International Conference on Case Histories in Geotechnical Engineering

(1988) - Second International Conference on Case Histories in Geotechnical Engineering

03 Jun 1988, 10:30 am - 5:30 pm

The Performance Behaviour of a Grain Silo Foundation in Jeddah Supported on Stone Columns

D. L. Jones
L.G. Mouchel & Partners, United Kingdom

G. J. Macdonald
L.G. Mouchel & Partners, United Kingdom

M. H. Golder
L.G. Mouchel & Partners, United Kingdom

Proceedings: Second International Conference on Case Histories in Geotechnical Engineering, June 1-5, 1988, St. Louis, Mo., Paper No. 5.44

The Performance Behaviour of a Grain Silo Foundation in Jeddah Supported on Stone Columns

D.L. Jones
L.G. Mouchel & Partners, West Byfleet, Surrey, United Kingdom

M.H. Golder
L.G. Mouchel & Partners, West Byfleet, Surrey, United Kingdom

G.J. Macdonald
L.G. Mouchel & Partners, West Byfleet, Surrey, United Kingdom

SYNOPSIS: This paper describes the ground treatment carried out and the subsequent load settlement behaviour of a grain silo in Jeddah, Saudi Arabia. Predicted performance based on the results of both SPT and cone penetration tests are compared with actual behaviour. The prediction based on the SPT results is poor, with the cone penetration analyses giving a significant improvement. A knowledge of cone resistance and hence modulus values for the full depth of influence of the silo would have further refined the prediction.

INTRODUCTION

This paper details the settlement behaviour of a port silo of 20,000 tonne capacity constructed at Jeddah Port (Saudi Arabia) for imported cereals and expellers. (See Fig 1).

The silo installation at the port acts in the capacity of transit storage, permitting vessels of up to 65,000 tonnes to be discharged at 600 tonnes per hour, and the cereals transferred to inland feedmill storage silos by road vehicles. This case history relates to Phase I of the silo construction contract.

The silo structure comprises a block of 12, 10.5 metre square steel bins, constructed from deep profile corrugated steel sheet supported by hollow section concrete filled posts and diagonal tie bars.

The silo structure is founded on a reinforced concrete cellular raft 32.5m x 42.5m imposing an average stress of 250 kN/m² and a maximum of 300 kN/m² when 8 out of the 12 bins are loaded towards the end of the silo.

GEOLOGY AND GROUND CONDITIONS

The coastal plain around Jeddah Port consists of Quarternary/Recent deposits of gravel, sand, coral limestone and silt underlain at depth by Quarternary Volcanics or Pre Cambrian basement rocks.

The ground investigation for the silo complex consisted of cable percussion boreholes and static cone penetrometer tests. The investigation revealed that the site which is partly in an area of reclaimed land, is underlain by very loose marine shelly sands and silts with layers or lenses of clay and gravel and coral limestone. Graded bed sequences with gravel at the base, fining upwards, were evident as was the local concentrations of heavy minerals due to wave action at former beach levels.

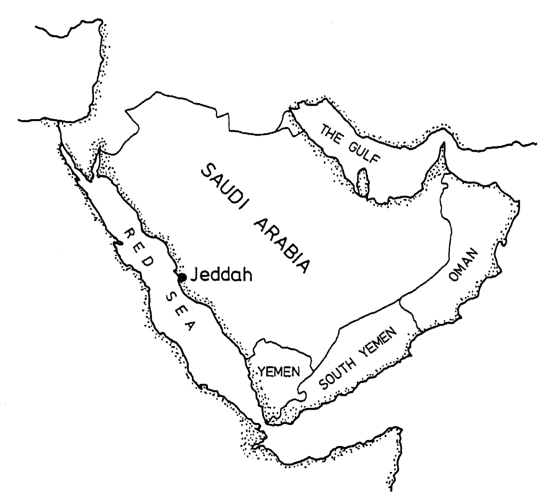

Fig. 1. Location Plan

The sequence contained thin laterally discontinuous bands of coral limestone up to 6m thick concentrated between depths of 2m to 9m and 18m to 32m respectively. The limestone is a breccioconglomeratic calcirudite composed of coral and limestone fragments with shell debris in a sandy matrix. Voids of between 20mm to 60mm were identified within the limestone layers. A further porous shelly limestone layer with dissolution cavities partially filled with sand gravel and clay was encountered from 49.0m to 59.5m depth but it is not known whether this is laterally persistent as only one borehole was taken to this depth, the others terminating between 40m and 50m. A typical section is shown in Fig 2.

Groundwater was encountered at some 1.5m below ground level, that is approximately at the founding level of the silo raft, a design criteria.

The Standard Penetration Test profiles recorded within the boreholes were generally similar with SPT 'N' values of between 2 to 20 to a depth of 16m reducing to between 0 and 12 to a depth of approximately 26m. (See Fig 2). Below this level SPT 'N' values increased significantly to between 25 and 50 with refusal being recorded after a short penetration into the limestone lenses. A number of cone penetration tests were subsequently carried out to further investigation the zone of low SPT results to a depth of 26m.

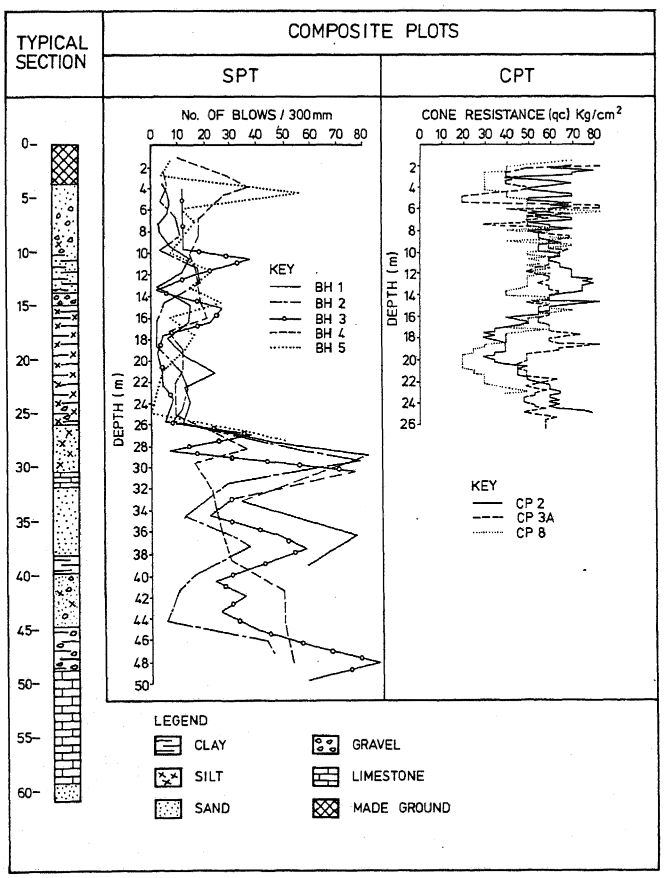

Fig. 2 Typical Section and Penetration Test Results.

FOUNDATIONS

In view of the low cone readings and low SPT 'N' values measured to a depth of 26m the possibility existed that a bearing capacity failure could occur under adverse silo loading conditions. The decision was therefore taken to adopt ground treatment to reduce adverse differential settlements and minimise the risk of bearing failure.

Options investigated included the formation of jet grouted columns, piling, dynamic compaction and vibro-replacement the latter being considered the most appropriate on the basis of financial and technical considerations.

The varying silt content within the ground suggested that vibro-replacement rather than vibro-compaction would be most effective. In view of the increasing friction ratio with depth, identified from the static cone testing, it was considered that a treatment depth of between 10m to 12m would represent the practical maximum depth throughout which useful treatment could be achieved. With friction ratios from the static cone penetrometer tests generally exceeding 3% within the zone to be treated by vibro-compaction, the treatment process becomes one of installing relatively stiff columns into the ground which itself shows little increase in relative density.

The ground treatment for the Phase I silo comprised the installation of some 500 stone columns to depths of 12m with a grid spacing varying from 2.0m to 2.5m.

PERFORMANCE BEHAVIOUR - PREDICTED

Settlement calculations were undertaken using the results of the SPT 'N' values and the static cone penetrometer tests. The SPT 'N' values exhibited a wide range which reflected the interbedded and lenticular nature of the deposits rendering a settlement analysis based on the results of average SPT 'N' values inappropriate. Typical settlements under an applied loading 250 kN/m² calculated by varing methods are 30mm and 40mm using Meyerhof (1965) and Schultze and Sherif (1973) respectively, and up to 70mm by Parry (1971). The more recent analysis by Burland and Burbridge (1985) produces a calculated settlement of 80mm.

Analysis based upon SPT testing would therefore suggest that the predicted settlements are within a range that could be accommodated by a silo raft where controlled loadings apply. However it is understood that severe settlement had been experienced on an adjacent silo site. A method of analysis based upon static cone penetrometer tests which provide a continuous profile of resistance with depth was therefore preferred. The results were analysed using Schertmann's (1970) procedure which assumes a triangular strain distribution up to a depth of twice the foundation width, that is some 65m. Although boreholes had been sunk to this depth the static cone testing met with refusal around a depth of 26m. Reference to the borehole records also indicated high SPT values below this level in dense sand and gravel with lenses of limestone.

A comparison of the measured penetration results with a chart for the interpretation of penetration tests in chalk by Searle (1979) suggest that the soils compare with a medium dense to dense structureless chalk and that the carbonate silts and sands are weakly cemented. An assumption was therefore made that the presence of high modulus materials below a depth of 26m would modify the stress distribution below the raft such that the majority of settlement occurred above this level.

A modulus value of 100 MN/m^2 was arbitarily ascribed to the materials below 26m depth. The effect of this assumption was to limit the predicted settlment to 25mm within the zone from 26m to 65m.

Based upon the above assumptions a calculated total settlement for the silo raft of 220mm was obtained which is significantly greater than that obtained using SPT results.

In assessing the reduction in settlement caused by the installation of stone columns reference was made to the method proposed by Priebe (1976). With the column spacings adopted, a settlement reduction factor of 2 could be applied. This is equivalent to doubling the modulus in the treated ground compared with the untreated ground. The effect on installing stone columns is thus limited to halving the settlement within the treated layer and is insignificant when compared with the overall anticipated settlement, the majority of which occurs below the treated zone. The reduction in settlement was calculated as being around 25mm. However, it was believed that the stone columns would significantly increase bearing capacity and by forming a layer of uniform stiffness would minimise differential movement.

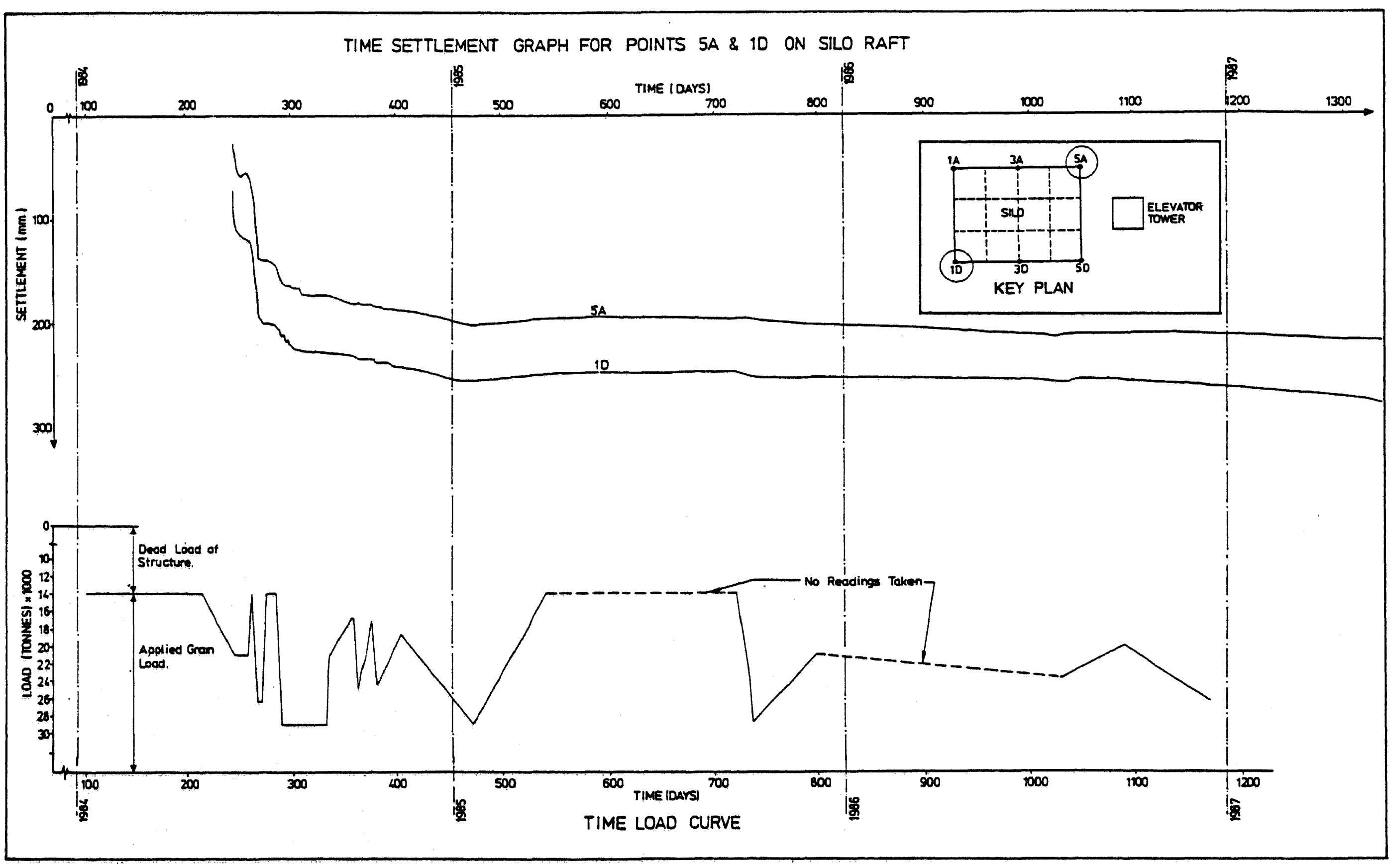

Fig. 3. Load Settlement Behaviour.

PERFORMANCE BEHAVIOUR - OBSERVED

Following completion of the silo raft in September 1983 steel targets were cast into corners and mid points of the long axis of the raft. Readings which were taken prior to the construction of the silo bins acted as datum for subsequent settlement measurements. The dead weight of the raft is 14000 tonnes giving an imposed bearing pressure of 100 kN/m². From the observations of subsequent load settlement behaviour it can be assumed that settlement of the raft was concurrent with construction.

The loading of the silos was carefully controlled by redistribution of grain to ensure uniform ground pressures and settlement. Reference to the load/settlement behaviour for two of the targets (Fig 3) indicates that settlement is virtually immediate upon application of load followed by a relatively minor time related settlement which lasts of the order of two to three weeks. The operational demands of the silo were such that full consolidation for a given load could not always be reached. As would be expected with subsequent unloading and reloading further settlement only occurred when the previous highest loading had been exceeded or where full consolidation has not been reached under previous loadings. As the full silo condition was approached only relatively small settlement increases occurred compared with those experienced during initial loadings. The magnitude of any elastic recovery during unloading was insignificant.

The design of the silo raft has allowed substantial redistribution of stresses to occur and can be thought of as approaching a rigid raft condition with regards to its settlement performance. Although the settlement of the centre of the raft was not monitored the performance of the silo suggests that there has been no adverse dishing at the centre. Relatively planar settlements can therefore be assumed.

The headhouse tilted towards the silo due to the influence of the silo loading on the settlement of the headhouse raft. This caused no structural or operational problems, but the access platforms between the headhouse and silo were adjusted to prevent damage by contact.

DISCUSSION

The observed settlements are large and exceeded that predicted. It should be noted that settlement readings were only taken after construction of the raft had been completed which accounts for approximately 40% of the load under a full silo condition. From the settlement observations, settlement under primary loading has been shown to be virtually concurrent with loading, followed by a minor consolidation period lasting 2 to 3 weeks. From this it can be assumed that settlement of the raft would have been essentially complete at the time of installing the steel targets. On a pro-rata basis the settlement of the raft alone could have been around 150mm.

For the carbonate deposits encountered, the ratio of observed to predicted settlement based on the results of SPT tests was high. Calculations using the cone penetrometer results superficially gave good agreement between predicted and observed, but if an allowance is made for settlement of the raft, this approach also underestimated total settlement. It is considered that the disparity is predominantly due to an overestimate of the modulus value below a depth of 26m.

The stone columns have provide very effective in reducing differential settlement and eliminating any bearing failure. The actual amount of total settlement has had little effect on the operational performance of the silos.

CONCLUSION

The load/settlement behaviour of the silos could not be adequately predicted using SPT based methods. The use of a static cone penetrometer enabled a better prediction to be made. However, as cone penetrometer tests were only able to penetrate to a depth less than half that influenced by the silo, a suitable estimate of the variation in modulus with depth could not be obtained. The use of a relatively high modulus at depth led to an underestimate of settlement.

The use of stone columns has prevented bearing failure and limited differential settlement. The silo has been fully operational since construction and has been unaffected by the settlement. The load/settlement behaviour of the silos shows that settlement has essentially ceased.

ACKNOWLEDGEMENTS

The writers wish to acknowledge Shiek A Fakieh of Fakieh Poultry Farms, Makkah, Saudi Arabia for permission to publish this paper. The civil contractors for the

development were Icori Estero SA and Berga Impianti Cereali SFS of Italy. The ground treatment was carried out by Cementation and Foundation Engineering Ltd, Great Britain and the ground investigations by Alhoty Stanger Ltd and Foundation Engineering Ltd, Saudi Arabia.

REFERENCES

Burland, J.B. and Burbidge, M.C. (1985) - "Settlement of Foundations on Sand and Gravel." Proc. Inst. Civ. Eng., Part 1, 78, Dec., pp 1325-1381.

Clarke and Walker (1977) - "A Proposed Scheme for the Classification and Nomenclature for Use in the Engineering Description of Middle Eastern Sedimentary Rocks." Geotechnique, Vol. XXVII, No. 1, pp 93-99.

Meyerhof, G.G. (1965) - "Shallow Foundations." ASCE, JSMFD, Vol. 91, SM2, pp 21-31.

Parry, R.G.H. (1971) - "A Direct Method of Estimating Settlements in Sands from SPT Valuves." Proc. Symp. Inter. Struct. Found. Mid. Soc. SMFE, Birmingham, pp 29-37.

Schmertmann, J.H. (1970) - "Static Cone to Compute Static Settlement over Sand." ASCE, JSMFD, Vol. 96, SM3, pp 1011-1043.

Schultze, E. and Sherif G. (1973) - "Prediction of Settlements From Evaluated Settlement Observations for Sand." Proc. 8th Int. Conf. Soil Mech. Fdn. Engng., Moscow, Vol. 1.3, pp 225-30.

Searle, I.W. (1979) - "The Interpretation of Begemann Friction Jacket Cone Results to give Soil Types and Design Parameters." Proc. 7th European Conf. Soil Mech. Fdn. Engng., Brighton, Vol. 2, pp 265-270.