CHAPTER V

PROJECT DESCRIPTION AND MONITORING SYSTEM

First this chapter gives a general description of the project, the location of the BMA flood diversion tunnel, the obstructions along the tunneling route and the specific locations for this study as well as the details of subsoil profile of the selected locations. Then an articulated EPB is introduced according to the geological conditions of the area and the tunnel alignment. Finally, the different monitoring systems are presented in order to monitor the different aspects responding to the tunnel construction. The monitoring method and data interpretation will also be given in this chapter.

5.1 General Description

As mentioned in the name of this project, the BMA flood diversion tunnel is responsible by Bangkok Metropolitan Administration (BMA). In order to protect Bangkok from flooding during the rainy season, which is one of the catastrophes to the city, by the end of 2003, this BMA gave its confidence and financial support to the joint venture of Italian-Thai Development PCL and Nishimatsu Construction Co., Ltd. for working on this construction. The present tunnel is the second shortcut flood-diversion tunnel, which has 5.55 m of outer diameter (OD) and about 5 km long. It is under construction in order to collect floodwater from the Saensaep and Ladphroa canals and divert it to the Phrakhanong pumping station. The intake shaft is located at the junction of the Saensaep and Latphroa canals while the outlet shaft and pumping station are located near the Phrakhanong canal connected directly to the Chaophraya River as shown in Figure 5.1. The slope of the tunnel is 1:10000 and the floodwater will be flowed by gravity in the tunnel under the Saensaep canal and Sukumvit 71 road before arriving the outlet shaft at the Phrakhanong pumping station, where it will be passed through some treatment process, pumped into the Prakhanong canal and subsequently flowed into the Chaophraya River.

Along the route, the tunnel was excavated underneath the Saensaep canal which is the main canal in Bangkok metropolitan, busy roads and some underground obstructions such as pile foundations of bridges and Bangkok Mass Transit System (BTS) sky train.

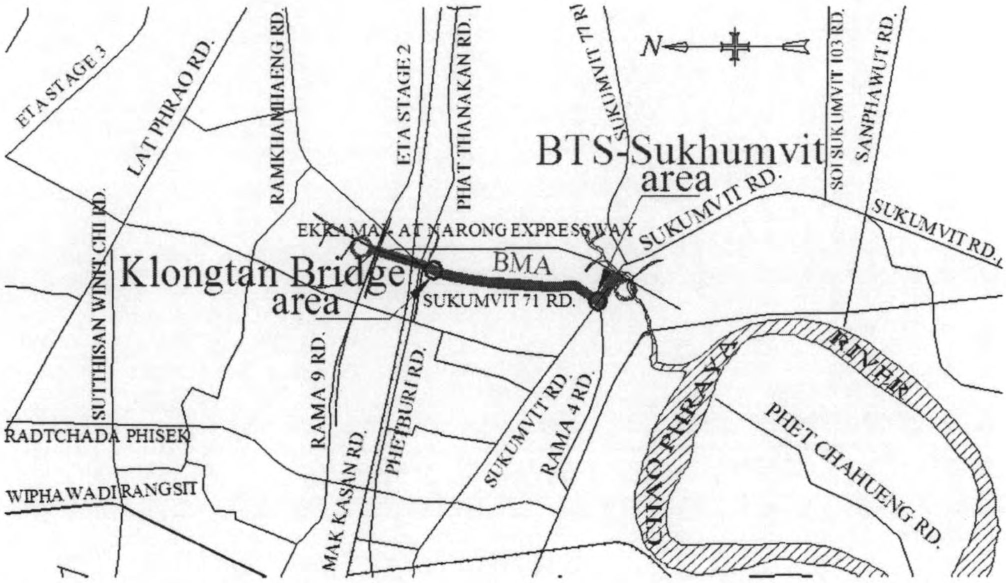

Figure 5.1 Location of BMA flood diversion tunnel (Saensaep-Latphrao Phrakhanong project)

Within the total length of the tunnel, only two locations where the most comprehensive monitoring system for this project was implemented are selected for this study: one is Klongtan Bridge area (Figures 5.2 and 5.3) where the tunnel was bored in dense silty sand and the other is BTS-Sukhumvit area (Figures 5.4 and 5.5) where the tunnel was bored in hard silty clay layer.

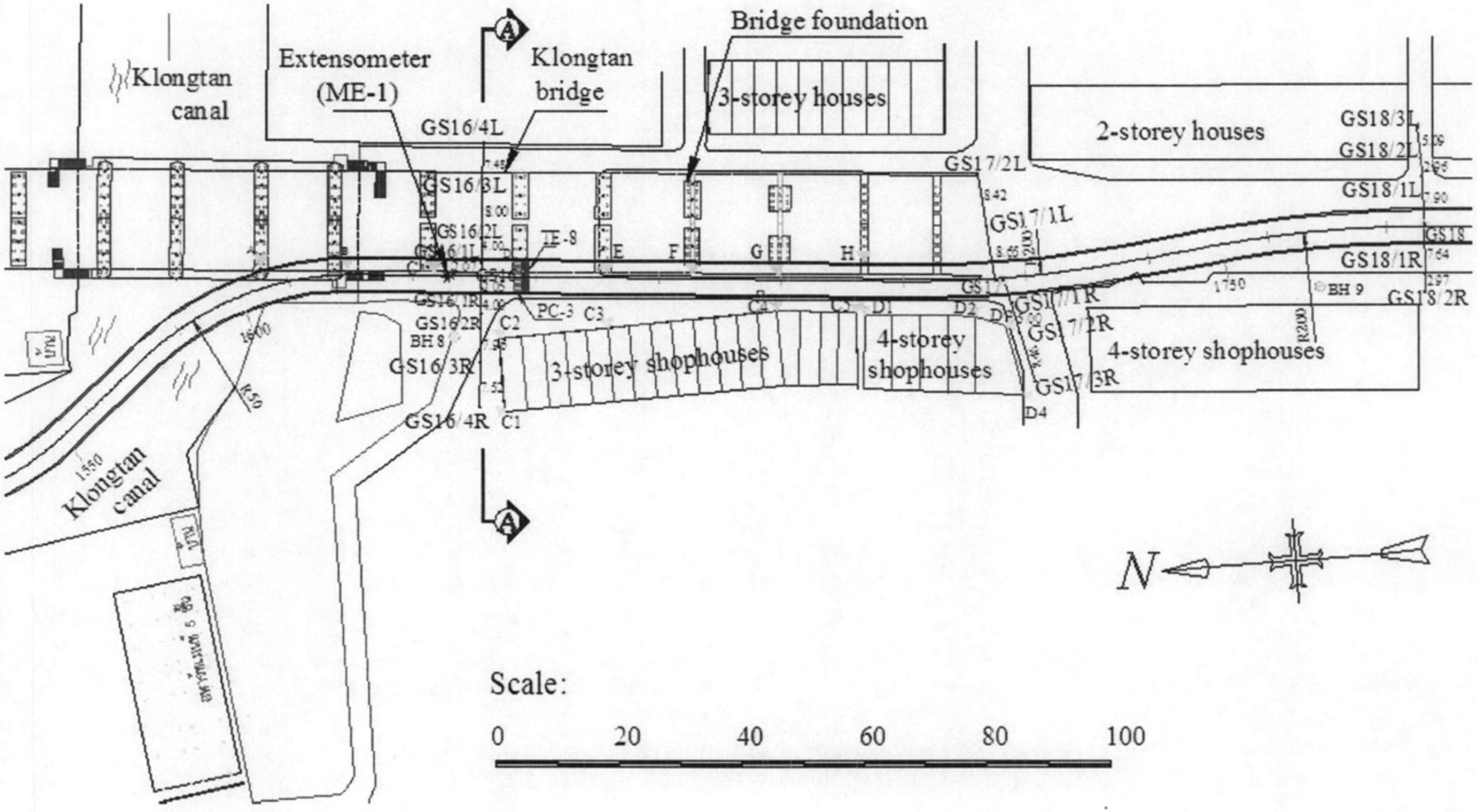

Figure 5.2 Klongtan bridge area (BMA flood diversion tunnel project)

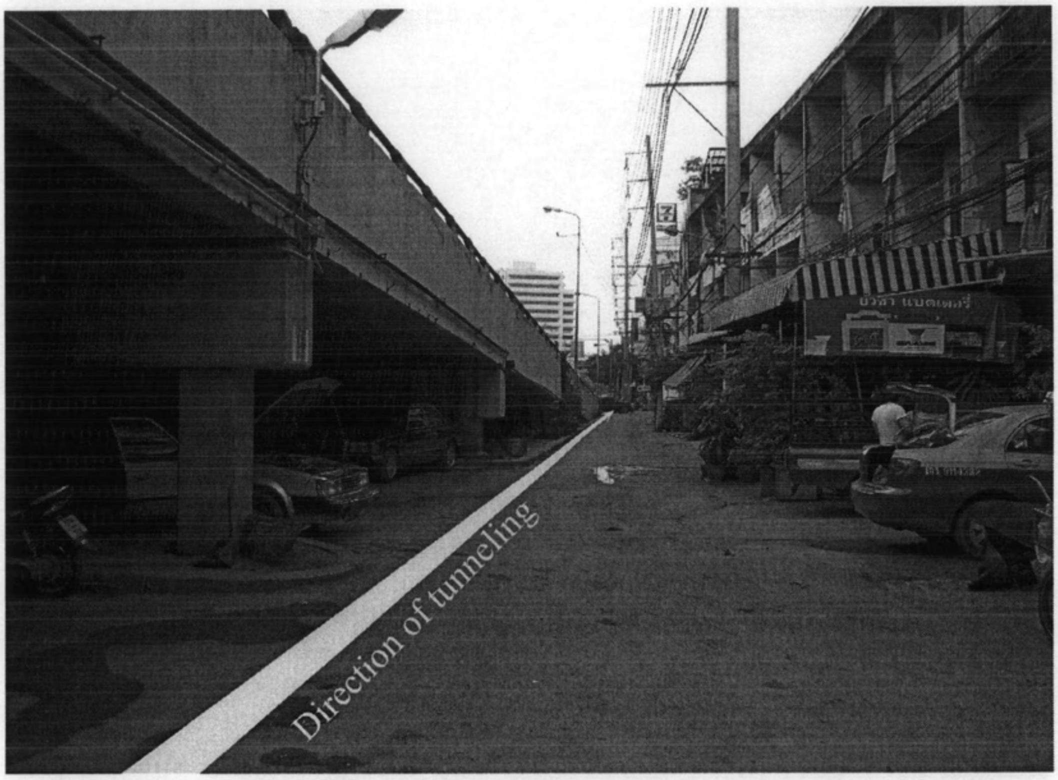

Figure 5.3 Klongtan bridge and old shophouses

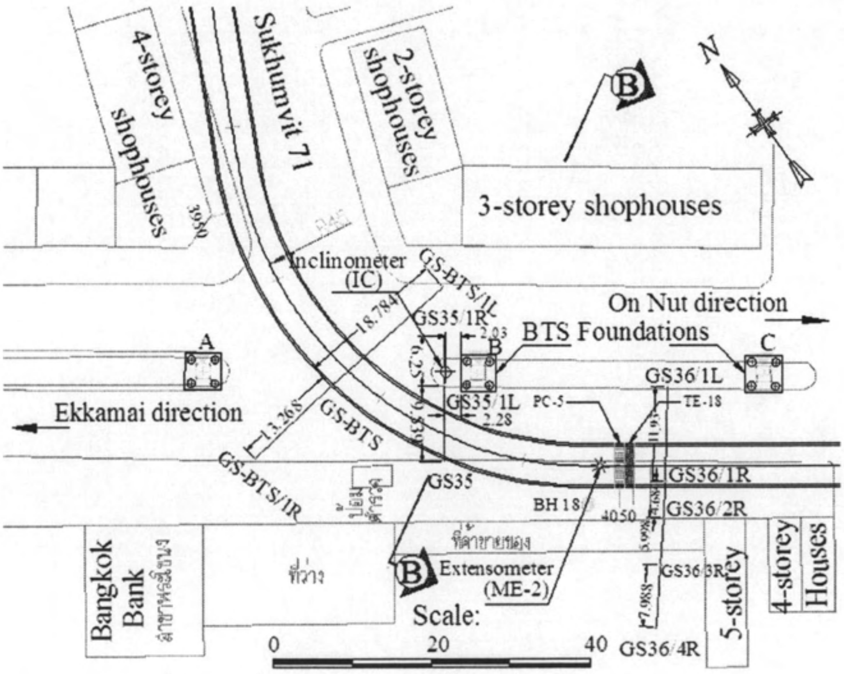

Figure 5.4 BTS-Sukumvit area (BMA flood diversion tunnel project)

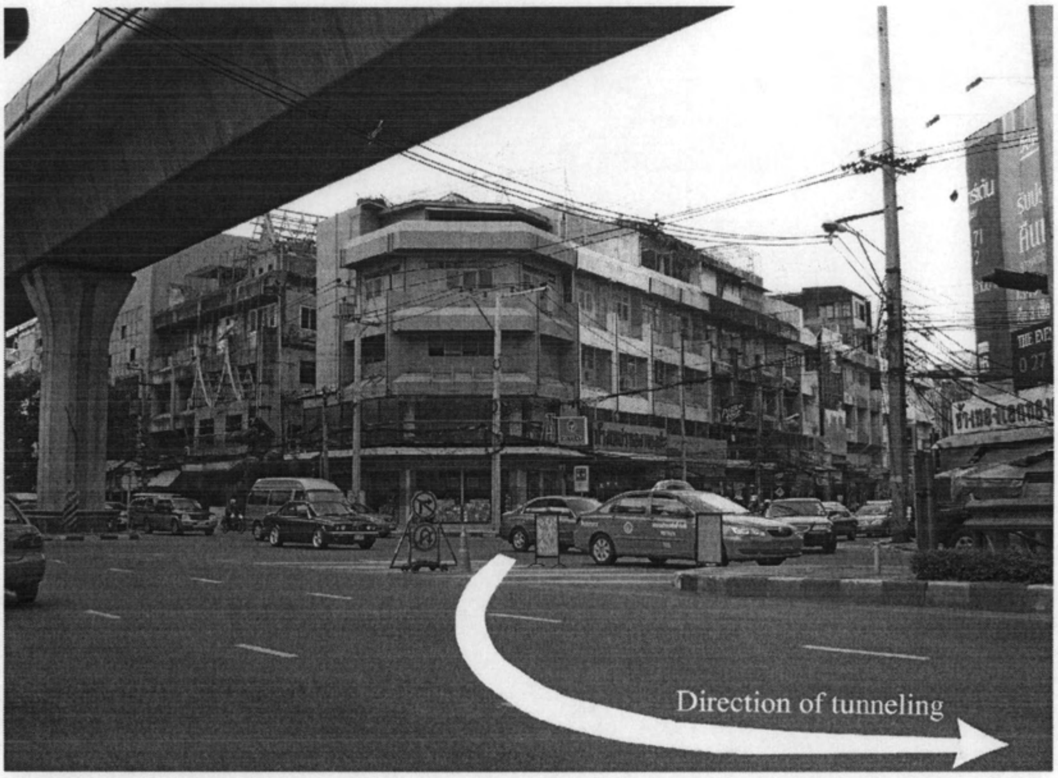

Figure 5.5 BTS sky train and shophouses above the curvature alignment

5.2 Soil Profiles of Selected Analysis Sections

As mentioned in section 5.1, only Klongtan Bridge and BTS-Sukhumvit area are selected for analyses in this research. The subsoil conditions are supposed to be identical for the whole selected area, but the obstructions are varied according to the real analysis section. At Klongtan Bridge section (Figure 5.6), the tunnel was fully excavated in dense silty sand layer while at BTS-Sukhumvit section (Figure 5.7), it was bored through the hard silty clay with the crown and invert cut in the very stiff silty clay layers. Two main important structures were found at the two selected areas: an old bridge foundation at Klongtan where the tunnel was bored about 3 m. underneath the tip of the pile, and the pile foundation of BTS sky train at Sukhumvit area where the tunnel was bored 3.65 m on the right side as shown in Figures. 5.6 and 5.7, respectively.

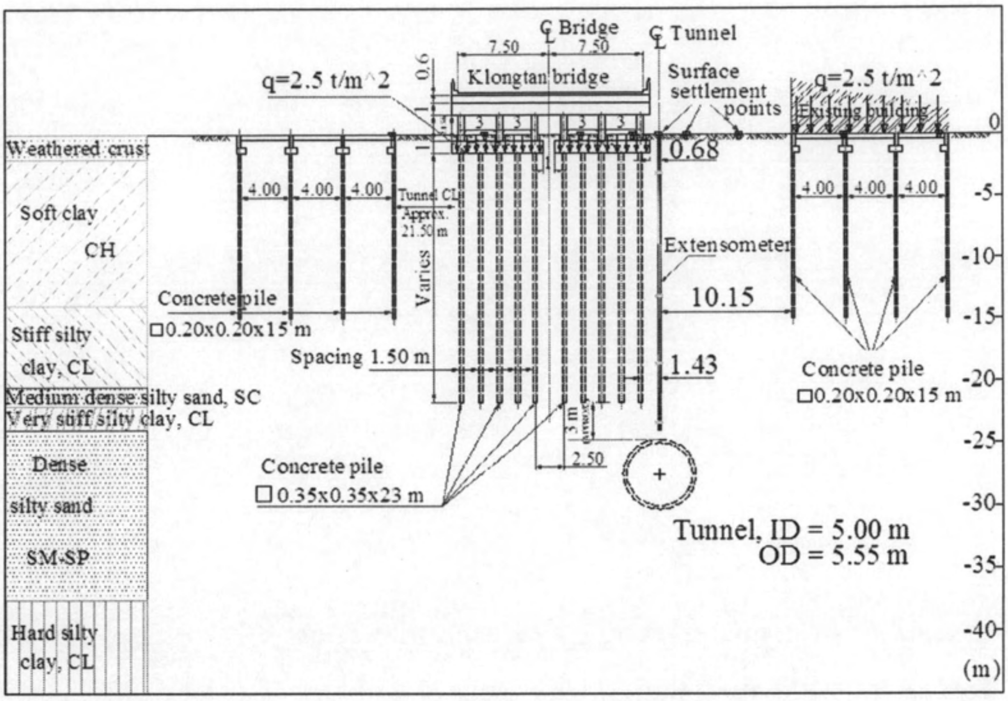

Figure 5.6 Subsoil profile at Klongtan Bridge area and cross section (section AA)

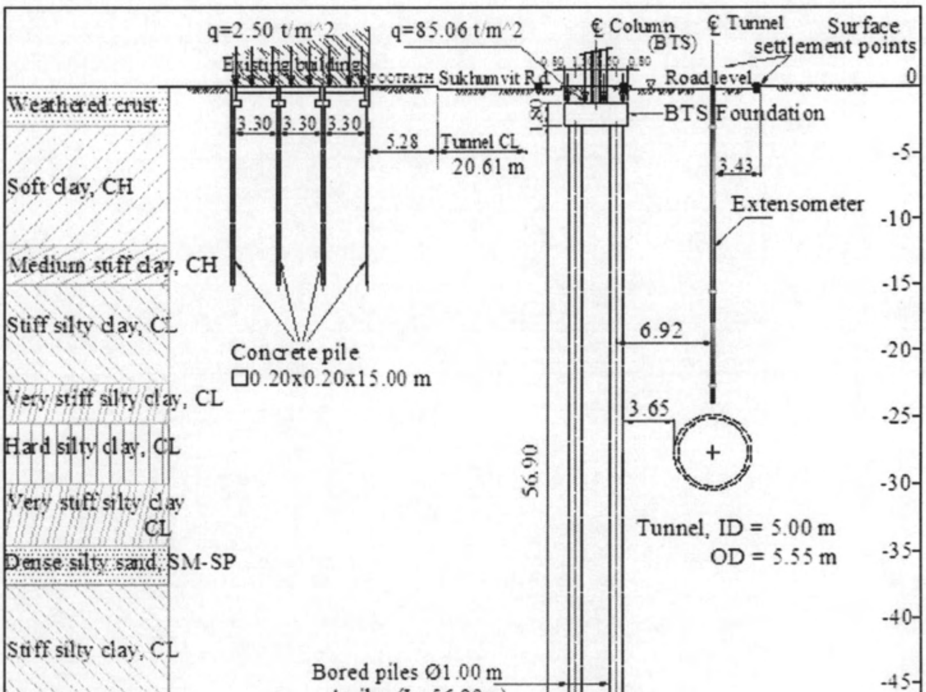

Figure 5.7 Subsoil profile at BTS-Sukumvit area and cross section (section BB)

5.3 TBM Used in the Project

Based on the geological conditions mentioned in section 5.2 and the criteria for selecting the TBM described in Chapter II, the EPB shield machine is the most appropriate tool for this project. Figure 5.2 shows that the tunnel was bored in double sharp S-curve with the radius of 50 m before reaching the straight alignment while the Figure 5.4 shows the radius of curvature alignment which is only 45 m. It is the first experience of tunneling project in Bangkok since the previous projects shown the minimum radius of the curved alignment was not less than 150 m and 93 m for the shield outer diameter of 4.18 m and 3.14 m respectively (Obayashi, 2006 and Moncrieff, 2006). Therefore, the EPB shield machine was specially designed with articulation, which made it possible to excavate in the curved alignment with such a minimum radius (40 m) as existed in the project. The eccentric force created by hydraulic jack to advance the shield against the face pressure and skin friction could cause cracks or failure of the tapered segment. Therefore, to avoid such incidents, the jack trust was not applied as high as when the shield excavated in the straight alignment. Figure 5.8 illustrates the general feature of articulated shield (Sramoon et al., 2006).

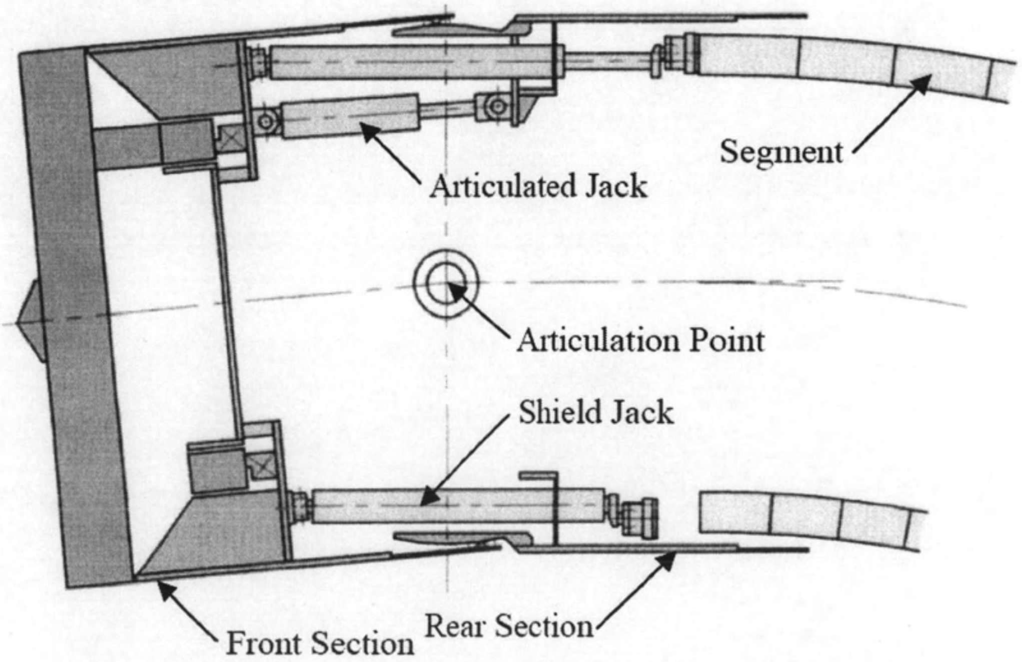

Figure 5.8 General feature of articulated shield (Sramoon et al., 2006)

The detail schematic of articulated EPB shield machine used for in this project is shown in Figure 5.9.

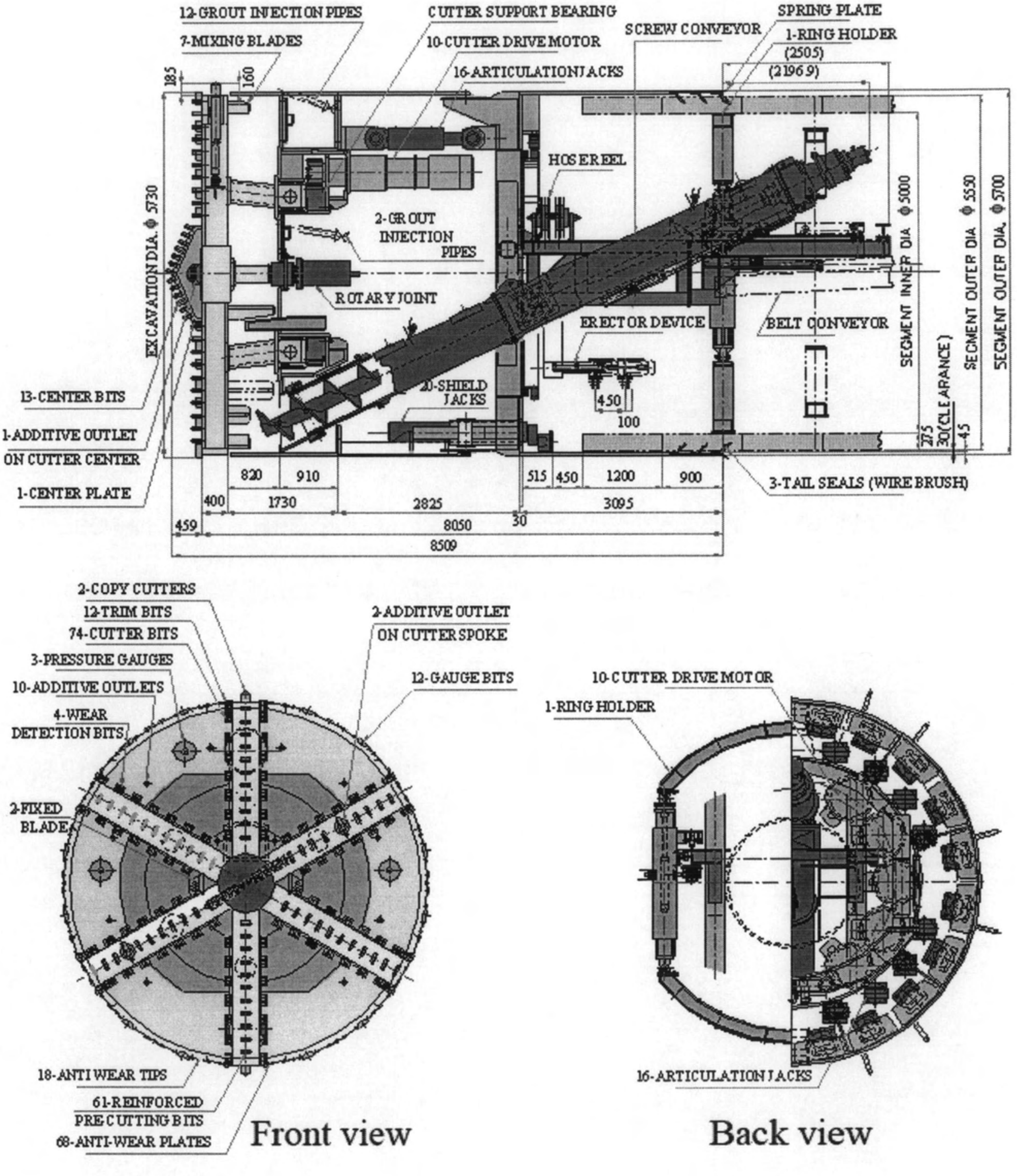

Figure 5.9 Schematic of articulated EPB shield for MBA flood diversion tunnel (Saensaep-Latphrao Phrakhanong project)

A normal EPB shield machine consists of two parts: cutting face or cutting wheel and the main part of the shield, which includes the shield body and tail together as one portion. However, the main part of EPB shield used in this project composes of two separate portions (Figure 5.9), body and tail, but they are connected by the articulation devices that allow the machine to be easily used in the curve alignment with a minimum radius of 35 m. The shield with total weight of 220 tones is advanced by 20 hydraulic jacks (shield jacks). Each hydraulic jack has a maximum jack force of 1500 kPa and a maximum speed of 10 centimeters per minute (Appendix C: picture of the actual EPB shield machine).

5.4 Tunnel Properties

The tunnel lining consists of pre-cast bolted reinforced concrete of 400 ksc of compression strength with six segments per ring in which one is called key segment (Figure 5.10). Each segment is 0.275 m thick and 1.2 m. wide for straight alignment, but this width is reduced to 0.6 m for curvature (tapered segment).

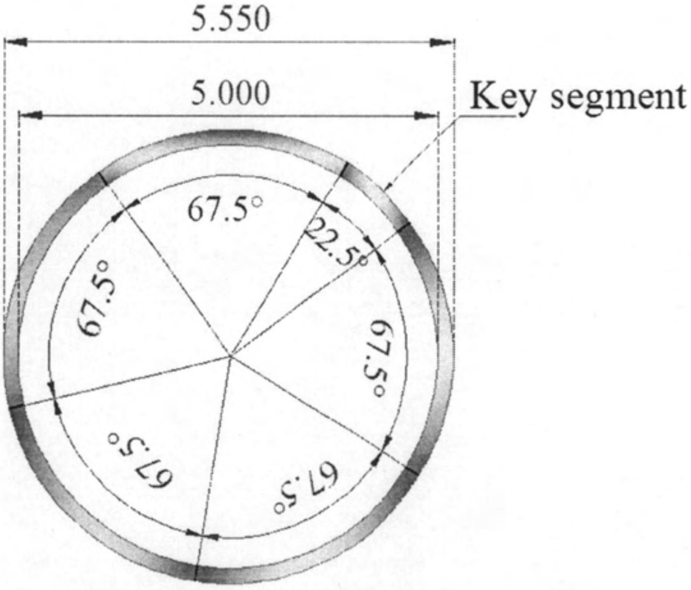

Figure 5.10 Sectional view of tunnel lining

The water sealing material named Hydrotite (RS type) is used to prevent the leakage of water at each joint (Figure 5.11).

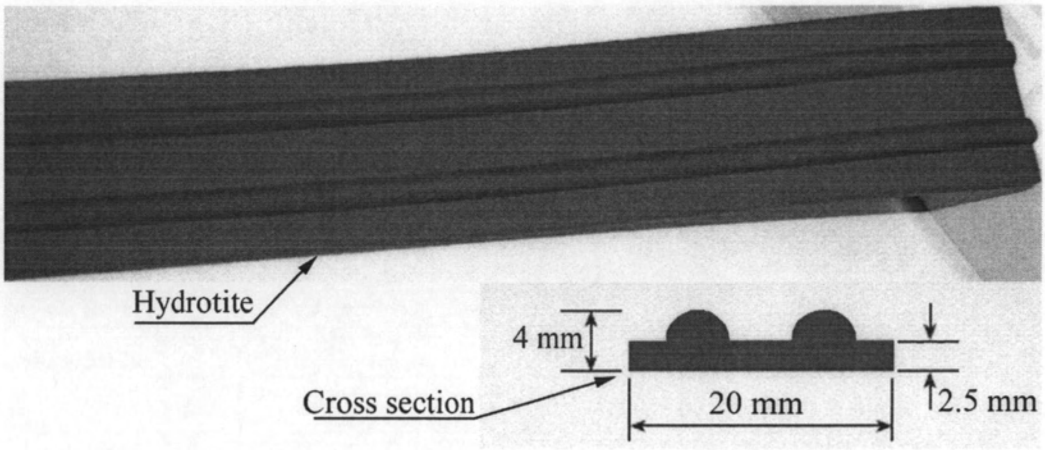

Figure 5.11 Water sealing material (Hydrotite, RS type)

5.5 Monitoring System

To keep the evaluation of the ground and structural deformations under control and for verification of the design assumptions, the defined monitoring systems were set up along the tunneling route. In this regard, Negro (1998) stated that field monitoring is necessary for the success of the tunnel construction because it makes the comparison between prediction and conformity assessment possible. In addition, the monitoring data allow the researchers to study the behaviors of ground and structural movements during construction, post construction and for long-term conditions.

The different types of instrumentation have been used in this research are listed in Table 5.1. The observation of ground surface, building and structural settlement points was done by the staffs of the construction company by means of survey equipment. However, the monitoring relative to inclinometers, extensometers, total pressure cells and convergent bolts was done by the GMT Corporation Ltd.

Table 5.1 Types of Instrumentation and Measurements

Types of Instrumentation	Measurements
Surface settlement points	Total ground surface settlements
Inclinometers	Subsurface horizontal movements in direction perpendicular to the axis of the tunnel
Extensometers	Subsurface settlements or heaves due tunnel excavation
Building and structural settlement points	Settlements of nearby buildings and structures such as bridges
Total earth pressure cells	Total pressure exerts on the tunnel lining
Convergent bolts	Deformation of tunnel geometry

Except the ground surface, building and structural settlement points in which the monitoring is simple and based on the basic knowledge of surveying, a summary of the monitoring methods and data interpretation for other instrumentation will be described in the following paragraphs. Nevertheless, only the devices and application related to tunnel excavation of this research will be mentioned.

5.5.1 Inclinometers

The inclinometers (sometimes called slope indicators) are described as devices used to monitor the deformation parallel and normal to the axis of a flexible pipe (inclinometer casing) by means of a probe passing along the pipe. The probe contains two gravity-sensing transducers (usually a force balance accelerometer) designed to measure inclination with respect to the vertical (EM1110-2-1908, 1995). The inclinometer casing can be a grooved metal (Aluminum alloy, fiberglass or steel) or plastic pipe inserted down a borehole. In order to obtain the good data of lateral deformation at different level below ground surface, the bottom of the casing must be fixed in a stable stratum and the whole casing must be placed as vertically as possible.

The main components of an inclinometer system are shown in Figure 5.12. These components consist of an inclinometer casing, a portable inclinometer probe, a control cable and a portable readout box. The casings which are suitable for most applications are manufactured from ABS (Acrylonitrile/Butadiene/Styrene) plastic, and available in various sizes. Figure 5.12 also presents the cross section of a casing showing its four orthogonal grooves. The detail of all inclinometer components can be found in the catalog of Slope Indicator Company (2004) or on the website "www.slopeindicator.com".

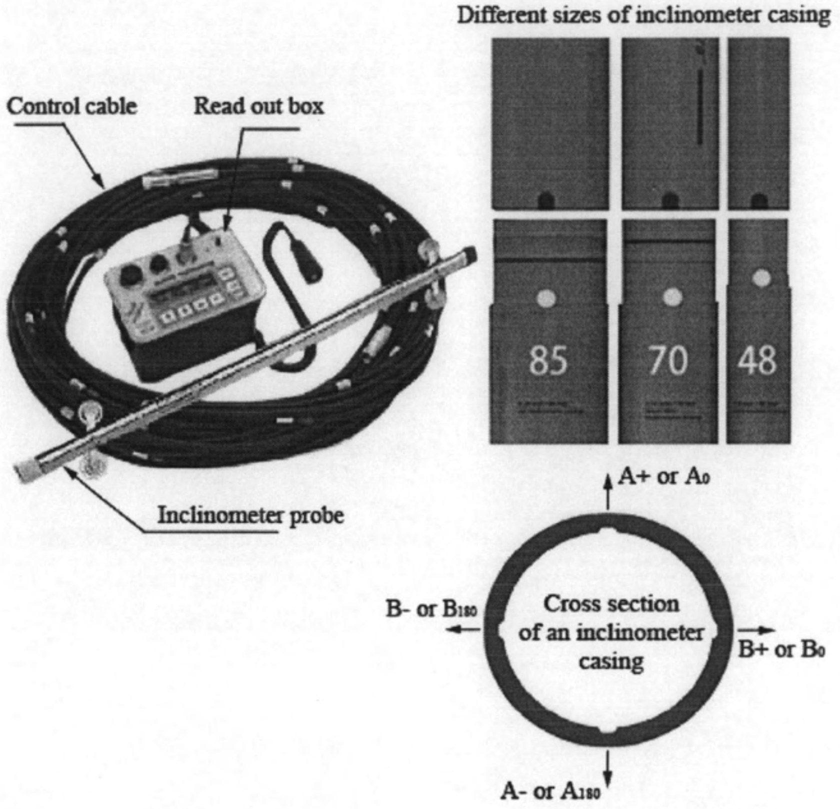

Figure 5.12 Inclinometer system (Slope Indicator Company, 2004)

After an installation of the casing and surveying of its tip location, the probe is lowered down to the bottom and an inclination reading is made. Additional readings are obtained as the probe is raised up incrementally to the top of the casing, providing data for determination of initial casing alignment (Dunnicliff, 1988). The differences between these initial readings and the successive readings, which have been taken over a period of time, give the tilt (angle of inclination) of the inclinometer casing (Figure 5.13). Therefore, the absolute horizontal deformation at any point along the casing can be determined and plotted as a function of depth. Typically, the probe is raised up at an interval of a half meter.

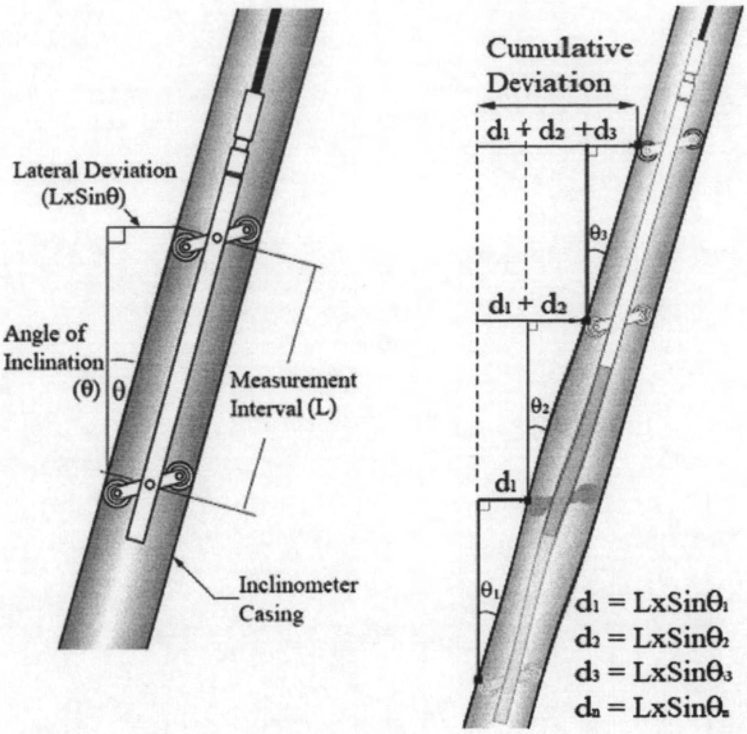

Figure 5.13 Incremental and cumulative deviation (Slope Indicator Company, 1994)

5.5.2 Extensometers

The extensometers here are referred to the magnetic extensometers, which are installed in boreholes in soil to monitor the vertical movements (settlement or heave) of points along the axis of a borehole above or at certain distances from the tunnel (Figure 5.14).

The components of magnetic extensometer consist of a probe, steel survey tape, tap reel with built-in light and a number of spider magnets (magnetic anchors) positioned along the length of an access pipe (Slope Indicator Company, 1994). Figure 5.15 illustrates the components of magnetic extensometer and their positions after an installation with the main components and other accessories.

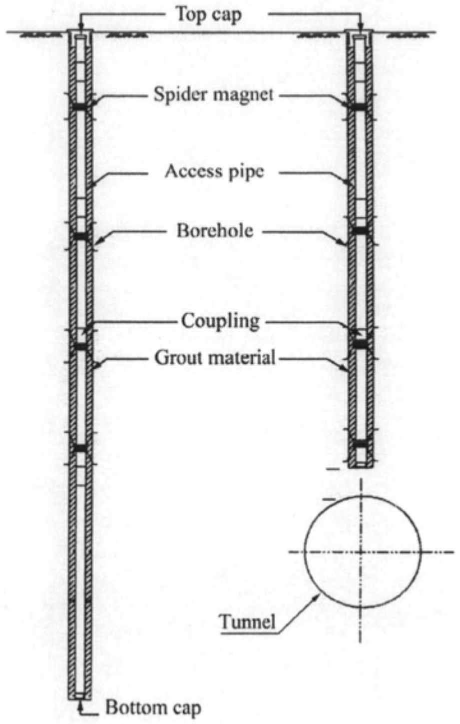

Figure 5.14 Extensometers above and at the side of the tunnel (BMA flood diversion tunnel project)

Based on the application guide of Slope Indicator Company (1994), the monitoring is done by lowering the probe to the bottom of the access pipe and raising it up to find the depth of each magnet. As soon as the probe enters a magnetic field and then a reed switch closes subsequently, the light and buzzer on the reel at the surface activate. The operator then refers to the 1 millimeter graduations on the tape and notes the depth of the magnet. If the access pipe is embedded in stable soil, the depth of each magnet is referred to a datum magnet fixed to the bottom of the pile. The settlement or heave is calculated by comparing the current depth of each magnet to its initial depth. However, if the bottom of access pipe is not embedded in stable soil, the depths of each magnet must be referenced to the top of the pipe that is precisely surveyed before starting the readings.

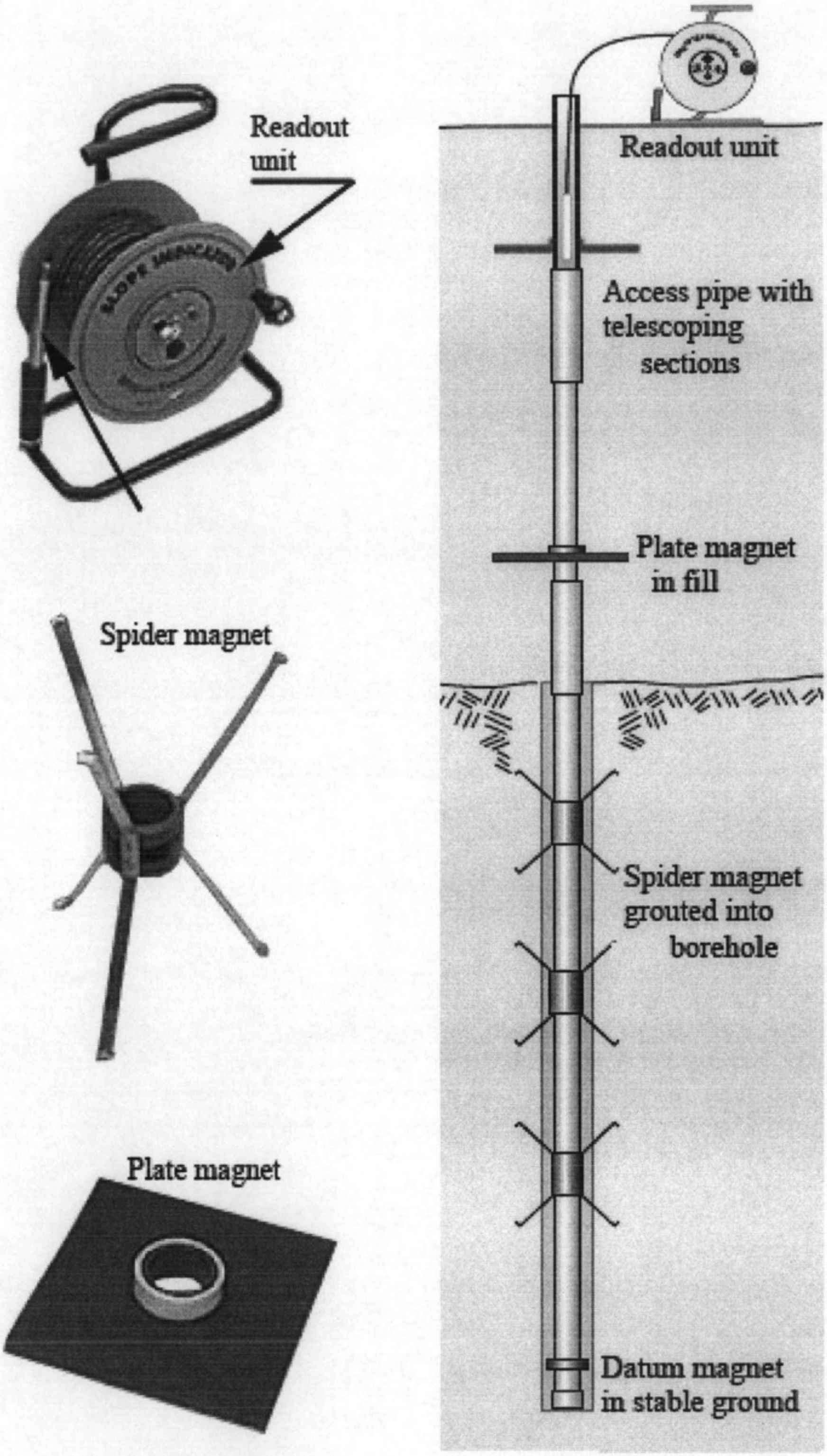

Figure 5.15 Components of magnetic extensometer and their positions after installation (Slope Indicator Company, 2004)

5.5.3 Total Earth Pressure Cells

In the tunneling work, the total earth pressure cells are used to measure the total stress exerting on the tunnel lining. In general, they are used to confirm the design assumptions, to signal a warning of soil pressures in excess of those the liner is designed to withstand, and to provide information for the improvement of future design (Dunnicliff, 1988; Slope Indicator Company, 1994).

The total pressure cell consists of two circular stainless steel plates of 229 mm in diameter and they are welded together around their periphery to form a sealed space. The cell is filled with de-aired liquid and a high pressure tube connected the cell to a pressure transducer as shown in Figure 5.16. The figure also displays the position of total earth pressure cell after embedding in the tunnel segmental lining (BMA flood diversion project, Saensaep-Latphrao Phrakhanong). The active face of the cell is placed in direct contact with the soil.

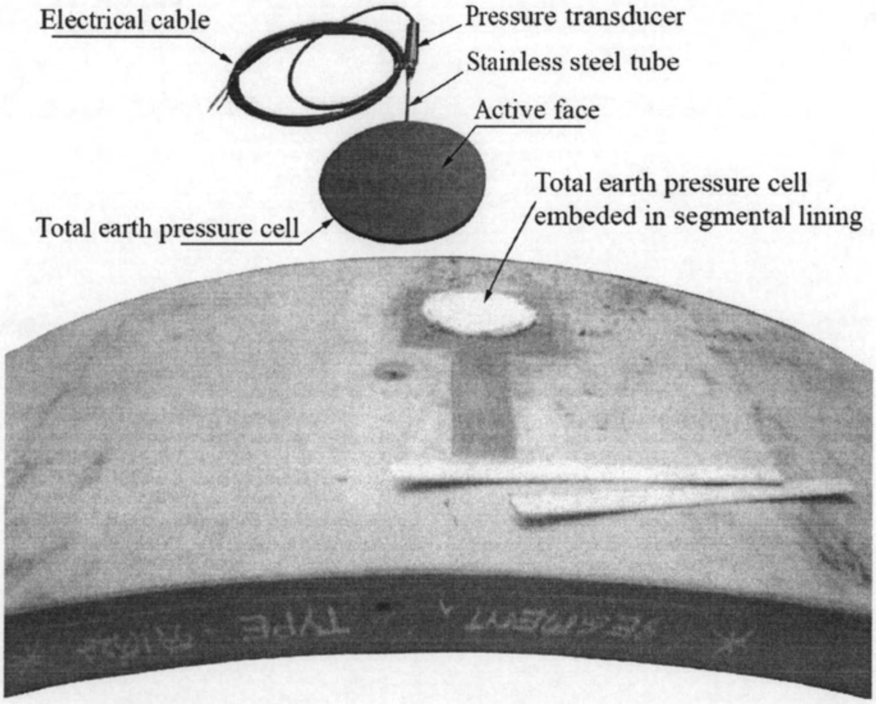

Figure 5.16 Total earth pressure cell and its position after embedding in the tunnel segmental lining (BMA flood diversion tunnel project)

Once stress is acted on the active face of the cell, it pressurizes the filled liquid which is automatically transferred to the pressure transducer. After that the pressure is converted into an electrical signal and transmitted to the readout device via cable.

5.5.4 Convergence Bolts

The convergence bolts described in this section referred to the tape extensometer system, which is used to monitor the changes in distance between reference points anchored in tunnel walls (Figure 5.17).

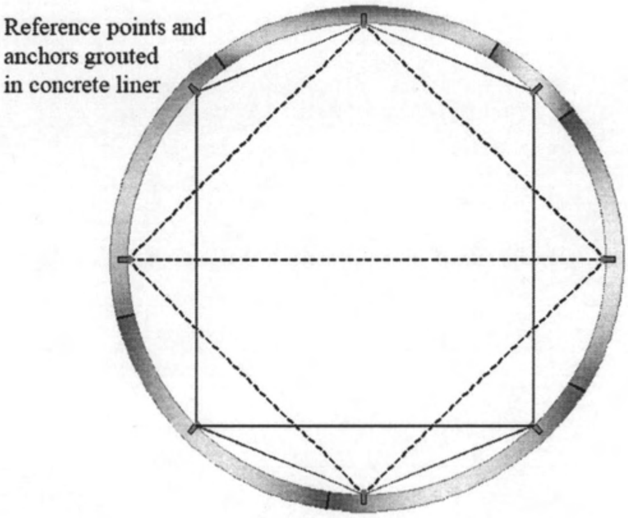

Figure 5.17 Typical installation of convergence bolts and monitoring patterns

The tape extensometer system consists of, a stainless steel tape with punched holes at regular intervals (2.5 cm), tape real, dial gage with resolution 0.01, collar for tension adjustment for applying a constant tension to the tape, steel reference bolts and two hooks or two joints attached on the instrument body and the free end of the tape (Figure 5.18).

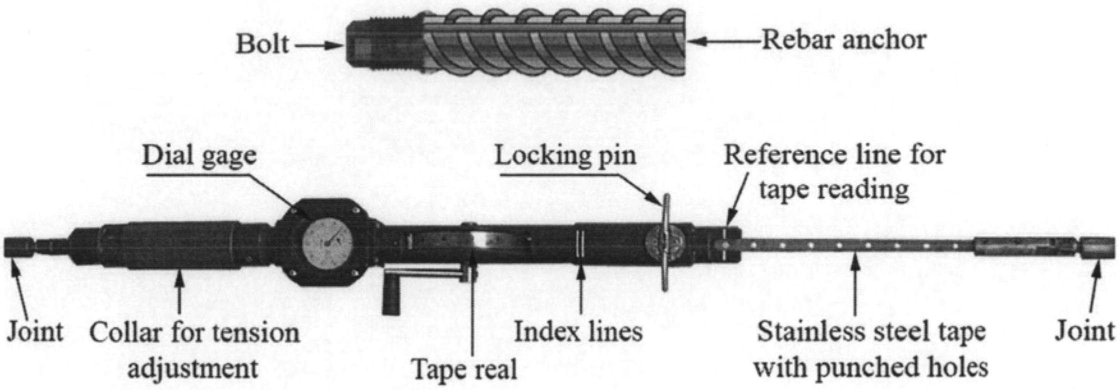

Figure 5.18 Tape extensometer (BMA flood diversion tunnel project)

To obtain a measurement, the operator stretches the tape between two reference points, connecting the free end of the tape to one point and the instrument body to the other. The operator tensions the tape by turning a knurled collar until two index marks are aligned, and then notes the reading from the tape, the internal sliding scale, and the dial gauge. The sum of these readings is the distance between the two reference points. This procedure is repeated for the remaining points at the measurement station. On comparing current readings to initial readings, the operator can calculate the change in distance between the two points (Slope Indicator Company, 2004).

5.6 Layouts of Instrumentation at the Sites of the Study

The layouts of instrumentation for the two selected areas (Klongtan Bridge and BTS elevated train) are shown in Figures 5.2 and 5.4.

At the Klongtan Bridge area (Figure 5.2), the instrumentation consists of:

- Ground surface settlement array GS16 placed below the bridge, GS17 close to the toe of the bridge and GS18 across the busy road;
- One extensometer (ME-1) placed above the tunnel centerline and close to the GS16;
- Total earth pressure cells installed at the contact between soil and a segment of ring number 1654;
- Convergence bolts attached inside the tunnel on rings numbers 1655;

- Structural settlement points fixed on the columns above the bridge foundations (Point A to H) and of the nearby old shophouse foundations (point C_1 to C_5 and D_1 to D_4).

Similarly to the Klongtan Bridge area, the instrumentation for BTS-Sukhumvit (Figure 5.4) consists of:

- Ground surface settlement array GS-BTS set at the curvilinear junction of busy roads and GS35 about 2.28 m close to the BTS pile foundation;
- One inclinometer (IC) placed about 7 m. from the tunnel centerline and about 2 m. close to the BTS pile foundation;
- One extensometer (ME-2) placed above the tunnel centerline and close to the GS36;
- Total earth pressure cells installed at the contact between soil and the segment of ring number 4050;
- Convergence bolts attached inside the tunnel on ring number 4051;
- Structural settlement points fixed on all columns of BTS pile foundations

The structural settlement points provide information regarding the stability of the structures under consideration, and the actions taken if the excessive settlements happen beyond the allowable limitation for such structures. In some circumstances, the ground surface settlements also allow researchers to evaluate the overall stabilization of the structures situated within the influenced zone. Moreover, the monitored data at the ground surface can be used to estimate the volume of surface settlement trough, which serves later as the input of the tunnel contraction for FEM analysis. Finally, the comparison of field monitored data with FEM results can be conducted and it leads to a confirmation of the various factors assumed in the FEM simulation.