Journal of Construction and Engineering Technology
Journal homepage: www.journal.fstu.uz

LOCAL SEISMIC LOAD ON THE RUNWAY BEAM OF A TOP RUNNING OVERHEAD CRANE

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Abstract

Runway beams are the primary load-bearing structures for top-running overhead cranes and serve as structural elements of industrial building frames. Vibrations of the crane and the suspended load, caused by vertical seismic acceleration, generate inertial interaction between the crane and the runway beam. This is the main topic of the presented article. A calculation model is proposed for determining the local seismic load resulting from vertical seismic acceleration. The main result is the independence of the seismic load from changes in any parameter characterizing a particular system, and the impossibility of applying a unified approach to such problems without adjusting the calculation model to the specific task.

Keywords: Seismic Load, Overhead crane, Industrial building, Stiffness, Frequency, Vibration mode.

1. Introduction

Top-running overhead cranes are very common lifting tools used in industrial buildings. They generate significant horizontal and vertical loads on the buildings. The nature of these loads—and consequently their effect on the performance of the building's frame—changes under seismic conditions. Consideration of this effect, for both the horizontal and vertical components of seismic acceleration, is partial and lacks clear requirements regarding the dynamic model of the top-running overhead crane-supporting structures in the current standards [1-4]:

– For the horizontal component, the inertial load from the crane mass on the frame of the industrial building is taken into account; and when a dynamic model in the form of a cantilever with a concentrated mass is used, the local seismic load on the column is also considered [5]

– For the vertical component, the weight of the crane and a load equal to the crane's capacity are taken into account with a coefficient of 0.3.

Runway beams are the main load-bearing structures for top-running overhead cranes, as well as structural elements that ensure the integral operation of the building frame [6]. They receive and transmit vertical and horizontal loads from the cranes to the columns.

Vibrations of the crane and the suspended load due to vertical seismic acceleration generate inertial interaction between the crane and the runway beam [7]. This issue—namely, a possible approach to fulfilling the normative requirements mentioned above—is addressed in this article.

2. Methods

In a discontinuous runway beam scheme, the maximum static design forces (moment M and shear Q) from the vertical crane load occur at the mid-span (for M) and at the supports (for Q). Accordingly, we consider the position of the crane at the center of the runway beam and the suspended load placed as close to the runway beam as possible. Moreover, various suspension heights will be considered. In such cases, based on the vibration model of the bridge girder with a load on the hook as given in [8], the compliance (flexibility) of the bridge girder does not influence the oscillation process of the runway beam.

This and/or similar problems can be addressed using software packages and/or analytical methods [9]. In all cases, the goal, required accuracy, and practical efficiency for engineering applications are decisive factors. In this case, the analytical solution is the most appropriate, meeting the conditions listed.

Received: 23 December 2025
Revised: 27 December 2025
Accepted: 10 February 2026

https://doi.org/10.24412/2181-4473-2026.4.102

The calculation model for determining the local vertical seismic load on the runway beam, taking into account the above conditions, is presented in Figure 1.

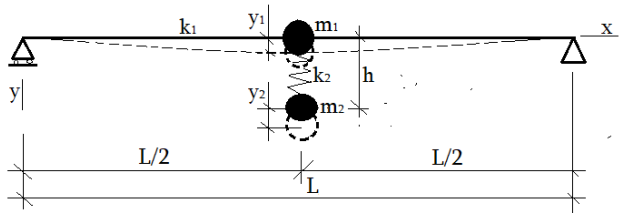


Figure 1. The calculation model

Here m_1 is the mass of the crane corresponding to the maximum wheel load, determined without considering the crane's load capacity, and is calculated using the following expression:

$$F_{max} = \left[\frac{G-G_1}{2} + \frac{G_1(l-l_1)}{l}\right] \cdot \frac{1}{n_0} \quad (1)$$

where l - is the crane span, l_1 is the minimum distance from the centerline of the hook to the centerline of the end beam, G is the total weight of the crane including the trolley, $G_1$1is the weight of the trolley n_0 - number of wheels on one side of the crane.

m_2- is the mass of the load which corresponds to the maximum load capacity of the crane, or a value slightly below it.

k_1 is the stiffness of the crane beam.

k_2 - stiffness of the wire rope, which is determined by the expression

$$k_2 = nEF/h \quad (2)$$

where h- is the length of the suspension, n - is the number of ropes in the chain block, E and F are the effective cross-sectional area of one rope and its modulus of elasticity, respectively.

The equations of vibration of the system will be written [10]

$$\begin{matrix} m_1\ddot{y}_1 + k_1y_1 - k_2(y_2 - y_1) = 0 \\ m_2\ddot{y}_2 + k_2(y_2 - y_1) = 0 \end{matrix} \quad (3)$$

frequency equation from (3)

$$\begin{vmatrix} m_1\omega^2 - (k_1 + k_2); & k_2 \\ k_2; & m_2\omega^2 - k_2 \end{vmatrix} \quad (4)$$

For frequency values from (4)

$$\omega_{1,2}^2 = \frac{1}{2}\left(\frac{k_1+k_2}{m_1} + \frac{k_2}{m_2}\right) \pm \sqrt{\frac{1}{4}\left(\frac{k_1+k_2}{m_1} + \frac{k_2}{m_2}\right)^2 - \frac{k_1k_2}{m_1m_2}} \quad (5)$$

For the vibration modes at s=1 and s=2 we will have

$$\frac{A_{2s}}{A_{1s}} = \frac{k_1+k_2-m_1\omega_s^2}{k_2} \quad (6)$$

Let's consider a specific example. Single-storey, single-span industrial building with a top running overhead crane with a load capacity of 12.5t. All necessary data for the calculation are given in Fig. 2, in [11] in Table 1 (for suspension length h=2m) and in Table 2 (for suspension length h=4m).

For suspension length h=2m

Table 1 Data for calculation

m_1 kg	m_2 kg	k_1n/m	k_2n/m	$\omega_1$rad/s	$\omega_2$rad/s	T_1s	T_2s
$5X10^3$	$10X10^3$	$1,16X10^6$	$32,34X10^6$	99,29	8,72	0,06	0,72

From the equation (6) for the first (s=1) and the second (s=2) vibration modes: A_{21}/A_{11} =-0,488; A_{22}/A_{12} =1,024. From the orthogonality of the vibration modes $m_1 + (A_{21}/A_{11}) \cdot (A_{22}/A_{12}) \cdot m_2 = 5 \cdot 10^3 + (-0{,}488) \cdot 1{,}024 \cdot 10 \cdot 10^3 = 0$. From the normality condition A_{1s} =1 (s=1,2) we have A_{11} =1, A_{21} =-0,488 for the first mode; A_{12} =1, A_{22} =1,024 for second mode. Coefficients of vibration modes for determination of seismic load:

- for the first vibration mode

$$\eta_1 = (5 \cdot 10^3 \cdot 1 - 0{,}488) \cdot 10 \cdot 10^3) \,/\, (5 \cdot 10^3 \cdot 1 + (-0{,}488^2) \cdot 10 \cdot 10^3 = 0{,}016;$$

$$\eta_2 = 0{,}016 \cdot (-0{,}048) = -0{,}008$$

- for the second vibration mode

$$\eta_1 = 0{,}984 \quad \eta_2 = 0{,}984 \cdot 1{,}024 = 1{,}008$$

$$\sum \eta_1 = 0{,}016 + 0{,}984 = 1; \sum \eta_2 = -\,0{,}008 + 1{,}008 = 1.$$

The values of dynamic coefficients from [1] $\beta_1 = 2{,}5$ $\beta_2 = 2{,}3$. Accordingly, the seismic load for the first vibration mode

$$S_1 = 0{,}25 \cdot 1 \cdot 0{,}016 \cdot 0{,}17 \cdot 2{,}5 \cdot 5 \cdot 10^4 = 85N = 0{,}085kN$$

$$S_2 = 0{,}25 \cdot 1 \cdot (-0{,}008) \cdot 0{,}17 \cdot 2{,}3 \cdot 10 \cdot 10^4 = -78N = -0{,}078kN$$

for the second vibration mode

$$S_1 = 0{,}25 \cdot 1 \cdot 0{,}984 \cdot 0{,}17 \cdot 2{,}5 \cdot 5 \cdot 10^4 = 5228N \approx 5kN$$

$$S_2 = 0{,}25 \cdot 1 \cdot 1{,}008 \cdot 0{,}17 \cdot 2{,}3 \cdot 10 \cdot 10^4 = 9853N \approx 10kN$$

Considering that in this particular example we have a top running overhead crane with a double-bridge girder and a four-wheeled trolley, the seismic load S_2 will be statically applied to the runway beam from one half of the double- bridge girder. Accordingly, for the first vibration mode $S_2 = -0{,}039kN$, for the second - $S_2 = 5kN$. Based on the above mentioned and taking into account the very high stiffness of the wire ropes in the vertical direction, it will be applied at the same point as the load S_1.

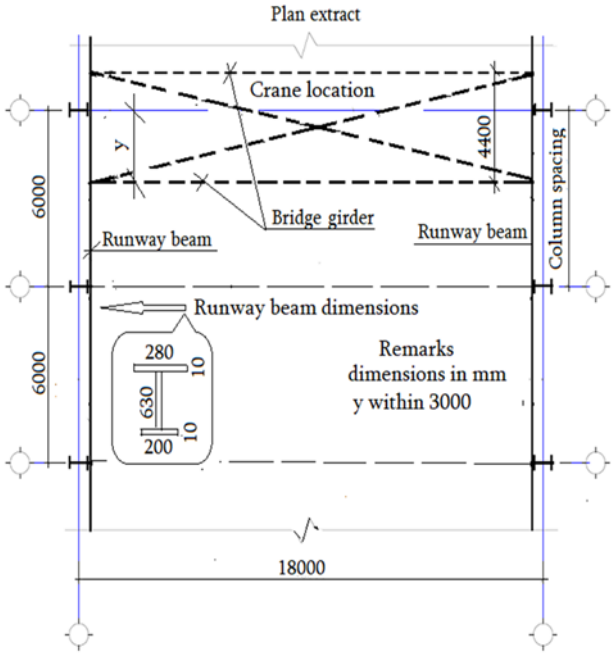


Figure 2. Plan extract of industrial building

For suspension length h=4m

Table 2 Data for calculation

m_1 kg	m_2 kg	k_1n/m	k_2n/m	$\omega_1$rad/s	$\omega_2$rad/s	T_1s	T_2s
5X10^3	10X10^3	1,16X10^6	16,17X10^6	70,76	9,00	0,09	0,70

From the equation (6) for the first (s=1) and the second (s=2) vibration modes: A_{21}/A_{11} =-0,476; A_{22}/A_{12} =1,047. From the orthogonality of the vibration modes $m_1 + (A_{21}/A_{11}) \cdot (A_{22}/A_{12}) \cdot m_2 = 5 \cdot 10^3 + (-0{,}476) \cdot 1{,}047 \cdot 10 \cdot 10^3$. From the normality condition A_{1s} =1 (s=1,2) we have A_{11} =1, A_{21} =-0,476 for the first mode; A_{12} =1, A_{22} =1,047 second mode. Coefficients of vibration modes for determination of seismic load: for the first vibration mode η_1 =0,033; $\eta_2 = -0{,}015$ for the second vibration mode $\eta_1 = 0{,}969$ $\eta_2 = 1{,}015$; $\sum \eta_1 = 0{,}033 + 0{,}969 = 1$; $\sum \eta_2 = -0{,}015+1{,}015=1$. The values of dynamic coefficients $\beta_1 = 2{,}5$ $\beta_2 = 2{,}3$. Accordingly, the seismic load for the first vibration mode

$$S_1 = 0{,}25 \cdot 1 \cdot 0{,}033 \cdot 0{,}17 \cdot 2{,}5 \cdot 5 \cdot 10^4 = 175N = 0{,}175kN$$

$$S_2 = 0{,}25 \cdot 1 \cdot (-0{,}015) \cdot 0{,}17 \cdot 2{,}3 \cdot 10 \cdot 10^4 = -147N = -0{,}147kN$$

for the second vibration mode

$$S_1 = 0{,}25 \cdot 1 \cdot 0{,}969 \cdot 0{,}17 \cdot 2{,}5 \cdot 5 \cdot 10^4 = 5147N \approx 5kN$$

$$S_2 = 0{,}25 \cdot 1 \cdot 1{,}015 \cdot 0{,}17 \cdot 2{,}3 \cdot 10 \cdot 10^4 = 9922N \approx 10kN$$

Similar to the above mentioned, the seismic load S_2 for the first vibration mode $S_2 = -0{,}074kN$ and for the second vibration mode $S_2 = 5kN$.

This article proposes a calculation model for the top-running overhead crane–supporting structure as one possible approach to meeting normative requirements for considering vertical seismic acceleration (see above). The obtained results—specifically, the dynamic characteristics of the system and seismic loads—indicate that variations of any single parameter within realistic limits do not significantly affect the seismic load values.

3. Discussion

Seismic resistance standards require (see above) consideration of loads from cranes during seismic impacts, but without clear requirements for the dynamic model of the top running overhead crane supporting structural system/structural element. Due to the variety of design solutions for overhead cranes and their load-bearing structures, as well as the location of the crane with or without a load relative to the structural system of the building, the problem of a general and/or individual approach to such tasks arises. The consideration of individual tasks in this and the previous article [12], as well as in subsequent articles on this topic, serves as the basis for the formation of a general approach to determining and accounting for seismic loads from top running overhead cranes.

4. Conclusions

At the same time, the abrupt variation in seismic load values depending on vibration modes highlights the impossibility of applying a unified approach to such problems. This reinforces the need to adjust the calculation model according to the specific task, given the structural and technological diversity of top-running overhead cranes and their supporting structures.

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