Effect of strong correlation between response seismic accelerations and its importance for evaluating of general equipment for Reactor building

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Abstract. This paper deals with the verification of the general assumption used in dynamic analysis of equipment under a seismic excitation — assumption about uncorrelated components of in-structure response accelerations (RA). With the help of examples of seismic dynamic analyses of two reactor buildings (VVER-1000) the violation of such assumption is demonstrated. The reasons for appearance of RA components' correlation and importance of this effect are discussed.

1. Assumption about statistic independence of RA components in seismic analysis of equipment

According to Russian standards [1] and international practice [2, 3, 4], consideration of seismic excitation is obligatory for nuclear power plant (NPP) design. Moreover, for new NPPs the peak seismic ground acceleration should not be less than 0.1 g [1, 3].

A seismic excitation received by a structure can be defined by earthquake ground motion. Usually a ground acceleration time history is used for this. One of the main characteristic features of a seismic motion is its probabilistic nature. On the basis of numerous earthquake records, it is determined that ground acceleration time history components are nearly statistically independent [5, 6]. To measure a statistic dependence of acceleration components the correlation coefficient r_{ij} defined below is usually used:

$$r_{ij} = \frac{E(x_i - m_i)(x_j - m_j)}{(s_i s_j)}, \quad i,j = \{x,y,z\},\ i \neq j,$$

where E is the operator of mathematical expectation , m_i and m_j are means of random variables x_i and x_j, s_i and s_j are their mean square deviations. According to [1, 2] correlation coefficient of ground acceleration components should be less than 0.3.

Seismic analysis of equipment can be carried out jointly with a main supporting structure such as a building. But often it is fulfilled separately by using seismic RA calculated at the in-structure bearing points.

According to Russian and American standards [1, 2] and recommendation of IAEA, dynamic analysis of equipment subjected to a seismic excitation can be carried out by time history integration or by response spectrum analysis (RSA). In the first case, seismic calculated RA and response displacements (for multisupport units) are used as the seismic load. In the second case, response spectra are calculated on the basis of RA. Here the assumption of statistic independence of RA components is traditionally used [6]. Additionally often RA can be calculated through synthesis of artificial accelerations based on some generalized response spectra. According to [2] it is necessary to synthesize artificial RA with components' correlation coefficient lesser than 0.3.

Thus, in dynamic analysis of equipment subjected to seismic excitation the assumption of statistic independence of RA components is often used. But three statistically independent components of ground motion are transmitted through the same elastic system (main structure with a soil base) and may be modified en route. Therefore, the assumption of the statistic independence of in-structure RA components should be verified.

2. Verification of assumption about statistic independence of RA components under seismic excitation

To calculate correlation coefficients of RA components, dynamic analysis was carried out for two NPP reactor buildings. For this purpose the finite element approach (FEA) was used. With the help of a FEA modeler FEMAP (EDS, USA) comprehensive mathematical models of the buildings were created. Generally the models consisted of *beam* and *shell* elements as the main element types.

To define seismic excitation, the 3D synthesized artificial acceleration satisfying requirements of [1, 2, 3] was used. The horizontal acceleration components were scaled to peak ground acceleration of 0.25 g. Vertical one had the absolute maximum acceleration of 0.17 g. Accepted acceleration had the time duration of 30 s, time step increment of 0.01 s and correlation coefficients $r_{XY} = -0.02$, $r_{XZ} = -0.14$, $r_{YZ} = 0.01$. Dynamic analysis of buildings was fulfilled using the FEA solver SOLVIA-99.0 (SOLVIA Engineering AB, Sweden). Modal superposition technique and time step integration was used.

The section of first reactor building considered in analysis is shown in Fig.1. Seismic dynamic analysis has shown that for this building and its real soil conditions RA correlation coefficients changed within the following limits: $-0.20 \leq r_{XY} \leq 0.14$, $-0.77 \leq r_{XZ} \leq 0.73$, $-0.71 \leq r_{YZ} \leq 0.73$. The distribution of coefficient r_{XZ} on building is represented on Fig. 2. It can be noticed that correlation coefficient of two horizontal RA components in internal points of structure remains less than 0.3. But the correlation coefficient for vertical and any horizontal RA components reaches large values. The reasons for this will be discussed below.

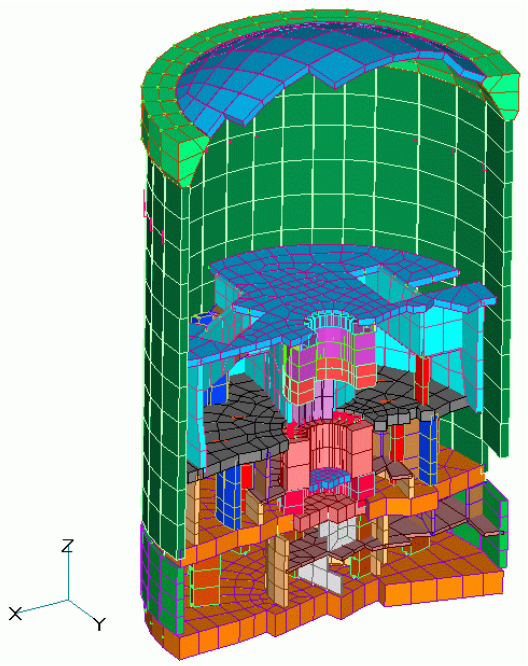

Fig. 1. Section of the reactor building model

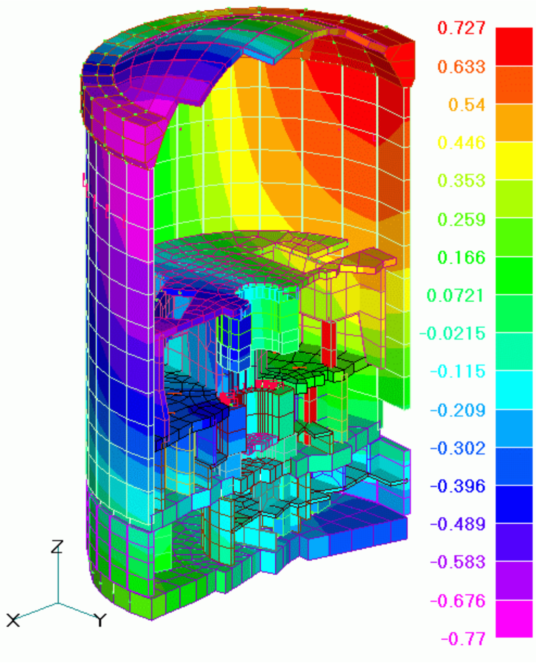

Fig. 2. Distribution of correlation coefficient r_{XZ}

Same dynamic analysis was also applied to another NPP reactor building. General view of the model of this second reactor building is given in Fig.3. For this reactor buildings three types of soil base were considered with density of 2000 kg/m^3, Poisson ratio of 0.4 and shear modulus G= 1.3e+8 N/m^2, G= 8.0e+8 N/m^2, G = *inf*. As a result of dynamic analysis RA correlation coefficients were calculated for a few selected characteristic points. These points are shown in Fig.4. In Fig. 3 the distribution of RA coefficient r_{YZ} is represented for the rock base (G = *inf*).

Maximal RA correlation coefficients in selected points are given in Table 1 for all considered soil types. These results show that RA correlation coefficients can take on values up to 0.5 - 0.7. Therefore, in-structure RA components could not be treated as statistically independent.

Table 1. Absolute maximal values of RA components for specified points

Point	r_{XY}	r_{YZ}	r_{YZ}
1	0.70	0.59	0.62
2	0.53	0.43	0.46
3	0.51	0.15	0.24
4	0.53	0.17	0.24
5	0.56	0.69	0.63

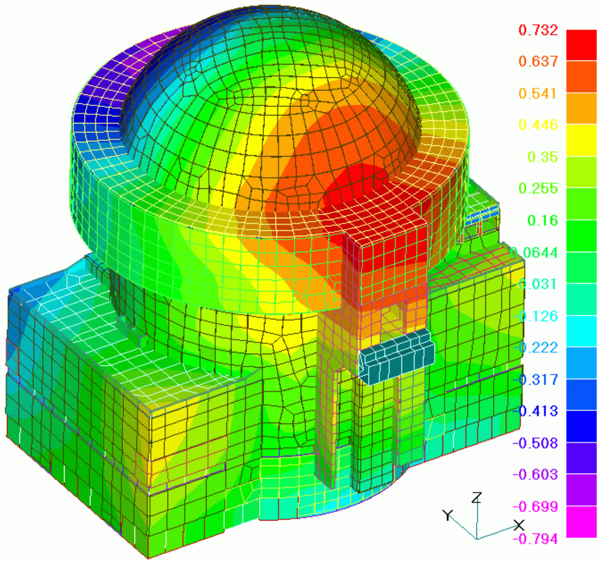

Fig.3. The reactor building model. Distribution of correlation coefficient r_{YZ}

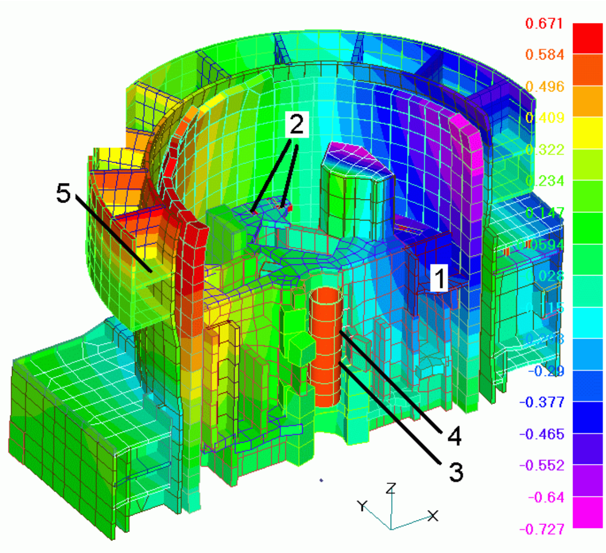

Fig.4. Specified points to calculate RA correlation coefficient

3. Reasons for statistical dependency of RA components under seismic excitation

The example of the first building under consideration clearly manifests an absence of statistical dependency of RA, due to its almost axially symmetric structure. On the other hand, pairs of RA components X — Z and Y — Z can be strongly correlated. This can be attributed to the soft soil base of the building. Due to the fact that the building can rock substantially in vertical planes, the points, located far from vertical plane of symmetry, can experience strong vertical motion. The appearance of RA correlation is also possible for points on flexible walls and slabs.

The second building under consideration has a strong correlation of RA horizontal components for internal containment structures. These structures have unsymmetrical shape and principal inertia axes that do not lie in vertical plane of symmetry of the whole building. The same can be said about the pairs of vertical and horizontal RA components subjected to seismic rocking of the building.

To generalize given results, the following conclusion can be made — appearance of strong statistical dependencies of in-structure RA components is possible when the seismic excitation along one global axis can produce strong structure response in another global axis.

4. Consideration of statistical dependency of RA components under seismic analysis of equipment

Strong statistical dependency of RA components signifies that maximum values of seismic response of equipment to each of these components happen almost at the same time instance. As a result the usual implementation of SRSS rule in RSA or using of uncorrelated synthesized artificial RA components lead to non-conservative results.

This non-conservatism of results can be demonstrated with the help of a boundary case of full statistic dependence of RA components. Under this condition if the response to each RA component equals to R then total response reaches $3R$ instead of $R\sqrt{3}$, which is the total response value according to RSA with SRSS-rule. Indeed, usually for real system even with a strong correlation of RA components the difference is not so large. However, this example shows that neglecting this correlation can bring to non-conservative results.

It should be noted that the buildings considered in this work are almost symmetrical and rather rigid. A larger correlation of RA components can be expected in more flexible buildings such as turbine halls.

5. Conclusions

The examples of dynamic analyses of two reactor buildings have demonstrated that the assumption of uncorrelated components of seismic response acceleration is not always appropriate. That assumption can cause non-conservative evaluation of seismic response for general in-structure equipment.

Zones of structure with large statistic correlation of RA components can be determined during dynamic seismic analysis. For conservative analyses it is reasonable to use absolute summation rule for combination of responses to different spatial RA components in these zones.

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