

STORMWATER MANAGEMENT AND ROAD TUNNEL (SMART) PROJECT

STORMWATER MANAGEMENT AND OPERATION

BY

Ir. Ng Koh Hing, Ir. David N. Welch & Subathra Devi Ramachandram

Sepakat Setia Perunding (Sdn.) Bhd

ABSTRACT

The Stormwater Management and Road Tunnel (SMART) is an avant-garde and cost-effective solution that addresses two evident issues in Kuala Lumpur Central Business District (CBD): major flooding caused by heavy downpour during the monsoon seasons and severe traffic congestion along city streets during peak hours. Its dual-purpose tunnel will divert floodwaters away from the confluence of the two major rivers running through the city centre while its central section will double up as a two-deck motorway to relieve traffic congestion at the main southern gateway into the city centre.

This paper specifically discusses the operation sequences for the various components within the SMART system especially the bypass tunnel and how these components are designed to provide the first of its kind dual-purpose tunnel in the world with an effective and fail-safe operation.

1.0 INTRODUCTION

The stormwater component of the SMART system is designed and operated as a fully automated system. The system diverts flood water from entering the critical stretch of Sungai Klang immediately after the confluence of the two main rivers via a holding pond, the bypass tunnel and a storage reservoir. The stormwater tunnel between the holding pond and the storage reservoir is about 9.7 km long and runs beneath the city limits, mostly under public roads. The three kilometer motorway mid-section of this tunnel directs traffic into and out of the motorway from the existing and congested stretches of Jalan Tun Razak and Kuala Lumpur-Seremban highway.

A sophisticated flood detection system (FDS) has also been designed and developed to function as the nucleus of the SMART system. This system provides real time flood prediction to determine the severity of the flood events to enable the selection of the appropriate mode of operation for the tunnel system. The FDS also plays a major role in piecing together the various individual physical components of the project to work together as an integrated system.

2.0 PHYSICAL COMPONENTS OF THE SMART STORMWATER SYSTEM

The SMART system is a sequence of storage, attenuation and regulated flow. The system diverts flood discharges from the city centre and subsequently releases them downstream while ensuring the flood problem is not transferred elsewhere. The system also optimizes the storage, attenuation and regulation to ensure no overflow shall occur within and adjacent to the system. The main physical components of the stormwater bypass system are the intake system of SMART (see figure 1) and the outlet system of SMART (see figure 2) which include the following:

- A debris removal system complete with floating booms, a trash rack, a debris removal and disposal unit each in Sg Ampang and Sg Klang upstream of the confluence of the two rivers (see figure 3).
- A river flow diversion system complete with a 4-bay diversion weir structure and an 8-bay offtake structure. This system regulates the flow in Sg Klang by means of a weir type structure, complete with hydraulically actuated radial gates.
- A Holding Pond with a storage capacity of 600,000 cubic metres located at the upstream of the tunnel. Flow is directed into this pond via the offtake structure (see figure 4).
- A 9.8 km long, 11.8 m internal diameter stormwater diversion cum double deck road traffic tunnel (see figures 5 & 6). The tunnel has a storage capacity of approximately 1,000,000 cubic metres when it is flowing full. When the water level in the Holding Pond reaches a level of 34mLSD, flow enters the tunnel via a bellmouth tunnel intake structure.
- A storage cum attenuation pond with a storage capacity of 1,400,000 cubic metres is located at the downstream end of the tunnel. At slightly upstream of the outlet of the tunnel outfall structure, there is another set of gates used to isolate the tunnel from the storage reservoir. The purpose is to stop backflow from the storage reservoir and enable the tunnel to be dewatered between storms.
- A set of twin box culverts, gated at both ends conveys the discharge from the storage reservoir to Sg Kerayong whenever the water level in the river is at a permissible level.
- An outfall structure to discharge water from the downstream storage reservoir into Sg Kerayong.
- A vehicular tunnel enters the diversion tunnel system approximately 4.6 kilometres downstream from the holding pond and exits a further 3 kilometres downstream. The section of the tunnel where the vehicular traffic is included will have three main compartments i.e. 2 traffic decks and a lower channel for stormwater flow (see figures 5 & 6).

3.0 OPERATION OF THE SMART SYSTEM

3.1 Non Flood Operation of the SMART System

Between floods when the SMART system is not in use, the following conditions will prevail:

- All stormwater service and emergency gates will be closed and the road decks will be used for traffic.
- The Klang Offtake gates will be closed and all flow from Sg Klang and Sg Ampang will be passed downstream.

- The water level in the Holding Pond will be drained to provide 600 000 m³ storage in the pond.
- The tunnel outfall gates will be closed and water in the tunnel will be pumped out into the Attenuation Pond, thus maximizing the available flood storage.
- The water level in the Attenuation Pond will be drained and maintained to the level of the twin box culvert (approximately 20.0 mLSD).

3.2 Operating Rules for Flood Diversion into SMART

A flood detection system has been set up to provide advance warning of floods and their likely severity so that timely decisions can be made for the closure and evacuation of the traffic tunnel.

When a flood occurs, the flow right after the confluence of Sg Klang and Sg Ampang is monitored and the following rules are used to control the diverted flows:

- a. When the flow exceeds 70 m³/s, the Offtake gates are opened to send flow into the Holding Pond and the diversion gates are operated so that the flow that is sent downstream of Sg Klang is controlled at 50 m³/s.
- b. When the flow exceeds 150 m³/s, more flow is diverted into the Holding Pond so that the flow that is sent downstream of Sg Klang is controlled at 10 m³/s. This is necessary due to the additional discharges that are contributed by various other sources downstream of the diversion.
- c. The discharge from the Attenuation Pond through the twin box culverts and eventually the outfall structure will be controlled by regulating gates at the outfall structure so that the total flow in Sg Kerayong does not exceed 300 m³/s and so that the discharge from SMART does not exceed 200 m³/s. In practice, these regulating gates will probably remain closed until the peak flows in Sg Kerayong has passed and there is sufficient capacity in the river.

Once the flood detection system indicates that a major flood is expected, requiring the use of the road decks, the road tunnel evacuation procedures will be commenced. The evacuation process as well as the closing down should take approximately 45 minutes. This provides enough time for the ingress / egress road gates in the tunnel to be closed and for the water gates to be opened before the flood flow reaches them.

The following points about the peak capacity of the system should also be noted:

- The SMART system is not merely a flood diversion system. The storage, attenuation and regulation within the system is crucial to its ability in minimizing flooding.
- The maximum flow that the SMART tunnel can handle (with all road decks open and available) depends on the water levels in the storage ponds. As the Attenuation Pond fills, the flow capacity of the tunnel reduces.
- It is important that releasing discharge into Sg Kerayong is started as early as possible and not delayed when there is capacity available in the river.

3.3 Operation Modes for the Tunnel

The SMART system has three modes of operations (see figures 5 & 6), i.e.:

MODE I	All stormwater flows through city centre. No diversion of water into the tunnel is required.
MODE II	Stormwater is diverted into the Holding Pond, flowing through the upper barrel of the stormwater tunnel, the lowest drainage chamber provided in the traffic tunnel, the lower barrel in the stormwater tunnel and the Attenuation Pond before discharging into Sg Kerayong. Vehicles within the traffic decks remain uninterrupted. The traffic tunnel will be isolated from the flood tunnel by a set of watertight flood gates. Mode II is expected to operate about twelve to fifteen times a year.
MODE III	The middle barrel (vehicular decks) is evacuated of all traffic. Traffic decks will be sealed to prevent vehicular entry by using various sets of gates. Stormwater is diverted into the Holding Pond, flowing through the upper, middle and lower barrels of the tunnel, and the Attenuation pond before discharging into Sg Kerayong. Mode III is expected to be an annual event.

3.4 Tunnel Gate Operation Sequences

During a flood event, flow is diverted from Sg Klang into the SMART system to store, attenuate and regulate the flood water before releasing it into Sg Kerayong when the river is at a permissible level. When the flood diversion starts, the flow first fills the Holding Pond, then weirs over the tunnel intake structure when the water level in the pond is at 34mLSD.

Depending on the magnitude of the expected flood, the road decks may be opened to the flood waters or if not required, may remain in use by traffic. If the road decks are required, the emergency gates and the service gates in both the lower and upper decks will be opened to flood flows.

The following two sequences for operating the road decks have been defined for use under different conditions:

- Sequence 1 – Normal Opening
- Sequence 2 – Delayed Opening

See figures 7 and 8 for the sequence logic block diagram for both sequences.

3.4.1 Sequence 1

The following 2 criteria must be satisfied to use sequence 1:

1. The water level upstream of the Tunnel Outfall gate must not be more than 10mLSD.
2. The water level in the tunnel just upstream of the road decks must be lower than 26mLSD.

Evacuation of the road decks starts as soon as the Flood Detection System can provide a warning (see figure 9 for schematic of tunnel gates). If the evacuation is started by the time flood diversions starts, and when there are no delays in the evacuation of the tunnel, the gates are fully opened in sequence in the dry before floodwater reaches them. The significant features of this sequence are as follows:

- Immediately after floodwater diversion commences, tunnel evacuation is started.
- The emergency gates opening (TG1, TG10) are started as soon as the tunnel evacuation is complete. Closure of the ingress / egress road gates takes place simultaneously.
- The upstream service gate opening (TG3) starts after the downstream service gate (TG9) to ensure that during opening, the downstream gate always has an opening of at least 0.9m greater than that of the upstream gate. This also applies to the upper deck.
- Opening of the upper deck commences only when the lower deck gates have cleared the upper deck by more than 1m.
- The full capacity of the tunnel at the motorway sections are achieved when the service gates are more than half open.
- The tunnel outlet gates (TG11) operate independently of the ingress / egress road gates.

When this sequence is used, the road decks are filled progressively by the floodwater starting at the downstream end. The lower channel and road decks run full at their upstream ends before water reaches the downstream end with air being expelled from the downstream end.

3.4.2 Sequence 2

This sequence is used when either one of the 2 criteria specified for Sequence 1 is not met.

If water is already present in the tunnel at both ends of the lower deck, then the gates at both ends must be opened in a way that restricts the flow into the road decks during filling. The aim of the restriction is to limit water level in the surge shaft by limiting the flow and to avoid any risk of high surge pressures being generated.

For both the upper and lower decks, sequence 2's operation can be generally defined as follows:

- Open the downstream service gate.
- Open the upstream service gate to a preset condition.
- Wait until road tunnel is full.

- Open the upstream gate fully.

When this sequence is being used, the restricted flow through the gates at the upstream end of the road decks ensures that the deck is filled progressively from downstream to upstream and that air is expelled from the upstream end. Most of the filling takes place by water that has already passed through the lower channel.

3.5 Tunnel Draindown Sequence

The main features of the draindown process are as follows:-

1. Immediately after the flood diversions have stopped, the penstock gates at the tunnel intake are opened.
2. All tunnel gates are left open until the Attenuation Pond has drained down to 22mLSD.
3. Emergency water gates are shut and road deck pumps are started.
4. Once the road decks are drained, the service gates are closed. At this point the road decks are reopened to allow maintenance crew to commence cleaning and to prepare the traffic tunnel for reopening.
5. When the water level in the Attenuation Pond has fallen to 21mLSD, the Tunnel Outfall gates are closed and the Tunnel Outfall pumps are started.

3.6 Tunnel Outfall Gate Opening

As the flood flow reaches the downstream tunnel, through the lower culvert and the road decks, the outfall gates remain closed until the water level immediately upstream of the gates reaches a level of 18mLSD.

4.0 SEQUENCE FAILURES

The sequence for closing the ingress / egress road gates and opening the water service gates and emergency gates to flood flows have been designed to be fail safe. In the worst case scenario, if a failure in gate operation occurs, the gates should stop in their current positions and their sequence halted. The sequences do not require further action or movement to ensure the safety of the structure. The exception to this 'stop everything' rule is given for special cases below:

- Failure in the Tunnel Outfall gate opening sequence does not affect the road deck opening sequence.
- If the opening of any of the emergency or service gates is more than 75% open, then the opening sequence should continue as normal.

5.0 FLOOD ON FLOOD OPERATION

When a second flood occurs before the tunnel has been returned to its pre-flood state, the system will be operated as follows:-

1. If the second flood was predicted or arrived before the emergency gates had been closed and the road decks isolated, then no action would be required. If the second flood required the road decks to be open when the first flood did not, then the sequence selection process would be restarted and sequence 2 will be selected automatically.
2. If the second flood was predicted (and road decks were required to pass the flow) and it arrived after the flood drain down has reached a stage where the emergency gates have been closed and the pumps were dewatering the road decks, then the pumps should be turned off, the road deck water service gates closed and the opening sequence restarted from the beginning. The Tunnel Outfall gates would remain open. If the Holding pond was draining at this time, the drainage penstocks would be closed. Since the lower barrel (after the road decks) of the tunnel will already be full, sequence 2 would automatically be selected for the second event.
3. If the second flood was predicted or arrived after the tunnel has been dewatered and after the tunnel outfall gates have been closed, the system would react as follows:-
 - a. If the water level in the tunnel is greater than 16mLSD, then the dewatering pumps should be turned off and the gate opening sequence restarted.
 - b. If the water level in the tunnel was less than 13.5mLSD, the gate opening sequence should be restarted and the dewatering pumps should be left running until the water level starts to rise. At this point, they would be turned off.
 - c. If the water level in the tunnel was greater than 13.5mLSD and less than 16mLSD, the pumps should be turned off and one of the tunnel outfall gates should be opened by 0.3m. This gate should remain in this position until the tunnel gates were reopened under their normal opening position.

6.0 THE NUCLEUS OF SMART: THE FLOOD DETECTION SYSTEM (FDS)

The purpose of the Flood Detection System is to enable the safe and efficient dual use of the tunnel system for stormwater diversion from the CBD and for traffic movement.

This has been made possible through the design and development of a sophisticated system of radio telemetered hydrological data collection network including rainfall, river level, real-time flow and holding / attenuation pond water level monitoring. Data from these stations will be input in real-time to a dynamic hydrological and hydraulic model for forecasting flood potential and making recommendations for storm water diversion strategies for the SMART system. The FDS plays the major role of deciding the mode in which the tunnel will operate based on its detailed hydrological and hydraulic analysis and finding through its operation hub located in Kg Berembang, adjacent to the Holding Pond. Among the other duties of the FDS are:

- To regulate the flow in Sg Klang downstream of the Diversion Weir structure.

- To control the diversion of flow into the Holding Pond and the tunnel.
- To monitor the water pressure and flows within the tunnel via a network of pressure sensors that are placed in various critical locations in the tunnel.
- To monitor the ponds, intake and outlet structures as well as critical locations in the CBD via the CCTV network.
- To ensure that the operation of various sets of gates for the selected mode of the SMART system is in accordance with the defined operating rules.

In a nutshell, the FDS involves the collection, transmission, processing and analysis of hydrological data to forecast the storm characteristics, the result of which dictates the operation mode of the SMART system. The FDS also controls and monitors all the other physical components of the SMART system via the Stormwater Control Centre (SCC) to ensure a seamless operation of the entire system (see figures 10 for a typical display of the SMART system on the video wall at the SCC). Instruments and communication networks at critical locations are provided with built-in double and triple redundancies to ensure an effective and fail safe operation of the system.

7.0 CONCLUSION

A particular structure, or a certain system, however fantastic an engineering feat it may be, is of no use if not operated, maintained and managed efficiently. SMART not only boasts of being the only one of its kind in the world but has also earned a name as an effective answer to mitigate the flooding in the CBD as well as to relieve traffic congestion in the main southern gateway to the city. SMART was operational in July 2007 and the operation and performance of the system in meeting its objectives was evident in the recent eight (8) mode III storm events (up to the end of April 2008) where stormwater was diverted successfully from the CBD. During this period when the tunnel was utilized fully for stormwater diversion, it was observed that the traffic build-up in major roads in the CBD was overwhelming. This only further reinforces the need of the midsection of the SMART tunnel as a motorway tunnel during non-flood times to relieve the traffic congestion in the city centre.

SMART has not only protected the city centre from a number of flood events which would have caused grave economic losses and a disruption in services but also improved the public welfare significantly by reducing the traffic congestion to and from the city centre.

REFERENCES

Perrot J.M.A., "Tunnel Filling Hydraulics and Surge Analysis (Revision F) for Stormwater Management and Road Tunnel (SMART)".

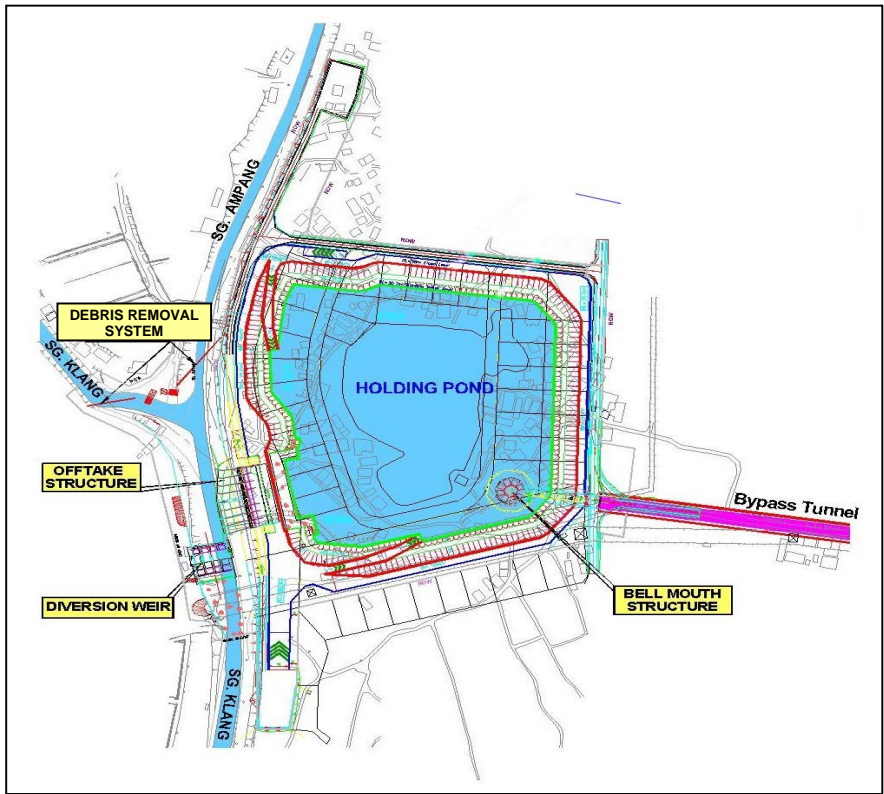


Figure 1: The Intake System of SMART

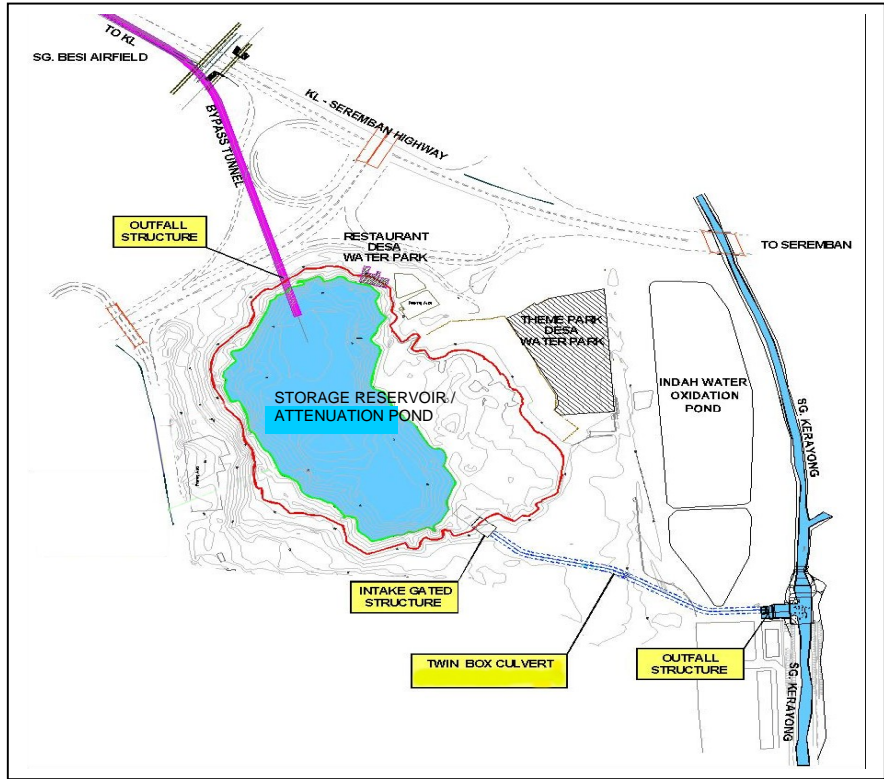


Figure 2: The Outlet System of SMART



Figure 3: The Debris Removal Systems for Sg Ampang & Sg Klang Situated at the Confluence of the Two Rivers



Figure 4: The Holding Pond: Baffle Walls with the Sg Klang Offtake Structure in the Background



Figure 5: Tunnel Operation Modes

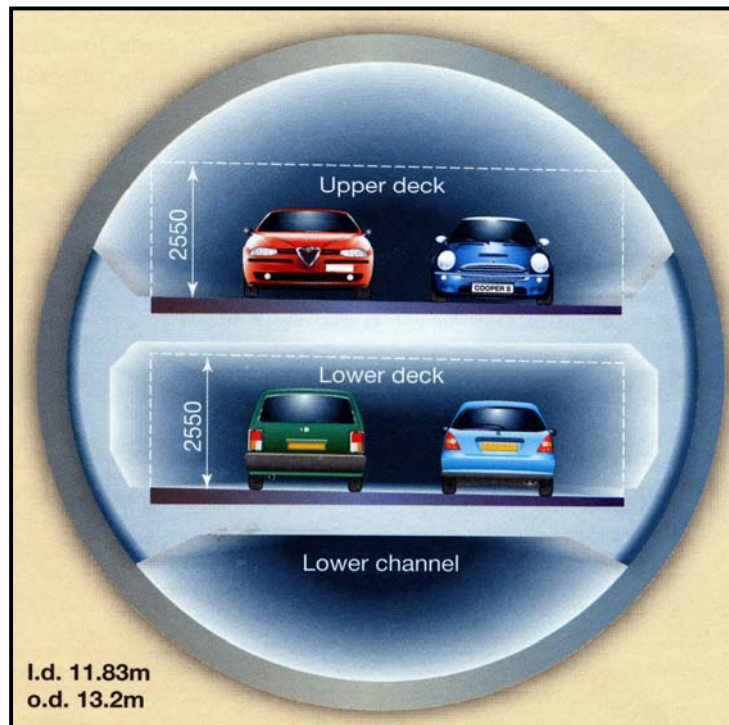


Figure 6: Cross Section of the Motorway Tunnel

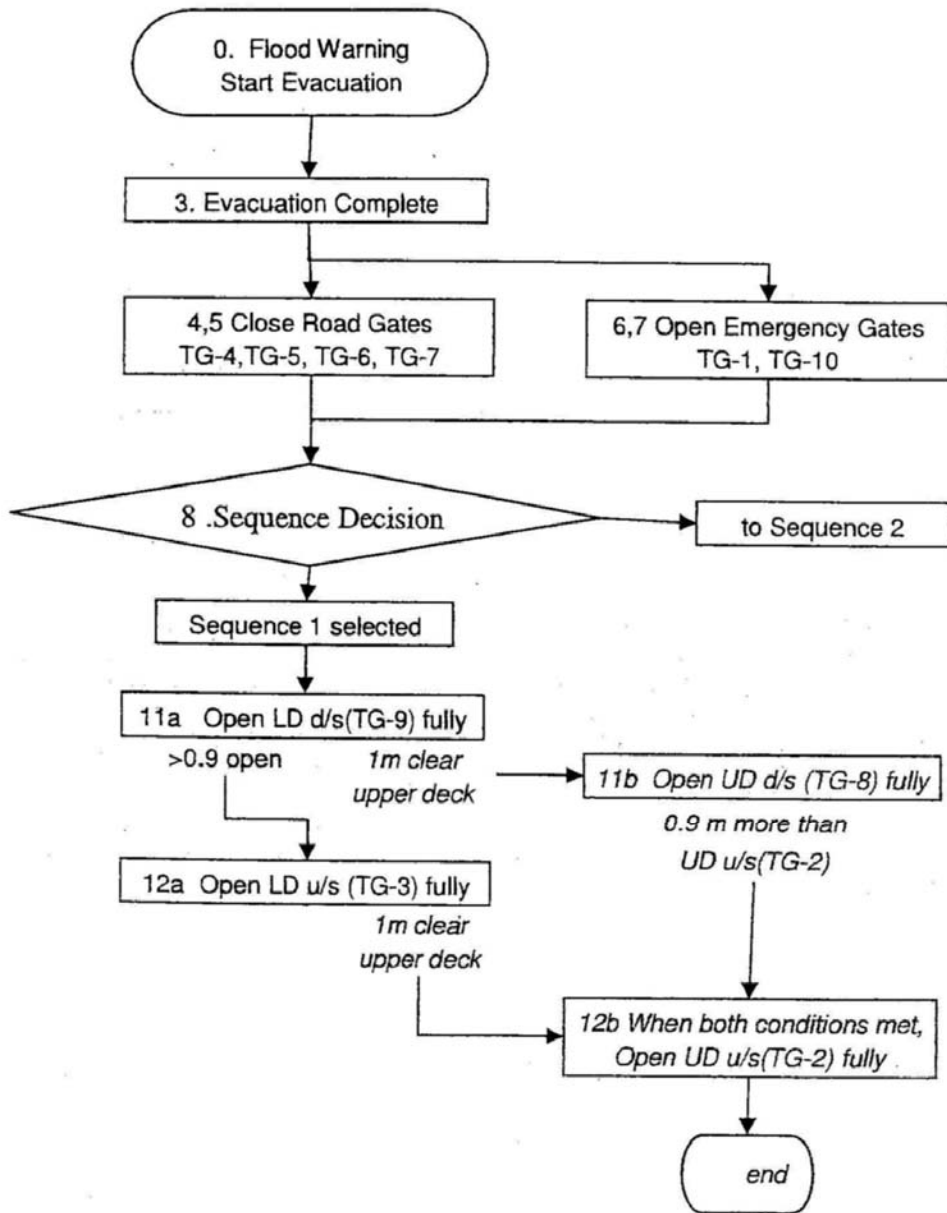


Figure 7: Sequence 1 Logic Block Diagram

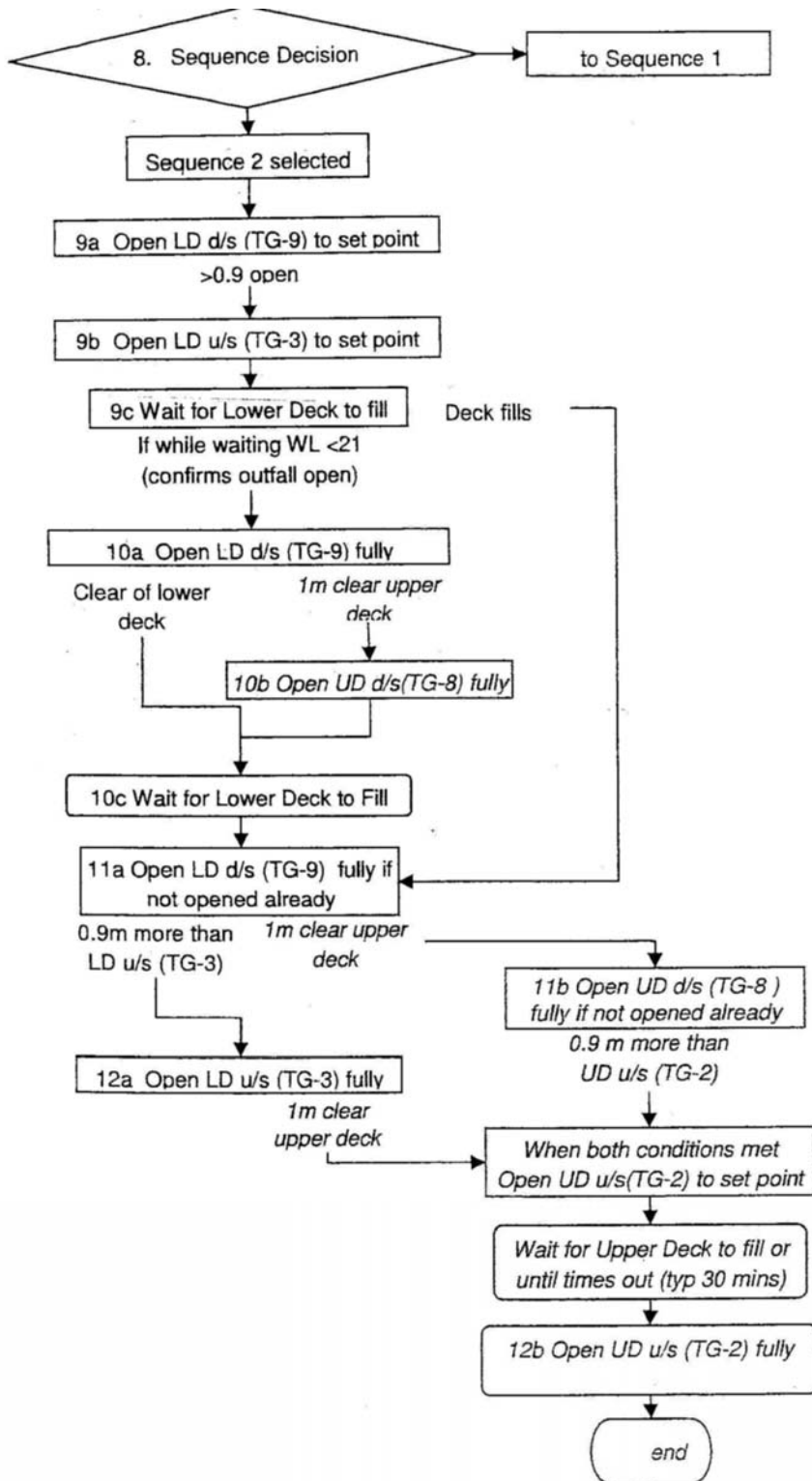


Figure 8: Sequence 2 Logic Block Diagram

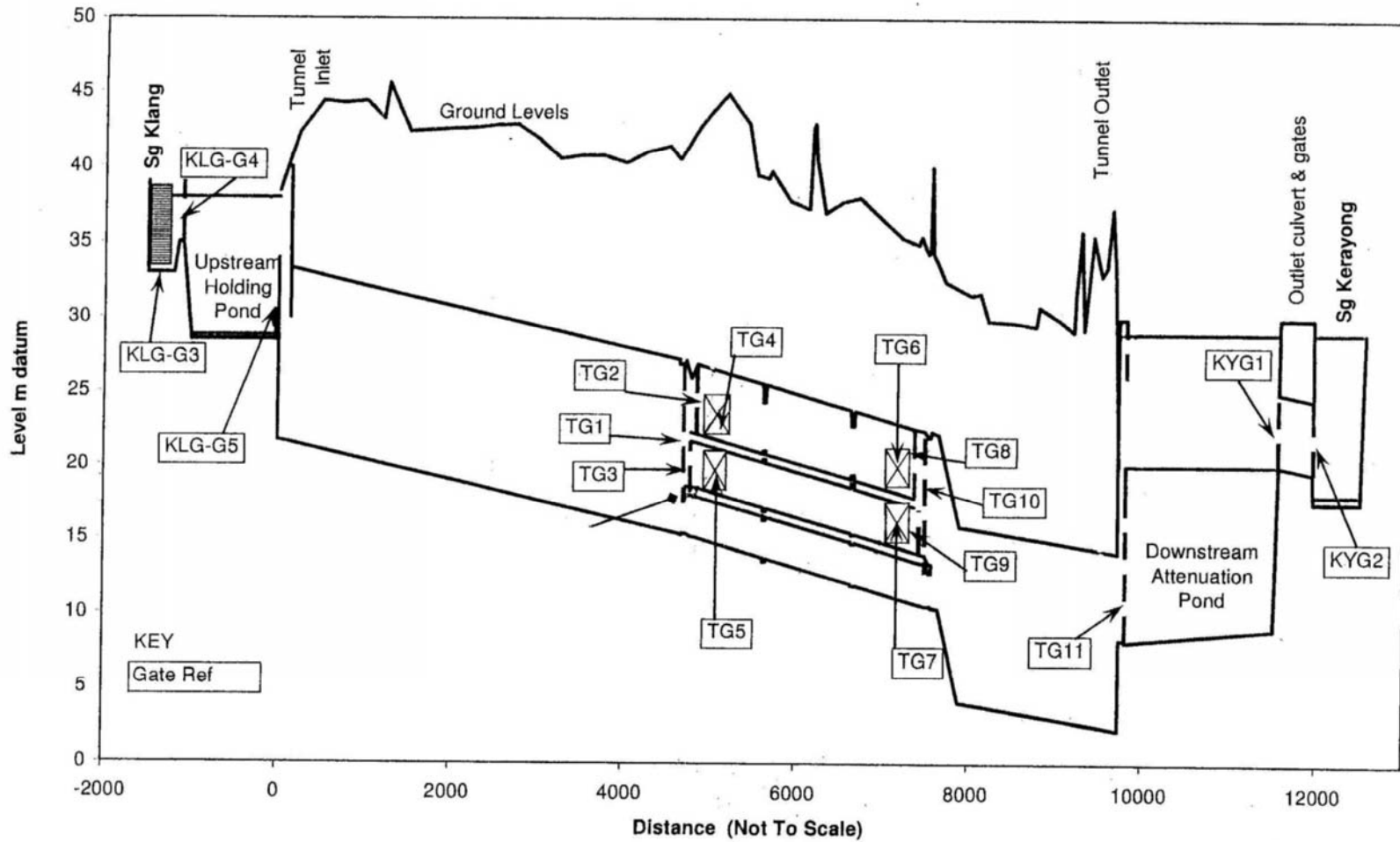


Figure 9: Schematic Layout of the Gates for the Intake System, Tunnel Bypass System and Outlet System of SMART

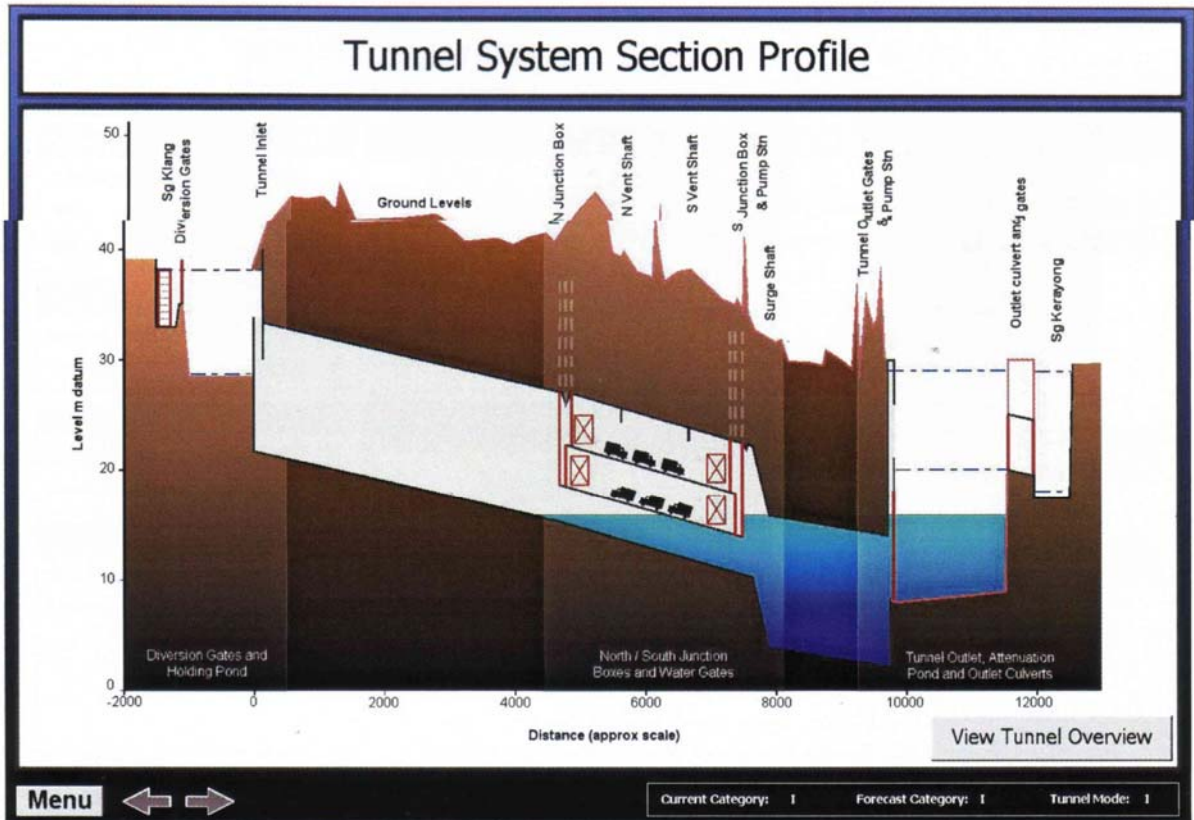


Figure 10: A Display on the Video Wall at the SCC Showing the Tunnel System Section Profile