ON ASEISMIC RESISTANCE OF STRUCTURES TAKING INTO ACCOUNT THE DIFFERENT BEHAVIOUR OF MATERIALS TO SHOCKLOADS, WITH SPECIAL APPLICATION TO THE ASEISMIC FORM OF SHELLS

by

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Earthquake action on a structure is made manifest by the impact of an external energy. The impact may be applied as:

a. - A seismic shock (fig. 1 and 2), if the building is situated not too far away (in a terrestrial scale) from the epicentre.

This is the case of the city of Bucharest situated at 170 km from the focus of earthquakes in Rumania.

b. - An accelerated vibration movement (fig. 3) when the building is far away from the epicentre.

This distinction is considered to be important, as the material of the structure may have a quite different behaviour to the two categories of impacts mentioned above.

In the first case the structure recives the impact of a sudden seismic shock, whereas in the second the building gets into a pondular movement due to the oscillation of the soil of an increasing amplitude.

The yield point of the constructional steel is fairly increased when a shock stress is applied (fig. 4). Constructional steel is so far a kind of a "quick" material, quickly adapting itself in the elastic range to sudden loads. Therefore steel structures subject to an earthquake stand fairly well. As the increase in stresses due to earthquake (up to a fraction of the gravitational value) does not attain the factor of increase of the yield point, it may be set forth that steel structures subject to seismic shocks do not need any special measures regarding their elastic resistance.

Measures have to be taken through regarding the stability according to the axial forces increased. To increased vertical loads the horizontal seismic loads are added, giving birth to the transverse buckling. However the influence of transverse loads on the critical buckling load is relatively small (fig. 5); thus the influence of this horizontal load on the stability of structure may be neglected (fig. 6 and 7).

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Regarding the behaviour of reinforced concrete structures, the phenomenon as above described, of the different behaviour of a material under shockloads, as compared with that under static loads is not well elucidated.

Researches are carried out at the Chair for Reinforced Concrete in the Bucharest Institute for Civil Engineering by Prof. V.Nicolau. The first results of this researches, as well as remarks made directly on reinforced concrete structures damaged by the 1940 earthquake of the VIII-th degree in Bucharest (the photographs delivered by courtesy of Prof. A.A.Beleş), alow us to set forth some conclusions:

Concrete itself is a "lazy" material which does not develop rapid elastic strain when acted on by sudden loads, and so far by reinforced concrete structures the shock load increment is transmitted to the rods. This causes rods to be subject to a greater strain than the concrete itself, and to part from the latter.

Damaged reinforced concrete struts present the buckling of rods and parted from the concrete. As the rods in the struts are rather understressed by static loads it was to be presumed that this state of stress would remain under the increased axial load due to earthquke. The strong buckling of the rods and a small damages in the concrete show that the rods were given the main part of the load increment. Struts should be therefore checked to the axial load increased the entire load increment alloted to the rods, with checking the buckling of rods between stirrups (fig. 9).

The direction and width of cracks in beams, their occuring near the joints, show that the oblique (even surface) overstrained bars parted from the concrete, when no important cracks were observed at the bays of the beams. The beams were thus damaged as a consequence of shear force increase than by the bending moment increase (fig. 10).

The concrete being not capable to resist a sudden shear force increase, the latter has to be entirely alloted to the bars. The same as to the horizontal earthquake shear loads acting on the struts, which also have to be entirely alloted to bars, even to oblique bars especially provided for at the base of struts. The sections of struts should not be too narrow.

When a seismic shock occurs plastic strain in the concrete can't be taken into account and the whole load increment has to be given to the bars which if possible these should not be even (in order to encrease steel-concrete adhesiveness). Plastic structural analysis can and should be applied to structures situated for away (in a terrestrial scale) from the epicentre, where the earthquake is manifest as a wave of an increasing amplitude and the concrete "has his time" to follow the strains of the bars.

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* The damaged struts provided with a supplementary rods, were bandaged and fresh concrete torkreted; they behave fairly well in subsequent earthquake of the IV-th degree (fig. 11)

The energy alloted to a shell by an earthquake is stored in two forms (fig. 12 and 13):

a. - one due to stresses with a resultant in the medium surface of the shell, denoted by U_o and

b. - another due to the elastic bending of the shell denoted by U_i.

In order to resist an earthquake, the shell must be capable to absorb as much energy as possible. The energy stored in the form U_o is greater than that in the form U_i, as in the first case the whole section of the shell works up to the strength limit, whereas in the second, the energy up to the strength limit can be stored only by the extreme fibres on both faces of the shell (seismic energy applied as a shock, as previously mentioned).

To the more, in regions where the shell works as a sail it stores energy almost exclusively in the U_o form. Only in sections where the influence of the function of displacements (w) is noticeable it stores energy in the U_i form unfavourable for the purpose.

Thus, in order to store maximum energy a shell (for example a cupola) most be high enough, as in such a case the influence of (w) is limited to a region in the vicinity of supports, the rest of the shell working as a sail.

The energy stored in the region of the shell working as a sail is:

$$U_o = \frac{h}{2E}\iint\left[\sigma_x^2 + \sigma_y^2 - 2\mu\sigma_x\sigma_y + 2(1+\mu)\tau^2\right]dx\,dy.$$

Referred to the principal axes at the considered point, of the shell, the expression to be integrated has the form:

$$\sigma_1^2 + \sigma_2^2 - 2\mu\sigma_1\sigma_2$$

Poission's factor (μ) having a subunit value (for instance for reinforced concrete $\mu = 1/6$) the expression to be integrated, and consequently the energy stored in the shell, shall reach a maximum value when ($\sigma_1 = \sigma_2 = \sigma_0$) that is when the shell has a membrane form. In this case the unit stresses (σ_0) in the medium surface shall vary in the same proportion as the external load. In the region of a sail state, the shell being statically determined the load variation gives birth to an increment of the stress (σ_0) and not to a change in form worth to be taken into account. It will be enough to consider a safety factor equal to that increasing the vertical load. With these increased stresses the shell should be checked on buckling !

To achieve a membrane or a sail state a shell needs simple supports along their borders, as the reaction should be in the plane tangent to the medium surface (fig. 14). This can be achieved by placing the shell on rolls or spheres (in the case of cupolas). Though this leads to construction difficulties the realization of such supports for cupolas of a not too great span are not insurmontable (for example the mobile cupolas of astronomical observatories.

In the case of big span shells the supports give birth to bending moments in the shell due to the influence of the displacement function (w) - known as the influence of supports !

For high and elevated shells the influence of the supports is noticeable only over a relatively small distance (fig. 15 and 16), and the damages on reinforced concrete cupolas of Bucharest by 1940 earthquake confirm this behaviour of high shells (Photo 17).

For reasons given in the previous paper, the seismic load increment should be allotted to the bars, in zones where the influence of supports is of importance. In such zones, double reinforcement must be laid.

In saml1-hight shells the influence of supports is felt over a large part if not over the entire shell. Such shells work predominatly on bending, being consequently unsuitable for the purpose, even if they have an initial form of a membrane according to the given external load. The variations (κ_x, κ_y) of curvatures, which are of importance in such a case result in absorbtion by the shell of the energy

$$U_i = \frac{D}{2}\iint\left[(\kappa_z + \kappa_y)^2 - 2(1-\mu)(\kappa_x \kappa_y - \chi^2)\right] dx\,dy$$

smaller than that which could be absorbed in U_0 form.

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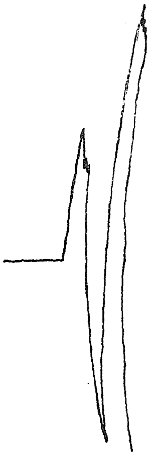


Fig. 1

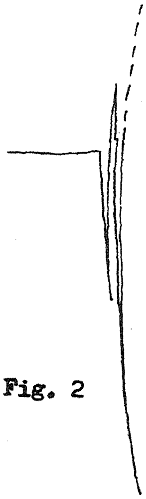


Fig. 2

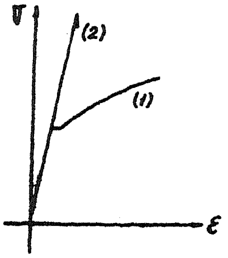


Fig. 4

Fig. 5

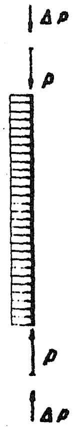


Fig. 6

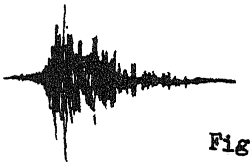


Fig. 3

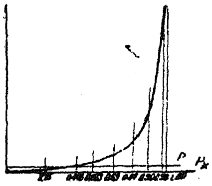
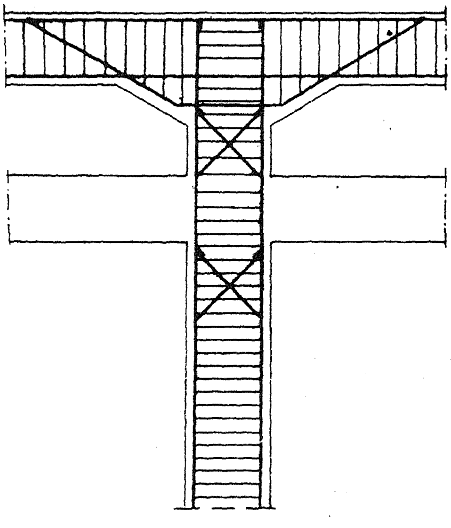


Fig. 7



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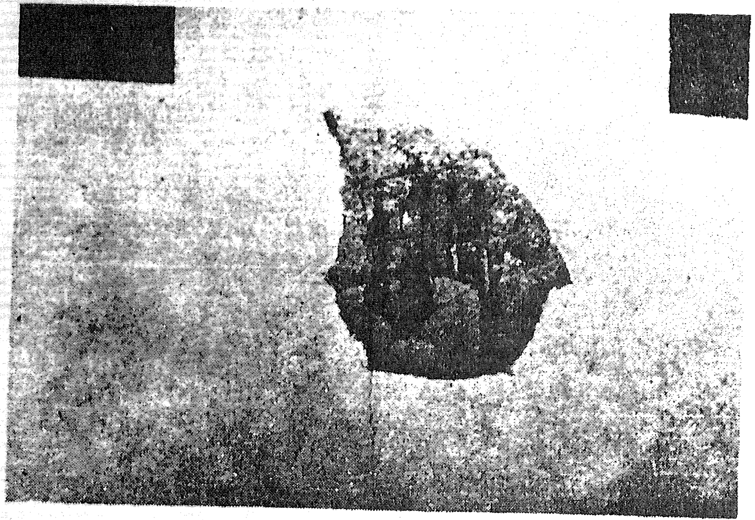

Fig. 9

Fig. 10

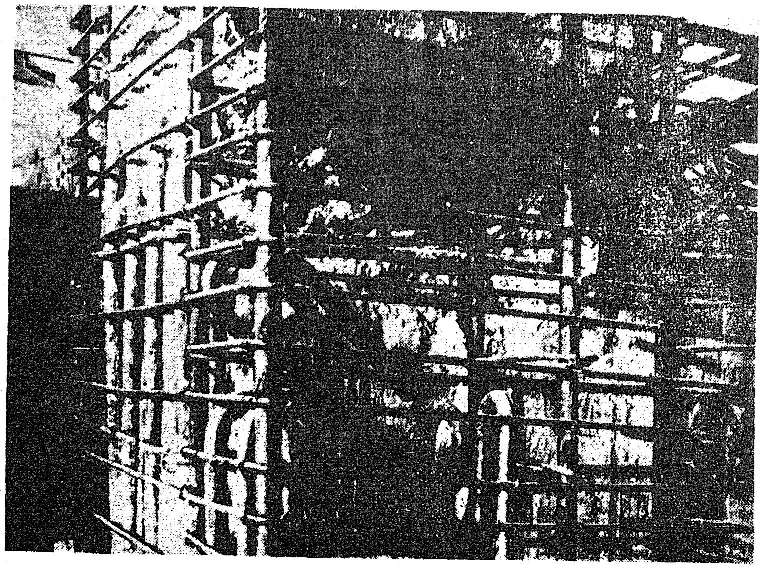

Fig. 11

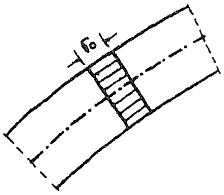

Fig. 12

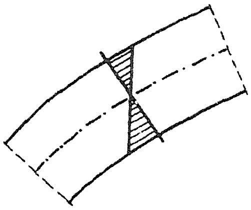

Fig. 13

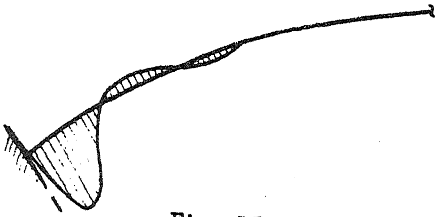

Fig. 15

Fig. 14

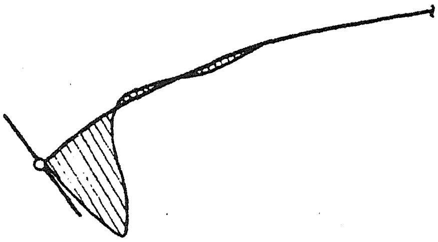

Fig. 16

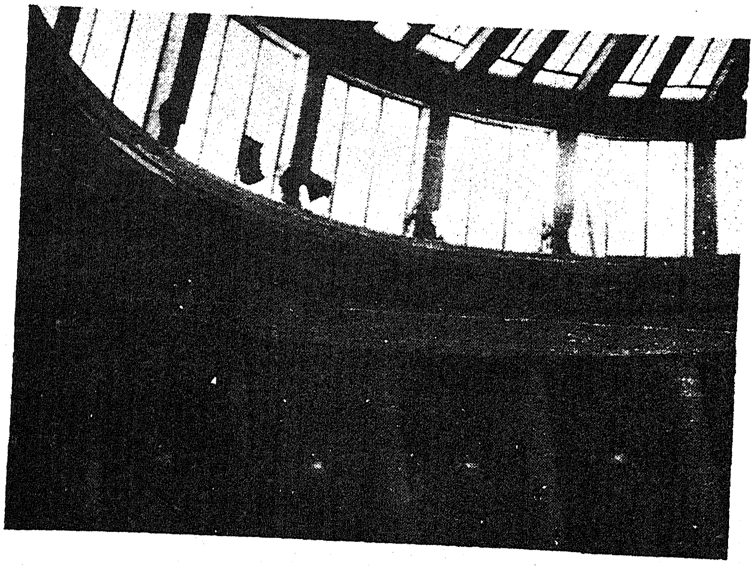

Fig. 17