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Keywords

probabilistic design, application of ANSYS, reliability analysis, prefabricated steel bridge

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Application of ANSYS to Reliability Analysis of Prefabricated Steel Bridge

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Keywords: probabilistic design; application of ANSYS; reliability analysis; prefabricated steel bridge

基于 ANSYS 的装配式公路钢桥可靠性分析

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摘要：装配式公路钢桥是一种临时性或半永久性的桥梁结构，当车辆通过时会产生较大的内力和变形，对可靠性提出了较高要求。概率设计是评估随机设计变量对有限元分析结果影响的一项技术，*结合大型通用有限元分析软件 ANSYS 提供的概率设计功能，对装配式公路钢桥主桁架的挠度、弯曲应力和压杆失稳进行了可靠性分析，得到了相应的可靠指标和体系可靠指标。*通过分析计算，说明了 ANSYS 概率设计系统在装配式公路钢桥结构可靠性分析中的精确性和可靠性。

关键词：概率设计；ANSYS 应用；可靠性分析；装配式桥梁

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Introduction

Some parameters such as material properties, the geometric properties of the component and the exterior loads are uncertain or discrete in structures analysis, although they are given specific numbers and values during a deterministic analysis processes. An uncertainty (or random quantity) is a parameter whose value is impossible to determine at a given point in time (if it is time-dependent) or at a given location (if it is location-dependent). An example is ambient temperature; you cannot know precisely what the temperature will be one week from now in a

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given city. It is neither physically possible nor financially feasible to eliminate the uncertainty or the scatter of input parameters completely. The reduction of scatter is typically associated with higher costs either through better and more precise manufacturing methods and processes or increased efforts in quality control; hence, accepting the existence of scatter and dealing with it rather than trying to eliminate it makes products more affordable and production of those products more cost-effective. To satisfy requirements both security and economical efficiency, a probabilistic design analysis of the structure must be performed.

Probabilistic analysis design is an analysis technique for assessing the effect of uncertain input parameters and assumptions on a calculation model. Making use of the probabilistic analysis design the influence of uncertainty factors on the analysis result of a finite element model can be figured out. The ANSYS program- large universal finite element analysis software offers the probabilistic design function that is advanced effective. Using the ANSYS probabilistic design system the following questions can be answered:

1. If the input variables of a finite element model are subjected to scatter, how large is the scatter of the output parameters? How robust are the output parameters?

2. If the output is subjected to scatter due to the variation of the input variables, then what is the probability that a design criterion given for the output parameters is no longer met? How large is the probability that an unexpected and unwanted event takes place (what is the failure probability)?

3. Which input variables contribute the most to the scatter of an output parameter and to the failure probability? What are the sensitivities of the output parameter with respect to the input variables?

Probabilistic design can be used to determine the effect of one or more variables on the outcome of the analysis. In addition to the probabilistic design techniques available, the ANSYS program offers a set of strategic tools that can be used to enhance the efficiency of the probabilistic design process. For example, you can graph the effects of one input variable versus an output parameter, and you can easily add more samples and additional analysis loops to refine your analysis.

The ANSYS offer two basic probabilistic design methods: the Monte Carlo Simulation method and the Response Surface Method

The Monte Carlo Simulation method is the most common and traditional method for a probabilistic analysis. This method lets you simulate how virtual components behave the way they are built. One simulation loop represents one manufactured component that is subjected to a particular set of loads and boundary conditions. The method is always applicable regardless of the physical effect modeled in a finite element analysis, but the technique has one drawback: it is not very efficient in terms of required number of simulation loops.

The Response Surface Method is based on the fundamental assumption that the influence of the random input variables on the random output parameters can be approximated by mathematical function. Hence, the Response Surface Method locates the sample points in the space of random input variables such that an appropriate approximation function can be found most efficiently; typically, this is a quadratic polynomial. The fundamental idea of the Response Surface Method is that once the coefficients of a suitable approximation function are found, then we can directly use the approximation function instead of looping through the finite element model, and we can afford to evaluate the approximated response parameter thousands of times. Assuming the approximation function is suitable for your problem, the Response Surface Method requires fewer simulation loops than the Monte Carlo Simulation method, and can evaluate very low probability levels. The goodness-of-fit parameters tell you how good the approximation function is (in other words, how accurate the approximation function is that describes your "true" response parameter values). Because the number of required simulation loops depends on the number of random input variables, if you have a very large number of random input variables (hundreds or even thousands), then a probabilistic analysis using the Response Surface Methods would be impractical. This method is not usually suitable for cases where a random output parameter is a non-smooth function of the random input variables.

1 Basic concepts

In probabilistic analysis design, all parameters are classified as random input variables and random output parameters. The random input variables are independent variables in a design, and they influence the result of an analysis. The type of statistical distribution the random input variables follow and the parameter values of their distribution functions must be specified. In a probabilistic analysis, statistical distribution functions (such as the Gaussian or normal distribution, the uniform distribution, etc.) describe these uncertain random parameters. If two (or more) random input variables are statistically dependent upon each other, the correlation between the two (or more) random input variables must be given. The random output parameters are dependent variables in a design. They are typically a function of the random input variables, and they are also the results of a finite element analysis. The random input variables and random output parameters are collectively known as probabilistic design variables. In the ANSYS Probabilistic Design System, we must identify which parameters in the model are random input variables and which are random output parameters. We can define up to a total of 5,000 probabilistic design variables (random input variables and random output parameters).

Sample is a unique set of parameter values that represents a particular model configuration. A sample is characterized by random input variable values. Simulation is the collection of all samples that are required or that we request for a given probabilistic analysis. The simulation contains the information used to determine how the component would behave under real-life conditions (with all the existing uncertainties and scatter); therefore, all samples represent the simulation of the behavior

Analysis file is an ANSYS input file containing a complete analysis sequence (preprocessing, solution, and post-processing). The file must contain a parametrically defined model using parameters to represent all inputs and outputs to be used as random input variables and random output parameters. The probabilistic design loop file (Jobname.LOOP) is created automatically by ANSYS via the analysis file. The ANSYS Probabilistic Design System uses the loop file to perform analysis loops.

Probabilistic design model is the combination of definitions and specifications for the deterministic model (in the form of the analysis file). The model has these components: random input variables, correlations, random output parameters, the selected settings for probabilistic method and its parameters.

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If any part of the probabilistic model is changed, then we will generate different results for the probabilistic analysis (that is, different results values and/or a different number of results).

Probabilistic design database contains the current probabilistic design environment, which includes: random input variables, correlations between random input variables, random output parameters, settings for probabilistic methods, which probabilistic analyses have been performed and in which files the results are stored, which output parameters of which probabilistic analyses have been used for a response surface fit, the regression model that has been used for the fitting procedure, and the results of that fitting procedure. The database can be saved (to Jobname.PDS) or resumed at any time. The results of a probabilistic analysis are not stored in the database but in separate files. Figure 1 shows the flow of information during a probabilistic design analysis.

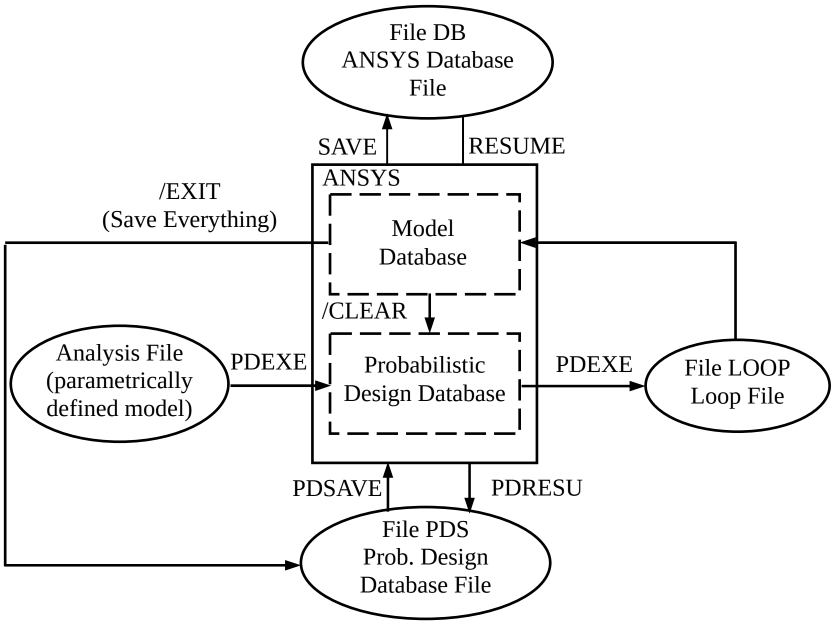


Fig.1 Probabilistic design data flow

The steps to perform the ANSYS probabilistic design can follow along with Figure 1, and the details will not be discussed in this paper.

With simple structure, rapid operation and good economy, combined structure system, strong interchangeability, easy assembly, wide application and strong adaptability, prefabricated steel bridge that is a temporary or semi-permanent bridge structure plays a prominent role in emergency traffic guarantee such as military transport, emergency rescue and disaster relief, etc. As continuous development of modernization construction of our country, all kinds of transport vehicles and military technology weapons develop along fast and heavy direction. Therefore, when the vehicles or troops maneuver and pass through the bridge, large internal force and deformation of the bridge structure will occur, and higher requirements of the bridge structure reliability are put forward.

Making use of the ANSYS Probabilistic Design System, the reliability analysis of deflection, bend stress and compression member stability of a 15m-span single-layer single-row prefabricated steel bridge is carried out, and the corresponding reliability indexes and the bridge system reliability index are given.

2 Construction of calculation model

A 15m-span single-layer single-row prefabricated steel bridge is a through truss bridge, and the clear-width of its deck is 3.7m. The bridge has a single roadway, and the spacing between two main trusses is 4.2m in landscape orientation of the bridge. A main truss is composed of 5 sections of truss assembling unit (Figure 2), and each section is 3m long and 1.4 high. The between two sections of assembling unit are connected by pins. The top chord and bottom chord of the assembling unit is made up of two channel steels of size 10, and web members are made up of double T steel of size 8. The two end posts at both bridgeheads are made up of two channel steels of size 12. All components are made of 16Mn steel. During finite element analysis, when the calculation model of the bridge structure system is constructed, in fact only one main truss is calculated because of symmetry of the bridge structure system. Because the bridge deck system is connected with main trusses by crossbeam, its gravity can be analyzed and simplified, and be treated as uniform load acting on the bottom chord. The gravity of the main truss can also be treated as uniform load acting on the bottom chord, and vehicle loads can be considered as concentrated loads. Considering actual restriction ability of every node, which isn't perfect hinged connection, and for the calculation model being more closed to the actual structure and the calculation results being more reasonable, the top chord and the bottom chord of the main truss and the two end posts at both bridgeheads are dealt with 2-D beam element Beam 3, and all web members are dealt with 2-D spar element Link 1. So the main truss structure is transformed into a composite structure. Based on these analysis and disposition, the main truss structure in finite element calculation model is divided into 77 nodes and 132 elements (the number of beam elements of the top chord and the bottom chord is 60, the number of beam elements of the two end posts at both bridgeheads is 2, the number of spar elements of the web elements is 70).

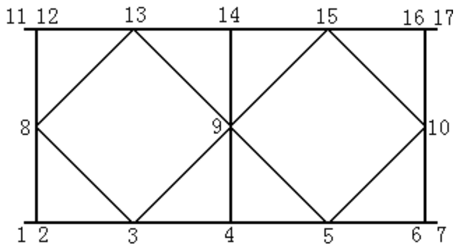
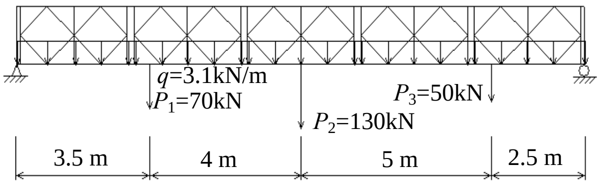


Fig. 2 Truss assembling unit

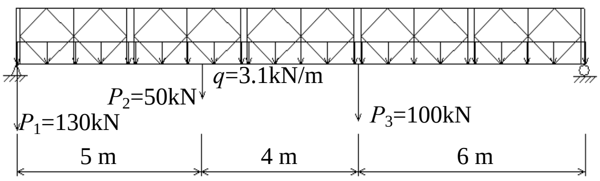
Because the bridge is a simply supported steel bridge, the nodes at which the bottom chord intersects the end posts at both bridgeheads are treated as simple supported bearers in the calculation model.

The finite element calculation model, which is constructed according to above measures, comparatively accords with the actual structure in both the restriction ability of the nodes and the stress of the structure, so it is reasonable.

To figure out the maximal vertical displacement, maximal bending stress of the chord and maximal axial force of the web member of the 15m-span single-layer single-row prefabricated steel bridge, based on the worst loads position the vehicles are laid as Figure 3 (Figure (a) is for solving the maximal vertical displacement and the maximal bending stress of the chord, and Figure (b) is for solving the maximal axial force of the web member). The vehicle loads are arranged according to vehicle-15 standard load, and impact coefficient and loads landscape orientation distribution coefficient are not taken into account; but influence of the impact coefficient and the loads landscape orientation distribution coefficient must be considered during practical computational process (the impact coefficient is 1.2857 and the loads landscape orientation distribution coefficient is 0.607).



(a) Loads position for solving the maximal vertical displacement and the maximal bending stress of the chord



(b) Loads position for solving the maximal axial force of the web member

Fig. 3 Calculation diagram of the 15m-span single-layer single-row prefabricated steel bridge

Because the crossbeams transfer vehicle loads to the main truss, the loads shown in Figure 3 are transformed into corresponding nodal loads during practical computational process.

3 Analysis of reliability result

After the right reasonable calculation model has been constructed, structural analysis of the main truss is performed by means of the ANSYS Structural Analysis System. The calculation results show that vertical displacement of the node at the mid span is maximal, bending stress of the node at the bottom chord mid span is maximal and axial force of the slanting web member at left bearer is maximal, and these results accord with ones in practical test. Because compression member is prone to instability and a generic rod is worse under compressive stress, reliability analysis of the axial compression member stability is carried out.

During reliability analysis of the main truss structure, 12 random basic variables such as sectional area A_1, section moment of inertia I and section height h of the chords, sectional area A_2 of the end posts at both bridgeheads, sectional area A_3 of the web members, material elastic modulus E, uniform load q, total weight G_1 of the heavy vehicle, total weight G_2 of the main vehicle, material yield strength f_y, allowable deflection $[\upsilon]$, stability tolerance $\varphi[f_y]$ of the compression member are taken into account, and their mean μ and their coefficient of variation δ are given in Table 1. Suppose that every variable obeys normal distribution except the total weight G_1 and G_2 of the vehicles that obey I-type extreme value distribution.

Table 1 Statistical parameters of variables of prefabricated steel bridge

	A_1/mm^2	A_2/mm^2	A_3/mm^2	I/10^{4}mm^4	h/mm	E/10^{5}MPa	q/N·mm^{-1}	G_1/10^{5}N	G_2/10^{5}N	f_y/MPa	$[\upsilon]$/mm	$\varphi[f_y]$/MPa
μ	2 180	2 660	958	348	100	2.06	3.689	1.574	1.180 5	399	50	216
δ	0.05	0.05	0.05	0.05	0.05	0.03	0.031	0.194	0.194	0.065	0.05	0.164

Making use of the ANSYS Probabilistic Design System, the probability distribution of deflection, bending stress and compression member stability of the main truss the prefabricated steel bridge are gotten, and the corresponding reliability indexes β are obtained. Then the system reliability index β of the 15m-span single-layer single-row prefabricated steel bridge is gotten by means of the close limit theory for reliability analysis. The reliability indexes are given in Table 2.

Table 2 Reliability analysis results of prefabricated steel bridge

	Deflection	Bending stress	Compression member stability	Bridge system
μ	30.73	232.8	123.3	
δ	4.413	36.12	18.48	
β	3.799	3.7376	2.320	2.314

In literature [6], the system reliability index of the prefabricated steel bridge is 2.353, which is obtained by the Response Surface Method, and the error between them is only 1.7%. This shows that the ANSYS Probabilistic Design System is exact and reliable in structure reliability analysis of the prefabricated steel bridge. The ideal targeted reliability index β_0 should be 2.5 in the structure design of the prefabricated steel bridge based on the correlative research findings, while the reliability index of the compression member stability and one of the bridge system are less the targeted value, so we make suggestions that some relevant improvements should be adopted to enhance the bridge reliability.

4 Conclusions

The structure reliability analysis of the prefabricated steel bridge is discussed by means of the ANSYS Probabilistic Design System. The results are reasonable and credible, and they show the precision and accuracy of the ANSYS Probabilistic Design System. During the finite element model of the main truss structure of prefabricated steel bridge is constructed, to deal with every components and every nodes must reasonably take measures to analyze and optimize them according to actual characteristic under stress. This is very important, and this can make that the calculation model is more close to actual structure and the results are more reasonable and more credible.

The ANSYS probabilistic design is an advanced analysis technique. For raising of efficiency of probabilistic design some suggestions are made:

1. Reduce the number of the probabilistic design variables. No matter which method (the Monte Carlo Simulation method and the Response Surface Method), the more is the number of the probabilistic design variables, the more is the number of the degrees of freedom, the more is the calculation workload. So the principle of selecting the probabilistic design variables is fewer and better. In other words, those parameters that have greater influence on the random output parameters should be selected the random input variables, while the other parameters can be treated as constants; the other technique to reduce the number of the probabilistic design variables is to combine some among variables.

2. Select the probabilistic design method reasonably. According to the practical situations of the structure analysis and the characteristics of the two basic probabilistic design methods (the Monte Carlo Simulation method and the Response Surface Method), one reasonable method should be adopted to raise of efficiency of probabilistic design.

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