ON THE NON-LINEAR DEFORMATIONS BASE OF EARTHQUAKE-PROOF BUILDINGS UNDER OSCILLATIONS

by

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SYNOPSIS

It is assumed that compressive deformation of the ground are elastic-plastic and the ground Cannot act under tension. Basing on these assumptions, there was developed a non-linear calculation model of the large-panel building base under rocking vacillations. Cood corroboration of the calculation model was obtained in the vibration tests of 1/4 life size model of the 10-storey building erected on the ground base. Principal dynamic propertis and seismic response of buildings on the non-linear ground base are dealt with in this paper.

INTRODUCTION

It is known that the base deformability bears an important effect up on the performance of the large-panel building under vibrations. For example, displacement caused by rocking vacillations of the 8-9-storey large-panel building amounts to so per cent complete upper floor displacement by small vibrations [2].

It is natural to assume that the non-linear response of the building has to an even groater degree to depend on the non-linear response of bases. According to the data of high-capacity vibration tests the stiffness of bases can be considerably reduced as the intensity of vibrations inreases. The authors often elicitated this dependence by the vibration tests of buildings and models [2].

In contrast to non-linear structural stiffness that of the base comes back almost completely after vibrating has been stopped.

However, the non-linear processes taking place in the ground base of the building under heary vibrations and theiz inflience on the dynamic behaviour of system "building-ground" has not been studied asyet.

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THEORETICAL RESEARCH

It is very important to take into assount the fact that the non-linear deformations of the ground take place even under small strains and the residual deformations are considerable.

The common stress-stroin relation for the ground under compression is shown in Fig 1 [1].

However, this diagram is normally used for calculating centrally loaded foundations which are not taken off base.

The displacement caused by rocking of the building like rigid massif on the ground accounts for a large part of complete vibration displacement. The breaking of coutact between the foundation part and the ground can take place in the large-panel multistoray building under roking of this type.

It will be convenient in the following analysis to accept the calculation scheme of vacillating building as an absolutely rigid massif and to add the diagram of the ground deformation column to horisontal section 3-4-3. This part of the diagram shows an arbitrary motion of the foundation part when breaking contact (Fig.1).

The above assumption that the building is an absolutely rigid massif allows for simplifying the problem of the pure deformation of ground base. The vibrations of designed model can be written in the form of an equation:

$$\ddot{\varphi} + \gamma\omega\dot{\varphi} + \frac{M(\varphi)}{mH^2} = \frac{P(t)}{mH}, \qquad (1)$$

in which

φ - angle of foundation rotation,

γ, ω - coefficient of resistance, and natural frequency of linear vibrations,

$M(\varphi)$- non-linear force characteristics of the base,

m, H - building mass reduced to the point of applying the external load, and building height,

$P(t)$- external load: vibrational $P\cdot\alpha^2 \sin\alpha t$ or seismic $m\ddot{y}_0(t)$

The complete diagram of elementary ground column in mathematic terms is the following relation:

$$P_i = C_i y_i + d_i$$

Coefficients $C_i d_i$ depend on the sequence of loadings. Force characteristics $M(\varphi)$ can be found from the equilibrium equation

$$\begin{cases} M - N\frac{\Delta\ell(n-1)}{2} + \Delta\ell^2\sum_{i=1}^{n}[(C_i y_i + d_i)(i-1)] = 0; \\ N - \Delta\ell\sum_{i=1}^{n}(C_i y_i + d_i) = 0, \end{cases} \qquad (2)$$

From (2)

$$M(\varphi) = \varphi\left(S_1 - \frac{S_2^2}{S_3}\right)\Delta\ell^3 + N\Delta\ell\left(\frac{n-1}{2} - \frac{S_2}{S_3}\right) + \Delta\ell^2\left(\frac{S_2 S_4}{S_3} - S_5\right), \qquad (3)$$

$$y_{left} = \frac{N + \varphi\Delta\ell^2 S_2 - \Delta\ell S_4}{\Delta\ell \cdot S_3},$$

$$y_i = y_{left} - \varphi\Delta\ell(i-1),$$

where

$$S_1 = \sum_{i=1}^{n} C_i(i-1)^2, \quad S_2 = \sum_{i=1}^{n} d_i(i-1),$$

$$S_3 = \sum_{i=1}^{n} C_i, \quad S_4 = \sum_{i=1}^{n} d_i, \quad S_5 = \sum_{i=1}^{n} d_i(i-1)$$

Taking into account (3), the motion equation (1) can be integrated by numerical method, for example, by modified Runge)Cutt's method. The procedure of numerical method corresponds to successive loading of the system.

To calculate the above system under vibrational or seismic effects, the programe for the computer has been elaborated. This programe can be too used for calculating system under static alternating load. In this case, the procedure of step by step method is the same as the above, but the integration of equation (1) is substituted with the following calculation:

$$\varphi = \frac{M - N\Delta\ell\left(\frac{n-1}{2} - \frac{S_2}{S_3}\right) - \Delta\ell^2\left(\frac{S_2 S_4}{S_3} - S_5\right)}{\Delta\ell^3\left(S_1 - \frac{S_2^2}{S_3}\right)} \qquad (4)$$

THE PECULIARITIES OF NON-LINEAR BASE DEFORMATIONS UNDER VIBRATIONS

Results of calculations show that partial breaking of contact between the foundation and the base exerts the greatest influence on the base respouse (Fig.2).

If the ground deformations are elastic, the base stiffuess can be decreased in 2.5 times, when $\ell_{Bz} = 0{,}5L$ (Fig.3). The plastic deformations enlarge the angle of foundation rotation and reduce the stiffuess in addition (Fig. 2,3). The plastic condensation of the ground enlarges the breaking area of the foundation under rocking vibrations as shown in Fig.3.

At the same time, the forms of hysteresis loops, angle rotations, resonance curve and small value of absorption coefficient testifies to the insignificant display of plastic properties of ground. For the system with single-side ties that insignificant display is caused by a sharp decrease in the area of hysteresis loop (to compare Fig. 4a and 4b). The non-linear-elastic nature of building vibrations under vibration tests is too explained by this fact.

EXPERIMENTAL STUDY OF NON-LINEAR BASE DEFORMATIONS

To verify the calculation scheme there were made the vibration tests of 10-storey building model. The seale of the model was 1/4. The model was erected on the ground. The tests were carried out by means of vibration generators which were placed ou the upper floor. In These tests displacement of the foundation as related to the ground was specially measured. The 4,5 mm crack after breaking the contact was reached (Δ_{cr}) as well as the 1,5 mm chink by ground condensation (Δ_{ch}) - (Fig. 3,6). The relations hip $M(\varphi)$ (Fig. 2) valuse of crack form of resonance curves and the line well confirm the theoretical values.

Therefore the above calculation scheme may be used for calculating actual buildings.

THE ANALYSIS THE BASE NON-LINEAR DEFORMATION EFFECT UPON VIBRATIONS AND SEISMIC RESPONSE OF A 8-STOREYS LARGE-PANEL BUILDING IN ALMA-ATA

The building bases upon boulder bed. Dimensions of foundation slab are 34,6 x 16,1 x 0,5 m.

For this building the non-linear processes noted above lead to the 2-3 times decrease in the bases stiffuess. If the deformations of the structure is not taken into account, the narutal frequency is decreased 1,4-1,75 times, and it is decreased 1,25-1,5 times if the elastic deformations of the structure are considered. (Fig.7). Hence the impulsive load is approximately twice decreased deformations of the structure is not taben into account, the natural frequency is decreased 1,4-1,75 times, and it is decreased 1,25-1,5 times if the elastic deformations of the structure are considered (Fig.7). Hence, the impulsive load is approcimately twice decreased.

But it is necessary to take into account that the about 2 times reduction of the contact area corresponds to the above decrease of the load (Fig.2). This makes the conditions of ground strength worse.

There was made the calculation of the building base under accelerogram of Hollister, 1949 [5]. In this accelerogram the accelorations were 2 times increased. If the non-linear base deformation is taken into account, the moment, applied to the base is 2,5-3 times less, but the length breaking area can exceed 0,5 (Fig.8). Therefore in line with the USSR Building Codes [3] the stability of the ground way be unprovided for.

CONCLUSIONS

On the basis of theoretical and experimental studies there was developed a design model of the base of large-panel and stone buildings with regard to the breaking of the foundation off the ground, and to the plastic deformations of the latter. Such a design scheme makes it possible to calculate the bass for the static, vibro and earthquake effects.

The most important result of the base non-linear deformations is the decrease in the forces under vacillations as well as in the foundation resting area on the base.

The partial breaking of the foundation off the ground, as well as the formation of the crack caused by ground compression may lead to the appearance of a certain suspension of building structures, which calls for additional forces and ought to be taken in to account in design, for instance, when applying methods [4].

Under earthquane loads notwithstanding the double or even triple reduction of forces, there may arise in the non-linearly deformable bases the short-term combinations of the moments exceeding rated values, as well as of the breaking area lengtha exceeding the allowable values (0,5 foundation length, which threatens the stability conditions of the base.

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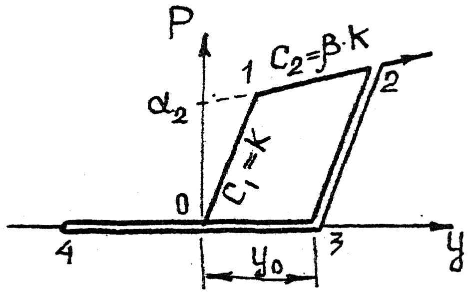

Fig.1

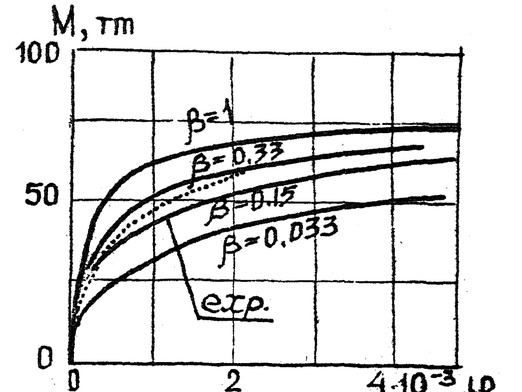

Fig.2

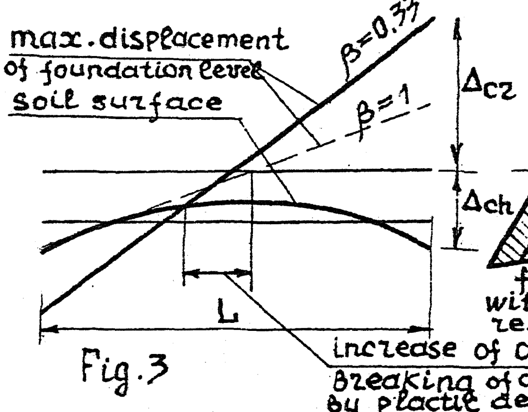

Fig.3

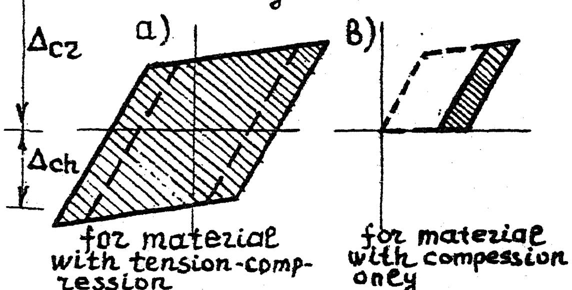

Fig.4

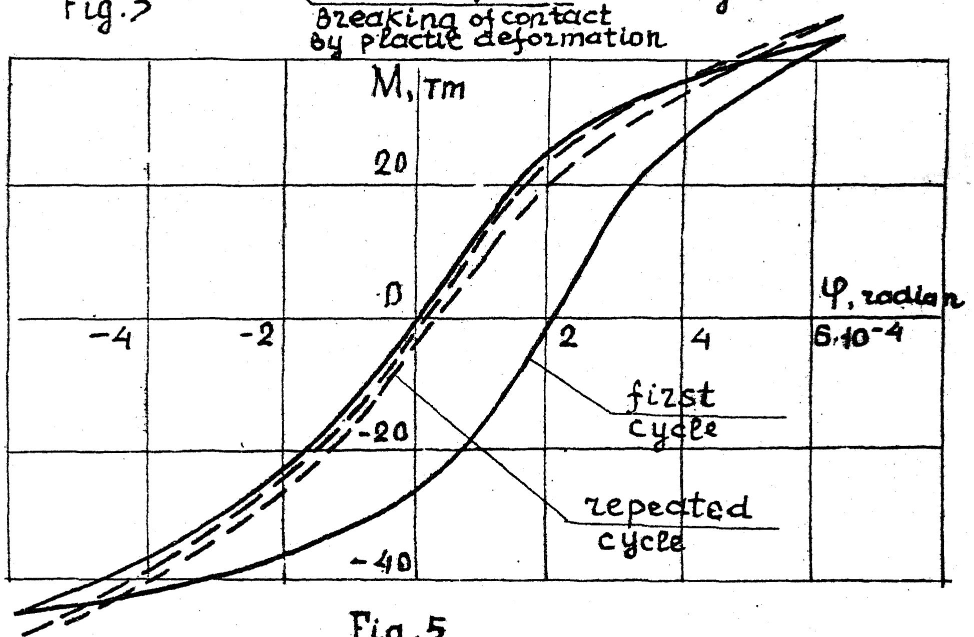

Fig.5

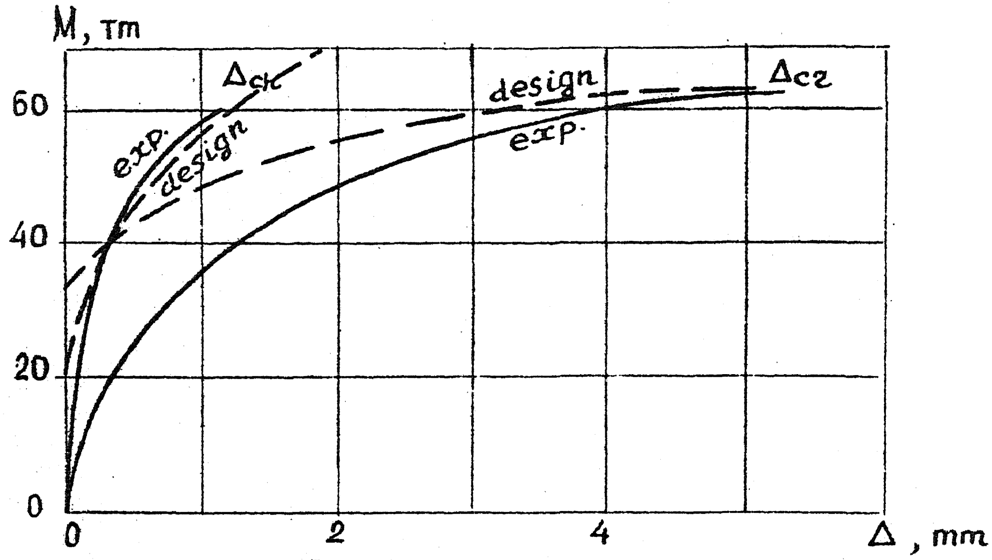

Fig.6

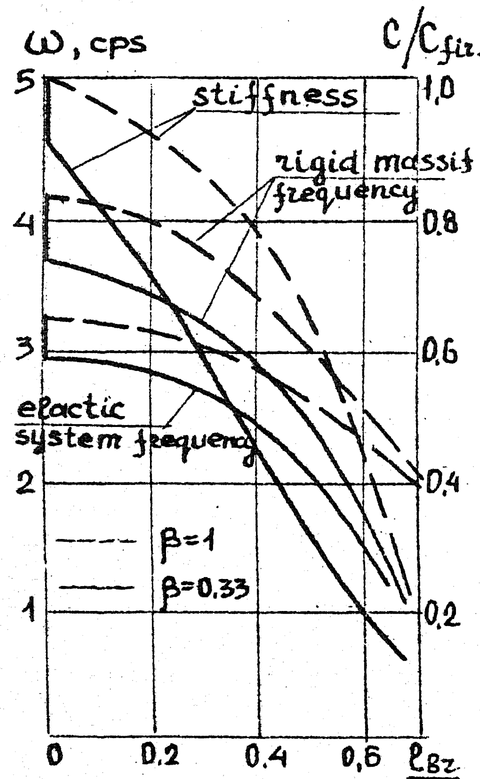

Fig.7

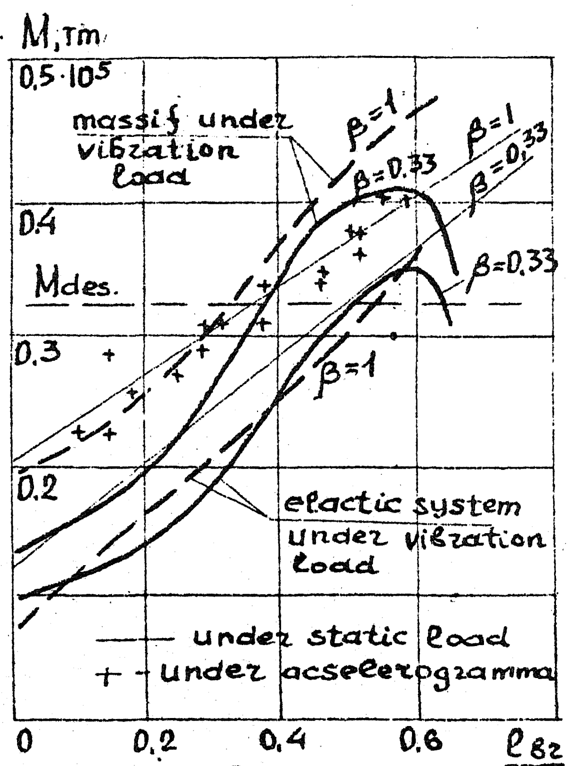

Fig. 8