# Reanalysis of a Vacuum Distillation Unit Foundation

M. N. Viladkar
*University of Roorkee, Roorkee, India*

Swami Saran
*University of Roorkee, Roorkee, India*

Proceedings: Third International Conference on Case Histories in Geotechnical Engineering, St. Louis, Missouri, June 1-4, 1993, Paper No. 1.22

# Reanalysis of a Vacuum Distillation Unit Foundation

M. N. Viladkar and Swami Saran
Civil Engineering Department, University of Roorkee,
Roorkee, India

**SYNOPSIS :** This paper deals with the reanalysis of the foundation of an already existing Vaccum Distillation Unit in an oil refinery. The reanalysis is required to suggest if the existing foundation of the unit would be capable enough to withstand an additional pressure intensity to which it would be subjected due to proposed expansion of the unit. The paper therefore discusses the geotechnical investigation program undertaken for evaluating the relevant design parameters and the methodology adopted to compute the sustainable pressure of the foundation.

## INTRODUCTION

The petroleum products are difficult to purify by distillation at ordinary pressures. This is due to the fact that very high temperatures are required to vapourise the material so as to decompose it. In the absence of such high temperatures, the operation becomes impractical. The petroleum products are therefore usually distilled at subatmospheric pressures thereby reducing the required temperature according to vapour pressure-temperature relationship of the material to be distilled. This operation is performed in a Vaccum Distillation Unit (VDU) in an oil refinery which is a tall column structure.

## PROBLEM

This paper therefore deals with the reanalysis of the foundation (an annular raft in this case) of an already existing Vaccum Distillation Unit (VDU) in an oil refinery. The reanalysis is essential in order to decide the additional pressure intensity which the annular raft would be able to sustain so that the proposed program of expansion of the VDU could be undertaken.

## GEOTECHNICAL EXPLORATION

In view of the inflammability of the oil, the field tests could not be conducted in a close vicinity of the structure. Figure-1 shows the layout plan of VDU alongwith the various test locations. The test location-1 is at a distance of 64.0m from the VDU and the second test location is at 121m.

The geotechnical exploration consisted of :

i) Obtaining soil samples, both representative and undisturbed, during boring for classification and other laboratory tests.

ii) Assessing the in-situ load-settlement characteristics of soil at the proposed depth of shallow foundation.

iii) Obtaining the soundings of penetration resistance through standard penetration tests in boreholes.

It was decided to conduct one boring on either side of the VDU upto a depth of 12.0m or refusal, whichever is earlier. The standard penetration tests (SPT) were conducted at every 1.5m interval during boring or change of soil strata, whichever is earlier. The undisturbed samples were collected during boring and ground water table also observed. The plate load test was conducted at a depth of 1.5m which is the depth at which the annular raft tests on soil. The laboratory tests included those for classification purpose. Also, the unconfined compresion and the consolidation tests were conducted on undisturbed samples collected at 1.5m and 6.5m depths in borehole $B_1$ and 1.5m and 3.0m depths in borehole $B_2$.

## TEST DATA AND INTERPRETATION

### Soil Strata

Figure-2 shows a typical borelog obtained during boring at location-1 (Fig.1). It is found that the soil is essentially plastic in nature throughout the depth of boring and consists of clay of low compressibility (CL) with intermittent layers of clay to silt of low compressibility (CL-ML) or silt of low compressibility (ML) or clay of intermediate compressibility (CI). The soil found in other borehole was also of almost the same nature.

The ground water table was observed at a depth of about 1.5m below the ground surface. The average value of field density was found to be 2.0 $t/m^3$.

**SPT and Plate Load Tests Data**

The plate load test conducted at location no.1 on a 30 x 30cm plate at a depth of 1.5m gave the ultimate capacity of the plate as $q_{up}$ = 21 t/m$^2$. A similar test conducted at location no.2 gave the value of $q_{up}$ = 27 t/m$^2$.

**Unconfined Compression and Consolidation Tests :**

These tests were conducted in the laboratory on undisturbed samples collected during boring from different depths. Figure-3 shows a typical e-$\log_{10}$ p plot obtained from

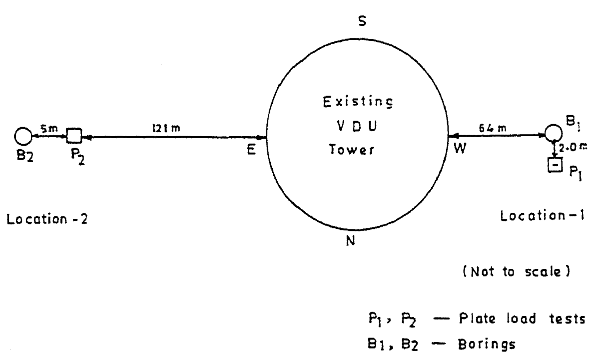


Fig.1 — Layout plan of VDU Showing test locations

the consolidation test conducted on an undisturbed sample collected at a depth of 3.0m from borehole, $B_1$. Table-1 gives values of unconfined compressive strength, $q_u$, the compression index, $C_c$ and preconsolidation pressure, $P_c$ corresponding to different depths.

**TABLE 1 : Unconfined Compression and Consolidation Test Data**

| Bore Hole | Depth (m) | $q_u$ (kg/cm$^2$) | $C_c$ | $P_c$ (kg/cm$^2$) |
|---|---|---|---|---|
| $B_1$ | 1.5 | 1.51 | 0.13 | 1.64 |
| | 6.0 | 1.57 | 0.10 | 1.05 |
| $B_2$ | 1.5 | 1.72 | 0.13 | 1.55 |
| | 3.0 | 1.67 | 0.14 | 1.20 |

**APPROACH**

**Step-i :** In order to decide the additional pressure intensity to which the tower foundation can be subjected, it is first essential to know the capacity/allowable bearing pressure of the tower foundation.

**Step-ii :** It is essential to know the total permissible settlement for the foundation and the settlement which the foundation can undergo due to the existing pressure on the foundation.

**Step-iii :** Difference of the two settlements in step-ii gives the additional permissible settlement which the existing foundation can undergo due to additional pressure, if any.

| (m) | I. S. Classification Description | Hatching | Sand (%) | Fines (%) | $W_n$ (%) | $W_{PL}$ (%) | $W_{LL}$ (%) | Water table | $q_u$ kg/cm$^2$ |
|---|---|---|---|---|---|---|---|---|---|
| 0<br>1.5 | CL | | 23.50 | 76.50 | 21.42 | 14.98 | 23.77 | $\nabla$ | 1.51 |
| 3.0 | CL – ML | | 32.25 | 67.75 | 18.21 | 19.75 | 25.10 | | — |
| 4.5 | ML | | 19.05 | 80.95 | 20.11 | 21.28 | 24.53 | | — |
| 6.0 | CL | | 7.00 | 93.00 | 22.94 | 17.74 | 25.27 | | 1.57 |
| 7.5 | CL – ML | | 19.70 | 80.30 | 23.35 | 19.16 | 25.32 | | — |
| 9.0 | CI | | 6.75 | 93.25 | 19.50 | 24.76 | 42.03 | | — |
| 10.5 | CL – ML | | 23.55 | 76.45 | 20.45 | 17.37 | 21.90 | | — |
| 12.0 | ML | | 23.60 | 76.40 | 22.08 | Non-plastic | | | — |

Fig.2. Bore log details at borehole location B1

**PERMISSIBLE SETTLEMENT**

As per the Indian Standard, IS : 1904-1978, the permissible tilt for the tower type of structures is 1:400. Using the charts (Fig.4a/4b) due to Bjerrum (1963) for arriving at the maximum differential settlement corresponding to the permissible tilt and the maximum permissible total settlement, it has been found that maximum permissible settlement for the VDU is 120mm.

**SETTLEMENT DUE TO EXISTING PRESSURE**

The existing pressure on the foundation is 7.0 t/m$^2$. On the basis of the borelogs (Fig.2), compressible plastic soil layer may be considered to be extending upto a depth of 10.0m. Assuming 2:1 distribution of pressure below the annular raft and dividing the soil mass into three layers, and considering the configuration as shown in Fig.5, the total consolidation settlement of the VDU has been computed to be 105.8mm (Appendix-I). The permissible settlement due to any additional pressure therefore can be taken to be (120-105.8) = 14.2 mm.

**SETTLEMENT DUE TO ADDITIONAL PRESSURES**

With a margin of settlement of 14.2 mm, additional pressures which could be allowed to act on the foundation could be computed. Applying therefore an additional pressure of 1.0 t/m$^2$ on the annular raft, the settlement computations of the raft are done using the same configuration of the raft as shown in Fig.5 and on the same lines as Appendix-I. It

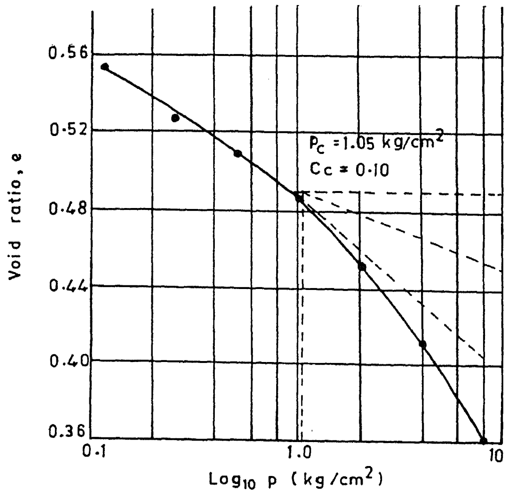


Fig. 3 : e-log p curve for borehole-$B_1$ (3.0m)

is found that the foundation would undergo a settlement of 11.7mm due to this pressure and the total consolidation settlement would therefore be 105.8 + 11.7 117.5mm which is less than 120mm.

The pressure imposed by the existing structure (i.e. 7 t/m$^2$) must have consolidated the soil and therefore may be considered as a preload for the additional pressures. The permissible value of the settlement may therefore be considered to be higher than 120mm when compared with the total settlement consisting of preload settlement and settlement due to additional pressure. This will improve the e-$log_{10}$P curve to a large extent. It can therefore be safely assumed that the settlement caused by the additional pressure of 1.0 t/m$^2$ will be less than 11.7mm and may be taken to be about half i.e. 6.0mm. The total settlement would therefore be 105.8 + 6.0 = 111.8 mm.

If therefore an additional pressure of 2.0 t/m$^2$ is applied on the foundation, instead of 1.0 t/m$^2$, the consolidation settlement which the foundation would experience due to this additional pressure would be 22.6mm (Appendix-II). However, with the same argument as given above, the effective consolidation settlement will be 11.3mm and therefore, the total consolidation settlement would be 105.8 + 11.3 = 117.1mm which would be less than the permissible settlement of 120mm. The VDU column may therefore be subjected to an additional pressure intensity of 2 t/m$^2$ during its expansion. Incidentally, the allowable pressure of the annular raft also works out to be 9.0 t/m$^2$.

**TIME FOR CONSOLIDATION**

On the basis of the consolidation test data, values of coefficient of consolidation, $C_v$ were computed for different pressure ranges for all the four undisturbed samples using the square root of time fitting method. These values are listed in Table-2 and typical time consolidation curve has been shown in Fig.6. The average value of $C_v$ has been found to be 2.0 x $10^{-4}$ cm$^2$/sec.

**TABLE 2 : Values of Coefficient of Consolidation :**

| Borehole | Depth (m) | Pressure increment (kg/cm$^2$) | Coefficient of consolidation $C_v$ (cm$^2$/sec)x$10^{-4}$ |
|---|---|---|---|
| $B_1$ | 1.5 | 0.5 | 2.208 |
| | | 2.0 | 2.075 |
| | | 8.0 | 19.4 |
| | 6.0 | 0.25 | 3.142 |
| | | 1.00 | 12.14 |
| | | 4.00 | 31.45 |
| $B_2$ | 1.5 | 0.25 | 2.28 |
| | | 1.00 | 2.04 |
| | | 4.00 | 13.13 |
| | 3.0 | 0.5 | 0.78 |
| | | 2.0 | 1.436 |
| | | 8.0 | 1.198 |

**Existing Pressure**

Considering the settlement corresponding, to 95 percent degree of consolidation (U=95%) as almost the whole settlement of 105.8mm due to existing pressure, the time required to reach this settlement can be computed using the expression :-

$$T_v = \frac{C_v t}{H^2} \quad ..(1)$$

where $T_v$ = Time factor corresponding to a certain degree consolidation.

t = time required for consolidation.

H = thick of the draining layer.

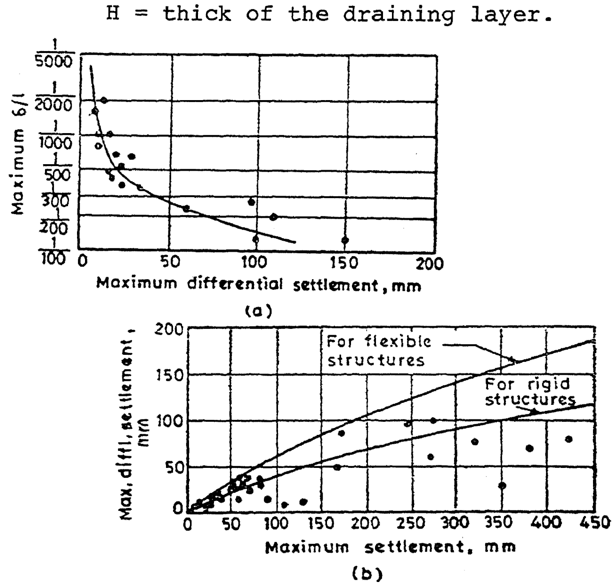


Fig. 4 : Settlement characteristics of structures on clay

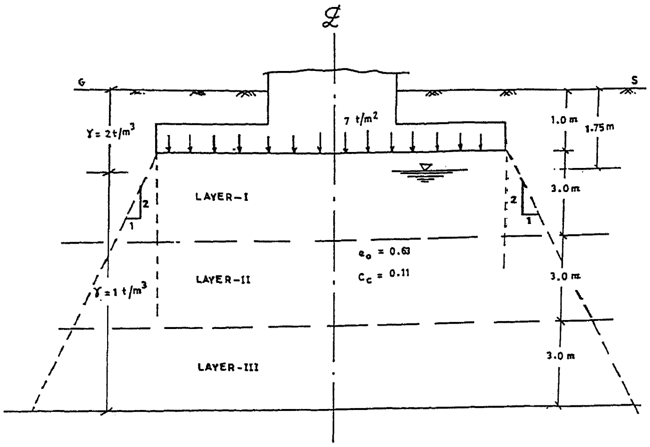


FIG.5 COMPUTATION OF CONSOLIDATION SETTLEMENT

In the present case, looking at the borelog (Fig.2), it is found that only one way drainage is possible and therefore time factor, $T_v$ for U = 0.95 is found to be 1.129 and the time for consolidation due to existing pressure of 7.0 $t/m^2$ would be 36 years. However, till today, the time elapsed after the construction of the VDU is 17 years. Therefore, the corresponding time factor could again be computed using eqn.-1 and has been found to be 0.53 which corresponds to degree of consolidation U = 0.776 or a settlement, S = 0.776 x 105.8 = 82.10mm. Therefore the remaining settlement of 105.8 - 82.1 = 23.7mm will occur over a period of 36 - 17 = 19 years provided the pressure continues to be 7.0 $t/m^2$.

**Additional Pressure**

If the VDU is subjected to an additional pressure intensity of 2.0 $t/m^2$, superimposed over the existing pressure, the settlement of 117.1 - 82.1 = 35.0mm will also take the same time i.e. 19 years if there is no change in the value of $C_v$. As discussed earlier, if the effect of preloading is considered, the value of $C_v$ is expected to reduce. It will therefore enhance the duration of occurence of settlement.

**CONCLUSION**

The reanalysis of the annular raft supporting a Vaccum Distillation Unit in an oil refinery is carried out to suggest the additional pressure intensity to which the existing foundation could be subjected to so that the expansion capacity of VDU can be decided.

It has been found that the foundation could be subjected to an aditional pressure intensity of 2.0 $t/m^2$ only.

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**Appendix-I : Consolidation Settlement due to Existing Pressure of 7 $t/m^2$.**

| Layer No. | $P_o$ $t/m^2$ | $\Delta p$ $t/m^2$ | $e_o$ | $\Delta e$ | H (mm) | S (mm) |
|---|---|---|---|---|---|---|
| 1 | 4.25 | 5.58 | 0.514 | 0.028 | 3000 | 55.5 |
| 2 | 7.25 | 3.78 | 0.498 | 0.015 | 3000 | 30.0 |
| 3 | 10.25 | 2.73 | 0.483 | 0.010 | 3000 | 20.3 |
| | | | | Total | | 105.8 |

**Appendix-II : Consolidation Settlement due to an Additional Pressure of 2 $t/m^2$**

| Layer No. | $P_o$ $t/m^2$ | $\Delta p$ $t/m^2$ | $e_o$ | $\Delta e$ | H (mm) | S (mm) |
|---|---|---|---|---|---|---|
| 1 | 9.03 | 1.60 | 0.49 | 0.005 | 3000 | 10.0 |
| 2 | 11.03 | 1.08 | 0.48 | 0.0035 | 3000 | 7.1 |
| 3 | 12.98 | 0.80 | 0.47 | 0.0027 | 3000 | 5.5 |
| | | | | Total | | 22.6 |

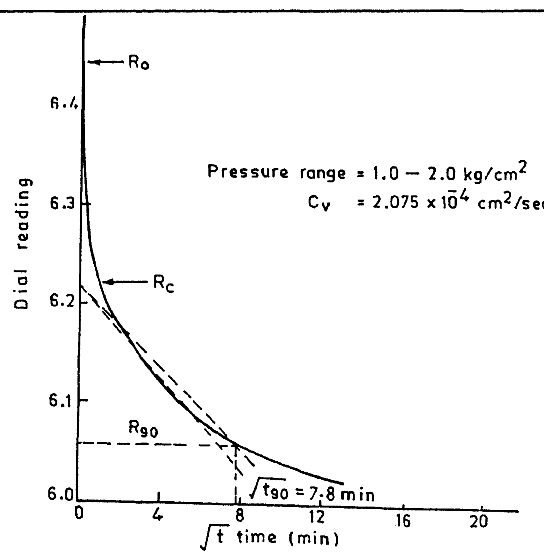


Fig. 5 Time-consolidation curve (square root of time fitting method) Borehole – B1 (1.5m)