SEISMIC ANALYSIS OF THE TURBINE BUILDING OF A BWR NUCLEAR POWER PLANT

by

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SYNOPSIS

Considering the requirements imposed by the Swiss Regulations, the preliminary seismic design of the turbine building of NPP Graben-Switzerland has been carried out by using dynamic seismic analysis methods. The turbine building of the GE-Mark III BWR NPP is an extremely complicated structure. The main difficulty for the analysis of the turbine building lies with the idealization of such a complicated structure into a 3D mathematical model with a reasonable number of degrees-of-freedom, yet providing suitable amount of response information that could allow a detailed stress analysis. The mathematical model created has 330 active degrees-of-freedom. The responses are calculated by employing the response spectrum program included in E+B's Dynamic Analysis Package.

INTRODUCTION

In many of the countries where nuclear power plant technology is under establishment, the US NRC Regulations are adapted almost without any alteration. According to these regulations, nuclear power plant structures, systems and components important to safety should be designed to withstand the effects of earthquakes without loss of capability to perform necessary safety functions. In US NRC R.G. 1.29 and SRP Section 3.2.1, those plant structures, systems and components that are designed to remain functional if the SSE occurs are designated SEISMIC CATEGORY I. SRP sections 3.7.1, 2 and 3 require sophisticated dynamic analysis methods for design of Seismic Category I structures, systems and components.

The rest of the structures, systems and components are designated NON-SEISMIC CATEGORY I and the use of conventional seismic design methods specified in local building codes (such as UBC) are allowed for these structures, systems and components.

According to the above mentioned US NRC regulations, the turbine building is classified as a Non-Seismic Category I structure and in those countries where US NRC Regulations are adapted without any alteration, no special attention is paid for the seismic design of the turbine building.

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In Switzerland, however, plant structures, systems and components are classified in the following three seismic categories:

The SEISMIC CATEGORY I structures, systems and components are designed to withstand SSE. Generally US and Swiss Seismic Category I structures, systems and components are in accordance.

The SEISMIC CATEGORY II structures, systems and components are designed to withstand OBE. Those are required for continuous operation, without undue risk to the health and safety of the public, shall remain functional during and after an OBE. Swiss Regulations require that, those structures be designed by means of dynamic seismic analysis methods.

Requirements for SEISMIC CATEGORY III civil structures are in accordance with the conventional building regulations (such as SIA Code 160). For other equipment in this category, there is no seismic requirement.

According to these Swiss Regulations, the turbine building is designated as a Seismic Category II structure and it should be designed by using dynamic seismic analysis methods to withstand OBE.

SEISMIC DESIGN OF THE TURBINE BUILDING

Considering the requirements imposed by the Swiss Regulations mentioned above, the preliminary seismic design of the turbine building of NPP Graben-Switzerland, has been carried out by using dynamic seismic analysis methods. At this preliminary design stage, well known Response Spectrum method is employed.

Earthquake input is defined by the US NRC R.G. 1.60 horizontal and vertical response spectra normalized to 0.09 g and 0.06 g OBE horizontal and vertical maximum accelerations, respectively. Three components of earthquake exitation have been considered and applied simultaneously to the 3D mathematical model of the turbine building.

MODELING TECHNIQUE OF THE TURBINE BUILDING

The turbine building of the GE-Mark III BWR nuclear power plant is one of the most complicated structures of the whole plant, comprising:

- A thick reinforced concrete base mat,
- Reinforced concrete main building up to the operations floor, consisting of outer walls, inner shear walls, columns and floor slabs,
- Steel roof construction supported by steel columns and steel bracings,
- Turbine-Generator-Condenser complex and its reinforced concrete foundation plate, resting on the elastic springs

and dashpot elements, which are supported by the main building.

The soil-structure interaction considerations require the addition of the soil elements to those already complicated and heterogenous structural complex (Figure 1).

The main difficulty for the dynamic seismic analysis of the turbine building lies with the idealization of such a complicated complex into a 3D mathematical model with a reasonable number of degrees-of-freedom, yet providing suitable amount of response information that could allow a detailed stress analysis.

An optimum solution has been reached, after studying the general behaviour of the structure very carefully. The complex structure has been first divided into the following family of members, then these are reassembled to maintain homogeneity (Figure 2):

- SOIL: Lumped parameter soil springs are calculated considering half-space theory and rigid rectangular base mat, then these springs are distributed along the longitudinal centerline of the base mat.
- BACKBONE: The longitudinal behaviour of the reinforced concrete main structure, including the base mat, is represented by an eccentric continuous beam having variable cross-sections of the whole reinforced concrete structure along the longitudinal axis of the building.
- CANTILEVERS: Transversal behaviour of the reinforced concrete structure is represented by 14 concentrated cantilevers connected to the backbone at their bases.
- CONNECTIONS: In order to maintain homogenous behaviour, whereever it is appropriate, an elastic or a rigid connection is provided between corresponding degrees of freedoms of pairs of cantilevers or between a cantilever and the backbone. For this, extensive use of so-called rigid elements of NASTRAN program is employed.
- STEEL ROOF: The roof deck is represented by a longitudinal beam, supported vertically by 14 concentrated steel columns, and horizontally by 4 steel bracings. Those hinged columns and bracings are supported by reinforced concrete cantilevers. Again, extensive use of rigid connections is employed between the roof deck and the column and bracing heads.
- TURBINE-GENERATOR-CONDENSER complex: First represented by a series of distributed mass points, then they are concentrated into a single master mass point by using rigid connections. The original locations of the sup-

port points of the turbine-generator-condenser table are maintained and spring elements are employed between these points and the cantilever supports. This arrangement maintains the overall dynamic behaviour of the turbine-generator-condenser complex.

EIGENVALUE CALCULATIONS

The described mathematical model consists of 90 BAR, 22 ROD and 186 ELAS2; total 298 finite elements and 234 grid points. With 6 degrees of freedom per grid point, altogether 1404 total degrees of freedom exist. However, with the extensive use of rigid connections this total is reduced to 330 independent degrees of freedom.

With this mathematical model, NASTRAN program is utilized for the calculation of eigenvalues and the necessary modal information of the structure. 50 modes are determined (Table 1) up to 24 Hz. and these modal information is used in the response calculations employing the response spectrum program built in E + B's Seismic Analysis Package.

RESPONSE OF THE TURBINE BUILDING TO SEISMIC EXCITATION

Maximum dynamic element forces and stresses so obtained are combined with the results of the other relevant loading conditions, and the stability of the turbine building during an OBE is ensured.

On the other hand, for each floor level of the building and also for the turbine-generator-condenser complex, the maximum pseudo-accelerations are provided (Figures 3 and 4). These accelerations are used to check the stability of various electro-mechanical equipment attached onto those floors of the building.

The maximum relative displacements between the building supports and the turbine-generator-condenser table are also calculated in order to ensure that the allowable limits are not exceeded (Figure 4).

TABLE 1 - MODAL INFORMATION FOR TURBINE BUILDING

MODE NO	FREQUENCY Hz.	CONTRIBUTING ELEMENT	MAIN DIR. OF VIB.	MODAL DAMP. %
1	1.41	Roof	Y	2.32
2	2.32	Roof	X	2.53
3	2.67	T/G/C	Y	12.10
4	2.81	T/G/C	X/Z	12.13
5	2.82	T/G/C	Z+X	11.53
6	3.02	T/G/C	X	11.36
7	3.07	Roof	X	2.41
8	3.34	T/G/C	Y/X	11.75
9	4.37	T/G/C-Build.	Y	10.57
10	4.92	Build.-T/G/C-Soil	Y	13.67
11	6.00	Build.	Y/Z	4.77
12	6.60	Build.-Soil	Y	9.77
13	6.73	Soil	X	37.75
14	7.74	Build.-Soil	X+Y	20.93
15	8.04	Build.	Y	5.91
16	8.17	Build.	Y/Z	4.57
17	9.49	Build.-Soil	Y+Z	7.20
18	9.60	Build,	Y/Z	5.50
19	9.83	Build.-Soil	Z/Y	7.38
20	10.42	Build.-Soil	Z+Y	8.84
21	10.49	Build.-Soil	Z/Y	15.41
22	10.62	Build.	Z+Y	4.13
23	10.88	Build.-Soil-Roof	Z/X	15.85
24	10.92	Build.-Soil-Roof	Z	13.89
25	11.27	Build.-Soil-Roof	Z	10.84

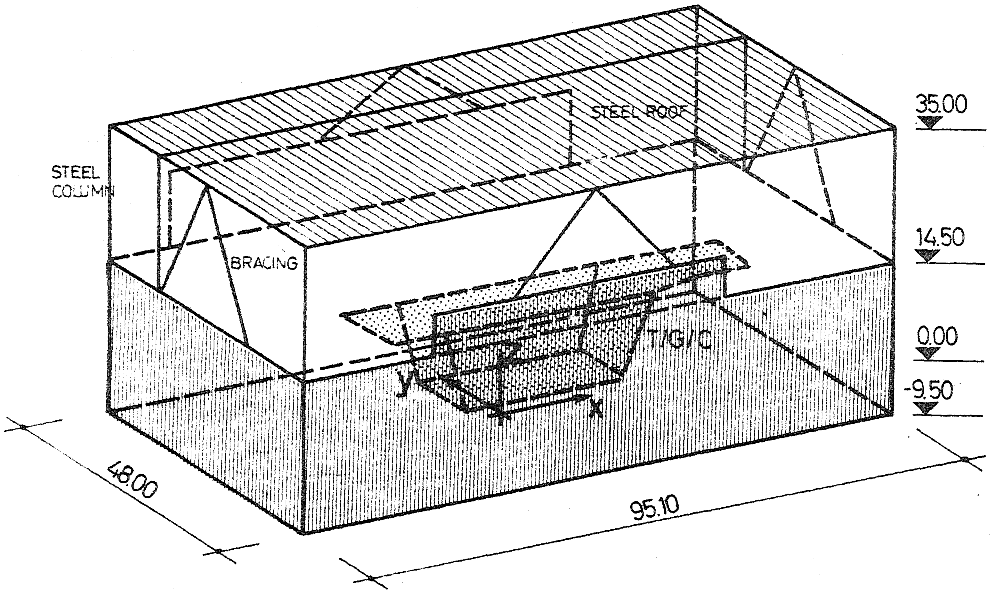

FIG. 1 - STRUCTURAL COMPONENTS OF TURBINE BUILDING

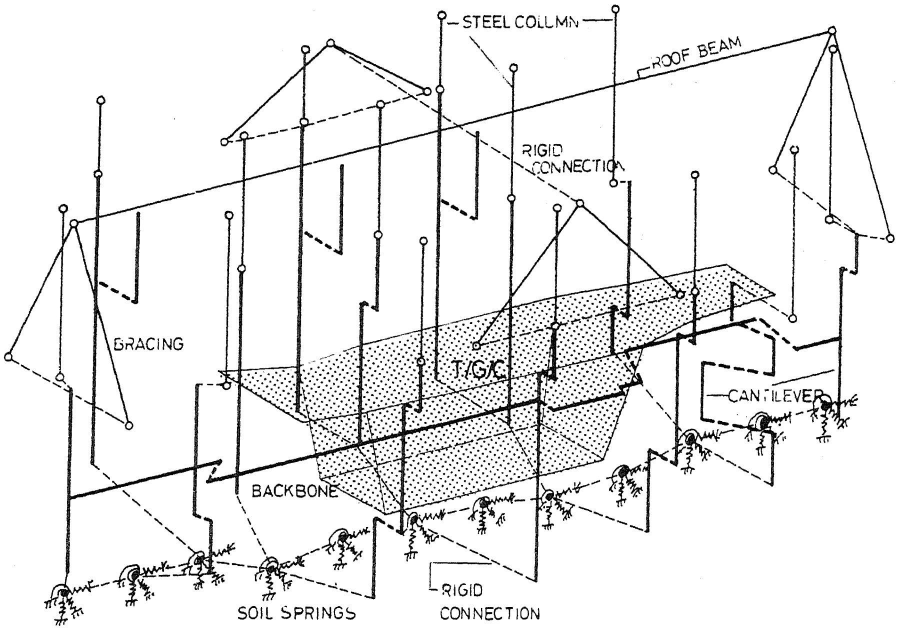

FIG. 2 - MAIN STRUCTURAL ELEMENTS USED FOR MATHEMATICAL IDEALIZATION

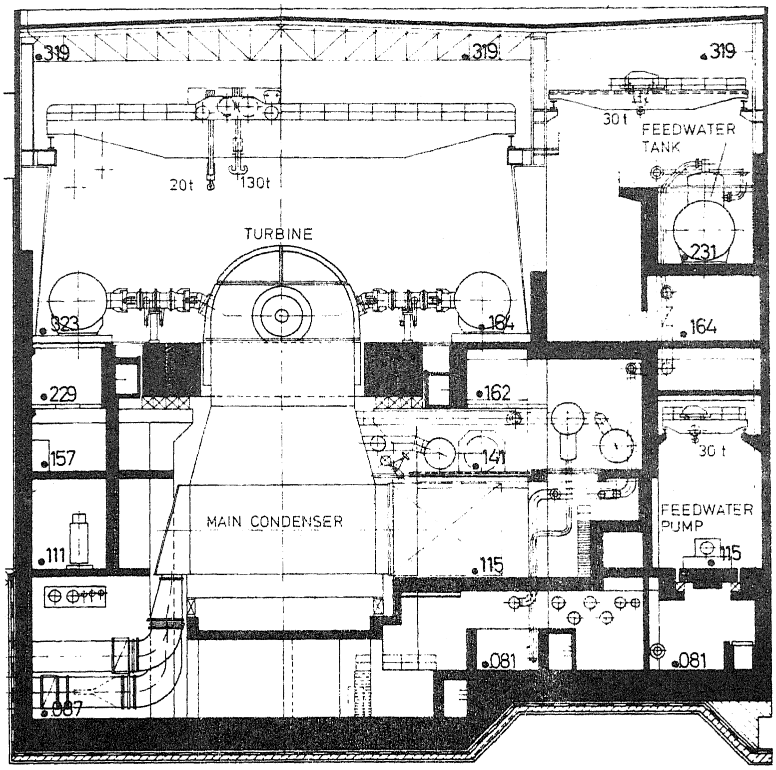

FIG. 3. PSEUDO-ACCELERATIONS(g) OF THE FLOORS IN TRANVERSAL HORIZONTAL DIRECTION.

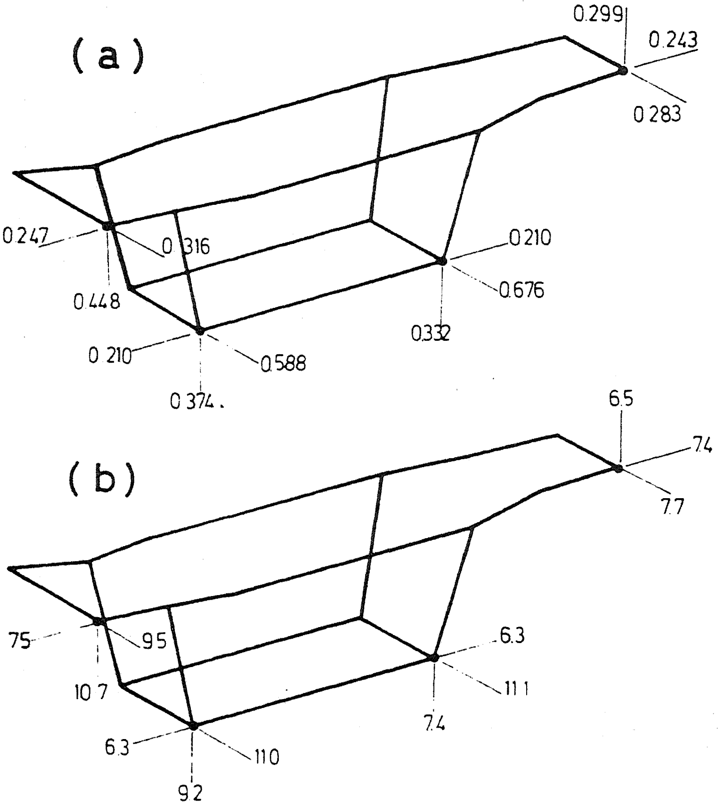

FIG.4. RESPONSE OF TURBINE/GENERATOR/CONDENSER BLOCK
(a) PSEUDO-ACCELERATIONS (g)
(b) DISPLACEMENTS RELATIVE TO SUPPORT POINTS (mm)