# Seismic Loads and NPP Reliability

**Yu. K. Ambriashvili**
*Atomenergoproject, Moscow, USSR*

ABSTRACT

This paper presents the result analysis of investigations and designing for seismic proof nuclear power plants considering general safety requirements, structural reliability of building and technological systems subjected to earthquakes.

Some theoretical and practical approaches in seismic reliability calculation both for the building as a whole and its separate elements are cited herein.

## INTRODUCTION

Nuclear Power Plant seismic stability investigations constantly put forward a great number of new problems which require systematical improvement of general design principle conception, theoretical developments and design techniques. The questions of probability approach wide applications in nuclear power plant seismic reliability evaluation within the terms of its serviceability are related to the above mentioned problems.

## ANALYTICAL APPROACH IN SEISMIC RELIABILITY EVALUATION

As a result of extensive investigations held in the USSR and abroad in the recent 20 years there have been established the standard main rules of nuclear power plant (NPP) design and analytical, numerical and theoretical-experimental methods of NPP seismic stability control. Presently, a number of specifications, which are obligatory for NPP design and in accordance with which control over NPP is exercised, act in the USSR. They are, in particular, "Aseismic NPP Design Standards" (general requirements), "Strength Analysis Specifications for NPP Equipment under Seismic Loads", "Specifications for Controlling NPP Electrical and Instrumentation Equipment under Seismic Loads" and others regulating experimental-design control over the NPP operating elements during the earthquake.

By the results of scientists' and designers' scientific and practical activity concerning a definite unit, it has been ascertained that in NPP stability analysis even low seismic loads are to be taken into account as the seismic effect considerably intensifies for the equipment installed in the NPP building structures different zones.

In the acting standards and specifications the definitions of reliability, serviceability, failures, false start-ups of the whole NPP technological system and its sub-systems are given. However, it should be noted that the failure tree analysis and calculations of preservation have been carried out ignoring earthquake influence on both the main equipment and on the stand-by ones, therefore the principles of NPP technological structures building were based on the concepts of seismic reliability of the elements forming seismic category I and II technological systems.

In the NPP design for seismic loads, much outcome information, the authenticity degree of which, in particular, influences essentially the taken decisions concerning the NPP reliability improvement, is used. On the other hand, trying to use the outcome information and design methodology of great probability factor may lead to unjustified high loads and additional large expenses. The seismic reliability investigation result can be systematized as shown in Tables I and II.

Table I. The parameters of the item in zone under control.

| Item state | Stationary signal | | | | | | Seismic signal | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $H_T^k(f)$ | $\delta$ | $S_T^k(f)$ | $a_{OT}$ m/s$^2$ | $f_{OT}$ g | failure type | $S_t^{ka}(f)$ | t, c | $a_{OT}$ m/s$^2$ | failure type |
| Prior to seismic protection | | | | | | | | | | |
| After seismic protection | | | | | | | | | | |

where: k = control zone index (e.g. evaluation); $H_T^k(f)$ = item transfer function; $\delta$ = damping characteristics; $S_T^k(f)$ = spectral density of response to the stationary signal $a_o(t)$ at item maximum loads; $a_{oT}$ and $f_{oT}$ = acceleration amplitude (displacements, velocities) and item natural oscillations frequency respectively, at which failures have been registered; $S_T^{ka}(f)$ = spectral density of response to the random signal $a_o(t)$, spectral density of which is equal to stationary signal $a_o(t)$ spectral density $S_o(t)$; t = random signal duration period.

Table II. Item reliability indexes in control zone.

| Functional purpose | Total structural reliability | | Item seismic reliability factors |
|---|---|---|---|
| | Prior to seismic load | After seismic load | |
| | $\Pi_1$ | $\Pi_2$ | $K_{CH}$ |

Note: seismic reliability factor $K_{CH}$ is calculated as per the following formula:

$$K_{CH} = 1 - \Pi_2/\Pi_1 \geqslant 0$$

where $\Pi_1$ and $\Pi_2$ = item reliability indexes prior to and after the seismic load, respectively.

The data for item reliability assessment, presented in Table I, have been achieved on the basis of the following conditions:

1. It is necessary to know the dynamic load values at which the ultimate state (loss of load-carrying capacity, occurence of plastic deformation, leaks, jamming, incomplete optimization of regime, false start-up, contact fault, short circuit, change of physical parameters) of the given item ensues and which can be determined by the results of investigations and earthquake consequence analysis (Ambriashvili, 1979).

2. Load values of the item ultimate state must be achieved by the results of probabilistic and statistic analysis of input seismic signals $a_o(t)$ and, accordingly, their spectral density $S_i(t)$ physical-mechanical characteristics of soil $V(t)$ and structure $U(T)$ state, of "soil-structure" system complex transfer function $H_c\,[(f), V(T), U(T)]$ as well as technological equipment transfer functions in installation zones ot items tested for reliability $H_T(f)$ (Kirillov, 1985).

3. For checking each definite item reliability it is necessary to have information on damping characteristics $\delta$ , spectral density responses to stationary $S_T^k(f)$ and seismic signals $S_T^{ka}(f)$ $a_o(t)$ and $a_i(t)$. That will allow to provide the system with the most optimal seismic protection.

Failures being detected and measures being developed for their reduction and elimination, the item tests for structural reliability are repeated.

Under this statement of the problem, the probabilistic-statistic approach to reliability parameters and values basis used in calculations is of great concern.

For this purpose special theoretical-experimental investigations are carried out to gain statistical data of soil influence on "soil-structure" system dynamic characteristics. In this case soil physical-mechanical qualities vary within the limits, typical for actual NPP sites, and building geometrical, physical-mechanical and inertial characteristics vary within admissible deviation limits for building structures, including modulus of concrete $E_\varsigma$ and soil plasticity, structure mass m, cross-section area of structure and soil S, cross-section inertial moment J.

By the results of theoretical-experimental investigations the data concerning amplitude and frequency characteristics of typical NPP buildings erected in seismic regions sites with different types of soil can be gained for the input data different combinations considering the probable range of parameters deviation. That makes it possible to calculate probability density, curves of amplitude maxima distribution and frequency modification range, depending on variability of all the factors concerned.

Thus for development of NPP seismic resistance equipment it is necessary first of all to determine the "soil-structure" system amplitude and frequency characteristics and find out probability $P[H(f)]$ , proceeding from the following expression:

$$P[H(f)] = \Omega\ [m, S, J, V(T), U(T)] \qquad (1)$$

where $\Omega$ = region of admissible states, parameters comprised in the expression.

The adequate approach should be applied to calculation of synthesized seismic signals. Let a number of seismic signals with different intensity value for a definite site or region be N. Then spectral densities $S_i(t)$ can be calculated for each signal; and probability density and maxima distribution curves in a specified frequency range $P_N[S_N(f)]$ , as well as spectral density $S_N(f)$ on the level of probability specified confidential interval can be calculated as per the whole set of seismic signals.

The problem can be handled in probabilistic statement for specified probability factor $P_N[S_N(f)]$, considering that $S_j(f) = H_j(f) \cdot S_o(f)$, where $S_o$ and $S_j(f)$ = spectral densities at soil level and at the structure j elevation, respectively; $H_j(f)$ = "soil-structure" system transfer function at the j elevation.

In this case

$$P_p \, [S_j(f)] \iint P \, [T, H(f)] \, S_N(f) dfda \qquad (2)$$

Furthermore, according to the relation $P_p[S_j(f)]$, spectral density at the level of specified confidential probability is calculated. As per technique 3, design seismic signals at the j elevation are synthesized. Moreover, it should be noted that this spectral density $S_N(f)$ can differ from the set of loads for definite sites. To assess the degree of difference relation analysis of functions $S_N(f)$ and $S_j(f)$ in a specified frequency range is also needed, in this case authenticity of design seismic load is characterized by factor $K_B = S_1(f)/S_N(f)$. Thus element structural reliability H under seismic load condition can be calculated by the following relation:

$$H = 1 - F \, (K_{CH}, K_B) \qquad (3)$$

where $F \, (K_{CH}, K_B)$ = failure in factors' function of structural reliability and seismic load authenticity.

In accordance with the proposed technique the problem solutions have been developed, relating, in particular, to the determination of seismic load, synthesized seismic signals and other parameters. This technique can also be applied for assessment of technological system reliability of other power and industrial units.

## EXAMPLE OF PRACTICAL APPROACH FOR SEISMIC RELIABILITY CALCULATION

If the probability of design failure in NPP is equal to $P \, [A(T)] = A$, consequently all the reliability values H, used for equipment and structural design, may not exceed the level

$$H = 1 - P \, [A(T)] \qquad (4)$$

Proceeding from this, to evaluate the reliability of the element, installed on the i floor, it is necessary:

1. To choose the design load $A_o(t)$ on a free field with required probability of recurrence period $P \quad A_o(T)$. The probability of excess for the safe shut-down earthquake with recurrence period of 10,000 years is

$$P \, [A_o(T)] \leqslant 10^{-4} \qquad (5)$$

2. To calculate the curve of acceleration amplitude $a(t)$ maxima distribution for such an earthquake with different probability factors.

3. To assess the authenticity degree of specified design scheme, "soil-structure" system dynamic and physical-mechanical properties for different probability factors $P \, [V(t)]$; and to modify the design loads $A_o(t)$ by synthesizing technique.

4. To assess the authenticity degree of structure adopted design scheme, physical and geometrical parameters used for different probability factors and modify each floor accelerograms and response spectra $P \, [U(T)]$.

5. To investigate the dynamic characteristics $H_T(f)$ variability of the equipment in which the analysed element is installed, and to modify each floor accelerogram considering equipment dynamic characteristics.

Thus the NPP reliability under seismic loads can be checked by

$$P\,[A(T)] > P\,[A_o(T)] \cdot P\,[a_o(t)] \cdot P\,[V(T)] \cdot P\,[U(T)] \cdot P\,[m(t)]$$

Consequently, if we assume that $P\,[A(T)] = 10^6$; $P\,[A_o(T)] = 10^{-4}$; $P\,[a_o(t)] = 2 \cdot 10^{-2}$; $P\,[V(T)] = 5 \cdot 10^{-1}$; $P\,[U(T)] = 5 \cdot 10^{-1}$; $P\,[m(T)] = 5 \cdot 10^{-1}$ then the probability of excess of load over NPP important elements may be $P\,[\Pi(T)] = 250 \cdot 10^{-9}$, thus we follow to $P[A(T)] > P\,[\Pi(T)]$.

## CONCLUSIONS

The proposed approach may be one of the methods for the stated problem solution. It is necessary to collect the statistic data, related to all units, for the purpose of seismic reliability detail analysis of NPP and its element structure.

## REFERENCES

Ambriashvili Yu.K. (1979). Consequences analysis of earthquake of March 4, 1977 in the power units. Energeticheskoye stroitelstvo, N 7, p.35-37.

Ambriashvili Yu.K. (1984). To the question of design accelerograms selection considering the expenses for the equipment seismic protection. In: Seismostoikost' energeticheskogo oborudovanija, issue 2, p.28-31.

Kirillov A.P., Ambriashvili Yu.K. (1985). Seismic resistance of nuclear power plants. Energoatomizdat, 186 p.