ON THE EFFECTIVE USE OF LIGHT CONCRETE AND REINFORCED CONCRETE IN CONSTRUCTION IN SEISMIC REGIONS

BY

E.A. Sekhniashvili[I]

The use of lightweight concrete and reinforced concrete in construction has a number of advantages including a smaller weight of structures, better thermotechnical and acoustic properties of buildings and their better fire resistance. In addition, in industrial construction larger sizes of the mounted parts are made possible as the profile of the built-up members are less with the light concrete, the overall cost of the construction being significantly lower than with ordinary types of concrete.

The above advantages of the lightweight concrete and reinforced concrete are even greater in seismic regions, since the smaller the structure's weight, the lower the seismic loads acting upon it. In the seismic districts of the USSR and elsewhere the lightwight concrete and reinforced concrete are quite widely used for the enclosing structures, floors and roofings of residential and public buildings; however, it is rarely used for the supporting structures designed for horizontal seismic loads.

Meanwhile, a remarkable economic effect can be achieved only by a complex use of the light concrete and reinforced concrete in the supporting and enclosing structures because it ensures an additional reduction of seismic loads due to a higher flexibility of the structures which is caused by the light concrete'e elastic modulus lower than that of common types of concrete, and by a higher oscillation energy in the light concrete. The equation given below provide a justification of these presumptions.

According to the spectral technique of determining the seismic forces adopted in /1/, the design seismic load for a system with distributed parameters is derived from /2/

$$S_i(x) = q(x) K_c \beta_i \eta_i(x) \qquad (I)$$

Values K_c and $\eta_i(x)$ do not depend on the material of the structure, while $q(x)$ and β_i do. Load $q(x)$ inducing the force of inertia is compiled of a constant and a temporary loads. Hāving admitted that $pq(x)$ is the temporary load and the part of the constant load which is independent of the material, and $(1-p)\,q(x)$, the remaining part of the constant load, is

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[I] Associate Member of the Academy of Sciences of the Georgian SSR, Doctor of Engineering, professor, Head of Department of Applied Mechanics of the Georgian Agricultural Institute, Tbilisi, USSR.

the own weight of the suuporting and enclosing members of a building, and that the common type concrete is replaced by the light concrete, i.e., the bulk mass γ is replaced by the bulk mass γ^*. Then,

$$q^*(x) = pq(x) + (1-p)q(x)\omega = q(x)[p + (1-p)\omega] \qquad (2)$$

or

$$\frac{q^*(x)}{q(x)} = p + (1-p)\omega, \qquad (3)$$

where $q^*(x)$ is the load inducing the force of inertia in case of the light concrete with $\omega = \gamma^*/\gamma$.

The dynamic response factor β_i corresponding to the i-th tone of natural oscillation of the structure is found from /1/:

$$\beta_i = 1/T_i, \qquad (4)$$

with $0.8 \leqslant \beta_i \leqslant 3$.

The period of bending and shearing oscillations of a structure considered as a system with distributed parameters is /3/

$$T_i = a_i\sqrt{\frac{qH^4}{EJq}} \qquad (5)$$

where a_i is some coefficient, H is the height of the structure, EJ is its flexural rigidity and q is the gravity acceleration.

The above expression shows that the greater the period T_i, the lower the seismic load, if β_i is reduced, regardless of the dependence of the natural oscillations period and of β_i on the bulk mass and strain characteristics of the material. Therefore, it seems reasonable to use the light concrete and reinforced concrete in the construction of such buildings for which the oscillation period of the fundamental tone $T_1 \geqslant 0.33$ s.

Considering Eq. (5), the period of natural oscillations of a structure built with the light concrete and reinforced concrete will be

$$T_i^* = a_i\sqrt{\frac{q^*H^4}{E^*Jq}} = a_i\sqrt{\frac{q[p+(1-p)\omega]H^4}{nEJq}} = T_i\sqrt{\frac{p+(1-p)\omega}{n}}, \qquad (6)$$

where $n = E^*/E$ is the relation of the elastic modulus of light concrete to that of ordinary concrete.

Meanwhile, considering Eq. 1, the horizontal seismic load is

$$S_i^*(x) = q^*(x)K_c\beta_i^*\eta_i(x) = q(x)[p+(1-p)\omega]K_c \times \frac{1}{\sqrt{\frac{p+(1-p)\omega}{n}}}\beta_i\eta_i(x) = S_i(x)\sqrt{n[p+(1-p)\omega]} \qquad (7)$$

or

$$\frac{S_i^*(x)}{S_i(x)}=\sqrt{n\,[p+(1-p)\omega} \qquad (8)$$

The curves of $S_i^*(x)/S_i(x)$ and $q^*(x)/q(x)$ against p and ω are given in Fig.1 (n = 0.5).Both the curves and Eqs. (3) and (8) seem to be true for the design scheme of a structure as a system with discretes loads. The curves in Fig. 1(a) present a case with all the members are of the light concrete (including the bearing frame designed for horizontal seismic forces and vertical loads); Fig. 1(b) presents a case when all the members are made of the light reinforced concrete but the bearing framework is made of an ordinary one; Fig. 1(c) corresponds to a case of all the members made of an ordinary kind of reinforced concrete while the bearing frame is of the lightweight one. These characteristics show clearly that replacement of an ordinary kind of reinforced concrete by a light one results in lower horizontal seismic loads and vertical forces. However, the greatest effect is observed with a complex use of the light concrete (case (a)) because the horizontal seismic loads reduce more drastically than the vertical ones. Note, that the above expressions disregard the reduction of β_i due to a greater absorbtion of the oscillation energy in ligh reinforeced concrete than in ordinary one, which can make the seismic load even lower in cases (b) and (c).

The bearing framework made of light reinforced concrete provides more favourable conditions in case of earthquakes than the one made of a common type of reinforced concrete, due to the former's reduced vertical and horizontal loads. A more intensive reduction of horizontal loads will ensure a lower eccentricity of application of normal loads to the framework members section, thus equalizing the strains along the frame's section. The strains will become more uniform along the base of foundation. Therefore, the bearing frame can be made of light concrete of a lower durability (grade) than ordinary concrete, or if the concrete grade is preserved, the framework's member sections or the reinforcement's area can be made smaller; also, the size of the foundation can be reduced.

The above results have served as a basis for development of designs for experimental pre-cast large panel (both framed and frameless) buildings constructed in 7 - 9-force seismic regions. The projects were made at the Tbilisi Zonal Research Institute for Experimental Design of Residential and Public Buildings of the USSR State Civil Engineering Board under the guidance of the author.

Fig. 2 presents the plan of a standard storey and the vertical section of a framed 9-storeyed residential building, while Fig. 3 gives its design scheme[I]. The table supplies the values of vertical loads (Q_k and Q_k^*), of horizontal seismic loads for the seismic force 7 with the structure's oscillations along the fundamental tone (S_k and S_k^*), and of their respective bending moments (M_k and M_k^*) in points k along the height of the building. The calculated periods of natural cross oscillations of a building are $T_1 = 1.04$s, and $T_1^* = 0.77$ s, while the dynamic response coefficients are $\beta_1 = 0.96$ and $\beta_1^* = 1.30$ [II]. The frame columms with the plan dimensions 0.4 x 0.4 sq.m, are reinforced at the foot 4 Ø 32 for the common concrete and 4 Ø 25 for the light concrete, the strength of the concrete being 30 MN/sq.m, and 25 MN/sq.m, respectively.

The use of rigid bearing reinforcement is reasonable for the columms and cross-beams in framed buildings, since such kind of reinforcement combines antiseismic advantages both of steel and reinfoced concrete frames. It has been proved in /4/ that favourable conditions are provided by the lightweight concrete combined with rigid reinforcement even for the members in compression, in eccentric compression and in bending.

The above discussion justifies the use and the economic efficiency of the complex application of the lightweight concrete and reinforced concrete in construction of high buildings in seismic regions.

[I] Calculated by N.A.Kapanadze,engineer of the mentioned Research Institute.

[II] The asterisk stands for the data of complex use of light reinforced concrete; the data without the asterisk are for common reinforced concrete in the bearing framework.

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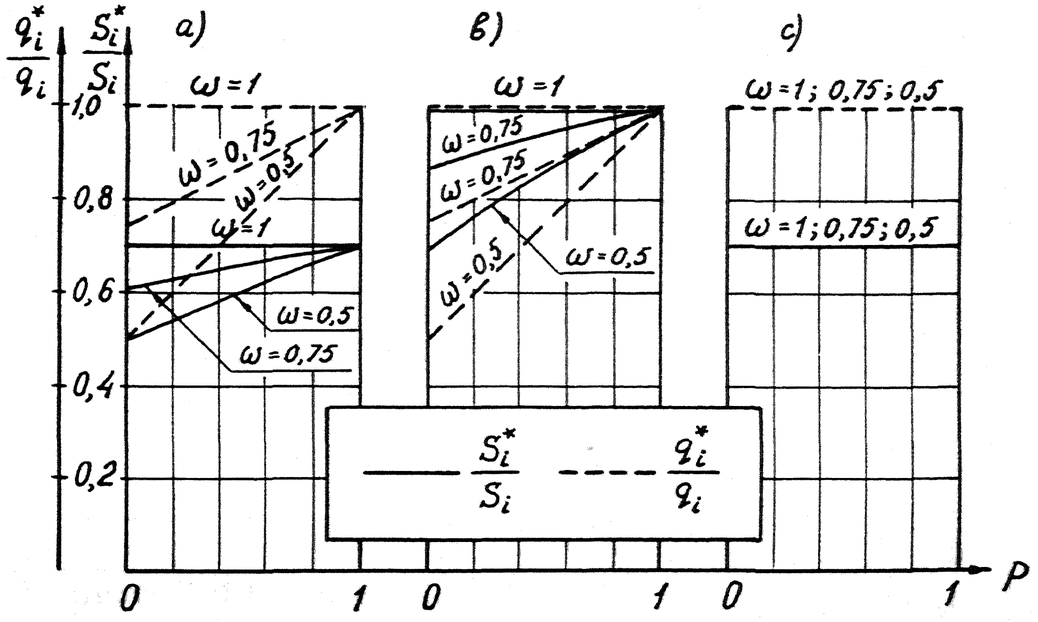

Fig. 1. Relationship S_i^*/S_i and q_i^*/q_i of P and ω

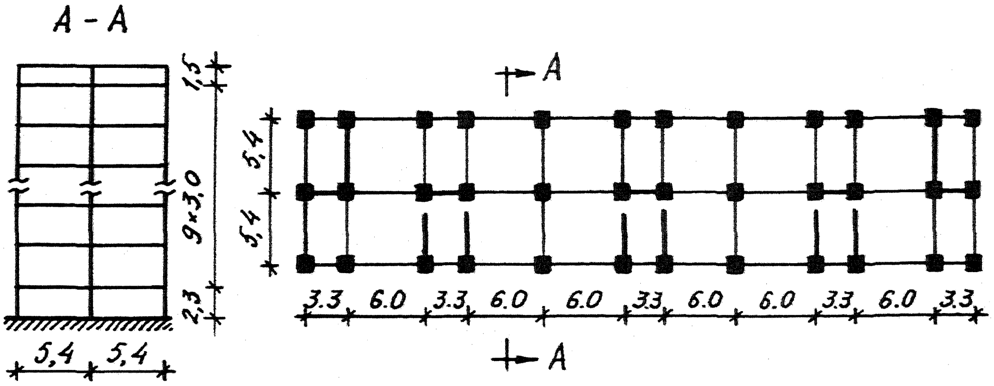

Fig. 2. Tipical floor plan and vertical section of building

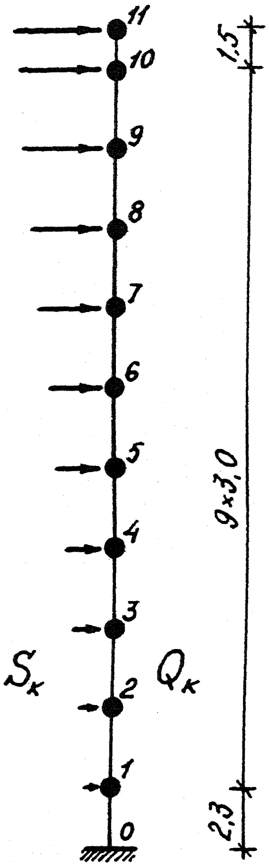

Fig.3. Design scheme of structure

Table

NN k	Q_k kN	Q_k^* kN	S_k kN	S_k^* kN	M_k kNm	M_k^* kNm
11	6429	4550	368,6	201,5	–	–
10	5013	3620	270,5	142	553	302
9	6530	5142	305,7	187	2470	1333
8	6530	5142	258	158,3	5305	2924
7	6530	5142	210	129,2	8913	4991
6	6530	5142	163	100,5	13151	7445
5	6530	5142	119	73,2	17879	10200
4	6530	5142	79	48,4	22963	13175
3	6530	5142	45	27,3	28285	16296
2	6530	5142	19,3	11,3	33741	19498
1	6804	5300	4,1	2,1	39255	22734
0	–	–	–	–	43492	25219
	ΣQ_k = =70486	ΣQ_k^* = =54606				