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**Diaphragm wall and barrette construction for Thiam Ruam Mit
Station Box, MRT Chaloem Ratchamongkhon Line, Bangkok**

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DIAPHRAGM WALL AND BARRETTE CONSTRUCTION FOR THIAM RUAM MIT STATION BOX, MRT CHALOEM RATCHAMONGKHON LINE, BANGKOK

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ABSTRACT

Construction experience of cast-in-situ diaphragm walls and foundation barrettes for the Thiam Ruam Mit Station, Chaloe Ratchamongkhon line of Metropolitan Rapid Transit Authority (MRTA) is briefly reported in this paper. The construction activities in the midst of heavily congested traffic and in the vicinity of underground utilities to meet the specified quality and safety controls are also presented.

INTRODUCTION

The Chaloe Ratchamongkhon line is the first underground mass rapid transit project in Bangkok, Thailand being constructed under the supervision of Metropolitan Rapid Transit Authority (MRTA). The project involves the construction of about 22km-long, twin bored, single track tunnels, 18 station boxes and cut-and-cover tunnels. The project was divided into two separate contracts, South and North. The south contract was awarded to BCKT Joint Venture consisting of Bilfinger + Berger Bauaktiengesellschaft, Ch. Karnchang Public Co., Ltd., Kumagi Gumi Co., Ltd. and Tokyu Construction Co., Ltd. The north contract was awarded to ION Joint Venture, comprising Italian Development Public Co., Ltd., Obayashi Corporation and Nishimatsu Construction Co., Ltd. This paper presents experience on construction of diaphragm walls and foundation barrettes for Thiam Ruam Mit Station (station no. 12) of the North contract where heavy traffic conditions prevail.

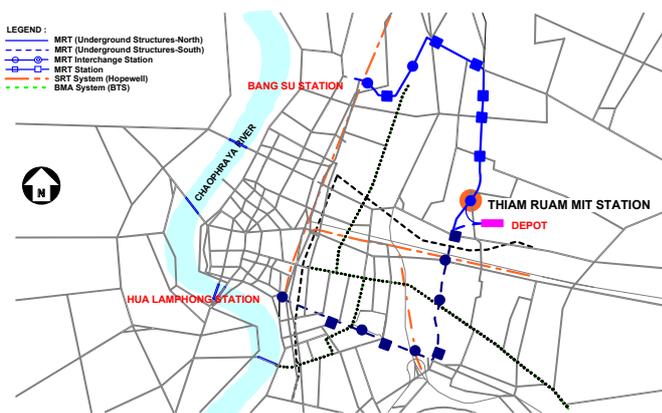


Figure 1. Layout of MRT Chaloe Ratchamongkhon line

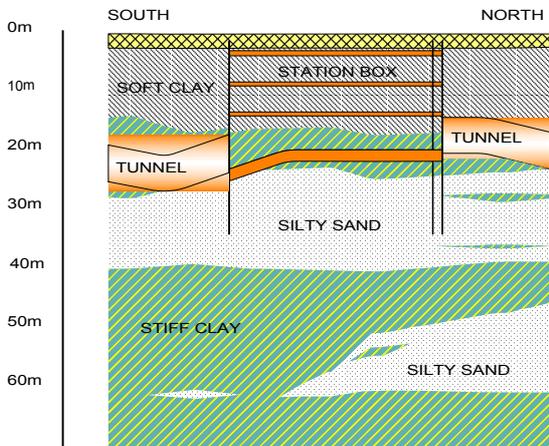
The station is one of the biggest stations and located on the Ratchadaphisek Road. The station box is enclosed by principally 1.0m thick side walls and 1.20m thick end walls 32.0-42.0m deep. A Tunnel Boring Machine (TBM) launching shaft was included in the north side of the station. To facilitate top-down construction, 63 Barrettes (1.2mx3.0m) embedded 44.5-55.0m deep in conjunction with pre-placed stanchions at the top were used.

Three basement levels were planned for the station. The excavation depth inside the station box was up to 24.5m for tunneling and basement slab construction. As deep excavation required stringent tolerances for the diaphragm walls and barrettes, a high level of quality control was necessary.

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Construction of diaphragm walls and barrettes of the Thiam Ruam Mit station was carried out by an experienced local foundation contractor in which the authors worked while international contractors undertook similar work for the remaining 17 stations.

SUBSOIL CONDITIONS



The subsoil profile, as shown in Fig. 2 consists of made-ground up to 2.5m thick for pavement underlain by a series of clay and sand layers. Below the made-ground is 12.0m to 14.8m-thick Bangkok Soft Clay. The first stiff clay layer occurs below 14.0m depth and extends to 21.0m, overlying the first sand layer. The sand layer is about 20.0m thick at this location and has two thin (about 2-4m thick) very stiff clay layers at the top. Below the sand layer is stiff to hard clay layer which extends beyond 60.0m in depth. Within the clay layer, from 48.0m depth, a 14m thick sand layer occurs in the north and lenses out to the south. The properties of soil layers are summarized in Table 1.

Figure 2. Profile of soil layers and station box.

Table 1. Summary of soil properties

Soil Type	Depth to Top of Layer (m)	w %	γ_s kN/m ³	C_u kPa	SPT- N Blow/ft
Made-Ground	0.0	40	17.0-19.0	30-45	5-9
Bangkok Soft Clay	0.2-2.6	64-100	14.6-16.8	15-31	-
Stiff Clay	14.2-17.3	16-51	18.3-21.8	107-250	13-17
Sand	24-28.6	-	20.8-21.1	-	27-59
Stiff to Hard Clay	40.8	16-20	21.0-21.1	61-410	11-61

The depth of ground water table at the site generally varies from 0.9m to 2.2m. Piezometers installed in the project area indicate the pore pressure is hydrostatic below 23m depth due to pumping of ground water.

SITE CONDITION AND PREPARATION

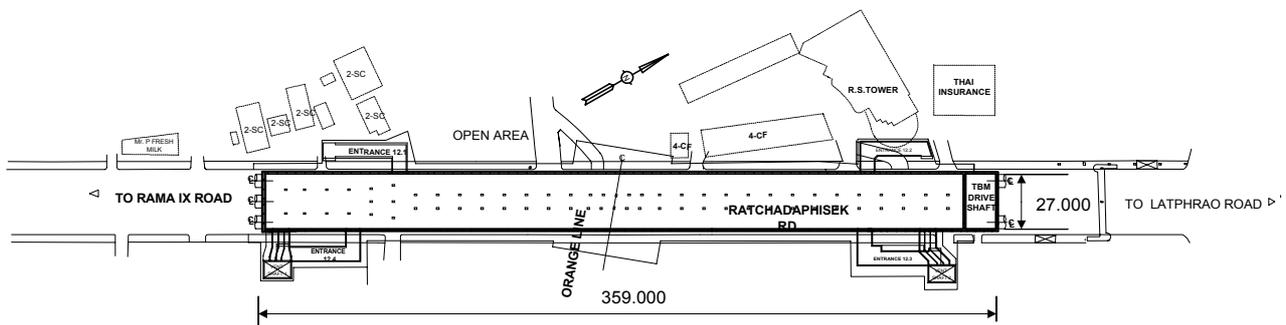


Figure 3. Layout of station box

Traffic Management

The construction site was on a 35.0m-wide main road with 4 inbound and 4 outbound traffic lanes. During the construction period a maximum of only two traffic lanes could be occupied at a time, allowing 3 or 4 lanes for each traffic direction. The width of the working area available was about 11.0m. Sometimes, the

width of the work area needed to be widened locally to position the grab crane for diaphragm wall panel excavation.

Utility Diversion

The site is bounded by some underground utilities, including a 1.0m diameter water pipe and telecommunication cables in the close vicinity of the work area, particularly on the east side. Above ground, 69kV electricity lines, telephone cables, drainage and sewage pipes (1.5m dia.) lay on both sides. The water pipe ran along the planned diaphragm wall at about 3.0m depth and thus it was diverted by the other subcontractor to the west, outside the station box prior to construction. The face-to-face clearance distance between the diverted water pipe and the outer face of the station wall was only 35cm due to space constraints. A reinforced concrete wall to protect the pipe was constructed and it formed the bottom part of the guide wall for diaphragm wall panel excavation.

Two duct banks of the telecommunication cables were located 5-10cm away from the wall face at a depth of 3.04m. 15mm thick steel plates were used in these locations as both guide walls and protection systems for the duct banks.

CONSTRUCTION SPECIFICATION

Generally construction specifications were in line with the commonly practised specification for foundation works. Regarding construction tolerances, verticality of the walls and barrettes is specified within 1:200 while for pre-founded steel stanchions, the verticality allowed is within 1:400.

Table 2. Test and compliance values for bentonite slurry

Property	Test	Freshly Mixed	Prior to Placing Rebar & Concrete
	Specification API RP13B-1 Section		
Density	3	< 1.05g/ml	< 1.10g/ml
Viscosity	4	29-50	29-50
Fluid loss	5	< 30ml	< 30ml
Sand content	7	< 1%	< 2%
pH	9	8-12	8-12

Properties of supporting fluid for wall and barrette excavation were maintained within the ranges as shown in Table 2. In addition, design assumptions required that total construction time below the soft clay layer was limited to minimize the effects of bentonite on shaft friction and in order to achieve optimum shaft friction capacity of foundation elements.

CONSTRUCTION PHASES

Throughout the project, the main construction schedule for the station comprised several interfacing and parallel work activities such as for utilities and traffic diversions, temporary decking, substructure work for station box and the TBM driving shaft which other subcontractors undertook. This meant that guide wall construction in particular needed to follow utility diversion as the same area was to be excavated for relocation of the utilities, removal of abandoned water pipes and construction of guide walls. The temporary decking and excavation for the TBM launching shaft followed the diaphragm wall construction.

DIAPHRAGM WALL AND BARRETTE CONSTRUCTION

Equipment and Plant

Mechanical rope-suspended grabs with crawler cranes (80tons) and service cranes (50-80tons) were used as main construction equipment. Grabs, 1.0mx2.0-3.0m and 1.2mx3.0m were used to cut the required dimensions of panel excavations. Bentonite slurry was used as supporting fluid for panel and barrette excavation. Silos having a total of 300 cu.m storage capacity and de-sanding and de-silting units (80cu.m/hr capacity) were used to supply the slurry required for up to two-panel excavation at a time.



Figure 4. General view of the site

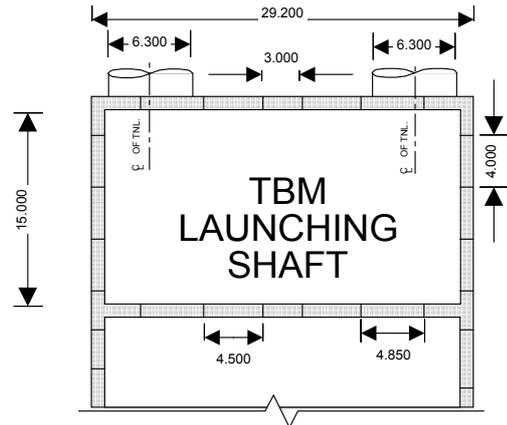


Figure 5. Panel layout of TBM launching shaft

Guide Walls

Generally 1.5m deep guide walls were used for panel excavation. In the location of underground water pipes and duct banks, up to 3.0m-deep guide walls were used. Individual panels were sized with the following considerations: (1) type of reinforcement, (2) size of grabs used, (3) thickness and depth of panels, (4) location of slab and wall openings for entrances and TBM, (5) stability of trench in connection with location of underground utility and (6) location of public accesses and streets.

Panel Layout

The walls were divided into 184 panels with horizontal lengths varying from 2.5m to 4.85m. L-shaped and T-shaped panels were used to form box structures of the station and TBM launching shaft (see Fig. 5).

Sequence of Construction

Construction activities took place day and night. To maintain the traffic flow, comply with local authority regulations, construction sequence and activities were planned to allow concrete pouring and spoil removal to be done before and after rush hours, in most cases at night. Generally panel excavation was carried out at least 6.0m away from the recently cast panel or 16hrs after casting of the adjacent panels to avoid any damage induced by excavation.

Supporting Fluid

Locally available bentonite powder was used for preparation of slurry. This product had been used for more than a dozen completed diaphragm wall projects. Approximately 496 tons of bentonite powder was consumed for excavation work. The last portion of slurry displaced by concrete or contaminated with cement was usually discarded. Soil volumes of about 26,274cu.m and 10,740cu.m were excavated for diaphragm walls and barrettes respectively.

Reinforcement

Steel bars of SD50 were used for the main reinforcement bars. The reinforcement cages were 30.0m to 42.2m long and up to 4.5m wide, with 4 levels of box-out for slab connections for diaphragm wall panels. For barrettes, cages were 48.1 to 54.6m long. 4 to 5 cage sections with lengths of 6-12m were joined to form one continuous cage for individual panels and barrettes. The cage sections were fabricated off site and no more than two were joined for transporting to the site. Cage sections were connected prior to and during lowering into the trench. In order to place the box-out in position and to achieve an exact match of the cage sections, markings were made on the main bars of each cage. U-shaped bolts were used for cage connections. Couplers were generally used for slab connection and both couplers and bent-out bars were used for beam connections at the wall openings for entrances and slab openings. The large panel cages weighed up to 34.8 tons.

For panels with glass fibre reinforcement polymer (GFRP) for openings of TBM break-through, a temporary steel frame was necessary to hold the cage section due to different stiffness between GFRP and steel. The frame was then cut away section by section while lowering the cage. Diaphragm wall panels were rein-

forced with 136-218 kg/m² of steel bars while barrettes were reinforced with about 50kg/m³ of steel bars. The wastage of steel was about 7% in which most quantity was consumed for cage hanging bars and frames for soft eye openings. A total of 4,756.15 tons of reinforcement bars was used for diaphragm wall and barrettes. Steel pipes 150mm in diameter were installed inside the diaphragm wall panels at 5 locations as a void former for inclinometer access tubes. 28 sets of vibrating wire strain gauges and total jack-out pressure cells were also installed in the wall panels of TBM launching shaft.

Concrete Casting

Ready mixed concrete grades 40 (cube strength 40MPa at 28 days) and 35 (35MPa at 28days) to BS5328 were used for diaphragm walls and barrettes respectively. Two sets of tremie pipes were used in pouring concrete for both diaphragm walls and barrettes. The largest single concrete pour was about 232cu.m for L-shaped panels. Total concrete volumes of 27,480cu.m and 6,611cu.m were poured for diaphragm walls and barrettes respectively. Concrete over-consumption in diaphragm wall caused by old, sand back-fill in the area of abandoned water pipes was estimated to be an average of 7.8% with a concrete wastage of up to 38.0% occurring in one panel. However, the average concrete wastage was 5.0%. For barrettes, the average concrete wastage was up to 14%. The high wastage compared to building and elevated highway projects (up to 7%) was caused by overcasting of concrete well above the cutoff level of 22m depth to ensure that sound concrete reached above the cutoff. Aggregates were used to backfill the open trench of barrettes above the concrete after casting.

Installation of Stanchion in Barrettes

Conventional plunging method was not adopted in view of the site conditions, low cutoff level, the stanchion design and horizontal bar arrangements in the reinforcement cage. Two specially designed installation frames with adjustable screws were used for installation of stanchions to ensure high accuracy for verticality and plan position. A removable 10m-long, steel column was fixed on top of the stanchion to check the verticality and alignment.

PRODUCTION RATES



The construction time required for a typical panel and barrette is detailed in Table 3.

Table 3. Average construction time for typical diaphragm wall panels (1.0x4.5x35.0m, cutoff 0.0m) and barrettes (1.2x3.0x44.5m, cutoff - 22.5m).

Activities	Diaphragm wall Hours	Barrette Hours
Excavation	18	16.5
Checking verticality with Kodan	1	2
Desanding	4	5
Cage installation	2.5	4.5
Stanchion installation	-	3
Tremie preparation	2.5	3.5
Concrete pouring	4	3.5

Figure 6. Guide frame for steel stanchion installation in barrettes

Throughout the construction period, a total of about 867hrs, approximately 15% of construction time (excluding mobilization and site preparation period) was consumed by equipment maintenance and repair. Grab teeth were broken and changed often during chipping off the concrete overbreak behind the stop-end plate caused by loose material below the guide walls. Additionally, steel wire ropes for the grab also needed to be changed frequently as they were worn out by both the chiseling action and broken concrete pieces. 17% of construction period was rainy, but this usually had no significant effect on the production rate. A flash flood

occurred at one time by a heavy downpour. Standby time (14% of construction period) took place and was contributed by (1) obstructions by overbreak concrete during panel excavation and stop-end plate removal and (2) standing time after panel excavation reached below the soft clay to allow subsequent construction activities such as spoil removal and concrete delivery taking place outside rush hours. Traffic diversions were carried out in multi-phases and took at least 5% of construction period.

QUALITY, SAFETY AND ENVIROMENTAL CONTROLS

As the alignment of diaphragm wall and barrettes is critical, every excavated panel and trench was checked with Kodan monitoring equipment. Monitoring was carried out after excavation reached about 22.0m (ie. at the levels of base slab and barrette cutoff) and toe levels. Necessary corrections to trench verticality were made during excavation if required. Panel ends, especially for those panels with soft-eyes for TBM break-through were also checked to achieve high levels of accuracy for positioning. During excavation, reference posts were used for checking the grab position and observing rope position relative to the trench sides at all times. Prior to lowering the reinforcement cage into the trench, any mudcake built-up on the trench faces and panel joints was scraped off by a grab to which brushes were attached. Finally, any sediment or loose materials deposited at the bottom of the trench were also removed by using the grab.

Reference bars attached to the top of reinforcement cage were extended above ground level to check the position of the cage with survey equipment during installation of the cage into the trench.

Delivered concrete was checked for slump and cohesiveness prior to casting. As per specifications, adequate embedding length of tremie pipes in the concrete and slurry properties were maintained to achieve good-quality concrete casting. Plugging materials and shutters were introduced in the tremie pipes to separate first concrete pour and slurry in the trench. Samples of reinforcement bars and concrete were taken as specified for testing in the lab. 37 barrettes were provided with 6 steel tubes each for sonic logging to test the barrette concrete quality. No significant anomalies were detected by sonic logging test, and integrity and quality of barrette were found adequate.

As the site was in a busy public area, site and public accesses were kept clean all the time. Flagmen were also provided for traffic control at each construction zone. All workers were inducted in safety procedure prior to assuming duty. Construction activities were also supervised by a full-time safety officer. The safety officer ensured that all labor used mandatory personal protection equipment and observed the safety regulations. All heavy equipment and cranes were checked for safety and certified for operation prior to use and for regular maintenance. Additionally, regular safety patrols and inspection were also conducted by the main contractor and supervising engineers.

CONCLUSION

Construction work on the public road, involving various activities parallel with different teams/subcontractors demanded comprehensive construction sequences and planning to meet the targeted milestones. Proper coordination, planning, supervision and strict safety and environmental control by the parties involved thus brought about the successful completion of diaphragm wall and barrette construction on one of the busiest roads in Bangkok without any serious accident. When the paper was finalized, excavation inside the station box had been completed and it revealed good quality of workmanship without requiring any significant remedial work.

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