Dynamic consolidation as an alternative foundation

J. M. WEST, BSc, PhD and B. C. SLOCOMBE, MSc, GKN Foundations Ltd.

IN 1971 Redpath Dorman Long (North Sea) Ltd. took over an abandoned colliery at Methil on the northern shore of the Firth of Forth and since then the site has been redeveloped to form an important centre for the construction of North Sea Oil rigs. Currently two rigs are being built at Methil and this article deals with slipway foundations for the 13,000 ton Brent rig. The Brent rig is understood to be the largest currently being built for the North Sea and some idea of the size can be gauged from the fact that, when erected, it will be some 40 m taller than the London Post Office Tower.

The RDL site extends over an area of about 50 ha and the original mounds of colliery waste have been levelled to produce a level site standing at about 9.0 m AOD. As far as possible sub-assemblies are fabricated in a series of large workshops and finally assembled in the open resting on the slipways. The principal loads are therefore carried on the slipways and for the Brent rig a total of 16 bogies will apply line loads of approximately 130 tonnes per metre run during erection and launching.

**Soil conditions**

A large number of site investigation boreholes were put down over the slipway site and while the thickness of the colliery waste was comparatively uniform at approximately 10.0 m, standard penetration test N values varied widely over a range 10 to 92 blows. The fill was underlaid by alternating layers of marl and sandstone and a typical borehole log is shown on fig. 1 together with a particle size distribution curve for the colliery waste on fig. 2.

It was clear from the site investigation information that the slipway foundations could not be supported directly on the fill and unless the colliery waste could be stabilised it would be necessary to pile the entire length of each slipway. While it was considered essential to use piles at the seaward end, to continue piling over the rest of the slipway would have been very costly and also delayed construction.

Consequently RDL asked GKN to assess the feasibility of stabilising the colliery waste to meet stringent requirements. Based on a slipway width of 5.5 m RDL required a safe bearing capacity of 250 kN/m² with a maximum settlement of 38 mm. Tighter tolerances were also required adjacent to the piled section of each slipway to minimise differential movement between the different foundation types. After considering the specification and ground conditions, GKN Foundations, in joint venture with Menard Techniques, prepared a scheme based on carrying out the soil stabilisation using their Dynamic Consolidation technique, and this proposal was accepted by RDL (Contracting) Ltd., the main contractor.

Referring to the slipway site layout plan (fig. 3) the problem was to compact and strengthen the fill beneath 4 sections of slipway each approximately 220 m long and 5.5 m wide. In order to ensure that most of the applied stresses would be dispersed within compacted soil, the actual zone of treatment was set at 9 m giving an overall site of treatment of 7,900 m². The compaction technique was also selected to ensure that the full depth of fill would be improved to produce an equivalent modulus of deformation of 65 mN/m², a value required by RDL to allow an economic structural design of the slipways themselves. It is of interest to note that plate loading tests on the untreated fill gave modulus values in the range 15-45 mN/m².

**Technique**

In the Dynamic Consolidation process, weak soil is consolidated by means of repeated surface tamping using weights of 8 to 20 tonnes dropped in free fall from heights of up to 26 m. The high intensity stresses developed by the tamping can therefore penetrate deeply into the ground enabling compaction to take place to depths of as much as 12 m. While the tamping operation itself may lack the apparent sophistication of most specialised foundation techniques, it is important to recognise that complex changes occur in the ground and these must be carefully controlled if the technique is to be effective. Specifically, great care must be taken in establishing the treatment pattern, tamping energies, number of passes, etc., and this must be accompanied by intensive in situ testing as the work proceeds.

A 2 m square 14 tonne tamper was used at Methil suspended from a 61RB crane and dropped from heights varying between 10 and 25 m. The 9 m wide strip of stabilised ground provided along the length of each slipway was treated on a
chequer board pattern where the number and intensity of the tamping blows was varied to achieve a sensibly uniform degree of compaction.

At the beginning of the contract, tests were carried out using various energies in order to determine the most efficient treatment pattern for the main slipways and also to establish the maximum possible standard of compaction that could be obtained. Surface settlements of up to 2 m were obtained under maximum intensity tamping.

Control

In view of the granular nature of the fill at Methil pore water pressure measurements were not necessary and site control of the consolidation work was exercised by levelling to record ground settlement and intensive pressuremeter testing. On average the level readings revealed a surface settlement of 570 mm increasing to 1 m as compaction intensity increased to the maximum value at the end of the transition zone. The pressuremeter test is not familiar to most UK engineers but is well-established in France and other continental countries.

Briefly, the pressuremeter is a load cell device capable of measuring strength and compressibility in situ at varying depths.

**Left below—Tamper at point of impact**

**Right upper—2 m square 14 tonne tamper used at Methil**

**Right lower—Crater caused by dropping tamper, this being about 1 m deep**

**Fig. 3—Diagrammatic representation of slipways at Methil.**

**Fig. 4—Typical pressuremeter results for slipways at Methil.**
in small diameter boreholes. The measuring probe consists of a cylindrical metal body with surrounding rubber membranes arranged to form 3 independent cells. The central measuring cell contains water under pressure while the upper and lower guard cells are pressurised with gas only. Deformations are measured by the central cell only where conditions of plane strain are deemed to exist due to the presence of the guard cells. A volumeter controls the injection of water and gas into the test probe and readings of volume change are obtained from a manometer.

Thus, the pressure-volume change relationship gives a direct means of measuring modulus of deformation and ultimate bearing capacity. Approximately 300 pressuremeter tests were carried out at Methil and typical results are shown in fig. 4. The limit pressure values can be regarded as a direct measure of ultimate bearing capacity and it can be seen from fig. 4 that the Factor of Safety after treatment is well in excess of 3. To obtain the equivalent Young's modulus value, the standard modulus of Deformation results should be multiplied by a factor of between 3 and 4 and in this case also the treatment meets the specification.

Calculations of slipway movement based on the field tests showed that RDL's original specification was comfortably met by the Dynamic Consolidation treatment with predicted settlements of approximately 20 mm. Considerably smaller movements are expected in the transition area.

Other applications
The fill material at Methil is essentially granular in character but Dynamic Consolidation is not restricted to free draining soils. In low permeability soils, the tamping stresses compress the voids and develop very high excess pore water pressures. It has been found that in this state of partial liquefaction the pore water pressures create a new many channelled drainage network in which in turn allows consolidation to occur much more rapidly than is the case under static loading. Therefore by carrying out tamping in a number of passes at carefully controlled energy levels it is possible to improve many fine-grained, low permeability soils as well as virtually all free draining materials.

Conclusions
This article describes the successful application of a new foundation engineering process, and on a more general level, illustrates the important advantages that can accrue from using ground improvement techniques to deal with adverse soil conditions. It is important to recognise that ground improvement or soil stabilisation represents a departure from the traditional concepts used in foundation design in that it recognises the fact that techniques such as Vibro Replacement, Vibro Flotation and Dynamic Consolidation can compact and strengthen many soils such that deep foundations on piles are neither necessary nor the most economic answer.

References

Above—Lifting the tamper with a 61-R8 crane
Left below—The basic pressuremeter test equipment: on the right of picture the measuring probe and volumeter with manometer and gas bottle. On the left equipment for bore holes not remaining open when unsupported: smaller diameter probe and slatted casing, the test being performed inside the casing and—right lower—a pressuremeter test underway