# DESIGN AND CONSTRUCTION OF FLOOD PROTECTION SYSTEM FOR BANGPA-IN INDUSTRIAL ESTATE

Teerawut Juirnarongrit[1], AmnarjYanuviriyakul[1], and Veerayut Kolvilas[1]

[1]Geotechnical & Foundation Engineering Co., Ltd, a member of TEAM GROUP, Bangkok, 10230, Thailand

**ABSTRACT.** Bangpa-in Industrial Estate, an industrial park in partnership between government sector: Industrial Estate Authority of Thailand (IEAT) and private sector: Bangpa-in Land Development Co., Ltd., was affected by the crisis of severe flooding in 2011. As a result of the unexpected large volume and heavy flow of water, the original flood protection dike was overtopped causing dike failures at two locations and on October 15, 2011 the industrial park was fully inundated.

Bangpa-in Industrial Estate appointed TEAM Consulting Engineering and Management Co., Ltd. as the Engineering Design Consultant to carry out flood study and to obtain an optimal engineering and economic design of the Flood Protection System. Based on the flood study, the level of flood protection is needed to be increased from +4.00m MSL to +6.00m MSL. The new flood protection system was designed to ensure the stability, durability and safety during flooding. It consists of a well-compacted earthen dike topping with a 1.6-m high reinforced concrete flood wall. By raising the level of flood protection along with enhancing the strength and stability of the dike, the new flood protection system will be capable of protecting the industrial park from future potential flooding with confidence. This paper presents the background of 2011 Thailand flood, results of flood study, as well as the design and construction of flood protection system for Bangpa-in Industrial Estate.

**Keywords:** Flood Protection, Dike, Flood Study, 2011 Thailand Flood

## INTRODUCTION

In 2011, five major storms hit the northern part of Thailand. The first storm is Maima on June 25 followed by Nook-Ten on July 3. Nook-Ten almost filled up the capacity of two major dams in the upper Chao Phraya basin namely, Bhumibol Dam and Sirikit Dam. During 8 days from September 28 to October 5, there were three consecutive storms that hit the northern part of Thailand and totally filled up all the storage capacity of Bhumipol and Sirikit dams as shown in FIGURE 1. Large amount of water had to be released daily to avoid dam break. The large water release from the dams is the major cause of flooding in 2011.

Bangpa-in Industrial Estate, which is located in the lower Chao Phraya river basin, was also affected by the crisis of severe flooding in 2011. Heavy storms with long period of rainfall in the Northern and the Central parts of Thailand created large amount of flood volume in the flood plain of the Chao Phraya River Basin. The flood water in the north moved downstream through the central area to drain into the sea. As the drainage capacity of the river could not cope with the huge flood, water spilled over both river banks. The flood water spread over very large area, inundating urban and rural areas including communities, agricultural areas and industrial estates. The flood situation is shown in FIGURE 2. The flood overtopped the protection dike of Bangpa-in Industrial Estate and subsequently caused the dike failures at 2 locations on October 15, 2011. All factories inside Bangpa-in Industrial Estate were then entirely inundated.

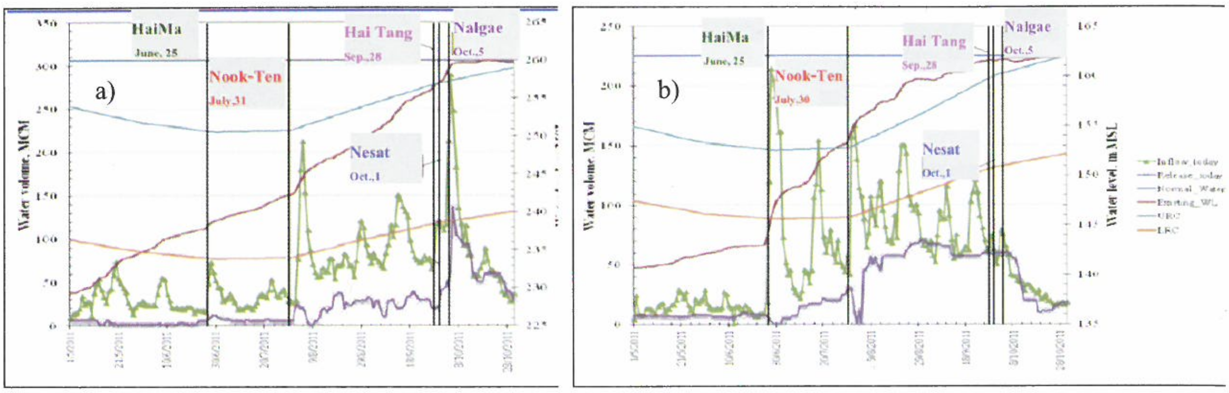



**FIGURE 1.** Water level and water volume in a) Bhumipol dam and b) Sirikit dam before flood in 2011

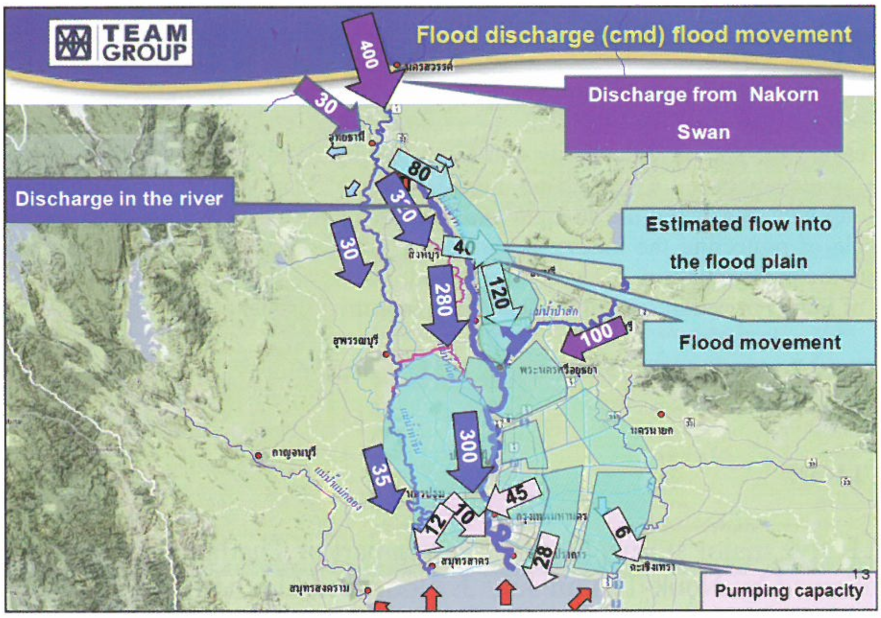



**FIGURE 2.** Flood situation in the lower Chao Phraya river basin

## PROJECT BACKGROUND

Bangpa-in Industrial Estate is an industrial park in partnership between government sector: Industrial Estate Authority of Thailand (IEAT) and private sector: Bangpa-in Land Development Co., Ltd., It is located at Bangpa-in District, Ayutthaya, Thailand as shown in FIGURE 3. The Industrial Estate has its own flood protection dike with 10 km in length to protect against flood from outside. There is a main entrance located at Udomsorayuth road. The industrial estate also has internal drainage system to prevent flooding from rainfall in its own area. The existing flood protection dike is a close system with the dike level of about +4.1 m above mean sea level (MSL). The water from rainfall is collected by the internal drainage system which consists of a retention pond and 11 pumping units each of 0.5 cubic meters per second capacity.

FIGURE 4 shows the condition of existing dike after the 2011 flood. From this figure, it can be observed that approximately 1 m in height of earthen bun was constructed above the existing dike to increase the level of protection during flooding. However, due to time constraint, the earthen bun was constructed from excavated soil with high water content and had no time for soil compaction. As a result, the dike was not strong enough to resist water pressure for a long period of time and earthen buns at some locations were damaged and flood water overtopped into the industrial estate.


**FIGURE 3.** Location map of Bang Pa-In industrial estate

**FIGURE 4.** Condition of existing dike of Bang Pa-In industrial estate after 2011 Flooding in Thailand

## GEOTECHNICAL INVESTIGATION

A total of 26 boreholes at approximately 500 m interval along the perimeter of existing dike were performed to obtain geotechnical condition of the dike as well as subsurface condition of the project area. In addition, a series of field permeability of existing dike were performed to evaluate if the existing dike can continue to be used as flood barrier or some improvement is necessary to be conducted.

Based on the soil investigation data, the subsoil condition generally consists of a crust layer with a thickness of 1-2 m underlain by a 3-6 m thick soft to medium stiff clay overlying a stiff to very stiff clay to the end of boring (20 m depth). Since the soil condition consists of a very thick clay layers, seepage problem underneath the foundation soils is not expected.

According to the permeability test results, it was found that about 30% of the upper 1-1.5 m of the existing dike has coefficient of permeability above the design requirement indicating that the capability in resisting water seepage does not meet engineering standard. The results suggested that the upper 1.5 m of existing dike must be removed and recompacted to obtain the required density and to ensure that the dike becomes well impervious as required. For the lower part of the dike, the results indicated that over 90% is still in good condition and can continue to be used without any improvement. However, it was decided by the client that all of existing dike would be removed and reconstructed to ensure the safety against future floods.

## DESIGN OF NEW FLOOD PROTECTION SYSTEM

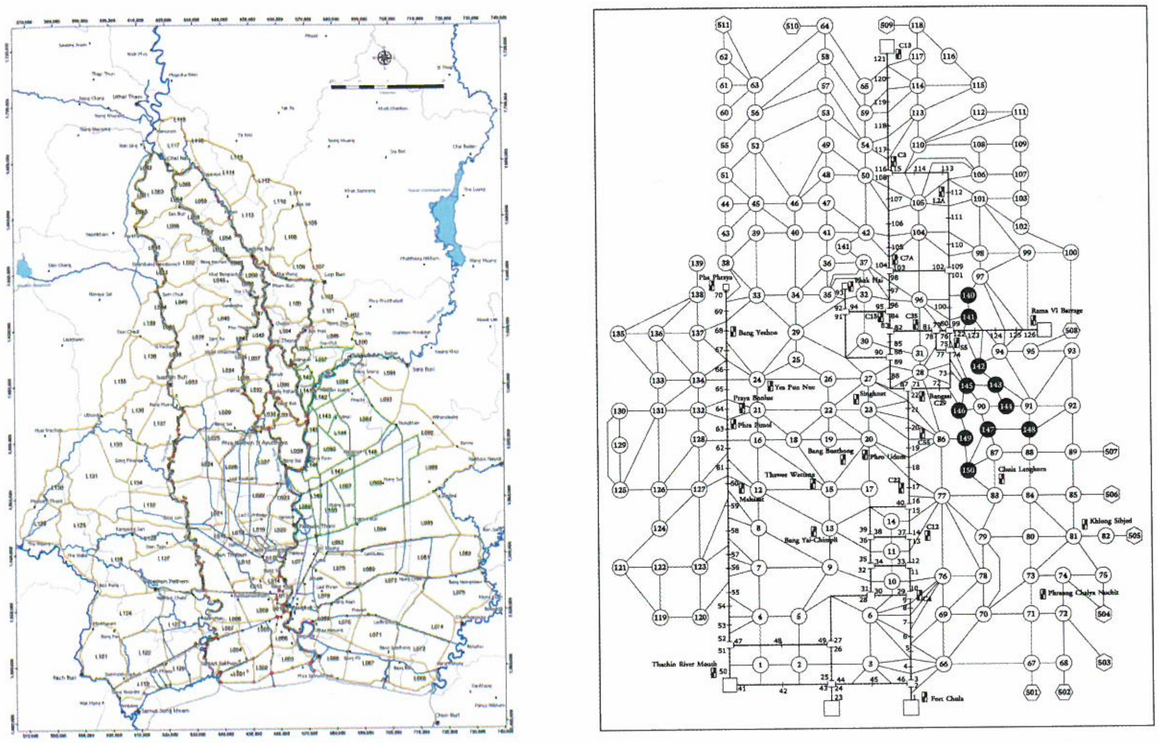
### Design Flood Level

To identify the situation of flooding in the river with overflow to flood plain, a simplified 2D model (quasi two-dimension model) called River Network model was used as shown in FIGURE 5. The model area covers the lower Chao Phraya river basin, the Ta Chin river basin and the Pasak river basin. The model was calibrated against 2011 flood condition. The calibration results show good agreement between the computed water levels from the model and the observed water level especially in the river and therefore the model is reliable to predict the design flood level.

The calibrated model was used to compute the design flood level. The climate change condition was also considered for this study for the next 50 years (2061) and 100 years (2111) conditions. The climate change condition will increase rainfall volume in the river basin and uplift the sea level in the gulf of Thailand. The increasing of rainfall volume and the sea level rise give negative effects to the flow of water in the Chao Phraya river and resulted in increasing flood level in the Chao Phraya river basin. From the study report of World Bank in 2009, the climate change effects for the lower Chao Phraya river basin in 2061 are 3% rainfall volume increasing and sea level rise of 0.29 m. For 2111, the rainfall volume will increase by 7% and sea level rise of 0.58 m.

The design of flood protection dike level usually fixed based on 100-year return period. For industrial estate in Thailand, the new Industrial Estate Authority of Thailand (IEAT) regulation suggests 70 years return period for dike level design. To design the new flood protection dike level for the industrial estate in Thailand, it is suggested that the most severe case which is 100-year return period with climate change to year 2111 plus free board should be used. The free board is usually added for water fluctuation in canal or river and long term residual settlement of the dike. For Bangpa-in industrial estate, 1.00 m of freeboard was used.

TABLE 1 summarized the design flood level used for Bangpa-in industrial estate compared with design criteria required by IEAT. It can be observed that Bangpa-in industrial estate used more stringent design criteria than IEAT's recommendations in order to build up the confidence of factories' stakeholders with highest level of flood protection of the new flood protection system.



a) Physical layout b) River Network model

**FIGURE 5.** Physical layout and schematic diagram of River Network model for Lower Chao Phraya river basin

**TABLE 1.** Comparison of Design Criteria Required by IEAT and used for Bangpa-in Industrial Estate

| Topic | IEAT Design Criteria | Design Criteria Used for Bangpa-in Industrial Estate |
|---|---|---|
| FloodReturnPeriod | > 70 Years | 100 years with considering climate change effect(Yr 2111) |
| DesignFloodElevation | > 4.30 m MSL. | 5.00 m MSL. |
| Freeboard | > 0.50m | 1.00 m |
| Design Elevation of Flood Protection System | >4.80 m MSL. | 6.00m MSL. |

## Selection of Flood Protection System

Since the average height of existing dike is at +4.00 m. MSL which is lower than the design flood elevation, +5.00 m MSL, it is therefore necessary to increase the height of flood protection system to be capable of preventing the design flood level. Typically, there are three different types of flood protection systems being used as shown in FIGURE 6.

Type 1: Earthen Dike or Embankment
Type 2: Reinforced Concrete Structure/ Wall
Type 3: Hybrid System (Combine Type 1 and Type 2)

Each type has different advantages and disadvantages and it is necessary to carefully consider for selecting the best solution for the industrial estate. The area around the existing dike is quite limited and most of the dikes are already next to the property lines or factory boundaries in the industrial estate. Increasing height of flood protection system by using Type 1 will require more space to extend the base width of the dike and that is practically not possible for this case. Although, Type 2 requires much less space than Type 1, the construction cost for this flood protection system is significantly more expensive than others. Furthermore, a large amount of materials of the existing dike will need to be removed from the site resulting in increase of environmental effects to community.

Therefore, Type 3 which combines the features of Type 1 and Type 2 was chosen for the industrial estate. With the selection of Type 3, the existing dike materials can be reused and the space required for construction of this type is almost the same as the original dike. There are 2 alternatives for Type 3 (i.e., I-Wall on Dike and T-Wall on Dike). Since after Hurricane Katrina, several failures of this type of flood protection dike were found as shown in FIGURE 7 and therefore USACE has proposed not to use it until completed improvements on this design are developed. Therefore, T-Wall on dike was chosen for this project. The schematic of flood protection system for Bangpa-in industrial estate is shown in FIGURE 8.

The flood protection system was designed to have sufficient height to resist the maximum design flood level. In addition, the dike and RC wall was designed to be safe against slope instability, sliding, and overturning as well as can prevent seepage of water through the dike and underneath the foundation soils in all load cases. The features of the new flood protection system can be summarized as follows.

- The compacted earthen dike is at El. +4.40 m MSL which is higher than the measured 2011 maximum flood elevation (i.e., EL. +4.28m MSL). There is also a 1.60 m high RC flood wall placing on top of the dike giving the total flood protection level of +6.00 m MSL which is sufficient to resist 100 year return period flood with considering the effect of climate change.
- The dike material is made of compacted clay which is impervious and excellent for preventing seepage through the dike.
- Since foundation soils consist of a very thick clay deposit, it is excellent for preventing seepage through the foundation and therefore no any improvement on foundation soil is required. However, to eliminate risk of having other permeable fill material as a thin layer of sand, a 1-m deep concrete cut off trench was introduced in the design at the water side of the slope toe to increase the creep path and minimize possible seepage.
- Toe drain on the land side was introduced in the design to assist in lowering phreatic line inside the earthen dike and hence prevent slope instability on the land side when subjected to long duration flood.
- Geotextile spread underneath the RC flood wall will serve as a filter layer to prevent piping of soil particles at the interface between RC wall and dike.
- The concrete lining on both sides of slope will serve as erosion protection to the soil slope surface, reduce the amount of seepage through the dike, protect animals from making their habitats inside the dike.
- In case of emergency, excess water can spill inside the U-shape RC flood wall and drain to internal drainage system in manageable manner. This is to avoid damage from overtopping.

- Service road is constructed along the dike to serve as emergency access to the dike during flooding and also to be used for inspection and maintenance during normal period.

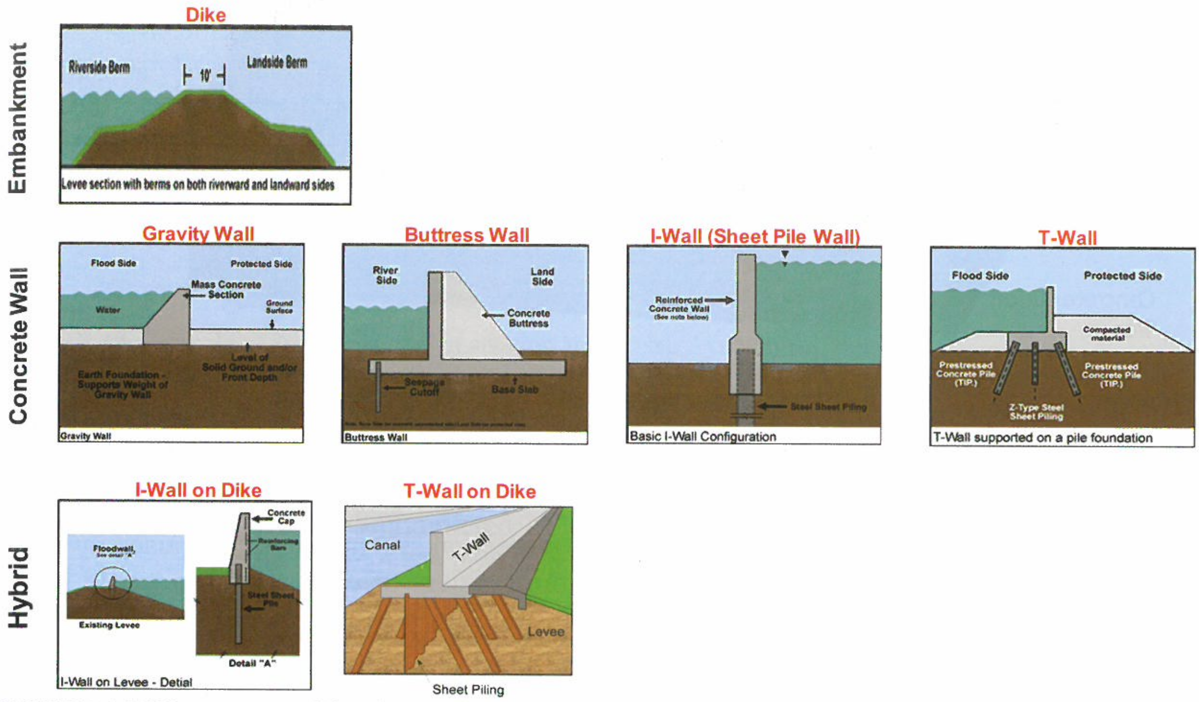



**FIGURE 6.** Different types of flood protection system

**FIGURE 7**. Examples of failed I-wall on levee after Hurricane Katrina (Photos Courtesy of ASCE)

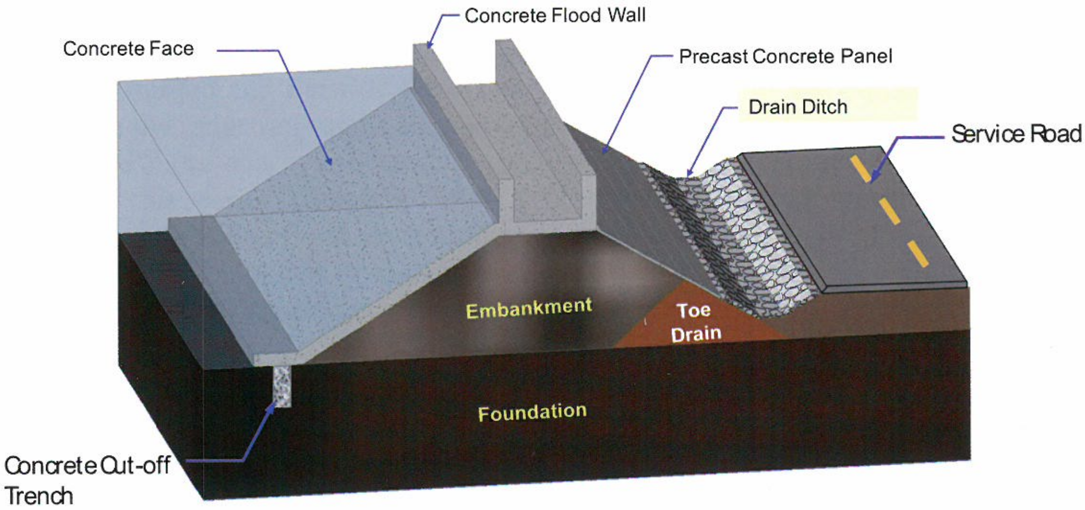



**FIGURE 8.** Typical section of new flood protection system

## Flood Protection System at Entrance

At the main entrance, the height of flood protection system cannot be raised up as the typical flood protection system design because the gradient of entrance ramp would be too steep for vehicles and trucks to enter. Therefore, stop logs was introduced to be used at the main entrance as shown in FIGURE 9. These stop logs offer a lightweight, strong and rapidly deployed flood protection system. The stop log panels are stacked in multiples of 400mm allowing us to increase or decrease the level of flood protection in short period of time as water levels rise and fall. The silicone sponge gasket ensures the stop logs maintains its watertight integrity on almost any surface. This flood protection system has been tested successfully for its capability in maintaining 2 m high of water for a pilot study in Bangsai, Ayutthaya as shown in FIGURE 10.

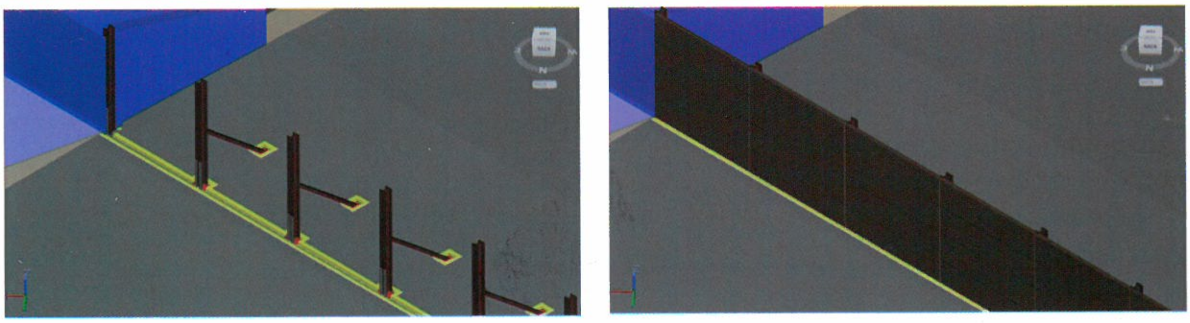


**FIGURE 9.** Stop logs at main entrance of BPI


**FIGURE 10.** Example of Stop Logs Implementation at Bangsai, Ayutthaya

## CONSTRUCTION

The construction started immediately after the flood in December 2011. The compacted earthen dike was completed in July 2012 and capable to resist the 2011 flood water level. The RC flood wall has completed in February 2013 with a total construction time of 15 months. The other construction works such as service road, internal drainage system and reinstallation of pumping stations will be completed by the end of 2013. The followings summarize the sequence of construction of flood protection system for Bangpa-in Industrial Estate (see also FIGURES 11 through 18).

- Remove existing earthen dike to the original ground level and prepare area for spreading soil and compaction.
- Construct concrete cut-off trench at the toe of the dike on the water side. The trench is 0.50 m wide and 1.00 m deep.
- Compact earthen dike layer by layer to the required density at 95% Maximum dry density of standard proctor until getting the required height.
- After completion of dike compaction, excavate trench for concrete keys of the RC flood wall and spread geotextile on top of the dike. Then install steel reinforcement and pour concrete keys.
- Install steel reinforcement of RC wall. In this project slip formworks were used in order to speed up the construction.
- Install expandable water stop at the expansion joint every 10 m interval to prevent water leakage through the joint from future differential settlement.
- Install drainage material at the toe of dike Construct concrete lining on both sides of soil slope for preventing erosion from rain and flood.
- Construct drainage ditch to collect and drain water from rain and seepage flow from the dike during flooding.
- Construct service road and accesses to the dike for future inspection and maintenance.

**FIGURE 11.** Removal of existing dike

**FIGURE 12.** Construction of concrete cut-off trench to prevent seepage

**FIGURE 13.** Soil compaction to required elevation (El. +4.40 m MSL.)

**FIGURE 14.** Trench excavation and spreading of geotextile before concreting

**FIGURE 15.** Concrete lining at side slope for erosion protection

**FIGURE 16.** Preparation of Steel Reinforcement and concreting using slip formwork

FIGURE 17. Water Stop at expansion joint of RC flood wall

FIGURE 18. Completed RC Flood Wall

## CONCLUSIONS

Bangpa-in Industrial Estate, which is located in the lower Chao Phraya river basin, was affected by the crisis of severe flooding in 2011. Heavy storms with long period of rainfall in the Northern and the Central parts of Thailand created large amount of flood volume in the flood plain of the Chao Phraya River Basin. The flood water in the north moved downstream through the central area to drain into the sea. As the drainage capacity of the river could not cope with the huge flood, water spilled over both river banks. The flood water spread over very large area, inundating urban and rural areas including communities, agricultural area and industrial estates. The flood caused water overtopping to the protection dike of Bangpa-in Industrial Estate and subsequently collapsed on October 15, 2011. All factories inside the industrial estate were then inundated.

Bang pa-in Industrial Estate appointed TEAM Consulting Engineering and Management Co., Ltd. as the Engineering Design Consultant to carry out flood study and to obtain an optimal engineering and economic design of the Flood Protection Management System. The new flood protection system consists of a well-compacted earthen dike topping with a 1.6-m high reinforced concrete flood wall. The new flood protection system has the level of protection at +6.00 m MSL which is 2 m higher than the original flood protection dike and approximately 1.3 m higher than the 2011 maximum flood elevation. The design flood level was based on 100 year flood return period with considering effect of climate change and 1.00m freeboard.

The construction of the flood protection system started in December 2011, and completed in July 2012 with a total construction time of 15 months. With an increase in the level of flood protection along with enhancing the strength and stability of the dike, the new flood protection system will be capable of protecting the industrial park from future potential flooding with confidence.

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