1. Project background
The Underground alignment of Bangkok MRTA Blue Line Extension Project as a part of the 3 mass transit lines project in Bangkok (Figure 1) has a total length of 5 kilometers comprising of 4 stations. Starting at Hua Lamphong, the tunnel alignment runs underneath Khlong Phadung Krung Kasem, curving into the middle of Charoen Krung road and proceeds to Wat Mangkon Station. To minimize the width of station, a stacked track alignment for Wat Mangkon Station is the most feasible for the limited width of Chareon Krung road’s right of way. From Wat Mangkon to Wang Burapha Station, the route alignment stays mainly in the middle of Charoen Krung road in order to minimize the impact to the busy traffic road during the construction stage. Reaching at Wang Burapha Interchange Station (with the future Purple Line route), stacked-platform station excavated by NATM (New Austrian Tunneling Method) with partial Cut and Cover Method, continues along Charoen Krung road, the route alignment runs underneath Khlong Khu-Muang Doem, turn left before entering Sanam Chai road, where it reaches Sanam Chai Station. Since the width of Sanam Chai road is sufficient for twin tunnels, then the transition from stacked to normal alignment is starting between Wang Burapha and Sanam Chai Stations [1].

For reasons of minimizing the impact of Blue Line construction to the adjacent structures, the route was aligned to run underneath Khlong Khu-Muang Derm before it turns right toward the Chao Phraya River, crosses and runs with a curve before get through beneath Khlong Bangkok Yai and entering Itsaraphap station. The route alignment continues to the left turn, runs beneath a few buildings in residential area and gradually rises up to the ground level and run on elevated structure about 500 m. before joining to an elevated track above Tha-Phra intersection such as Figure 2. To implement this underground project, a variety of construction methods will be adopted which are (1) shield tunneling method for excavating stacked tunnels and side-by-side tunnels, (2) Cut and Cover method, and (3) NATM.
2. Constraints and Public Concerns
Alignment of this project will pass through many critical locations as shown in Figure 3, where the excavation area is very limited. Especially at Wat Mangkon Station near to Chinese Shrine located on Charoen Krung Road, the narrowed road of 14 m. width controls the alignment. Furthermore, the station shall fulfill the commuting demand of people living in the China Town on Yao Waraj Road. Commuters can walk 150-200 m. from Yao Waraj Road through the sub-road to catch the MRT train at this station.

Wang Burapha Station is planned to be a large underground interchange station between Blue South Line and the future Purple Line. As one of two stations located within historically sensitive area so called “Rattanakosin Island,” the station is surrounded by commercial/business places, historical/ancient sites including many tourist attractions, such as Historical Park “Romaneenat” (800 m), Play House/Theater “Chalem Krung” (100 m), “Wat Suthat” Temple (100 m), BMA’s Car Park and Giant Swing Poles (550m), The Old Siam Plaza and Phahurat Road (100m), and a few hotels.

Sanam Chai Station also located within “Rattanakosin Island,” the old city area is very near to the famous historical/ancient sites such as the temple of “Emerald Buddha,” Grand Palace.
(500 m.) and Phra Maine Ground “Sanam Luang” (750 m.), Rajinee School, Pak Klong Market, Army Reserve Command and former Ministry of Commercial site. The site of former Ministry of Commerce will be turned to Learning Museum where the museum entrance and the station entrance shall be proposed to coexist to facilitate the tourists’s visits. After Sanam Chai Station, the route shall underpass the Chao Phraya River to reach the opposite side (i.e., Thonburi).

Itsaraphap Station is the first station that the route shall reach after leaving the Chao Phraya River. Located between Tha Phra Station and Sanam Chai Station, the station shall occupy a gas station compound on Itsaraphap road near Wat Rajsudhitharam. This station is placed nearly at the right angle to Itsaraphap Road, almost like a cross. Station entrances shall be limited to two entrances only; one opposite the other at each side of the road, however, provision of an emergency exit shall be made at the other end of the station. According to the constraints and public concerns mentioned above, this underground project needs to consider the followings:

- Narrowed road
- Poor traffic
- Congested area
- Large business and residential community
- Old buildings with poor supports
- Historical buildings

3. Instrumentation Scheme for Tunnel
Experiences from the construction of the initial Blue Line Project (Phienwej et al., 2006, and Suwansawat, 2004) informed us that the ground response induced by EPB tunnelling is very complex and difficult to understand since many factors are involved [2], [3]. All agree that to understand the governing mechanisms, comprehensive information including geological conditions, reliable settlement measurements, and operation records of EPB shields are needed. Therefore, in the Blue Line Extension project, extensive instrumentation system shall be installed to ensure safety and to make the public confident of the project. Importantly, negative effects on the ground surface and existing structures can be minimized or controlled beforehand if the instrumentation scheme is designed properly. This paper describes the definitive instrumentation scheme for the Bangkok MRTA Blue Line Extension Project where critical locations discussed below needs to place instruments carefully [4].

3.1 TBM (Shield) launching and break-in locations
At TBM launching and break-in station box has a significant effect on the magnitude of surface settlements. It quantitatively represents a combination of several effects including the learning skill of tunnelling crews and shield performance. In this part of the initial drive, shield operators often determine by trial and error an optimum pressure balance mode that causes the smallest
settlement by varying face pressure, penetration rate, and other operational parameters. All of this often causes either large settlements or surface heave. Therefore, these locations need to install extensive instrumentation for measuring surface settlements. Intentionally monitoring array of settlement markers shall be installed at the layout shown in Figure 4(a) and (b) for launching and break-in, respectively.

![Monitoring array for launch and break in](image)

**Figure 4. Monitoring array for launch and break in**

### 3.2 Typical tunnel alignment

Normally, during the construction of tunnels, surface settlement troughs are expected along the alignment as shown in Figure 5(a). Influenced zone is based on the typical assumption that the ground movement occurs extending from the source (tunnel) 45 degree to the surface (i.e. 1Z from tunnel alignment) [3]. However, since the alignment is located within critical areas explained earlier, instruments will be placed within the area as a result of extending 1.5Z from center of each tunnel as illustrated in Figure 5(b).

Along the tunnel alignment, the following instruments are planned to be installed:

- Surface settlement markers shall be installed at intervals not more than 30 m. apart on the centerline over the tunnel alignment.
- Surface settlement marker array shall be installed at intervals not more than 150 m. apart over tunnel alignment.

![Influenced and monitoring zones](image)

**Figure 5. Influenced and monitoring zones for tunnel construction**
All adjacent buildings and structures (unless specified otherwise) if any part of the building and structure falls within the monitoring zone as defined in Figure 5(b) shall be monitored with:

- 4 building settlement monitoring points, one at each corner of the building (type of points to be installed on the structures shall be acceptance to the Engineer);
- 2 prisms mounted on columns in case the height of the building is more than 2 stories;
- 2 set of wireless EL tilt meters in case the height of the building is more than 2 stories;
- Wireless Electrical Crack meters and Crack gauges (tell-tale type) to measure existing or new cracks in case of real time and manual monitoring system respectively;
- where the side of the building is more than 20 m. long, additional settlement monitoring points shall be installed at every 20 m.; and
- At least 60% of existing buildings or structures located within monitoring zone shall be installed with above mentioned instruments for monitoring works.

If any part of the tunnel is directly below any part of a building (height more than 2 stories) or structures, the following monitoring system shall be considered as a minimum:

- A comprehensively monitored test zone shall be set up within the area 50 m before the tunnel reaches the building or structure. The test zone is required to confirm that the tunnelling is being carried out in such a way that the settlements are less than or equal to that expected from the design.
- The building or structure shall be considered as a structure/ building subject to protective works and instrumented on that basis.
- The monitoring of existing buildings/structures and the test zone instrumentation shall be carried out on a 6-hourly basis when the tunnel face is within 25 m. of the buildings or structures.
- The monitoring system shall be automatic real-time basis.

The contractor shall monitor all existing pedestrian/vehicular bridges (unless noted otherwise), which are lying in the monitoring zone at least but not limited with following instruments:

- 8 building settlement monitoring points
- 2 prisms mounted on the piers/supports; and
- 2 tilt meters in case of vehicular bridges, or
- At least 50% of existing pedestrian/ vehicular bridges located within monitoring zone shall be installed with above mentioned instruments for monitoring works.

3.3 Tunnel alignment underneath Chaophraya River

The tunnel alignment underneath Chaophraya River needs to be installed fully automatic real-time monitoring system. Instruments shall be installed at least in four sections. All instruments shall be connected with data logging system for data collection. The monitoring system shall have function of alarming system. The tunnel shall be monitored at least but not limited with following instruments:

- Wireless EL beam sensors
- 3D monitoring system
- Wireless basset convergence system
- Embedment type concrete strain gauge
- Monitoring array at the beginning and end of tunnel
3.4 NATM Tunnel

New Austrian Tunneling Method (NATM) was adopted for the first time in Thailand to construct platform of two subway stations which are Wang Burapha and Sanam Chai stations and passenger adits to intervention shafts. Since NATM requires observational criteria to achieve the technique and it needs careful construction procedures, instrumentation plays a major role for monitoring the ground reaction as shown in Figure 6. Mainly, the instruments will be installed at the opening surface to report any deformation. Automatic records are also necessary in this case.

![Figure 6. Instrumentation for NATM tunnel](image)

4. Instrumentation scheme for cut and cover box

In the Blue Line Extension Project, there are six locations constructed by Cut and Cover Method such as the Cross-over (ch 0+100 to 0+210 from Hua Lamphong Station), Wat Mangkon Station, Wang Burapha Station, Sanam Chai Station (both station will be constructed by Cut and Cover in cooperated with NATM), Itsaraphap Station and The Transition Box (ch 5+290 to 5+530 before connecting with elevated structure). All of these cut and cover boxes have constrains so that each location shall be appropriately excavated and needs instrumentation for monitoring effects on adjacent buildings and structures. Additional instrumentation for the temporary works scheme also needs to comply with the instrumentation requirements. All excavations shall include Type A, B and C monitoring arrays, as shown in Figure 7 on the following basis:

- **Array Type A** for every 50 m. / 10 m. for cut and cover method / NATM partial cut and cover method of perimeter wall.
- **Array Type B** for every 100 m. / 50 m. for cut and cover method / NATM partial cut and cover method of perimeter wall.
- **Array Type C** for every 200 m / 100 m for cut and cover method / NATM partial cut and cover method of perimeter wall.
Vibrating wire rebar transducers shall be installed in those retaining walls where the Type B or C monitoring arrays. One pair of brother bar shall be installed at the specific depth needed to be observed. Vibration monitoring shall be also carried out for all structures in the zone of influence and/or close vicinity of the excavation zone. The monitoring is also needed where the construction activity involves processes which are likely to result in significant vibrations and where the vibration could adversely affect adjacent buildings, structures or equipments. Moreover, it shall be carried out continuously where any construction activity is carried out near to sensitive buildings, structures, equipment and existing MRTA system. The vibration monitoring typically installs on the ground floor and the highest floor of the buildings. In addition, if the building has more than 4 floors, vibration sensors shall be installed on intermediate floors for every 4 floors. The vibration sensors shall be able to measure in three directions.

Every underground station shall have 3 nos. of heave indicator locations installed at the base of excavation.

5. Automatic and real-time technology

Based on experiences learned during the construction of previous excavation and tunneling projects, instrumentation data always take a long time to process and to deliver to decision makers. This often leads to excessive ground deformation causing significant damages to surrounding structures; in fact, in some cases, collapse occurred before the engineer receives any warning caused by the delay of instrumentation reports [5]. Therefore, this project will adopt automatic and real-time instrumentation system to guarantee that all important observation and data will deliver to one who is in charge as quick as possible so that any counter measure can be done beforehand. Wireless system and electronic system are also encouraged. Additionally, some partly-manual instruments can also be used for measuring at site locations and then send data to monitoring office by today communication.
media such as ADSL, GPSR and WI-FI etc. Moreover, this project has camera monitoring system, operate 24 hours for real-time monitoring of construction activities and safety. The system shall have a network base system via local, wide and metro area network. The cameras at any standalone site shall be managed from the Central Control Station (CCS) which has a server and controlling facilities to view images on-line and to integrate with other instrumentation (i.e. surface and building settlement markers, inclinometer) recorded at the concerned area. The CCS shall distribute the images and the instrumentation records to the Employer/Employer Representative on the real-time basis in order to secure the safety of the project.

6. Conclusions
The Bangkok MRTA Blue Line Extension Project is one of the most challenging underground projects in an urban environment because there are many expected difficulties such as narrowed road, congested area, large community, old buildings with poor supports and sensitive historical building/area. All of this makes the construction very difficult. Furthermore, a variety of construction techniques such as Shield Tunnelling, Cut and Cover Method, and NATM will be adopted depending on constraints. To achieve the safety during and after construction, the instrumentation and monitoring play a significant role. Thus, extensive instrumentation is needed based on specific locations and construction procedures. Monitoring shall be reported on real-time basis to guarantee quick response of contractor and owner.

References