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Parametric investigation in Malaysian separate sewer systems

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Flow characteristics are significant in the design of sewerage systems in that poor analysis of the flow design parameters may influence the capacity of a sewerage system, causing health and environmental problems. The aim of this study is to verify the design parameters in the peak flow factor equation in Malaysian Standard Code of Practice MS 1228:1991. Data collection was conducted in a residential area at Taman Lepar Hilir Saujana, Kuantan, Pahang. ISCO 2150 Area Velocity Flow Meter and ISCO 674 Rain Gauge were used in this study to collect flow rate and rainfall intensity data, respectively. The resultant analysis shows that the flow design parameters, per capita flow and design criterion, were unexpectedly 42·2 and 16% lower than the value of per capita flow and design criterion described in MS 1228:1991, respectively. This indicates that the separate sewer systems in Malaysia may be overdesigned if using the flow design parameters recommended in MS 1228:1991. Thus, a revision of the flow design parameters may be necessary, taking into account the rising cost of materials around the world.

Notation

K	design criterion
PE	population equivalent
PFF	peak flow factor
Q_{ave}	average daily flow
Q_{pcf}	per capita flow
Q_{peak}	peak flow

1. Introduction

Sewerage systems are critical infrastructures that convey wastewater to sewerage treatment plants. In Malaysia, the sewerage systems are designed as separate sewer systems (Essays UK, 2013). The degree of misconnections with storm sewer is virtually zero, as stated in a conference speech in Trenchless Asia 2016 by Mohd Zainal Zakaria, General Manager of Operation & Maintenance Department, Indah Water Konsortium Sdn Bhd (IWK) (Zakaria, 2016). As of December 2014, the total sewer length connected to the public sewerage system was 18 075·7 km nationwide, whereas Pahang state contained 582·3 km, about 3·2% of the total recorded length (SPAN, 2015). These sewerage systems are located underground and are made up of pipes of different materials, lengths and diameters (Ansari *et al.*, 2013; Rahman *et al.*, 2007) although normally, most of the sewer pipes are made from vitrified clay with diameters of 0·225 m while the distance between manholes are usually between 60 and 100 m (MS 1228: 1991 (MS, 1991); MSIG, 2009). Expansion of sewerage systems is still inappropriate in several cities (Burian and Edwards, 2002).

Fundamentally, the determination of flow characteristics is significant to the design of sewerage systems. Generally speaking, sewerage systems may be inappropriately designed without analysis of flow characteristics (Imam and Elnakar, 2014). The Malaysian Standard that the Malaysian industry refers to when designing sewerage systems follows its counterpart found in the British Standards collection (MS 1228:1991 (MS, 1991)). However, the original British Standard referred to has been revised twice and is now known as the BS EN 752:2008 (BSI, 2008; Ngien and Ng, 2013). Therefore, parameters in the peak flow factor equation in MS 1228:1991 (MS, 1991) are dubitable in terms of appropriateness as they depend on the climate, topography and geographical situation as well as on the amount of sewage flow, which differs from country to country (Rahman *et al.*, 2003). In this research, the return period of design storm is not applicable due to the separate sewer system. Future population growth is also not considered in the local construction scene as each new development comes with its own sewerage network and sewage treatment plant. In addition, separate sewer systems in Malaysia are already designed for full capacity as the design is normally based on the population equivalent (PE) of each respective development without the capacity for future expansion.

Several researches have been conducted to analyse the flow characteristics of sewerage systems in the early stage. Benefield (2002) had conducted a research in Washington State. The result has shown that the minimum wastewater flow rate from the community was 75–400 gallons/d, which was much higher than the design flow of 240 gallons/d. From another point of view, peak flows should be complemented with a safety factor in the design of sewage flow. Rahman *et al.* (2003) undertook a study in Taman Sri Pulai, Skudai Johor and showed that the value of actual per capita flow and the actual design criterion was 0·2 (m^3/d)/person and 1·8, lower than the parameters in MS 1228:1991 (MS, 1991) by 11 and 61·7%, respectively. As Ngien and Ng (2013) have reported, a similar research conducted in the hostel vicinity of SEGi University, Kota Damansara, Kuala Lumpur has also shown that the actual design criterion was 38·7% lower than the value of design criterion 4·7 mentioned in MS 1228:1991 (MS, 1991).

A more comprehensive research was conducted by Rahman *et al.* (2007) where the authors have shown that the value of actual per capita flow and design criterion in their research was also lower than the value in MS 1228:1991 (MS, 1991). Imam and Elnakar (2014) studied several small catchments in Egypt and in the Kingdom of Saudi Arabia. The result has shown that the sewerage system should be designed to a critical flow rate. The wastewater treatment plant is typically affected by flow rate variation. A more recent research by Yap and Ngien (2015) conducted at the hostel catchment of Universiti Malaysia Pahang has shown that the value of actual per capita flow and design criterion was also lower than the value of design criterion and per capita flow in MS 1228:1991 (MS, 1991).

By analysing all the research previously described, it shows that those results are not enough to give a clear picture of the flow characteristics in the local sewerage system. Thus, sewerage flow characteristics in Malaysia have to be reanalysed to check the suitability and revise any parameters needed in the MS 1228:1991 (MS, 1991). This is the reason as to why this research was implemented.

2. Objective and scope

The objective of this study is to verify the flow parameters in the local separate sewer systems. This study is divided into information gathering, site survey, data collection and data analysis phases. Data were collected in the form of flow rate, velocity and depth of wastewater. Once flow rate was collected, the flow parameters such as the actual per capita flow and the actual design criterion can be calculated using equations. The calculated parameters will then be compared with the per capita flow and design criterion in MS 1228:1991 (MS, 1991). Rainfall intensity data were also collected using the ISCO 674 Rain Gauge.

3. Methodology

3.1 Study site

At the start of this research, there was a meeting with the staff from IWK. With assistance from IWK, this research was conducted in several residential areas, but the content in this paper will focus on the data obtained from Taman Lepar Hilir Saujana, Kuantan, Pahang. The design PE for Taman Lepar Hilir Saujana is 2500 PE. To verify the PE, a site survey was performed in the residential area, house to house. The final PE was calculated at 1235 PE. Manhole (MH 84) was selected for this research and it is connected to the sewerage treatment plant named as KUN 239.

3.2 Selection criteria of sewer line

Before choosing a suitable manhole, preliminary test and data collection were carried out to check whether the sewage flow inside the sewer pipeline fulfils the criteria or not. Choosing a suitable manhole depends on the condition of the sewer pipeline. The following criteria were used in the selection.

- The manhole must connect to the nearest sewerage treatment plant.
- The sewer pipeline of the research area must face no surcharge and no backflow.
- The foul water flow in the sewer pipeline is steady and has little head loss.
- The selected manhole must have no turbulence happening in the sewer pipeline.

3.3 Equipment adopted

The flow rate measurement in this research was carried out based on the area velocity method using continuous Doppler technology (Solliec and Teufel, 2010). ISCO 2150 Area Velocity Flow Meter was used in this research. The flow meter was hung inside MH 84 that has a sewer depth of 10·5 m. The sensor of the flow meter was placed at the bottom of the sewer pipe, whereas the flow meter itself was hung where it is easily accessible to facilitate battery swapping and data downloads. Value of the flow rate was registered once every 5 min.

Meanwhile, ISCO 674 Rain Gauge was installed within the sewerage treatment plant area. The rain gauge was attached to the top of a surveying tripod which was not more than 400 m away from the sewer line where the flow measurement was taken and placed in an open space clear of any plant cover. It is one of the most common methods to obtain rainfall intensity (Teledyne ISCO, 2011). After data were logged, the software Flowlink 5·1 was used to retrieve the data. Flowlink 5·1 is user friendly and it will provide the flow rate of wastewater in the sewer pipeline as well as the rainfall pattern in graph form (Teledyne ISCO, 2013).

3.4 Calibration of equipment

Accuracy and precision of instrument is very important to this research. The aim of performing calibration is to make sure that the flow meter and rain gauge are ready to use and the data extracted is reliable. Thus, the calibration of the flow meter and the rain gauge is necessary to check for the error and accuracy before the equipments are placed at the site. Calibration of both equipments was performed in the Hydrology and Hydraulic Laboratory of Universiti Malaysia Pahang, Gambang campus. The calibration of the flow meter was performed by comparing the results registered by the flow meter with the readings from the open channel apparatus. Any errors encountered were calibrated into the flow rate data and rainfall level before analysis on the data was performed. The following observations can be made through the calibration.

- A waiting time of 1–2 min is needed after the sensor is placed in the channel before recording of the data begins in the flow meter.
- The maximum and minimum percentage error of depth between ISCO 2150 Flow Meter and open channel was 3·4 and 0·08%, respectively.
- The maximum and minimum percentage error of flow rate between ISCO 2150 Flow Meter and open channel was 8·9 and 2·4%, respectively.

3.5 Governing equation

The design equations from MS 1228:1991 (MS, 1991) were used. The design criterion and per capita flow used to design the sewerage system can be determined using the following equations. Per capita flow can be calculated using the following equation

1. $$Q_{\text{pcf}} = \frac{Q_{\text{ave}}}{\text{PE}}$$

where Q_{pcf} stands for per capita flow in units of (m^3/d)/person; Q_{ave} is the average of daily flow in the sewerage system in units of m^3/d; PE is the population equivalent. Equation 2 shows the peak flow calculation in the sewer pipeline

2. $$Q_{\text{peak}} = \text{PFF} \times Q_{\text{ave}}$$

where Q_{peak} is the peak flow in units of m^3/d; PFF stands for peak flow factor and Q_{ave} is the average daily flow as mentioned previously. The peak flow factor equation stated in MS 1228:1991 (MS, 1991) is shown in the following equation

3. $$\text{PFF} = K\left(\frac{PE}{1000}\right)^{-0{\cdot}11}$$

where K is the design criterion, which is unitless, meanwhile PE is the population equivalent as previously mentioned. Equation 4 was combined and rearranged from Equations 1–3 to determine the value of the design criterion

4. $$K = \frac{Q_{\text{peak}}}{(Q_{\text{pcf}} \times \text{PE})\ (\text{PE}/1000)^{-0{\cdot}11}}$$

The value of the design criterion, K is 4·7 and the value of the per capita flow, Q_{pcf} is 0·225 (m^3/d)/person stated in MS 1228:1991 (MS, 1991), Clause 3·6 and 3·2, respectively. To achieve the objective in this research, both parameters need to be verified.

4. Results and discussions

Data were collected in two phases. These two phases were separated into ten different periods in September, October and November 2015. Weekdays and weekends were analysed separately. The maximum and minimum duration of data collected was 143 h 50 min and 14 h 50 min, respectively. Collection was also done in dry period and as well as in wet period to provide a clear picture to support the flow characteristics in this study. Concurrently, the rainfall intensity data were also collected continuously. Calibration for the errors associated with the flow meter and rain gauge were incorporated into the raw data of flow rate and rainfall level after extraction from the flow meter and rain gauge. Table 1 shows the summary of each set of data collected from MH 84.

4.1 Per capita flow

Sewage flow rate data was retrieved in units of l/s. To facilitate comparison with MS 1228:1991 (MS, 1991), the unit of flow rate was changed to m^3/d in this study.

The Q_{peak} and Q_{ave} were calculated separately for weekdays and weekends. The detailed data concerning all phases is presented in Table 2. The data show that for weekends, the range of Q_{peak} is from 4·33 to 6·36 l/s, whereas the magnitude varies

Data set	Duration	Weekday or weekend	Rainfall intensity
MH 84-01	55 h 25 min	Weekdays	No
MH 84-02	71 h 55 min	Both	No
MH 84-03	71 h 55 min	Weekdays	No
MH 84-04	143 h 50 min	Both	No
MH 84-05	71 h 55 min	Weekdays	Yes
MH 84-06	71 h 55 min	Both	Yes
MH 84-07	71 h 55 min	Weekdays	Yes
MH 84-08	71 h 55 min	Both	No
MH 84-09	14 h 50 min	Weekdays	Yes
MH 84-10	71 h 55 min	Weekdays	Yes

Table 1. Summary of each data collected from MH 84

	Weekend		Weekday		Average			
Data set	Q_{peak}: l/s	Q_{ave}: l/s	Q_{peak}: l/s	Q_{ave}: l/s	Q_{peak}: l/s	Q_{peak}: m^3/d	Q_{ave}: l/s	Q_{ave}: m^3/d
MH 84-01	NA	NA	4·15	1·93	4·15	358·56	1·93	166·75
MH 84-02	6·36	2·19	3·92	1·78	5·14	444·10	1·99	171·50
MH 84-03	NA	NA	6·99	2·04	6·99	603·94	2·04	176·26
MH 84-04	4·88	2·05	6·92	1·96	5·9	509·76	2·01	173·23
MH 84-05	NA	NA	6·34	1·87	6·34	547·78	1·87	161·57
MH 84-06	5·99	1·88	5·65	2·68	5·82	502·85	2·28	196·99
MH 84-07	NA	NA	11·71	2·15	11·71	1011·74	2·15	185·76
MH 84-08	4·33	1·97	7·84	2·21	6·09	525·74	2·09	180·58
MH 84-09	NA	NA	6·02	0·95	6·02	520·13	0·95	82·08
MH 84-10	NA	NA	8·33	1·21	8·33	719·71	1·21	104·54

NA, not available

Table 2. Peak flow and average flow for weekdays and weekends in each phase

between 3·92 and 11·71 l/s for weekdays. The same analysis was carried out for Q_{ave}, resulting in a maximum value of 2·19 l/s and a minimum value of 1·88 l/s for the weekends as opposed to a maximum value of 2·68 l/s and a minimum value of 0·95 l/s during weekdays. By comparing weekends and weekdays, it is shown that the average Q_{ave} during weekends is 2·02 l/s, 6·9% higher than the average Q_{ave} during weekdays at 1·88 l/s. Conversely, the average Q_{peak} for weekends shows 5·39 l/s which was 26% lower than the average Q_{peak} during weekdays at 6·79 l/s (Table 2).

The average flow rate and PE values of the sewer pipeline are needed to calculate per capita flow using Equation 1. Per capita flow of weekends and weekdays are also analysed in Table 3. During weekends, only four sets of per capita flows were calculated. The maximum value of per capita flow is 0·153 (m^3/d)/person, whereas the minimum value of per capita flow is 0·132 (m^3/d)/person. Furthermore, the value of per capita flow during weekdays ranges between 0·066 and 0·155 (m^3/d)/person. In Malaysian Standard MS 1228:1991 (MS, 1991), Clause 3·2 the value of per capita flow is stated as 0·225 (m^3/d)/person. A comparison between the per capita flow value measured, averaged between weekdays and weekends, and the value of per capita flow given by MS 1228:1991 (MS, 1991) shows that the measured value is 42·2% lower than the value in MS 1228:1991 (MS, 1991) (Table 3).

Data set	Weekend			Weekday			Average
	PE for sewer pipeline	Q_{ave}: m^3/d	Q_{pcf}: (m^3/d)/person	PE for sewer pipeline	Q_{ave}: m^3/d	Q_{pcf}: (m^3/d)/person	Q_{pcf}: (m^3/d)/person
MH02-01	1235	NA	NA	1235	166·75	0·135	0·135
MH02-02	1235	189·22	0·153	1235	153·79	0·125	0·139
MH02-03	1235	NA	NA	1235	176·26	0·143	0·143
MH02-04	1235	178·85	0·145	1235	169·34	0·137	0·141
MH02-05	1235	NA	NA	1235	161·57	0·131	0·131
MH02-06	1235	162·43	0·132	1235	231·55	0·187	0·160
MH02-07	1235	NA	NA	1235	185·76	0·150	0·150
MH02-08	1235	170·21	0·138	1235	190·94	0·155	0·147
MH02-09	1235	NA	NA	1235	82·08	0·066	0·066
MH02-10	1235	NA	NA	1235	104·54	0·085	0·085

NA, not available

Table 3. Computation of per capita flow

4.2 Design criterion

According to Malaysian Standard MS 1228:1991 (MS, 1991), the value of design criterion is mentioned as 4·7. Design criterion can be calculated using Equation 4. The parameters involved in this equation are per capita flow, peak flow and PE for the sewer pipeline. The peak flow was calculated for weekends and weekdays separately (Table 2). An analysis of average peak flow and per capita flow was carried out prior to the calculation of the design criterion parameter as described in Table 3. Consequently, the calculated average of peak flow and per capita flow used to obtain the design criterion with the PE is shown in Table 4.

The foregoing data show that the design criterion calculated from each phase is less than the design criterion mentioned in MS 1228:1991 (MS, 1991) except for the sets MH 84-07, MH 84-09 and MH 84-10. The similarity between these sets of data was the heavy rainfall happening on weekdays. When the value of actual per capita flow is replaced with the recommended design per capita flow, 0·225 (m^3/d)/person as described in MS 1228:1991 (MS, 1991), the resultant design criterion was calculated (Table 5). For the set of MH 84-07, it shows that the resultant design criterion is 3·73, a reduction of 32·9% when using the recommended design per capita flow. The same trend was found for the sets of MH 84-09 and MH 84-10, where

Data set	Average		PE for sewer pipeline	Design criterion, K	Actual peak flow factor, PFF
	Q_{peak}: (m^3/d)/person	Q_{pcf}: (m^3/d)/person			
MH 84-01	358·56	0·135	1235	2·20	2·15
MH 84-02	444·10	0·139	1235	2·65	2·59
MH 84-03	603·94	0·143	1235	3·50	3·42
MH 84-04	509·76	0·141	1235	3·00	2·93
MH 84-05	547·78	0·131	1235	3·47	3·39
MH 84-06	502·85	0·160	1235	2·60	2·54
MH 84-07	1011·74	0·150	1235	5·59	5·46
MH 84-08	525·74	0·147	1235	2·96	2·89
MH 84-09	520·13	0·066	1235	6·53	6·38
MH 84-10	719·71	0·085	1235	7·02	6·86

Table 4. Flow parameters for each set of data

Data set	Design criterion, *K*	Resultant design criterion, *K*
MH 84-07	5·59	3·73
MH 84-09	6·53	1·92
MH 84-10	7·02	2·65

Table 5. Design criterion based on different parameters

the resultant design criterion was reduced to 1·92 and 2·65, respectively. Overall, the average design criterion is 3·95, still 16% lower than 4·7.

Furthermore, either Equation 2 or 3 was adopted to calculate the peak flow factor. Both equations give the same peak flow factor result when implemented. Current practice in sewerage system design applies the peak flow factor of $4{\cdot}7p^{-0{\cdot}11}$, where *p* is the PE per thousand. The resultant average actual peak flow factor is 3·86 as shown in Table 4. However, the range of actual peak flow factor actually falls between 2·15 and 6·86. Comparatively, the design peak flow factor is 4·59, which is 15·9% higher than the average peak flow factor. As foregoing data has shown, the average design criterion and per capita flow are lower than the values given in MS 1228:1991 (MS, 1991). Yet, the design peak flow factor mentioned in MS 1228:1991 (MS, 1991) is relatively high. Generally speaking, the sewer pipeline is efficient and sufficient to cater to the amount of PE at Taman Lepar Hilir Saujana. Nonetheless, it may save cost in terms of transportation of material and size of pipe if a smaller safety factor was applied.

4.3 Flow pattern

Flow pattern is presented in hydrograph form. Figure 1 shows the flow rate at MH 84, Taman Lepar Hilir Saujana against hourly time from Tuesday, 22 September 2015, 11.30 a.m. to Sunday, 18 October 2015, 11.30 a.m. In this phase, data were collected for a period of 31 d. There are 650 hourly slots in this period. Hourly maximum flow ($Q_{\text{max hourly}}$), hourly minimum flow ($Q_{\text{min hourly}}$), as well as hourly average flow ($Q_{\text{average hourly}}$) are calculated from each hourly slots. Furthermore, the daily average flow was investigated from 31 daily slots. From the hydrograph (Figure 1), it shows that the peak flow happened at 7.30 a.m., with an amount of flow rate 4·53 l/s equal to 391·39 m^3/d. This may occur due to people taking showers and using the toilets before going to school and work. Meanwhile, the second peak flow rate occurred at 8.30 p.m. with a flow rate of 3·87 l/s. Peak flow rate occurred during this time due to people back from work or school and preparing to have dinner. However, the average daily flow rate was 1·69 l/s, 59·8% higher than the amount of average daily flow rate of 0·68 l/s in the second phase (Figure 2). The average of daily flow rate in the first phase is

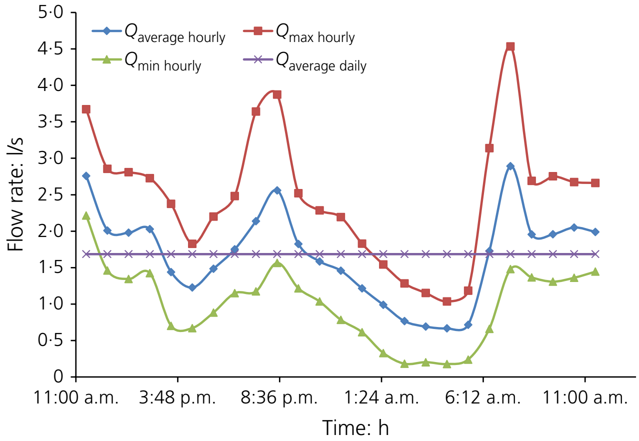

Figure 1. Hourly flow rate at MH 84 from 22 September 2015, 11.30 a.m. to 18 October 2015, 11.30 a.m.

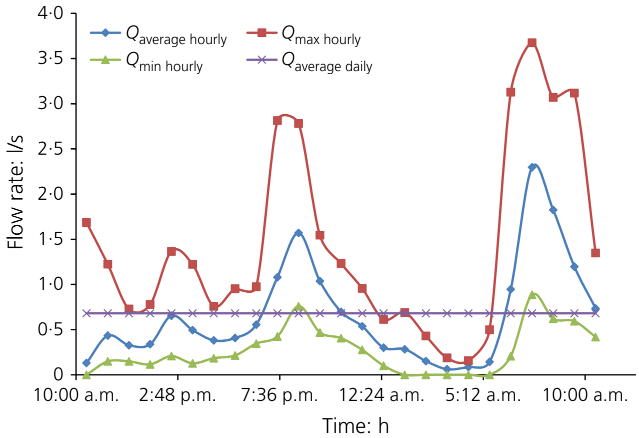

Figure 2. Hourly flow rate at MH 84 from 26 October 2015, 10.30 a.m. to 30 October 2015, 10.30 a.m.

higher due to the high amount of rainfall taking place during that period.

The second phase was monitored from Monday, 26 October 2015, 10.30 a.m. to Friday, 30 October 2015, 10.30 a.m. (Figure 2). The first peak flow occurred at 7.30 a.m., with an amount of 3·68 l/s. Meanwhile, the second peak flow during this period happened at 7.30 p.m. with an amount of 2·81 l/s. During monitoring, the minimum flow rate shown on the hydrograph is at midnight between 1.30 a.m. and 5.30 a.m. The zero flow rate occurred because people were sleeping and there is not much activity during midnight.

5. Conclusion

The design parameters of per capita flow and design criterion were analysed in this case study conducted in Kuantan, Pahang, and the objective was achieved. The value of the design criterion and per capita flow was found to be lower than the respective values mentioned in MS 1228:1991 (MS, 1991). The design criterion was found to be 3·95 instead of 4·7 mentioned in MS 1228:1991 (MS, 1991). Moreover, the parameter per capita flow was 0·160 (m^3/d)/person, lower than the 0·225 (m^3/d)/person described in MS 1228:1991 (MS, 1991). On the basis of these findings, it can be assumed that the sewer pipeline at Taman Lepar Hilir Saujana was designed sufficiently to cater to the amount of PE residing there. Cost of future development may be reduced by exploiting a revised equation. Moreover, to get better result the calibration discrepancies should be taken into account in the data before starting the analysis stage. Further studies focused on groundwater, inflow and infiltration are needed in order to determine and revise the flow parameters of the peak flow factor equation in MS 1228:1991 (MS, 1991). Other than that, more study is needed on how the per capita flow was obtained, although initial understanding was that the value of 0·225 (m^3/d)/person was based on a now-obsolete British Standard.

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