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FOUNDATIONS IN LIMESTONE AREAS OF PENINSULAR MALAYSIA

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ABSTRACT

This paper presents an update on the foundations in limestone areas of Peninsular Malaysia. The description on the geological and geotechnical information of the formation, methods of ground investigation and foundation designs especially on the use of concrete piles, bored piles and micropiles are presented and discussed.

This paper also highlights the problems associated with the construction of concrete piles, bored piles and micropiles. The importance of the construction methods and control at site are also emphasized.

GEOLOGY

Limestone formation is widespread in Peninsular Malaysia and the world. Sowers (1976) reveals that it comprises more than 10% of the earth crust by volume. In Peninsular Malaysia, the major limestone areas are Langkawi, Kedah-Perlis, Kuala Lumpur, Kinta Valley and Gua Musang. In Kuala Lumpur (capital of Malaysia), about one third of the area is on limetone formation. The limestone formation in Peninsular Malaysia is of Ordovician to Triassic age.

In Peninsular Malaysia, almost all limestone are re-crystallised and technically referred to as marble. Since their formation, the limestone has been subjected to high pressure and temperature accompanying the regional metamorphism and granite intrusion. Generally, the limestone is white, pale grey or slightly yellowish, fine to coarse re-crystallised rock. In some places, it is dark to almost black because of carbonaceous or argillaceous impurity. However, the limestone in Peninsular Malaysia is remarkably pure.

The Origin of Carbonate Karsts in Peninsular Malaysia

Karst refers to a characteristic topographic feature or landscape which can be developed by rock undergoing dissolution by downward percolating meteoric water (Jakucs 1977). Several rock types under such natural "weathering/solution" environment can develop karstic topography.

However, the most common are those developed by carbonates (calcite, $CaCO_3$ and dolomite, $[Mg,Ca]CO_3$).

In Peninsular Malaysia, under tropical humid conditions, calcite and dolomite limestones or their metamorphised equivalents develop tropical features which show spectacular tall steep-sided hills (tower karst or mogote) (Jennings 1982) and solution features such as pinnacles, sinkholes and cavities.

The treacherous and almost unpredictable karstic bedrock associated with extremely variable overburden soil properties is a typical feature of limestone (Yeap 1985), which lead to a variety of geotechnical problems and hazards. Some of these common engineering problems are discussed below:-

Pinnacles

Pinnacles are columns or cones of limestone or marbles left by dissolution of the surrounding rock. Pinnacles with soft or loose overburden immediately above them pose tremendous challenge to engineers to ensure proper seating of piles on the rock particularly, driven concrete piles.

Subsidence

Subsidence is described as several related localized or already widespread phenomena associated with the sinking of landscape. The vertical movements involved range from sudden collapse to slow settlement. Generally, subsidence can be caused by removal of subsurface fluids, drainage or oxidation of organic soil and surface collapse into natural or excavated subsurface cavities had taken place. The formation of subsidence in Kuala Lumpur and Ipoh areas are often associated with the occurrence of soft mining slime in ex-mining area upon which housing and roadwork projects. This is due to the consolidation of the underlying slime/clay upon loading and proceeding at a gradual or slow rate.

Sinkhole

This incident is a common phenomenon in the karst areas, which is covered by loose and non-cohesive sands over limestone bedrock. It is commonly known that limestone can be dissolved by acidic solution from rain or polluted groundwater. After certain period, flow or penetration of groundwater, through weak zone in limestone will develop channels and voids. These channels will act as passages for water together with the loose sand to flow into voids and cavities in the limestone. The movement of sand into existing cavities or voids will then develop empty spaces in the sand layer where arching occurred. This continuous process will reach a critical stage where the roof of the space will no longer support the weight of the overburden. This will result in the occurrence of sinkholes or cave-in. Sinkholes are hazards to both shallow and deep foundations as their formation or emergence is much more sudden and catastrophic.

Slump zone

Zones of weakness often occur immediately above the bedrock of limestone. The slump zone above limestone formation is usually identified by the very low SPT 'N' values or low cone resistance where SPT 'N' values of zero are often detected. The formation is either due to subsurface erosion as a result of overburden material slumping into cavities in the limestone or residual of weathering of ancient karst features with their resolution channels (Tan & Ch'ng 1986).

Caverns/Cavities

Cavities are voids form by dissolution of the rock in the limestone which will pose problems if the roof of cavities are not of sufficient strength to support the foundation resting on them, especially for empty or partially filled cavities.

GEOTECHNICAL INVESTIGATION

The geotechnical investigation in limestone foundation is quite similar to other formation except the scope and content are more extensive. The additional investigations should concentrate on the rock profile and its properties particularly the extent of weathering near the contact zone and karstic features especially cavities.

The geotechnical investigation in limestone would ideally be carried out in three stages. The preliminary stage normally includes conventional boreholes with geophysical survey such as seismic survey, microgravity and Transient Electromagnetic Method (TEM) unless a development site is very small where boreholes can be economically implemented to provide the required information with sufficient confidence.

In most of the highrise developments, particularly in the Klang Valley of Malaysia, basement for carparks is often required. The preliminary geotechnical investigation is generally planned along the boundary of the basement wall for the preliminary design of the basement wall.

In addition, few boreholes within the boundary are also carried out with at least one borehole for a small site to reach a depth of 100m. These boreholes should provide sufficient details for preliminary design up to a feasibility purpose for the developer to confirm the marketability of its intended scheme.

For a larger area of development, it is always more economical and useful to include geophysical survey during the preliminary stage instead of interpolating the boreholes between the unpredictable erratic limestone bedrock profiles.

A geophysical survey should be carried out to scan the ground profile to a depth of about 100m below ground level and capable of detecting rock profile, slump zones and cavities particularly cavities without infill.

Various techniques of Geophysical Survey have been used and the most promising appears to be Pulse Transient Electromagnetic Method, Radiowave Electromagnetic System and Seismic Refraction.

The main purpose of geophysical survey in the preliminary stage is to obtain an approximate bedrock profile. Geophysical methods generally are not very accurate but they can highlight on the potential areas of doubt or anomalies where direct ground investigation can be focussed on. TEM, which has recently been introduced to the industry and has shown to be a very promising economical technique because of its capacity to determine bedrock profile at great depth and detecting the presence of cavities and slump zones.

In critical areas of high concentrated load, a more accurate borehole geophysical methods are sometimes used to obtain detailed information of anomalies such as the extent of cavities. However, this technique is very expensive.

Boreholes with SPT, pressuremeter tests and collection of rock cores and undisturbed mazier soil samples along the proposed wall where possible and rock coring into cavity free zone of not less than 10m are usually required. It is also important to carry out SPT in the cavities with in-fill to rule out the possibility of limestone overhang.

Boreholes must be grouted especially at sites where deep excavation is required, to prevent risk of triggering sinkholes and blow up later as reported by Moh (1997) and GEO (1996).

Although the ground in limestone formation is generally non-aggressive to concrete and steel. Chemical tests should not be omitted for confirmation. The total sulphate content in soil is usually less than 0.01% and the pH is about 5 in soil and water in the cavities.

Detailed geotechnical investigation usually centres in the areas of high loading intensity and anomalies as indicated by the geophysical survey and preliminary boreholes.

Cavity probing before or in early phase of construction, is usually needed depending on the type of foundation selected. Cavity probing aims at the doubtful area or zone to collect additional information on the size of cavities and properties of the in-fill materials. However, micropiles installation when properly logged during drilling can significantly reduced the extent of cavity probing. This information is needed for the design review and modification to suit the soil and rock condition of the site.

Hence, input and design review from design team are very important during construction to ensure that the expected subsoil model interpreted during design stage is in reasonable agreement with the actual condition, otherwise modification to the design or additional measures are needed to ensure safety of the foundation to support the imposed loads. Inadequate site supervision by design team during construction is often dangerous and uneconomical.

FOUNDATION

Bored piles and barrets are generally used for highrise buildings. The size of bored piles ranges between 600 mm to 1500mm diameter although 2200mm have been installed in Malaysia. The maximum depth of installed bored pile is 82m for 1500mm diameter. Barrets are sometimes used in thick overburden where bored pile machines have difficulty in reaching its required depth.

The following types of foundations are normally used for low-rise buildings:-

- Footing on raft directly on limestone
- Footing with piles such as precast concrete, steel, bored and barrett as well as micropiles
- Raft with and without piles

Footings directly on limestone are usually selected for locations with shallow bedrock. Cavity probing to check the presence of cavities and their effects on the foundation must be analysed to ensure safety and stability of the foundation. Very often treatment to localised depression on bedrock by concreting or micropiles are needed.

Different types of piles including precast reinforced and prestressed concrete piles have been used in limestone formation. However, the geotechnical load carrying capacity is very much lower than the structural capacity of the pile because of the uncertainly on the bedrock profile and presence of cavities, solution channels, overhangs etc. In areas where the overburden soils are soft or loose, Oslo point rock shoe is required to prevent pile deflection during installation on contact with inclined rock surface as shown in Fig 1a. The hardness of the harden steel used for Oslo point rock shoe as shown in Fig. 1b should be larger than 300 (Brinell Hardness) and the yield strength of rock shoe should not be less than 760 MPa. The main purpose of the shoe is to reduce the bending stress generated during driving when the pile toe is in contact with inclined rock surface. The rock shoe shall be designed to take the full required load at the contact and extra care should be taken in the construction to prevent altering its property, in particular, by welding.

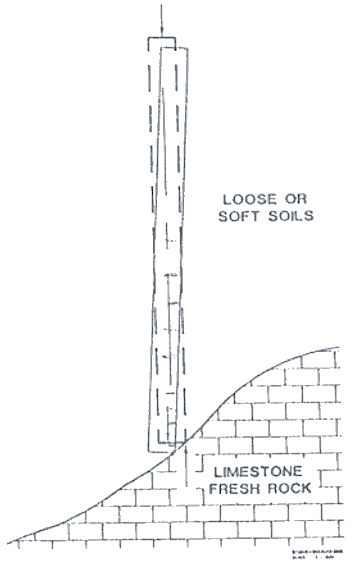

FIG. 1a PILE LIKELY TO DEFFECT/TILT WHEN REFUSAL IS REACHED

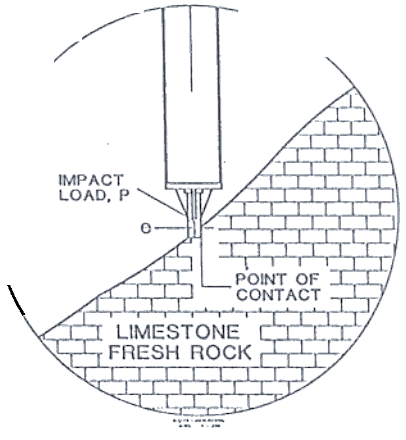

FIG. 1b ROCK SHOE (OSLO POINT) FOR CONCRETE PILE

Precast concrete piles have significant wastage due to the erratic nature of the limestone bedrock. Steel H piles or pipes piles were also commonly used especially during the seventies and early eighties. The popularity reduces because of the increase in the price of steel despite its advantage of reducing its wastage as compared to precast concrete where the steel H or pipe piles can readily be cut and welded for extension.

Precast concrete and steel piles are generally used for low to medium highrise buildings. However, sufficient redundancy and probing of the roof of limestone cavities are required to ensure safety.

Rafts with and without piles have also been used. The choice is often decided when the footings or pile caps become large and are closed to each other. This is common for high-rise building with basement.

Micropiles are generally not economical except when the bedrock profile is shallow and footings are not comparable in terms of time and cost. This is because the capacity of the micropiles is derived mainly from the high strength of the pipes. American Petroleum Institute (API) pipes have been used in micropiles to carry an allowable load of up to 280 tonnes for size of 350mm in diameter. The choice of foundation is often done by process of elimination after considering the ground condition and properties, type of structures, environment, cost and time.

The environmental considerations are usually focussed on noise, vibration and sensitivity of neighbouring structures, in addition to the ground condition and its properties.

Driven piles in most cities are disallowed except in some areas of low occupancy where only hydraulic hammer installation is permitted.

DESIGN

The allowable bearing pressure on limestone imposed by the footing at shallow depth is based on the strength of the rock and its discontinuity. The design curves of BS 8004, which limit the maximum allowable bearing pressure of up to 10 MN/m^2 can be used. Alternatively, a simple approach recommended by Canadian Geotechnical Society (1992) could also be used. The strength of the limestone is generally ranges between 30MPa to 100MPa and mostly between 40MPa and 60MPa. Settlement check is also required especially between two column loads of large difference.

The influence of the roof thickness of cavities and their dimensions on the footing should be investigated and analysed to prevent induced collapse of the roof. The allowable geotechnical capacity of driven piles is limited usually by the allowable capacity of the Oslo rock shoe which is slightly socketed into the limestone. For precast concrete piles, they normally should not exceed 75% of the allowable structural capacity.

The skin friction along the pile shaft could be considered to reduce the end bearing pressure on piles. Smaller pile should be preferred as it allows higher redundancy. In areas where doubt of potential collapse of roofs of cavities, further redundancy is needed by having deep ground beams to distribute the loads when one failed, otherwise the cavities should be treated.

The bored piles, barrets and micropiles are designed mainly based on friction in soils and rock socket. The base resistance should be ignored for the following reasons:-

The base is practically very difficult or impossible to clean or remove because of the erratic nature of the limestone bedrock and often loose sand overburden as illustrated in Fig. 2

To reduce base pressure on potential undetected thin roof of cavities

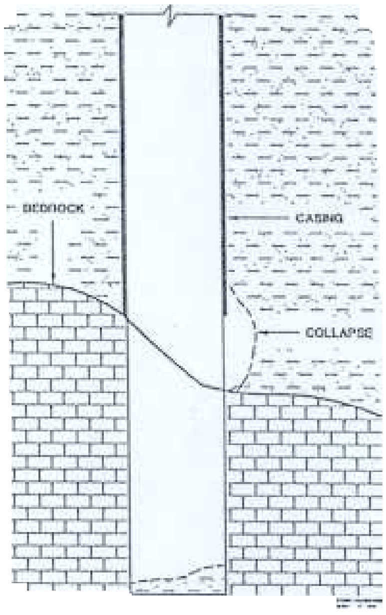

FIG. 2 ILLUSTRATION OF FULL LENGTH CASING ON LIMESTONE FORMATION CANNOT PROVIDE FULL PROTECTION FROM THE COLLAPSING SOIL

The easier way to design the above piles is based on the commonly used SPT (Standard Penetration Test) 'N'-value and the detailed classification of the soil. The friction resistance between the concrete and the soil varies from 1.5N (kN/m^2) to 2.5N depending on the SPT N-values and types of materials. For N-values exceeding 100, a further reduction on skin friction should be imposed.

The shaft friction between pile and limestone is generally based on the rock quality in terms of unconfined compression strength (q_u), Rock Quality Description (RQD) and method of forming the socket. Coring would give a high friction. The allowance friction resistance should be limited to 2.5% of the unconfined compressible strength. The lower of the unconfined compressive strength of rock or concrete should be used unless confirmed by instrumented pile tests. The value is reasonable when compared with some commonly used allowable adhesion of about 0.05 q_u for other sound rocks.

The socket friction is significantly higher when coring is used instead of chiselling technique. Neoh (1997) has reported an ultimate socket friction of more than 3.8 MPa for micropiles using air flushed down-the-hole percussion hammer in limestone having RQD of more than 90% and the ultimate socket friction of 1.5MPa in limestone having RQD of 0-4%.

The presence of cavities and their influence on the performance of the foundation particularly, in relation to potential collapse of cavities, must be analysed. An example is shown in the Fig. 3.

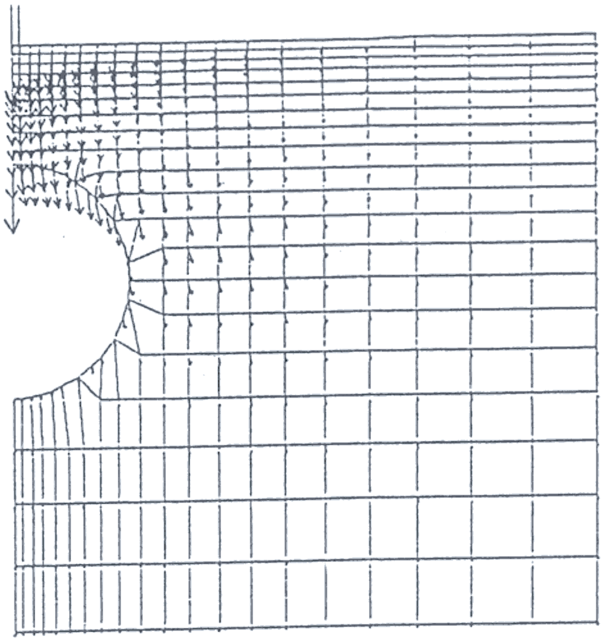

FIG. 3a DEFORMATION OF ROCK MASSES UNDER LOADING (CAVITY)

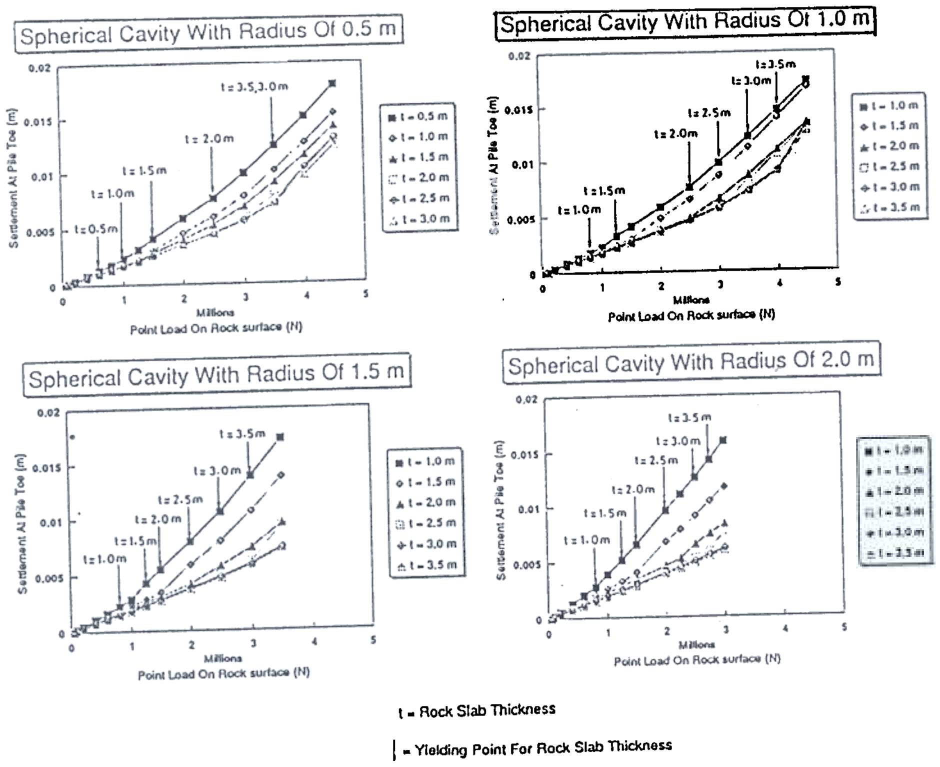

FIG. 3b LOAD-SETTLEMENT RELATIONSHIP (LOADING ON A SPHERICAL CAVITY)

The high risk of collapse to the roof of cavities for highrise must be reduced by compaction grouting or piles penetrating to the next level of cavities-free limestone.

The group effect due to long and short piles must also be analysed to ensure that individual piles are not unduly overstressed. Overstressing of an individual pile can normally be allowed up to about 25% of the normal allowable structural load. However, as a group, the normal factor of safety of not less than two should not be compromised.

CONSTRUCTION

Understanding of the design is important to ensure successful installation of piles for their intended purposes. Adequate site supervision from consultant and input from the design team throughout the construction are essential particularly for the limestone formation. A supervision plan should be drawn up by the design team to guide the supervision team for the pile installation and construction control. The purpose of the plan is to highlight the critical components of the pile installation and construction control together with its checklist.

A qualified and experienced team should be assembled for competent supervision. Assess the construction methods with the actual ground conditions and possible variation within the site. It is also necessary to verify that the design assumptions are compatible with those used in the designs.

The piling platform has advantage to be levelled and overlaid with a layer of lean concrete especially on the cohesive materials to have a good working platform for the movement of plant and machinery over a site especially during monsoon seasons. The lean concrete platform has the benefit of ensuring minimum down time after each rain and enhances pile installation to achieve the normal pile verticality especially during monsoon seasons.

Installation of Driven Piles

The damage of concrete pile during installation is very common especially when the overburden consists of loose or soft soils as illustrated in Fig 1a. Continuing piling of a tilted pile would break the pile. Damaged concrete piles as high as 25% to 40% have been reported by Omar (1985), Neoh (1997) and Ting & Ladchumanan (1974). Sehested and Wong (1985) reported the use of rock shoe (Oslo Point) reduces the damage of H-piles significantly.

A recent project undertaken by the author has indicated the percentage of damaged piles has been controlled to 1.5% from the initial 15%. The case involves some 5000 piles points of reinforced concrete piles of 250m x 250m and 300m x 300m with a length variation from 17m to 76m and the average of 30m.

Damage of piles during installation could easily pass undetected and resulted in failures of superstructures due to excessive settlement of the columns supported by piles that had achieved set or refusal and subsequently deflected. Detection becomes difficult as it is a common perception to accept piles of great variation in length, some even varies by tens of metres between two adjacent piles. Hence full-time competent site supervision is a must to detect the common signs of pile damage such as deviation, tilting, rotation and set of refusal follows by further penetration.

The damage is usually more significant when diesel hammer is used. This is because the energy of subsequent impact is greater upon the preceeding blow near or at refusal. Diesel hammer should be avoided unless the overburden consists of a reasonable thick layer of medium dense sand or stiff soils above the bedrock to buffer the high impact of the hammer.

The use of large strain dynamic pile test to calibrate the permissible drop height to prevent damage is most useful in ensuring the success of pile installation for driven piles and also to serve as a useful tool for quality control during the pile installation and detection of damage piles. In certain cases, the drop height has to be reduced to 100mm and tapping in for proper seating to prevent damage of concrete pile with an Oslo point. The short term maximum compressive and tensile stresses should be limited to 0.8 f_{cu} and 0.1 f_{cu} respectively. The above case with only 1.5% of damaged piles was achievable with competent site supervision input from the design team. The percentage of large strain dynamic pile test was reduced from the initial 10% of the piles to 5% subsequently.

Installation Of Bored Piles, Barrets And Micropiles

Although the design of bored piles, barrets and micropiles generally ignores the base resistance, adequate full-time and proper site supervision is still much needed to ensure the design socket length is achieved. Otherwise the socket length may be significantly reduced by accumulation of the soils at the base of the pile from the in-filled cavity or collapsible soil above the toe eventhough temporary casing as shown in Fig. 2 is used.

The figure also shows that casing is unable to totally protect the collapsible soils from entering the bored hole due to the uneven bedrock unless the material at and around the casing is jet grouted. This is of course seldom done, simply because the casing would have to be left in place. The loss of stabilizing fluid during drilling and grouting/concreting is common in limestone with fissures, channels or cavities. In this situation, pre-grouting in stages has shown to be effective.

Overbreak for micropiles is difficult to estimate especially in fractured limestone or limestone with fissures because the significant loss of grout through fissures. The overbreak for bored piles usually varies 10% to 40%.

CONCLUSIONS

Foundations in limestone need extra knowledge and special skill in the investigation, analysis, design and installation. Geotechnical investigation is usually carried out in three stages, namely preliminary, detailed and during construction.

In addition to the conventional boreholes, geophysical method for profiling and detecting problematic areas such as slump zones, cavities and channels are particularly useful for a big site. Boreholes should extend beyond the stress influence zone. In most cases, the boreholes should extend at least 10m beyond the cavity free zone. For highrise structures, some boreholes should extend to a depth of 100m and significantly beyond the influence for block failures.

The analysis of foundation particularly highrise structure should go beyond the analysis and design of single or group piles effect. The influence of cavities and potential of collapsed roof of cavities should be analysed. Cavities that would affect the performance of the foundation should be treated by compaction grouting or structural bridging.

In addition to the required skill and knowledge of the construction team, plant and equipment, full-time site supervision by the experience and competent staff and input from design team is imperative for the construction to reduce wastage and damage. Hence, delay during construction could be eliminated, particularly driven piles in limestone formation to identify damage due to 'kicking' of piles when they strike the inclined bedrock with loose or soft overburden.

Special care should also be taken for bored piles, barrets and micropiles to prevent excessive accumulation of collapsible soil forming soft toe at the base of pile and reduces its socket length.

In addition to the normal confirmation tests for piles, bored piles and barrets should have provision and pre-installed tubes to confirm the required socket length by coring later.

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