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# Siting for a Nuclear Power Plant in Saudi Arabia

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**SYNOPSIS** A site reconnaissance study was conducted in the mid-western coastal area of Saudi Arabia to select the most suitable site for a nuclear power plant. Three potential sites near Yanbu, Rabigh and Jeddah were selected, evaluated and ranked according to their acceptability based on the U.S. Atomic Energy Commission Regulatory criteria. Based on this preliminary investigation, it was found that the area south of Yanbu city is the most feasible site. Geotechnical properties of the soil and rock, seismicity and proximity to load center played an important role in Yanbu site selection. More detailed study is recommended for this site. It is equally important to carry a similar reconnaissance study along the Arabian Gulf.

## INTRODUCTION

Although Saudi Arabia possesses the highest oil reserve, it is still feasible to investigate the potential sources of nonconventional energy in the country. The industrial and urban development along the mid-western coastal area and the increase in power demand encouraged the authors to investigate the possible sites for a nuclear power plant within Yanbu, Rabigh and Jeddah regions using the U.S. Atomic Energy Commission Regulatory Guide. The evaluation criteria included geology, population, seismicity, proximity to load center, power demand, site accessibility, sea water depth, flood potential and climate.

## REGIONAL SETTING OF SITE REGIONS

The spreading of the Red Sea along its axial trough creates a tectonically active zone to a depth of 200 to 300 km inland (Barazangi, 1981). The three considered site regions are also subjected to considerable volcanic activities associated with fault zones cutting the crystalline rocks (Skipwith, 1973). Some faults located 40 km east of Jeddah can be classified as potentially active (Barazangi, 1981). Moreover, raised coral terraces have been observed in some places along the coastal area (Morris, 1975). A major source of information for evaluating the seismic risk along the western coast is that obtained from the studies of historical records (Ambraseys, 1961). About 23 events were reported in different locations within the site regions during the period 497-1889 A.D. In more recent studies, Merghelani (1980-1981) has instrumentally recorded 76 earthquakes in Yanbu region and 32 earthquakes in Jeddah region both with a maximum magnitude of 3.0 (Richter scale) during a recording period of three months. The maximum intensity, based on the historical records, was used to calculate the corresponding acceleration by means of an appropriate acce-

leration - intensity relationship. Fig.1 illustrates the regions' locations and the maximum expected seismic intensity contours based on the MM scale.

Flood potentials were investigated for the mid-western coastal area of Saudi Arabia by Sabtan & Shehata (1982) who indicated that flood hazard is equally important for the three site regions.

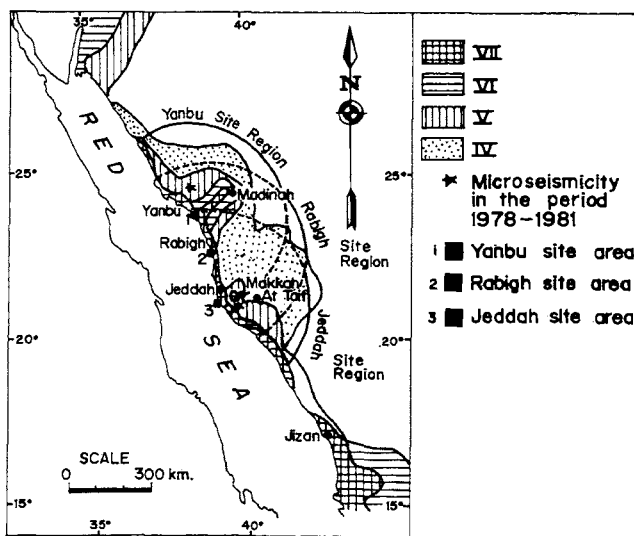


Fig.1: Maximum Expected Seismic Intensity Map.

## SELECTION CRITERIA AND SITE INVESTIGATION

The preliminary selection of site areas within the site regions accounted for the proximity to

load centers although it was kept a distance of at least 16 km off highly populated areas. Taking the wind direction in consideration the site areas were located down-wind or south of the cities of Yanbu, Rabigh or Jeddah. Based on relative ground elevation, flood potential and rock and soil distribution, sites were selected within site areas.

### Yanbu Site

Yanbu site area is located 55 km southeast of the city of Yanbu and 15km west of the Jeddah-Madina road. The ground surface is hummocky in nature having an average elevation of 3 m above sea level (Fig. 2). The area is characterized by moderate flood spreading with the groundwater depth varies between 1 and 5m below the surface. Three soil units cover Yanbu site area: dense sand and gravel, gravel and fine sand, in addition to elongated chain of coralline limestone. The dense sand and gravel dominates the area and is composed of brown, dense, well graded, subrounded to rounded sand with trace of gravel. The gravel unit is restricted to an elongated area parallel to the shoreline

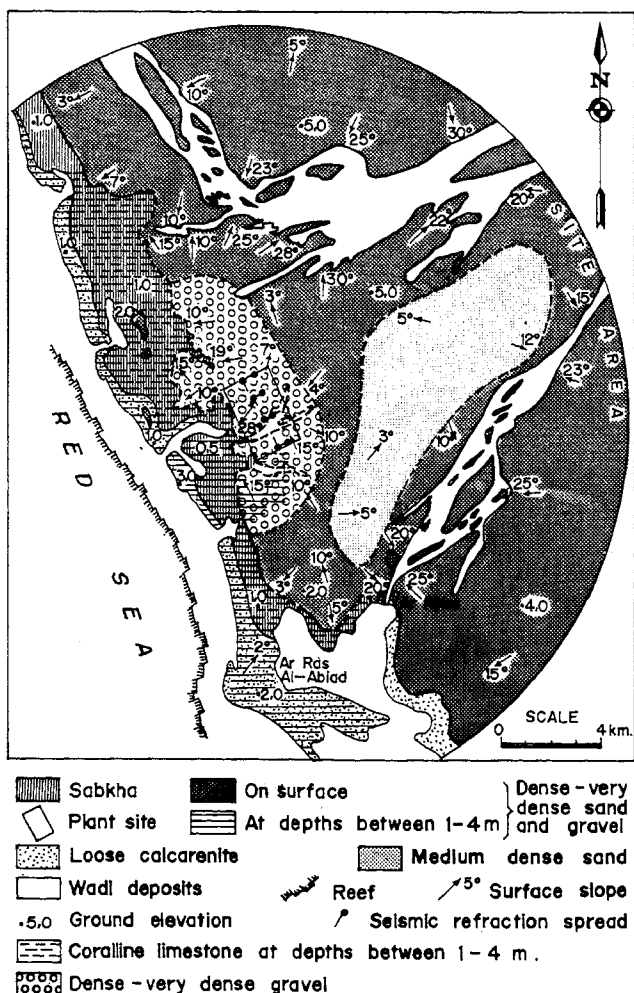


Fig.2. Geotechnical Map of Yanbu Site Area.

and is composed of subrounded to rounded fine gravel of granitic, andesitic or rhyolitic composition. The fine sand unit occurs as three subunits. The first subunit occupies most of the eastern part and consists of light yellowish brown, medium dense, rounded, well graded sand while the second subunit consists of loose rounded, well graded calcarenite forming minor dunes adjacent to the shoreline with a maximum height of 2m. The third subunit forms the sabkha with a maximum elevation of 1m above sea level and is protected seawards by off-shore bars, reef chains or quiet lagoon waters. The top 0.5 to 1m of the sabkha consists of brown fine to medium sand followed by dark gray silty sand occasionally mixed with gravel or shell fragments. The coralline limestone occurs either as raised beaches having an elevation of 2 to 3m above sea level or underlying the soil cover at shallower depths.

In the selected site, the ground is covered by fine gravel to a depth of 1 to 5m followed by coralline limestone to a depth of at least 15m. The dry unit weight of the gravel layer is 2.14 g/cm<sup>3</sup>, its angle of internal friction is 35° and its estimated permeability is 5 x 10<sup>-1</sup> cm/s and the reported SPT value is 50 blows/ft. The in situ P-wave velocity for the gravel layer ranges between 450 and 1000 m/s while its average S-wave velocity is 300 m/s. The dry unit weight of the coralline limestone is 1.92 g/cm<sup>3</sup> and its Schmidt hardness ranges between 10 and 35 which corresponds to an average compressive strength of 280 kg/cm<sup>2</sup> and a modulus of elasticity of 8.1 x 10<sup>4</sup> kg/cm<sup>2</sup>. The average dynamic modulus of elasticity of the limestone is 3.9 x 10<sup>3</sup> kg/cm<sup>2</sup> and its Poisson's ratio is 0.4

### Rabigh Site

Rabigh site area is located 190 km southeast of Yanbu, 110 km northwest of Jeddah and only 2km west of Jeddah-Madina road. Topographically, the eastern and northern parts of Rabigh site area are similar to that of Yanbu, while the western part is characterized by flat terrain of coralline limestone having an average elevation of 5 to 6m above sea level. The average depth to groundwater level is 5m while the flood water is restricted to only one main course (Fig. 3). The soil and rock in Rabigh site area are geologically in continuation with Yanbu site area. The soil includes the dense sand and gravel, the gravel and the fine sand (as calcarenite and sabkha) units. The coralline limestone occupies most of the western part of the area.

In the selected site, the ground is covered by coralline limestone to a depth of at least 20m. The dry unit weight of the coralline limestone varies between 1.4 and 2.5 g/cm<sup>3</sup> and the Schmidt hardness ranges between 10 and 40. This corresponds to an average compressive strength of 320 kg/cm<sup>2</sup> and a modulus of elasticity of 1 x 10<sup>5</sup> kg/cm<sup>2</sup> which is comparable to the static properties measured on core samples where the uniaxial compressive strength ranges between 15 and 230 kg/cm<sup>2</sup> and the tangential modulus of elasticity varies between 2.1 x 10<sup>5</sup> and 5.0 x 10<sup>5</sup> kg/cm<sup>2</sup>. The static Poisson's ratio was found to range between 0.1 and 0.38. The dynamic modulus of elasticity determined in the laboratory ranges between 2.1 x 10<sup>3</sup> and

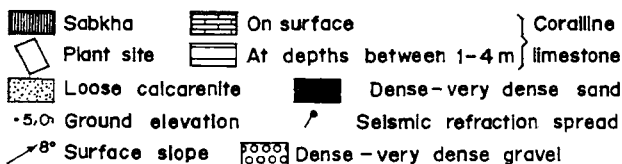
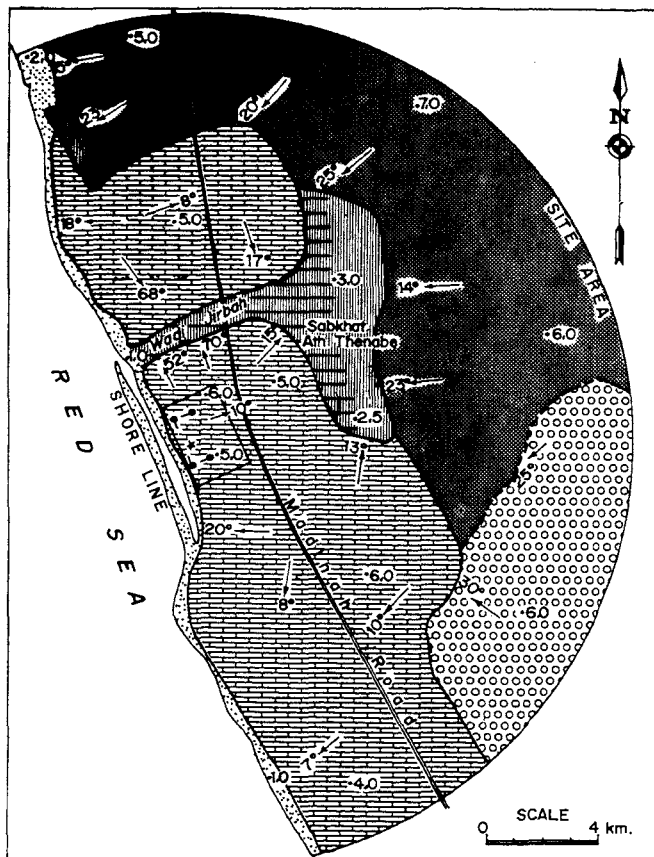


Fig.3. Geotechnical Map of Rabigh Site Area.

$2.0 \times 10^4$  kg/cm<sup>2</sup> and the Poisson's ratio is 0.26, while those determined in situ show a relatively lower Modulus of elasticity of  $5.1 \times 10^2$  to  $9.7 \times 10^3$  kg/cm<sup>2</sup> and a relatively higher Poisson's ratio value of 0.42. This variation in the dynamic properties could be related to the presence of calcarenite filled cavities.

#### Jeddah Site

Jeddah site area is located approximately 45 km southeast of Jeddah and can be reached by a desert track parallel to the shoreline. This site area is mostly flat with the occurrence of several 3 to 4m high elongated dunes in the eastern part of the area trending in the northwest-southeast direction. The flat ground surface rises between 2 and 3.5m above sea level with the depth to water level ranging between 1 and 3.5m. In general, Jeddah region has extensive flood plains, however, the elongated sand dunes act as barriers against flood and restricting the flow to only one water course occurring in the southern part of Jeddah site area (Fig. 4). The soil in the area consists of brown, rounded well graded, dense sand and gravel dominating the area and forming flat surface with thin

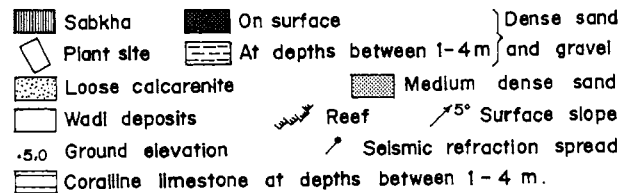
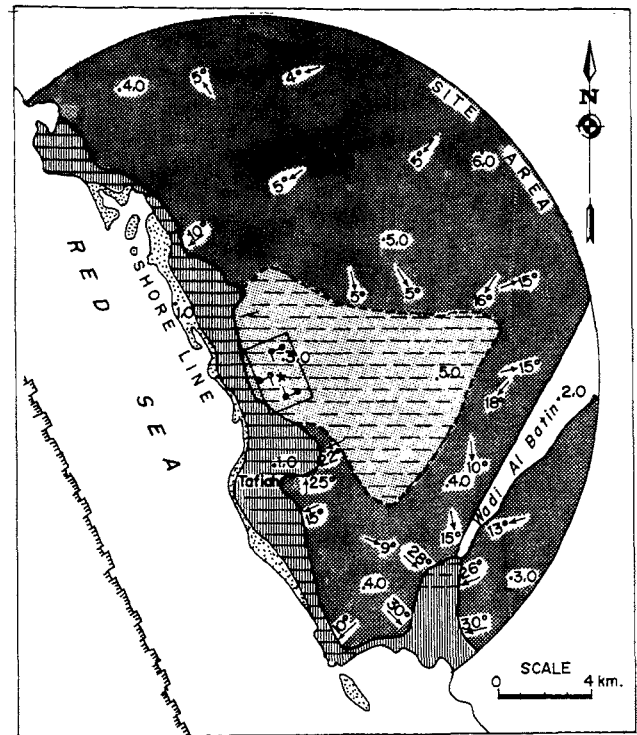


Fig.4. Geotechnical Map of Jeddah Site Area.

cover of wind blown sand. A part of the middle section is covered by yellowish brown, rounded well graded, medium dense sand having a thickness of 1 to 3 m followed by the brown sand. Calcarenite is restricted to a narrow area along the shoreline and consisting of white, medium grained, rounded, well graded, loose sand with trace of shell fragments. The sabkha is composed of brown, well graded, medium grained, loose sand. The coralline limestone underlies all the soil units.

In the selected site, the ground is covered by the brown sand mixed in places with calcarenite to a depth of 3 to 5m followed by the coralline limestone to a depth of at least 15 m. The dry unit weight of the brown sand is 1.75 g/cm<sup>3</sup>, its angle of internal friction is 33°, its permeability value is approximated as 1.0 cm/s and its SPT value amounts to 32 to 40 blows/ft. The dry unit weight of the coralline limestone is 1.9 g/cm<sup>3</sup> and its Schmidt hammer hardness ranges between 12 and 32. This indicates that the compressive strength is averaged as 168 kg/cm<sup>2</sup> and its modulus of elasticity is  $7.0 \times 10^4$  kg/cm<sup>2</sup>. The dynamic modulus of elasticity as

measured in situ is averaged as  $3.4 \times 10^4$  kg/cm<sup>2</sup>, while its Poisson's ratio is 0.28.

#### COMPARATIVE STUDY

The selection of a particular site out of the three potential sites required the consideration of all the investigated criteria and their relative importance. Therefore, a rating value was given for each criterion in each site and a weighing factor was also given for each criterion. The evaluation score point of each criterion in each site is obtained by multiplying the rating value for the criterion in the site by the weighing factor of the criterion. Table 1 summarises the numerical evaluation of the three potential sites which indicates that Yanbu site is the most feasible with a score of 97 followed by Rabigh site with a score of 95 and finally Jeddah site with a score of 91. Geotechnical properties of soil and rock, seismicity and proximity to load center played an important part in the selection of Yanbu site.

Table 1. Numerical evaluation of the criteria of the three sites in the mid-western Saudi Arabia.

Criterion	Weigh- ing factor	Yanbu site		Rabigh site		Jeddah site	
		Rating value	Score points	Rating value	Score points	Rating value	Score points
Volcanism	3	3	9	4	12	5	15
Geotechnical properties	3	5	15	4	12	2	6
Population	5	4	20	4	20	5	25
Seismicity	4	3	12	3	12	1	4
Proximity to load center	2	5	10	4	8	5	10
Power demand	2	3	6	5	10	5	10
Site acces- sibility	1	1	1	1	1	1	1
Sea water depth	2	4	8	4	8	3	6
Flood	2	5	10	4	8	3	6
Climate	2	3	6	2	4	4	8
Total Score	-	-	97	-	95	-	91

#### CONCLUSIONS AND RECOMMENDATIONS

As a result of this investigation it can be concluded that there are at least three possible sites for a nuclear plant along the mid-western coastal area of Saudi Arabia. The comparative study of these sites using the U.S. Atomic Energy Commission Regulatory Guide Criteria indicates that Yanbu site emerges as the most feasible. However, this does not mean that Yanbu site is the best in the country and thus it would be equally important to carry out a simi-

lar study in the Eastern Region along the Arabian Gulf.

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