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Design of water supply networks for water transfer to the urban area Case study: Balikpapan city

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Abstract: The growing population and the development of industries in all countries of the world have created a very important and complex issue for water supply to cities. Today, many parts of the world are facing the problem of water shortage and this problem cannot be easily solved. In addition to the proper use of water resources and preventing the loss of natural water, the establishment of regional water supply networks is effective in meeting the future needs of the people. A water distribution network (water supply network) is a set of interconnected pipelines used to transport and distribute water in a complex. In designing the water distribution network, factors such as the type of water distribution network, water pressure, water velocity, design flow, minimum pipe diameter, pipe material and many other factors should be considered. In this study, we have tried to design the water supply network of a part of Balikpapan city in Indonesia. The design method led to the determination of pressure values in the connection nodes, pipe diameters, flow rate and velocity in the pipes. All the existing criteria are considered in the design of the water supply network. Although this study has been implemented for a specific study area, it can be of great help to designers in designing the water supply network.

Keywords: network design, water distribution, water shortage, water supply network, water transmission

INTRODUCTION

Water supply network is the most important and vital component of urban infrastructure [Bensoltane *et al.* 2018; Sulianto *et al.* 2021; Willet *et al.* 2020]. The internal water supply network was very small in the past [Qiao *et al.* 2007]. Untreated industrial effluents flowed directly into lakes and rivers, many of which were sources of drinking water [Alonso, Barceló 1999; Ilyas *et al.* 2019; Martínez-Santos *et al.* 2018; Mereta *et al.* 2020]. Efforts to purify water were steadily declining, and few cities were found to treat wastewater. Today, due to the increase in urban population, industrial development, water shortages, migration of people from rural to urban areas, modern life and attention to public health has created many problems with water supply. Therefore, access to safe drinking water is one of the most important human needs. For this reason, proper and standard design of urban water supply network is one of the primary priorities for the construction and development of residential, industrial and agricultural spaces [Cunha, Sousa 1999; Eusuff, Lansey 2003; Willet *et al.* 2021]. In designing water supply networks, it should be noted that the required water supply is provided by four main units [Batish 2003; Gurung *et al.* 2015; Herrera-León *et al.* 2018], which are: 1 – supply of drinking water to people and water required for sanitary facilities (baths and toilets), 2 – water required for small and large factories and various workshops, 3 – providing the necessary water for irrigating green spaces and washing the streets, and 4 – supplying water required by the facilities of fire departments during fires. The main components of the water supply network include tanks, pipes, valves and pumps [Geem *et al.* 2011; Lucas *et al.* 2010; Young 1994]. Water supply network is a large set of a series of pipes that are connected by connections such as tees, elbows, transformers, etc., so that when water enters from one point, from other places, water can be withdrawn [Fathollahi-Fard *et al.* 2020; Iwanek *et al.* 2020; Montalvo *et al.* 2008]. The main water supply systems and facilities include five general sections, which are: 1 – reservoirs (such as wells, springs, dams, rivers) and facilities related to water abstraction from them, 2 – sources (such as wells, springs, dams, rivers), 3 – water storage tanks and creating pressure in the network, 4 – water distribution and transmission lines, and 5 – sections related to consumer branches. Due to the increasing importance of urban water supply, in this project, the design of Sawahlunto city water supply network has been considered. The design steps are presented in a completely accurate and organised manner. Lattice pipes are selected from uncovered cast iron. The project period is considered 20 years.

MATERIALS AND METHODS

In order to design the water supply network of the desired area, 13 general steps have been considered. The following 13 general steps will be mentioned.

- **Determine the location of the network:** the topography and area characteristics are two important factors in the location of nodes and network pipes.
- **Determine the alignment of the nodes:** based on the topography of the study area, the level of each node will be determined.
- **Determine the length of the pipes:** in order to get the actual length of the pipes, we use their length values on the map. The scale of the map is 1:20,000. Using Equation (1), the actual length of the pipes is obtained.

$$L_a = \frac{L_M}{\mathrm{s}} \tag{1}$$

where: L_a = the actual length of the pipe, L_M = the length of the pipe on the map, s = the scale of the map.

- **Estimate the area:** in order to determine the area, the length of the pipes is first measured from the existing map. Then the network location is plotted in AutoCAD software. Finally, having a map scale, the area of the study area is determined using the area command.
- **Determine the population of the city at the beginning and end of the network design period:** the population of the city at the beginning and end of the project period is determined using Equations (2) and (3), respectively.

$$P_0 = 100D \cdot A \tag{2}$$

$$P_T = P_0(1+r)^T \tag{3}$$

where: P_0 = the initial population of the city, D = the city density, A = the area of the city, P_T = the population of the city after T year, and r = the population growth rate.

The population growth rate of the study area is approximately 2.5%. The study area density is 0.45 people per km^2.

- **Determine the average per capita daily consumption:** per capita household, general, commercial, industrial consumption, unaccounted for water and public green space should be determined.
- **Determine $Q_{d,\mathrm{av}}$:** This parameter is obtained from Equation (4).

$$Q_{d,\mathrm{av}} = TC \tag{4}$$

where: $Q_{d,\mathrm{av}}$ = average design flow, TC = total per capita consumption.

- **Determine $Q_{d,\max}$ and C_1:** The maximum daily coefficient (C_1) is assumed to be 1.8. $Q_{d,\max}$ is also calculated using Equations (5)–(8). It is necessary to mention that the Q'... parameters are only considered to determine the Q'... parameters and have no specific description.

$$Q'_{d,\mathrm{av}} = \left(TC - W_{\mathrm{not},d}\right)P_T \tag{5}$$

$$Q'_{d,\max} = Q'_{d,\mathrm{av}}\, C_1 \tag{6}$$

$$W_{\mathrm{not,av}} = Q_{d,\mathrm{av}} - Q'_{d,\mathrm{av}} \tag{7}$$

$$Q_{d,\max} = Q'_{d,\max} + W_{\mathrm{not},d,\mathrm{av}} \tag{8}$$

where: $W_{\mathrm{not},d}$ = the per capita daily water consumption is not taken into account, $W_{\mathrm{not},d,\mathrm{av}}$ = the average daily water consumption is not taken into account.

- **Determine $Q_{h,\max}$ and C_2:** for the population range between 20–100 thous. people, C_2 should be selected between 1.3 and

1.9. Since the population at the end of the project period is 100,942 people, the coefficient C_2 is considered to be a median of 1.8. $Q_{h,\max}$ is also calculated using Equations (9)–(12).

$$Q_{h,\mathrm{av}} = \frac{Q_{d,\max}}{24} \tag{9}$$

$$Q'_{d,\mathrm{av}} = \frac{Q'_{d,\max}}{24} \tag{10}$$

$$Q'_{h,\max} = C_2 \cdot Q'_{h,\mathrm{av}} \tag{11}$$

$$Q_{h,\max} = Q'_{h,\max} + W_{\mathrm{not},h,\mathrm{av}} \tag{12}$$

where: $W_{\mathrm{not},h,\mathrm{av}}$ is the average hourly water consumption is not taken into account.

- **Determine the design flow (Q_{des})**: is determined using Equation (13):

$$Q_{\mathrm{des}} = \frac{Q_{h,\max}}{3600} \tag{13}$$

- **Determine the flow rate of network pipes Q_i':** this parameter is determined using Equation (14), in which the superscript *i* is the pipe number.

$$Q_i' = \frac{L_{i,a}}{\sum_i L_{i,a}} Q_{\mathrm{des}} \quad \text{so,} \quad \sum_{\mathrm{i=1}}^{\mathrm{n}} \mathrm{L_{i,a}} \tag{14}$$

- **Determine the hypothetical diameters for the grid pipes:** we consider hypothetical values for the flow rate in the pipes so that the continuity equations in the consumption nodes are satisfied. After controlling the continuity equations for the whole network with hypothetical flow rates, we calculate the diameter of the pipes so that the flow velocity in the pipes is in the range of 1.0–1.2 $\mathrm{m \cdot s^{-1}}$. Assuming the velocity is 1 $\mathrm{m \cdot s^{-1}}$, the pipe diameter (d_i) can be calculated using Equation (15).

$$d_i = \sqrt{\frac{4Q_i}{\pi}} \tag{15}$$

In the next step, we convert the obtained diameters for the pipes to the closest diameter available in the market.

- **Control the pressure and velocities obtained in the network in terms of allowable values:** the minimum pressure head is 18 m H_2O. Also, the allowable water velocity in the pipes is 0.3–2.0 $\mathrm{m \cdot s^{-1}}$.

RESULTS AND DISCUSSION

WATER SUPPLY NETWORK DESIGN

Figure 1 shows the location of nodes and pipes in the water supply network. In the study area, nodes 13 and 31 have the lowest and highest alignment, respectively. The length of the pipes was obtained using Equation (1). Pipe number 46 is the tallest pipe (1762.1 m). By drawing the network in AutoCAD software, the area was estimated at 13.6 ha. The current population of the region is about 61,602 people (Eqs. (1) and (2)). At the end of 20 years, the population will reach 100,942 people. Due to the large number of residential buildings and the increase in the level of health compared to the past, per capita household consumption is considered to be 135 $\mathrm{dm^3}$ per capita per day (Lpcd). Due to the existence of medical and educational centers and especially the large number of religious places in this area, the per capita general consumption is 20 Lpcd. Due to the lack of commercial premises and the lack of factories in this area, the per capita commercial and industrial consumption is 12 Lpcd. It is considered 15 Lpcd unaccounted for water. Because the climate of the study area is desert, the per capita green space consumption is 48.82 Lpcd. It should be noted that the total per capita is obtained from the sum of all per capita. So the total per capita is 230.82 Lpcd.

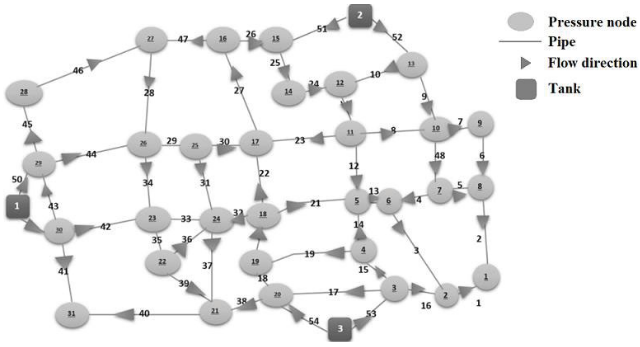

Fig. 1. Location of water supply network; source: own elaboration

To determine the flow rate of each node, we first consider the value of $0.5Q_i'$ for each node. In this study, the active volume of the reservoir is 6,109.16 $\mathrm{m^3}$. Three fire storage tanks each with a volume of 225 $\mathrm{m^3}$ are considered. The expected storage volume is 20,363.87 $\mathrm{m^3}$. Therefore, the total volume of available tanks is 27,148.03 $\mathrm{m^3}$. Since the topography of the area is smooth; preferably we consider a reservoir for each part of the network to ensure that the necessary pressure is supplied to all nodes. In addition, we try to place the tanks close to the network. Also, due to the flatness of the area, we use a ground tank next to each of the air tanks. Figure 1 shows the location of all three tanks. In this study, underground reservoirs are twin and cubic with a length and width of 27.5 m and a height of 6.5 m. Air tanks are also assumed to be a twin cylindrical tank. The volume of each air tank is 339.9 $\mathrm{m^3}$. The hypothetical direction of flow in network pipes is as shown in Figure 1. Using Equation (15), the diameter of the pipes is obtained. For example, the diameter of pipe number 1 was 90 mm.

After obtaining the pipes flow, the network was drawn in EPANET. Then the data was given to the software and the software was run. It was observed that in some nodes the existing pressure head is less than the minimum pressure head. In some pipes, the velocity is not within the allowable range (0.3–2.0 $\mathrm{m \cdot s^{-1}}$). Therefore, with a trial and error process, we changed the diameter of the pipes to the minimum required.

PRESSURE AND VELOCITY HEADS IN PIPES AND NODES

Velocity, flow, pressure, and final diameter of pipes were obtained (with a trial and error process). For example in pipe number 1, velocity, flow, pressure in node 1, final diameter of pipe are obtained 0.55 $\mathrm{m \cdot s^{-1}}$, 4.3 $\mathrm{dm^3 \cdot s^{-1}}$, 31.86 m, and 100 mm, respectively. The criteria provided in the 13 steps mentioned are met. Due to the priority of providing minimum pressure over velocity, in some pipes we did not provide minimum velocity to some extent.

CONCLUSIONS

In this study, the design of Sawahlunto water supply pipes network has been done. In order to design water supply networks, 13 general steps are presented, which are: determine the location of the network, determine the alignment of the nodes, determine the length of the pipes, estimate the area, determine the population of the city at the beginning and end of the network design period, determine the average per capita daily consumption, determine $Q_{d,\mathrm{av}}$, determine $Q_{d,\max}$ and C_1, determine $Q_{h,\max}$ and C_2, determine Q_{des}, determine the flow rate of network pipes (Q'_i), determine the flow in consumption nodes (q_j), design network tanks, determine the hypothetical diameters for the grid pipes and control the pressure and velocities obtained in the network in terms of allowable values. After performing the 13 steps described, the water supply network was implemented in EPANET software. Then the amount of pressure in the nodes, velocity and water flow in the pipes were determined. Finally, with a trial and error process, the diameter of the water supply network pipes was determined.

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