SYSTEM "GIRDER CRANE-BUILDING" DYNAMIC ANALYSIS IN CASE OF EARTHQUAKE

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Abstract. There is a methodology suggested for system "girder crane-building" dynamic analysis in case of earthquake, which is based on lumped masses dynamic model. There is created a lumped masses dynamic model, which is appropriate for system "girder crane-building" dynamic researches in case of earthquake, by using the analytic dynamic common methodology. The created model includes the mechanical properties of the girder crane and the building and is appropriate for the seismic loads as a function of time representation.

Keywords: girder crane, dynamic model, seismic load

1. Introduction

Analyzing the previous developments in the girder crane seismic stability [3], there can be obtained the conclusion, that most of the performed researches in the field of girder crane dynamic analysis in case of earthquake are based on the finite elements method (FEM) by using a finite elements analytic models, which building at some kind of complicated constructions is very difficult and complex problem. FEM is based on the elasticity theory, which is constructed on the properties of rigid deformable body theoretical model, after acceptance of many simplifications. By using FEM, we obtain a complex system of many nonlinear differential equations, for which decision we need a special software and powerful PC [6].

In the engineer practice, there is not a whole and enough correct methodology for system "girder crane-building" dynamic analysis in case of earthquake, which methodology to be based on analytical model with lumped masses.

The present development purpose is to create such a dynamical model with lumped masses, which to be suitable for dynamical researches performance on the system "girder crane-building" in case of earthquake, by using the classical analytic mechanic methods [2]. This model must be created by reading not only the building construction mechanical properties, but also girder crane construction mechanical properties, and to be suitable for seismic excitation assignment as a function of time.

2. Simplifications by building the dynamical model

In accordance to [4] it is recommending the horizontal seismic excitation to be represented by two independent and concurrently operating to the base of the building structure, mutually perpendicular ground acceleration components, $\zeta_X(t)$ and $\zeta_Y(t)$ which direction is determined by the angle θ , which is make by one of the components and the horizontal building axes „x". The vertical seismic excitation is signified by $\zeta_Z(t)$ – figure 1.

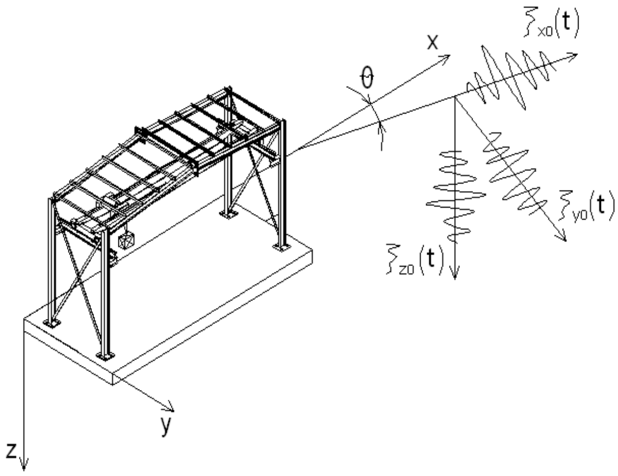

Figure 1.Seismic excitation

In the present development it is made the assumption that $\theta = 0°$ and that the direction of the horizontal seismic excitation $\zeta_X(t)$ coincide with the "x" axis of the workshop building structure in which take place the girder crane.

By the building structure dynamic analysis in case of earthquake, there can be made the assumption that these construction consist of vertical elements which resists the horizontal seismic excitation. These elements are frames, walls, columns, and connections etc., which are connected between by the floor constructions. The floor constructions in the common cases are explored as a horizontal diaphragm, because their stiffness in their own plane exceeded repetitively the construction common bending stiffness in vertical plane [5]. The building bearing structure is explored as a linear-elastic system, which masses are lumped at two levels-crane railroad level and roof level. This construction is explored such as uniform stiffness distribution in general layout and girder crane placed in the middle of the building. By this simplification the roof construction is presented as perfectly rigid body in crane railroad across direction, but as an elastic tie in crane railroad. The vertical building elements (columns) are presented as no deformable in axial compression and tension. This gives an opportunity the dynamic degrees of freedom of each building lumped mass to be reduced to only two horizontal movements, and the dynamic degrees of freedom of each girder crane lumped mass to two horizontal movements and one vertical movement.

There is made the assumption that the two girder crane main beams have the same dynamic movements during the seismic excitation and that is why they are presented as one corporate beam with seven lumped masses, uniform distributed along the beam. Because of the small angle of rope swinging in case of earthquake, the connection "load-main beam" is modeled as a horizontal elastic tie in horizontal direction. Because of that the seismic excitation from the building bearing structure to the girder crane bearing structure is transmitted by the dry friction forces through the girder crane traveling wheels, the connection "traveling wheel-rail" is modeled by a frictional connection with frictional coefficient μ.

3. Common system "girder crane-building" dynamic model

The created common system "girder crane-building" dynamic model is presented on figure 2, where:

a - the distance from the main beam end point to the crane trolley;

m_i - lumped masses;

x_i, y_i - lumped masses absolute coordinates;

c_2 - rope-pulley system stiffness in direction to axes „*x*” and „*y*” [N/m];

c_3 - rope-pulley system stiffness in direction to vertical axes „*z*” [N/m];

c_4 - building roof construction stiffness in direction to horizontal axes „*y*” [N/m];

β_1 - crane bridge damping coefficient in direction to horizontal axes „*y*” [N.s/m];

β_2 - rope-pulley system damping coefficient in direction to axes „*x*” and „*y*” [N·s/m];

β_3 - rope-pulley system damping coefficient in direction to vertical axes „*z*” [N·s/m];

β_4 - building bearing structure damping coefficient in direction to horizontal axes „*y*” [N·s/m]

β_5 - building bearing structure damping coefficient in direction to horizontal axes „*x*” [N·s/m];

β_6 - crane bridge damping coefficient in direction to vertical axes „*z*” [N·s/m];

ζ_{x0}, ζ_{y0}, ζ_{z0} - the input seismic excitation which operate in the building construction foundation.

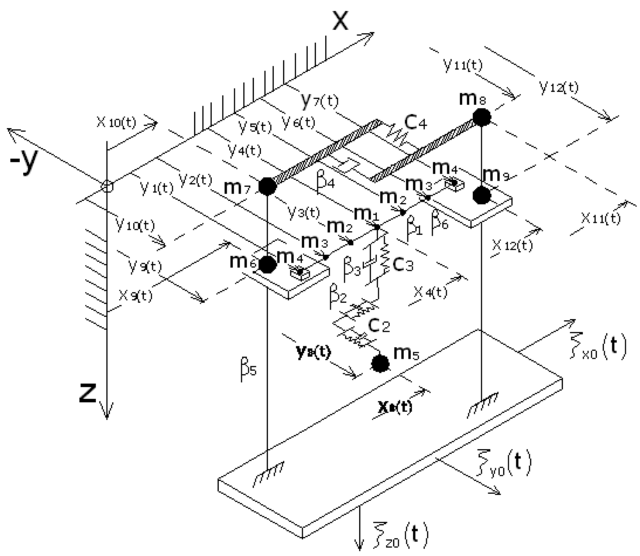

Figure 2. System "girder crane-building" dynamic scheme

This system "girder crane-building" dynamic model has commonly 24 degrees of freedom: 12 degrees of freedom in direction to horizontal axes “y”, 6 degrees of freedom in direction to horizontal axes “x” and 6 degrees of freedom in direction to vertical axes “z”. The masses are lumped in commonly 12 different points so that the point number to be equal to the movement coordinates index.

This dynamic model (figure 2) is solved by using the system approach, so that the task is divided into two sub-tasks:

First subtask – dynamic movement of the building bearing structure – here the crane bridge is removed from the dynamic model and is replaced by two lumped masses placed at the crane railroad level. These lumped masses are equal to the normal support reactions under the crane traveling wheels. This is the most adversely building construction dynamic behavior regarding the girder crane bearing structure. With the solution of this first sub-task we achieve the dynamic behavior of the two opposite crane railroad beams in direction to horizontal axes „x” and „y” respectively $y_6(t) = \zeta_{y1}(t)$ and $x_6(t) = \zeta_{x1}(t)$ for one of the crane railroad beam, and $y_9(t) = \zeta_{y2}(t)$ and $x_9(t) = \zeta_{x2}(t)$ for the other crane railroad beam, which after that operate as an input seismic excitations to the girder crane bearing structure.

Second subtask - dynamic movement of the girder crane bearing structure.

4. Dynamic model describing the girder crane bearing structure movements in the vertical direction

Taking into account the simplifications, there is a "girder crane-building" dynamic model created, which describes the dynamic behavior in vertical direction and is shown on figure 3.

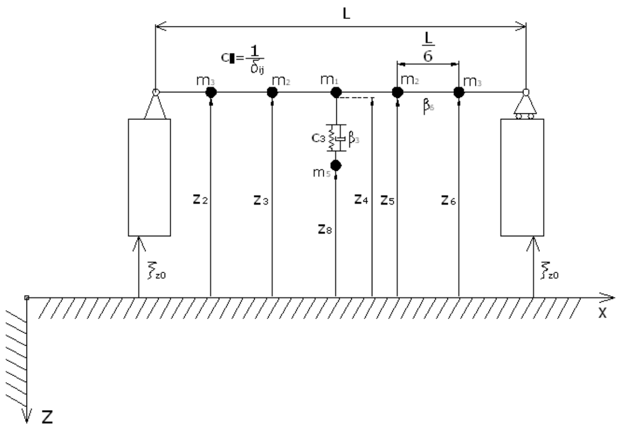

Figure 3. Girder crane scheme in vertical direction

The crane bridge is explored as a double-end hinged beam placed on two supports, and the building columns elastic properties in tension-pressure is neglected in accordance to the simplifications described figure 3.

By using the d'Alambert principle for each of the lumped masses is achieved:

$$z_{20} + z_2 = \zeta_{z0} + \delta_{22} \cdot \Phi_2 + \delta_{23} \cdot \Phi_3 + \\ + \delta_{24} \cdot \Phi_4 + \delta_{25} \cdot \Phi_5 + \delta_{26} \cdot \Phi_6 \quad (1)$$

$$z_{30} + z_3 = \zeta_{z0} + \delta_{32} \cdot \Phi_2 + \delta_{33} \cdot \Phi_3 + \\ + \delta_{34} \cdot \Phi_4 + \delta_{35} \cdot \Phi_5 + \delta_{36} \cdot \Phi_6 \quad (2)$$

$$z_{40} + z_4 = \zeta_{z0} + \delta_{42} \cdot \Phi_2 + \delta_{43} \cdot \Phi_3 + \\ + \delta_{44} \cdot \Phi_4 + \delta_{45} \cdot \Phi_5 + \delta_{46} \cdot \Phi_6 \quad (3)$$

$$z_{50} + z_5 = \zeta_{z0} + \delta_{52} \cdot \Phi_2 + \delta_{53} \cdot \Phi_3 + \\ + \delta_{54} \cdot \Phi_4 + \delta_{55} \cdot \Phi_5 + \delta_{56} \cdot \Phi_6 \quad (4)$$

$$z_{60} + z_6 = \zeta_{z0} + \delta_{62} \cdot \Phi_2 + \delta_{63} \cdot \Phi_3 + \\ + \delta_{64} \cdot \Phi_4 + \delta_{65} \cdot \Phi_5 + \delta_{66} \cdot \Phi_6 \quad (5)$$

$$\dot{z}_4 \cdot \beta_3 + z_4 \cdot c_3 - \ddot{z}_8 \cdot m_5 - \dot{z}_8 \cdot \beta_3 - z_8 \cdot c_3 = 0 \quad (6)$$

where:

δ_{ik} are the single movements;

z_{i0} - static vertical deflection of the lumped mass m_i;

z_i - dynamic vertical movement of the lumped mass m_i;

Φ_2, Φ_6 - vertical forces operating on the beam lumped mass m_3;

Φ_3, Φ_5 - vertical forces operating on the beam lumped mass m_2;

Φ_4 - vertical forces operating on the beam lumped mass m_1.

5. Dynamic model describing the girder crane bearing structure movements in the horizontal direction

Taking into account the simplifications, there is a "girder crane-building" dynamic model created, which describes the dynamic behavior in horizontal direction and is shown on figure 4.

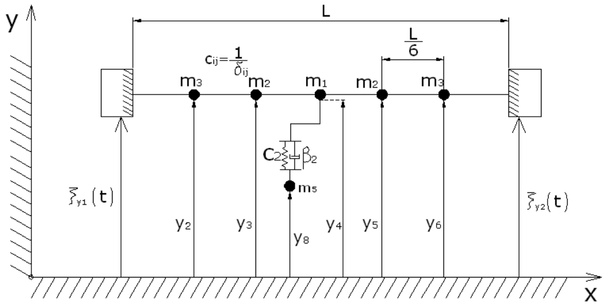

Figure 4. Girder crane scheme in horizontal direction

The crane bridge is explored as a double-end restrained beam placed on two supports.

By using the d'Alambert principle for each of the lumped masses is achieved:

$$y_2 = \frac{100}{108} \cdot \zeta_{y1} + \frac{8}{108} \cdot \zeta_{y2} + \delta_{22} \cdot \Phi_2 + \\ + \delta_{23} \cdot \Phi_3 + \delta_{24} \cdot \Phi_4 + \delta_{25} \cdot \Phi_5 + \delta_{26} \cdot \Phi_6 \quad (7)$$

$$y_3 = \frac{20}{27} \cdot \zeta_{y1} + \frac{7}{27} \cdot \zeta_{y2} + \delta_{32} \cdot \Phi_2 + \\ + \delta_{33} \cdot \Phi_3 + \delta_{34} \cdot \Phi_4 + \delta_{35} \cdot \Phi_5 + \delta_{36} \cdot \Phi_6 \quad (8)$$

$$y_4 = \frac{1}{2}\cdot\left(\zeta_{y1}+\zeta_{y2}\right)+\delta_{42}\cdot\Phi_2+\delta_{43}\cdot\Phi_3+ \\ +\delta_{44}\cdot\Phi_4+\delta_{45}\cdot\Phi_5+\delta_{46}\cdot\Phi_6 \qquad (9)$$

$$y_5 = \frac{7}{27}\cdot\zeta_{y1}+\frac{20}{27}\cdot\zeta_{y2}+\delta_{52}\cdot\Phi_2+ \\ +\delta_{53}\cdot\Phi_3+\delta_{54}\cdot\Phi_4+\delta_{55}\cdot\Phi_5+\delta_{56}\cdot\Phi_6 \qquad (10)$$

$$y_6 = \frac{8}{108}\cdot\zeta_{y1}+\frac{100}{108}\cdot\zeta_{y2}+\delta_{62}\cdot\Phi_2+ \\ +\delta_{63}\cdot\Phi_3+\delta_{64}\cdot\Phi_4+\delta_{65}\cdot\Phi_5+\delta_{66}\cdot\Phi_6 \qquad (11)$$

$$\dot{y}_4\cdot\beta_2+y_4\cdot c_2-\ddot{y}_8\cdot m_5-\dot{y}_8\cdot\beta_2-y_8\cdot c_2=0 \qquad (12)$$

where:

δ_{ik} are the single movements;

y_i - dynamic horizontal movement of the lumped mass m_i;

Φ_2, Φ_6 - vertical forces operating on the beam lumped mass m_3;

Φ_3, Φ_5 - vertical forces operating on the beam lumped mass m_2;

Φ_4 - vertical forces operating on the beam lumped mass m_1.

After this differential equations system solving by using the Couchy form method and a special file-program in software product MATLAB there are obtained the following results for the horizontal dynamic behavior of the main beam middle section, figure 5.

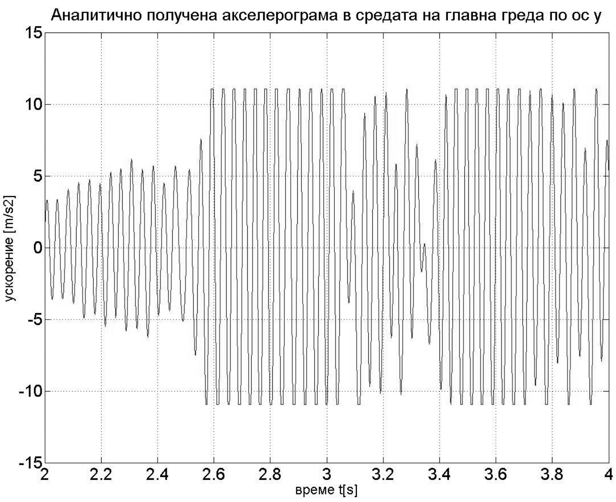

Figure 5. Diagram of acceleration in the middle cross section

After a comparison of the analytic achieved result with the experimental achieved result [7] there can be made the deduction that the deviation about the horizontal seismic acceleration of the main beam middle section is 9 % higher about the analytic result. So there can be made the conclusion, that the presented dynamic lumped masses model is correct enough and appropriate for system "girder crane-building" dynamic exploration in case of earthquake.

6. Conclusion

There is a methodology suggested for system "girder crane-building" dynamic analysis in case of earthquake, which is based on lumped masses dynamic model. There is created a lumped masses "girder crane- building" dynamic model, and a dynamic explorations on it performed and after a comparison of the analytic achieved result with the experimental achieved result [7] there can be made the deduction that the deviation is less than 10 %. Therefore, there can be made the conclusion, that the presented dynamic lumped masses model is correct enough and appropriate for system "girder crane-building" dynamic exploration in case of earthquake.

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