PROBLEMS OF LOCATING AN ATOMIC POWER PLANT ON AEOLIAN DEPOSITS

N.K. Mandwal*

Abstracts

Geological investigations carried out by the author, for locating an atomic power plant, in Hissar district, Haryana State, India, revealed that the area is largely covered with aeolian silty sands with occasional sand dunes. There is no rock outcrop any where in the vicinity of the proposed project area. The data obtained from the deep tube wells indicates the presence of bedrock (gneiss) at a depth of 250 m to 276 m below the overburden.

On the basis of the interpretation of surface and subsurface data collected by the author, available literature and historical records, a detailed account on the physiography, geology, geohydrology and seismicity of the project area has been given. Foundation characteristics and various problems which are likely to be encountered in the execution of the project have been discussed and remedial measures suggested.

Introduction

Site Selection Committee of the Department of Atomic Energy, Power Projects Enginering Division, Bombay, proposed an aotmic power plant in Hissar district of Haryana State. The author carried out geological investigations of the proposed powerhouse site about two decades back. These include reconnaissance traverses, geological logging of five bore holes of 60m depth each, recording of ground water table in dug wells, analysis of the data obtained from several exploratory bore holes drilled by Central Ground Water Board, in Hissar district, for developing the tube well net work, to get an idea of the nature and extent of Quaternary deposits and bed rock configuration.

Physiography and Climate

Hissar area is more or less a flat terrain with undulating sand dunes aligned in almost NE-SW direction, which is mainly controlled by the wind direction. Well-sorted and rounded quartz grains are predominant in the dune sands. Vegetation is scarce, except in the canal irrigated areas, where fields have been developed. The area is devoid of any natural drainage system, except for the northern most part of the Hissar district where it is drained by river Ghaggar. The drainage is of inland type and the entire rainfall is accumulated in the topographic depressions or tanks. Average rainfall is about 50 cm. The area is mainly irrigated by Bhakra canal system. The climate is sub-tropical, semi-arid, dry and extreme. Average winter temperature is 4^0 C and summer temperature is as high as 48^0C. Dust storms of severe intensity are common between April and June. Elevation of the area (RL) is around 212 m above M.S.L.

*Director (Retd.), Geological Survey of India; 414/7-Sarai Mali Khan. P.O. Chowk, Lucknow-226 003, India

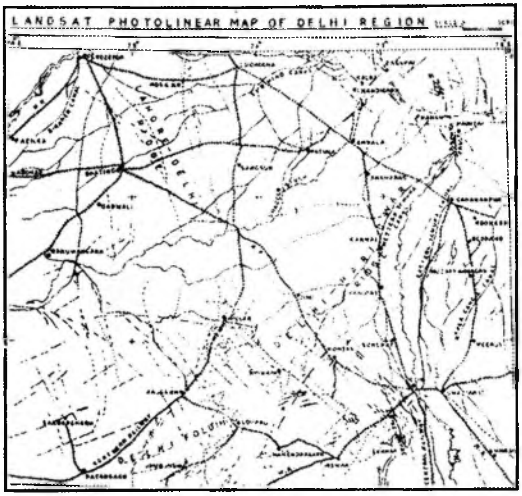


Fig. 1
Landsat Photolinear Map of Delhi Region

Palaeodrainage

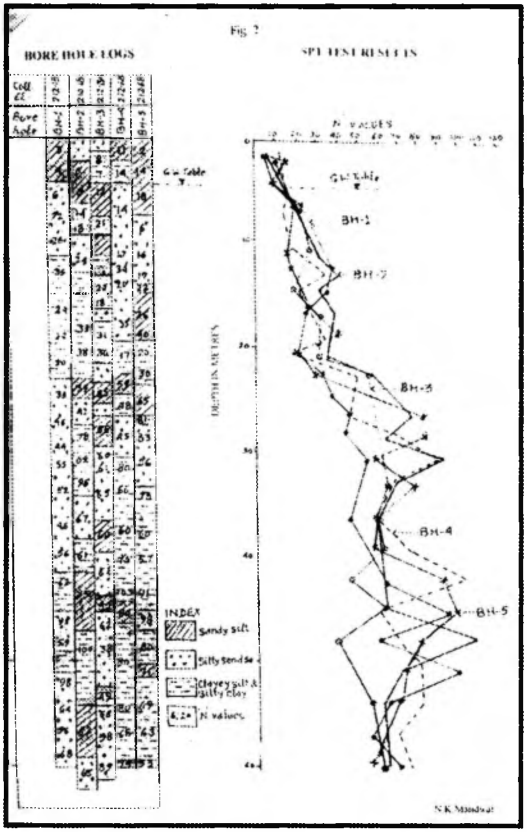
According to Pascoe, river Siwalik must have flowed along the foot of the Punjab Himalayas. With the passage of times, this river was reduced by the piece-meal capture of its course lying between Jamuna and Jhelum by its own tributaries. The capture took place in Post-Siwalik times and is probably quite recent. It may have been initiated by synclines produced by the tectonic movement from the NW. Along the synclines the tributaries cut their way back across the plains of Punjab in a NE direction and captured various portions of the parent river. Ghaggar must have been the final channel of the parent river.

According to Pascoe, the present upper Jamuna and Ghaggar (or Saraswati) formed at one time a single continuous river, which propbably received river Sutlej also. According to him the course of this old channel is still traceable across Rajasthan, Bhawalpur and Sind where it is variously known as Ghaggar, Hakra or Wandan to the Indus. The persistence of this river till histroical times (8th to 16th Century B.C.) would account for the old Vedic description that Saraswati was the chief and parent of rivers flowing from the mountains to the sea. After the Ganges captured the eastern branch of its head waters by means of Lower Jamuna and the old Beas captured the eastern branch of its head waters by means of Lower Jamuna and the old Beas captured the western branch (Sutlej), Saraswati dwindled to a small stream, which soon lost itself in the Rajasthan desert. The greater part of it remaining as dry Ghaggar or Hakra.

The pre-historical and historical data of well planned human settlements found in the excavations near Fatehabad and at Agroha give further testimony to Pascoe's view that river Saraswati was existing during that period. The presence of earthen pot pieces up to a depth of 20 m, from the existing ground surface, in the drill hole (tube well) at Agroha indicates, that the original ground surface level during historical period was around RL 192 m, over which about 20 m thick aeolian silty sands have been deposited.

Geology

A greater part of Hissar district is represented by Indo-Gangetic alluvium consisting of sand, silt and clay with kankar belonging to Upper Pleistocene to Recent age. These unconsolidated sediments are usually capped by aeolian deposits and underlain by hard rock formations of Archean age comprising granites, schists and gneisses. These rocks are exposed farther south-east in few isolated hills at Tosham, Khanak and Deosar, in Bhiwani district of Haryana. Hissar area is devoid of any rock exposure.



The data obtained from bore holes drilled at several places in Hissar district, by Central Ground Water Board, indicates the presence of Archean gneisses at a depth of about 276 m at Agroha, 245m at Adampur and 228m at Dhiranwas. The bed rock profile gradually goes down from South to North by 48 m within a distance of 30km.

Tectonically, the Indo-Gangetic area has been divided into following units by Negi and Ermenko (1968).

i. Frontal folded zone
ii. Aravalli axis of Delhi folding
iii. Rajasthan shelf
iv. Lahore-Delhi ridge
v. Punjab shelf
vi. Delhi-Haridwar ridge
vii. West Uttar Pradesh shelf
viii. Sharda depression.

The Delhi-Haridwar ridge is considered as probable prolongation of Aravalli Mountain as horst bounded by faults. Several tear faults cutting through the Aravalli basement and the overlying Vindhyans have also been postulated, Sonepat-Sohna fault is one of them. Moradabad fault delineating the western margin of Sharda depression is considered to be active.

Fig. 1 shows the landsat photo-linear map of the region around Hissar. Photolinears represent aligned topographic and other geomorphic features, which are indicative of fractures/ discontinuities. The major geological features namely Frontal folded zone, Axis of Delhi folding, Lahore-Delhi ridge, and Delhi Haridwar ridge are clearly reflected in the photo-linear regional trends. Near Delhi, the criss-cross linears represent the complexity of the area, which can be attributed to the conjoining of the above mentioned features. The lineament trending North-South from Sohna to West of Delhi is the Sohna fault. Aerial survey of Indo-Gangetic plains and Rajasthan by ONGC has revealed that the rocks below the alluvium are cut by transverse faults along which seismic activity has been noticed. Important amongst them are the Moradabad fault, Lucknow fault, Sone fault, Patna fault etc.

Geohydrology

The main source of ground water is precipitation down into soil and recharge the aquifer zones. Canal seepage and applied irrigation water also recharge the ground water to some extent. Near surface ground water occurs under water table conditions. Depth to near surface water table in the proposed powerhouse area, ranges between 1.6m and 6m below the ground level, it is fresh and potable. The depth to water is deeper(6m) in the SE part, which is away from the branch canal, while it is very near to the ground surface (1m) in the vicinity of the canal.

In the deeper aquifers, that is, below 20m depth, the ground water is generally under confined conditions in the pore spaces of unconsolidated Quaternary sediments (sand and silt). The hydraulic gradient in this part ranges from 0.5 to 0.7m/km and this receives ground water from almost all directions, being a ground water depression with an outlet towards West and SW. The general ground water flow is from NE to SW. The tube wells drilled by central Ground Water Board (CGWB), one each at Adampur, Agroha, Bahuna and Fatehabad down to the depths of 245m, 279.19m, 308.46m and 287.12m respectively have given a fair idea of the strata and the ground water conditions prevailing around the proposed Atomic power plant site. At Adampur, Agroha and Bahuna the water is brackish/saline, while at Fatehabad it is fresh/potable.

A review of the old records of ground water table data of 12 wells, located within a radius of 10km from the plant site shows that between the year 1900 and 1966, the ground water table in the area has risen by 4m to 21.3 m in different wells. Hydrographs of these wells indicate that the maximum rise was after 1962, that is, when the Bhakra canal became operations.

Regarding the chemical quality of ground water, the chemical analysis of the water samples indicates that it is highly mineralized. The salinity in the water and occasional ground surface efflorescence consisting chiefly of Sodium Carbonate, Sodium Sulphate, Sodium Chloride with small quantities of Magnesium, Calcium and Potassium salts is the result of accumulation by evaporation in a water logged land and to some extent it might have been derived from decomposition of feldspar, which was acted upon by water carrying CO_2 in solution. There is yet another explanation put forward, that is, during summers stormy winds from SW blow across the salt incrusted region of the Arabian sea and Rann of Kachchh (Kutch) and carry small particles of salt far inland; by the monsoon floods this salt is washed into local depressions to form the salt lakes and also percolate into the sub-soil and make the water brackish. The concertration is further distributed by irrigation canals, which raise the level of the reh polluted sub-soil water.

SUBSURFACE EXPLORATIONS

Drilling :

In accordance with the recommendations of the Site Selection Committee of Department of Atomic Energy Power Projects, Govt. of India, five bore holes of 60m depth each were drilled in a grid pattern, in order to explore the sub-surface conditions, i.e., extent and nature of foundation soil/rock. The summarized logs of these bore holes are given in Fig.2.

The drilling data has revealed that the bedrock is not available up to 60m depth for founding the structures and the power house will have to be constructed on the overburden/soil comprising silty sands, sandy silt, clayey silt and silty clay with plastic clay and kankar rich horizongs (Fig.2). The study also indicated, that there is no persistency in the different soil layers and they have the tendency to merge or grade into one another laterally. The percentage of sandy fraction is higher towards the North and East sides then the Sourth and West.

The over all percentage of the silty sand is 36.6, sandy silt is 19.5, silty clay and clayey silt is 44.33, within a depth of 60m, in the proposed powerhouse block. The silt content generally varies from 20 to 60% in the sandy horizons. The finer material having grain size<0.15 mm is generally more than 90% which calls for proper evaluation of the earthquake potential.

Electrical Logging of bore holes :

The strata charts/lithological logs prepared on the basis of samples/core recovered from drill holes particularly in the overburden material are some times not truly representative of sub-surface conditions, hence application of Electrical Logging Method (Resistivity and spontaneous potential), Radio Active Method (Gamma-Ray and Neutron-Gamma-Ray) were considered essential.

As a follow up, as well as, availability of the equipment and site conditions, Gamma-Ray Logging was conducted by CGWB in BH4 and BH5 up to 43.5 and 45m depths respectively using GOI-3200 (Multi Channel) Logger. The Gamma-Ray logging measures the natural radioactivity of the formations traversed in a bore-hole. Almost all natural soils contain some radioactive material, generally Uranium, Thorium and or Potassium. The radioactivity of a formation is usually expressed in terms of the equivalent amount of radium per ton of rock or soil required to produce the same Gamma-Ray intensity. Shales and clays i.e., argillaceous formations are generally several times more radioactive than clear sands or arenaceous rocks. Shales or clays containing organic matter have much higher radioactivity than ordinary shales and clays; they make excellent marker horizons for correlation purposes. The results of Gamma-Ray Logging are shown on Fig.3.

In BH-4 the minimum Gamma-Ray counts encountered against granular zones is 20 counts/second and maximum counts against clayey formations is 36 counts/second. In BH-5 the minimum Gramma-Ray counts encountered against granular zones is 13 counts/second and maximum against clayey formation is 38 counts/second.

Standard Penetration Tests in Bore Holes :

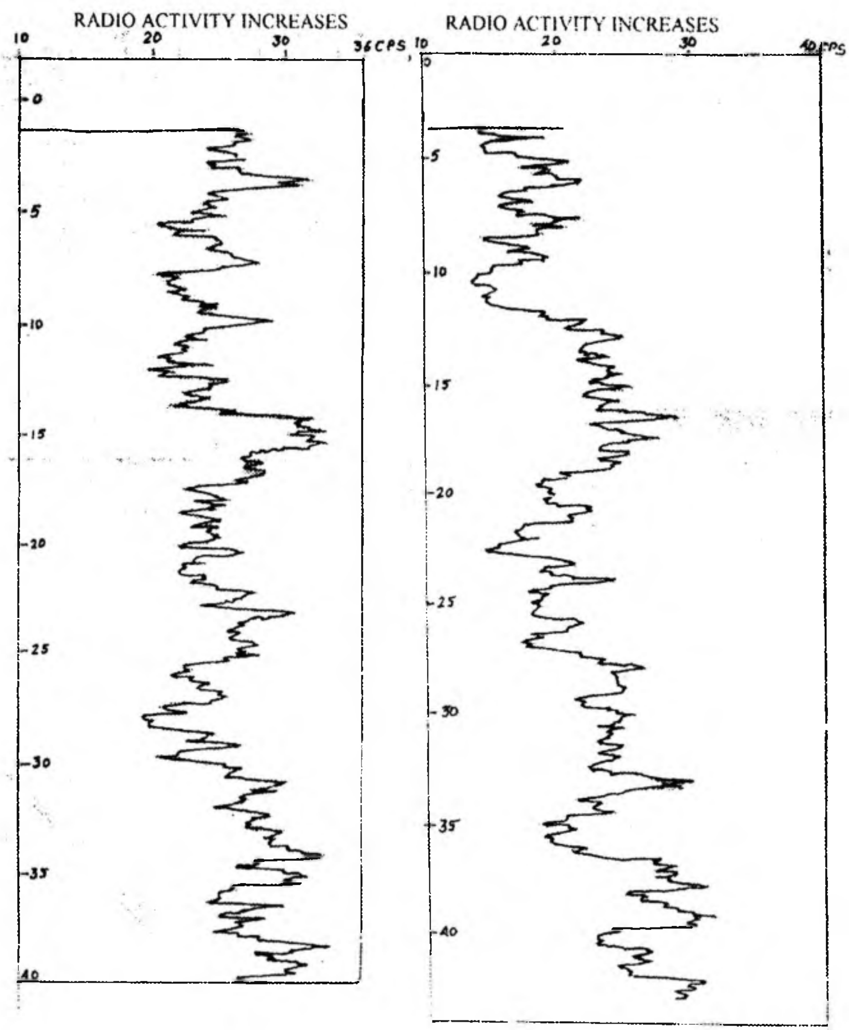
Standard penetration tests were conducted in all the five bore holes at regular intervals of approximately 2m depth to determine the strength and deformation chacacteristics of the soil. The SPT values 'N' plotted against the corresponding depths on Fig.2 show that they vary more or less uniformly with depths. The general trend in the range of 'N' values versus depth of each borehole, are shown on Fig.2 and also given in the following table No.1.

Fig 3

GAMMA RAY LOGS OF BH-4 & BH-5
(Logged by R N Singh, Jr.Geophysicist, CGWB)
Bore hole dia - 130 mm approx
Time constant - 3.0 Seconds
Logger used: - GOI-3200 (Multi channel)

Location: - BH: - 4
Logging Speed: - 6m/minute
Casing pipe: - Ground level to 32.0m bgl
Thickness of casing pipe: - 3.5 mm
Inner dia. of casing pipe - 125 mm
Back ground counts. - 16 CPS

Location - BH-5
Logging Speed - 5m/minute
Casing pip: - Ground level to 40.0m bgl
Thickness of casing pip. - 3.0 mm
Inner dia of casing pipe - 125 mm
Back ground counts: - 18 CPS



N.K.Mandwal

Table No. I

Range of values `N'	Depth of Test Section in meters				
	BH-1	**BH-2**	**BH-3**	**BH-4**	**BH-5**
10	0-5	0-3	0-4	0-0	0-5
10-20	5-6	3-10	4-9	0-10	5-14
20-30	6-12	10-12	9-20	10-21	14-22
30-40	12-23	12-21	20-21	21-21.5	22-23
40-50	23-30	21-25	21-22	21.5-22	23-23.5
50-60	30-42	25-25.5	22-28	22-23	23.5-24
60	42	25.5	28	23	24

From the above table and curves (Fig2.) it is evident, that the `N' values >30 exist at depths varying between 12m and 22m in different holes. A sudden decrease/ kink in the `N' values at 20m depth in all the bore holes appears to indicate a weak plane marking the contact of aeolian deposits with the underlying fresh water sediments. The soil below this depth is of hard consistency and its density varies from dense to very dense. Very dense strata (`N' values >50) are met at depths varying betwen 22m and 30m. It is considered that the soil below the depth of 20m is dense and generally posses a very high load bearing value. The Gamma-Ray logging also corroborated a sharp change in the strata below a depth of about 20m.

Seismicity

Seismicity is the most important factor in locating the so called `safety islands" for siting the nuclear power stations. A comprehensive analysis and evaluation of local and regional stability of the area is of great significance from seismological, as well as, engineering geological point of view. The study of regional stability includes the study of tectonic activity, seismic activity, magmatic activity, hydrothermal activity etc., within a radius of 300 km from the proposed site. A comprehensive evaluation is made after wards, for finally selecting a suitable area as base of nuclear power station or evolving a suitable design seismic coeficient for the civil engineering structures.

Non-availability of adequate historical records of the past earthquakes, as well as, instrumentation data of the creep/ tectonic movement and seismic status of the planes of discontinuities/faults, are the serious constraints in evaluating the seismotectonic setup. However, whatever data could be available from the records, on the basis of that, efforts have to be made to identy the basic earthquake intensity (BEI), which is an index used to decide and assess the maximum ground motion or the maximum earthquake intensity, which the area is likely to experience with in the next 50-100 years or the life time of the power project. A review of the available historical and instrumentation data on earthquakes reveals high seismicity and tectonic instability of the area with in a radius of 150 km from the proposed APP site. Most of the shocks are interpreted to be shallow focus and maximum concentrations are around Sonepat, Rohtak, Gurgaon. The main cause of seismicity is attributed to the number of fractures and faults resulting due to wedging of Aravalli-Delhi axis into the Lesser Himalayas. In particular trijunction of Delhi-Haridwar ridge, Lahore-Delhi ridge and Aravalli-Delhi axis of folding has ben interpreted as highly seismically active zone. Table No. II shows the number of incidence with maximum magnitude and radial distance of earthquake epicenters from the proposed APP site.

Table No. II

Sl. No.	Radial distance from APP site in km.	No. of earthquake	Maxim. magni tude
1.	50	1	5
2.	100	1	5.1
3.	100-150	2	4.7
4.	150-200	14	7.1
5.	200-250	6	6.7
6.	250-30	5	6.5
7.	300-350	6	8.0

From the above table, it is evident that there are at least 32 earthquake epicenters with magnitude>5 and three epicenters with magnitude>4.6, with in a radius of 350 kms. Out of these, 32 earthquakes have taken place during the last 173 years. The seismic risk analysis of the area around Delhi, carried out by different workers suggests 100% probability of magnitude 7.0, Hence to be on the safer side, it would be better to consider the seismic risk equivalent to magnitude 7.0, with in a radius of 150km. The probable epicentral M.M. intensity for such magnitude would be equal to IX. As per Seismic Zoning Map of India prepared by ISI (BIS), the proposed APP area lies in Zone III, for which the horizontal seismic coefficient for the APP should be around 0.24. However, it needs proper evaluation from the design point of view.

Geotechnical Evaluation of Anticipated Problems and Remedial Measures

The problems, which are likely to be encountered at the proposed powerhouse site can be broadly classified into the following categories.

i. Poor consistency and load bearing capacity of the foundation material.

ii. High seismic risk, liquefaction and differential settlement in the foundation.

iii. Stability of cut slopes in the powerhouse pit.

iv. Salinity and high sulphate content in the ground water.

Poor consistency and load bearing capacity of the foundation material :

The aeolian sands are generally low-density collapsing soils, which lose strength and are liable to sudden settlement even under their own weight, when wetted beyond a certain limit. If a structure is built on such soil without pre-compaction or adequate provision for keeping the soil dry, the structure may fail if the foundation soil becomes, wet, hence such soils are weak footings for buildings and structures.

As inferred from the drilling data, SPT test results and other historical records, the thickness of unconsolidated, low density aeolian deposits is about 20m, hence it is desirable that the foundation for the proposed APP is put below 20m depth (RL 192m), from the natural ground surface. Although, the engineering details i.e., the total area encompassed by the reactors and ancillary structures and their likely effective load on the foundation is not known to the author, however, it is presumed that the heavy loading may be confined to an area of about 25 m radius around each nuclear reactor unit where a net load of approximately 80,000 tons may be acting, as in the case of Narora Atomic Power Plant. It has been recommended that after removing the top 20m of aeolian soils, concrete piles of suitable depth as indicated by design studies may be driven in a grid pattern from RL 192m, over which, a raft of suitable thickness may be laid for proper distribution of loads as per design requirements.

High seismic risk, liquefaction and differential setlement in the foundation :

The amplitude of seismic waves in regions with thick alluvial cover, are often up to five times that of its amplitude on solid rock (Gutenberg 1956). At sites on alluvium, relatively strong shaking lasts several times more than the sites on crystalline rocks. In many areas it is generally noted that during a major earthquake the shaking is relatively strong where ground water table is very near, often sand blows or earthquake fountains are produced (Housner 1965). Maximum damage is done to the structures by partial or complete liquefaction of the soils, which is caused due to the reduction in shearing resistance of the soil because of the increase of pore pressure and decrease of cohesion in soil.The depth of ground water table of an area is thus an important parameter in studying the sismicity of a region. The factors, which affect the liquefaction characteristics of soils are given below:

i. Grain size distribution.

ii. Density of deposit/soil.

iii. Vibration characteristics i.e., nature, magnitude and type of dynamic loading.

iv. Location of drainage and dimension of deposit.

v. Magnitude and nature of superimposed load.

vi. Entrapped air/void ratio.

Fine and uniform sands are more prone to liquefaction than coarse sands under otherwise identical conditions. Since the permeability of coarse sand is higher than fine sand or silt, the pore pressure developed during vibrations dissipates more easily in coarse sand than in fine sand. Hence, the chances of liquefaction are reduced with the coarseness of sand.

Sands having lower Relative Density experience larger strains and hence larger settlements than those having higher initial Relative density. Liquefaction and settlement also depend on nature, magnitude and type of dynamic loading. Under shock loading the whole strata may be liquefied simultaneously, while under steday state vibrations, liquefaction may start from top and then proceed downwards. Horizontal vibrations lead to larger settlements than vertical. Damage to structures founded on soils undergoing liquefaction also depends on the duration for which the sand remains in liquefied state. In coarse sand due to high coefficient of permeability, duration of liquefaction may be smaller as compared to that of fine sand. Sands are generally more pervious than silts. However, if the extent of a pervious deposit is large, the drainage path increases and combined with quick loading as during an earthquake, the deposit may behave as if it were undrained, therefore, in such a deposit the chances of liquefaction are increased. The superimposed loads constitute the intital effective stress and if it is larger then the possibility of liquefaction is reduced. If air is entrapped in water in which pore pressure develops, a part of it is dissipated due to compression of air. Hence, the entrapped air helps in reducing the possibility of liquefaction.

The proposed APP area is located in close proximity of a high seismic activity zone, where earthquakes of magnitude 6.7 to 7.1 have been recorded. Recent to Sub-Recent movements along the major thrusts and faults have also been recorded hence the project area has a high seismic risk requiring detailed geo-seismological studies. The strata being about 250m thick extensive deposit of low-density silty soil with very shallow ground water table, it has been considered necessary to study in details the possibility of liquefaction and excessive settlement of the soil under the anticipated ground motion.

Stability of cut slopes :

The powerhouse foundation has been recommended to be taken down to a depth of about 20m (RL 192m) from the natural ground surface (RL 212m), hence it will pose the problem of stability of cut slopes in the loose and saturated soil. Slope stability must not remian mearly a constructional endeavour but has to be planned as a long term strategy for the safe functioning of the atomic power project.

From the nature of the aeolian/ sedimentary deposits containing free gound water table, it is felt that any slope steeper than 37 degrees may not be stable, as such, it is desirable to provide the slope cuts of 1.25(h) : 1 (v) with 3m wide berms at 8m height interval, with proper drainage arrangements, in the power house pit. However, it would be better to determine the necessary parameters of undisturbed samples of each layer of soil and then proper slope stability analysis under different conditions (saturated and unsaturated, static and dynamic loading) is done to evolve the safe cut slopes. In order to avoid the development of pore water pressure and heaving in the foundation, it is desirable that heavy-duty pumps are installed around the powerhouse pit and the ground water table is lowered to a sufficient depth.

Salinity and high SO_4 content in the ground water :

The chemical analysis of water samples from BH-2 has revealed that the water is highly mineralized having chlorides and soleplates of Ca, Mg, Na, K, Al, etc. in the order of 918mg/L and 1050mg/L respectively. These will have a deleterious effect on the cement concrete and reinforcement. The relative degree of attack on concrete by SO_4 is given in Table No. III.

Table No. III

SO_4 content in ppm	Effect on concrete
0-150	Negligible
150-1000	Positive
1000 -2000	Considerable
>2000	Severe

It appears to be obligatory to use special type of cement concrete, which is resistant to SO_4 attack, in the concrete piles and raft for laying the foundation

Conclusions

The area around the proposed Atomic Power Plant is an extension of Rajasthan desert, represented by aeolian -silty sands with occasional sand dunes and is devoid of any rock exposure. Bedrock is not available up to 60m depths and the structure will have to be founded on overburden consisting of silty sand, sandy silt and silty clay with kankar rich horizons (Quaternary deposits). However, the bedrock is met at a depth of 250m to 276m. The Standard Penetration Tests conducted in the boreholes, have shown that high density, stiff clays/silts having `N' values of over 30 are present at about 20m depths and over 60, beyond the depth of 26m.

The depth to near surface water table, which is fresh and potable varies from 1.6m to 6m. The deeper aquifers are saline/brackish and have high chloride and sulphate contents, which are detrimental to cement concrete, and hence speical type of concrete may have to be used for laying the concrete piles and raft in the foundation.

A seimsmically active zone is located about 150km SE of the APP site, at the tri-junction of Lahore-Delhi ridge, Delhi axis of folding and Delhi-Haridwar ridge. Approximately N-S alignment of epicenters near Delhi-Sonepat-Rohtak-Gurgaon appears to be related to Sonepat-Sohna fault. The area is prone to occasional seismic ground vibrations. Earthquakes of magnitude 5 to 7.1 have been recorded with in a radial distance of 150-200 km. As per `Seismic Zoning Map of India' published by ISI (IS:1893-1984) the proposed APP area lies in Seismic Zone III, for which, a horizontal seismic coefficient of 0.24 has been suggested. The strata being generally non-cohesive type silty sand and silty clay, with very near ground water table; there are chances of liquefaction in the aeolian sands during earthquakes.

For the ultimate safety of the vital installations, the foundation has to be taken down, to about 20m depth (RL 192m). Raft foundation on concrete piles of suitable depth and an appropriate design seismic coefficient in the superstructures are considered essential under the prevailing ground conditions.

For stability of cut slopes in the >20m deep power house pit, 1.25(h) : 1(v) slope with 3m wide berms at 8m height interval and proper drainage arrangments have been suggested. Heavy duty pumps will have to be installed around the power house pit, for lowering the ground water table to a suficiently low depth to avoid the development of pore water pressure and heaving under the foundation.

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