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COMPARATIVE ANALYSIS OF THE MODELS FOR DETERMINATION OF DEFLECTION IN THE COLUMN-MOUNTED JIB CRANE STRUCTURE

Goran Pavlović[1], Milomir Gašić[2], Mile Savković[2], Nebojša Zdravković[2], Goran Marković[2]
goran.pavlovic@li.rs, gasic.m@mfkv.kg.ac.rs, savkovic.m@mfkv.kg.ac.rs, zdravkovic.n@mfkv.kg.ac.rs, markovic.g@mfkv.kg.ac.rs

1) Lola Institute, Kneza Višeslava 70A, 11030 Belgrade
2) Faculty of Mechanical and Civil Engineering in Kraljevo, University of Kragujevac, Dositejeva 19, 36000 Kraljevo
SERBIA

***Key words**: column-mounted jib crane, deflection, finite element method.*

***Abstract:** Column-mounted jib cranes belong to the group of cranes which are the most widespread in plants. The increased development of industry requires shorter deadlines for the manufacturing and assembly of these cranes and, consequently, shorter design time. Deflection of these cranes often represents the main limiting factor in design. The paper presents the comparative analysis of expressions for analytical calculation of deflection of the jib tip defined by a lot of authors. The obtained results were compared by using the finite element method, as well as by experimental values. The recommendations for the selection of an adequate expression for calculation of deflection of the jib tip were given based on the comparison of results. The recommendation for the use of appropriate analytical expressions, which can considerably shorten the time of preliminary calculation in design of this type of cranes, was given based on the conclusions.*

1. INTRODUCTION

Column-mounted jib crane is a kind of portable hoisting equipment with advantages of low investment, small floor space required, safety, high efficiency, energy saving and easy using. Today's industry demands versatile, efficient, and cost effective equipment while at the same time providing more flexibility along with significant savings through increased productivity. A jib crane can help to improve material handling efficiency and work flow. Serious consideration should be given to jib cranes for applications requiring repetitive lifting and transferring of loads within a fixed arc of rotation.

Jib cranes are very useful for lifting and transferring heavy loads in circular work volume. Jib crane provides easy, safe and faster transfer of load from one place to another. Standard jib cranes can lift much heavier loads than other similar material handling equipment; with a standard capacity of 5 tons and span up to 6 meters. Jib crane provides flexibility in design. Therefore, jib cranes are available with many designs as per requirement.

There are various parts of jib crane like its column or mast which supports whole crane, cantilever beam, boom support leg and hoist which moves on the boom of crane.

2. DETERMINATION OF DEFLECTION FOR THE COLUMN-MOUNTED JIB CRANE STRUCTURE

Having in mind that the jib cranes are the most widespread cranes in industrial plants, there are a large number of papers which aim to simplify and quickly define the basic parameters of these types of the cranes. Modelling of the jib crane/calculation using FEM certainly gives the results relevant for dimensioning, but it also extends the time for the formation of calculation model.

Since the maximum deflection of the cantilever beam is critical criterion for the jib cranes, it is necessary to define the simple expression for the cantilever beam deflection, which is necessary for determining the basic parameters of the crane. In this way, basic geometric parameters can quickly be reached, which shortens the design time.

In the paper [01], the analysis of stresses and deflections for different cross-sections of the jib crane was performed. Final results of FEM and experimental tests were used to confirm the results.

It should also be noted that, unlike the analysis using 3D models, the analysis can be successfully performed through simplified line models. In the paper [02], the static and dynamic analysis of a different constructive solutions of the jib cranes was performed using several software packages. The aim of the analysis is to reduce the mass and stress, as well as the higher natural frequencies.

In the paper [03], the analytical verification of the lateral–torsional behaviour of the cantilever was performed. FEM was used to check the model and the obtained results. The results shown in [04] are also important, where the elastic lateral-torsional behaviour of the cantilever is analysed. The results presented in this paper can be largely applied in design of the cantilever of the jib crane. In [05], the analysis of stresses and deflections of the construction of the jib crane for different web thickness and web height of the jib structure was performed. Locations on the construction with the maximum deflection, as well as the locations with the maximum stresses, were determined.

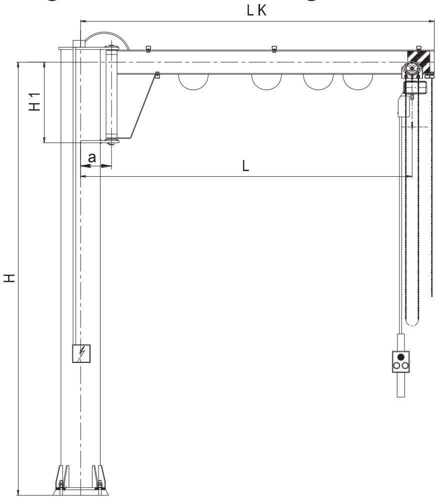
In the paper [06], the optimization of the jib crane was carried out. Evolutionary algorithm was used for optimization. By this optimization process, an appropriate savings was made in consumed material for crane manufacturing.

In the paper [07], optimization of the length of boom support leg for the connection of the jib with the column was carried out. The analysis was performed by FEM. In this paper, the influence of the height H_1 on the deflection of total structure is shown, and this dependence is shown graphically. In [08], the analysis was performed with different types of finite elements in order to obtain reliable results. In [09], stress and deflection analysis was performed by FEM, in the first phase, and after using analytical expressions, in the critical elements, the density of mesh was corrected. In the second phase of the calculation, the height and thickness of the web was varied.

In the paper [10], the analysis of stresses and deflections was performed by using FEM, in the first phase. In the second part, the analysis of individual parts for the connection with the fundament was carried out. In [11], dynamic response of the structure is considered, in the vertical and horizontal direction, using by FEM and the direct integration method. Forced vibration responses of the jib construction due to the action of equivalent moving forces are determined, where the mass matrix is time-dependent.

In the paper [12], integrated finite element analysis of whole jib crane model was established and arm-side deflection formula for this type of crane structure was derived.

Fig.1 shows one existing solution for structure of the column-mounted jib crane.



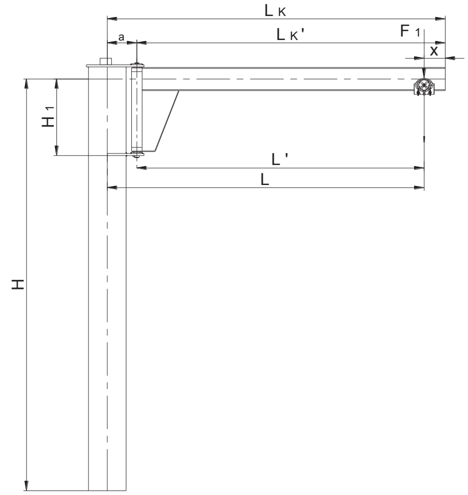


Fig.1 - The column-mounted jib crane   Fig.2 – Calculation model for the column-mounted jib crane

According to [09], the deflection of the cantilever beam is calculated as the superposition of the deflection from the force (concentrated load at the end of the cantilever beam) and the deflection from the self-weight (continuous load along the whole cantilever beam):

$$f_u = f_K + f_q = \frac{F_1 \cdot L_k^{\,3}}{3 \cdot E \cdot I_{x,K}} + \frac{q_K \cdot L_k^{\,4}}{8 \cdot E \cdot I_{x,K}} \qquad (1)$$

where:

$$F_1 = \gamma \cdot (\psi \cdot Q + m_k) \cdot g \qquad (2)$$

γ - the coefficient which depends on the classification class,
ψ - the dynamic coefficient of the influence of load oscillation in the vertical plane,
Q – the carrying capacity of the crane,
m_k – the mass of the trolley,
$I_{x,K}$ – moment of inertia for the cantilever beam,
q_K –weight per unit length of the girder,
while the influence of the column is not considered.

The author compared these results with the results obtained by FEM in ANSYS software package, and the results obtained are satisfactory.

In the paper [12], the effect of the column on the deflection of total structure, which depends on the geometry of the connection between the cantilever beam and the column, was also observed, while the self-weight of the cantilever beam was not taken into account. In this case, the deflection is calculated according to the expression:

$$f_u = f_S + f_K = tg\left(\frac{M \cdot (H - H_1/2)^2}{E \cdot I_{x,S}}\right) \cdot L_K + \frac{F_1 \cdot L_k^{\,3}}{3 \cdot E \cdot I_{x,K}} \qquad (3)$$

where:
$I_{x,S}$ – moment of inertia for the cantilever beam,

$$M = F_1 \cdot L_K . \qquad (4)$$

Equation (3) shows that the component of the deflection of the column depends not only on the height of the column H, but also on the height H_1.

In technical literatures and projects, expressions for the deflection which is the most suitable for use in engineering practice are presented in following way:

$$f_u = f_S + f_K = tg\left(\frac{M \cdot (H - H_1/2)^2}{E \cdot I_{x,S}}\right) \cdot L + \frac{F_1 \cdot L^3}{3 \cdot E \cdot I_{x,K}} \tag{5}$$

$$M = F_1 \cdot L + \frac{q_K \cdot L^2}{2} \tag{6}$$

as well as the following expression, which is based on different model than the previous one:

$$f_u = f_S + f_K = \frac{F_1 \cdot L^2}{E \cdot I_{x,S}} \cdot (H - 2 \cdot H_1/3) + \frac{F_1}{3 \cdot E \cdot I_{x,K}} \cdot \left[(L-a)^3 + L^2 \cdot H_1\right] \tag{5'}$$

As can be seen from the previous expressions, the span of the cantilever beam is observed, the self-weight of the cantilever beam is not taken as a member in the expression for the deflection, only its influence on the moment of bending.

3. MATHEMATICAL MODEL FOR THE DEFLECTION OF TOTAL STRUCTURE OF THE COLUMN-MOUNTED JIB CRANE

In order to make a comparison of all these expressions for determining the deflection, the next model will be considered, where all the influences that are of importance will be carefully considered.

It can be seen that the actual load position is not at the very end of the cantilever beam (Fig.2). It is offset for the distance *x* (depends on the design of the trolley and the way of control and handling of the jib) from the end of the cantilever beam. As seen in Fig.2, the length of cantilever part is taken exactly from the point at which it actually starts, at the distance *a* from the axis of the column. The deflection of connection between the jib and the column will not be taken into account, because it can be regarded as sufficiently rigid to move along with the column, primarily because of type of connection that the bracket and the axle make with the column, as well as the size of the distance.

If the case shown in Fig.2 is analysed, and all effects with all exact distances are observed, the following expression for the deflection can be written:

$$f_u = tg\left(\frac{M \cdot (H - H_1/2)^2}{E \cdot I_{x,S}}\right) \cdot L_K + \frac{F_1 \cdot L_K'^3}{6 \cdot E \cdot I_{x,K}} \cdot \left(\frac{L'}{L_K'}\right)^2 \cdot \left[3 - \left(\frac{L'}{L_K'}\right)\right] + \frac{q_K \cdot L_K'^4}{8 \cdot E \cdot I_{x,K}} \tag{7}$$

In this expression, all members who have influence on the deflection of total structure are present.

4. COMPARATIVE PRESENTATION OF THE OBTAINED RESULTS

Verification of above shown expressions will be performed on example of the existing solution of the column-mounted jib crane with load capacity 500 kg and span 3m. The mass of the trolley is 40 kg and classification class 2.

If 3D model of the column-mounted jib crane structure is analysed, it is defined in CATIA software package as assembly of the column part and the jib part. A simplified model was used without parts that are not relevant for this analysis. In Analysis&Simulation module, in CATIA, the preparation of FEM analysis model was carried out, and all necessary connections, relations and input data were defined.

Fig.3 shows the results obtained (displacements) in CATIA. Unlike the previous model, FEM analysis of the simplified line model of the structure, in SAP2000 software package was performed. Fig.4 shows the obtained values of displacements and angles of at end point of the cantilever beam in SAP2000.

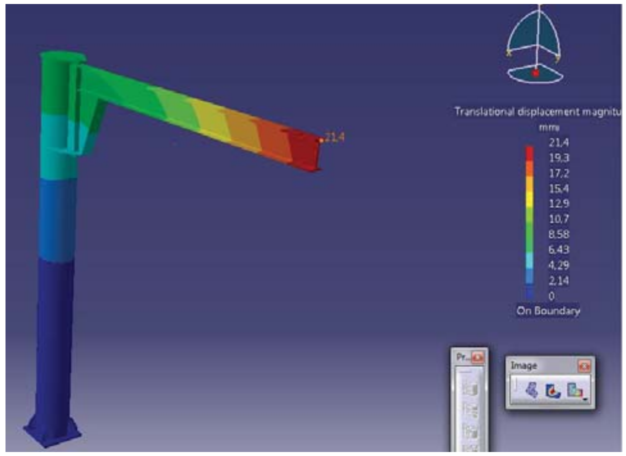


Fig.3 – FEM analysis in CATIA

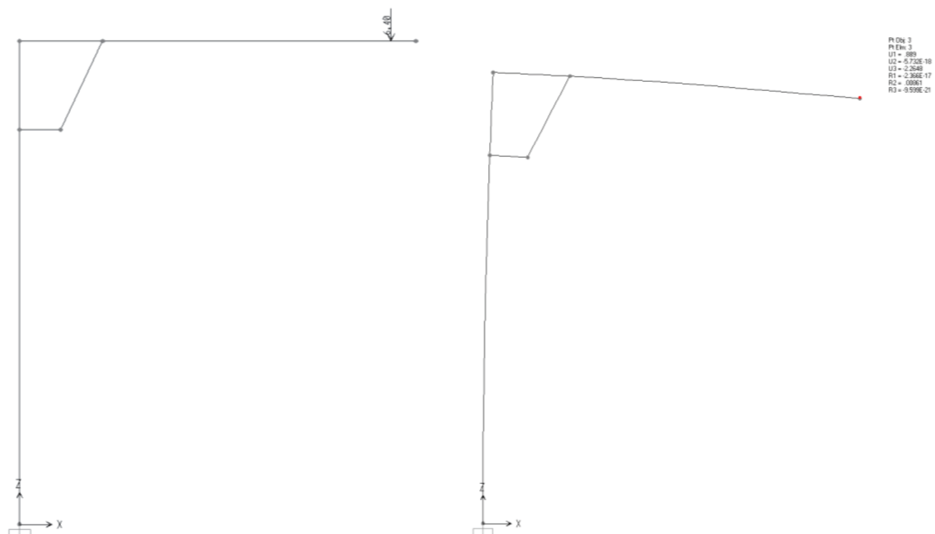


Fig.4 – Calculation model in SAP2000

Table 1 shows the results of the calculations of the deflection according to Eq. (1), (3), (5), (5'), (7) and the results obtained from software packages, respectively.

Table 1

Eq. (1)	*Eq. (3)*	*Eq. (5)*	*Eq. (5')*	*Eq. (7)*	*SAP2000*	*CATIA*
12,60 mm	*25,17 mm*	*22,13 mm*	*20,90 mm*	*21,74 mm*	*22,65 mm*	*21,40 mm*

5. CONCLUSIONS

Based on the results shown in Table 1, the following can be concluded:

- The deflection of the column must be taken into account, because it significantly affects the value of the deflection of the cantilever beam end (Eq. (1)).
- In comparison with the results from FEM, the Eq. (5), (5') and (7) give quite good results, wherein can be seen that the Eq. (7) for the deflection of total structure gives quite

good results in comparison with results obtained in CATIA. In SAP2000, the results are also in satisfactory limits and similar to the result from Eq. (5).

The main conclusions based on the obtained results are as follows:

1. FEM analysis can be successfully applied to these types of structures, where more precise 3D model gives better results than simplified line model. This line model makes it possible to reach the approximate results easily and quickly.

2. By detailed analysis of all influences, the correct expression for deflection can be defined very accurately by Eq. (7). Also, Eq. (5) and (5') give an approximate solutions that are often used in the calculation of these types of structures.

Further activities upon this research are referred to experimental measurements on the real-life column-mounted jib crane structure in order to confirm stated conclusions.

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СРАВНИТЕЛЕН АНАЛИЗ НА МОДЕЛИТЕ ЗА ОПРЕДЕЛЯНЕ НА ОТКЛОНЕНИЕТО В СТРУКТУРАТА НА СТРЕЛОВИ КРАНОВЕ

Горан Павлович[1)], Миломир Гашич[2)], Миле Савкович[2)], Небоя Здравкович[2)], Горан Маркович[2)]
goran.pavlovic@li.rs, gasic.m@mfkv.kg.ac.rs, savkovic.m@mfkv.kg.ac.rs, zdravkovic.n@mfkv.kg.ac.rs, markovic.g@mfkv.kg.ac.rs

1) Институт Лола, ул. Княз Вишеслав 70А, 11030 Белград
2) Факултет по механика и инженерство в Кралево, Крагуевацки университет, ул. Доситиева 19, 36000 Кралево
СЪРБИЯ

Ключови думи*: стрелови кран, отклонение, метод на крайните елементи.*

Резюме: *Стреловите кранове спадат към тези видове кранове, които намират най-широко приложение в производствените фабрики. Бурното развитие на индустрията през последните години налага производството и монтирането на различни видове кранове за индустриални нужди да се изпълнява за кратки срокове. Отклоненията в структурата на тези кранове често се възприема като ограничаващ фактор при тяхното конструиране. Настоящият доклад представя сравнителен анализ на методите за изчисляване на отклоненията в структурата на стреловите кранове. Сравнението на получените резултати е постигнато чрез метода на крайните елементи, както и с помощта на хипотетични стойности. Препоръките за избор на адекватен метод за изчисляване на отклоненията в структурата на стреловите кранове са предложени на база извършените сравнения. В заключението са предложени препоръки за избор на подходящ аналитичен метод, чрез който значително се съкращава времето за първоначално конструиране на стреловите кранове.*