SOME LONG-SPAN CONSTRUCTION IN EARTHQUAKE REGIONS AND CHOICE OF THE TYPE OF STRUCTURE ON THE BASIS OF WAVE DYNAMIC THEORY

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ABSTRACT

The report deals with investigations on seismic vibration of long-span roofs, as well as displacements and stresses in buildings from P and S waves.

It is very important to calculate the vertical earthquake forces which can increase the stresses in the construction.

For displacement analysis from P and S waves the model of a construction was assumpted as horisontal schistous surroundings.

On the base of these seismic parameters the connection of amplitudes and building vibration was found for different soils and buildings. Then there was found a displacement and stresses in building from P and S waves.

NOMENCLATURES

K_c : Seismic coefficient

β_i : Dinamic coefficient

η_{ik} : Free vibration from coefficient

Q_k : Weight part of a structure concentrated in point k

E :Young's modulus

ν : Poisson's ratio

K_e : An elastic characteristic of the material

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ρ : The density of the material

X, Y, Z: Three components of the propagation of waves

V_p : The speed of propagation of longitudinal waves

V_s . The sp ed of propagation of transverse waves

$V_э$: The effective speed of propagation of waves

d and h : The thickness of the layers

$\rho_э$: Effective meanings of the density

$E_э$: Effective elasticity.

It is very important to calculate the vertical earthquake forces wich can increase the stresses in the construction. The results of design and experiment analysis of shallow spherical, cylindrical and other shells rectangular and square contour with various boundary conditions subjected to vertical and horizontal earthquake forces are shown below.

According to the Structural Code of the Soviet Union earthquake forces in the point k of a structure must be determined by the formula

$$S_{ik} = K_c \beta_i \eta_{ik} Q_k \tag{1}$$

Dynamic coefficient β_i depends on period free vibration of a structure.

The limits of this coefficient are

$$3 \leqslant \beta_i \leqslant 0{,}8$$

Free vibration from the coefficient η_{ik} for a long-span construction can be expressed by this formula

$$\eta_{ik} = \frac{X_{i(\alpha\beta)} \int_0^{\alpha_0}\int_0^{\beta_0} q_{(\alpha\beta)} X_{i(\alpha\beta)}\, d\alpha\, d\beta}{\int_0^{\alpha_0}\int_0^{\beta_0} q_{(\alpha\beta)} X^2_{i(\alpha\beta)}\, d\alpha\, d\beta} \tag{2}$$

where $X_{i(\alpha\beta)}$ - form of free vibration

$q_{(\alpha\beta)}$ - surface load per unit area of shell surface

If suppose $q_{(\alpha\beta)}$ =const and assume $X_{i(\alpha\beta)} = \sin\frac{n\pi\alpha}{\alpha_o} \sin\frac{m\pi\beta}{\beta_o}$
$\eta_{i(\alpha\beta)}$ can be expressed as that

$$\eta_{i(\alpha\beta)} = \frac{16 \sin\frac{n\pi\alpha}{\alpha_o} \sin\frac{m\pi\beta}{\beta_o}}{mn\pi^2} \tag{3}$$

where α_o and β_o dimensions of a shell plan.

By this way vertical earthquake force to point $K_{(\alpha\beta)}$ of shallow spherical, cylindrical and other shells with rectangular and square hinge contour is expressed as follows

$$S_{iK} = 16 K_c q \beta_i \frac{\sin\frac{n\pi\alpha}{\alpha_o} \sin\frac{m\pi\beta}{\beta_o}}{mn\pi^2} \tag{4}$$

The horizontal earthquake force to shallow shells can be written as that

$$S_r = 3 K_c q \tag{5}$$

where q - the uniformly distributed load per unit area of shell surface and β_i =3.

Under the vertical earthquake forces (4) applying on shallow shells with rectangular and square hinge contour membranse stresses can be established as follows

$$\left.\begin{aligned} T_1^i &= A\mu_m^2 c_{mn} \sin\lambda_n\alpha \sin\mu_m\beta \\ T_2^i &= A\lambda_n^2 c_{mn} \sin\lambda_n\alpha \sin\mu_m\beta \\ S^i &= A\lambda_n\mu_m c_{mn} \cos\lambda_n\alpha \cos\mu_m\beta \end{aligned}\right\} \tag{6}$$

where T_1^i, T_2^i and S^i - normal and shearing forces acting on two perpendicular cross sections of a shell

$$A = \frac{4}{\alpha_o\beta_o} \int_0^{\alpha_o}\int_0^{\beta_o} S_{iK} \sin\lambda_n\alpha \sin\mu_m\beta \, d\alpha \, d\beta \qquad \lambda_n = \frac{n\pi\alpha}{\alpha_o} \qquad \mu_m = \frac{m\pi\beta}{\beta_o}$$

C_{mn} - depends on the type of a shell.

Under the horizontal earthquake force (5) applying on shallow shell with rectangular and square hinge contour membranse stresses can be expressed as follows

$$\left.\begin{aligned} T_1 &= \sum_m^{\infty}\sum_n^{\infty} A_{mn} \sin\lambda_n\alpha \ \sin\mu_m\beta \\ T_2 &= \sum_m^{\infty}\sum_n^{\infty} B_{mn} \sin\lambda_n\alpha \ \sin\mu_m\beta \\ S &= \sum_m^{\infty}\sum_n^{\infty} C_{mn} \cos\lambda_n\alpha \ \cos\mu_m\beta \end{aligned}\right\} \tag{7}$$

One of the tasks of the seismic construction is to consider the vibrations of the construction respectively to moving foundation. It is supposed that the speed of propagation of waves in the construction is endlessly large. Under the calculations of the constructions on seismic forces the design load is supposed to be the sum of inertia forces, acting along the main lines of vibrations.

The present work gives the approximate method of the calculations of speed of the propagation of waves in the building. According to this method the peculiarities of seismic forces are regarded here.

Under the propagation of seismic waves in homogenious material the speed of propagation is defined by

$$V = \left(\frac{K_e}{\rho}\right)^{0,5} \tag{8}$$

The magnitude K_e depends on Young's modulus E, Poisson's ratio ν , as well as it depends on the type of elastic deformations (compression, shear) and the respective sizes of medium (massive, a plate, a spindle).

In reality the construction is not a compact body and the volume of the constructing elements, coming into it (walls, floors, partition) constitute 0,2 - 0,3 out of the total volume of the construction.

For the designing of the speeds the building can be a medium with the structural heterogeineity. The seizes of structural heterogeineities are defined by the distances between the floors, walls, partitions and others. These distancies, constituting approximately 3-6m, as the designs show, are less than the lengths of waves, being measured by the hundreds of meters. Therefore it is possible to define approximately densities, elasticities and the speeds of propagation of waves for a building as a whole, as a medium, having structural heterogeineities.

If the sizes of structural heterogeineities are considerably less than the length of the waves, we can consider the propagation of waves to be in homogenious medium, the parameters of which that is elasticity K_e and density ρ are equivalent to the given heterogeineity.

In order to design the speeds of elastic waves a dwelling is considered to be a laminated medium, consisting of layers of two types. For example, during the propagation of the wave in vertical direction the layers are floors and the distances between the floors. The floors are regarded to be a compact layer and the distances between the floors are regarded as a heterogeineious layer. In this heterogeineious layer, which consists of the walls, partition and air distances between them, the elastic wave speeds along the lamination. The cases of the propagation of waves are considered in the direction of X,Y,Z. In all cases the task of the propagation of a flat wave in a flat laminated medium with consequent layers is regarded.

$$\frac{\partial^2 y}{\partial t^2} = \frac{E}{\rho} \cdot \frac{\partial^2 y}{\partial x^2} \qquad (9)$$

The present paper gives the main dependence and formula for the determination of $\rho_э$, $E_э$ and $V_э$, relating to a dwelling as a whole, regarding it as a complicated laminated structure.

For the case of the propagation of a longitudinal wave these values are equally

$$\rho_э = \frac{\sum^n \rho_d d_n + \sum^n \rho_h h_n}{\sum^n d_n + \sum^n h_n} \qquad (10)$$

$$E_{эp} = \frac{\sum^n d_n + \sum^n h_n}{\sum^n \frac{d_n}{E_d} + \sum^n \frac{h_n}{E_h}} \qquad (11)$$

$$V_{эp} = \frac{\sum^n d_n + \sum^n h_n}{\sqrt{\left(\sum^n \frac{d_n}{E_{dp}} + \sum^n \frac{h_n}{E_{hp}}\right)\left(\sum^n \rho_d d_n + \sum^n \rho_h h_n\right)}} \qquad (12)$$

All the values are given with corresponding indexes.

For transverse waves the structure of the formula is analogous to those given for longitudinal waves. Thus, the effective meanings of the density, elasticity and the speed of the propagation of the waves for a dwelling as a whole, in those formula depend on their meanings for main materials and on the geometric sizes of the elements of a dwelling.

On the base of these formula the designs of the effective values of elastic characteristics for the main types of dwellings such as large panel, large block dwellings, the dwelling of a volume block, the dwelling with brick walls have been made (table 1).

As a result of the designs the following conclusions were made:

1. The effective speed of the propagation of the elastic wave for a dwelling as a whole constitutes 80-90% out of the speed in the main material.

2. Tho effective density constitutes 20-30% out of the density of the main material.

3. The effective seismic harshness $\rho_э V_э$ constitutes 15-25% out of the harshness of the material.

Table 1 shows the design values of Z component four types of dwellings:

1 - largepanel dwellings

2 - large block dwellings

3.- dwellings of a volume block

4 - dwellings with brick walls

The expansion of the flat refracted wave along X direction of the building can be expressed by the equation

$$\frac{\partial^2 y}{\partial t^2} = V^2_{э(\rho,s)} \frac{\partial^2 y}{\partial x^2} \tag{13}$$

The solution of this equation for a harmonic wave is

$$y(x,t) = A \cos \omega \left(t - \frac{x}{V_{э(\rho,s)}}\right) \tag{14}$$

The deformation of building material is the first derivation to displacement X:

$$\mathcal{E}(x,t) = \frac{\partial y}{\partial x} = A \frac{\omega}{V_{э(\rho,s)}} \sin \omega \left(t - \frac{x}{V_{э(\rho,s)}}\right) \tag{15}$$

Suppose effective elasticity of building as $E_{p,s}$ function of stresses can be expressed by this formula

$$\sigma_{(x,t)} = \frac{A E_{э(p,s)} \omega}{V_{э(p,s)}} \sin \omega (t - \frac{x}{V_{э(p,s)}}) \quad (16)$$

The highest possible value of $\sigma(x,t)$ is possible when

$$\sin \omega (t - \frac{x}{V_{э(p,s)}}) = 1$$

When $E_э = V^2_{э(p,s)} \rho$ and $A\omega = S$

$$\sigma_{max} = S V_{э(p,s)} \rho \quad (17)$$

Where S - the spectrum of an action in accordance with G.Housner

$V_{э(p,s)} \rho$ - the effective seismic harshness for buildings.

The table 2 shows the average stresses in the buildings in accordance with their seismic harshness.

These stresses will be less than stresses in the material of a building because the effective value of seismic harshness can be evaluated as 20% from harshness of the main material.

Table 1

Speed V_p and V_s wave propagation, density of the material ρ and seismic harshness ρV_p and ρV_s for type of the buildings.

Parameters	Measure	Value of parameters of the buildings 1	2	3	4
$\rho \cdot 10^{-6}$	kg sec^{-2} cm^{-4}	0,53	0,44	0,29	0,56
$V_p \cdot 10^5$	cm sec^{-1}	1,95	2,48	1,78	0,92
$V_s \cdot 10^5$	cm sec^{-1}	1,22	1,51	1,08	0,60
$\rho \cdot V_p$	kg sec cm^{-3}	0,103	0,108	0,052	0,052
$\rho \cdot V_s$	kg sec cm^{-3}	0,065	0,067	0,031	0,034

Table 2

Normal and shearing stresses in the buildings

Type of building	Normal stresses kg cm^{-2}	Shearing stresses kg cm^{-2}
I - buildings with a lightened constructions	1,3-3,4	0,7-2,0
II - framework buildings with light filling, light concrete large block dwellings	3,4-6,7	2,0-4,0
III - dwellings with brick walls and concrete floor	6,7-13,4	4,0-7,4