UDC 624.042.7
SCOPUS CODE 2201
https://doi.org/10.36073/1512-0996-2023-2-63-67

Vertical Seismic Load on a Long-span Steel Truss

Sergo Esadze Department of Civil and Industrial Construction, Georgian Technical University, Georgia, 0160, Tbilisi, 68b, Kostava Str.
E-mail: s_esadze@gtu.ge

Nino Pavliashvili Department of Civil and Industrial Construction, Georgian Technical University, Georgia, 0160, Tbilisi, 68b, Kostava Str.
E-mail: ninopavliashvili1996@yahoo.com

Reviewers:
L. Kakhiani, Professor, Faculty of Construction, GTU
l.kakhiani@gtu.ge
D. Tabatadze, Professor, Faculty of Construction, GTU
E-mail: tabatadze@gtu.ge

Abstract.
The horizontal component of the seismic acceleration of the foundation during determining the seismic load according to the standard methodology for all types of buildings and their structural elements, is considered. The vertical seismic load calculation is required for certain types of structures. These include the steel beam truss considered in this paper, with spans ranging from 24 m to 40 m. The paper considers a simplified method for determining the dynamic characteristics required to determine the seismic load on the mentioned structure, taking into account the influence of supporting structures. To do this, the approach of reducing a truss to a beam with equivalent stiffness on elastic supports is used. The calculation model also makes it possible to take into account the influence of the considered structure on the supports.

Keywords: elastic support; fundamental mode; trussed beam.

Introduction

The significance of taking into consideration the vertical component of seismic impact on buildings as on a whole and/or on its individual structural elements is clearly indicated by the consequences of strong earthquakes [1]. Buildings located in epicenter zones and/or certain types of structural elements - consoles, large-span structures, etc. are especially vulnerable to the noted type of impact. Accordingly, consideration of vertical seismic load for certain types of structures is a mandatory requirement of all applicable seismic construction standards [2,3,4]. Almost for all mentioned codes, the large-span structures belong to such types of structures – difference only the span value. The standard vertical seismic load is also defined as horizontal – the same principles and formulas, the difference in the values of separate coefficients.

Main Part

Determination and analysis of dynamic characteristics in general and in compliance with the mentioned structures is the main stage in solving the problem of their vibrations and seismic resistance. To solve these problems, numerical technique (represented by specialist software application) and/or analytical methods are used. Significative in the selection are purposes of solvable problem, required accuracy and efficiency for engineering practice. The use of an analytical solution characterized by maximum simplicity, required accuracy and possibility of obtaining two-way estimate is most acceptable for design and engineering practice. It is necessary to obtain preliminary result. This approach is used in this work.

Considered vertical seismic vibrations of a large-span plane steel trussed beam of the covering of single-storey building to determine the seismic load on it, according to the standard method. Unlike the latter, we will consider the influence of adjacent [3] support structures on the dynamic characteristics of the truss, respectively, on the value of the seismic load.

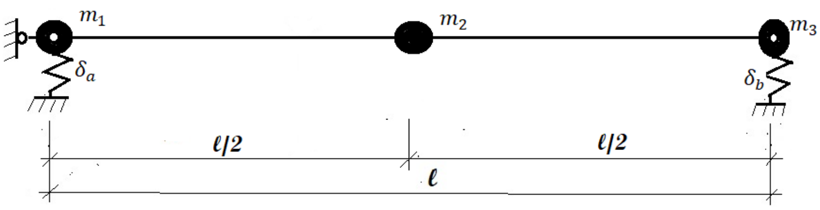

Fig.1 Three-mass beam on elastic supports

To solve the problem, we will proceed from the approach of reduction the truss to a beam with equivalent rigidity. Vibrations of trussed beam with the mentioned approach are considered in works [5,6,7.8.9.10,11,12,13,14]. This approach and its various modifications are justified in them [5,6,7,8,9,10,11]: considered and justified the possibility of expanding the method to determine higher frequencies [12]; considered simplification of the computer models [13]; considered the influence of static loading of support structures by introduction the equivalent stiffness of elastic supports [14].

The proposed solution takes into account the influence of the compliance of the supporting structures on the values of the desired dynamic characteristics. The need for such an approach is due to: asymmetric oscillations of supports of coating structure relative to horizontal axis caused by different static and dynamic effect of loading of structural elements in vertical direction, irregularity of supporting structures [15].

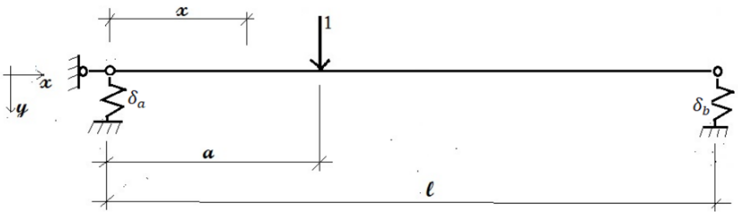

Fig.2 Applied of unit force

ISSN 1512-0996
www.shromebi.gtu.ge

Consider a large-span beam truss with irregular supports, i.e. with supports having different compliance [16,17]. The calculation model for determining the fundamental frequency of the system is represented as a three-mass beam on elastic supports (Fig. 1). Half of the total mass transferred to the truss is concentrated in the middle, and the remaining half is evenly redistributed concentrated on the two elastic supports. Thus, the above-mentioned features characterizing the vertical seismic vibrations of the structure are taken into account.

To determine the displacement from a single loading applied alternately on the supports and in the middle of the span (points of mass concentration), we use the equation [17]:

$$6EIy(x) = R_x a^3 + \Gamma_x (a-x)^3 + (C_x + \Delta_x)a + \Delta_b \quad (1)$$

where $R_x = -\left(1-\frac{x}{l}\right)$; $C_x = -\frac{1}{l}(3x^2 l - 2xl^2 - x^3)$; $\Delta_a = \frac{6EI}{l}\left(\delta_a R_x + \delta_b \frac{x}{l}\right)$; $\Delta_b = -3EI\delta_a$, Γ_x functional interrupter that has the following properties: $\Gamma_x = 0$ when $a < x$; $\Gamma_x = 1$ when $a > x$, δ_a and δ_b compliance of elastic supports, x and a are, respectively, the coordinates of the points of the desired unit displacements and concentrated masses.

When a unit force is applied alternately at the points $a = 0$; $a = l/2$; $a = l$ (Fig.2), after appropriate transformations for the compliance matrix we obtain:

$$\begin{bmatrix} \delta_{11} & \delta_{12} & \delta_{13} \\ \delta_{21} & \delta_{22} & \delta_{23} \\ \delta_{31} & \delta_{32} & \delta_{33} \end{bmatrix} = \begin{bmatrix} \delta_a & \frac{1}{2}\delta_a & 0 \\ \frac{1}{2}\delta_a & \frac{l^3}{48EI} + \frac{\delta_a+\delta_b}{4} & \frac{1}{2}\delta_b \\ 0 & \frac{1}{2}\delta_b & \delta_b \end{bmatrix} \quad (2)$$

Determinant of the canonical equations of dynamic displacements of the considered system

$$D = \begin{bmatrix} (m_1\delta_{11}\omega_i^2 - 1) & m_2\delta_{12}\omega_i^2 & m_3\delta_{13}\omega_i^2 \\ m_1\delta_{21}\omega_i^2 & (m_2\delta_{22}\omega_i^2 - 1) & m_3\delta_{23}\omega_i^2 \\ m_1\delta_{31}\omega_i^2 & m_2\delta_{32}\omega_i^2 & (m_3\delta_{33}\omega_i^2 - 1) \end{bmatrix} = 0 \quad (3)$$

is more convenient to reveal develop in numbers.

Determining the values of unit displacements (2), taking as geometric and inertial characteristics of the system the following values $l = 24m$, $I = 0{,}8 \cdot 10^{-2}m^4$, $m_1 = m_3 = 3{,}5 \cdot 10^3 kg$, $m_2 = 7{,}0 \cdot 10^3 kg$, $\delta_a = 0{,}04 \cdot 10^{-7} m/n$, $\delta_b = 0{,}8 \cdot 10^{-7} m/n$ and entering the label $k_i = 1/(m/4)\omega_i^2$, for the determinant (3) we obtain

$$D = \begin{bmatrix} 1-k_i & 1 & 0 \\ 0{,}5 & 96-k_i & 10 \\ 0 & 20 & 20-k \end{bmatrix} = 0 \quad (4)$$

reveal develop (4) in numbers, we obtain in expanded form

$$k_i^3 - 124k_i^2 + 238{,}5k_i - 2310 = 0$$

The roots of this equation are $k_1 = 98{,}551$; $k_2 = 17{,}455$; $k_3 = 0{,}994$.

According to the entered label $k = 1/(m/4)\omega_i^2$ for the frequencies of free oscillations we will have $\omega_1 = 26{,}92 rad/sec$; $\omega_2 = 64{,}55 rad/sec$; $\omega_3 = 316{,}23 rad/sec$ which correspond to the values of the periods $T_1 = 0{,}233 sec$; $T_2 = 0{,}097 sec$; $T_3 = 0{,}019 sec$.

Using the found frequencies, the fundamental modes are determined using the equation

$$\left.\begin{aligned} (1-k_i) + 1\rho_{21} + 0\rho_{31} = 0 \\ 0{,}5 + (96-k_i)\rho_{22} + 10\rho_{32} = 0 \\ 0 + 20\rho_{23} + (20-k_i)\rho_{33} = 0 \end{aligned}\right\}$$

by discarding one excess equation and considering that $\rho_{ni} = y_{ni}/y_{1i}$. That said, all $\rho_{1i} = 1$.

Similarly determine the dynamic characteristics for the considered type of structure at different values and ratios of their geometric and inertial characteristics.

Conclusion

The vertical seismic loads determined by the standard method using the values of the first fundamental mode of oscillations allows us to take into account both the effect of the supports on the structure and the effect of the structure itself on the supports expressed in the appearance of additional forces in the supporting structures.

References

1. Papazoglou, J., Elnashai, A.S. (1996) Analytical and field evidence of the damaging effect of vertical earthquake ground motion. *Earthquake Engineering and Structural Dynamics, 25,* 1109 – 1137.;
2. Government of Georgia. (2014). *Ordinance №71 by Government of Georgia. Technical regulation - Earthquake engineering.* (in Georgian);
3. Eurocode 8. (2004). *Design of structures for earthquake resistance – Part 1.* Brussels: European committee for standardization.;
4. Gosstroy of Russia. (2013). *SNiP II - 7 81 Construction in seismic areas.*
5. Central Research Institute of Industrial Buildings. (1977). *Guidelines for the design of single-storey and multistory industrial buildings with a steel frame in seismic areas.* (In Russian);
6. Bezukhov, I.I., Luzhin, O.V., Kolkunov, N.V. (1987). *Stability and dynamic of structures.* (In Russian);
7. Kiselev, V.A. (1980). *Construction mechanics. Special course.* (In Russian);
8. Khazov, P.A., kozhanov D.A., Anushenko, A.M. Satanov A.A. (2020). *Dynamics of building structures under extreme natural influences: vibrations, strengths, resource.* (In Russian);
9. Azhermachev, G.A., Azhermachev, S.G., Abdurakhmanov, A.Z. (2012). About seismic resistance of long span buildings and construction. *Collection of research papers, 9,* 72-78. (In Russian);
10. Shevchenko, F.A., Tsarenko, V.A. (2011). Common and different properties of beams and trusses. *Modern industrial and civil construction, 7*(4), 215-223. (In Russian);
11. Shaha, P. C., Kamatchi, P., Nayak, C. B. (2018). Effect of Vertical Ground Motions on the Response of Long Span Roof Truss. *IIT Roorkee, 57*.;
12. Giltner, B., Kassimali, A. (2000) Equivalent beam method for trusses. *Practice Periodical on Structural Design and Construction, 5*(2), 70-77.;
13. Sekhniashvili, E.A. (1958). On the application of the replacement beam method to the determination of the higher frequencies of vibrations of rod trusses. *Proceedings of the Academy of Sciences, 20*(1), 75-82 (In Georgian);
14. Esadze, S., Pavliashvili, N. (2022). Vertical Seismic Vibration of the Large-span Trussed Beam. *Work of GTU 4*(526), 62-66.;
15. Elnashai, A.S., Papazoglou, A.J. (1997). Procedure and spectra for analysis of RC structures subjected to strong vertical earthquake loads. *Journal of Earthquake Engineering, 1*(1), pp.121-155;
16. Ananjin, M.Y., Fomin, N.I., Tshernogubov, D.E. (2009). Method of the account of pliability in nodes of metal designs of building. *Academic Bulletin of the Uralniiproekt, 3*, 80-85. (In Russian);
17. Abashidze, A.I. (1960). Dynamics of steam turbine foundations. (In Russian).

UDC 624.042.7
SCOPUS CODE 2210
https://doi.org/10.36073/1512-0996-2023-2-63-67

ვერტიკალური სეისმური დატვირთვა ფოლადის დიდმალიან ფერმაზე

სერგო ესაძე	სამოქალაქო და სამრეწველო მშენებლობის დეპარტამენტი, საქართველოს ტექნიკური უნივერსიტეტი, საქართველო, 0160, თბილისი, მ. კოსტავას 68ბ E-mail: s_esadze@gtu.ge
ნინო პავლიაშვილი	სამოქალაქო და სამრეწველო მშენებლობის დეპარტამენტი, საქართველოს ტექნიკური უნივერსიტეტი, საქართველო, 0160, თბილისი, მ. კოსტავას 68ბ E-mail: ninopavliashvili1996@yahoo.com

რეცენზენტები:

ლ. კახიანი, სტუ-ის სამშენებლო ფაკულტეტის პროფესორი
E-mail: l.kakhiani@gtu.ge
დ. ტაბატაძე, სტუ-ის სამშენებლო ფაკულტეტის პროფესორი
E-mail: tabatadze @gtu.ge

ანოტაცია. ნორმატიული მეთოდიკის შესაბამისად სეისმური დატვირთვის განსაზღვრისას, ყველა ტიპის შენობისა და მათი კონსტრუქციული ელემენტებისთვის განიხილება ფუძის სეისმური აჩქარების ჰორიზონტალური მდგენელი. ვერტიკალურ სეისმურ დატვირთვაზე გაანგარიშება მოითხოვება გარკვეული ტიპის კონსტრუქციებისათვის. ასეთი ტიპის კონსტრუქციებს მიეკუთვნება მოცემულ სამუშაოში განხილული ფოლადის კოჭოვანი ფერმა, მალით ზღვრებში 24–40მ. აღნიშნულ კონსტრუქციაზე სეისმური დატვირთვის განსაზღვრისათვის აუცილებელი დინამიკური მახასიათებლების დასადგენად განხილება გამარტივებული მეთოდი. ამისათვის ხდება ფერმის დაყვანა დრეკად საყრდენებზე მდებარე ეკვივალენტური სიხისტის კოჭზე. საანგარიშო მოდელი ასევე საშუალებას იძლევა გათვალისწინებული იყოს განსახილველი კონსტრუქციის გავლენა საყრდენებზე.

საკვანძო სიტყვები: დრეკადი საყრდენები; კოჭოვანი ფერმა; ქცევის ძირითადი ფორმა.

The date of review 13.02.2023
The date of submission 16.02.2023
Signed for publishing 29.05.2023