ANALYTICAL AND FINITE ELEMENT IN-PLANE VIBRATION ANALYSIS OF A GANTRY CRANE

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Abstract: *Every object in nature has an infinite number of vibration frequency and amplitude as called "Natural Vibration Frequency". Developing computer capacities allow calculating of natural frequencies and shapes of complex structures more accurate and understandable. In this study, a dual-trolley (2x400 tons) heavy-duty overhead gantry crane that can carry loads up to 800 tons was analysed by mathematical and finite element methods. The mathematical method is based on Euler-Bernoulli transverse vibration approach. On the other hand, finite element method is one of the most common numerical methods that can solve many engineering problems in a range from solid mechanics to acoustic. The generated solid model was analysed by the finite element method with the help of ANSYS Workbench 14.5 which is a commonly used analysis program. The obtained values of natural frequencies at mathematical calculations and finite element analysis were compared and presented.*

Keywords: GANTRY CRANE, EULER-BERNOULLI TRANSVERSE VIBRATION, VIBRATION ANALYSIS, FINITE ELEMENT ANALYSIS

1. Introduction

The cause of environmental impact and other reasons, vibration is a problem in gantry crane constructions. Vibrations can lead to serious consequences, sometimes leading up to the collapse of a crane. Concepts of "Natural Frequency" and "Resonance" should be examined firstly when determination of mentioned vibrations. The calculation of "Natural Vibration Frequencies" and to know the amplitudes of them are essential in solving of the vibration-induced engineering problems. Natural frequency is a frequency which depends on mass and flexibility of a structure and if it is induced at that frequency, it will vibrate continuously at high amplitude. If an object is excited by a frequency coincides with the natural frequency of that object, a resonance occurs and it vibrates structure excessively. Different methods can be used to avoid the resonance problem during the design of structures. Analytical approaches for non-complex system makes it easy such as verifying by numerical methods for detecting errors in the calculations and preventing the problems that may be encountered. Although analytical calculations can be made, for calculating of complex shapes numerical methods should be applied, such as finite element method [1].

In this study a dual-trolley, 2×400 tons, heavy duty overhead gantry crane (Fig. 1) that can carry loads up to 800 tons was analyzed by mathematical and finite element methods.

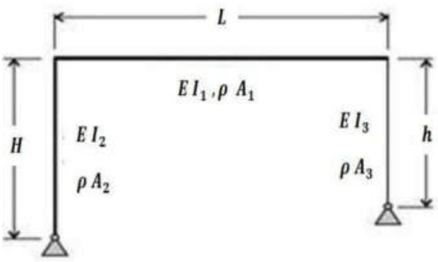

Fig. 1*Vibration model of the crane*

In this figure, dimensions and other parameters are L = 103.85 m; H = h =74.27 m; A_1 = 1.04 m^2; I_1 = 2.078 m^4; ρ = 7850 kg/m^3; E=210 GPa and the relation of this parameters with unknown parameters for α=0,332; β=75,643; ξ=0,8846; η=1,1663 are;

$$s = \frac{H}{L}\ , p = \frac{h}{L}\ , \alpha = \frac{I_1}{I_2}\ , \beta = \frac{I_1}{I_3}, \xi = \sqrt[4]{\alpha\ \frac{A_2}{A_1}}\ ,\ \eta = \sqrt[4]{\beta\ \frac{A_3}{A_1}}$$

The more precise dynamical analysis of engineering structure is based on the assumption that a structure has distributed masses. In this case, the structure has infinite number degrees of freedom and mathematical model is presented with a partial differential equation. Additional assumptions allow construction of the different mathematical models of transversal vibration of the beam. The simplest mathematical models consider a plane vibration of a uniform beam with, taking into account only, bending moments; shear and inertia of rotation of the cross sections are neglected. The beam upon these assumptions is called as Bernoulli-Euler beam.

2. Mathematical Modelling

The mathematical method is based on Euler-Bernoulli transverse vibration approach [2]. Early researchers recognized that that the bending effect is the single most important factor in a transversely vibrating beam. The Euler Bernoulli model includes the strain energy due to the bending and the kinetic energy due to the lateral displacement. The Euler-Bernoulli model dates back to the 18th century. Jacob Bernoulli (1654-1705) first discovered that the curvature of an elastic beam at any point is proportional to the bending moment at that point. Daniel Bernoulli (1700-1782), nephew of Jacob Bernoulli formulated the differential equation of motion of a vibrating beam. Later, Jacob Bernoulli's theory was accepted by Leonhard Euler (1707-1783) in his investigation of the shape of elastic beams under various loading conditions. Many advances on the elastic curves were made by Euler. The Euler-Bernoulli beam theory, sometimes called the classical beam theory, Euler beam theory, Bernoulli beam theory, or Bernoulli-Euler beam theory, is the most commonly used because it is simple and provides reasonable engineering approximations for many problems. The differential equation of a uniform beam [2]:

$$EI\frac{d^4y}{dx^4} = q$$

The elastic modulus is *E*; the moment of inertia is *I*, the transverse load that applied on a unit length of the beam is *q*. The load that applied on a unit length in case of free vibration:

$$q = -\rho A\frac{d^2y}{dt^2}$$

Here, *ρ* is density of the material and *A* is the sectional area. The mathematical model of plane vibration of Euler-Bernoulli Beam when the beam is under a force *f(x,t)*.

$$EI\frac{d^4y}{dx^4} + \rho A\frac{d^2y}{dt^2} = f(x,t)$$

Here, *y(x,t)* is the lateral displacement and *x* and *t* are x-axis and time respectively. The initial and boundary conditions are:

$$y(x,0) = u(x);\ \frac{dy}{dx}(x,0) = v(x)$$

The lateral displacement of the beam when t = 0 is *u(x)* and the first derivative of the displacement is *v(x).* However, the Euler Bernoulli model tends to slightly overestimate the natural frequencies. The procedure of determining Eigen frequencies at complex systems (systems with large number of the freedom degrees) is the most crucial phase of dynamic analysis. Accurate determination of Eigen frequencies was limited to the simple supporting structure (simple beam and console). Finding out solutions of frequent equation for complex elastic bodies is very difficult, because it contained the trigonometric and hyperbolic functions. Mathematica software enables routine solving of frequency equations for complex elastic bodies oscillation.

3. Finite Element Analysis

By Finite Element Method (FEM), structural analyzes can be made rapidly, reliably and nondestructively. Its popularity comes from his realistic results which were taken from the comparisons between FEM and analytical approaches. A variety of specializations such as mechanical, aeronautical, biomechanical engineering commonly use integrated finite element method in design and development of their products. As finite element method software, ANSYS helps tremendously in visualization of stiffness and strength and also in minimizing weight, materials, and costs. In this study, ANSYS is used to determine the natural frequencies with modal analysis. In analysis, 260991 meshed elements and 666104 nodes were used. Finite element method allows entire designs to be constructed, refined, and optimized before the design is manufactured.

4. Results

The maximum displacements in different mods are shown in Figure 2. The natural frequencies and relative error between mathematical and finite element analysis are shown in Table 2. The maximum difference is 7.02%. In modal analysis of a crane, the reliable results can be obtained by using of finite element analysis. It can be used in the design stage of a crane to avoid the resonance situations.

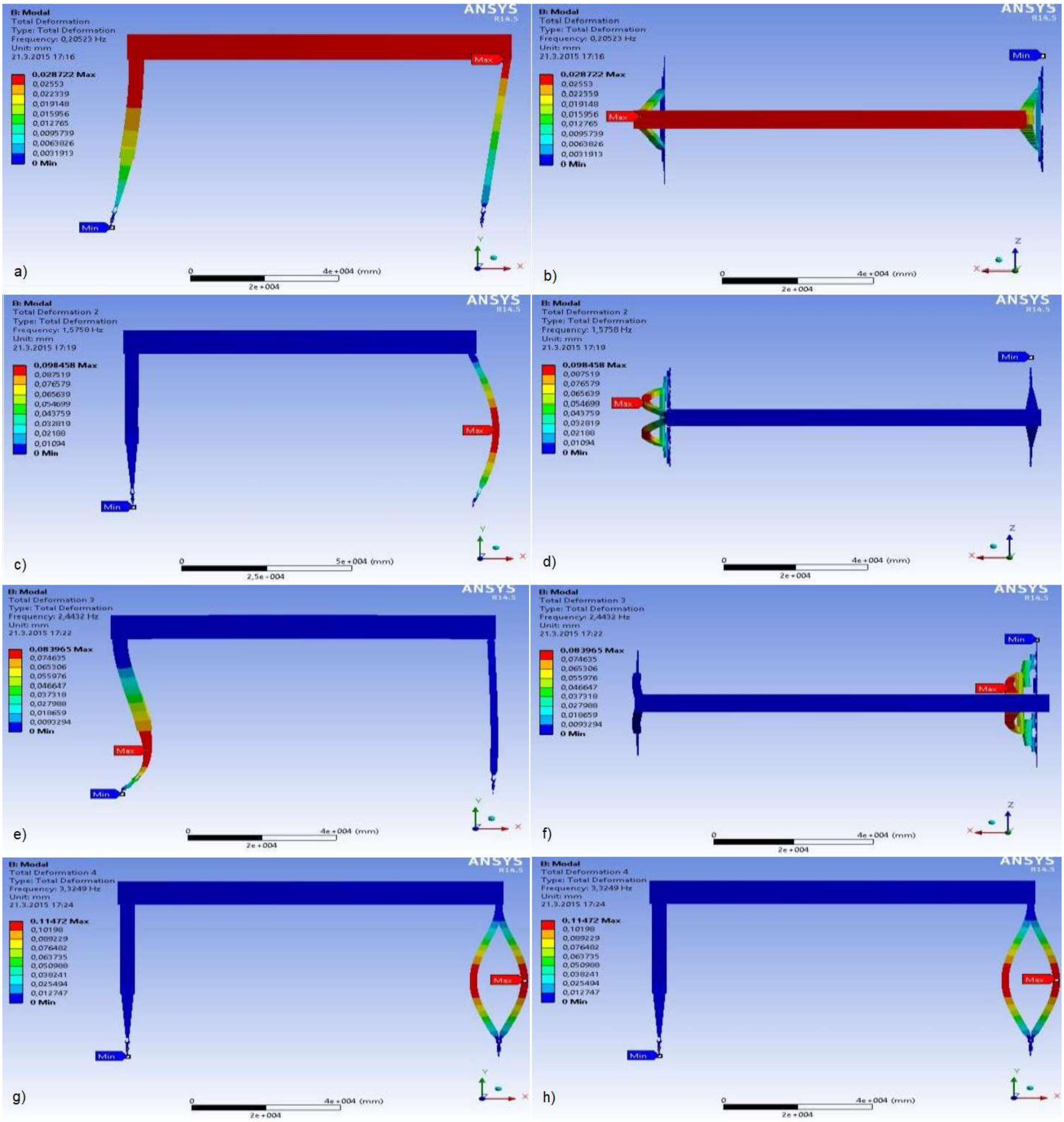

Fig. 2 *Maximum Displacements in Different Mods: a, b) Front and Top View in Mod 1; c, d) Front and Top View in Mod 2; e, f) Front and Top View in Mod 3; g, h) Front and Top View in Mod 4.*

Table 1: *Comparison of Mathematical and Finite Element Analysis Natural Frequencies [Hz]*

Mod	Natural Frequency [Hz] Mathematical Analysis	Natural Frequency [Hz] Finite Element Analysis	% Relative Error
1	0.1908	0.2052	7.02
2	1.4526	1.5758	7.81
3	2.3861	2.4432	2.33
4	3.3048	3.3249	0.60

5. Conclusion

In the first chapter, historical development of cranes and crane types are introduced primarily. Then, according to Euler-Bernoulli transverse vibration approach, the applied method for the creation of the mathematical model of the in-plane vibration of a gantry crane is introduced. For the mathematical model, the differential equations are prepared by using Fourier and Krylov-Duncan Methods. By the methods Fourier and Krylov-Duncan, the differential equation of the transverse vibration of the uniform Bernoulli-Euler beam changed to uncoupled ordinary differential equations with respect to unknown functions which are depend on coordinate and time. Eigen functions and eigenvalues, the natural frequencies of this crane was obtained. In the same section, the modal analysis of the crane made by using finite element method and natural frequencies are obtained. Before running the program, the general settings of modal analysis were prepared. Most important parts of the settings are, entering the engineering data, sizing and the tolerance value. After the settings, meshing was generated.

In the next section, the finite element method and the modal analysis has described. In order to apply this method to the problem, firstly, all parts creating the crane were 3-D modeled by using the SOLIDWORKS drawing program.3-D modeled parts were assembled by using the same drawing program. All 3-D models were created with the help of the draft drawings which were formed by mechanical calculations and the selection of the structural elements. The generated solid model was analyzed by the finite element method with the help of ANSYS Workbench 14.5. Mesh quality is the most important factor that affects the finite element results. Increasing mesh quality increases the accuracy of the finite element method. Although minimizing size of the meshes can be an effective method to increase mesh quality, the solving capacity of the computers limit us. Then, the boundary conditions were applied. It was applied by fix support and displacement commands.

In the last section, the obtained values of natural frequencies at previous section are compared and the results of comparison are presented.

5. References

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