"SEISMIC RESPONSE OF ELEVATED WATER-TOWERS, WITH TRONCONIC TANKS AND CENTRAL TUBE, TAKING INTO ACCOUNT THE WATER SWINGING EFFECT"

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SYNOPSIS

This paper presents the principal elements of the total seismic response, the evaluation of oscillation characteristics of water and the determination of seismic and resonant pressures performed by the mass of the liquid (situated at various levels) upon the walls for tronconic tanks with central tube acted at their base.

It is also presented the total coupled seismic response of the members of the ensemble tronconic tank - infrastructure (water-tower), the tank being loaded with a critical volume of water up to failure as well as some aspects of its collapse.

INTRODUCTION

The documentary study [1] has pointed out the fact that the liquid swinging effect produced by the seismic action upon the tanks or water-towers refers especially to spherical,cillindrical,conic or parallepipedic shape without interior discontinuities and theoretically solved in stationary regime. The experimental data are limited either in describing some damages caused by earthquakes or in determining only the dynamic characteristics variation,carried out,in the majority of cases,on very small scale models, acted in harmonic regime.

Since the data in the specialised literature are not reprezentative for typificated constructive systems(water volume of 2oo m^3,3oo m^3,5oo $m^3$and 75o m^3),adopted in R.S.Romania,the tronconic tank located at various hights on a central slided tube,one has developped, togheter with the Industrial Constructions Design Institute (I.P.C.)-Bucharest,a large research programme in order to supply the essential data for design, so that to assure also to those types of structures which are not conformable by their function,a certain seismic conformation.

The study has been focused on the 25 m hight water-tower,with tronconic tank corresponding to a water volume of 3oo m^3 designed for the 8th degree of seismic intensity(scale MKS).The proper tank has been tested with various levels of water acted in seismic and harmonic regime, by means of the

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15 tf seismic shaking-table (fig.1) and the water-tank has been gradually acted in seismic range up to failure, loaded with a critical mass of water, by means of the 14o tf seismic shaking-table (fig.2). Both for the proper structure and for the liquid, the similitude principles of Froud type including condition that the model-prototype acceleration ratio to be 1 have been applied to both the models. The chosen lenghts scale has been 1/3.5 and the resulted time scale has been 1/3.3 for the structure and 1/1.87 for water.

EXPERIMENTAL RESULTS

Having in view the multitude of experimental data, the results' presentation will be made for the tank and for the water-tower respectivelly, grouped in ranges concerning the liquid dynamics, the structure dynamics and the ensemble liquid structure dynamics [2] .

Water tank

The analyse of experimentally determined dynamic characteristics of water into the tank, have allowed to establish the following aspects:

- For a variation of the water volume from 1/3 V_{water} up to 1/1 V_{water}, the period of the natural mode of water have increased with 1o %. The IInd mode has presented a variation in the same proportions as the Ist mode, while in the IIIrd mode this influence is greater.
- The elaboration of some design relations for the periods of Ist, IInd and IIIrd modes of the water into the tank in terms of the liquid volume (fig.3).
- The oscillation shapes of water; under seismic actions it is stationnary excepting one zone arround the central tube where a transitory regime is produced and the peripheral zones where, owing to the wawes'return a transitory almost turbulent regime is produced.
- In seismic range the preponderance of the natural oscillation mode of water is greater than 8o %, the higher modes superposed onto the natural mode are interfering like an accentuation or a diminution of that mode.
- The dependance of the seismic wave hight, for a constant energy level of actionning the seismic moving-table corresponding to an envelope of the maximum accelerations of 2.6 m/s^2, in terms of the water volume is presented in fig.4.

It is noticed, that when actionning the moving-table in harmonic regime at resonance frequences of water, the volume hight is four times higher for 1/3 V_{water} and 3 times for 2/3 and 1/1 V_{water}, than the corresponding ones in seismic regime.

- By using the relations proposed by G.Housner, K.Muto and E.Rosenblueth, that have been adopted for the studied shape as well as the experimental data, the ratio free water -total water has been determined, the variation of which - in terms of certain geometric parameters-being presented in fig.5.

The period of foundamental mode of the proper tank has increased with about 22 % with the increase of water volume while the increasings of the damping percentage are far smaller and differentiated in time.

The distributions of the recorded hydrodynamic pressure envelopes along to horizontal rings and generator lines at 0°, 30° and 60° to the actionning direction, in seismic regime, corresponding to an energetic level of the average of maximum basic accelerations ranged from 2.12 up to 3.24 m/s^2, and in harmonic regime at the liquid resonance are presented in fig.6 a and 6 b (2/3 V_{water}).

The ratio of the resultant of the seismic pressures envelopes to the resultant of the hydrostatic pressures (fig. 7) has varied from 14.77 % to 19.81 %, while to the resonance the ratio of hydrodynamic pressures to the hydrostatic ones has varied differentiatedly in terms of volume and cross-section, the supplement being of 21.82 % up to 68.17 % (fig.7), a decrease being observed when water volume increased.

In fig.8 the variation of the application point position of the hydrodynamic pressure resultant (Z_c) as regards the tank bottom, is presented in terms of the water volume.

The distribution of these pressures in a horizontal plane is antisymmetrical with a maximum discrepancy of 30° compared to the actionning direction which produces an oval-shape of the tank.

It is also noticed that the accelerations amplifications along the tank hight have differentiatedly varied, in terms of the type of the programmed earthquake, of its intensity and of water volume, reaching maximum values of +53 %.

The water-tower

The critical mass of the tank for which the ratio of seismic pressure to - hydrostatic pressure is maximum, has resulted to be 2/3 of the water volume, which maintained constant in all the seismic experiments up to the collapse.

By analysing the dynamic characteristics carried out in various stages of work of the structure and at various levels of energetic actionning, the following aspects have resulted:

- The filling of the tank with 2/3 of the maximum volume of water increases the oscillation period of the ensemble with 12 % and the damping percentage with about 2 %.
- In the testings II-1 and II-2 (table 1) the ensemble periods remained pratically constant, at the first cracking appearition (exp.II-3), they have increased with 6 % and the dampings with 27 % compared to the initial stage.

In the cracking development stage (exp.II-3...II-7) the periods have increased with 31 %, the critical damping percentages with 190 %, and at failure (exp.II-8...II-9)with 180 % and 200 % respectively. At collapse (exp.II-11...II-12), the periods have increased of 2.65 times and 3.5 times respectively compared to the initial stage (fig.9).

- The influence of the liquid mass and its swinging is of major importance upon the oscillation period of the ensemble. The reciprocal is not true since water makes use of the structure oscillation only as perturbating agent.
- During the seismic actionning the tank (T_{tank} = = 0.088 s) behaves as a rigid body, in relation to the

oscillation of the water-tower structure (T_{tower} = o.375 s), which is also confirmed by the pattern of the average instantaneous deformest shapes obtained in seismic range testings (fig.lo).

- If the coupling mode of the water tower and liquid oscillations is analysed during a seismic perturbation one founds that in the initial phase when it works like a damper, the water oscillates on the frequence of the foundamental mode of the water-tower, than passing to its natural oscillation (6.5 times longer than the water-tower oscillation) on which the water-tower oscillations being superposed, and when the seism stops, the water-tower natural oscillations are rather rapidly damped while the water continues to oscillate, compeling the structural ensemble to oscillate on its natural period.

The height of seismic wawes'corresponding to the same energetic level, at the bottom of the tank mounted onto the water-tower, as was in the testing of the tank itself, are pratically the same, onto the surface but in the boundary zone their hight is two times greater as a consequence of the ensemble deformations of the water-tower. The other aspects, previously established, regarding the dynamic characteristics of the liquid, remain also valid in the case of water-towers.

The envelopes of the maximum seismic pressures, obtained on the tank walls of the water-tower, at an energetic level, just like in the experiment carried out on the 15 tf shaking-table, maintains the same distribution in horizontal and vertical plane, but presents greater amplifications, up to 22 % of the hydrostatic pressure, due to the tank rotation in the structural ensemble. The resultant arm (Z_c) has increased, on an average, with 9 %, compared to the previously established values.

Some instantaneous mean deformed shapes and the acceleration distribution along the hight, on various structural work-stages (table 1) and energetic levels of actionning are presented in fig.lo. The survey of residual crackings before failure is presented in fig.11 and in fig.12 and 13 the collapse instant and structure distruction respectively, are presented.

The synthesis of experimental data were used as a base for elaboration of some technical recommendations regarding the design of tronconic-shaped water-tower with central tube where the swinging effect of the liquid, produced by the seismic action, is also to be taken into account.

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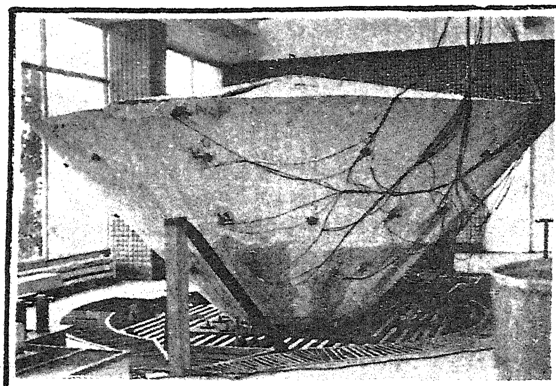


Fig.1

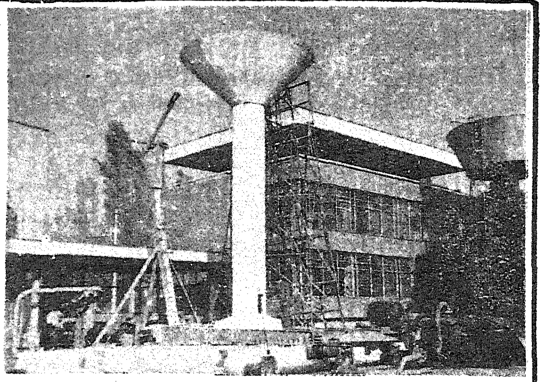


Fig.2

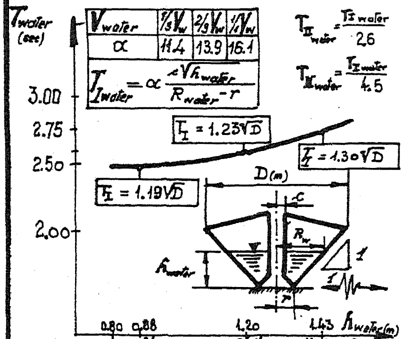


Fig. 3

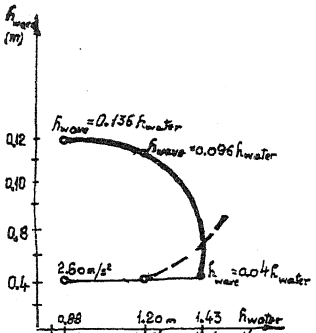


Fig. 4

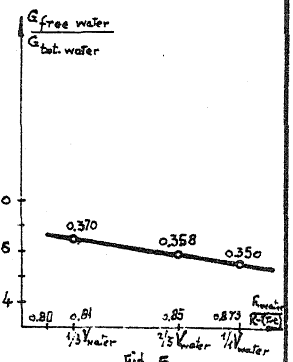


Fig. 5

TANK TEST

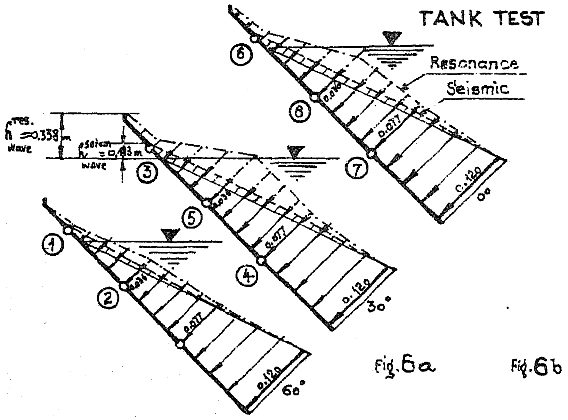


Fig.6a

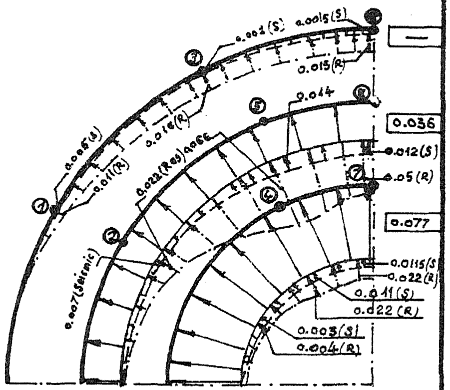


Fig.6b

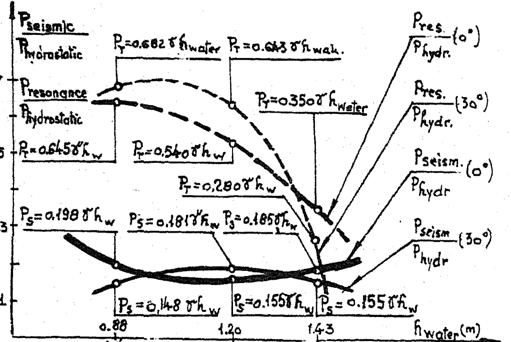


Fig.7

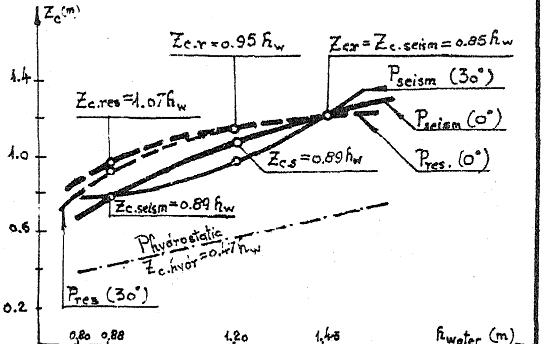


Fig.8

TABLE 1

TEST	WORKING STAGE	$TD_{top\ max}$ (cm)	$a_{top\ max}$ (m/sec²)	$a_{bottom\ max}$ (m/sec²)
II-1	quasielastic	0,50	2.83	1.62
II-2		0.75	2.76	1.74
II-3	appearition and development of crackings	1.04	4.55	2.67
II-4		1.23	5.51	2.44
II-5		2.43	5.31	2.90
II-6		2.03	5.18	3.36
II-7		2.50	6.21	4.18
II-8	failure and rupture	2.78	8.98	6.97
II-9		3.56	6.16	4.65
II-10	collapse of structure	6.66	7.59	7.71
II-11		5.55	5.18	6.38
II-12		4.44	4.49	5.80

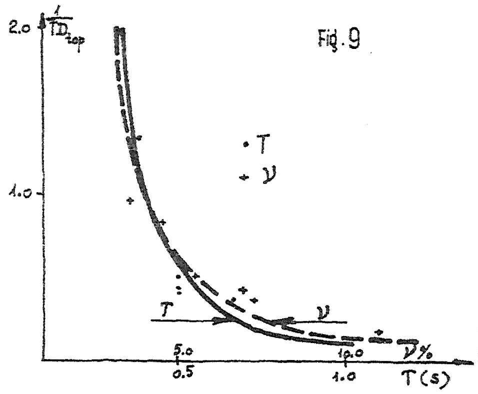


Fig. 9

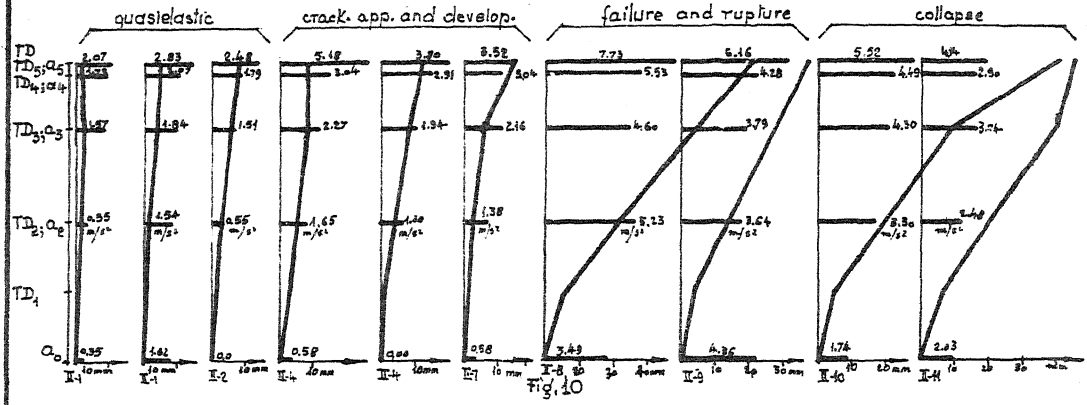


Fig. 10

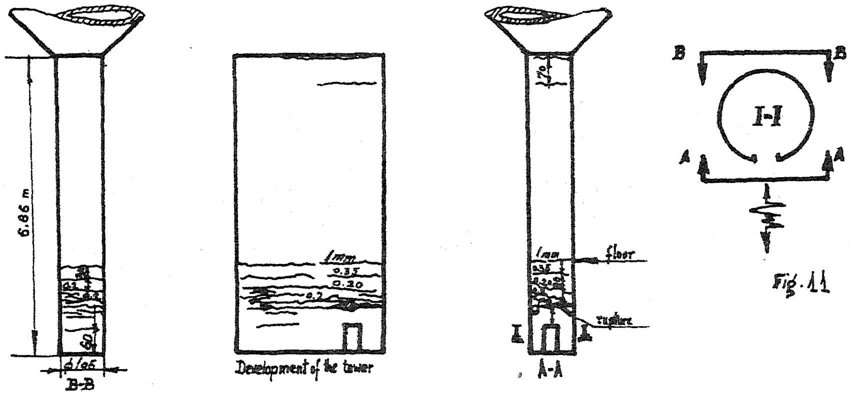
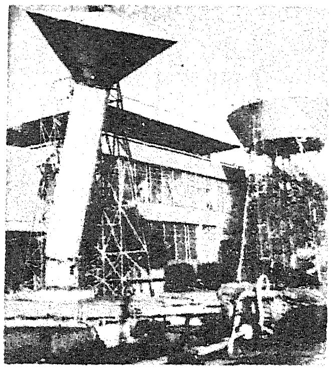


Fig. 11

Fig. 12


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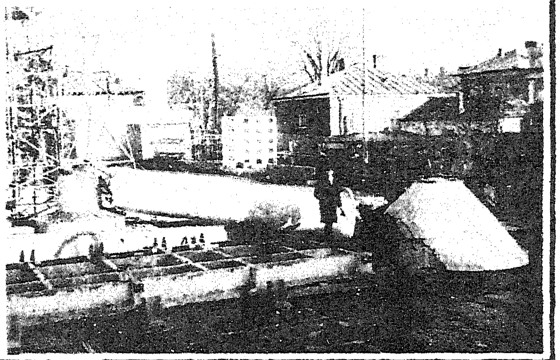

DISCUSSION

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The diameter of the supporting tube is comparatively small against the tank, as such shall make it very weak against earthquake forces. A bigger diameter of tube and the tube strengthened with a monolithic frame work of columns and beams shall be very effective.

Author's Closure

Not received.