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Vertical Seismic Vibration of the Large-span Trussed Beam

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Abstract.

Our country is located in a seismically active zone of the Earth. Accordingly, it is very important for us to consider the seismic load in the design of the building. The vertical component of the seismic acceleration of the base is often the cause of destruction of buildings during strong earthquakes. Consideration of the mentioned effect for certain types of structural elements of buildings is a standard requirement. Large-span steel truss belongs to these types of structures. The dynamic characteristics of the structure are the main parameters that form the seismic load. This paper considers a method for determining the dynamic characteristics of a large-span steel trussed beam, considering the influence of their bearing structures.

Keywords: dynamic characteristics; large-span trussed beam; seismic load.

Introduction

The vertical component of the seismic acceleration of the base, especially, for the strong earthquake epicenter zone, is one of the main factors causing damage and/or destruction of the building or its structures. Vertical seismic acceleration is especially dangerous for specific building structures. The list of these structures, with the requirement to take into account vertical seismic acceleration during their calculation for aseismic strength, is given in almost all applicable standards of earthquake engineering [1,2,3,4]. Large-span trussed beams of roofs belong to these types of structures. According to the noted standards, the same algorithm has been proposed for determining the vertical seismic load as for the horizontal seismic load, but taking into account different values of parameters that characterize the acceleration of the base and the dynamic response of the building. One of the main parameters determining the value and behavior of both horizontal and vertical seismic loads are the dynamic characteristics of the structural system.

Main Part

In this paper, our goal is to determine dynamic characteristics for the steel large-span beam truss (they are significative for the standard seismic load values) for determination of the standard seismic load on it, taking into account the factor of influence of the bearing structures of the truss. In this case, in the form of supports are considered: columns of the same stiffness (Fig.1, a) and the column - secondary truss (Fig.1, b), on which a large-span truss freely bearing. In this case, give consideration to [5,6]:

- strains from static loads in bearing structures of truss influencing on dynamic characteristics of the large-span trussed beams;
- asymmetric oscillations of the examine structure towards to the horizontal axis caused by effect specified in paragraph above.

To determine the dynamic characteristics of the examined beam truss, with consideration of the above listed features of its behavior, we consider the design model in the form of an equivocal beam [7]. By this model the first period of natural oscillations or the period of the fundamental mode is determined. As a rule, it has the most important applied meaning. Besides of that for the purpose of our task (see above), the definition of the first period is sufficient and at the same time aligned with the standard requirements [8,9].

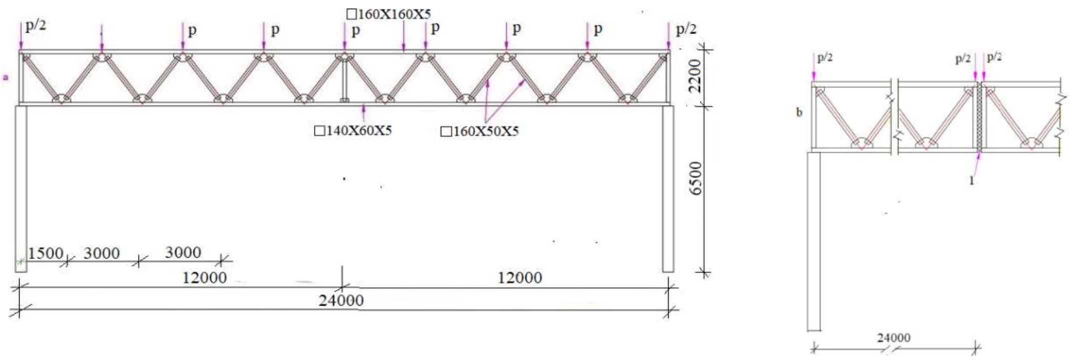

Fig. 1 Steel large-span beam truss – a) supports - columns of the same stiffness; b) supports - column - secondary truss (1)

By the calculation model shown in Fig.2 it considerate the rigidity of adjoining bearing structures (k1); static loading of bearing structures (k2); m-half of the total mass devolving to the truss. The standard form of the equation for determining deflections of a single-span beam on elastic bearings loaded with the concentrated mass will be [10]

$$6EIy = R_x \cdot a^3 + (C_x + \Delta_a)a + \Delta_b \qquad (1)$$

where $R_x = -\big(1 - (x/l)\big)$; $C_x = (-1/l)(3x^2 - 2xl^2 - x^3)$; $\Delta_a = (6EI/l)\big(\delta_a R_x + \delta_b (x/l)\big)$;

$\Delta_b = -6EI\delta_a R_x$; δ_a, δ_b – deformability of the elastic bearings; a- coordinate of the concentrated mass; x-coordinate of the desired unit displacement (Fig 3).

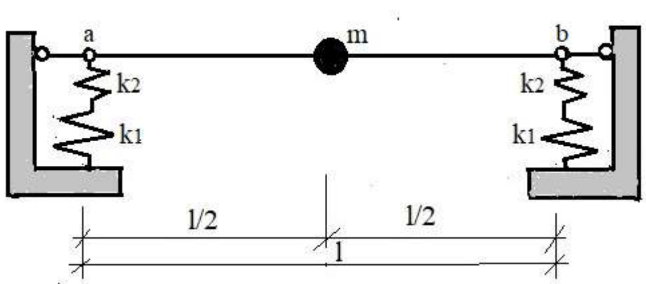

Fig. 2 Calculation model

Taking into consideration that:

a) for the load-bearing columns with the same stiffness $\delta_a = \delta_b = \delta$; $a = x$ for the value of the coefficients of equation (1) we have $R_x = -1/2$; $C_x = (3/8)l^2$; $\Delta_a = 0$; $\Delta_b = 3EI\delta$.

b) for the load-bearing structures (column – secondary truss) with the various stiffness $\delta_a \neq \delta_b$; $a = x$ for the value of the coefficients of equation (1) we have $R_x = -1/2$; $C_x = (3/8)l^2$; $\Delta_a = (3EI/l)(\delta_b - \delta_a)$; $\Delta_b = 3EI\delta$.

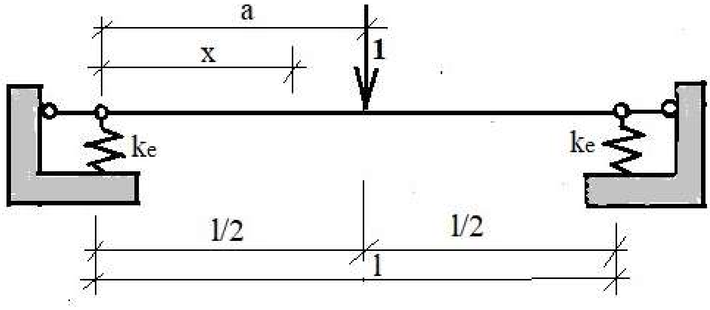

Fig. 3 Calculation model with equivalent spring constant

Accordingly, for the unit displacement of the mass concentration point, we have:

for the case of bearing structures with the same stiffness – a):

$$\delta_{l/2} = l^3/48EI + \delta/2 \qquad (2)$$

for the case of bearing structures with the various stiffness – b):

$$\delta_{l/2} = l^3/48EI + (\delta_a + \delta_b)/4 \qquad (3)$$

For the value of the circular frequency of natural oscillations, we have:

$$\omega = \sqrt{\frac{1}{\delta_{l/2} m}} \qquad (4)$$

Consider a specific numerical example. Define the dynamic characteristics of the steel trussed beam with a span 24 m (Fig.1), which is the part of the transverse frame. Its pin connection with columns of the equal rigidity (Fig.1, a), as well as with a column and a secondary truss (Fig.1. b). According to the geometrical dimensions of steel elements (Fig.1) we have $P = 34kN$; $m = 13,6t$. The second moment of area of the equivocal beam is determined from condition that the deflection of the middle points of the truss and the equivocal beam from the design load are equal. Considering that: the deflection in the middle of the truss is 30.1 mm (Fig.4), columns spacing is 6m, the load on lineal meter is $q = 11,31 \cdot 10^3 kN/m$, for the value of the second moment of area of the equivocal beam:

$$I = (5ql^4)/(384E \cdot 0,031) = 0,775 \cdot 10^{-2} м^2$$

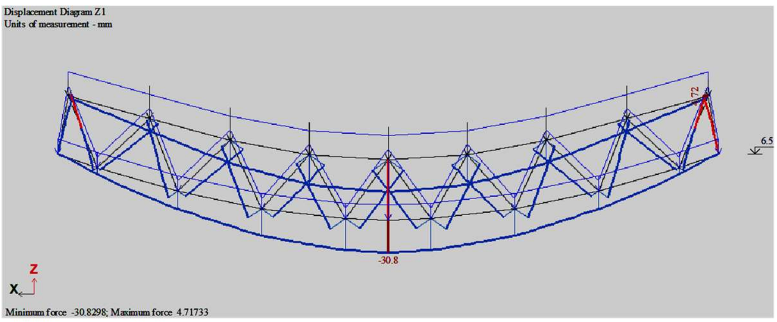

Fig 4 Deflection in the middle of the truss

Determining the equivalent spring constant [11]:

$$k_e = k_1 k_2/(k_1 + k_2) \quad (5)$$

First case. Both supports have the same stiffness $k_1 = 24{,}04 \cdot 10^7 N/m$ considering the strain from the static load $k_2 = 1{,}75k_1$. From (5) $k_e = 0{,}64k_1 = 15{,}30 \cdot 10^7 N/m$; $\delta = 0{,}065 \cdot 10^{-7} m/N$. From (2) and (4) we have $\delta_{l/2} = 180{,}26 \cdot 10^{-9} m/N$; $\omega = 20{,}29 rad/sec$; $T = 0{,}310 sec$.

Second case. The truss is supported by the column and by the secondary truss (Fig.1 b) - $k_e = 0{,}64k_1 = 15{,}30 \cdot 10^7 N/m$; $\delta_a = 0{,}065 \cdot 10^{-7} m/N$. Deformability of the secondary truss $\delta_b = 0{,}79 \cdot 10^{-7}$м/н. From (3) and (4) we have $\delta_{l/2} = 204{,}26 \cdot 10^{-9} m/N$; $\omega = 18{,}98 rad/sec$; $T = 0{,}331 sec$.

The period corresponding to the fundamental mode of the considered truss, accordingly to the standard is determined by the formula [9]:

$$T = 0{,}177\sqrt{\Delta} \quad (6)$$

where Δ is the truss deflection from the design load in cm. For our case, we will have

$$T = 0{,}177\sqrt{3{,}01} = 0{,}307 sec.$$

Conclusion

The obtained values of the period corresponding to the fundamental mode, with consideration the influence of strain in bearing structures, differ from the same value determined according to the standard method – in the first case by 1%, in the second – 8%. The latter indicates the importance of considering the influence of structural solutions of the bearing structures of the large-span steel beam trusses at determining the vertical seismic load.

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