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Physical Simulation to Determine the Surface Water Profiles and Point Velocities for The Flow Conditions of Sungai Bunus Stilling

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Abstract: Over the years, Sungai Bunus has undergone hydrological changes and has become lower and narrower. Under a flood mitigation project, a flood diversion channel is proposed to reduce the volume of water in Sungai Bunus furthermore avoid the spill over into Sungai Klang and reduce flooding events in Kuala Lumpur city. This research describes the physical modelling of the flow state of the Sungai Bunus stilling basin. Physical model was constructed to verify the design criteria of the stilling basin that will be adopted for construction. Experimental work has been carried out both with and without piers under three specified discharges (52 L/s, 86 L/s and 121 L/s) and subsequently the measurement of the water surface height profiles and point velocities through the proposed system. Consequently, there are no significant differences of outcomes between the two circumstances. The results show that there is no overflow of water at discharges of 52 L/s and 86 L/s. The water level at the Sungai Bunus section starts to flood on one side of the package when the flowrate is 121 L/s both scenarios. All test conditions with and without piers shown that the point velocity measured at the beginning of the stilling basin (inlet) is much lower than the point velocity reported near the end of the stilling basin (outlet).

Keywords: Physical modelling, flood diversion, stilling basin, point velocity, water surface height profiles

1. Introduction

While Kuala Lumpur has had yet to witness another massive flood since the 1970s, flash floods have recurred over the years. The worst flash floods happened in 2007, during which many sites in the region became buried under a meter of water. Areas such as Jalan Masjid India, Jalan Ipoh, Kampung Baru, Kampung Chubadak and Sentul were severely affected at the time. The following major flash floods of a similar proportion occurred in 2011 and 2012, which damaged major roads surrounding Jalan Tun Razak due to a spillover from Sungai Bunus. In 2011 and 2012, the rains exacerbated the Sungai Bunus Flood Mitigation Program carried out by the Department of Irrigation and Drainage (DID) at the beginning of 2013. The scheme is an integrated initiative under the River of Life (ROL) programme and the Regional Agenda 21 plan of Kuala Lumpur City Hall [1]. This project was initiated to alleviate regular flooding in the Sungai

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Bunus catchment area. The old existing catchment area of Sungai Bunus (known as *lencongan lama*) built in 1968 could not bear the current capacity [2]. Kuala Lumpur like other urban areas has experienced changes in the hydrodynamic conditions due to land use changes causing the level of overtopping to deviate from the initial design considerations [3].

Therefore, modification to the present structures is required to find an effective solution for flood problem in Sungai Bunus catchment area. Moving water usually contains a large amount of energy, particularly during a flood event. This energy will induce corrosion at the source, which can lead to instability in the hydro-environment. To overcome the problems, a stilling basin is selected as a flood diversion channel for Sungai Bunus. A stilling basin is a hydraulic structure that is usually located below dam's bottom outlet, chutes and culverts for the purpose of energy dissipation or storage [3], [4]. Nevertheless, in this study the main function of stilling basin is for flood diversion channel besides its purpose to dissipate the energy of the flood water during flood events. A stilling basin helps preserves the specific area from flooding and depletion [5].

However, failure to properly design, install, or maintain a stilling basin could lead to problems such as undermining and erosion of the outlet channel and/or embankment material. Physical simulation is widely used during design processes to refine the system and ensure a safe function of the framework [5]. This method is used alongside computational modeling to achieve great success in the studies and evaluation of fluid-structure interaction and dissipation potential [1], [5]. Physical model testing is recommended for any hydraulic structure in which the geometry differs from the recommended standards, in particular where prior experience with them is not available. Design research may also be used to identify solutions to problems in current systems. If a problem's cause is unknown, identifying the cause and seeking solutions may be economical by concept experiments rather than by a full-scale test and error. Therefore, the main purpose of this research is to evaluate the hydraulic efficiency of the flood diversion channel using physical modelling; to ensure that the water level and the plan discharge of the fresh basin portion meets the design criteria and does not contribute to upstream flooding or overcrowding. The scope of present study includes:

- General performance of the structures for a range of flow conditions
- Assessment of flow capacity of the structures
- Investigation of flow patterns in the Stilling Basin

2. Study Area

Sungai Bunus measures some 9 km from upstream to the shore, joining the Sungai Klang. The river can be located from the center of Wangsa Maju, in the northern part of Kuala Lumpur. From there, the river flows south to Setapak, Kampung Boyan Detention Pool, and finishes at Kampung Baru. Many people are not aware that they cross Sungai Bunus like some parts of the city, such as Kampung Periok near the Jalan Dewan Sultan Sulaiman in Kampung Baru, as it has been tarred above. Over the years, the channel has experienced hydrological shifts and has become lower and narrower. When there is no storm, the river is just a spot where the water runs. When it rains, the precipitation does not fall into the surface or move into the channel, which induces erosion and contributes to flooding. This is the condition confronted by the other tributaries of Sungai Bunus and Sungai Klang. Fig. 1 shows the location of the proposed project.

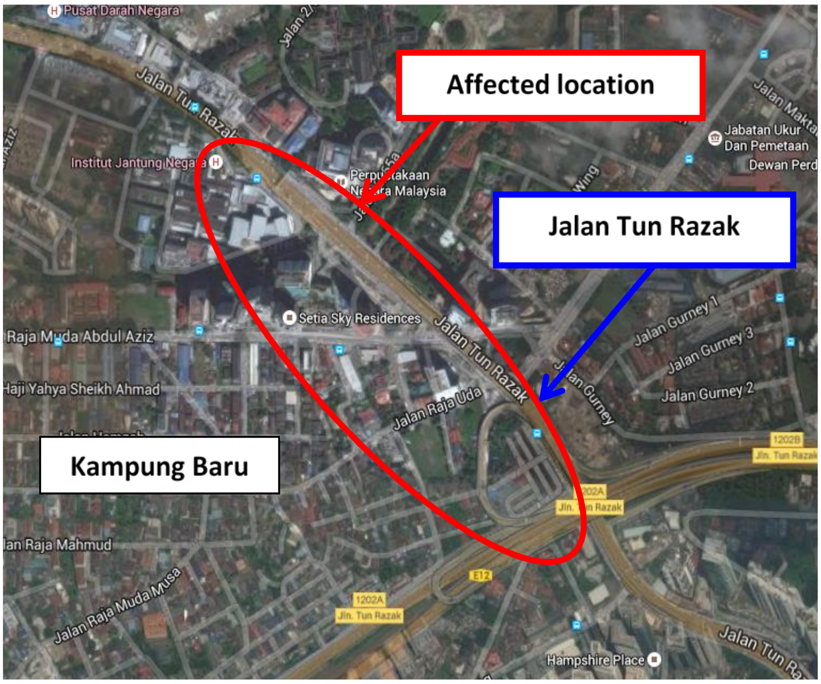


Fig. 1 - Location of project (Source: Google Maps Online)

3. Methodology

3.1 Experimental Setup

The stilling basin was designed from the conceptual design specifications provided by the Consultants prior to present study. The model designs consist of a stilling basin with 2 piers inside as well as a symbolic portion of the Sungai Bunus with an actual box culvert spanning the Jalan Tun Razak upstream and a planned box culvert downstream (about 5 m span in total). The overall design would provide adequate space and space to carry out tests to study the hydraulic characteristics of the stilling basin. Fig. 2 shows the schematic plan view of the model setup. The construction of the model comprised of the following components:

- Water Supply and Circulation System
- Receiving Chamber (upstream)
- Model and Support Structure
- Stabilizer Tank (downstream)
- Outflow Measuring Structure

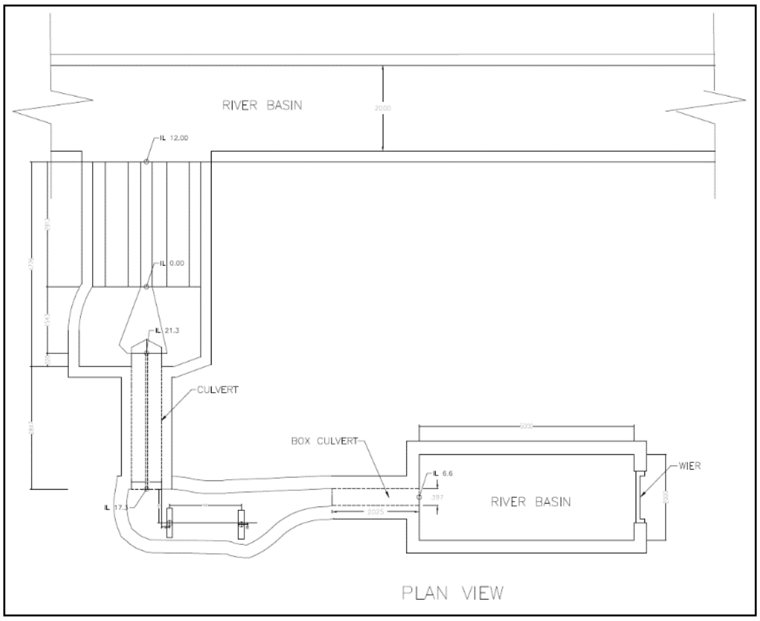


Fig. 2 - Schematic plan view of the model setup

The model was developed on the Froude scale, as is common for open channel flows controlled by gravitational forces. The ratio of 1:15 is introduced and is assumed to be broad enough to adequately represent the flow conditions (and mitigate any scaling effects). The studies were carried out with the same ratio of inertia to gravel forces as on the prototype, as the studied flows were mainly gravitational and as losses of friction could be negligible. This relation contributes to the retention of the non-dimensional amount of Froude's model and prototype [2], [6]. The platform was built without distortion and designed with solid frames. The related model and prototype relations were therefore outlined in Table 1 in keeping with the Froude principle in the line. Froude Law is expressed as in Eq. (1).

Table 1 - The relationship between prototype and model values

Quantity	Dimensions	Scale
Length	L	1:x = 1:15
Time	T	$1:x^{0.5}$ = 1.387
Velocity	LT^{-1}	$1:x^{0.5}$ = 1.387
Discharge	L^3T^{-1}	$1:x^{2.5}$= 1.87142

$$Fr = \frac{V}{\sqrt{gL}} \tag{1}$$

where V = velocity of the fluid in the model, g = acceleration due to gravity, and L = linear dimension.

3.2 Test Scenarios

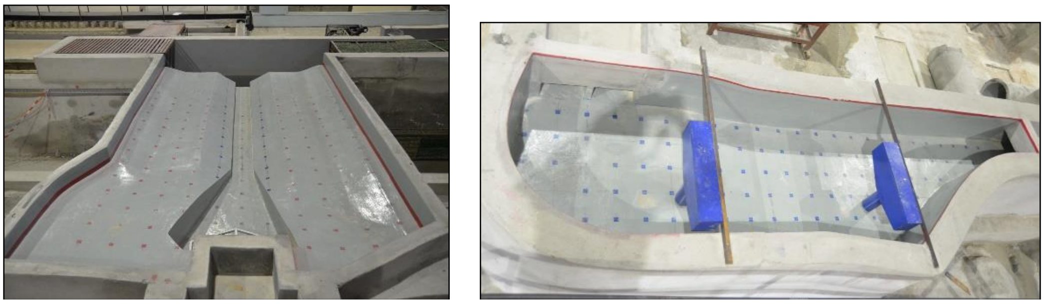
The experimental runs were carried out for both conditions: (i) without piers (scenario 1) and (ii) with piers (scenario 2) for pre-specified discharge values, to study the flow conditions imposed to the proposed structure. The design procedures for the model are carried out based on the specifications as shown in Table 2. A total of 6 experimental runs were conducted to determine the efficiency of the proposed system. In all test runs, the incoming flow was first stabilized before it reaches the inlet opening of the model (in this case at the upstream portion of Sungai Bunus). Each change of discharge values will require approximately another 20 minutes for the water to stabilize over again.

Table 1 - Test programme in physical modelling laboratory for stilling basin model

Test	Model Discharge (L/s)	Prototype Discharge (m^3/s)	Scenario
1	52	45	Without piers
2	86	75	Without piers
3	121	105	Without piers
4	52	45	With piers
5	86	75	With piers
6	121	105	With piers

3.3 Experimental Measurement

The collected data from the model include water levels and velocity values in the vicinity of the structure to determine the need for any energy dissipator (or to assess whether the proposed measures are appropriate). Fig. 3 displays grid meshes of 20 cm by 20 cm marked on the stilling basin model bed and 25 cm by 25 cm marked on the Sungai Bunus bed to measure node velocities and water levels (equivalent to 3 m and 3.75 m of sample grids). Measurements of the water levels were achieved by using the point gauge at the above listed nodes within the Sungai Bunus and the stilling basin portions of the site. The velocity within the model was measured at the same positions as the water level measurements. Measurements of velocity were produced using a current meter type propeller. Generally, in all tests carried out, the incoming flow was stabilized prior to the inlet opening of the model (in this case upstream of Sungai Bunus). Increasing adjustment in the discharge rate should take between 10-20 minutes for the water to settle.

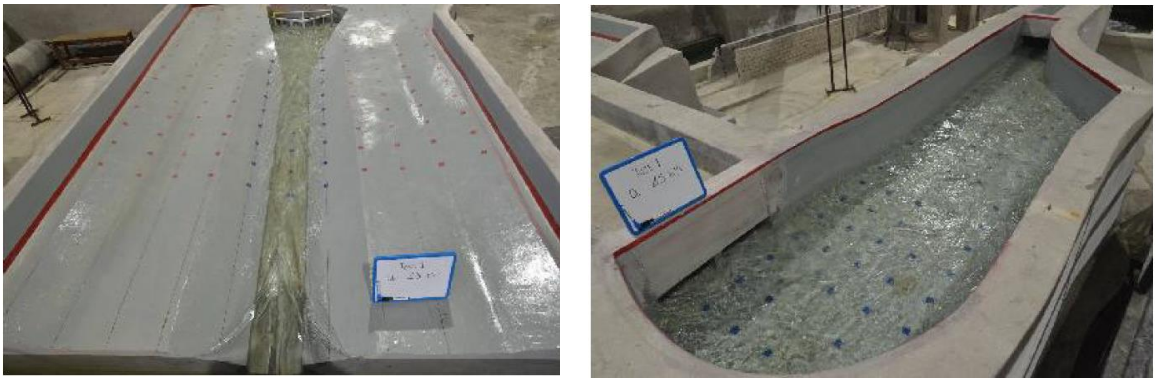


(a) (b)

Fig. 3 - Data collection points grid mesh at (a) Sungai Bunus, and; (b) stilling basin

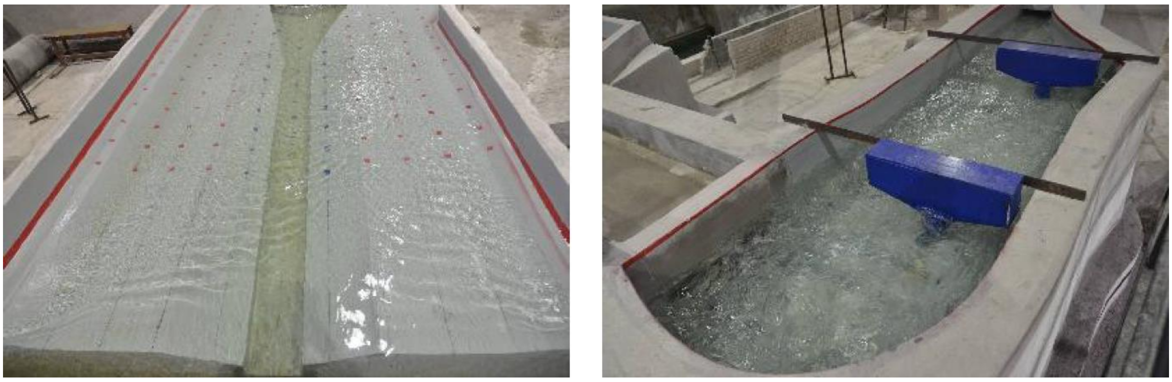
4. Results and Discussion

Fig. 4 and Fig. 5 portray the flow condition in Sungai Bunus and stilling basin at discharge of 52 L/s and 121 L/s. The velocity in Sungai Bunus was observed to decrease as the incoming discharge increases. However, the velocity trend in the stilling basin increases gradually as the flow rate increases. Greater runoff values also provide higher water levels at all points of the plan. Several ripple eddies happened at the beginning and center of the stilling basin. The test shows that, at the stage when the water begins to spill Sungai Bunus, the water inside the stilling basin can still be preserved within the system with some freeboard to play with. Observations to the flow during the experiment does not indicate any phenomenon of a backflow impact in the stilling basin.



(a) (b)

Fig. 4 - Flow at discharge of 52 L/s at at (a) Sungai Bunus, and; (b) stilling basin (without piers)



(a) (b)

Fig. 5 - Flow at discharge of 121 L/s at at (a) Sungai Bunus, and; (b) stilling basin (with piers)

4.1 Water Surface Profiles

Fig. 6 reveals water surface level profiles (with and without piers) for the flow of 52, 86 and 121 L/s, respectively. The results show that no overflow of water at discharges of 52 and 86 L/s. The water level at the Sungai Bunus section starts to flood on one side of the package when the flowrate is 121 L/s which equivalent to 105.5 m^3/s prototype for both scenarios. The average level at Sungai Bunus for testing without piers was approximately 39 cm from inverted level of water (equivalent to the 5.8 m prototype). In the stilling basin, the mean water level recorded was 29 cm from the inverted point (equivalent to the 4.3 m). Meanwhile the mean water level for the piers tests was about 39 cm from the inverted water level (equivalent to the prototype of 5.8 m). The medium level of water measured in the stilling basin was about 30 cm from the inverted stage (equivalent to the 4.5 m prototype).

4.2 Point Velocities

The result for all test conditions (without and with piers) have shown that the point velocity measured at the beginning of the stilling basin (inlet) is much lower than the point velocity reported near the end of the stilling basin (outlet). For test without piers (Fig. 7 to Fig. 9), the highest velocity occurred in the slender part of the stilling basin, i.e. at the inlet of the flood diversion culvert. The highest reported velocity was around 165 cm/s during the high-flow scenario just prior to the Sungai Bunus flood (121 L/s). In the meantime, for the experiment with piers (Fig. 10 to Fig. 12), the highest velocity occurs in the stilling basin at the bypass culvert edge, where it is the thinnest part of the stilling basin. During the high-flow scenario just prior to the Sungai Bunus flood, the highest reported velocity was around 165 cm/s (equivalent to a prototype of 6.4 m/s). At the right wall of the stilling basin, which is about 5 cm/s, the lowest velocity rate of test without piers was observed. While the lowest pier test speed was located at the sharp corner next to the current culvert outlet in the stilling basin, which is approximately 5 cm/s (equivalent to 0.2 m/s prototype). Consequently, due to the nature of its hydraulic property this specific area is prone to sediment deposition. The initiation of motion for sediments could be determined based on the criteria of minimal velocity and Chezy equation developed and condensed by Neil and Maynord [3], [7]. Any sediment greater than 0.1 mm can collect around this area and be accumulated on a long-term basis as reported by [4],[8].

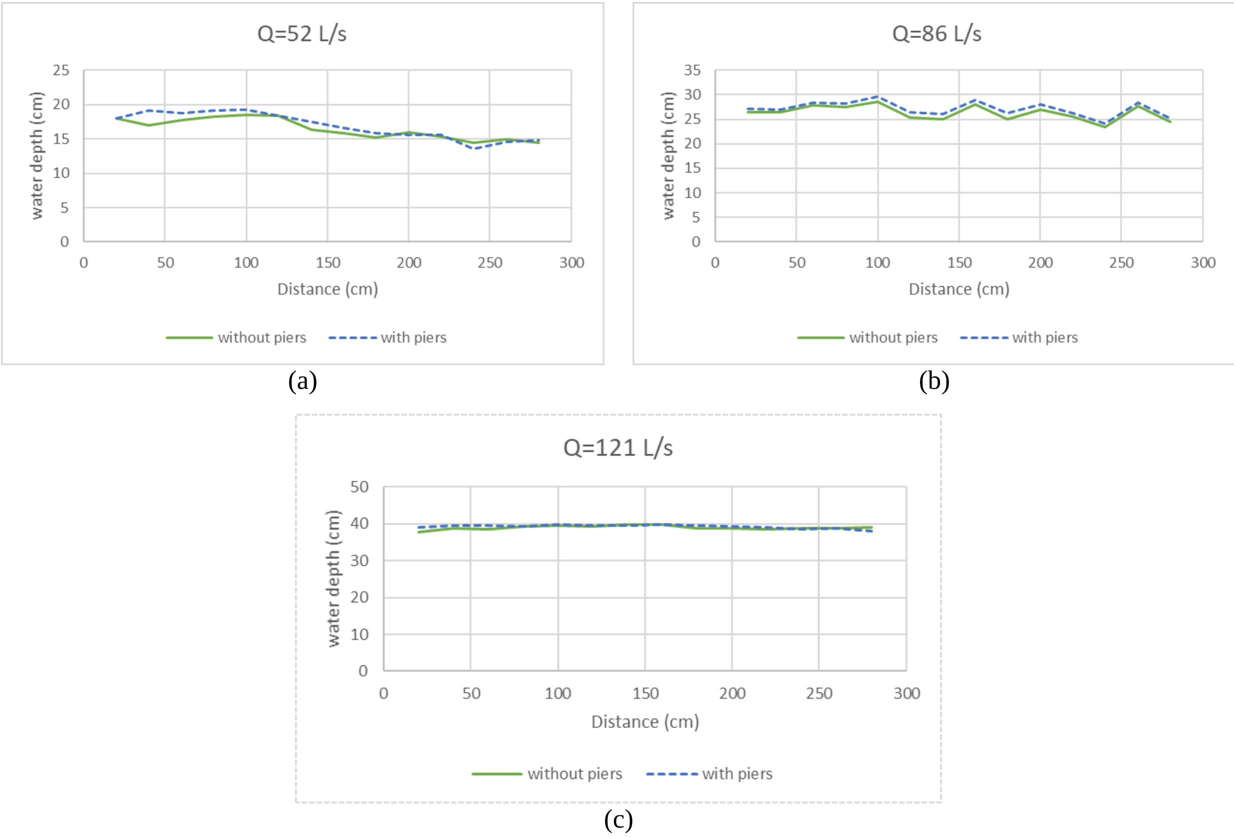


Fig. 6 - Water surface height profiles for the stilling basin at discharge (a) 52 L/s; (b) 86 L/s; (c) 121 L/s

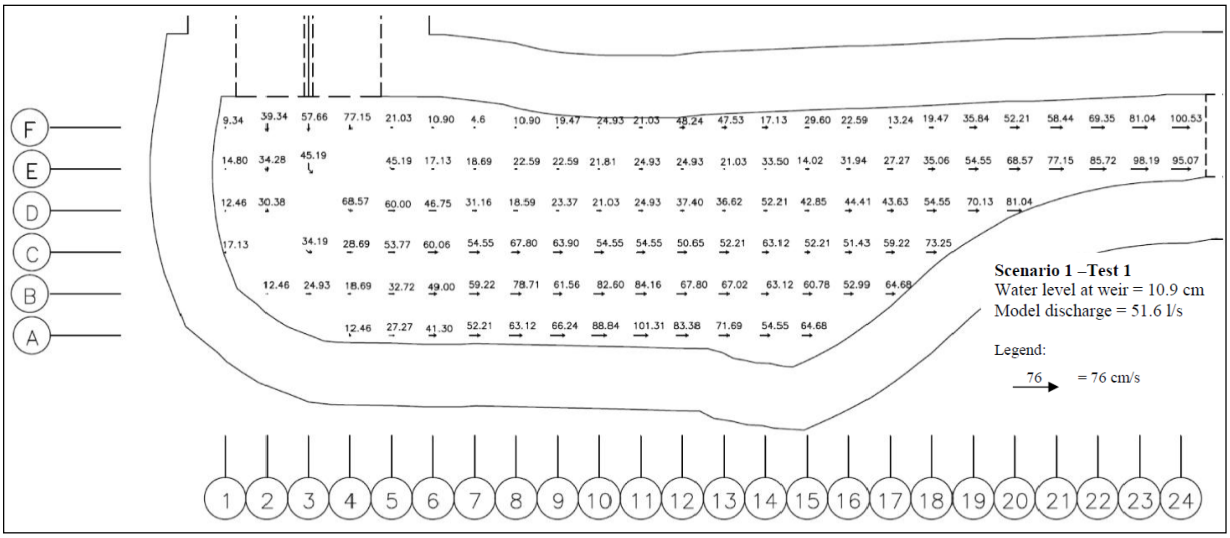


Fig. 7 - Stilling basin velocity distribution maps for 51 L/s (without piers)

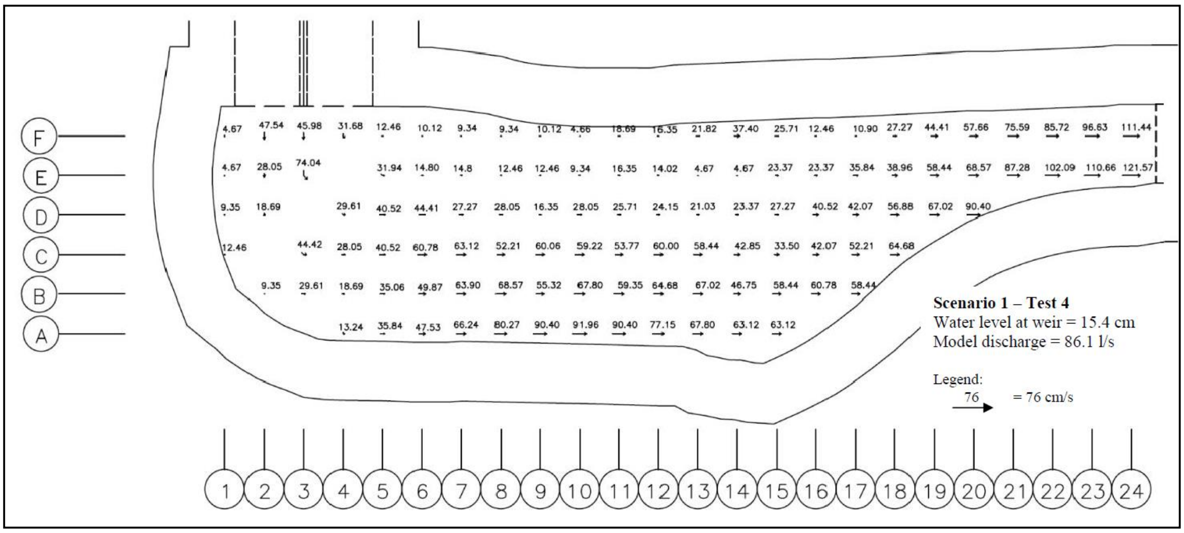


Fig. 8 - Stilling Basin velocity distribution maps for 86 L/s (without piers)

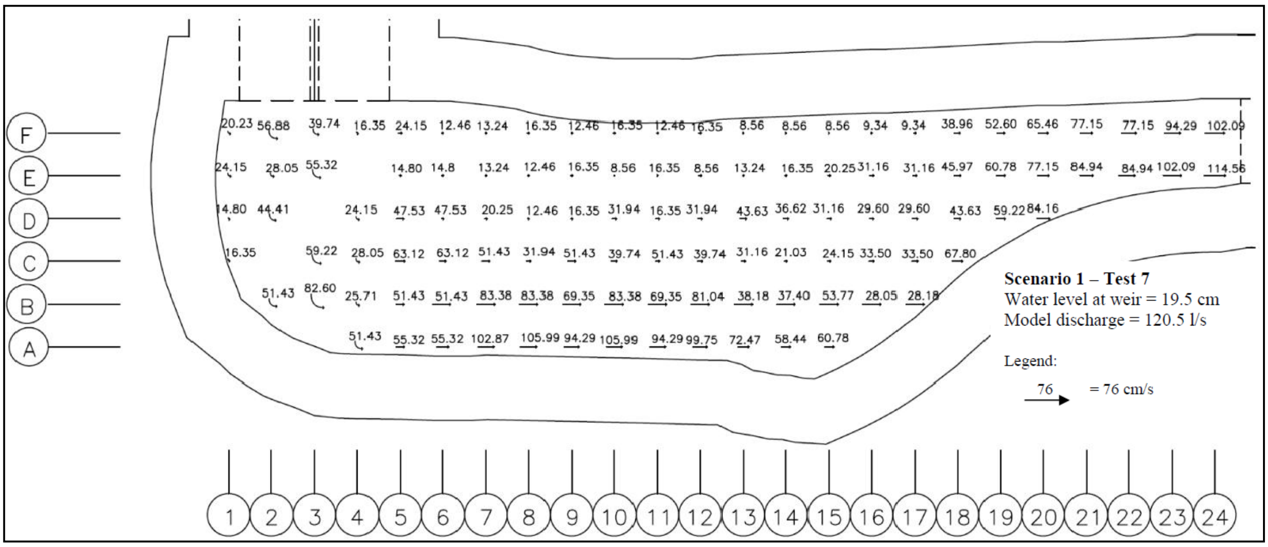


Fig. 9 - Stilling basin velocity distribution maps for 121 L/s (without piers)

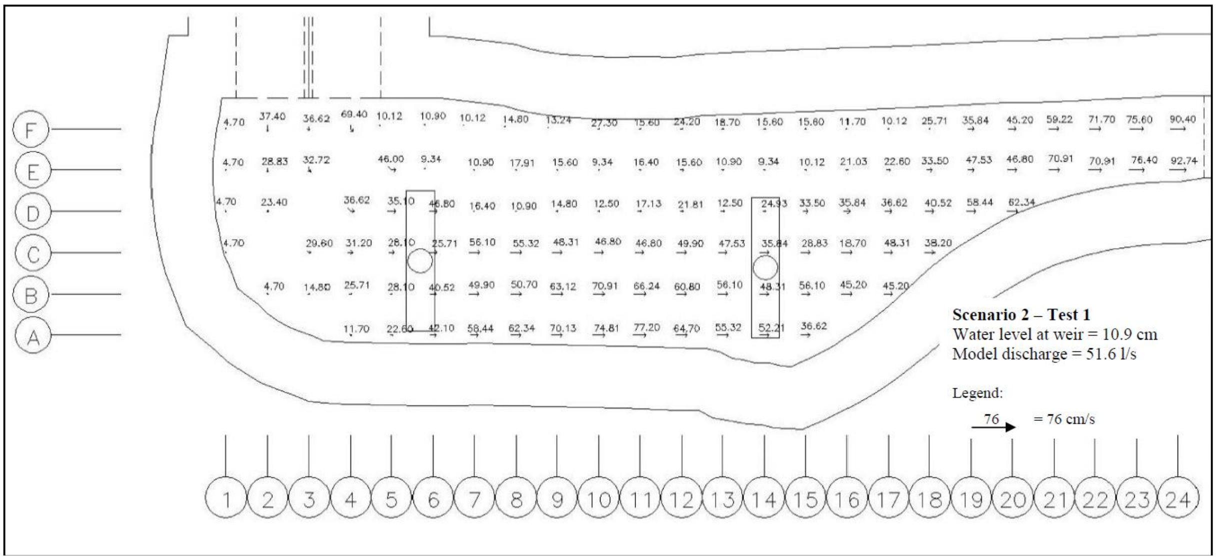


Fig. 10 - Stilling basin velocity distribution maps for 51 L/s (with piers)

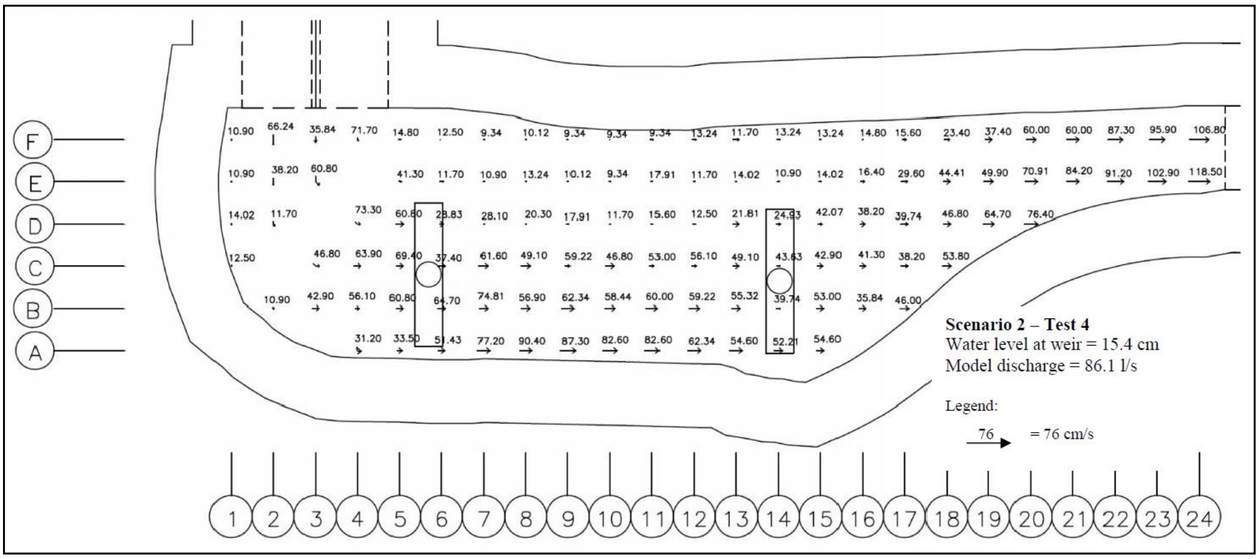


Fig. 11 - Stilling basin velocity distribution maps for 86 L/s (with piers)

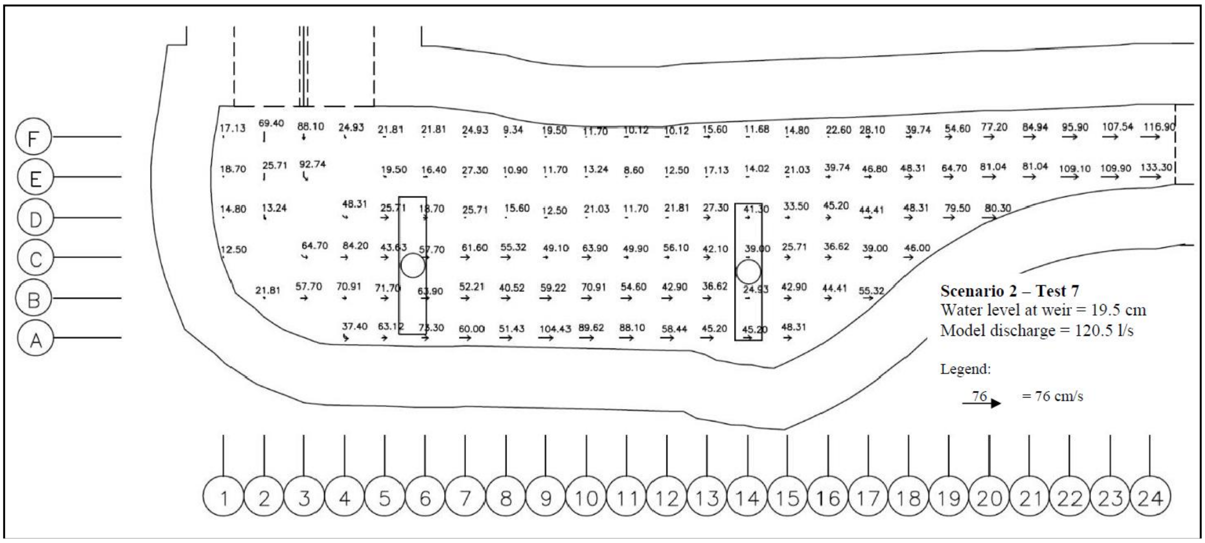


Fig. 12 - Stilling basin velocity distribution maps for 121 L/s (with piers)

5. Conclusion

Based on the observations of the tests and their results, a number of critical elements of the modeling process need to be considered. There are no significant differences in result between the two conditions with and without piers. In a real situation, the water level of the Sungai Bunus would continue to surpass the bund at a discharge rate of 105.5 m^3/s. At this phase, the stilling basin can still handle the discharge rate and there is no water overflowing out of the basin given that the downstream pump gate is fully open and the Klang River water level is in normal condition. The freeboard left inside the stilling basin is about 2.5 m. Nonetheless, a standard swirl eddies develops during the test, which does not inflict structural damage. In the stilling basin, there are also areas where, regardless of the discharge level, the flow rate is extremely small (approximately 0.2 m/s). The regions are situated on the sharp edge, next to the present tube exit and the right side of the drain. Sediment formation and sediment accumulation have a high potential of 0.1 mm in these areas. Future research should experimentally investigate the hydraulic characteristics of forced hydraulic jump (if exist) in the stilling basin and classification of possible flow patterns within it under different hydraulic conditions.

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