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Improvement of Bearing Capacity for Foundations of Kotri Gas Turbines Extension Project

BY

Engr. Mohammad Rashid Chaudhry
Chief Engineer (Civil) WAPDA.

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IMPROVEMENT OF BEARING CAPACITY FOR FOUNDATIONS OF KOTRI GAS TURBINES EXTENSION PROJECT

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Muhammad Rashid Chaudhry (*)

SUMMARY

1. The 50 MW Kotri Gas Turbines Extension Project of Units 5 & 6 was prepared by WAPDA and approved by the Executive Committee of the National Economic Council in December, 1979. The contract for the Civil Works, supply and erection of the plant and equipment was awarded to M/s. Marubeni of Japan in May, 1980. These two units were commissioned by 15th May, 1981. The estimated cost of the Project was 201 million with a Foreign Exchange Component of Rs.108 million. The turbines and generators including other major equipment were manufactured by M/s. Hitachi. The consultancy services were provided by M/s. EPDC International Ltd., of Japan.

2. The Contractor was responsible for investigations, design and execution including all Labour, Material and Equipment needed for the Civil Works of this Project. The purpose of the investigations was to evaluate the nature and characteristics of the sub-surface materials at the site for the proper selection and design of foundations for the Gas Turbines and other structures.

3. The scope of the investigations was limited to the drilling of 3 Nos. bore holes at the indicated locations upto a depth of 15 meter performing the Standard Penetration Tests at one meter interval in all the bore holes and carrying out the laboratory tests on the representative soil samples, according to the ASTM Standards. When chalky limestone was encountered during the drilling operation it was considered essential to obtain rock cores for strength tests.

(*)Chief Engineer (Civil) WAPDA.

4. The investigations at the bore hole locations reveal that the sub soil strata at the site follow a uniform pattern. The subsoil upto the drilled depth of 15 meter can be divided into three distinct layers. The top soil (Layer-1) is brown clayey silt. The thickness of this layer varies upto 1 meter. The next layer (Layer-2) consists of brown weathered limestone extending in depth upto 4.5 meter at the location of bore hole No.1 and upto 3 meter at bore hole No.3. Underlying this layer there is brown chalky limestone throughout the drilled depth except for a thin seam of shale 0.6 meter thick, at a depth of 7 meter at bore hole No.1 and 1.5 meter thick layer of chalk at a depth of 10.5 meter at bore hole No.3.

5. The recommended bearing capacity was of 2 Kg per Cm^2 (approximately 2 tons per sq. ft.) at a depth of 1.5 meter, 2.5 Kg per Cm^2 (approximately 2.5 tons per sq.ft.) at a depth of 2 meter. These bearing capacities were determined without considering the possibility of rain water seeping into the soil or entering into the fissures/ faults/cracks in the weathered limestone as during heavy rains lot of water enters in this area. It was later determined that the bearing capacity under such conditions will be 0.5 Kg per Cm^2 (approximately 0.5 ton per sq.ft.). The foundations for Turbines was to be designed both for static load and the effect of vibrations. The required bearing capacity according to the turbine loads was 1.0 Kg/Cm^2 (approximately 1.0 ton per sq.ft.). It was decided that the safe bearing capacity should not be taken more than 0.5 Kg per Cm^2 (approximately 0.5 ton per sq.ft) for shallow foundations.

6. The Contractor initially proposed shallow foundations at 1.1 meter below the ground level having 150 mm lean concrete and 1.35 meter deep reinforced cement concrete

having compressive strength of 4,000 psi. This proposal was rejected by the Author because the soil could not take the turbine loads under wet condition. The Contractor then suggested pile foundations consisting of 560 mm diameter (22 inches diameter) cast in situ upto a depth of 3.9 meter. The number of piles for each Turbine foundation was twelve. The pile foundations were not included in the contract. This proposal was not accepted as this would have involved additional cost to Wapda and more time for execution of the work. The Author suggested a practically feasible proposal by excavating weathered rock approximately 1.5 meter below the reinforced concrete foundation and re-filling with compacted Bholari Sand. Ultimately it was decided that 1.35 meter compacted sand fill mixed with 1 to 2% cement by weight to avoid liquefaction should be provided after removing the existing weathered limestone. The Bholari sand has very good grading. The filling will be done in 150 mm thick layers and each layer will be compacted with vibratory compactor to achieve minimum 85% relative density.

7. The cost comparison of 3 possible type of fill materials for foundations i.e. pile foundations, 1:3:6 cement concrete and compacted sand mixed with cement was carried out. The pile foundations is the costliest and sand is the cheapest type of fill material. The 1:3:6 concrete fill would have added more weight on the foundation soil than the sand fill. Therefore, the cement sand mix having 2% cement by weight was approved for filling on the basis of maximum dry density of 1.74 gm/cc achieved in the trial test and to avoid any chances of liquefaction.

8. The 1.35 meter depth was excavated below the reinforced cement concrete foundation of the turbine and then filled with approved sand mixed with 2% cement by weight with

maximum slump of 1½ inches. The cement sand was mixed in the Standard Concrete mixer. This mix was placed in the excavated foundation in a layer of 150 mm thick and compacted with vibratory plate compactor to achieve a minimum Relative Density of 85% according to the United States Bureau of Reclamation (USBR) Relative Density Test. The cement mixed sand filling operation was done continuously round the clock in 3 shifts and density tests were carried out by the Field Laboratory on each layer after compaction. The vibratory compactor started compaction from the outer ends of the excavated foundation and then moving towards the centre giving overlaps so that no area is left without compaction. The moisture content was controlled continuously with a speedy moisture testing equipment and density was also tested by the Field Laboratory Staff. The relative density achieved in each layer was from 87% to 100%.

9. The plate load test has confirmed that the bearing capacity of the soil was increased from 0.5 ton per sq.ft. to 5 ton per sq. ft. by using sand fill mixed with 2% cement by weight. It was found the most economical method for improving the bearing capacity of foundation of Gas Turbines Extension Project Units 5 & 6. If pile foundations were adopted then the additional cost to Wapda would have been Rs. 282,000. Therefore the Author saved additional cost by adopting cement sand fill for the foundations. The cement sand mix was at the cost of the Contractor and no additional payment was made for this fill. The foundation was stabilized and bearing capacity was improved which will last more than the life of the Gas Turbines.

1.0 INTRODUCTION

The 50 MW Kotri Gas Turbines Extension Project of Units 5 & 6 was prepared by WAPDA and approved by the Executive Committee of the National Economic Council in December, 1979. The contract for the Civil Works, supply and erection of the plant and equipment was awarded to M/s. Marubeni of Japan in May, 1980. These two units were commissioned by 15th May, 1981. The estimated cost of the Project was Rs 201 million with a Foreign Exchange Component of Rs 108 million. The turbines and generators including other major equipment were manufactured by M/s. Hitachi. The consultancy services were provided by M/s. EPDC International Ltd., of Japan.

2.0 SCOPE OF CIVIL WORKS IN CONTRACT

2.1 The Contractor shall be responsible for design and execution including all Labour, Material & Equipment needed for the Civil Works for this Project. The work will include but will not be limited to the following:

2.2 Sub-Surface investigation of the Project Area.

2.3 Evaluation of sub-surface data and fixing of soil parameters (in dynamic loading) for designing foundations.

2.4 Design of foundation and super structure.

2.5 Execution of the works mentioned below:

2.5.1 Clearance of site and removal of all top soil and grade to the level as approved by the Engineer.

2.5.2 Excavation of the foundation for the Gas Turbine Units, Switchyard equipment, roads and back fill.

2.5.3 Providing all reinforced cement concrete or plain concrete as required to complete the work and foundations for all machinery and equipment.

2.5.4 Extension of the Road and Rail track to the Switchyard Extension as required and also the fencing.

2.5.5 Construction of Roads and Paths & cement concrete flooring in-between and around the gas turbine units.

2.5.6 Providing shingle in the Switchyard as required.

2.5.7 Construction of all cable and pipeline trenches and all other miscellaneous Civil Works.

2.6 Piling work is not included under the contract. Prior to final decision on the necessity of the piling work, further soil investigation shall be carried out by the Contractor.

2.7 The design of the foundations and other civil works shall be carried out in sufficient detail with proper drawings. The foundation design should include structure and dynamic loading. The design computation will be submitted to the Engineer for review and drawings for approval. The approval of the design by the Engineer shall not absolve the Contractor from his responsibility for safe design and proper execution of the work.

2.8 The investigations made earlier in 1978 on the location of units 3 & 4 indicated a safe load carrying capacity of the soils as 0.5 kg/Cm^2. This however, cannot be taken as basis for designing

the civil work by the Contractor. The Contractor will carry out his own sub-soil investigations for designing the foundations.

3.0 SOIL INVESTIGATIONS

3.1 Purpose

The purpose of the investigations is to evaluate the nature and characteristics of the sub-surface materials at the site for the proper selection and design of foundations for the Gas Turbines and other structures.

3.2 Scope

The scope of the work is limited to the drilling of 3 Nos. bore holes at the locations indicated on the site Plan (Fig.1) upto a depth of 15 meter performing the Standard Penetration Tests at one meter interval in all the bore holes and carrying out the laboratory tests on the representative soil samples, according to the ASTM Standards. Originally, sampling of rock cores was not required. When chalky limestone was encountered during the drilling operation, it was considered essential to obtain rock cores for strength tests.

3.3 Drilling of Bore Holes

The bore holes were drilled by the rotary method using the roller bit in the upper soil or weak weathered rock strata. Drilling in the lower rock strata was done by using a double tube core barrel and rock cores of NX size were taken for crushing strength tests.

3.4 Field Tests

Standard Penetration Tests were performed at 1

meter interval as given in the bore hole logs. The rock cores of NX size were obtained for crushing strength tests from all the bore holes at the depths stated in the statement of laboratory test results (Fig.5). The "recovery ratio" in percentage is shown in the bore hole logs.

As the bore holes were dry upto the drilled depth of 15 meter the water samples could not be collected for testing.

3.5 Laboratory Tests

All the representative soil and rock samples were tested at the Soil Mechanics Ltd., Laboratory. The test results are given in Fig.5 &6).

3.6 Bore Hole Records

The bore hole logs (Fig. 2 to 4) show the description of various sub-surface materials encountered during drilling at the specified depths. The standard penetration test values and the percentage recovery of core samples are also given on the bore hole records.

3.7 Stratigraphy

The important features of the borings were noted as follows:

3.7.1. Bore Hole No.1

The upper 0.7 meter portion consisted of brown clayey silt with traces of very fine sand followed by 2.3 meter thick layer of brown weathered chalky limestone with traces of sand which was underlain by 1.5 meter thick layer of chalky limestone with traces of silt. Drilling in the upper 4.5 meter depth was done by using roller bit.

Standard Penetration Tests (SPT) are not generally carried out in rock. These tests were, however, done in the upper 4 meter depth to get an idea of penetration resistance in chalky limestone which is very soft rock. The SPT values varied from 48 to refusal.

From 4.5 meter to 15 meter depth drilling was done using a double tube core barrel. Rock cores of NX size were obtained. The material encountered was mostly chalky limestone except for a 0.6 meter thick layer of shale at a depth of 7 meter for which the recovery ratio was only 25%. From 12 meter to 15 meter depth 100% water loss was observed. The bore hole was found to be dry upto the maximum depth of drilling.

3.7.2 Bore Hole No.2

The top 1 meter soil consisted of dark brown hard clayey silt with traces of very fine sand. The material upto 5 meter depth was weathered chalky limestone. Drilling by Roller Bit was done upto 9 meter depth. Below this depth core drilling was done using double tube core barrel upto 15 meter depth. In this bore hole Standard Penetration Tests were done upto 9 meter depth and the values were from 60 to 100.

The material from 5 meter to 15 meter was brown chalky limestone. The recovery ratio varied from 66% to 90%. From 12

meter to 15 meter depth 100% water loss was found. This bore hole was also found dry.

3.7.3 Bore Hole No.3

In this bore hole the material from the ground level to 3 meter depth was weathered chalky limestone. Drilling of the upper 4 meter depth was done by roller bit. The SPT values varied from 49 to 90. Core drilling was done from 9 meter to 15 meter depth using double tube barrel. The strata from 3 meter to 15 meter consisted of brown chalky limestone with recovery ratio ranging from 50% to 80% except for 1.5 meter thick layer of brown chalk at a depth of 10.5 meter for which the recovery ratio was only 23%. This bore hole was also found dry. From 12 meter to 15 meter depth 100% water loss was found.

3.7.4 The investigations at the bore hole locations reveal that the sub-soil strata at the site follow a uniform pattern. The sub-soil upto the drilled depth of 15 meter can be divided into three distinct layers. The top soil (Layer-1) is brown clayey silt. The thickness of this layer varies upto 1 meter. The next layer (Layer-2) consists of brown weathered limestone extending in depth upto 4.5 meter at the location of bore hole No.1 and upto 3 meter at bore hole No.2. Underlying this layer there is brown chalky limestone throughout the drilled depth except for

a thin seam of shale 0.6 meter thick, at a depth of 7 meter at bore hole No.1 and 1.5 meter thick layer of chalk at a depth of 10.5 meter at bore hole No.3.

3.8 Groundwater

As mentioned earlier, all the three bore holes were found dry upto the maximum drilled depth of 15 meter. Since groundwater was not encountered, the chemical analysis of groundwater could not be done.

3.9 Standard Penetration Tests

The Standard Penetration Tests were carried out at 1 meter interval upto a depth of 4 meter, 9 meter and 4 meter in bore hole No.1,2 and 3 respectively. The minimum value for the top soil at the location of bore hole Nos. 1 & 2 is 48 which suggests that the clayey silt is in a very dense state of compaction. The bearing capacity for isolated footings or rafts at a depth of 1.5 meter may be taken as 2 Kg/Cm² (approximately 2 tons/sq.ft). Below the top soil the SPT values in the weathered limestone are very high upto refusal and the bearing capacity for footings or raft may be taken as 4 Kg/Cm² (approximately 4 tons/sq.ft) provided the rock is free from structural defects such as shear zones, cavities, solution channels and porous zones. Weathered rock is not reliable for supporting heavy loads. Moreover, limestone as a foundation material may become weaker due to solution along cracks. In view of these considerations the bearing capacity of the weathered limestone upto a depth of 5 meter below ground surface may be limited to 2.5 Kg/Cm² (approximately 2.5 tons/sq.ft) for shallow foundation.

3.10 Laboratory Tests

Except for the top soil at the location of bore hole Nos. 1 & 2, for a maximum depth of 1 meter the material was mostly chalky limestone. Grain size analysis (Fig.6) of top soil and chemical analysis for CaO, MgO and sulphates (Fig.7) were done on samples from the top soil. Rock cores from the three bore holes were tested for unit weight and crushing strength.

The unit weight of rock core samples varied from 2.13 to 2.97 gm/cc. The crushing strength of limestone varied from 0.9 to 18 Kg/Cm^2 (Fig.5) excluding the very high values of 3 samples, i.e. 18.0, 9.0 and 9.0 Kg/Cm^2, the average value of the remaining 15 samples is 2.5 Kg/Cm^2 (approximately 2.5 tons/sq.ft.). The chalky limestone is thus a very weak rock.

3.11 Chemical Tests

The chemical analysis to determine the sulphate content of soil as well as the calcium and magnesium oxides of soil was carried out on 6 samples, two samples each from the three bore holes. The soil samples used in the analysis were those obtained with the split spoon sampler after performing Standard Penetration Tests No.1 and 3 in each bore hole. The soil samples were, therefore, taken from 1 meter to 3.46 meter depth from the ground level.

The sulphate content of the soil (SO_4) ranges from 0.03 to 0.15%. The maximum value is within the permissible limit for allowing the use of normal Portland cement without the danger of sulphate

attack. Therefore, the use of sulphate resisting cement will not be necessary.

The calcium oxide (CaO) varies from 0.03 to 0.16% and the magnesium oxide (MgO) from 0.01 to 0.03% in the soil samples analysed. These oxide contents of the soil are not significantly high from the durability point of view of the concrete.

3.12 Recommendations

The results of this investigation lead to the following recommendations:

3.12.1 The sub-soil strata at the site is fairly uniform. The top soil is hard clayey silt varying in thickness upto 1 meter overlying weathered limestone extending to a depth of 3 meter to 5 meter below ground level. This is underlain by chalky limestone upto the maximum drilled depth of 15 meter.

3.12.2 Both the isolated footings and raft foundations are considered to be feasible for building structures. The allowable bearing capacity for footings and raft laid at a depth of 1.5 meter is recommended to be 2.0 Kg/Cm^2 (approximately 2 tons/sq.ft). For the foundations laid at a depth of 2 meter the allowable bearing capacity may be taken as 2.5 Kg/Cm^2 (approximately 2.5 tons/sq.ft).

3.12.3 For turbines and other heavy machinery, the foundation should be designed with due consideration of the vibration affects. Raft foundations are recommended. The allowable bearing capacity for raft or pad foundations