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When to use piles

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Dr Whitaker said that it was difficult to present the picture of 'When to use piles' without considering 'When not to use piles', so his talk included both these aspects.

Piles could be of many forms, ranging from a straight tree trunk driven into the ground, through steel and concrete copies of the tree trunk, to holes 6 in. to 6 ft in diameter bored in the ground and filled with concrete, or even columns of soil stirred up in the ground with cement grout and allowed to harden. Defining a pile by its function rather than by its composition or mode of installation, it was essentially an elongated or columnar body installed in the ground for the purpose of transmitting forces to the ground.

Historically piles were of great antiquity, going back to Neolithic times some 12 000 years ago. Then houses were built on piles driven into the beds of lakes in Switzerland and in the glacial lake at Pickering in Yorkshire in order to give protection from marauding animals and hostile neighbours. The first bridge constructed in Rome, in about 620 BC (defended by Horatius), was a piled structure, as was the bridge built by Julius Caesar across the Rhine in ten days. Bridge builders were great users of piles from Caesar's time onwards but piles were also used beneath fortifications, cathedrals and other heavy structures.

If solid ground was not quickly reached in the foundation or if water hampered the digging, a close pattern of piles would be driven, cross-timbers laid on them, the timbers packed around with rubble to form a platform and the masonry commenced from this level. Elm piles were used under the Tower of London, Hadleigh Castle and the Bulwark at Sandwich, beech piles at Winchester, and alder at York. The first completed lighthouse on a submarine sandbank was in Morecombe Bay at the entrance to Fleetwood Harbour; this was finished in 1840, founded on wrought iron screw piles with 3 ft dia. cast iron screw heads. The examples showed that two of the traditional uses of piles had been to carry loads to an underlying stratum through water or through a layer of weak or compressible soil which it was not possible, or maybe not economical, to remove.

In all foundation designs the engineer aimed to establish an adequate margin between working load on the foundation and the load at which he estimated it would fail, and to ensure that the foundation did not settle more than could be tolerated under the working load. Whether or not the load could be most satisfactorily carried by a piled foundation depended also on the influence of the new construction on the surroundings, and the cost. Of these requirements, the first three were dependent principally on the nature of the ground and the geometry of the chosen foundation and its temporary works. There might be alternative

solutions that would satisfy these three requirements, in which case cost became the deciding factor.

Before any foundation design could be undertaken the engineer should confer with the architect and client and decide on an acceptable settlement. Next, a knowledge of the nature of the ground at the site was needed. Even when the sequence of strata was known with assurance it would probably be advisable to put down one or more boreholes to identify the series with precision and to check depths and thicknesses. On a site where the geology was little known a complete site investigation was necessary; if possible, the way this should be done should be decided by the engineer who was to design the foundation. It might need two parts, the first exploratory, to study what kind of foundation was possible, the second a detailed study to obtain engineering data about the strata, their strengths, compressibilities etc., so that the most satisfactory foundation design could be evolved. The engineer should not start his task with the preconceived idea that piling or any other type of foundation had to be used.

Thus the ground should determine the type of foundation—shallow footings, piling or a displacement type. Piling would probably give the most satisfactory solution where there was a firm stratum underlying a soft layer and this was within a convenient distance for piling, and where beneath the pile tips the ground was strong for some great depth. Parts of the Thames estuary were examples; West Thurrock Power Station and the Southern Outfall Works were built on piles driven through soft clay–silt to end bearing in gravel.

Where the underlying strong stratum in which the piles were end-bearing was of insufficient depth and underlain by weaker material, individual piles might give excellent test results as the bulb of pressure would be completely in the strong stratum, but the bulb of pressure from a completed piled foundation would penetrate deeply into the weak stratum, leading to serious stressing with attendant consolidation. This was the situation at New Orleans Hospital, built in 1939, where the structure on a piled raft settled over 1 ft. In such cases the site investigation had to be taken a sufficient depth into, and if possible below, the underlying weaker stratum to determine the complete sequence of strata and to find their compressibilities.

When faced with conditions of this sort, economic considerations as well as engineering ones would dictate whether very long piles to penetrate to a more suitable stratum or a displacement or bouyant foundation was to be preferred. At Grangemouth on the Forth estuary, where there was a deep bed of silt filling a glacial channel, some heavy buildings were on piles, but bouyant foundations had also been used.

Where there was a deep bed of stiff clay, piles would obtain their bearing almost entirely by skin friction on the shafts. This was the condition obtaining in much of the London area and extensive use was made of bored piles. For a foundation on a few piles, or one that was narrow relative to the pile length, this was a perfectly satisfactory method. With a broad foundation the benefit obtained might not be commensurate with the extra cost, because the bulbs of pressure were substantially the same. Settlement observations on comparable structures on London Clay with and without piled foundations[1] showed that piling could reduce total settlement to a half or even a fifth of that of the unpiled structure, but gave little or no improvement on differential settlement. Since the total settlements without piling were 2–4 in. only, the client and engineer in such cases should seriously consider whether the saving in settlement was worth the cost of piling.

The construction of foundations of this kind in glacial till (boulder clay) was sometimes called for. The engineer should first find out if boulders were present. If they were large, the only kind of pile suitable might be one formed by an excavation method such as the Benoto, which permitted the boulders to be broken up. It might be more practical and economical to obtain the appropriate net foundation load by the construction of basements to give a displacement foundation.

A common example of the use of piles was in the construction of a wharf or quay along a river bank. The general pattern consisted of a front row of piles or sheet piles with a capping beam, and a platform from this beam to the top of the bank, the rear of the platform being supported on piles. The bank might be natural or formed by tipping suitable material. Deep berthing might be obtained by dredging, which would generally require the use of a retaining bulkhead of sheet piling.

There were many maritime situations where piling rather than spread foundations offered the most convenient and economical solution, such as a mooring dolphin, a deep water jetty or an oil rig. But for a permanent oil platform a surface foundation with a concrete tower had advantages. In harbour work where shelter was required as well as a place to tie up, some form of heavy construction was needed.

Raking piles were often included in a typical design. This was because the platform would be subjected to horizontal forces, from earth pressure in one direction and from impact in the other. Similarly, raking piles were often used to take the lateral earth pressure in a retaining wall foundation. These designs were the result of applying elementary mechanics as if everything were pin-jointed. Both raking and vertical piles in designs of this sort were actually subjected to lateral forces, and so not everyone liked raking piles, since vertical piles could withstand considerable lateral loads and were much more easily installed. A mooring dolphin or a jetty might be entirely on vertical piles of such a length that they functioned appropriately.

Piles might be used to resist upward forces, as, for example, those due to water pressure on the under side of the floor of a dry dock, or beneath the legs on the windward side of a pylon.

Piling in weak rock (i.e., strata such as chalk and Keuper marl) was a controversial subject. Often where there was chalk to the surface, laboratory tests on extracted specimens of the material showed low strength and large compressibility and piling was therefore installed. Engineers were currently beginning to learn that the apparent weakness of chalk was often a sampling problem and also that any disturbance, such as installing a pile, would show chalk to be weak, yet when undisturbed it behaved differently. Piling could of course be installed but it might be an unnecessary expense.

Generally the engineer hoped to keep clear of any soil that was highly sensitive, but piling through sensitive soils became necessary where heavy structures were to be built, and the steel H pile, having little displacement relative to its bearing capacity, had made this more easily achieved, as was seen from work in Norway and Sweden.

Since any disturbance of the ground, whether by excavation or by loading, caused displacement in the zone surrounding the disturbed area, it was important in urban conditions to assess this problem and choose the foundation design that would cause the least trouble to adjacent properties. Non-displacement piles carried to some deeper bearing stratum would generally minimize movement of adjacent foundations. Cases were known, however, where displacement piles had

been driven into water-bearing sand, causing liquefaction due to pore water pressure and vibration, with serious settlement of adjacent structures. If settlement movement of adjacent properties that were on footings was foreseen, those buildings might be underpinned by piles.

Ground that was amply strong enough to carry a foundation load might be troublesome due to shrinkage or swelling. The annual cyclic movement in a clay soil, and particularly progressive shrinkage where there were growing trees, was best met by founding on piles carried to a depth where movement was negligible. Swelling of clay soils was generally thought to be a problem associated with tropical conditions, but it could also occur in the UK. A mature tree growing in clay would produce an area around it in which the water content of the clay was lower than that in an open field. If the tree was felled and a light building, such as a house, that exerted a smaller foundation load than the swelling pressure of the clay, was erected within this zone, it would be lifted as the soil returned to its natural water content and swelled. The process was slow and movement had been known to go on for about 15 years. Foundations had been constructed in swelling soils by piling into the stable ground below and either forming a sleeve around the pile in the swelling zone, or making the pile long enough in the stable ground to serve as an anchor against the uplift forces caused by swelling. The pile had to be appropriately reinforced and of course the structure had to be supported clear of the ground.

In work where underpinning was required, piles offered a convenient solution in many cases. Use of micro-piles involved drilling 6 in. dia. boreholes, often through the existing structure and its foundation, inserting a grouting tube which also served as reinforcement, and filling up the bore with a strong cement grout. The more traditional sized piles had been used in underpinning for many years. Pairs of piles were installed with cross-beams supporting the existing foundation. Piles had also been jacked into place using the weight of the structure for reaction, the piles being built up in place from precast concrete units added at the top as the lower ones were jacked down. (Care was needed to ensure that the jacking force did not exceed the available reaction.) Another method was to jack down sections of steel tube, open-ended at the base, the entering soil being cleaned out with a miniature grab. The tube was finally filled with concrete when the required depth had been achieved.

In the discussion, a speaker commented that the highest structure in London, the Post Office Tower, was not supported on piles.

A contributor though that raking piles should be used to resist horizontal forces and sheet piles should be used to hold back soil or water. Differential settlement should be kept to less than 1 in 300 or, in very sensitive cases, such as a turbine in a large area, to 1 in 1200. (These figures referred to the slope of settlement across the diagonal.) One of the most important things was to take care that piles were not used unless they were going to do the right thing. Care should be exercized in choosing the right type of pile—preformed, driven cast in place or bored cast in place—and one should consider the expected life span. In the West Indies this could be as short as 15 years. The possibility of chemical action had to be taken into account and a suitable type of cement used. Vibration during driving had also to be watched and pre-augering could help there. The qualities of chalk could be very various.

A speaker expressed doubts about the use of raking piles. He preferred to use only vertical piles. The answer to whether to use piles or not was currently different from what it was 5–10 years ago. Finance had forced people to look at piles more

carefully. However, piles were attractive because they were constructed by experts and the main contractor was relieved of much responsibility. Piling contractors were well versed in ground conditions and could change the system of piling if this became necessary. With improvements in machines and techniques, the time required to construct piles had grown shorter. There were many publications to assist in the consideration of piling matters, notably the ICE's *Piling: model procedures and specifications*, but also the recent CIRIA publications, reports of ICE piling conferences, and publications by BRE and FPS. Currently the solution of foundation problems was being made more difficult because clients were cutting down on the money spent on site investigation. Too little use was made of the CRP test for ultimate bearing capacity.

A contributor remarked that dynamic consolidation or other forms of ground treatment could substantially reduce settlements and often provided an alternative to piling. The design of the structure was also a factor in the question of when to use piles.

A speaker remarked that settlement criteria were much easier ten years ago.

Another speaker expressed the opinion that one should rely on the bending capacity of piles to absorb horizontal loads.

A contributor spoke of the danger of piles losing set in some types of soil and quoted an example of a building on 60 ft long steel tube piles which had lost set; the building had settled 10 in. In deciding whether to use piles, the whole building had to be considered as large groups of piles meant that there would be consolidation settlement. A good site investigation was essential. Vibro-replacement could be a useful alternative. A five-storey structure on shallow foundations on ground treated by vibro-replacement had settled 12–15 mm, whereas 60 ft long piles in the same ground untreated had had bigger settlements.

A speaker emphasized the importance of carrying foundations below the seasonal water level in cotton soils. He also remarked on the ability of structures to adjust to settlements and quoted the case of a conveyor tunnel built on sand above rock where the ground consolidated up to 6 in. maximum. Piles were not used and the conveyor easily adjusted to cover the settlement.

Dr Whitaker mentioned oil storage tanks.

In this connection Dr Whitaker mentioned oil storage tanks. These were often constructed on a mat of rubble, and as load was applied slowly during water testing the settlement occurred slowly, thus incurring no damage.

Another use mentioned for piles was that of absorbing energy, as in fenders for marine structures.

Contributors to the discussion included Mr Palmer, Mr Haswell, Dr Fleming, Mr Buckley, Mr Lucas, Mr Price, Mr Thorburn, Mr Humphreys and Mr Manhas.

Reference

1. MORTON K. and AU E. Settlement observations on eight structures in London. *Proc. Conf. Settlement of structures.* Pentech Press, London, 1975, 183–203.