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Barrettes : A versatile foundation for transmission line towers

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BARRETTES; A VERSATILE FOUNDATION FOR TRANSMISSION LINE TOWERS

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ABSTRACT

An efficient design of foundations for transmission line towers has always been a challenge for the engineers due to the variety and cyclic nature of the loads. Foundations, especially for the four-legged towers, are subjected to all types of loads (compression, tension, torsion and shear) in different combinations. The cyclic nature of the loads further complicates the situation. Available design parameters proposed by different researchers are also mostly based on the monotonic loading conditions and are not directly applicable for tower foundations. This paper presents the analysis, design and construction practice of the barrettes used for the transmission line towers in Thailand. Adaptability of the barrettes under different site constraints like sensitive underground pipelines is also described.

INTRODUCTION

The 230kV-transmission line project presented in this paper involved construction of 40 transmission towers, 400m apart. The project site was located about 200km, east of Bangkok, Thailand. The transmission line was planned to convey electricity from the power plant to a sub-station. The alignment of 15.6km-long transmission line partially runs along the boundary of an Industrial Estate and thus the foundations of these towers are in close vicinity of existing underground gas pipelines and utilities above ground (Fig.1). Foundation layouts, construction method and the work area were thus restricted by presence of these utilities.

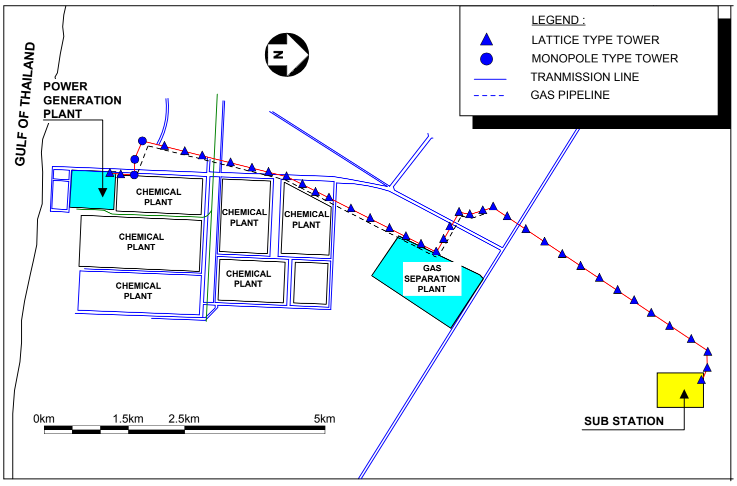

Figure 1. Layout of project site

Initially, the structural designer proposed large diameter bored piles of 2.0m in diameter for tower foundations. Construction of such large bored piles would require heavy equipment and plant, and would induce unacceptable vibration level to the existing underground gas pipe lines located within and along the construction area. As an alternative construction method and foundation type to suit the site conditions, barrette construction that utilizes relatively less equipment and induces less vibration than conventional bored pile construction was adopted.

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Construction of barrettes in a site with limited headroom and constraints and performance of barettes in Bangkok soil has been reported by Thasnanipan et. al. (1998) and (1999). The past experience indicated the feasibility of this project.

SOIL CONDITIONS

Initially, only a few boreholes were made to investigate subsoil conditions. However as the great distance between towers meant that substantial variations in soil conditions could occur. An extensive soil investigation was later carried out at all tower locations by drilling to verify subsoil condition to optimize barrette design and for excavation feasibility. The general subsoil profile revealed fine to coarse sand at the top, overlaying silty clay (lateritic soil) with varying thickness. The lateritic soil was not present at some locations. Below the sand and lateritic soil was completely decomposed granite at varying depths. Figure 2 shows cross sections of subsoil at tower locations along the transmission line. The groundwater level found also varied from about 0.6m to 9.2m below ground surface.

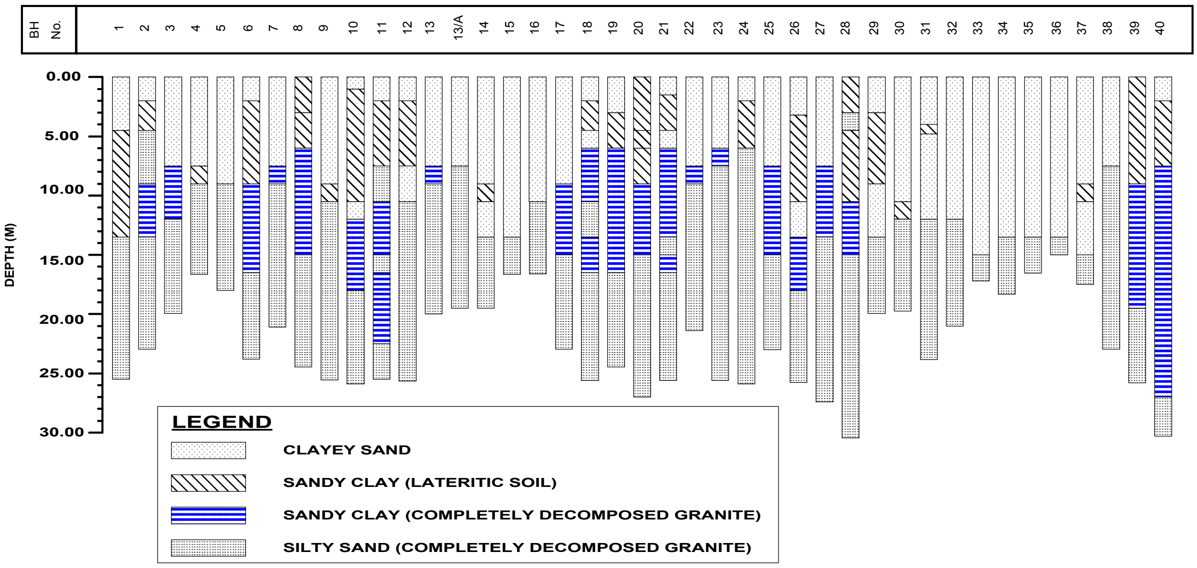

Figure 2. Soil profile along the transmission line

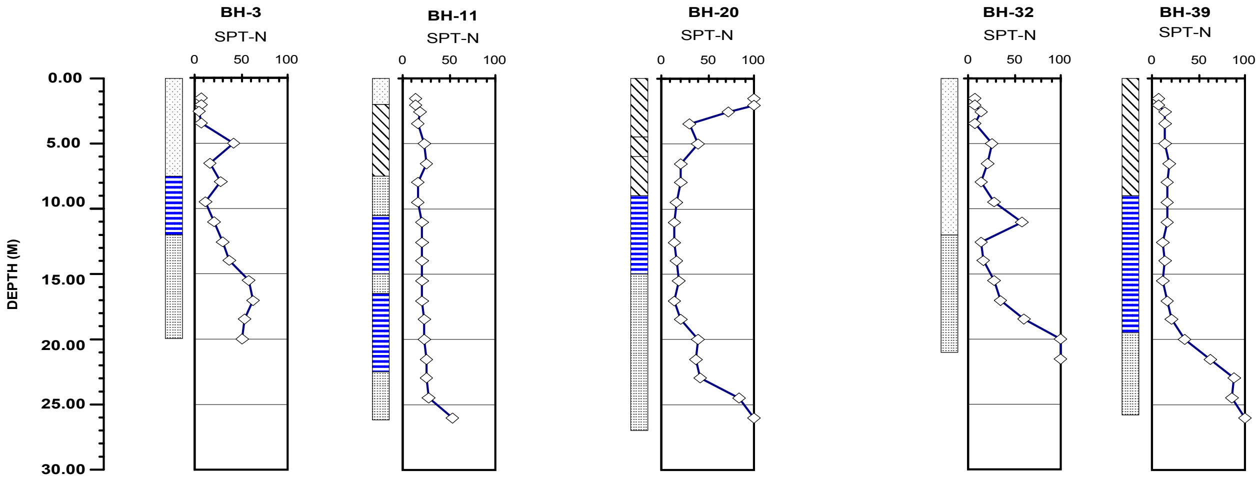

Figure 3. SPT test results at some tower locations.

SPT N values of soil layers from different boreholes indicated that the depth of competent layer varied significantly (Fig. 3). This meant that penetration depth of barrettes would vary with soil conditions and barrettes need to be designed individually.

BARRETTE DESIGN

The design of barrettes mainly involved (1) layout arrangement and (2) structural and geotechnical capacity of barrettes in connection with load, site and soil conditions and construction practicality. Regarding the layout, a four-barrette group (Fig. 5) was selected to support 38 lattice towers (up to 61.4m high) individually where a large area was available. Otherwise, a cruciform barrette (Fig. 6) was used for monopole towers (51.4m high). Compression, uplift and lateral forces were considered the significant loads to barrettes and they depended on the position of the tower in the line, the natural forces (wind) exerted on towers and cables and the weight of tower and cables. The towers were generally classified according to their positions on the line; end towers, edge towers and towers on a straight line between two other towers. The end towers were longitudinally loaded from one side by the cables and the overturning moment on such towers was large. The edge towers were loaded both vertically and transversally while the towers on straight line mainly carried a vertical load. A summary of estimated loads on the individual barrettes of the towers is presented in Table 1. To achieve load carrying and uplift capacity based on the imposed load and soil conditions, barrette sizes of 1.0x2.7m and 0.8x2.7m with depths from 11.0m to 22.0m were selected.

Table 1. Summary of Loads on individual barrettes

Tower Classification	Compression (kN)	Uplift (kN)	Horizontal (kN)
End Tower	3792	3078	1087
Edge Tower	3479-3792	2804-3078	898-1087
Tower on straight line	1370-2039	1032-1565	309-505

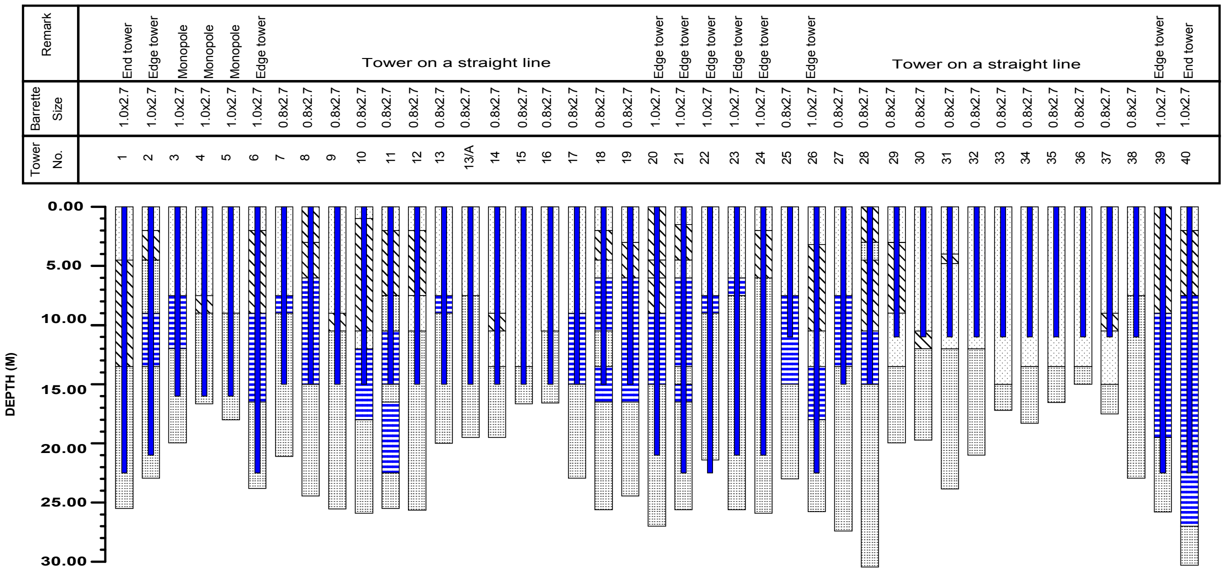

Figure 4. Dimensions and type of barrettes for the towers

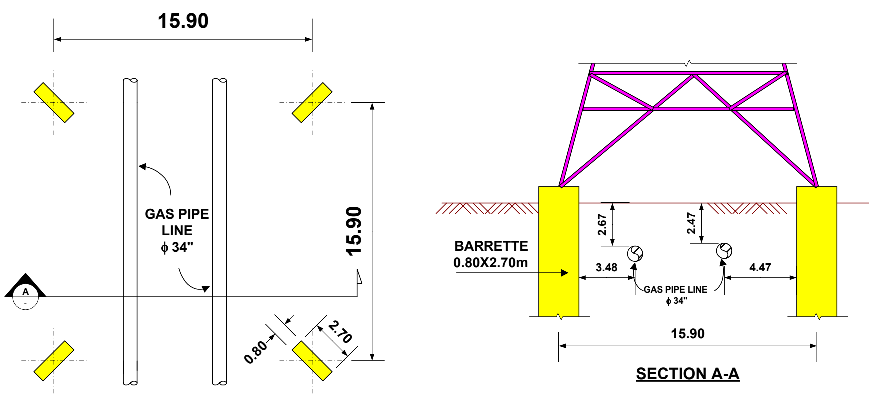

Figure 5. Typical barrette layout for a transmission tower (Lattice Type)

Generally, a safety factor higher than 2.3 and 1.2 was adopted for compression and uplift load capacity respectively. For uplift capacity, reduced friction capacity (up to 50%) in the cohesionless soil above fixity level was used in calculation since barrettes were subjected to horizontal cyclic loading. Alexander J. Verstraeten. (1987) has described decrease of friction by dynamic loading patterns in details. Finite element method (FEM) was used for calculating bending stesses in the barrettes and prediction of lateral movements. A total of 6 pile types was classified according to imposed loads, pile dimensions and soil conditions, and then analysed by FEM. Reinforcement of barrettes was designed using strength design method. A concrete cover 75mm was used for all barrette types.

The lattice towers were anchored in the barrettes by stubs and cleats which were cast into the extended barrette section after trimming the barrette top. For monopole towers, anchor bolts and steel flanges were used.

Three monopole towers were used where the lattice type tower could not be allocated. Due to the presence of underground gas pile lines and the narrow area available, it was difficult to allocate barrette groups with adequate alignment to resist the maximum bending moment and horizontal force up to 25,840kN-m and 635kN respectively. Cruciform barrettes were then designed to resist such high bending moments and forces acting on the base of the monopole.

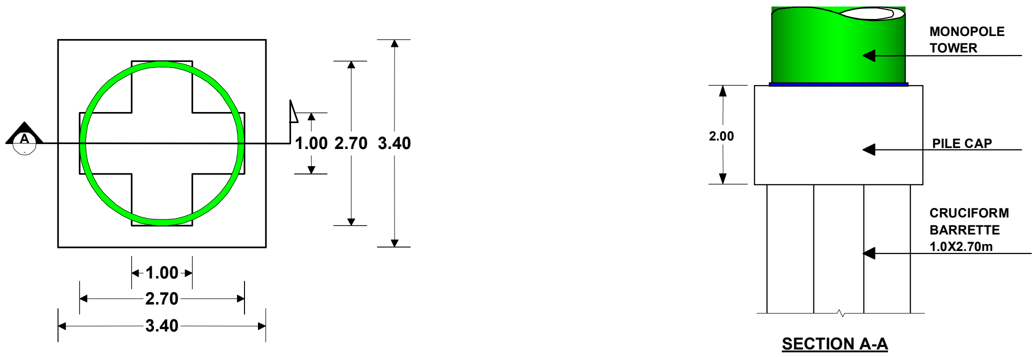

Figure 6. Cruciform barrette for a monopole type tower

BARRETTE CONSTRUCTION

A mechanical rope grab was used to excavate the trench under bentonite slurry. The same crane was used for excavation and lifting reinforcement cages as well as construction plant and facilities. A guide wall with inside clear dimensions slightly more than the nominal size of the barrette was used to guide the grab. Circulation of slurry was continuously done to keep the bentonite slurry agitated, to minimize the building up of filter cake on trench wall surfaces. Properties of bentonite slurry were maintained within the specified ranges in wide use. Construction sequences are shown schematically in Figure 7.

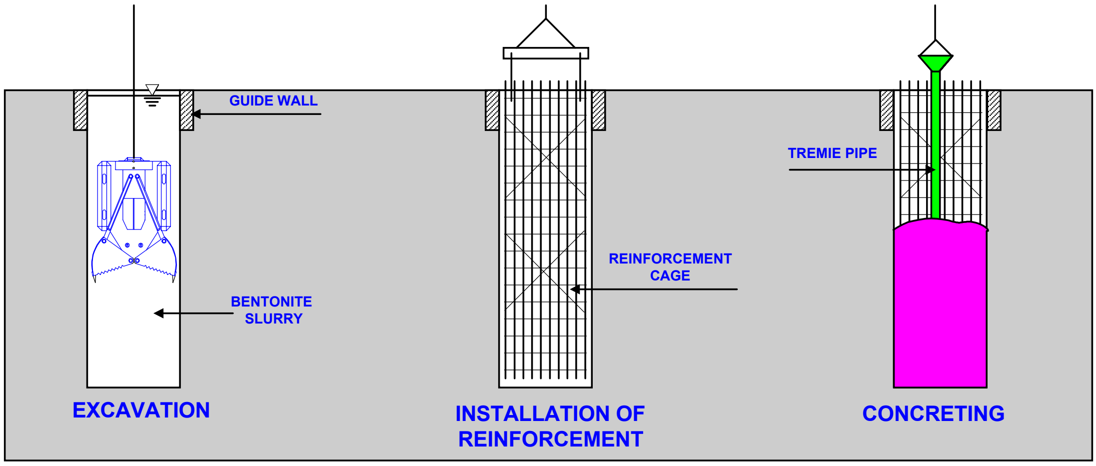

Figure 7. Barrette construction sequences (schematic)

Figure 8. Guide wall for a cruciform barrette

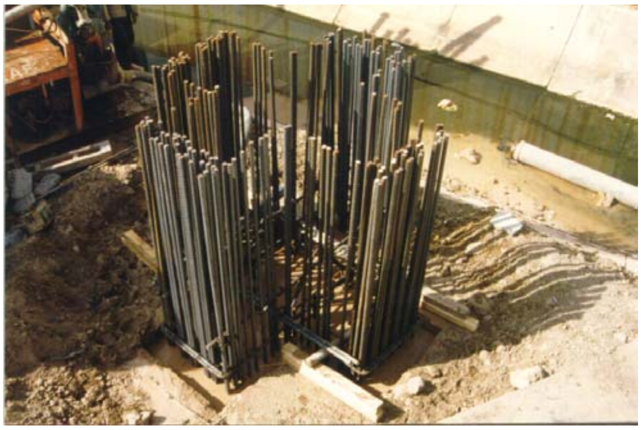

Figure 9. Reinforcement being installed in the trench

Sediment or loose materials at the bottom of the trench were removed and any built-up filter cakes were scraped off by the grab before reinforcement cage installation. Entire barrette length was fully reinforced and up to 24m-long reinforcement cages were fabricated in one complete section, for installation into the trench. The reinforcement cage of the cruciform barrette was as the same shape as the barrette. For the purpose of lifting and handling the cage, temporary stiffeners, lacing and tie bars were necessary. These temporary bars were removed section by section while the cage was lowered into the trench.

After excavation, the trench profile was checked with Koden drilling monitoring equipment. Tremie concreting method was used for casting the barrettes. Since the cutoff level of barrettes was generally at ground level, ready-mixed concrete was poured until all slurry and slime in the trench was completely displaced and fresh concrete could be seen.

Up to 172kg/m^3 and 381kg/m^3 of SD40 steel bars with maximum steel percentage at barrette top section (about 12.0m) were used to reinforce the group and cruciform barrettes respectively. Ready-mixed concrete with cube strength of 38MPa at 28days was used for casting barrettes.

CONSTRUCTION PROBLEM AND CORRECTION

A trench collapse was reported during desanding operation after trenching was completed for a barrette of lattice tower. A sudden fall of bentonite slurry level by a few meters in the trench was observed and then the trench was found filled with soil up to 10m depth. Mode of failure of the trench was found to be in the form of a localized cavity failure in the loose sand present at 2.0m to 6.0m depth. Failure surface did not extend up to the ground surface and the guide wall was still intact without any distortion or damage. The most probable cause of the trench collapse was due to heavy rainfall during construction. Surface water was seen in the vicinity of the construction area. The rain had raised the groundwater level to near the ground surface and caused a groundwater flow reversal towards the trench, triggering cavity formation in the loose sand stratum. The cavity progressively increased in size, leading to the collapse of the trench during the desanding operation. The collapse trench was backfilled with cement-bentonite mix, and wooden piles were driven into the collapse area outside of the barrette outline. The guide wall was then raised up to 1.5m above ground level. The trench was re-excavated under the slurry head 1.5m above the expected groundwater level and the barrette was completed.

QUALITY CONTROLS

All trenches were checked for verticality and dimensions prior to reinforcement cage installation to avoid any obstruction associated with trench inclination. In particular, all sides of the cruciform trench were checked. If necessary, verticality of trench was improved by careful chiselling with the grab. Profiles of the trench for a cruciform barrette is shown in Figure 10.

As the subsoil conditions varied from one location to another, they were observed during trenching process and verified with the soil conditions assumed in design, especially in the lower section of the barrette. Slurry quality was regularly tested and maintained within the specified ranges. Since barrettes were highly reinforced, in order to achieve a good flow of concrete, the concrete mix was checked for appropriateness of slump and cohesiveness prior to casting.

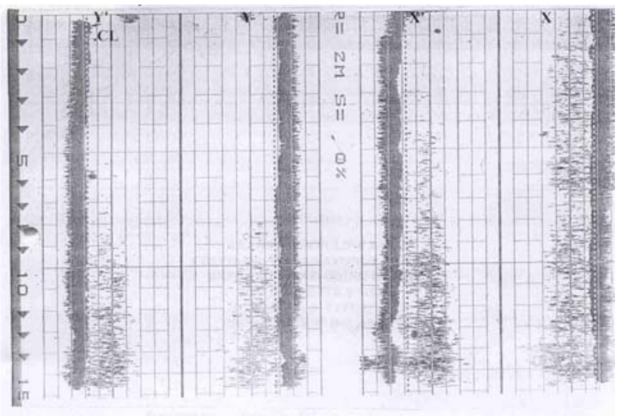

Figure 10. Trench profile of a cruciform barrette recorded with Koden equipment - Tower no. 5

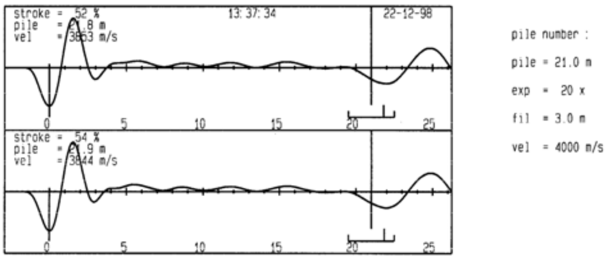

Figure 11. Test signal showing sound integrity and toe reflection of a barrette - Tower no. 2

Sonic integrity/seismic test was carried out on all barrettes about 5 days after casting for checking barrette integrity. The test indicated that integrity of all barrettes were sound. Figure 11 shows a signal acquired by sonic integrity test on the cruciform barrette.

DISCUSSION AND CONCLUSION

For barrette piling in loose cohesionless soil, chances of rapid groundwater level rise due to the rain, tide, etc., need to be considered during trenching. If necessary, guide wall with appropriate height above the possible highest groundwater level must be used.

Barrettes are versatile and can be used efficiently in the areas where conventional bored piling cannot be done. Moreover, barrette construction uses less quantity of equipment than bored piling and thus it is suitable for the piling work requiring shifting from one location to another.

Verticality of trench is critical for barrettes with complex cross-sectional shape, such as cruciform, T and H for reinforcement cage installation. A thick concrete cover up to 100mm is thus recommended, in particular for cruciform barrettes for ease of reinforcement cage installation and to maintain the adequate concrete cover, considering trench verticality against high stiffness of rebar cage.

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