SEISMIC RESPONSE OF A GREAT PANNEL STRUCTURE WITH TEN STORIES

by

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SYNOPSIS

This paper deals with some aspects regarding the variation of seismic response of a ten-story structural model* made up of large pannels (a model of an entire structure at a large scale) excited by means of a large capacity movable shaking table. The results of both static and seismic tests refer to linear as well as non linear range of structural behaviour. It was also pursued the changes in seismic response after repairing the tested structure.

1. INTRODUCTION

The achievement of multistory building composed of large pannels as load-carrying members in seismic areas, requires the solution of some specific problems regarding the whole resisting structure as well as the manner of making up the pannels and joints.

Taking into account the results of some previous investigations [1] ...[8] referring to the possibility of increasing the number of stories in case of large pannel-buildings, a project of structure with ten stories able to fulfil the requirements of utility, strength and arhitecture was drawn up in ISART Bucharest.

Since such kind of buildings have not been subjected to strong earthquakes, a ten stories structural model made up of large pannel (Fig.1,2,3), was tested by means of the 14o tf shaking table in Jassy. The model was composed of reinforced micro-concrete so that to fulfil the dynamic similitude laws of Froud type (the length scale being 1/4).

The experiments of the model under static forces (equivalent to the degree 7 on M.M.scale) and under forces of seismic type of increasing intensities up to collapse, as well as the tests carried out after repairing the structural model, have pursued to obtain data and the characteristics of seismic response of those structures within the elastic

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and post-elastic range in view of using the results in practical design and execution.

2. THE ACHIVEMENT OF STRUCTURAL MODEL, OBJECTS AND ACTIONNING PROGRAM

The structural model making up is similar to that of the real structure which is composed of four bodies connected to each other by means of floor slabs, the vertical continuity being provided by means of proper shear walls.

The adopted joining system (as continuous junctions along pannel borders) is that of a loop form having an uniform little size crenelation at monolithic surfaces between the pannels. The horizontal joints are also of loop form and are made up by superposing the reinforcements and then by building with concrete in situ, so that a proper continuity of vertical shear wall to be pursued (Fig.2).

Some members of vertical rigidity were eliminated in the design of structural model (i.e. staircase box and two elevatory shafts) so that the tested model to work in conditions less favourable than the real structure and also to lead to maximum the possible stresses at the joints during a prescribed seismic action. A view of the model ready for testing on the 14o tf shaking table is shown in Fig.3.

The main object of the experimental investigations was that of obtaining the response characteristic data within the elastic and post-elastic range of structural behaviour in view of applying them into design so that to be able to improve the structure and thus to provide it with a certain ductility and an optimum safety when subjected to strong earthquake motions.

The purposes of studies performed for determining the characteristic data were the following:

- estimation of the true stiffnesses of the whole structure and of elasto-mechanical characteristics by static horizontal actionings of moderate intensities;
- determination of deformed shapes displacements between vertical pannels at horizontal joints and unitary stresses in characteristic members of shear walls at the mentioned actioning level;
- determination of the dynamic characteristics of the model to low intensity actions, both before and after cracking, as well as the variation of those characteristics when strong actions are involved, including two stages, i.e. before and after repairing the tested model;
- emphasizing the possible nonsynchronous oscillations of the bodies composing the structure by means of both low and high intensity tests, within different behavioural stages;
- determination of instantaneous shapes to seismic actions;
- determination of the cracking forces, of the manner of ap-

pearance and development of cracks, ductility and capacity of energy absorbtion;

- measurements of specific deformations in zones of stress concentration within the structure bodies and connection members;

- determination of forces and manner of collapse, pursuing also the structural accomodation to large deformations both before and after repairing.

The experimental program has comprised some tests in static regime (namely a static force applied horizontally in steps up to an intensity of 2,5oo kgf, corresponding to a degree of the seismic intensity of 7 on M.M.scale), determination of the dynamic characteristics at various stages, under the action of microseisms and under low intensity shocks, gradual actions in dynamic regime complying with the time scale (using various actual and artificial seismograms on 15 program cycles), as well as repeating some seismic actionings of certain characteristic program cycles, performed on the repaired structure.

The picking-up and recording apparatus of building kinetic was so set up to enable the registration of the shaking table displacement (D_o) and acceleration (a_o), relative displacements of various levels within central (D_i) and marginal (D_i') bodies, related to a rigid reference system, fixed on movable table, story level accelerations (a_i) as well as specific deformations of some particular members (ε_i).

3. MAIN EXPERIMENTAL RESULTS

The static tests lead to the following remarks:

- Before the cracked stage, the ten story average deformation was o.4 mm/tf (corresponding to a total displacement of 1.24 mm), while the sum of relative slidings between vertical pannels along the story height was o.o5 mm/tf, which means about 1o % compared to the story deformation (Fig.4 a). The deformations corresponding to the stage in which the joints begin to work, have been reached at a force of about 1,ooo kgf applied to the entire model. The values of the rezidual deformations to unloading, as well as their shape, indicate a quasi-elastic behaviour of the structure which corresponds to a force of 2,5oo kgf (degree 7 on M.M.scale). The unitary stresses in the characteristic sections were of 4...6 kgf/cm^2 in case of frontal pannels at the bottom and of 1.5...2.5 kgf/cm in pannel lintels and parapets at the second and third level and have had less values, of 1.o kgf/cm in the connectioning floor slabs between the structure bodies at the upper levels.

The above mentioned values are leading to the conclusion that the magnitude of the structure limit elastic deformation ($y_{lim.el}$) may be considered to be equal to 1.24 mm.

- After cracking, which occured as a result of seismic actions, the static tests were carried out in similar conditions, and it was found that in the range of 0...2,65o kgf, the ten

story deformations increased to o.53...o.93 mm/tf which emphasizes a sensible increase of the horizontal deformations compared to those of the noncracked stage, Fig.4 b (2.5 times greater in the case of the last load increasing interval).

The corresponding whole deformation was of 1.86 mm which indicates a static structural adaptability of 1.5 (for an acceleration range of o.2...o.3 g).

Under the action of these rather small forces as compared to the corresponding seismic forces, no significant slidings occured at the first level, as a result of friction forces excited by the higher levels. As the large deformations, due to seismic force action, occured at the first level, it results that for higher levels, microcracks and vertical cracks have appeared, -which will influence the structural ductilities.

The experimental investigations carried out for determining the variation of dynamic characteristics, within various working stages, have shown the following:

- within noncracked stage for low intensity vibrations, corresponding to microseisms or to some dynamic force of several tens kgf, applied at the upper level, the values of the natural periods (T_o) and of critical damping coefficients (ν%) were of o.15 sec for longitudinal direction, of o.13 sec for the transversal one, and of 3 % for the both directions. Although the actioning force was applied on a single structure body, no phase difference was observed between the vibrations of the three bodies.

For strong vibrations, corresponding to some seismic forces of about 5,ooo kgf distributed along the whole structure, it was obtained: T_{long} = o.18 sec and ν_{long} = 3.5 %.

After the cracking, the above mentionned values in case of dynamic forces of low intensities were: T_{long}=o.17 sec; T_{trans}= o.14 sec; ν_{long}= 5.o % and ν_{trans} = 4.5 %. For strong actions, a_o = (o.3...o.5)g as well as for a sudden breaking of in the shaking table movements the values of the natural periods in longitudinal direction have increased to o.23...o.3o sec, while the percentage of critical damping has increased to 9 %.

After the structure has been repaired the early values of dynamic characteristics were: T_{long} = o.23 sec and ν = 8 %. After the reopening of the first cracks, the following values were obtained: T_{long} = o.27 sec and ν_{long} = =11 %, while for forces corresponding to the collapse of the repaired model, those characteristics reached greater values: T_{long} = o.45...o.58 sec and ν_{long} = 15 %...28,8 %. It should pointed out that after the occurence of cracks, the values of dynamic characteristics have varied continously, the values presented here, being those determinated when the shaking-table has stopped to move.

Synthesis of the performed experimental investigations in seismic actioning regime, has emphasized the characteristic aspects of some distinct stages of structural behaviour.

Therefore, for movable table accelerations up to 2 m/sec^2, the ratios between the absolute level displacements and the foundation displacements, as well as the ratios between the higher level accelerations and accelerations of the movable table, have not exhibited sudden variations or phase differences between the structure bodies, while the unitary stresses were under collapse limit. All these remarks lead to the conclusion that in this actioning stage, the structure has behaved quasi-elastically, as it is confirmed by the average deformation shapes (Fig.5).

For excitations of the upper table of 2...3 m/sec^2 it can be seen that the structure deformations (Fig.6) increase appreciably (the maximum deformation being of 12 mm) when comparing with the first stage one could found an increase of the maximum dynamic deformations of 2.4 times. This increase is closed to that obtained for deformations in case of static tests.

As a result of the fact that the structure bodies decrease differently their stiffnesses, it may be established some phase differences between their oscillations, as well as a certain influence of the second mode upon the deformations. In the same time, it is found a continue and gradually cracking process at the first level, begining with the body corners, and also a transformation of the connecting floor slabs into double articulated members. The tensile stresses in the characteristic members have reached values closed to the rupture strength.

The carrying on the seismic program with accelerations between 3...7 m/sec and further actionings with high intensity seisms, has had the effect of increasing the horizontal displacements up to a maximum value of 23 mm (Fig.7) and a more pronounced influence of higher modes, which was especially emphasized by the occurence of the vertical cracks within the central body at the 6th, 7th and 8th levels and by a strong variation of stresses into the horizontal joinings between the bodies. The unitary stresses in the vecinity of the breacks diminished appreciably, then varying with the excitation level of the seismic force and with the cracking state of the structure.

It should be also emphasized that the deformations and their maximum values are not in a direct dependent relation with the table acceleration values, because of the influence of the previous vibrations and frequency distribution within the seism, as well as the natural structure frequency, cracking state etc.

Also, the appearance and development of the cracks at the first level (Fig.8 and 9) lead to a significant increase of damping, assuring, however, a diminishing transfer of seismic energy to the higher stories.

The collapse of the structure (Fig.lo), without having a breakable feature, has occured for seisms with maximum accelerations at least of 8 m/sec (the maximum crack width reached about 6 mm during those seisms). The collapse has begun by the partial ruptures of the vertical members

of the first story shear walls and also by cracks and local faillures of the horizontal connections between the respective bodies, as well as by tearing out the vertical reinforcement as the corner zones at the first level and by rather large cracks of the vertical corner joinings of the central body at the 6th, 7th and 8th level.

Since the structure did not lose its general stability, it may be stated that the maximum deformation of 23 mm obtained at collapse, represents the allowable limit deformation, the corresponding dynamic ductility factor at collapse being 4.6.

The repair of the structure was carried out by establishing the continuity of the reinforcements and of concrete in the destroyed zones within the first level and in the zones of the body coupling. The cracks were filled in with a mortar prepared on a plastic adhesive base and the prestressing of the second level was performed by means of some steel ties fastened in the movable table (Fig.11). All these measures have the effect of the stress redistribution, the change of deformation and cracking state as well as the increasing of variation in seismic response.

From the synthesis of the experimental data obtained on the repaired model, the following significant aspects were emphasized:

- Up to accelerations of about 2.5 m/sec^2 the structural bodies have worked nearly in phase, although the recracking of the structure have begun from an acceleration of 1 m/sec^2.
- For various actioning programs and oscillation characteristics, the structure have responded differently (Fig. 12), a significant influence upon the structural response having the shear-force variation along the height. This effect upon the building is comparable with the intensity of the base shear-force, from a certain stage of cracking development.
- For movable table accelerations beyond 2.5 m/sec^2, the body oscillation nonsynchronism was frequently remarked, some oscillations in phase opposition being present.
- A new collapse of the structure has occured for an acceleration a_c = 6 m/sec^2. This values is 25 % less than that recorded at the initial collapse. The collapse manner emphasized an accentuated cracking and dislocations of the concrete at the first and second level (in lintels, vertical members, parapets) as well as the rupture of the connecting members between the bodies and large vertical cracks at the bottom and upper levels (Fig.13 and 14).

4. CONCLUSION

The use of the continue joining system with reinforcements as loops along the entire border, for ten stories large pannel structure, has proved a proper ductility of the system under internal horizontal forces. This fact was pointed out by the good stability of the structure as well as by the

4. D.Diaconu, M.Manolovici, C.Mihai, M.Iţicovici, M.Groper L.Strat, I.Rotaru

"Etudes expérimentales des bâtiments élastiques et rigides, actionnés en régime harmoniques et séismique à l'aide des platformes mobiles de grande capacité".
Al 3-lea Simpozion European de lucrări seismice - sept.1970 Sofia, Bulgaria.

5. * * * "Perfecţionarea metodelor de calcul al construcţiilor supuse acţiunii seismice"
- Construcţii din panouri mari cu diferite sisteme de îmbinări
- Cercetări experimentale pe îmbinări din panouri mari
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6. * * * "Perfecţionarea metodelor de calcul al construcţiilor supuse acţiunii seismice
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Symposium on Plastic Analysis of Structures Jassy - România, 1972.

possibilities of seismic energy dissipation within post - elastic range, both before and after repairing the structure.

Although the whole system proved that it is able to withstand high intensity earthquakes, for the design of large pannel buildings it arises, however, the necessity of a suitable method which to take into account the relative slidings between the pannels of vertical diaphragms. In the same time, the method should incorporate the effects of the shear force variation along the structure height, which has a significant influence upon the stories 7, 8 and 9, being comparable with the base shear-force.

The studies carried out by means of electric analogy have shown that the maximum values of the base shear-force and the average deformed model shapes are comparable with those obtained by testing the model.

By comparing the results of various analysis methods used in the elastic behavioural range, to the experimental data, it was found that the most suitable method is that of the equivalent frame, whose stiffnesses and coefficients are determined by considering the influence of both bending and shearing deformations.

In the same time, these investigations have put into evidence the influence of the shear-force variation of the higher modes upon the stories 7, 8 and 9, this fact being in accordance with the performed experimental works.

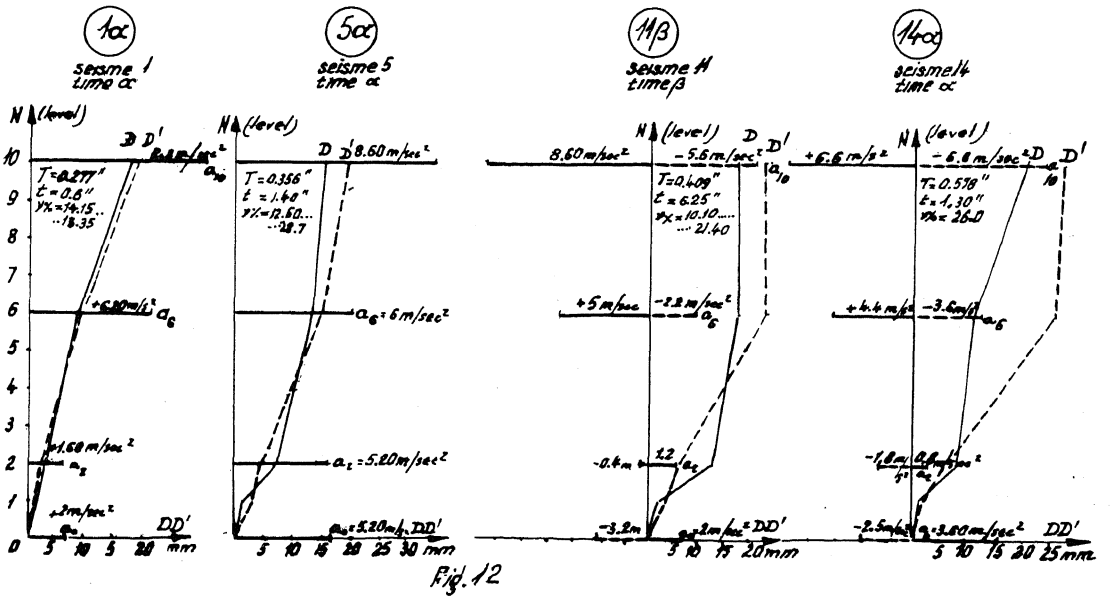

Fig. 12

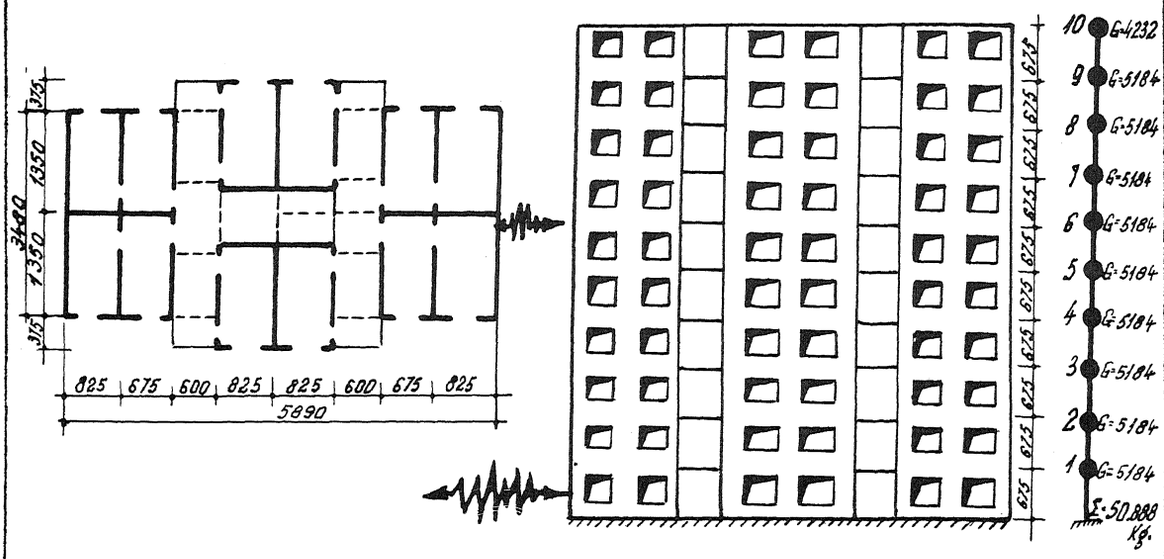

Fig. 1

Fig. 2 - Assembling stage

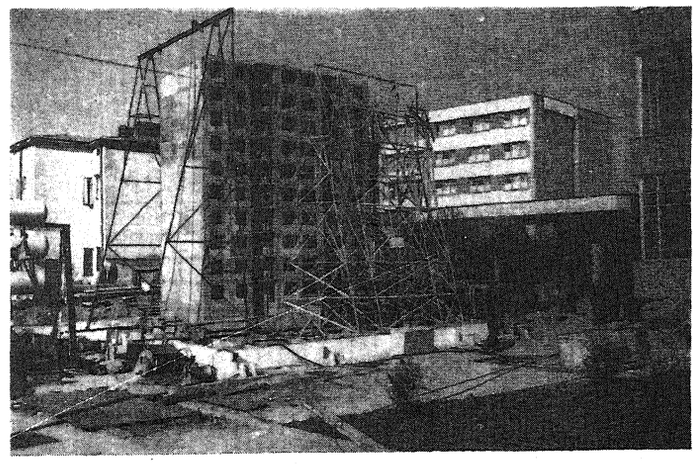

Fig. 3. Model prepared for testing

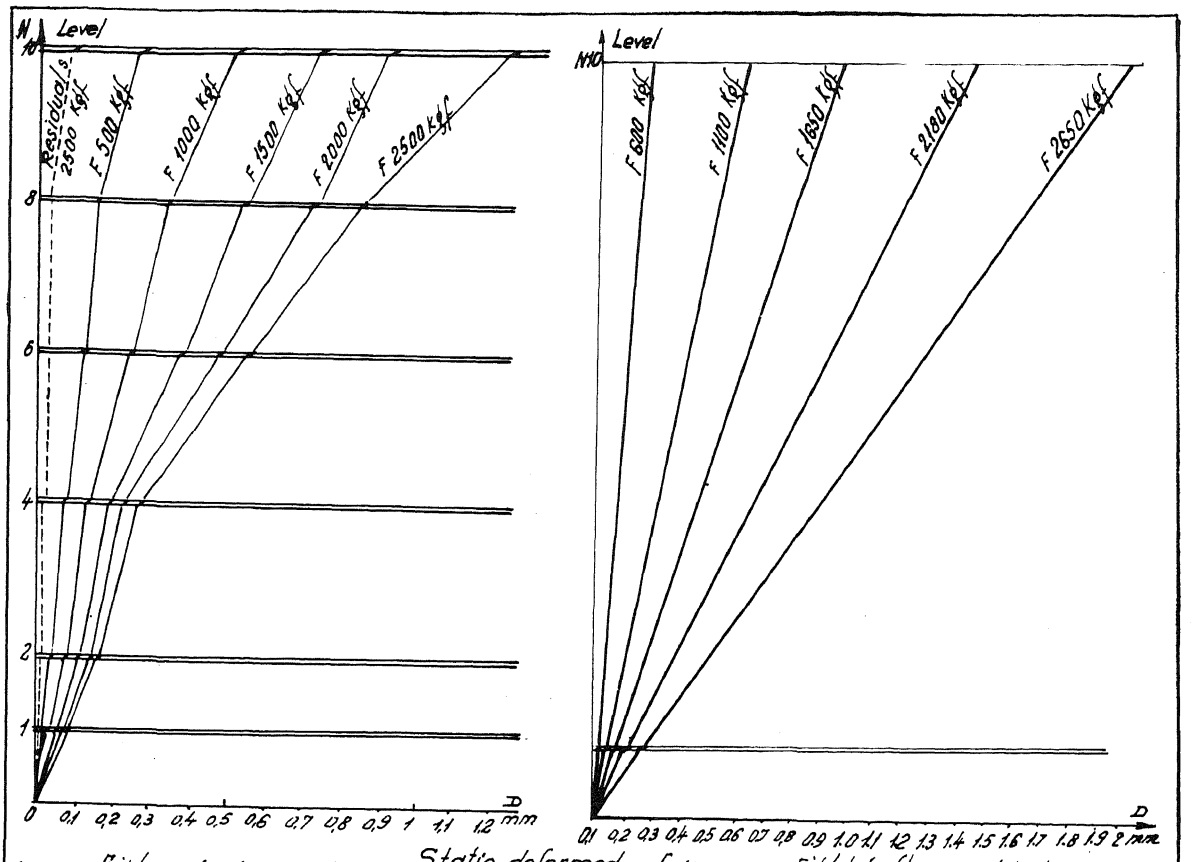

Fig 4a - (before cracking) Static deformed shapes Fig 4b - (after cracking)

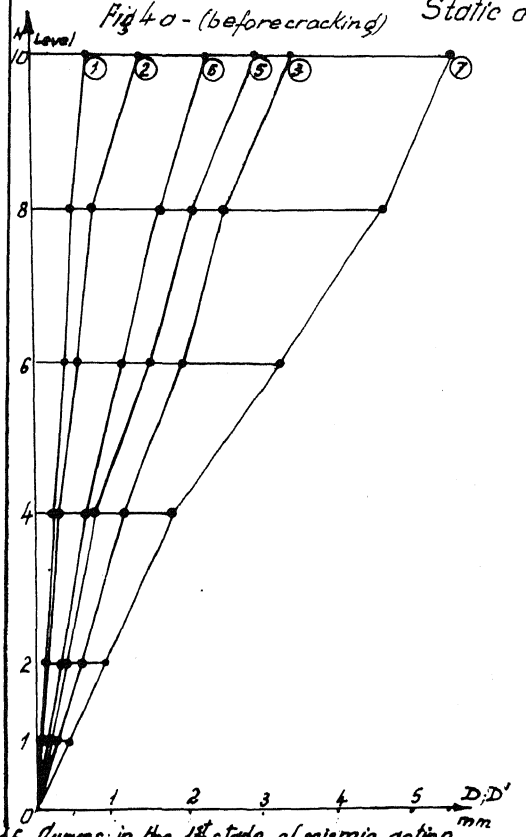

Fig 5.- Curves in the 1st stage of seismic action

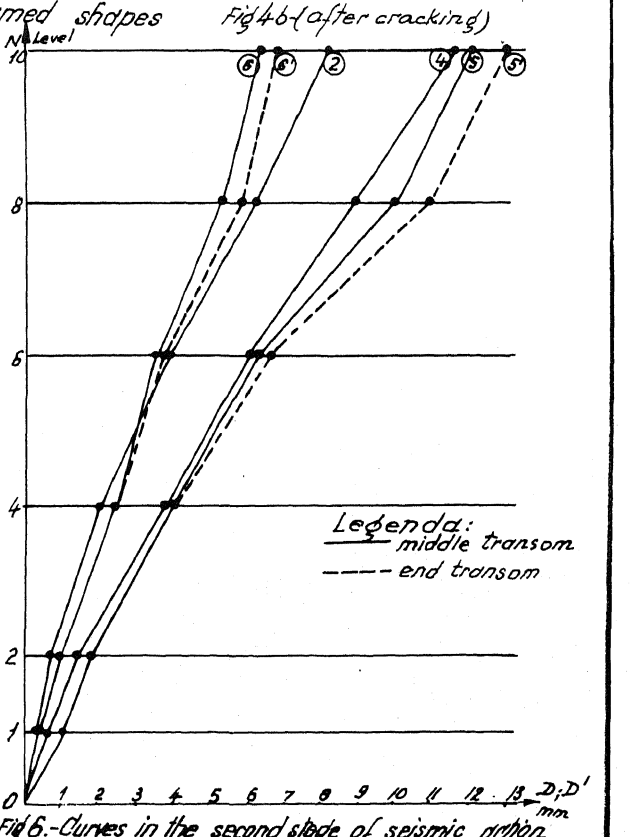

Fig 6.- Curves in the second stage of seismic action

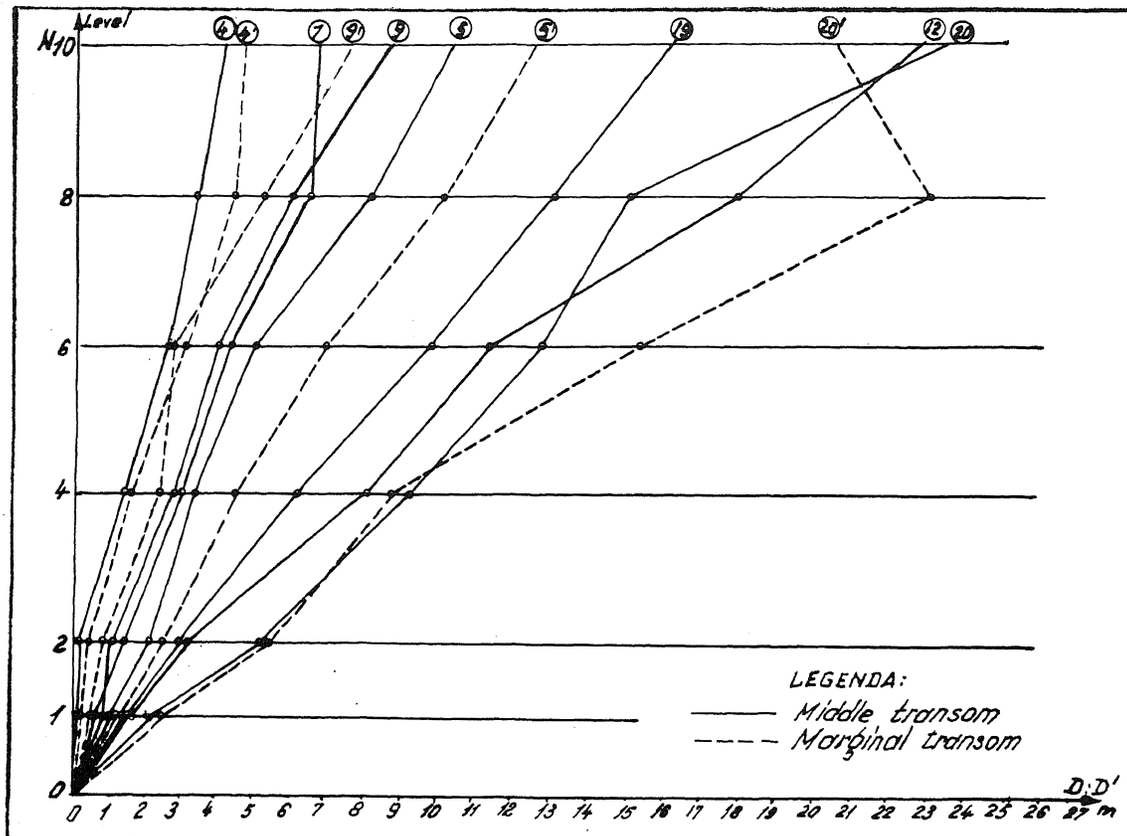

Fig. 7 - Deformed-shape curves in the 3rd stage of seismic action

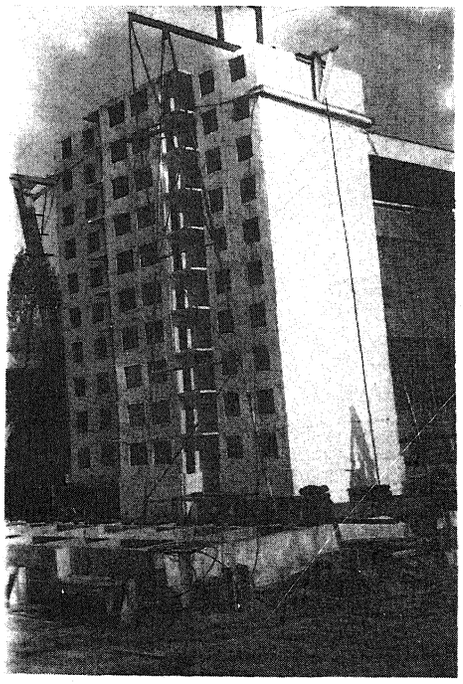

Fig. 8

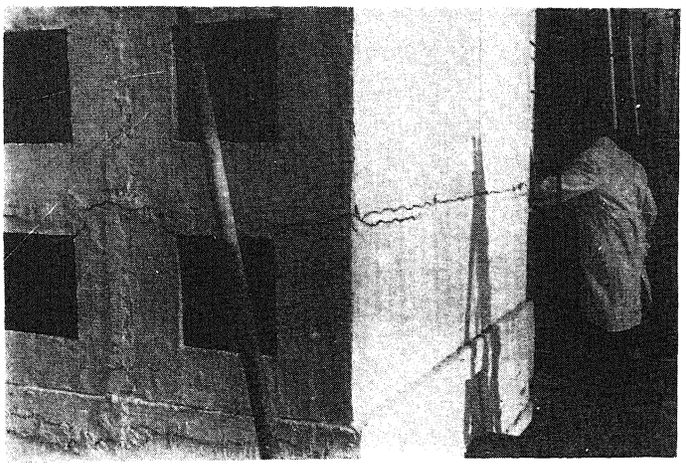

Fig. 9