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Model experiments concerning the seismic behaviour of nuclear power-plant turbo-generator platform

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ABSTRACT:The reinforced concrete basement of a 700-800 MW turbo-generator is an unsymetric,mixed structure of frames and diaphragms with high variations in the mass and stiffness distribution on horizontal and vertical plane and which in most cases is unique.As the action to which the structure is subjected during its service life(assembly, damage and earthquake)differ greatly in terms of distribution,intensity,frequency and shape, an experimental check-up of the analytical model used became necessary. The papar presents the dynamic analysis of a basement for a nuclear power plant turbo generator, so as to validate the block diagram used in the elaboration of the project.

1.INTRODUCTION

The analysed basement has a mixed structure,made up of frames and rigid diaphragmes,uniformly distributed in plane having large size technologic cavities.The general stiffness of the structure is concentrated around four areas:two nuclei at extremities,made up each of a frame and a diaphragme (R1 -R2 and R5 - R6)interconnected by floors and two intermediary diaphrag mes R3 and R4 fastened one to another at the top in longitudinal direction by the beams R7 and R8 fig.1.

The basement is 68 m long,15 m wide and 23.4 m high.An experimental analysis of the structure on a reduced scale model was performed so as to be to choose the most accurate diagram.

2.MODEL CHOICE AND DESIGN

The tested model was made of reinforced concrete at a 1:12 scale.This scale was chosen depending on the performance of the testing machine, taking into account the high stiffness of the structure and the nonlinear behaviour of concrete.

The model dimensions,fig.1 are 5.671 m length,1.25 m width,and 1975 m height.The vertical supports have a section of 33.4 x 33.4 cm;the thickness of the diaphragm is 8.3 cm while that of floors is 5.8 cm. and the beams are 38 x3o cm in section.

The prototype has a raft-type basement placed on a rocky foundation soil.As a consequence the model was embedded an a 25ox85o cm,slab type raft which was 35 cm thick;it was fastened to the testing stand by loo mm diameter serews disposed on a loo cm side lattice.

The model was cast form concrete of the same mark with that of the prototype,only the granularity of aggregate being different from the concrete used in the model(aggregate sizes of up to 12 mm were used).After the construction of the model,a compressive strength of concrete of 345 daN/cm^2 and a longitudinal modulus of elasticity at static loads of 3.53xlo^5 daN/cm^2 were measured by tests.

The reduction in scale of steel reinforcing bars was not always possible.In such a case there were preserved the same longitudinal and transverse reinforcing coefficient and the same distribution of reinforcing bar sections.

The experimental actions were static and dynamic of different intensities, many successions of similitude scales being necessary .The extrapolation of experimental results to the prototype had to consider the majority of distorsions inherent in modelling by using some additional coefficients.

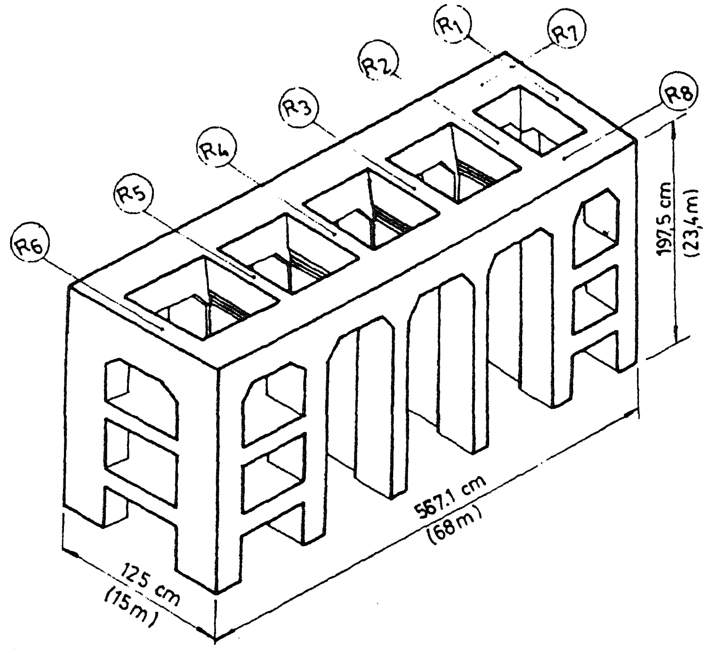

Fig.1.Specimen

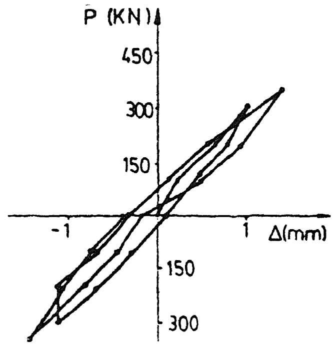

Fig.2 Experimental Hysteresis curve P-Δ

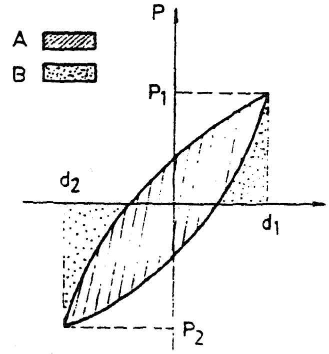

Fig.3 Diagrammatic representation of energy dissipation(damping calculation)

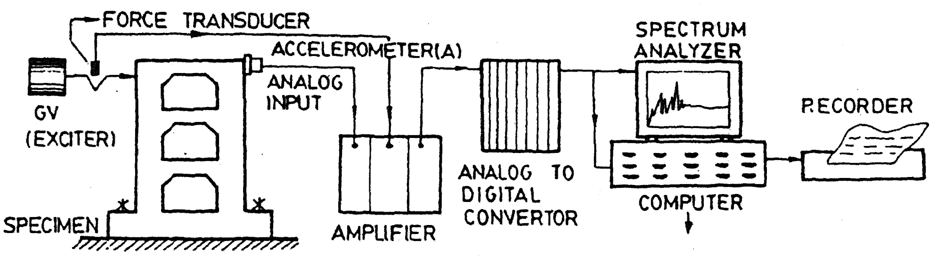

Fig.4. Automated control for specimen test systems

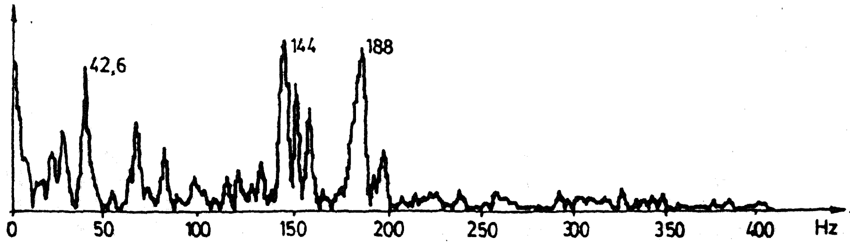

Fig.5. Frequency analysis

3. EXPERIMENTAL PROGRAM AND TEST RESULTS

The big number of tests necessary to carry out the experimental program and the high cost of the model required that the model testing be made initially only in the elastic domain up to the limit of concrete micro-cracking.
In the first stage, static tests in lateral loadings of max 350 kN were carried out on the direction of dynamic degrees of freedom in order to enable the estimation of the experimental flexibility matrix of the model. At the same time, hysteretic curvs at alternating forces were plotted, fig.2 to determine the damping of the modelled structure. According to fig. 3 the critical damping ratio was calculated using.

$$\nu = \frac{1}{2\pi} \frac{A}{A+B}$$

where A = dissipated energy and A+B= total energy accumulated during a loading cycle.

By processing the data is resulted. ν=5,9 ... 6,2%.

During the second stage dynamic tests were carried out for three situations:

-model without equipment mass (M1)

-model with equipment mass, included in the similitude theory as an additional mass(approx 1.65 t)on the top surface of the structure.(M2)

-ballasted model with a mass of 19.7 t equal to approx.eleven times the mass of equipment placed on the top surface (M3).

The model was tested in conditions of:

-impact (A1)produced with a pendulum for M1 and M2 models

-random excitation forces(A2)produced by an electromagnetic generator with variable frequencies in the 10 Hz band for model M1

-disturbing forces(A3)produced by a eccentric vibration generator reaching a variable force of max.200 kN for a 40 Hz frequency in the model M3.

Fig.4 shows the scheme of the equipment used in loading, as well as in recording and processing experimental data. Excitation GV was gradually applied on different nodes of the structure. The dynamic response was received by means of an accelerometer A or some inductive transducers for the recording of displacements.

The dynamic tests aimed at measuring the model normal frequencies damping characteristics and identifying modal parameters of the foundations taken as a discrete linear system with several dynamic degrees of freedom, by using experimental techniques with a single excitant.

The frequency analysis originate in the Fouries analysis of signals from the accelaration transducers and were made with a specialized computer with definitions of 0.2 - 100 Hz and 1 - 500 Hz. Such an exemple of analysis is shown in fig.5.

The damping characteristics were measured by resonance methods the excitation being an harmonic force of constant amplitude. For the fundamental frequency of the model M2 there resulted a fraction of critical damping of 3,1%.

The high intensity test on Model 3 with action A3 was performed at a frequency of 23 Hz to obtain the following results:

-an acceleration of 1.23 g on a transverse direction in the middle of the foundation, at its top surface

-an acceleration of 2.61 g on a transverse direction at foundation extremities

-an acceleration of 1.24 g on a longitudinal direction.

During these high intensity tests there appeared no microcracks in the model concrete.

Several block diagrams have been provided for the full scale structure and for the model:

S1 - Frames and plane diaphragm on each transverse and longitudinal direction interconnecter at their lower part and in front of the floors

S2 - Equivalent Spatial Frames

S3 - Frames - diaphragms discretized in beam hyperfinite elements and thin shells.

S4 - Frames - diaphragm discretized in tridimensional finite elements and thick slab.

The results obtained in this case are shown only to the extent they are of interst for a comparison with the experimental results.

4. CONCLUSIONS

a)The static and dynamic tests(in both directions and in torsion)have shown that between the structural elements frames and diaphragms, out of which the foundation is made, there is no connexion sufficient to enable a homogenous interrelation on the whole. It is possible the testing machine frame may compensate for the lack of interconnection which shoued be checked up experimentally on the foundation with the equipment mounted.

b)The small scale model stiffness proved to be higher than that of the design one for the model and prototype using the diagrams S1,S2,S3.The closest values were obtained on the longitudinal direction,the difference between flexibility magnituds being only of 6%. On the transverse direction the differences are higher and the corrections necessary by the identification applied to flexibility (or stiffness) matrix on the direction of dynamic degrees of freedom are much too important.This is due to the influence of diaphragm massiveness and their position which cannot be accurately estimated by models with beam and shell-type elements,specific for simple stresses.Therefore there was applied the S4 diagram made up of finite elements adeqvate to spatial stress.

c)Between the design frequencies and the experimental ones there is a good concord.The fundamental mode of vibrations of the small scale model has a design frequency of 37.893 Hz and a measured one of 38.4 Hz.There follow the theoretic frequencies 63.9,72.1 and 92.8 Hz higher than the experimental ones of 44.6,5o.4, 51.6 and 88,6 Hz.Frequencies continued to show a good concord.

d)The critical damping fraction values obtained by alternating static tests(of approx.6%) and by dynamic ones(approx.3%) for the fundamental mode)range within the domains of values recommender for the calculation of such types of structurs

e)The high intensity dynamic tests have led us to obtain the design accelerations on the model.During M3-A3 testings there were generated accelerations of 2.31 g for a frequency of disturbing forces of 23 Hz which corresponds for the prototype to an acceleration of o.139g very close to the design seismic acceletion of o.2o4 g.

f)The turbo-generator has a regime revolution of 15oo r.p.m.(frequency 25 Hz),which corresponds for the model to a frequency of 3oo Hz.The frequency analyses of the experimental data have shown that in this range of frequencies there appear no significate amplitudes,fig.5,therefore, there is no possibility for resonance to occur.

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