International Conference on Case Histories in Geotechnical Engineering

(1988) - Second International Conference on Case Histories in Geotechnical Engineering

01 Jun 1988, 1:00 pm - 5:30 pm

Seismic Response Analysis of Forebay Structure for CW Pump House of a Nuclear Power Project

Malay Basu Ray
Development Consultants Pvt. Ltd., Calcutta, India

Dhiman Kr. Ghosh
Development Consultants Pvt. Ltd., Calcutta, India

Follow this and additional works at: https://scholarsmine.mst.edu/icchge

🔴 Part of the Geotechnical Engineering Commons

Seismic Response Analysis of Forebay Structure for CW Pump House of a Nuclear Power Project

Malay Basu Ray
Project Engineer (Civil), Development Consultants Pvt. Ltd., Calcutta, India

Dhiman Kr. Ghosh
Dy. Chief Engineer (C&S), Development Consultants Pvt. Ltd., Calcutta, India

SYNOPSIS: The paper reviews the current state-of-the-art on the seismic response analysis of complex RCC structure like forebay which is usually connected with CW Pump House frame at its rear end for fullfilling circulating water requirement in power plant - nuclear or thermal. The need to include in such analysis and design effects of 3-Dimensional mathematical model and soil-structure interaction for studying overall behaviour of the structure are highlighted. The paper also discusses the usefulness, if any, of such rigorous analysis and identifies some problem areas in finalising realistic design data and adopting suitable models to represent the structural system.

INTRODUCTION

From the basic requirement of process engineering of nuclear power plant, CWPH complex has its own importance in supplying the flow of water for APW and APCW point of view, for the safe functioning of the plant. The particular CWPH complex has been designed to provide process water to 2 x 235 MW capacity units. The entire complex has been divided into three separate structures from functional and other relevant aspects and the structures are basically RCC framed units and are partially buried into the subsoil. In front of two units of pump house structure, fan type forebay structures have been placed for controlling the flow of incoming water through the tunnels from the intake point before the water enters the pump house complex. For safety reasons detail seismic analysis of the aforesaid structures under both OBE & SSE conditions, have been carried out so that the safety regulation or such vital structures for the said nuclear power plant is fulfilled. Because of the unconventional shape of forebay structure unequal loadings arises out of various load combinations at the bottom of forebay raft. Hence a rigorous analysis for the said structure has been felt absolutely essential utilising FEM and considering soil-structure interaction. Since the design basis earthquake is of moderate intensity the corresponding ground strain level has been assumed to be 10^{-2}. With respect to this strain level, the relevant soil dynamic parameters, i.e. low strain shear modulus of soil, 'G' and Poisson's ratio, ν have been considered for the entire structure under SSE earthquake condition.

The soil part in soil-structure interaction has been done with frequency independent soil springs considering elastic half-space theory. The validity of such assumption can be amply justified due to the presence of more or less hard and compact ground condition. The 'Ground Response Spectra' and 'Accelerogram' for the particular site have been supplied by the Nuclear Power Board authorities after carrying out necessary tests and statistical data analysis.

This paper highlights synthesis of the present state-of-the-art in the analysis and design of such partially buried and predominantly rigid RCC fan-shaped type structure and the results are presented and briefly discussed hereunder.

DESIGN CASE STUDY AND MODELLING OF IDEALISED SYSTEM

The dynamic seismic response analysis of the aforesaid forebay structure for CWPH complex have been carried out using 3-D analytical mathematical model as shown in Fig.4 comprising prismatic beam elements and boundary elements from the element library of the software package 'SAP VI' used in this case. The model consists of 232 nodes, 297 prismatic beam elements and 84 nos. of boundary elements, and the basic parameters considered in the analysis are as follows:

(a) Dynamic modulus of elasticity of structural concrete of grade M-25 (as per IS Code) have been considered as 3.0×10^6 t/m^2 and for structural steel 2.0×10^7 t/m^2 respectively.

(b) The overall viscous damping value for the entire mathematical model have been presumed as 10% of critical for SSE condition.

(c) Poisson's ratio of structural concrete has been assumed as 0.20 and that for steel as 0.30 respectively.

(d) Dynamic shear modulus of soil,'G' have been assessed as 1600 t/m^2 and Poisson's ratio, ν has been considered as 0.40.

Fig.1 indicates the key plan of CWPH complex for the nuclear power plant showing relative position of cooling water pump house structures and the forebay structures and how these are interlinked with each other. Fig.2 indicates typical sectional plans at two different elevations with relevant dimensions, while Fig.3 shows a typical sectional elevation of the forebay structure so that a clear idea of the actual structure may be obtained. The reader may correlate these

figures with Fig.4, i.e. mathematical model of the real structure. In order to show as many as many number of nodes as possible, the 3-D mathematical model have been shown in isometric view. The smoothend acceleration spectra for ground motion during safe shutdown earthquake for the typical plant site has been shown in Fig.5 using various percentages of damping, i.e. 2%, 5%, 10%, 20% etc.

The reason for considering a 3-D model with soil-structure interaction for the analysis and design of CWPH forebay structure may be attributed to its peculiar configurations from functional point of view and its rigidity also. Since it is basically rigid fan-shaped partially buried structure, by considering soil-structure interaction in the global analysis of the entire linear elastic system, the apparent rigid body motion of the entire structure as a whole during initial excitation due to ground movement could be well-recognised in the subsequent analytical results of eigen solution and corresponding response spectrum analysis part. The torsional deformity of the entire structure and also its individual members could only be computed by analysing the structure with 3-D FEM model. Thus the analytical result reveals the movement of structure as a whole and also the deformation of its various components within the structure during occurrence of the design basis earthquake. These aspects could not have been observed had the structure not been analysed using 3-D FEM model and also utilising soil-structure interaction concept. The above observations are particularly true for the forebay structure because this being a closed form RCC structure having cris-cross wall connections, the overall behaviour of the structure becomes very rigid, and in case of a fixed base model, the entire results of analysis would have been far from realistic.

TABLE 1. Eigen Values

Mode No.	Circular Frequency (rad./sec.)	Frequency (Hertz)	Period (Sec.)
1	27.84	4.431	0.2257
2	29.36	4.673	0.2140
3	33.50	5.332	0.1876
4	35.28	5.615	0.1781
5	36.46	5.803	0.1723
6	39.68	6.315	0.1584

TABLE 2. Modal Participation Factors

Mode No.	X-direction	Y-direction	Z-direction
1	4.126	2.725	-2.556
2	-4.392	0.738	-4.456
3	4.710	-6.664	-2.507
4	-4.760	-4.562	-2.289
5	1.388	2.043	-6.951
6	-0.592	2.935	-0.819

TABLE 3. Forces and Moments in Typical Structural Members

Direction	Axial Force (t)	Shear (t)	Shear (t)	Torsion (tm)	Moment (tm)	Moment (tm)
Member (6):						
X	15.80	3.17	5.37	0.36	12.23	4.29
Y	9.57	1.51	3.56	0.15	7.81	2.07
Z	26.27	2.43	4.83	0.31	11.61	3.35
Member (148):						
X	10.37	1.50	6.92	0.10	13.42	0.86
Y	3.73	0.71	4.02	0.05	7.85	0.31
Z	11.23	1.17	5.18	0.08	9.92	0.73
Member (215):						
X	4.40	2.16	2.39	0.22	2.91	1.28
Y	2.33	1.07	1.31	0.11	1.67	0.64
Z	8.93	1.73	1.58	0.20	3.06	1.04
Member (272):						
X	0.58	1.85	2.82	0.22	11.21	4.14
Y	0.38	1.32	1.42	0.28	5.81	0.03
Z	0.43	1.53	3.66	0.38	14.69	3.46

TABLE 4. Deflections and Rotations at Typical Nodes

Direction	δ_x (mm)	δ_y (mm)	δ_z (mm)	$\theta_x \times 10^{-4}$ (rad.)	$\theta_y \times 10^{-5}$ (rad.)	$\theta_z \times 10^{-4}$ (rad.)
Node (2):						
X	2.40	5.48	1.56	3.33	6.45	3.71
Y	1.74	3.51	0.94	1.42	4.60	1.95
Z	1.50	3.30	2.50	3.21	4.02	2.60
Node (14):						
X	2.49	2.77	1.89	3.53	7.96	3.75
Y	1.29	1.89	0.72	1.47	5.34	1.99
Z	1.93	1.73	2.42	3.32	5.14	2.59
Node (49):						
X	3.07	2.32	2.98	4.98	9.28	4.87
Y	1.21	1.81	0.93	1.72	6.54	2.31
Z	2.47	1.49	3.06	4.67	6.00	3.36
Node (82):						
X	11.21	2.02	13.65	32.70	49.00	7.34
Y	6.15	1.62	5.64	15.90	59.70	4.14
Z	8.83	1.24	14.57	41.60	77.20	7.25

PLAN AT EL. 99000.

FIG.-2

PLAN AT EL. 94000.

SECTION A—A.
FIG.-3.

KEY PLAN
SCALE 1/500
FIG-1

SMOOTHENED ACCELERATION SPECTRA FOR SAFE SHUT DOWN EARTHQUAKE
FIG-5.

ISOMETRIC VIEW OF 3-D MATHEMATICAL MODEL
FIG.-4

GLOBAL AXES
(AS PER LAP IV/LAP VI CONVENTION)

Y (VERTICAL)

X (HORIZONTAL)

Z (HORIZONTAL)
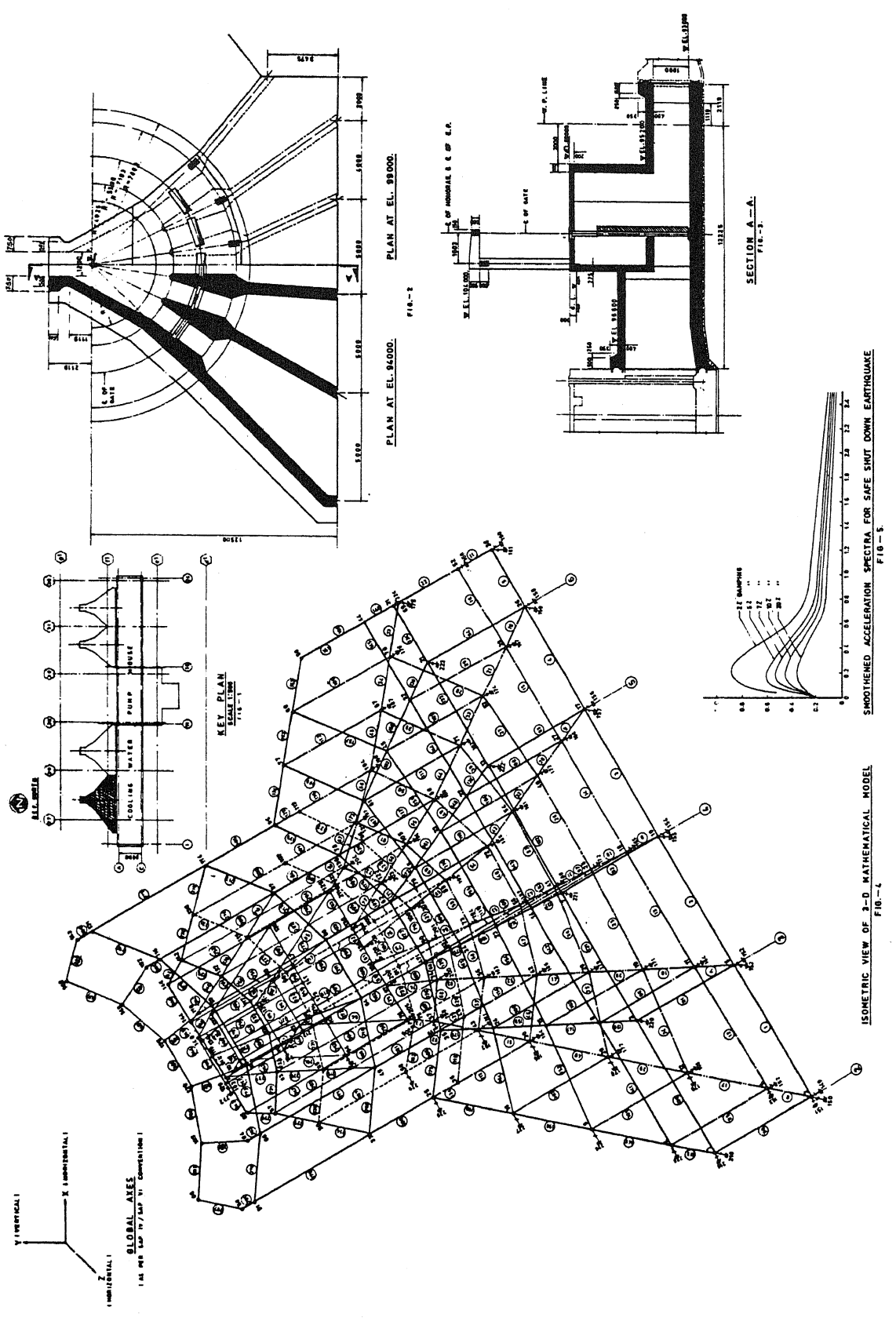
DISCUSSIONS ON RESULTS OF ANALYSIS

A close look at the computer response spectrum
analysis output shown in very much abridged form
in Table 1 thru' 4 shows that the entire struc-
ture has been basically low tuned and moved a
bit as a whole along with the ground in its
fundamental modes. Moreover, the resultant
moment and forces in its various members due to
inertial loading which have been generated with
the corresponding response of the entire struc-
ture corresponding to ground excitation may be
observed to be of considerably lower magnitude,
thereby, confirming the basic fulfilment on the
part of the designer to opt for such elaborate
analysis at a relatively higher cost than going
in for conventional 2-D fixed base quasistatic
analysis under abovementioned earthquake.
Table 1 gives a resume of eigen values in the
first six fundamental modes; Table 2 indicates
the modal participation factors along the three
directions for the six fundamental modes, while
Table 3 summarises typical values of forces and
moments due to generation of inertial forces
during earthquake in some of its important
structural members. Table 4 indicates the
deformations and rotations of corresponding
nodes in which the abovementioned members are
connected structurally. The forces and moments
on the individual members due to ground motion
have been found to be extremely low because the
stiff forebay structure has a tendency of rigid
body motion in the fundamental modes as stated
earlier and corroborated subsequently by compu-
ter results.

During analysis, the main difficulties which had
been faced by the analyst are realistic assess-
ment of 'G' value for soil, corresponding to the
particular strain level at which the response
spectra of the ground motion have been consi-
dered for the analysis. It will be more useful
if elaborate data on 'stress-strain' relation-
ship for the subsoil at the location of the plant
are available under various magnitude of ground
motion and subsequent ground movement. Regard-
ing structural modelling use of beam element or
combination of beam and plate element should
yield realistic results.

Assessment of appropriate damping parameter has
also been uncertain because all the available
standard software packages can only take care of
an average value of overall viscous damping of
the entire system comprising superstructure,
substructure and soil in the form of Rayleigh
damping parameter involving both mass and stiff-
ness matrix only. Whereas in actual practice,
there is considerable material damping from sub-
soil which cannot be simulated in exact manner
in the abovementioned case. The structural part
derives its damping parameter mainly from its
geometry, mass and stiffness array. While
carrying out the seismic response analysis under
safe shutdown earthquake condition, dynamic
modulus of elasticity for both structural con-
crete as well as subsoil have been utilised and
the entire analysis have been done in linear
elastic domain.

To facilitate initial strength design of various
structural elements of the forebay structure,
response spectrum analysis have been carried out
first and subsequently, detail time history ana-
lysis have also been done to find out the spec-
tral response at predetermined nodes which are
of interest to other mechanical and service
installations of the said structure. The fore-
bay structure as shown in Fig.1 between grid 16
and 24 is almost similar in configuration to
that between grid 1 and 11. Considering the
magnitude of seismic forces and moments it can
be concluded that a separate analysis for the
structure between grid 16 and 24 may not be
warranted. The detailing may be done based on
the analytical output for the part between grid
1 and 11.

CONCLUSIONS

It can be emphasised that whatever may be the
different load combinations and however uncon-
ventional may be the form of the structure,
under seismic loading, systematic FEM analytical
approach utilising soil-structure interaction
concept may yield significant results which help
the designer to understand the actual behaviour
of the structure under complex dynamic loading;
and it is felt in view of uncertainty of dynamic
soil data pertaining to specific strain condi-
tion, a range analysis may be much more meaning-
ful.

REFERENCES

1. Clough, R.W. & Penzien, J. (1975),
   "Dynamics of Structures", McGraw-Hill.

2. Dowrick, D.J. (1977),
   "Earthquake Resistant Design",
   John Wiley & Sons.

3. Prakash, S. (1981),
   "Soil Dynamics", McGraw-Hill.

4. SAP VI User's Manual (1980),
   University of California, Berkeley.