RESEARCH ON STRESSES IN FRAME UNITS OF SEISMO-RESISTANT EXPANDED CLAY CONCRETE SKELETON

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ANNOTATION

The concern of the report is the efficiency of expanded clay concrete application in rigid frame antiseismic buildings. There are given the results of investigations on full-scale frame units of a skeleton under non-symmetrical loading.

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The application of light structural materials, particularly, concretes, is a very perspective trend in the field of seismoresistant construction. At present, great experience is accumulated in the field of light concrete application in bearing and enclosing structures of buildings made out of large-size elements, in-situ concrete buildings as well as in enclosing structures of frame buildings. Light concretes for posts and cross-bars in rigid frames are used only in certain cases as the behaviour of structures, elements and their connections under intensive dynamic (seismic) loads is unknown.

The application of light concretes and, particularly, expanded clay concrete (keramzite concrete) in bearing rigid frames of seismoresistant buildings ensures a number of advantages compared with analogous structures of heavy concrete. It is conditioned by the following considerations. Possessing approximately the same mechanical properties as heavy concrete of the same strength, keramzite concrete is characterized by a lower elastic modulus resulting in the reduction of horizontal rigidity of a bearing rigid frame. In its turn, it conditions the reduction in the oscillation frequencies of a building and in horizontal seismic loads. The obtained effect can be evaluated by the coefficient of the rated seismic load reduction [3]:

$$K_{\text{с.н.}} = S_{\text{к.б.}} / S_{\text{т.б.}} = \sqrt{E_{\text{к.б.}} / E_{\text{т.б.}}} < 1 \qquad \text{(Eq.1)}$$

where $S_{\text{к.б.}}$ ($S_{\text{т.б.}}$) – the rated seismic load on the frame made out of keramzite concrete (heavy concrete)

$E_{\text{к.б.}}$ ($E_{\text{т.б.}}$) – initial elastic modulus of keramzite concrete (heavy concrete).

According to the existing building norms, the use of keramzite concrete instead of heavy concrete is efficient in rigid frame buildings

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BUILDING RESPONSE

The periods of the three modes of the computing center are indicated on the spectrum of Fig. 6. The fundamental mode period is somewhat shorter than the period of peak spectral response, and one must recognize that any deviation from the ideal structural conditions, e.g., flexure in the column bases, floor flexure, or structural damage, would lengthen the period and shove it over into the region of even greater spectral response.

A computation of the steel and concrete stresses that would result from the equivalent static lateral forces stipulated in the Romanian building code reveals that the building did comply with the stress limitations of the code. A spectrum analysis of the response, however, indicates stresses far in excess of the code limits and far in excess of the strength of the concrete. For spectral response to exceed code limits is not unusual, but in this case the margin was abnormally large. It is unfortunate that the dynamic properties of the structure tuned it so well to the ground motion of that event.

ENGINEERING IMPLICATIONS

Three factors are identifiable as strong contributors to the collapse of the computing center, namely, the column ties, the long period, and the lack of a second line of defense.

The column tie scheme proved inadequate. Fig. 7 shows the failure of one of the ground story columns. All failed at the top, with the longitudinal bars buckled, concrete shattered, and ties spread open or fractured. Here it can be seen that some of the longitudinal bars stopped short of the capital, and some are outside of the visible ties. The 8 mm. Ø ties were smaller than permitted by some codes; the Uniform Building Code, for example, requires No. 3 bars (9.5 mm. Ø) as the smallest permissible ties. The use of hairpin bars instead of closed loops was evidently permitted by the Romanian code, but is banned by some other codes. UBC requires that every corner bar and alternate longitudinal bars be located in the corner of a tie, and that framing members subject to stress reversals shall have closed ties, closed stirrups, or spirals extending around the main reinforcement.

The long period of the building resulted from the heavy mass and the absence of shear walls to contribute to the stiffness. More than half a century ago, Dr. Tachu Naito endorsed the principle of using abundant shear walls, symmetrically disposed, to improve earthquake resistance. His admonition proved sound in the disastrous Tokyo earthquake of 1923, and it remains equally sound today. Yet modern seismic building codes tacitly foster its neglect. In the great majority of codes, design forces are reduced if the period is lengthened. American codes make the seismic coefficient C proportional to either $T^{-1/2}$ or $T^{-1/3}$. The ATC-3 recommendations use $T^{-2/3}$. The Romanian code transverse force and the moment at the base of the cross-bar.

The first micro crack in the second unit appeared when Q = 32.4 kN = 0.41 Q_{ult}. Quickly developing along the compressed diagonal the crack was opening and, as a result, the cross rod fixed in the central zone of the unit was included in the structural work. With an external load being increased, the steel rod underwent plastic deformation. These tensile deformations concentrated around the crack, while at the adjacent concrete areas along the extended diagonal the value of stress was changed. At Q = 79.5 kN the deformations along the extended diagonal sharply enlarged and the unit was destructed.

On the basis of the methodics described in the reference [2], the angles of distortion φ_u for the supporting sections of cross-bars and the central zones of the units were calculated, the graphs are presented on fig. 3a. The graphs being combined, there was built a summed diagram of deformation in axes $M - \varphi_u$ (fig. 3b), for which the ration of the maximum angle of distortion φ_{max} to the angle of distortion under ultimate load φ_0 equals 4.0. In view of the fact, it was recommended to strengthen the central zones of the frame unit by placing horizontal reinforcement nets and it was introduced into construction practice[4].

From the above graphs it follows that the moment when the unit behaviour transfers into a plastic stage is conditioned by the deformation nature of cross-bar supporting section, however, the further non-linear behaviour and the parameters of the unit ultimate state were completely determined by the reliability and deformation of its central zone.

The stress state of the unit and the adjacent areas of columns and the cross-bar in an elastic stage was analysed by computer using the finite element method. The results of calculations are given on fig. 4, 5, they come to the following:

- depending on the stress state there are four zones (I, II, III, IV) in the unit;
- in the peripheral zones of the unit certain components of stress state reach its extreme values; their trajectories do not coincide with the directions of the unit diagonals;
- in the centre of the unit all the components of stress state simultaneously reach big values; their trajectories rather closely coincide with the directions of unit diagonals;
- the cracks developed during tests at the lower corner of the unit central zone and at the base of the cross-bar coincide with the locations predicted by elastic calculations.

With the loads being increased and with the ties being excluded from the structural work of the cracked keramzite concrete, the stresses in the unit are sharply growing, their trajectories are more closely approaching the directions of the diagonals and it entails cracks in the centre of the unit along its compressed diagonal.

Conclusions

1. The true evaluation of keramzite concrete frame unit behaviour under big loads can be made by calculations with due regard to the heterogeneous of the material and non-linearity of structure deformation.

2. The diagonal crack in the unit can be explained by combined interaction of the main normal and the highest tangent stresses whose trajectories under ultimate state approach the direction of the unit diagonal.

3. The ultimate state of the unit is determined by the behaviour of its central zone. By strengthening this zone, the bearing capacity of the unit and the whole structural system can be increased.

References

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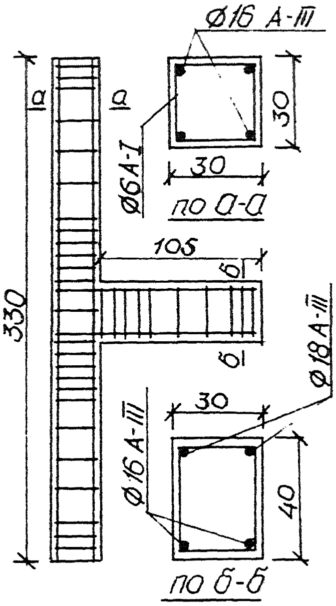

Fig. 1. Structure of the unit

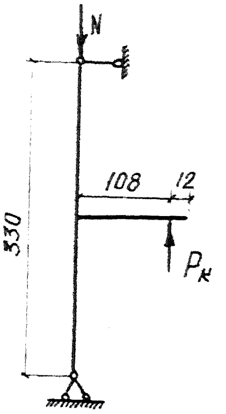

Fig. 2. Rated scheme of the unit

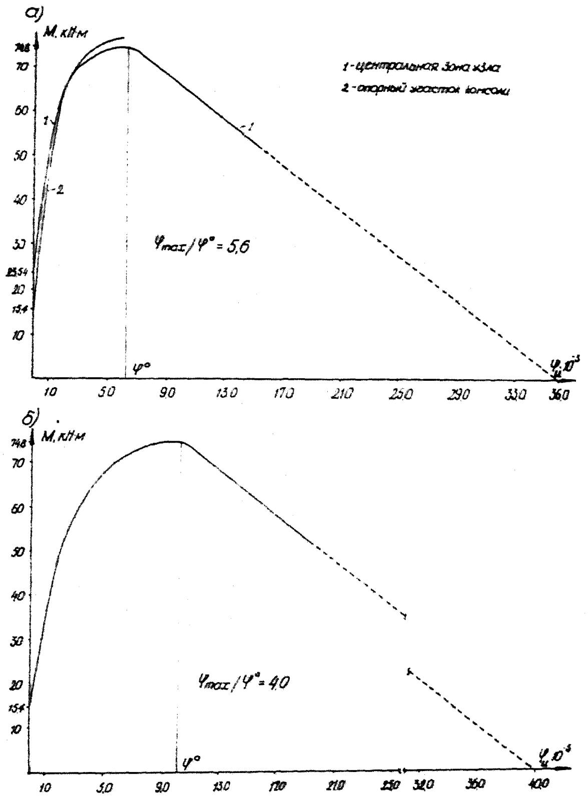

Fig. 3. a) Dependence of angle distortion of the central zone-1 and a cross-bar supporting section-2 on the bending moment at the base of the cross-bar
b) Summed diagram

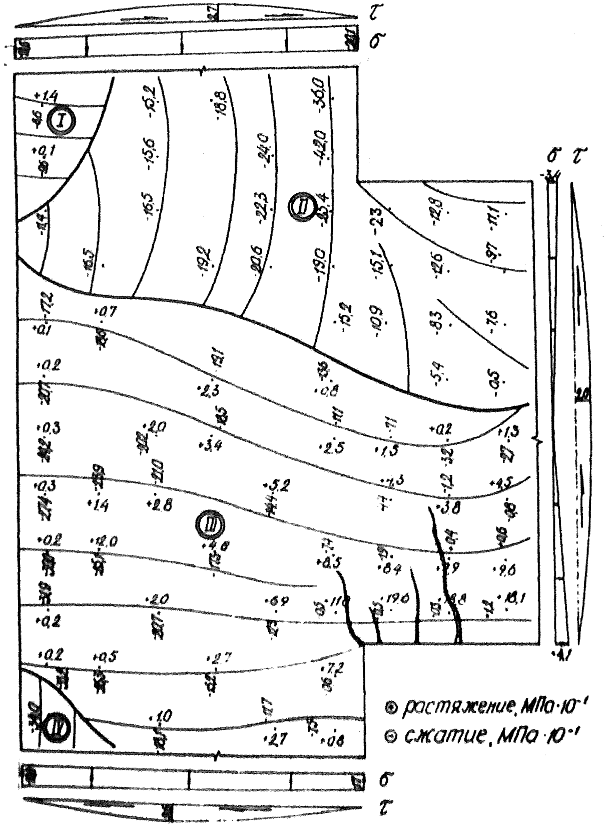

Fig. 4. Trajectories and values of the main stresses σ_1 and σ_2 in the unit

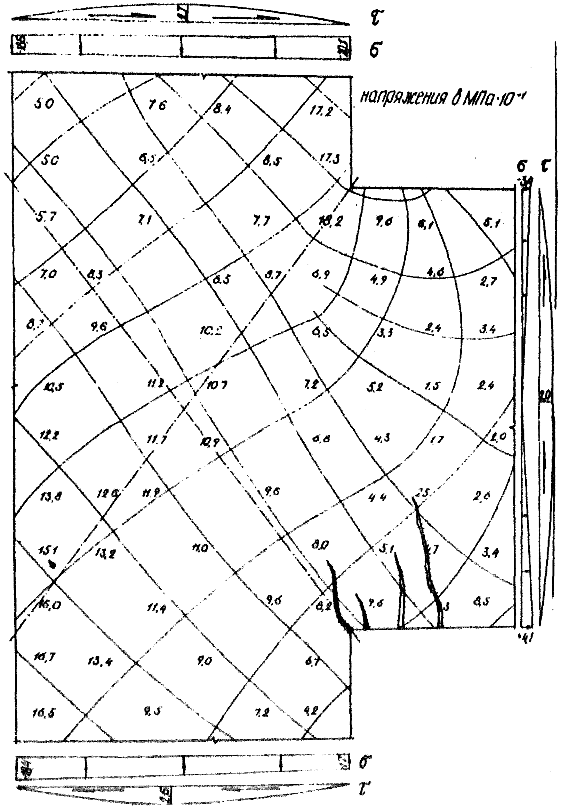

Fig. 5. Trajectories and values of the highest tangent stresses