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Reliability analysis of curved on plane hoist beam using coupling of Ansys APDL and Matlab

Mariusz Poński[1]

ABSTRACT:
The paper presents a reliability analysis approach of curved on plane hoist beam using the coupling of two programs: Ansys and Matlab. The analysis takes into account warping and geometrically nonlinear approach to determine the deformation of the structure. Two approaches of building a reliability function are presented: the first is based on probabilistic–deterministic design conditions and the second is based on a full probabilistic approach. The analysis showed high effectiveness of the approach used in the reliability analysis.

KEYWORDS:
reliability; hoist beam; finite element method

1. Introduction

In many industrial construction buildings there is a need to use various types of lifting and moving cranes. These devices provide close transport to facilities such as storage stations, industrial halls (Fig. 1) or free–standing technological equipment (e.g. servicing the maintenance work of the bucket feeder head). Besides of bridge cranes and overhead cranes the basic type is a monorail hoist (Fig. 2). This device is equipped with a drum and a system of ropes or chains and the hook sling which is driven manually or electrically. It moves along the bottom flange of a straight or curved on plan beam (Fig. 3). The most commonly used suspended monorail hoists have a lifting capacity of 5 to 50 kN. Due to the possibility of lateral forces [1, 2], the hoist beam should be analyzed taking into account restrained warping (bimoment). In the case of checking the ultimate limit condition for curved beams, this effect is of particular or even decisive importance.

This paper presents a method of reliability analysis of this type of objects using the coupling of two programs: Ansys and Matlab. The first of these gives a great opportunity to analyze a variety of structures including different kind of civil engineering constructions using the finite element method. The second one allows to create own programs and algorithms based on a broad base of numerical methods. The combination of these two tools gives a wide range of analysis possibilities, including probabilistic and stochastic analysis. The coupling consists in using the Ansys program as a subroutine in the Matlab program. The starting point is to build and generate a batch file (input.txt) in the Matlab program. This file, written in the APDL programming language, contains all the necessary information to create, calculate and generate output files with results (this language is based on the FORTRAN language syntax). Then, the APDL Ansys program running in batch mode is called with the appropriate command using a batch file. The result of this operation is that the Ansys APDL program generates an output file

[1] Czestochowa University of Technology, Faculty of Civil Engineering, ul. Akademicka 3, 42–218 Częstochowa, e–mail: mponski@bud.pcz.pl, orcid id: 0000-0002-5173-0930

with the desired results (txt). The next step is to read Matlab's results and their possible analysis and processing. The above steps can be repeated the required number of times by using a loop [3, 4].

2. Reliability analysis – brief description

The reliability analysis is an integral part of the design process of building constructions, and its basic task is to determine the probability of failure (destruction). This probability can be written using the following integral [5, 6]:

$$P_f = \int_{g(\mathrm{x})\le 0} f_{\mathrm{X}}(\mathrm{x})d\mathrm{x} \tag{1}$$

where $g(\mathrm{x})$ is a random reliability function ($g(\mathrm{x})\le 0$ – failure space Ω_f, $g(\mathrm{x})=0$ – failure surface, $g(\mathrm{x})>0$ – safety space Ω_s), and $f_{\mathrm{X}}(\mathrm{x}) = f_{X_1,\ldots,X_n}(x_1,\ldots,x_n)$ is a joint probability density of basic random parameters $\mathrm{X}=\{X_1,\ldots,X_n\}$. The integral (1) is most commonly calculated numerically.

Wide description of the reliability analysis problems, the graphical interpretation of the failure function and the integral (1) can be found in [5, 6].

Fig. 1. An example of realization of a curve on plane hoist beam in a industrial plant (photo: author)

3. Numerical analysis of the curved on plane hoist beam

The reliability analysis of the curved on plane hoist beam was carried out using coupling of Ansys APDL and Matlab. For the analysis two–node beam finite elements (Timoshenko beam theory, I200–section, BEAM188) with six degrees of freedom in each node and seventh, an additional one taking into account the restrained warping (bimoment included) were used. The analysis was carried out taking into account geometric nonlinearity (2nd order theory). The material used was linearly elastic steel ($E = 200.0$ MPa, $\nu = 0.3$). Two variants of the analysis were taken into account. n the first one, the dimensions of the cross–section were assumed as random parameters ($X_1 \div X_5$), including: upper and lower flange width (mean value $\mu = 100.0$ mm, standard deviation $\sigma = 3.0$ mm), upper and lower flange thickness (mean value $\mu = 8.5$ mm, standard deviation $\sigma = 0.5$ mm) and web thickness (mean value $\mu = 5.6$ mm, standard deviation

$\sigma = 0.5\ \text{mm}$). The probability density distribution of random parameters was assumed to be log–normal:

$$f_X(x) = \frac{1}{x\sigma_{\log}\sqrt{2\pi}} \exp\left(-\frac{\left(\ln(x) - \mu_{\log}\right)^2}{2\sigma_{\log}^{\ 2}} \right) \tag{2}$$

where parameters in function (2) take the form:

$$\mu_{\log} = \ln(\mu) - \frac{\sigma_{\log}^{\ 2}}{2} \tag{3}$$

$$\sigma_{\log} = \sqrt{\ln\left(\frac{\mu^2 + \sigma^2}{\mu^2} \right)} \tag{4}$$

As a failure function, the relation was assumed:

$$g(\mathrm{X}) = 1 - \frac{|w(\mathrm{X})|}{w_{\max}} \tag{5}$$

where $w_{\max} = 45.0\ \text{mm}$ is a maximum vertical deflection, and $w(\mathrm{X})$ is the computational displacement of the end of the cantilever beam (Fig. 4). End of cantilever beam was loaded with concentrated force ($F_z = -1.5\ \text{kN}$, $F_y = 0.15\ \text{kN}$, $F_x = 0.15\ \text{kN}$). The support points are shown in Figure 4. The length of the straight beam was assumed equal to $2.0\ \text{m}$, and the radius of the curved part equal to $1.0\ \text{m}$.

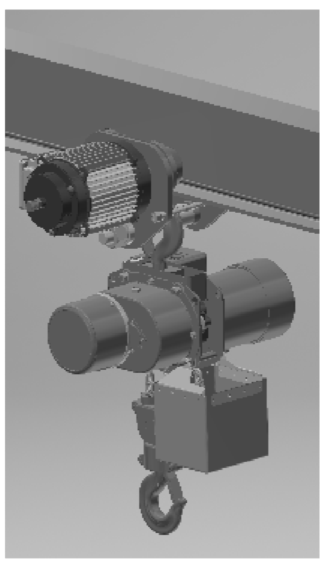

Fig. 2. Electric chain hoist, suspended to the bottom flange

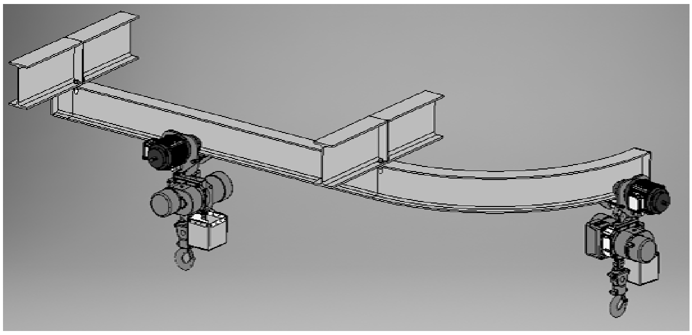

Fig. 3. An example solution of a curved on plane hoist beam suspended to the supporting structure

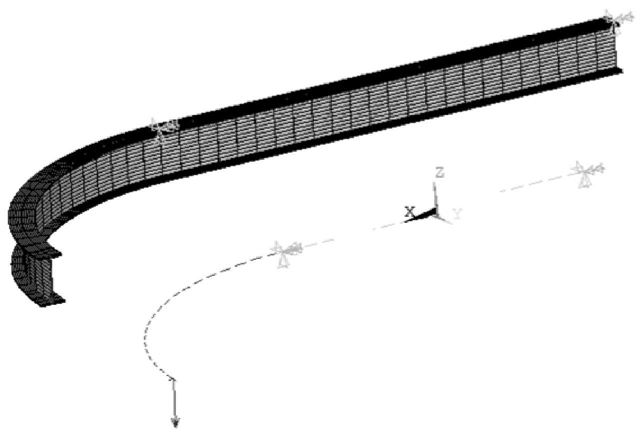

Fig. 4. The computational model of the analyzed system

In the second variant of analysis following relation was assumed as a failure function:

$$g(\mathrm{X}) = 1 - \frac{s_{num}(\mathrm{X})}{s_{\max}} \tag{6}$$

introducing a new, additional random parameter in the form of steel strength $s_{\max} = X_6$ (mean value $\mu = 145.0\,\mathrm{MPa}$, standard deviation $\sigma = 20.0\,\mathrm{MPa}$). To determine the probability of destruction, numerical integration using the importance sampling method was used [5] (2000 samples). In the first variant, the probability of failure was $P_f = 25.26\%$, and in the second $P_f = 23.60\%$. A graphical representation of the integral (1) for the analyzed variants is shown in Figures 5 and 7. The marginal probability density functions of computational stress and maximum stress is shown in Figure 6.

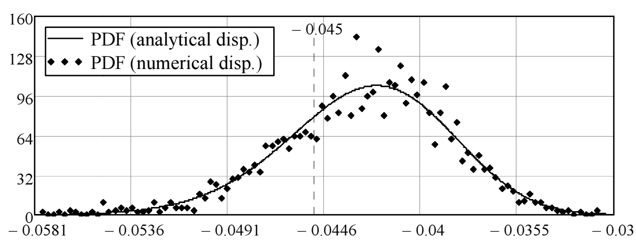

Fig. 5. Graphical representation of the integral (1) for the variant I of the analysis (vertical axis – probability density [–], horizontal axis – vertical displacement of the end of the cantilever beam [m])

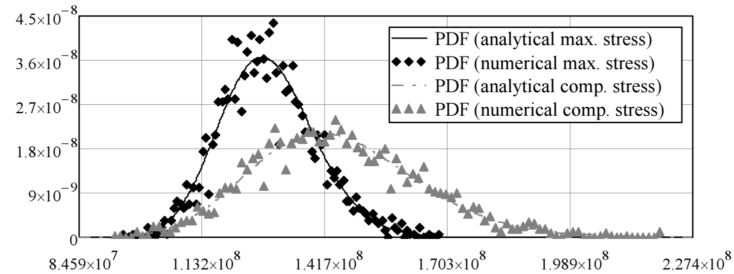

Fig. 6. Graphical representation of variant II of the analysis. The marginal probability density functions of the of calculated [Pa] and maximum [Pa] stresses (vertical axis – probability density [–], horizontal axis – stress [Pa])

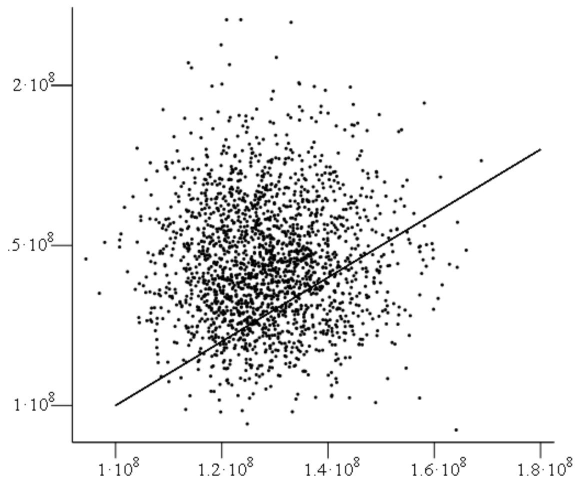

Fig. 7. Graphical representation of the integral (1) for the variant II of the analysis (vertical axis – maximum stress [Pa], horizontal axis – computed stress [Pa])

4. Conclusions

The article presents an reliability analysis of curve on plane steel hoist beam plan using coupling of Ansys APDL and Matlab programs. The presented variants use two approaches to building the failure function. In the first one, mixed probabilistic–deterministic design conditions were used taking the computational displacement as a random one, and the maximum displacement as deterministic. In the second variant, a full probabilistic approach to the design conditions was used, taking the computational stresses and the maximum stresses (steel strength) as random. The conducted analysis showed high effectiveness of the proposed approach in reliability analysis and can be successfully applied to the more complex structures.

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Analiza niezawodnościowa zakrzywionej w planie belki wciągnika podwieszanego z zastosowaniem sprzężenia programów Ansys APDL oraz Matlab

STRESZCZENIE:
W pracy przedstawiono metodę analizy niezawodnościowej zakrzywionej w planie belki wciągnika pod–wieszanego z wykorzystaniem sprzężenia dwóch programów: Ansys oraz Matlab. W analizie uwzględniono występowanie skręcania skrępowanego oraz zastosowano podejście geometrycznie nieliniowe do wyznaczenia odkształcenia konstrukcji. Przedstawiono dwa podejścia do budowania funkcji granicznej: pierwsze oparte na probabilistyczno–deterministycznych warunkach projektowych oraz drugie oparte na pełnym podejściu probabilistycznym. Przeprowadzona analiza wykazała dużą skuteczność zastosowanego podejścia w analizie niezawodnościowej.

SŁOWA KLUCZOWE:
niezawodność; belka wciągnika; metoda elementów skończonych