FEASIBILITY STUDIES FOR AN ATOMIC POWER PLANT ON ALLUVIAL SOIL IN SEISMIC ZONE

by

Jai Krishna, A.S.Arya, A.R.Chandrasekaran,
Brijesh Chandra, S.K.Thakkar & P.Nandakumaran*

SYNOPSIS

The studies carried out for investigating the feasibility of locating an atomic power plant on deep alluvium in moderate seismic zone are described herein. These mainly include a) choice of maximum probable earthquake accelerogram, b) liquefaction potential determination and c) dynamic response analysis of containment shells and major structural and equipment units inside the reactor building. It was found that the nuclear power plant could be located at the site with adequate safety at small extra cost.

INTRODUCTION

In view of the electric load centres and cooling water facilities, atomic power plants are required to be constructed in seismic areas where the foundation soil consists of large depths of alluvium. The complete feasibility study carried out for one such plant may be divided in three main parts as follows:

a)   Based on past seismological data and the tectonics of the area, to select the probable maximum accelerogram and work out its response spectrum;

b)   In view of the soil at the site being deep alluvium with considerably high water table, to determine its liquefaction potential;

c)   To compute the dynamic response of the containment shells, Calendria vault and end shields, inner steel structure and other equipment.

This paper highlights only the main points of the above studies.

CHOICE OF EARTHQUAKE PARAMETERS

The recorded seismic history of the area is too meagre to permit a statistical study. Figure 1 shows the tectonic setting and past epi-centres near the site. The maximum magnitude of earthquake that had occurred so far in the fault nearest to the site is about magnitude 6. The maximum magnitude of earthquake that could probably occur has been assumed to be one scale above than that recorded, that is magnitude 7.

---

* School of Research and Training in Earthquake Engineering, University of Roorkee, Roorkee, India

The nearest distance to the causative fault is 40 km from the site. The probable depth of focus is taken as 15 km.

The earthquake parameters resulting from such an earthquake were worked out on the basis of experience in various countries as available (Seed, Idriss and Kiefer, 1969). The peak ground acceleration at bed rock level was taken as 0.10g with the peak value at the surface magnified to 0.2g in conformity with available published information.

Small size blast tests carried out at site indicated a value of 7 cps as the predominant frequency. Since the blast test would involve only small strains in the soil, it was assumed that during the strong earthquakes, predominant frequencies would be of the order of 5 cps.

Among various recorded accelerograms, the El Centro, May 18, 1940 record was obtained in similar conditions of earthquake parameters and soil. It was estimated that the El Centro record had a predominant frequency of about 4 cps (based on zero crossing in the severe portion of the record). Hence it was proposed that the accelerogram for the structures may be a modified El Centro motion with the amplitude toned down so that the peak acceleration was 0.3g and the time axis was modified by linear factor of 0.8 giving a frequency of 5 cps. The linear elastic response spectra for the chosen accelerogram are given in Figure 2. The peaks and valleys of the spectra have been smoothened. For more risk involving structures like containment shells, the spectrum values have been proposed to be 50% higher.

SOIL TESTS

Following field tests were carried out at the site for obtaining data on the behaviour of the alluvial deposit during earthquakes: a) Blast tests at depths of 6m and 16m to measure the velocity of longitudinal wave propagation and to observe the general behaviour of the ground during vibrations, and b) Cyclic plate load tests and block vibration tests for determining elastic properties of the soil. Longitudinal wave velocity of 1400 m/sec was observed which indicated fairly dense deposit. This was also corroborated by the predominant frequencies observed in the neighbourhood of 7.0 cycles/sec. Further, the attenuation of ground accelerations due to blast obtained from observations at various distances showed a gradual trend. This was also indicative of a fairly stiff soil.

LIQUEFACTION ANALYSIS

Liquefaction potential was checked in two ways: a) by using results of oscillatory shear tests (D'Appolonia, 1970 and Seed, Idriss, 1970), b) by shake table test results at Roorkee Earthquake School (Prakash, Gupta, 1970). The former method requires the knowledge of probable maximum ground acceleration, unit weight of soil, average grain size and the relative densities with depth. Using this method an analysis of the deposit was carried out and it was found that the soil below 13m depth

(that is below foundation raft) was free from the risk of liquefaction
at all points; and that at upper levels, the depth of the moist or dry
soil above the water table had an important bearing on liquefaction.
A minimum of 6m surcharge of soil above the water table would ensure
freedom from danger of liquefaction.

The second approach is mainly concerned with pore pressure develop-
ment during shaking. The relationship of relative density with pore
pressures developed during shaking is shown in Fig. 3. It is seen that
the pore-pressures developed decrease as the relative density increases.
At a relative density of 50%, the increase of pore pressure is negligi-
ble indicating smaller value of hydraulic gradient than the critical
value and hence no liquefaction. The relative density of soil deposit as
obtained in relation to N values indicated the relative density to be
higher than 50% every where below the level where the reactor foundation
is proposed to be laid.

DYNAMIC ANALYSIS OF STRUCTURES AND EQUIPMENTS IN REACTOR BUILDING

The reactor building consists of two containment shells, the inside
one being of prestressed concrete having domical roof and the outer one
reinforced concrete without roof (Fig.4). Besides other equipment, the
building houses the calandria vault which supports the main components of
the reactor viz. the calandria and the end shields. The vault directly
rests on solid concrete block which in turn rests on the raft. The other
equipment units either rest on or are suspended from several floors which
are supported on structural steel framework. In addition there are
massive reinforced concrete walls provided for shielding purposes.

The accelerations of the various floors were computed for the adopted
accelerogram and used as input for the determination of dynamic behaviour
of the equipment. It was found that it was possible to engineer the
connections of the equipment and its mountings without much addition to
the cost. Special attention however was necessary for friction mounted
equipment so that it does not have more than permissible relative dis-
placement. As far as the structures within the plant were concerned they
were massive due to functional requirement and could safely withstand the
inertia forces with little extra cost. A layout of structural system has
been adopted so that torsion effects were reduced to a minimum.

The two containment shells were required to remain elastic during
maximum probable earthquake condition. For dynamic analysis the two
shells were treated as independent 'bendingshear type ' cantilever
structures and were each replaced by an equivalent lumped multi-mass
system. Their free vibration characteristics and dynamic response were
computed by root mean square combination of the first two modes. A
damping value of 2% of critical was assumed in each mode. The equiva-
lent seismic coefficients on the basis of shear at base were found to
be 0.692 and 0.59 respectively in the external and internal shells.
The corresponding values on the basis of base moments were 0.916 and
0.887. The effective seismic coefficients at higher elevations were

even higher than these values. Under these high forces and moments, the shells were designed on no crack basis but no additional concrete was needed to what was required for shielding purposes.

CONCLUSION

On the basis of the dynamic studies of soils, structures and equipments for the maximum probable ground motion, it could be concluded that the nuclear power plant could be constructed with adequate safety provisions at the alluvial site lying in a moderate seismic zone. Additional expenditure on account of seismic considerations was indicated to be small due to the dimensions being adequately large for other reasons.

REFERENCES

1. D'appolonia, E, "Report No. 3, Calculation Brief, Liquefaction Analysis, EERC, 70-9 Simplified Procedure, ENEL, W, Nuclear Power Plant, Piacenza Italy.

2. Prakash, S., and Gupta, M.K. "Liquefaction and Settlement Characteristics of Loose Sands Under Vibration" Conference on Dynamic Waves in Civil Engineering, University of Wales, Swansea, London, 1970, pp 229 - 246.

3. Seed, H.B., Idriss, I.M. and Kiefer F.W., "Characteristics of Rock Motions During Earthquakes" Journal of Soil Mechanics and Foundation Division, ASCE, Vol. 95, No. SM5, Sept. 1969, pp 1199 - 1218.

4. Seed H.B., and Idriss, I.M. "A Simplified Procedure for Evaluating Soil Liquefaction Potential Report No. EERC 70-9, College of Engineering, University of California, Berkely, California, Nov. 1970.

FIG·1 _SEISMO-TECTONIC MAP OF THE AREA AROUND NARORA

FIG. 2 _SMOOTHENED ACCELERATION SPECTRA FOR NARORA SITE

FIG. 3 _EFFECT OF INITIAL RELATIVE DENSITY ON PORE PRESSURE DEVELOPMENT

FIG. 4 _DIMENSIONS OF CONTAINMENT SHELLS