J. Kej. Awam Jil. 7 Bil. 2 1994

DEVELOPMENT OF A COMPUTER PROGRAMME FOR THE DESIGN OF MUNICIPAL WASTEWATER TREATMENT FACILITIES
Part 1: The Incoming Conduit and Screening Facility

by

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Abstract

A computer programme was developed using Fortran77 utilizing IBM-PC compatible microcomputers to design the incoming conduit and screening facility in municipal wastewater treatment plant. The programme calculates the dimensions and capacity of the facilities and determines the hydraulic flow profile of each of the facility. The programme runs successfully given the input data which is the total number of population served, the incoming conduit diameter and Manning's n. The results are easy to interpret and appeared automatically on an output file.

Introduction

Municipal wastewater is the general term applied to the liquid waste (containing suspended solids, organic matters and microorganisms) collected from residential and commercial areas and conveyed by means of a sewerage system to a centralised treatment plant before discharging it into natural water bodies. Normal centralized municipal wastewater treatment plant contains different individual treatment units in which each unit operate for different purpose in order to achieve the desired degree of treatment. These units include the intercepting sewers, the incoming conduit, the aerated grit removal facility, primary sedimentation basins, aeration basins, final clarifiers, disinfection contact chamber, effluent disposal facility, sludge thickening and blending tanks, anaerobic digester and sludge dewatering facility. Each facility is connected in series by using pipes. Each individual unit is designed in such a manner that it's capacity are capable of handling and treating a certain amount of wastewater.

The design calculations use simple method but may be time consuming because trial and error and iteration processes are involved in the calculations. A computer programme is needed to solve the time constraint problem. A computer programme was developed using Fortran77 to design each individual unit of wastewater treatment plant. This paper will discuss on the development of the computer programme for the design of the incoming conduit and screening facility. The development of computer programme for the design of the other treatment facilities will be presented in another paper.

Design Information and Input Data

The volumetric flow rate of municipal wastewater generated in a community in the service area depends on the total number of population and per capita contribution of wastewater. Therefore it is very important to estimate the population to be served at the design year since the total number of population is the main input data to the computer programme. The procedure to obtain or to forecast the total number of population that served the treatment plant is not included in the computer programme and it must be done separately by the designers. The computer programme could only read the provided total number of population as the main input data.

The average design flow rate (Q_{av}) of wastewater used in this case is based on per capita contribution which is equal to 225 litre/day/person [1]. By multiplying the per capita contribution of wastewater, the total number of population in the design year and 86400 second per day, the average design flow rate in litre per second is determined. Dividing the peak design flow rate of wastewater (Q_{pk}) and the average design flow rate, a non-dimensional factor called the *peaking factor* (P_f) is determined, based on the equation [1]

$$P_f = 4.7\,P^{-0.11} \tag{1}$$

where P is the total number of population in thousand.

The minimum design flow rate of wastewater (Q_{mn}) which is useful in the design of pumps and to investigate the velocity in conduits is determined by multiplying the average design flow rate and the *minimum flow rate factor* (M_f). The graphical form of the minimum flow rate factor is obtain from [2] and is converted into equation form using the least square curve fitting method. Equation expression can be easily transferred into computer codes compare to graphical form. The equation form of minimum flow rate factor is

$$M_f = 0.22\,P^{0.14} \tag{2}$$

The Incoming Circular Conduit

Sewers are underground conduits for conveying wastewater to the treatment plant. The design of sewer system is not included here and it must be designed separately. The computer programme only includes the design of the final sewer from the junction wastewater collection chamber of sewerage system i.e the incoming conduit to the treatment plant. The main task in designing the conduit is to determine the diameter of the conduit (D) in which for all flow conditions (peak design flow, average design flow and minimum design flow) the flow depth (y) in the conduit must not exceed the conduit diameter or in other word the flow must not induce pressure or the flow must be considered to be an open channel flow. The fundamental equation used in the design is the Manning's equation which is (in SI units system)

$$Q = \frac{A^{5/3}\sqrt{S}}{nP^{2/3}} \tag{3}$$

where n = Manning's n of the conduit
S = the bottom slope of the conduit.

The term Q may be the peak design flow rate (Q_{pk}), the average design flow rate (Q_{av}) or the minimum design flow rate (Q_{mn}). The cross sectional area (A) and the wetted perimeter (P) is represented as

$$A = \frac{D^2}{8}\left(\theta - \sin\theta\right) \tag{4}$$

and

$$P = \frac{\theta D}{2} = \theta r \tag{5}$$

respectively in which r is the conduit radius. The angle θ is dependent on the flow depth where

$$\theta = \pi + 2\sin^{-1}\left(\frac{y - r}{r}\right) \tag{6}$$

Using Eq. (4) to (6), Eq. (3) can be rewritten as

$$f(y) = \frac{\left[\frac{D^2}{8}\left[\pi + 2\sin^{-1}\left(\frac{y-r}{r}\right) - \sin\left(\pi + 2\sin^{-1}\left(\frac{y-r}{r}\right)\right)\right]\right]^{5/3}}{\left[\left(\pi + 2\sin^{-1}\left(\frac{y-r}{r}\right)\right)r\right]^{2/3}} - \frac{nQ}{\sqrt{S}} = 0 \qquad (7)$$

The calculation to obtain y is based on trial and error basis in which Newton Raphson iteration technique is used in the computer programme to determine the value of D in which flow depth y must be slightly less than D (for peak flow condition) so that the flow is not under pressure. The Newton Raphson iteration uses the equation

$$y_{k+1} = y_k - \frac{f(y)_k}{f'(y)_k} \qquad (8)$$

where k is the iteration number and $f\,'(y)_k$ is the derivative of Eq. (7). Figure 1 shows the flowchart which outlines the calculation process in the design of the incoming conduit.

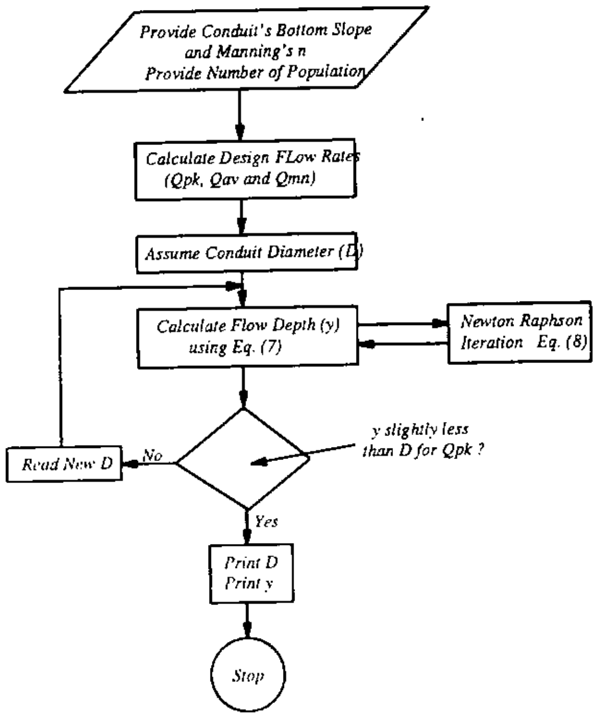
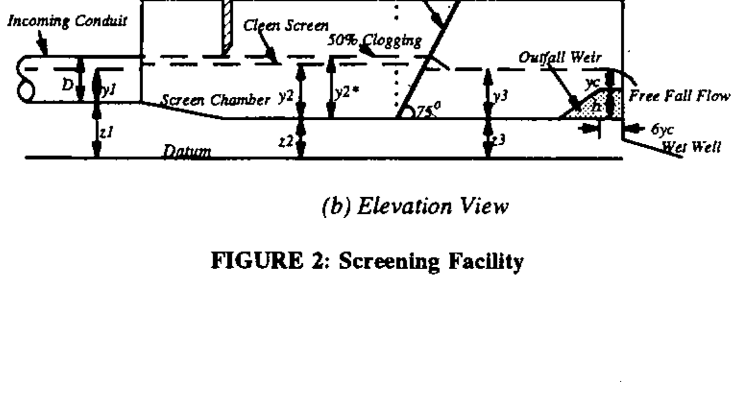


FIGURE 1: Flowchart for the Design of Incoming Conduit

Screening Facility

Wastewater screening is normally the first unit in the treatment plants. It is used to remove large objects such as rags, paper, plastics, etc which may cause damage to pumps, block valves, hang over weirs, pipelines and the like that create plant operation and maintenance problems. There are two main components in the wastewater screening facility ; the bar screens and the screen chamber. The design calculations for bar screen are mainly to determine the bar clear spacings, bar width, total number of bars and the incline angle of the bar screen. The quantity of screenings will depends on the clear spacings between bars. In this computer programme, the clear spacing between bars is fixed to be 25 mm and therefore the quantity of screenings at average design flow and peak design flow are 20 and 30 m^3 per million m^3 of flow respectively [2].

Two identical screen chambers (Figure 2) are designed where each is capable of handling peak design flow condition. One chamber could be taken out of service for routine maintenance (cleaning the clogging at bar screen) without interrupting the normal operation of the treatment plant. Mechanical sluice gate is provided in each chamber to control flow and/or to block flow to one chamber for routine maintenance. The design task for the screen chamber is mainly to determine the chamber width (*W*) and the flow depths (*y*). The invert level of the chamber is fixed to be 8 cm below the invert of the incoming conduit. The bottom slope of the chamber is fixed to be horizontal. The chamber width is calculated based on the peak design flow through one chamber.



(b) Elevation View

FIGURE 2: Screening Facility

The flow depth at Section 1 (Figure 2) was previously determined in the design of the incoming conduit. At Section 2 and 3 the flow depths are determined for clean screen and for 50% screen clogging. Energy equation is used to determine these flow depths which are

$$z_1 + y_1 + \frac{v_1^2}{2g} = z_2 + y_2 + \frac{v_2^2}{2g} + h_{LI} \tag{9}$$

and

$$y_2 + \frac{v_2^2}{2g} = y_3 + \frac{v_3^2}{2g} + h_{L2} \tag{10}$$

where g is the gravitational acceleration and v is the flow velocity ($v = Q_{pk}/yB$: B is the chamber width). The head loss (h_L) of Eq. (9) and (10) is calculated using equation

$$h_{LI} = \frac{0.3}{2g}(v_1^2 - v_2^2) \tag{11}$$

and

$$h_{L2} = \frac{1}{0.7(2g)}(v_s^2 - v_2^2) \tag{12}$$

where v_s is the flow velocity through the clear spacing of the bar screen. Therefore Eq. (9) and (10) can be rewritten as

$$z_1 + y_1 + \frac{Q_{pk}}{2g y_1 B} = z_2 + y_2 + \frac{Q_{pk}}{2g y_2 B} + \frac{0.3}{2g}\left(\frac{Q_{pk}}{y_1 B} - \frac{Q_{pk}}{y_2 B}\right) \tag{13}$$

and

$$y_2 + \frac{Q_{pk}}{2g y_2 B} = y_3 + \frac{Q_{pk}}{2g y_3 B} + \frac{1}{0.7(2g)}\left(\frac{Q_{pk}}{A_n} - \frac{Q_{pk}}{y_2 B}\right) \tag{14}$$

respectively where A_n is the net area of the screen openings which is equal to y_2 times the clear width of the screen openings. The flow depths y_2 and y_3 are solved implicitly using Eq. (13) and (14) respectively in which the calculation is performed using trial and error basis. The Newton Raphson iteration technique is used in the computer programme to solve the flow depths.

The flow depth at Section 2 for 50% screen clogging (y_{2*}) could also be determined using Eq. (10) but the head loss term h_{L2} will become

$$h_{L50} = \frac{1}{0.7(2g)}\left(\frac{Q_{pk}}{A_{50}} - \frac{Q_{pk}}{y_{2*}B}\right) \tag{15}$$

where

$$A_{50} = (0.5)(y_{2*})(\text{clear width of screen openings})$$

After the flow depths have been determined, the hydraulic profile in the screen chamber can be plotted. The hydraulic profile is important to determine the flow characteristics and to determine the height of the screen chamber. Figure 2b shows the general hydraulic profile in the screen chamber during clean screen and during 50% screen clogging.

Screen Chamber's Outfall Weir

The flow depths and velocities in the screen chamber are previously calculated by assuming normal flow conditions in the chamber. If the chamber has a free outfall into the wet well, the actual depths in the chamber will be smaller than the normal depths calculated earlier and the velocities through the screen openings will be larger. Therefore in order to maintain the normal depths (previously calculated depths) in the screen chamber, the bottom of the chamber at the outfall must be raised or in other word an outfall broad crested weir must be provided before the wastewater flow drops into the wet well. This weir will force the flow to be a free fall flow from the weir crest into the wet well.

The design calculations for the outfall weir are mainly to determine the weir height (h), the weir thickness (d) and the flow depth above the weir which is the critical flow depth (y_c). The critical flow depth above the weir crest is determined using normal critical flow depth equation which is

$$y_c = \sqrt[3]{\frac{(Q_{pk}/B)^2}{g}} \tag{16}$$

because the screen chamber is a rectangular section. The weir height is calculated using energy equation (ignoring friction head loss which is relatively small) which is

$$y_3 + \frac{v_3^2}{2g} = h + y_c + \frac{v_c^2}{2g} \tag{17}$$

where v_c is the critical flow velocity. The weir thickness (d) is equal to 6 times the critical flow depth [2] and the weir slope is arbitrary and the computer programme uses a 45° slope.

The calculation process for the design of screening facility is outlined in a flowchart shown in Figure 3.

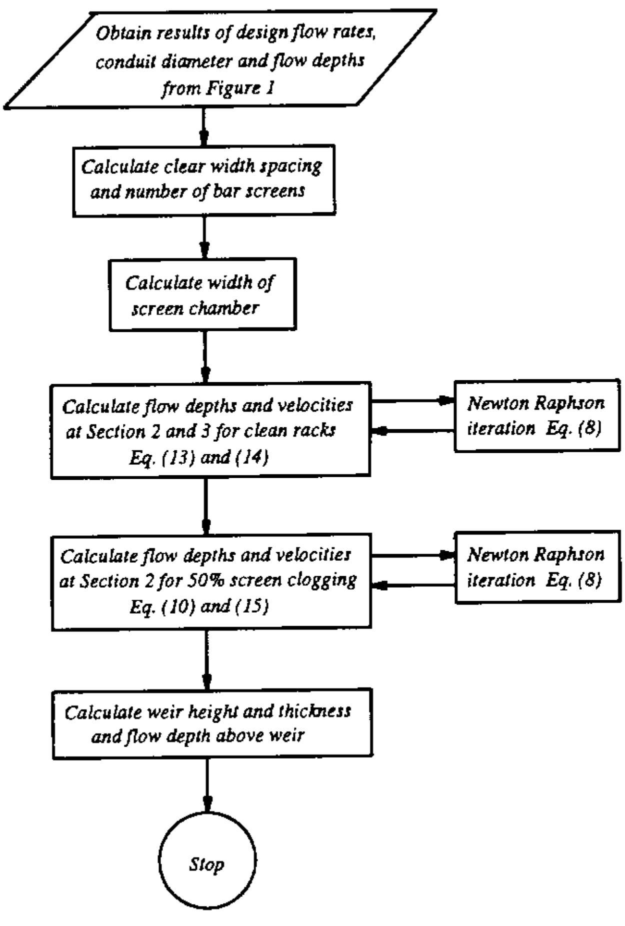


FIGURE 3: Flowchart for the Design of Screening Facility

Run Example and Results

The computer programme was written in Fortran77 utilizing IBM-PC compatible microcomputers. The programme runs easily after the command A:>WWTREAT which stand for WasteWater TREATment. Input data file is not needed to run the programme. The input data such as the total number of population, the slope and Manning's n of the incoming conduit is provided during the run of the programme. Appendix 1 shows the run example for a local wastewater treatment plant which serve the total population of 170.45 thousand people. The bottom slope and the Manning's n of the incoming conduit is provided as 0.0016 and 0.013 respectively.

Conclusion

The design calculations for the incoming conduit and screening facility use simple method and technique. However the process of calculation might take several hours if it is done manually since trial and error or iteration process is involved. For convenience and best results, the calculation have to be performed using computer programme. The programme is guaranteed to be accurate and faster compared to the manually calculation process, more versatile and easier to use and the results are easy to interpret and ready to be included in any design report of municipal wastewater treatment plant facilities.

References

[1] SIRIM (1991). Code of Practice for Design and Installation of Sewerage Systems, Shah Alam. PIA MS1228.

[2] Qasim, R. S. (1985). Wastewater Treatment Plant - Planning, Design and Operation. CBS Publishing, Tokyo, Japan.

APPENDIX 1

-- OUTPUT FILE --

```
W     W   W     W  TTTTT  RRRR   EEEEE    A    TTTTT
W  W  W   W  W  W    T    R   R  E       A A     T
W  W  W   W  W  W    T    RRRR   EEE    A   A    T
 WW WW     WW WW     T    R R    E      AAAAA    T
  W W       W W      T    R   R  EEEEE  A   A    T

*>>>>>>   DESIGN OF MUNICIPAL WASTEWATER      <<<<<<*
*            TREATMENT PLANT FACILITIES             *
*                                                   *
*                   programmed by                   *
*                 AMAT SAIRIN DEMUN                 *
*           Universiti Teknologi Malaysia           *
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Project Name      :  Pusat Pengolahan Airsisa Bandar XYZ
Program run by    :  Amat Sairin Demun
Organization      :  Universiti Teknologi Malaysia
Date              :  9 th October 1995
Output Filename   :  A:OUTPUT.OUT
```

DESIGN INFORMATION
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1. Number of Population Served, P = 170.450 thousand
2. Peak Design Wastewater Flow, Qpk = 1.185 m3/s
3. Average Design Wastewater Flow, Qav = 0.444 m3/s
4. Minimum Design Wastewater Flow, Qmn = 0.200 m3/s

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1.0 INCOMING CONDUIT AND SCREENING FACILITY

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Purpose: To remove large objects such as rags, paper, plastics, metals, and the like.

1.1 THE INCOMING CIRCULAR CONDUIT
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1. Selected Slope, S = 0.00160
2. Selected Manning's n = 0.013
3. Designed Conduit Diameter, D = 1.135 m
4. Peak Flow Depth, d = 0.827 m
5. Peak Flow Velocity, v = 1.500 m/s
6. Average Flow Depth, d' = 0.449 m
7. Average Flow Velocity, v' = 1.192 m/s
8. Minimum Flow Depth, d" = 0.296 m
9. Minimum Flow Velocity, v" = 0.954 m/s

APPENDIX 1 continued

1.2 BAR SCREEN AND THE CHAMBER
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1. Provide two identical screen chamber, each one capable of handling peak flow condition. One chamber could be taken out of service for routine maintenance without interrupting the normal plant operation.
2. Incline angle of bar rack, theta = 75 degree
3. Clear bar spacing, s = 25 mm
4. Bar width, w = 10 mm
5. Total number of clear spacing = 38
6. Total number of bars = 37
7. Width of each chamber, B = 1.326 m
8. Length of bars (0.5 m freeboard), h = 1.525 m
9. Efficiency coefficient = 0.717
10. Height z1 - z2 = 0.080 m
11. Flow depth at 2 (clean rack), d2 = 0.956 m
12. Flow velocity at 2 (clean rack), v2 = 0.935 m/s
13. Head loss thru rack (clean), HL = 0.059 m
14. Flow depth at 3 (clean rack), d3 = 0.890 m
15. Flow velocity at 3 (clean rack), v3 = 1.393 m/s
16. Flow depth at 2 (50% clogging), d2' = 1.025 m
17. Flow velocity at 2 (50% clog), v2' = 0.873 m/s
18. Heal loss thru rack (50% clog), h50 = 0.371 m
19. Critical depth above weir, dc = 0.434 m
20. Critical velocity above weir, vc = 2.062 m/s
21. Height of weir, zc = 0.339 m
22. Length of weir, Lc = 2.601 m
23. The invert level of wet well must be lower than the invert level of the screen chamber to allow free fall flow after the weir.
24. Quantity of Screenings :-
    * Average of screenings = 0.77 m3/day
    * Maximum of screenings = 1.38 m3/day
25. The screenings will be disposed of by proper sanitary landfilling. Detail design of the sanitary landfill is not included in this program.

End of Output File