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THEORETICAL STUDIES AND EXPERIMENTAL RESEARCH FOR THE INCREASE OF THE WORK SAFETY AT GANTRY CRANES

Gheorghe N. RADU[1], Ioana Sonia COMĂNESCU[2]
[1] Transilvania University of Brasov, Brasov, ROMANIA, e-mail: rngh@unitbv.ro
[2] Transilvania University of Brasov, Brasov, ROMANIA, e-mail: ioanacom@unitbv.ro

Abstract: *The need for cranes is extremely wide and various. The present research is focused on the gantry cranes, which are largely spreaded as destination and work conditions. The study of the above mentioned cranes is the subject of a classical analytical approach and also of an actual approach of high interest – the Finite Element Method (FEM) of the mechanical structures. An experimental approach which confirms the methods and the results obtained through other methods is also achieved.*
The analysis was performed on a particular structure – a 3D one consisting mainly on beams, loaded in static and dynamic regime. One emphasizes the fact that this above mentioned structure is a particular one, on which one tries to get some original contributions concerning the improving of the work safety.
The work safety of the mechanical structures subjected to the static and dynamic load's action represents a highly complex issue. The precise knowing and understanding through adequate techniques and technologies of the whole structure but of the components, too regarding the state of stress, stands at the base of the work safety. One established that the structure's answer analysis in static and dynamic regime, mainly expressed by the values of the displacements and stresses fields is essential for the work safety.
Keywords: *gantry crane, stress, deformation, main beam, windbracings*

1. PRESENT STUDIES

In a modern assumption, the cranes are complex hoist equipment, usually made of a metallic frame of variable shapes, designs and sizes; they are composed of a single or more mechanisms which are required to the uplift and to the loads displacement.
According to the action made or to the type of design the cranes may be classified by various criteria, as follows: fixed or movable on its own race, without own race, self – propelled or pulled.
The work area of the cranes mostly coincides with the activity area of the people.
Because of the particularities of the cranes work, these must satisfy many standards regarding the work security and safety. This is the reason why the present paper is focused on the improvement of the gantry cranes work safety.
The authors achieved an analysis, with help of the classical theory of strength of materials, of the main elements of the gantry crane (elements subjected to tension, compression, stability calculus – buckling, bending, the check of the trusses, the calculus of the main beam's strength – both fixed ends; one appeals at the classical calculus of the gantry crane, inclusively, which is recommended by the present standards. All the above mentioned calculations are made in order to achieve modern methods which should lead to the increase of the gantry cranes work safety.

2. THE APPLICATION OF THE FEM FOR THE DETERMINATION OF THE STATE OF STRESS AND STRAIN AT GANTRY CRANES

One starts from the assumption that the big dimensions structures may be studied on patterns (theoretical studies based on computational methods and experimentally for their validation, Fig. 1. On the base of the above assumptions stands the similarity criterion. The concept of similarity is used meaning that the study methods on pattern (generally, laboratory research) can be extended at any other sizes of the gantry cranes.

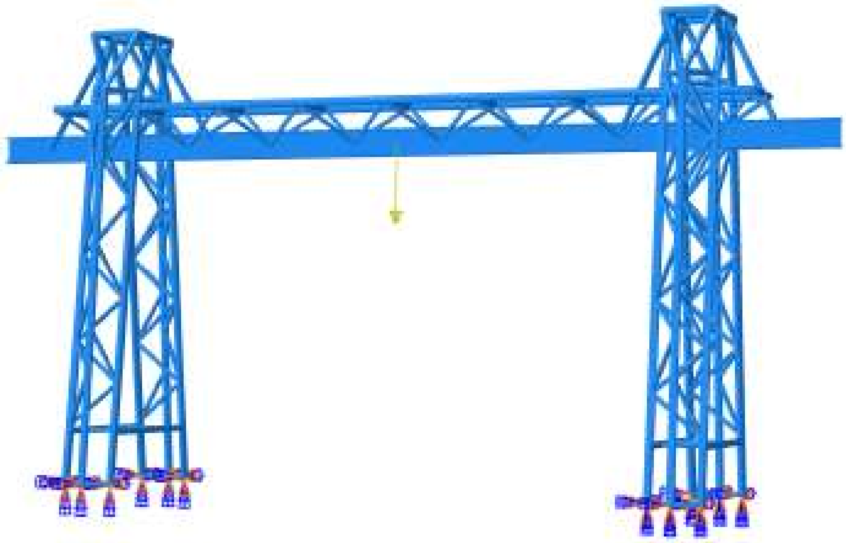

Fig. 1 Pattern of a gantry crane

One specifies further on some theoretical issue concerning the similarity criteria [6, 7].

1. Hook's similarity criterion

It goes from the general case where Hook's law states that in the case of elastic structures loads and displacements, stresses and strains, respectively, are directly proportional ($\Delta = \rho \cdot F$). Hook's similarity criterion is finally achieved, being written between the real body (subscript r) and its attached model (subscript m).

$$\varepsilon_r = \varepsilon_m; \qquad \varepsilon = \frac{\sigma}{E}$$

or

$$\frac{F_r}{A_r \cdot E_r} = \frac{F_m}{A_m \cdot E_m}$$

where F is the internal axial traction force developed in the cross section A.

Taking into account the similarity criteria, one may write also the proportionality between the forces scale K_F and the length scaleλ, as follows:

$K_F = \lambda^2 \cdot K_E$.

Hook's similarity criterion given by the above equation, which states the static similarity, yields as:

$$\varepsilon = \frac{\Delta \ell_r}{\ell_r} = \frac{\Delta \ell_m}{\ell_m},$$

Which emphasizes that the deformations have the same scale as the lengths ($K_{\Delta\ell} = \lambda$).

From the above presented issues, two important conclusions are emphasized:

- the above number H has the same value for the real body and for the prototype, as well; practical, the two compared elastic bodies are likely in terms of external loads;
- Hook's similarity criterion (concerning the finite elastic deformations) is satisfied when the geometrical similarity between the model and the prototype is achieved.

2. CAUCHY's similarity criterion

Cauchy's criterion is a similarity criterion applied to the dynamic loads due to the vibrations of the elastic systems. This criterion yields from the "cross – vibrations equation" of the prismatic beams of changing cross section; the below form of the criterion yields:

$$E\frac{\partial^2}{\partial x^2}\left(I\frac{\partial^2 y}{\partial x^2}\right) + \rho \cdot A \cdot \frac{\partial^2 y}{\partial t^2} - 0,$$

Where the meaning of the above quantities is:

- ρ - the material density;

- $\rho \cdot A$ – mass per unit length;
- $\rho \cdot A \cdot (\partial^2 y/\partial x^2)$ – force of inertia per unit length;
- I – axial moment of inertia of the cross section A;
- y – the deflection of the equilibrium position;
- x – current calculus distance (with respect to the origin);
- t – time.

As a result of some transformations (theoretical study), Cauchy's similarity criterion yields:

$$I_0/t_0 : \sqrt{E_0/\rho_0} = \frac{v}{c} = C;$$

Where:

- v – represents the oscillatory motion velocity of the beam's particles;
- c – the propagation velocity of the (axial) longitudinal waves.

From dynamical point of view the phenomenon on the model and that on the real structure are likely only if Cauchy's criterion has the same value on the prototype (the real case) and on the model, as the above equations emphasize.

From the performed analysis yields that Cauchy's similarity criterion and the ratio of the inertia forces and the really applied external loads are proportional; with the increase of the studied structures stiffness, Cauchy's number decreases and the similarity leads to accurate results.

In addition, to the two above presented criterion there is also FREUDE's similarity criterion which is adequate for researches of the patterned elastic systems, where the gantry has a significant meaning.

The complex issues of the similarity criteria lead to the significant conclusions. One emphasizes that in the case of two materials of the same Poisson's ratio and the same characteristic curve (in dimensionless coordinates) the general stress – deformation behavior is the same. In case of the present research, the model and the structure are executed from the same material and identical cross sections of the beams. The above mentioned similarity criteria lead to the statement that the load - displacement and the stress – strain dependence, respectively, are the same for the real structure and for the model (both in elastic state of load and at the limit of the elastic – plastic state). As a result of the fore mentioned issues, a functional pattern of the gantry crane was achieved; at 1/10 scale (Fig. 1). One used advanced software – ABAQUS, with highly efficient and accurate possibilities of modeling. This one was achieved for the entire structure, but the main element on which the attention is focused is the main beam, profile I, with the dimensions 42 x 80 x 2660 mm; the main beam is reinforced by help of a truss. One used 2818 Beam 3D elements. Two constructive versions are studied: structure with and without windbracings. By graphic post processing, the Von Mises stresses fields and deformations are presented. The achieved graphs show the change of the deflection along the main beam. Some results are shown in Table 1 and Figure 2.

Table 1

Load Application points	Analysis points													
	P1		P2		P3		P4		P5		P6		P7	
	Si (MPa)	S (mm)	Si (MPa)	S (mm)	Si (MPa)	S (mm)	Si (MPa)	S (mm)	Si (MPa)	S (mm)	Si (MPa)	S (mm)	Si (MPa)	S (mm)
P1	0	-0.32	2.9	-0.14	1	-0.035	0.5	0.0097	0.25	0.031	0.1	0.042	0	0.045
P3	0	0.0095	0.65	-0.06	1.94	-0.11	0.6	-0.14	0.3	-0.105	0.05	-0.05	0	0.01
P4	0	0.019	0.175	-0.056	1.5	-0.137	4.5	-0.231	1.5	-0.137	0.175	-0.056	0	0.019

The load is applied in the points P1, P3 or P4 while the state of stress and strain of the main beam is achieved in the initial established points: P1, P2, …, P7. Theoretical analysis for the windbracings crane is performed.

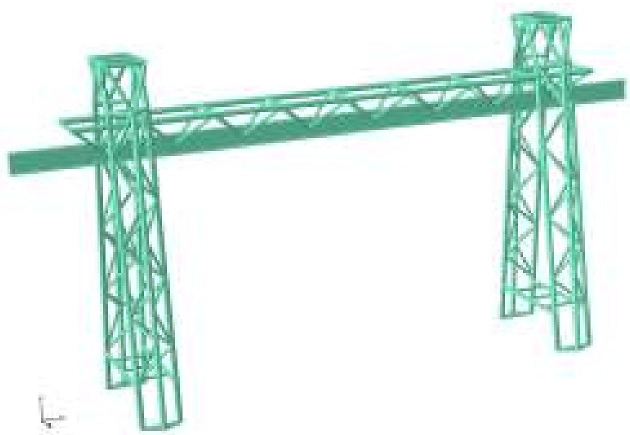

Fig. 2

3. CONCLUSIONS (THEORETICAL STUDIES)

- In terms of the state of stress, analyzing the structures of the crane with windbracings and wingbracingless (stiffeningless), the two constructive solutions present no significant differences; the value of the stress in the middle of the main beam is higher for the crane with windbracings.
- In terms of deformations, analyzing the values of the deformations in the points P1 … P7, relative to the external load in P4, one concludes that the constructive solution with windbracings in more convenient. The windbracings ensures the stiffness of the structure and decrease the state of deformation of the main beam.
- The windbracing crane is a better constructive solution than the windbracingless solutions.
- If the elements used for windbracings are provided with pre – stressing systems, the behavior of the gantry crane is improved (in terms of deformations).
- The concepts and theory of similitude is used meaning that the study methods on pattern may be extended to any size of the gantry crane.

Fig. 3

From the performed theoretical studies the main failure areas of the crane are emphasized. These are:

- The main beam, profile I, in the grip area and in the area 1;

- The main beam, the straight longitudinal tube in the welding area of the support leg, Si2, Figure 3;
- The stand , in the welding area of the longitudinal straight tube – Si3, Figure 3;
- The main beam, the left longitudinal tube in the welding area of the stand Si4, Fig. 3;
- The stand, in the welding area to the left longitudinal tube, Si5, Figure 3.

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