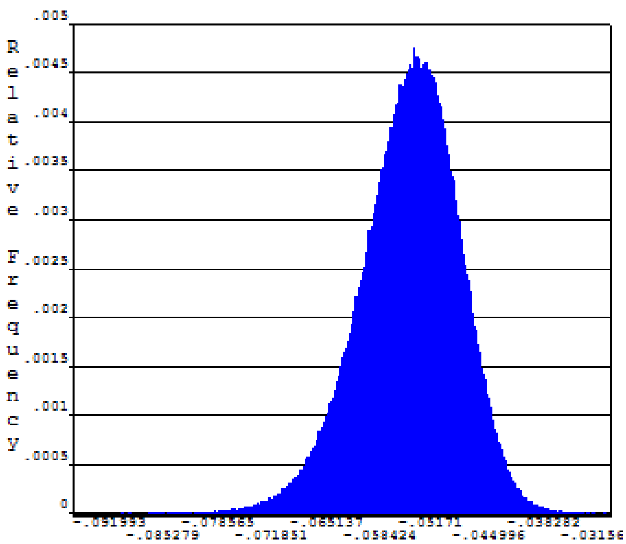

Fig. 5. Histogram of DMAX

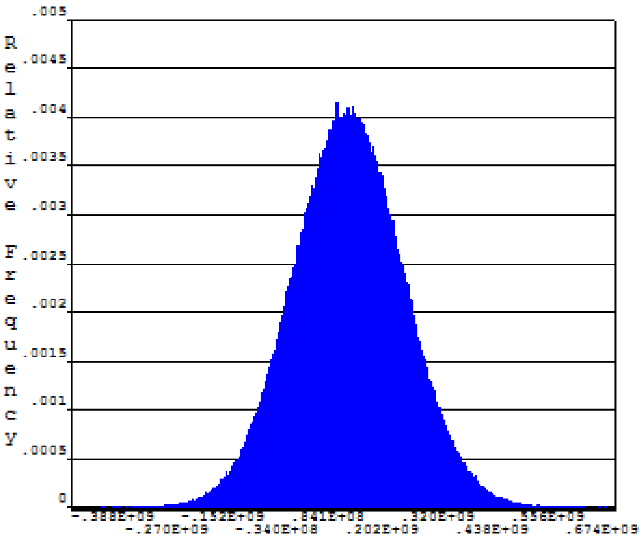

Fig. 6. Histogram of NSQ

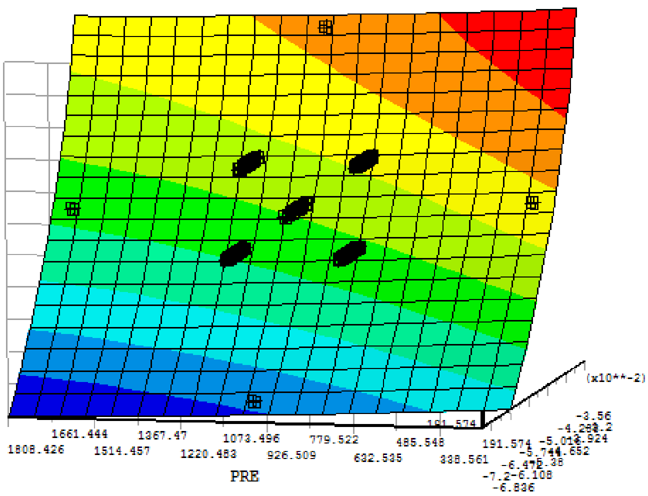

Fig. 7. Response surface of DMAX

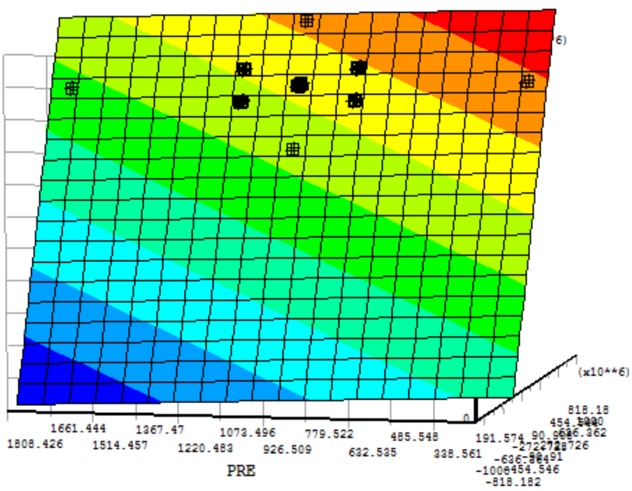

Fig. 8. Response surface of SAXL

As is shown in the sample history in Fig. 3 and Fig. 4, the mean and standard deviation of DMAX and NSQ is gradually convergent and the convergence curve tends to be level, with confidence boundary range meeting sampling requirements. As is shown in figure 5 and figure 6, the histogram curve of DMAX and NSQ is close to the probability function curve, smooth and with no big gap and visible cycle times enough to meet the requirements of the response surface analysis method. As is shown in Fig. 7 and Fig. 8, fitting equation is reasonable, meeting the requirements of the probability analysis.

B. Sensitivity Coefficient

The sensitivity size of the basic random variables to structural maximum displacement DMAX is shown in Fig. 9, the sensitivity size of the basic random variables to lifting cable stress DSQ is shown in Fig. 10.

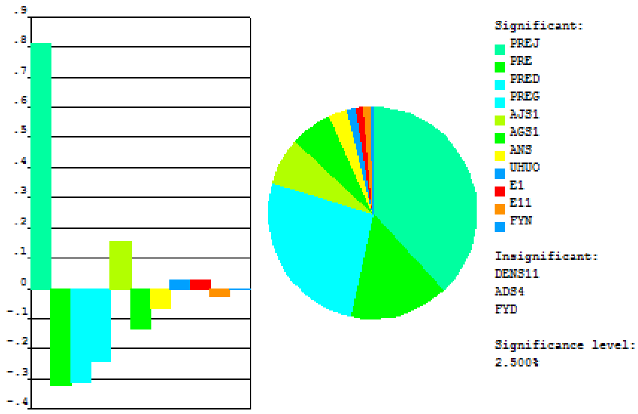

Fig. 9. Sensitivity Plot for DMAX

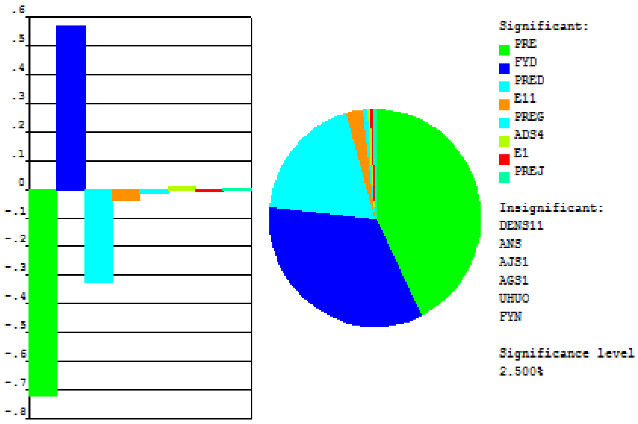

Fig. 10. Sensitivity Plot for DSQ

It is can be seen in Fig. 9 that the sensitivity of the largest displacement by different parameters differs greatly, of which the sensitivity of ridge prestress (PREJ) is the largest, the second is the inner ring cable prestress (PRE), lifting cable prestress (PRED), valley cable prestress (PREG) and the sectional area of ridge cable (AJS1), valley cable (AGS1) and inner ring cable (ANS), while the sensitivity of other parameters is smaller. It is can be seen in figure 10 that the sensitivity of the lifting cable stress by inner ring cable prestress (PRE) is the largest, the second is the ultimate tensile strength of the lifting cable (FYD), lifting cable prestress (PRED), elastic modulus of the inner ring cable (E11), valley cable prestress (PREG) and the sectional area of lifting cable (ADS1), while the sensitivity of other parameters is smaller.

V. Conclusions

In this paper, the structure sensitivity analysis was conducted taking into account the characteristics of saddle-shaped cables suspended and the sensitivity coefficient of the main parameters was obtained. According to the results of analysis, the conclusions follow:

1) The response surface analysis method probability-based can properly analyze the sensitivity of the design parameters of cable-suspended structure and provide reference for the similar structure analysis.

2) The sensitivity of different design parameters can reflect its importance to the mechanics performance of saddle-shaped cables suspended, so that it can be controlled in the design and construction to meet the requirements of codes, and make the structure reasonable and reliable.

3) The probability-based design thought of "on a performance basis" is the trend of the development of today's standard, how to promote the reliability theory in the application of prestressed structure design is also very important, so as to provide more sufficient scientific basis for the popularization of new prestressed structure.

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