PEAK FACTOR IN THE DESIGN OF WATER DISTRIBUTION- AN ANALYSIS

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ABSTRACT

Water distribution system , being an important components of a water supply system, consumes nearly 75% of installation cost. Population, minimum residual pressure, peak factor and demand variation mostly decide the pipe size and cost. Peak factor value adopted for the design of distribution system differs country to country around the world. A critical review of peak factor used by different countries has been made. The cost of the net work increases with the peak factor. In India, the actual peak factor observed in the field fluctuates from 3 to 12 due to intermittent water suppl. Peak factor 5 to 6 is found to be suitable for ensuring the reliability of the distribution system.

Key words: Water distribution system, peak factor, EPANET

INTRODUCTION

Water distribution system (WDS), being an important component of any water supply scheme, is commonly designed with an objective of distributing water at the required levels of service in satisfying quantity and quality. It accounts for a substantial portion of installation cost. Pipeline network in the water supply system stands for around 75% of the total investment (WSAA,1999 and Burn et al, 2002) In addition to the capital cost which is a function of pipe diameter and laying conditions, the present worth of energy costs included in the distribution system costs is also affected by pipe sizing ( Walski et al, 2003). Design of distribution network is governed by various parameters. The peak factor, defined as the ratio of the maximum flow during some specified time to the average flow (Mays,1999), is a crucial factor in the design of water distribution system, distribution capacity, and in customer metering ( AWWA,2004). The minimum pressure to be ensured for the supply of required quantity water is also depending on the peak factor. Pressure in the distribution system falls down considerably demanding consumers to go in for pit taps, if the actual flow increases more than the design flow i.e., when the actual peak flow during operation of the system in the most of the water supply schemes exceeds the design peak factor. In developing
countries like India, majority of the WDS work as intermittently. Ageing of water is another implication associated with peak factor. Therefore, it is essential to use carefully an appropriate peak factor on which the pipe sizing and quantity of flow depends, so that considerable savings can be achieved in expense on pipelines. Keeping the above factors in mind, the present work attempts to compare the peak factor followed in other countries with the CPHEEO recommendations in India, to study operation condition (Continuous and intermittent) and to analyze the cost variation.

LITERATURE REVIEW

In general, peak factor is highly related to the number of consumers, the service areas, and the duration of peak flow of a water distribution network. Johnson (1999) concluded that peak factor tend to increase with a decrease in the number of consumers. This is majorly oriented by simultaneity of consumption. Barrufet (1985) observed that peak factors increase from a constant 1.5 for more than 1,00,000 consumers to as much as 98 for a two person apartment. A strong inverse relationship between the number of inhabitants in a building and the peak factor as well as between flow and pressure (Tessendorff, 1980). Again , Mutschmann and Stimmelmayr (2007) stated that: Peak factors are greater in smaller water supplies areas”. This is because smaller coverage areas usually mean less water users. As a result, the variation of water demands is more difficult to predict.

METHODS

Comparison of Peak factor

As the water use varies greatly with location, varying regions often have their own methods for estimating the peak demands in their systems. Zhang (2005) explained two methods adopted in America. They are

Georgia Minimum standards for Public Water systems suggested a following relationship between peak factor and the number of connections as given below.

\[ Q_p = 43.40 C^{-0.54} \]  

Where \( Q_p \) is the peak instantaneous demand in litre/minute and \( C \) is the number of connections. Equation (1) holds for \( C \) value less than 500 only.

In the US Bureau of Reclamation Design Criteria, the peak instantaneous demand is expressed as

\[ Q_p = 18.19 N^{0.5} + 3.41 N + 22.36 \]  

Where \( N \) is the number of houses.

DVGW German Technical and Scientific Association for Gas and Water has stated that both peak day demand \( (Q_d) \) and peak hour demand \( (Q_h) \) depend on the population, and can be expressed by equations (3) and (4),

\[ Q_d = -0.1591 \ln E + 3.5488 \]  

\[ Q_h = -0.75 \ln E + 11.679 \]  

Where \( E \) –Population
Latest DVWG worksheet suggests the following relationships.

\[ Q_d = -3.9 E^{0.0753} \]  \hspace{1cm} (5)

\[ Q_h = -18.1 E^{0.1682} \]  \hspace{1cm} (6)

In India, the CPHEEO (1991) has recommended following values of peak factor based on population (Table 1) for the design of water distribution system.

\textbf{Table 1. Peak factor for various populations}

<table>
<thead>
<tr>
<th>Population</th>
<th>Peak factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upto 50000</td>
<td>3.0</td>
</tr>
<tr>
<td>50000 to 200000</td>
<td>2.5</td>
</tr>
<tr>
<td>Above 200000</td>
<td>2.0</td>
</tr>
</tbody>
</table>

The same values are plotted and a trend line is drawn (Figure 1). The relationship between population and peak factor is

\[ P_f = -0.5 E + 3.5 \]  \hspace{1cm} (7)

\[ Q_p = P_f * D \]  \hspace{1cm} (8)

Where \( P_f \)-peak factor, \( D \)- per capita demand. \( D \) depends on status of settlement ( corporation/ Municipality/ town panchayat/ rural)

\[ Q_p = (-0.5 E + 3.5) \times 135 \]  \hspace{1cm} (9)

\[ Q_p = (-0.5 E + 3.5) \times 90 \]  \hspace{1cm} (10)

\[ Q_p = (-0.5 E + 3.5) \times 70 \]  \hspace{1cm} (11)

\[ Q_p = (-0.5 E + 3.5) \times 40 \]  \hspace{1cm} (12)
Peak demand for Corporation, municipality, town panchayat and rural area is determined using the equations (9), (10), (11), and (12) respectively.

**PEAK FACTOR VERSUS COST**

A water distribution network, shown in figure 2, is chosen for demonstrating the cost of pipeline for various peak factors using EPANET software. The costs for various sizes of pipes including laying and jointing adopted are tabulated(Table 2). Peak factor is varied from 2 to 8.

![Figure 2 Layout of the distribution network](image-url)
Table 2 Cost pipe including charges for laying and jointing

<table>
<thead>
<tr>
<th>Sl.No</th>
<th>Diameter of pipe, mm</th>
<th>Type of material</th>
<th>Cost/metre, Rs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>500</td>
<td>DI</td>
<td>12924</td>
</tr>
<tr>
<td>2</td>
<td>450</td>
<td>DI</td>
<td>10672</td>
</tr>
<tr>
<td>3</td>
<td>400</td>
<td>DI</td>
<td>9153</td>
</tr>
<tr>
<td>4</td>
<td>350</td>
<td>DI</td>
<td>5668</td>
</tr>
<tr>
<td>5</td>
<td>300</td>
<td>DI</td>
<td>4639</td>
</tr>
<tr>
<td>6</td>
<td>250</td>
<td>DI</td>
<td>3727</td>
</tr>
<tr>
<td>7</td>
<td>200</td>
<td>DI</td>
<td>2798</td>
</tr>
<tr>
<td>8</td>
<td>150</td>
<td>DI</td>
<td>2218</td>
</tr>
<tr>
<td>9</td>
<td>160</td>
<td>HDPE</td>
<td>1425</td>
</tr>
<tr>
<td>10</td>
<td>110</td>
<td>HDPE</td>
<td>994</td>
</tr>
</tbody>
</table>

RESULTS AND DISCUSSION

Peak factor

Though the hydraulics of water distribution network is common throughout the world, the peak factor followed in the design of WDS varies with countries. It takes exponential form with number of consumers in US and log pattern of relationship is followed in Germany. In India, the relationship suggested by CPHEEO between the population and peak factor shows linear pattern. Developing countries like India, the design of WDS is done a continuous one i.e 24 hrs supply. But the operation of the most of the water supply systems is done intermittently (Petr Ingeduld, et al, 2006). In this case, peak factor observed at the field is higher than the design value rendering increased friction loss. In Manapparai Municipality, water supply is given only for two hours a day. In this case, the actual peak factor is 12 against 3 adopted for design resulting to pit taps. Moreover, CPHEEO recommends peak factor value based on only population. As the population density varies place to place, length of the network for a particular population may not be same in all the cases. It is felt that a detailed research to assess the effect of length besides population on the peak factor is required.

Peak factor versus cost

A water distribution network consisting of 26 links with 25 nodes were analyzed varying the peak factor from 2 to 8 keeping the minimum pipe size and maximum and minimum pressure advocated by CPHEEO to assess the impact of peak factor on the cost of pipeline. Figure 3 shows the impact of cost. It is noticed that the cost increases steeply from 2 to 5. The incremental when the peak factor is increased from 5 to 6 is very marginal. After 6, again it shoots up as in the initial range. The cost increase may be due to the higher size of pipe.
Required to carry increased flow. The CPHEEO suggests the minimum pipe size to be laid in the water distribution system as 100 mm. Full carrying capacity of such pipes may not be fully utilised. The marginal incremental in cost, in the case of peak factor 5 and 6, may be due to the said reason. Minimum and maximum pressure in the system in all the cases are 15.14 m and 31.30 m. The trend obtained in the figure 3 between the peak factor and cost is almost similar to the study reported from Germany by Diao et al (2010). It is noticed that the peak factor values recommended by CPHEEO are far lesser than the operational conditions. Water ageing problem shall not prevail in the case observed peak factor is higher than design value. The service reservoir capacity in the distribution system is commonly determined from mass curve analysis or empirically fixed as 1/3 rd of a day requirement. Three filling is needed to meet total demand. Intermittent supply may result in if three filling is not done. One filling has to serve for 8 hours a day. Peak factor in the range 5 to 6 may be considered instead of 2 to 3. The service capacity may also be given ½ of a day requirement. Increasing capacity will increase the reliability of system.

CONCLUSION

Peak factor, an important aspect associated with the sizing of pipe and corresponding cost in water distribution network, varies with countries. Linear relationship between the population and peak factor is observed for the values recommended by CPHEEO. In India, most of the systems are operated as intermittent ones. The peak factor observed in the field ranges from 3 to 12. No ageing of water is anticipated. Intermittent water supply deserves its own demerits like pollution, low pressure, leakages etc. The cost of the system is directly proportional to the peak factor. Marginal incremental increase is observed in the range 5 to 6. Peak factor in the order of 5 to 6 with service reservoir capacity as ½ of a day requirement may increase the reliability of the system.
REFERENCES


