DYNAMIC PROPERTIES AND SEISMIC RESPONSE OF FRAMED WALLS AND PANEL BUILDINGS.

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Abstracts.

A method of calculation of seismic response of multistory frame-wall structures is worked out, which had been applied to more than a hundred types of frame with structural walls buildings and checked by the testing of a reinforced concrete model. It had been found that the interaction of frames and walls decreases the bending moment at the base of the walls by 50% and shear force by 25%. The relation between the frames and structural walls total rigidities has been established which provides the efficient distribution of the moments and shears.

The general problem of dynamic characteristic determination and estimation scheme of space vibrations of three-dimentional structure under seismic effects is considered. It is found that the presence of openings in structure causes the change both in frequences and in vibration modes. The placing of additional mass has essentional meaning in computation.

In recent years the frame-wall structures for multistory buildings in the seismic regions has been regarded as the most efficient. The lateral strength and stiffness are provided by means of flescible element frames interacting with structural walls or rigid cores, interconnected with floor beams and slabs.

The proper design of these structures requires the investigation of the frames and walls interaction under the la-

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teral loads.

The method of calculation based on the deformation equations in the matrix form for an equivalent rod system has been worked out. The flexural and shear deformations of the rods, elastic yielding of the soil and the horizontal deformations of the floor constructions are accounted for. The structural walls with openings are subdivided in each story into piers and spandrel beams constituting an equivalent frame structure with finite cize of rods cross sections.

Equilibrium equations of N-story frame-wall structure are

$$
\begin{aligned}
A_1 X_1 &+ C_1 X_2 = D_1 \\
C_1^T X_1 &+ A_2 X_2 + C_2 X_3 = D_2 \\
&\dots \\
C_{n-1}^T X_1 &+ A_n X_n + C_n X_{n+1} = D_n \\
&\dots \\
C_N X_N &+ A_0 X_0 = D_0
\end{aligned}
\tag{1}
$$

A_n and C_n - reaction matricx in n-th story elements, defined with consideration of the ascial deformations and finite cross sections sizes.

X_n - column-matrix of group unknowns: nodal rotations and vertical and horizontal displacements in the n-th story.

D_n - column matrix of external lateral loads.

The set of equations (1) is of the cell, three-diagonal form and its solution may be obtained in terms of the recurrence formula

$$X_n = V_n \left[U_n - C_n X_{n+1} \right] \tag{2}$$

in which

$$V_n = \left[A_n - C_{n-1}^T \cdot V_{n-1} \cdot C_{n-1} \right]^{-1}; \quad U_n = D_n - C_{n-1}^T \cdot V_{n-1} \cdot U_{n-1}$$

The unknowns X_n are defined by subsequent exclusion beginning with the upper story. The last is the equation of boundary conditions at the base, which includes the displacement and rotation of the foundation. The last equation defines the group unknowns X_0.

More than a hundred specimens of frame-wall structures had been calculated, with different heights (the number of stories from 9 to 30), number and type of structural walls (solid and with one, two and three openings) and with different relations of the frames and walls stiffnesses.

The deformation shapes and force distribution are shown in "Fig.1". The frames have shear and walls-flexural shapes of the deformation curves. The deformation of the frame-wall structure is near to the flexural shape in the lower part and shear in the upper.

The distribution of lateral load between frames and walls has some peculiarities. In the upper stories the frames are the most loaded and the shear force even exceeds the total external lateral load, which corresponds to the inverse direction of the shear force in the upper level of the structural walls. On the contrary in the lower stories the walls carry the greatest part of the lateral load.

These features were peculiar to all calculated specimens of the frame wall buildings. The negative shear force in the upper end of the walls, the shear force in frames, the level and value of the bbending moment maximum in the upper part of the walls and the bending moment at the base of wall piers varied dependently on the number of stories and the relation of the frames and walls total rigities.

The analysis above leads to the following conclusion. Because of the discrepancy of the frame and wall deformation shapes, in the upper level of the system the frames take the greater share of the external lateral load than in the lower stories. So the unloading effect of the frames relative to the walls is more significant on the bending moment than shear force at the base of the walls. The share of the frames in common performance of the frame wall system must be evaluated by taking into consideration both the bending moments and shear forces and not shears only.

It has been stated in the course of investigations that the ratio of rigidities in the upper level, given by the formula (3) may serve as a stable characteristic of the frame wall structure

$$K = \frac{C_N^f}{C_N^W} \qquad (3)$$

in which

$C_N^f = 1/\delta_{NN}^f$ is the total rigidities of frames relative to the unit horizontal displacement of the upper level,

$C_N^W = 1/\delta_{NN}^W$ the same of the walls,

$\delta_{NN}^f, \delta_{NN}^W$ influence matrix elements of frames and walls relatively.

The ratio (3) defines the distribution of moments and shears between the frames and walls. In "Fig.2" are shown the shares of shear force (graph A) and bending moment (graph B) which carry the walls in dependance on the ratio K. The graphs show that there is a significant reducing of the bending moments at the wall base which provides an essential material economy in the walls and foundations constructions.

The graphs on "Fig.3." show the ratio of the unloading bending moment M_{un}^W to the total external moment at the base, $M_e = \Sigma P_i \cdot H_i$ depending upon the parameter K. The most effective unloading of the walls takes place with the rigidity ratio K variing from 1 to 3.

1).The following factors must be accounted for at the designing of the frame wall structures: flexural and shear deformations, overtical deformations of piers, finite sizes of element cross sections and the rigidity of straight arches in the construction of walls with openings. Neglecting of any of these factors may lead to errors near to 100%.

2).The frame wall structures performance is different from that of frames or walls regarded separatly. The deformation and force distribution must not be defined as a linear combination of strains and forces in frames and walls. The proper result may be reached by taking into account their interaction and common performance.

3).The frames and walls interaction may lead to the unloading of the walls by 50% of the bending moment and 25% of the shear force at the base.

4).The efficient decrease of the bending moments in the walls (in commonly used design schemes) takes place at the rigidity ratio variing in the range

$$1.0 \leq K \leq 3.0$$

The lower values are recommended for not very tall, up to 7-9 story buildings. The upper values - for the buildings up to 30 stories.

5).The reliability of these results had been confirmed by testing with horizontal loads of a reinforced concrete model in 1:5 natural size of a frame with rigid core nine story building.

The general problem of space seismic vibrations of structures in a linear statement can be solved by finite element method in the following way

Let us consider the arbitrary space structure connected with soil by supports, having numbers ν (ν =1,2... $\bar{\nu}$). In a more general case support points of the structure additionally to translatory effects can experience rotations; the full describing of seismic effect must include three rotation ones.

The seismic displacement of space system points are considered as

$$\{Y\} = \{y\} + \{y^*\}$$

Here $\{y\}$ - the vector of dynamic displacements, caused by inertia force effects of system masses; $\{y^*\}$ - the vector of kinematic displacements, corresponding to static effect of external seismic motion, applied to space system support points. Such displacements are determined by the following matrix relations

$$\{y^*\} = -[K]^{-1} \cdot [K_o] \cdot \{Y_o\}$$

where $\{Y_o\}$ s-dimensional vector of seismic effects, representing seismic displacements of soil in direction to s support connections, which can be changed in time irrespecting of each other;

$[K_o]$ - the matrix of base displacements effect on the response of the initial system.

Thus the system with $N + S$ degrees of freedom is considered where N - a number of degrees of freedom of the system; S - a number of possible displacements of support points. Then the equation for a whole system in matrix form will be

$$\begin{bmatrix} [M] & [M_0] \\ [M_0]^T & [m] \end{bmatrix} \begin{Bmatrix} \{\ddot{y}\} \\ \{\ddot{y}_0\} \end{Bmatrix} + \begin{bmatrix} [C] & [C_0] \\ [C_0]^T & [c] \end{bmatrix} \begin{Bmatrix} \{\dot{y}\} \\ \{\dot{y}_0\} \end{Bmatrix} +$$

$$\begin{bmatrix} [K] & [K_0] \\ [K_0] & [k] \end{bmatrix} \begin{Bmatrix} \{y\} \\ \{y_0\} \end{Bmatrix} = \begin{Bmatrix} \{0\} \\ \{F(t)\} \end{Bmatrix}$$

As the motion of support points of the structure is given, the number of unknown displacements and hence the number of motion equations will be

$$[M]\{\ddot{y}\} + [C]\{\dot{y}\} + [K]\{y\} = \{f(t)\}$$

where $\{f(t)\} = -([M_0] - [M]\cdot[K]^{-1}\cdot[K_0])\{\ddot{y}_0\} -$

$$- ([C_0] - [C]\cdot[K]^{-1}\cdot[K_0])\{\dot{y}_0\}$$

If soil conditions under all support points are equal, the difference in displacements $\{y_0\}$ of separate support points is caused only by unsynchronism coming of seismic waves to them, propagating with final velocity. In this case the functions $\{y_0(t)\}$ can be written in the form

$$\{y_0(t)\} = 0 \qquad \text{for } t \leq X_v / V$$

$$\{y_0(t)\} = \{y_0(t - X_v / V)\} \text{ for } t > X_v / V$$

Here X_v - the direction from v to the first support point of the base in the line of seismic wave propagation; V - velocity of seismic wave propagation.

Under the large velocity of propagation of seismic waves or the small extension of structure one can neglect non-synchronism of vibrations of structure support points and $\{y_0(t)\}$ can be taken constant for all support points in time moment considered.

Algorithm of problem solution of computation upon the real seismic effect allows to determine several of extreme natural frequances and forms of vibrations of structure considered; to obtain the displacements and force factors for the selected typical structure points.

These values are typed for each time moment with determination of their maximum values in all structure points at the end of computation. The average-square values of seismic forces along a whole structure are determinated. Also the forms of displacements, epures of seismic forces of a whole structure, corresponding to the criteria maxima of stressed state in three mutually perpendicular directions and time of coming of corresponding maxima are determined.

Suggested methods of investigation and estimation of the most safe stressed state in each structure section is suitable for the computation of space box-type systems such as: rectangular reservoirs, three-dimensional building blocks, bunkers, shaft wells, box-type stiffness nuclei of high-altitude buildings, span constructions of auto- and railway bridges etc.

Particularly the investigation of dynamic characteristics of multistoried structures of box-type, bearing in separate cases the additional mass is carried out. For the boxes without the floor slab, used in modern multistory buildings with stiffness nucleus it is of interest the fact that the first three frequences are close in value. It should be noted that in uniform rectangular nucleus due to equal stiffness in two directions some frequences are equal.

Under the analysis of dynamic characteristics of box-type shaft of wells with a floor one can note the presence of openings leads to the change of natural frequences and forms of vibrations "Fig.4." These changes in the behaviour of structure depend on the dimensions of openings and take place due to structure stiffness change.

Analysis of computation results of box-type wells with additional mass shows that such system holds qualitively new spectrum of natural vibrations in comparison with the well without mass. The placing of additional mass at the floor level has essential significance. For some points of local mass applying the frequency of fundamental mode is changed more than in two times in comparison with the case, when mass is applied to the centre of floor slab. In corresponding forms of vibrations one can note the significant rotations of the floor in plan.

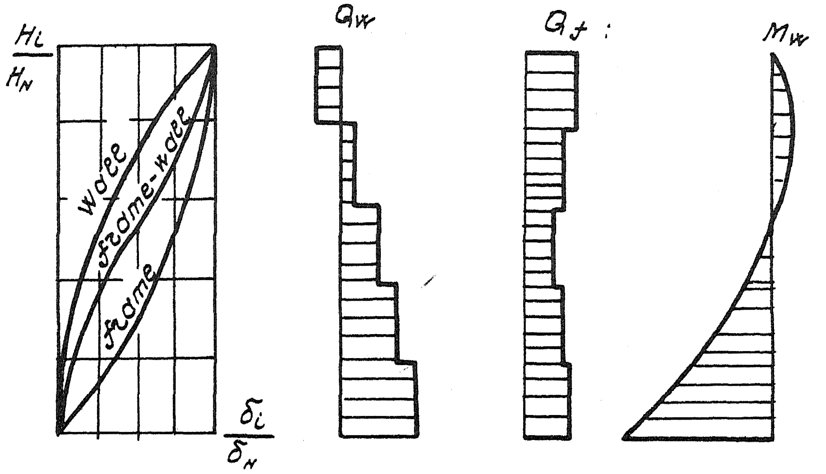

Fig. 1. Deformation shapes and force distribution in frame-wall structures.

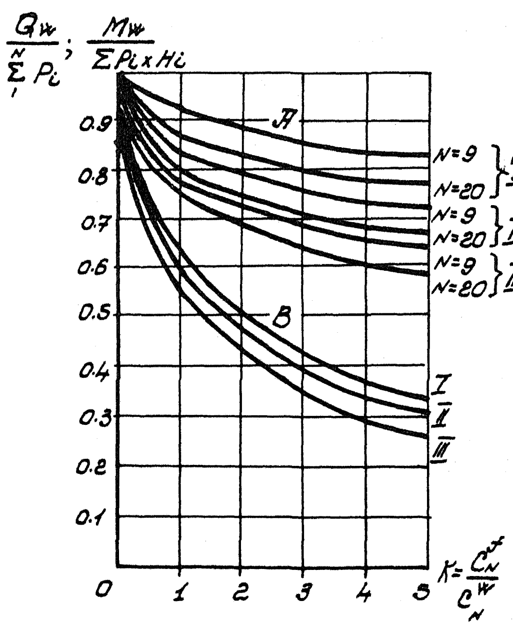

Fig. 2. Base shears (A) and moments (B) depending on K.

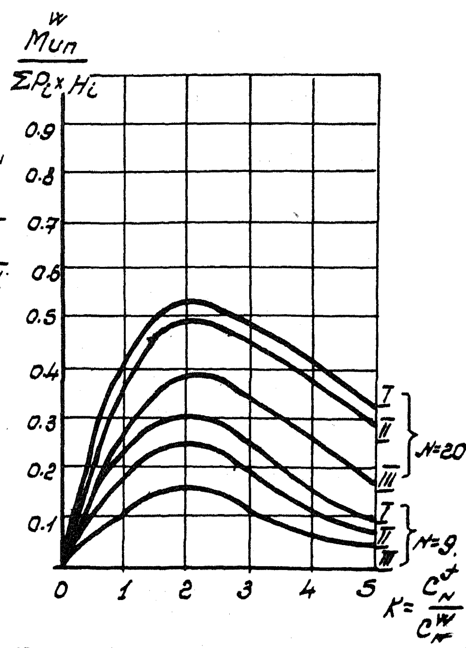

Fig.3. Ratio of unloading bending moment to extremal moment at the base.

1- solid wall; 2-one opening wall; 3- three opening wall.

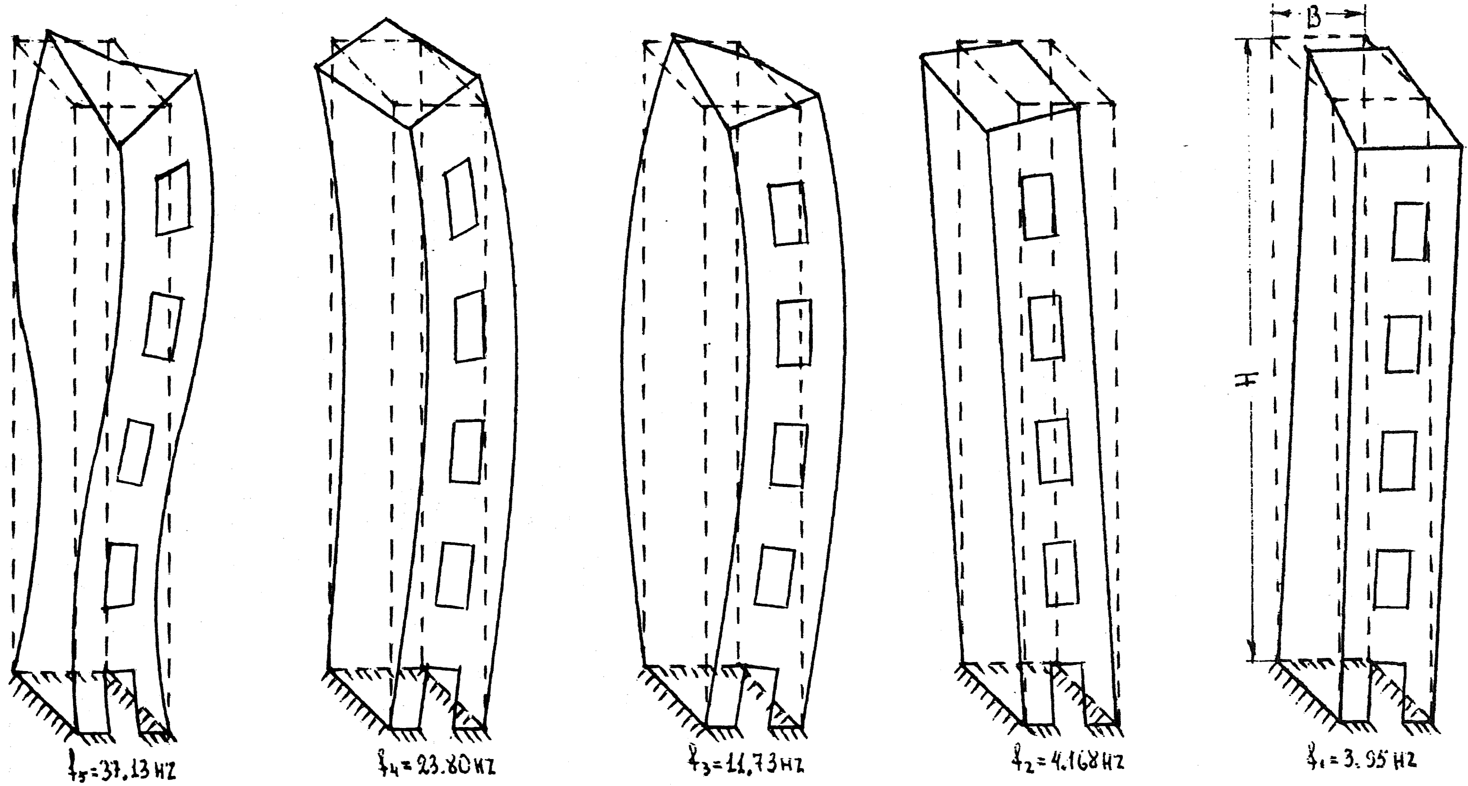

Fig.4. Vibration modes of shaft wells. (H/B=13)