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PEAK FACTOR CURVE FOR ESTIMATING PEAK FLOWS IN DESIGN OF SEWER NETWORKS: A CASE STUDY OF GADCHIROLI CITY

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ABSTRACT

Ratio of maximum to average flows, defined as a peak factor (PF), is observed to be dependent on contributory population. The Central Public Health and Environmental Engineering Organization (CPHEEO) recommended consideration of peak factors based on population range (CPHEEO Manual 1993). This type of consideration results in sudden reduction in PF as contributing population changes from one range to other. The sudden reduction in PF reduces the outgoing flows at a manhole and flow continuity at a manhole gets imbalanced. To overcome this problem of sudden reduction in PF, a new methodology is suggested in which peak factors are applied node wise to contributory population added at the manhole based on the total contributory population at outgoing sewer of that manhole. In the proposed methodology, thus the effective PF reduces continuously as the contributing population increases. The effective peak factors are compared with the PFs obtained by using both Babbitt's as well as Harmon's formula and observed to provide PFs on little higher side for lower flows. However, this difference diminishes as contributing population increases. Therefore, size and slope of sewers may not be much affected. Further, it is proposed to consider higher PFs than 3.0 as recommended by Haws (2013) for contributing population below 10000. The PFs of 4, 5 and 6 have been suggested for contributing population in range of 1000-10000, 300-1000, and below 300, respectively. This will avoid laying of sewer unnecessarily at higher gradient, or to make unnecessary arrangements of flushing when sewers are not laid at required gradient to achieve minimum velocity of 0.6 m/s at present peak flows. The proposed methodology of adopting PFs suits well to software SEWER 3.0 which allows consideration of PF node wise. The proposed methodology is applied to design the underground sewer network of the Gadchiroli Town. Salient features of the case study are presented.

I INTRODUCTION

Water after its domestic and industrial use converts to waste water. This waste water is required to be collected and treated before disposing safely to maintain hygiene and safeguard the health of citizen. A sewer network is to be designed to collect waste water from different locations in the city and transport it to the treatment plant. The Central Public Health and Environmental Engineering Organisation (CPHEEO) provides guidelines to design sewer network in India and these guidelines are amended from time to time based on recent advancement in technologies and experienced gained over years. The design of sewerage systems essentially consists of: (1) Selection of layout of sewer network which also involves selection of suitable site for treatment of waste water; (2) The estimation of the design flows; and (3) The selection of the size and the slope at which each pipe in the network is to be laid.

The layout of sewer network depends on topography, street pattern and the right way and is normally left to common sense and judgement of the engineer. The estimation of the design flows requires consideration of nature of flow i.e., domestic or industrial wastewater, or storm water runoff, addition due to infiltrations and peak factor to be considered. The size and slope of the sewers are decided either through optimization or using heuristic algorithms.

Guidelines are also provided by the CPHEEO to select appropriate gradient based on present peak flows and to select appropriate size based on design peak flows to ensure generation of minimum velocity in sewer at least once in a day (CPHEEO 1993). The estimation of design flows is very important step as over estimation of flows may make a sewer network costlier; while under estimation of flows may require a pipe to be laid at a greater slope to generate minimum self cleaning velocity and may also cause overflowing of sewer.

Peak factor (PF) is defined as ratio of maximum flow to average flow in sewer. Peak factor in sewer is affected by contributing population and reduces as contributing population increases. Babbitt suggested formula for PF as

$$PF = \frac{5}{P^{0.2}} \tag{1}$$

where P is contributing population in thousands.

Harmon's also suggested a formula for the PF and recommended the same to be used for population giving PF between 2.0 to 4.0. The formula is

$$PF = 1 + \frac{14}{4+\sqrt{p}} \tag{2}$$

CPHEEO Manual (1993) recommended peak factors slab wise based on contributory population as given in the Table 1.

Table 1. Peak factors in sewers (CPHEEO Manual 1993)

Contributory population	Peak factor
Up to 20,000	3
20,000 to 50,000	2.5
50,000 to 7,50,000	2.25
Above 7,50,000	2

Slab wise provision of PF by CPHEEO results in sudden reduction of peak factor as contributory population moves from one slab to other. This causes flows to get imbalanced at manhole. Therefore it is desirable to reduce PF gradually as also allowed by Eqs. (1) and (2).

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A minimum cost design of a sewer network involves selection of size and slope of sewers so as to minimise the sum of costs of sewers, manhole and excavation subjected to criteria of satisfying minimum and maximum velocities, minimum cover, maximum depth of excavation, minimum pipe diameter and diameter progression. Several optimization algorithms have been suggested based on linear programming (LP), non-linear programming (NLP), dynamic programming (DP) and evolutionary techniques like GA (Walsh and Brown 1973; Meritt and Bogan 1973; Argaman et al.1973; Gupta et al. 1976; Dajani et al. 1977, Gupta et al. 1983, Kulkarni and Khanna 1985, Mondal and Gupta 2002, etc.). However use of such optimization techniques to real life problems are limited either due to computational intensiveness (GA or DP) or due to assumptions like pipe diameter as continuous variable (NLP) or due to limited capacity of handling number of variables at a time.(LP technique). Heuristic algorithms are found to be better as they require less computational work and produce comparable designs (Miles and Heaney 1988, Charalmbous and Elimam 1989; Vijayan et al. 1998). Since design of sewer network requires large computational works, use of computer program has been suggested by several researchers. Desher and Davis (1986) proposed a computer program, SSD (Sanitary Sewer Design), in *Basic* language for design of sewer networks. Miles and Heaney (1988) suggested used of *spreadsheet program* based on DP. Charalmbous and Elimam (1990) prepared a program based on heuristic method using *C* language. SEWER VER 3.0 is a freely available software in public domain developed by World Bank for design of sanitary sewers. It provides a choice to t he designer to select a policy and based on the selected policy designs a sewer network.

SEWER allows inflows to be given at manholes along with peak factors, while CPHEEO recommendations and the Babbitt and Harmon's formulae require the consideration of peak factor based on contributory population along the link. To solve this problem, a methodology of applying PFs to contributing population at manhole is suggested. The PF at a manhole will be based on total contributory population at the outgoing of the manhole as recommended by CPHEEO (1993). Initially, the concept is explained and illustrated with the design of single line and later its application as used in design of sewer network of Gadchiroli town is described .

II PROPOSED METHODOLOGY AND PEAK FACTOR CURVE

As discussed earlier, CPHEEO manual has recommended peak factors based on contributory population. Considering two sewer links *ik* and *jk* meeting at a junction manhole *k*. *kl* being outgoing link at junction manhole *k*, as shown in Figure 1. Let the total population contributing flows in each of the links *ik* and *jk* are 10000 and population contributing inflow at junction manhole *k* is 5000. Considering sewage flow contribution of 150 lpcd, average flow in *ik*, *jk*, *kl* are 17.36, 17.36, 43.4 L/s respectively. Therefore, the PFs as per CPHEEO recommendations in link in the sewers *ij*, *jk*, *kl* would be 3.0, 3.0, and 2.5, L/s respectively, and peak flows in sewers would be 52.08, 52.08 and 108.5 L/s, respectively. This consideration results in sudden reduction in peak flows in link *kl*. Further, flow continuity is imbalanced. To solve this problem, it is proposed to consider applying peak factor node wise based on total contributing population in the outgoing link. For the network of Figure 1, since the contributing population in sewers *ik* and *jk* are less than 20000, peak factors for manholes *i* and *j* and also for all the manholes on upstream of the manhole *i* and *j* if

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any will be 3.0. The contribution population for sewer *kl* is 25000 which is in the range of 20,000 to 50,000. Therefore, peak factor for the population contributing at manhole is proposed to be considered as 2.5. Thus, effective Peak factor for sewer *kl* will be 2.9 {= 10000 x 3 + 10000 x 3 + 5000 x 2.5)}.

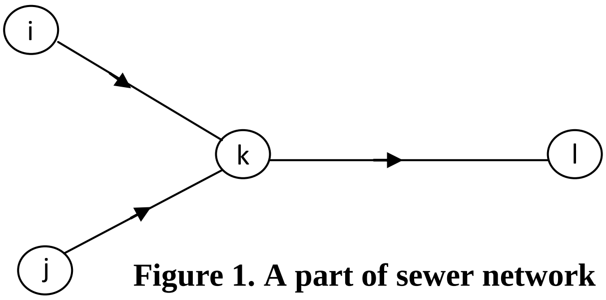

Figure 1. A part of sewer network

Table 2. Comparison of Effective Peak Factor with CPHEEO and other formulae

SN	Contributing Population	Peak Factors using			
		Proposed Method	CPHEEO recommendations	Babbitt's formula	Harmon's formula
1	300	5.0	3	4.08	6.36
2	1000	4.0	3	3.80	5.00
3	10000	3.0	3	2.95	3.15
4	20000	3.0	3	2.65	2.75
5	30000	2.833	2.5	2.48	2.53
6	40000	2.750	2.5	2.36	2.39
7	50000	2.700	2.5	2.26	2.29
8	100000	2.475	2.25	2.00	1.99
9	250000	2.363	2.25		
10	500000	2.340	2.25		
11	750000	2.295	2.25		
12	1000000	2.280	2.0		

Peak factors suggested by CPHEEO are lesser than those given by Harman's and Babbitt's formulae for contributing population 10000 or below. These are on higher side on contributing population more than 10000. For lower flows in sewer Haws (2013) suggested PF's to be considered based on uniform plumbing code. Consideration of higher peak factors for very low flows results in avoiding sewers to be laid as higher slope to achieve minimum velocity of 0.6 m/s, and also consideration of flushing tank can be avoided. It is suggested to adopt following values of peak factors: 4 for contributing population between 10000 and 20000; 5 for population between 3000 and 10000; 6 for population between 300 and 1000 and 8 for population less than 300. As more and more flows goes on increasing at subsequent manholes, the effective peak factor will be go on reducing. Once the contributing population at any sewer increases beyond 50000, the peak factor on upstream manhole on that sewer will be reduced to 2.25. The advantage of proposed methodology is that it allows PF to

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be considered at node and therefore it can easily be implemented by the SEWER. The effective factors for contributing population from 500- 7,50,000 are given in Table 2. These are compared with recommended values of CPHEEO and that obtained by Babbitt and Harman’s formulae. It ca n be observed that as contributing population increases, effective peak factor comes closer to recommended values. Effective peak factors are also plotted against population in Figure 2 as suggested herein.

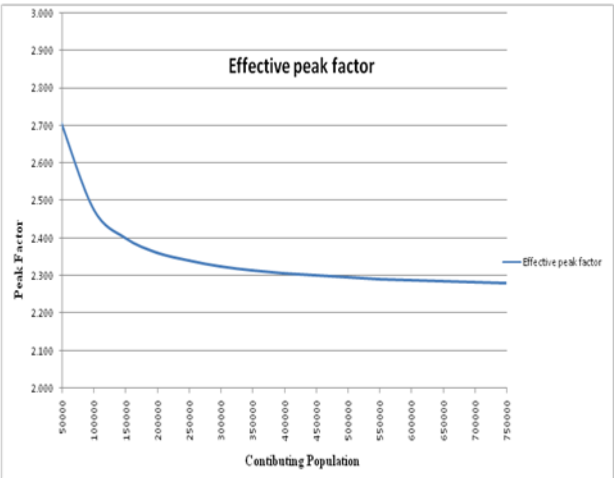

Figure 2. Effective peak factor curve

III COMPARISON OF DESIGNS

Let us consider the design of sewer *kl* in Figure 3 for comparison of designs with different peak factors. A partially filled sewers of size *D* having depth of flow as *d* is shown in Figure 3. The angle subtended by flow surface at centre is θ. Let *D* and *S* is the size and slope of sewer necessary to carry the design peak flow q_1 obtained using PF as per manual recommendation for $d_1/D_1 = 0.8$. Let D_2 becomes the size of sewer such that d_2/D_2 is 0.80 and sewer is laid at same slope to carry design peak flow q_2 which are obtained using proposed methodology.

Since, $\frac{d1}{D1} = \frac{d2}{D2} = 0.80$, therefore θ is same.

Now, $q_1 = a_1 v_1 = a_1 \frac{1}{n} r_1^{\frac{2}{3}} S^{\frac{1}{2}}$

and, $q_2 = a_2 v_2 = a_2 \frac{1}{n} r_2^{\frac{2}{3}} S^{\frac{1}{2}}$

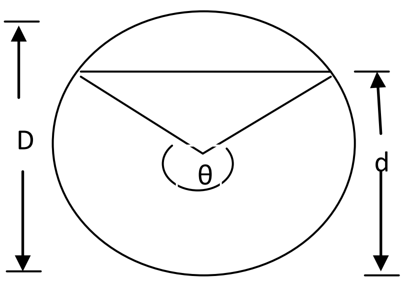

Figure 3. Partially filled sewer

$$\frac{q1}{q2} = \frac{\frac{D_1^2}{8}(\theta - \sin\theta)\left[\frac{D_1}{4}\left(1-\frac{\sin\theta}{\theta}\right)\right]^{\frac{2}{3}}}{\frac{D_2^2}{8}(\theta - \sin\theta)\left[\frac{D_2}{4}\left(1-\frac{\sin\theta}{\theta}\right)\right]^{\frac{2}{3}}} = \frac{D1^{\frac{8}{3}}}{D2}$$

For sewer *kl*, $\frac{q1}{q2} = 0.862$, therefore $D_2 = 1.057\ D_1$

Thus, theoretically increase in diameter will be about 5.7 percent. However, practically *d*/*D* might not reached 0.8 for the size and slope of the sewer adopted in the design using PF as 2.5. In such a case, with the higher peak factor of 2.9, the change would be only in depth of flow and thereby velocity will increase. Thus, consideration of PF as per proposed methodology might not change design significantly. Moreover, consideration of PF would be close to that suggested by Babbitt or Harmon in suggested range of PF between 2 to 4.

IV DESIGN OF SEWER NETWORK FOR GADCHIROLI

Gadchiroli Town

The town of Gadchiroli is the administrative head quarters of the district. The town has "B" class Municipal council with 23 words and population of 53823 souls as per census of 2011. It is situated in the south eastern corner of Maharashtra, and is bound by Chandrapur District to west, Gondia district to the north, Durg and Rajnandgaon of Chhattisgarh state to the east and Andhra Pradesh state to the south and southwest. The city falls under assured and heavy rainfall zone with the average rainfall of 1562 mm per year. The climatic conditions are extreme with mercury touching 47.3°C in summer and 9.4°C in winter.

Status of Water Supply

The source of water supply is River Wainganga. A WTP of 12.50 MLD is provided .The city also receive 1.5MLD water from old WTP and about 0.5MLD from secondary sources such as public and bore wells. Thus, water supply at approximate 135 LPCD is available to citizen as per standard requirement of CPHEEO.

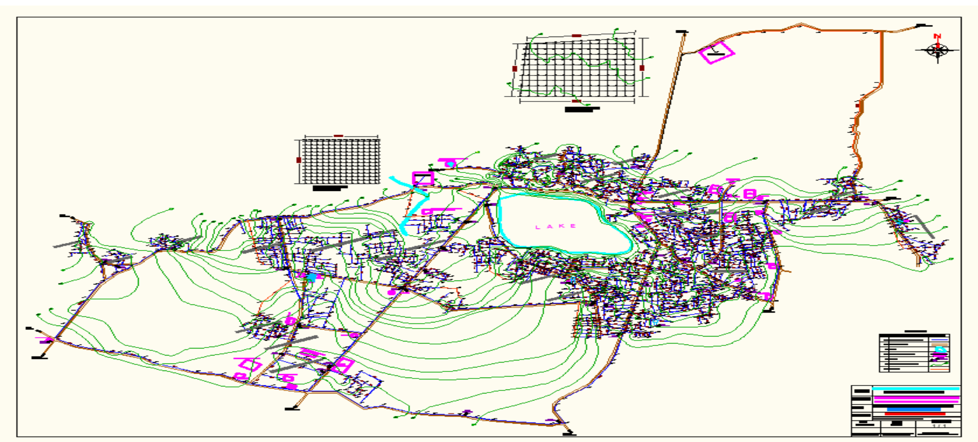

Figure 4. Layout of Sewer network for Gadchiroli Town

Design Criteria

Design criteria as suggested by CPHEEO and norms of MJP are followed for design for underground sewer network. Some important criteria are as below:

1. Sewer networks are designed for a period of 30 years and pumping machinery is designed for 15 years.
2. Sewage flow is taken as 80% of water supply. Ground water infiltration is taken as 10%.
3. Manning's formula is used for velocity calculation in sewer.
4. Minimum diameter for RCC sewer is taken as 150 mm.
5. Sewers network is designed using SEWER 3.0 with following policy: (i) Manning's n is considered varying with depth of flow; (ii) Sewer diameters for d/s sewers are considered either same as that of u/s or higher than that; (iii) Sewers are laid parallel to ground surface; (iv) Sewers diameters are allowed to be selected automatically; (v) Sewer drops are provided to assure minimum cover of 1.0 m.

Layout of the Sewer Network

Considering the street pattern and the topography, entire area is divided into two zones: Zone 1 and Zone 2 (Figure 4). Sewerage from these Zones 1 and 2 are carried to two separate treatment plants STP-1 and STP-2, respectively. Further, for the purpose of ease in the design Zone 1 is divided into 4 parts and Zone 2 is divided into 17 parts. General flow diagrams for Zones 1 and 2 are shown in Figures 5 and 6, respectively.

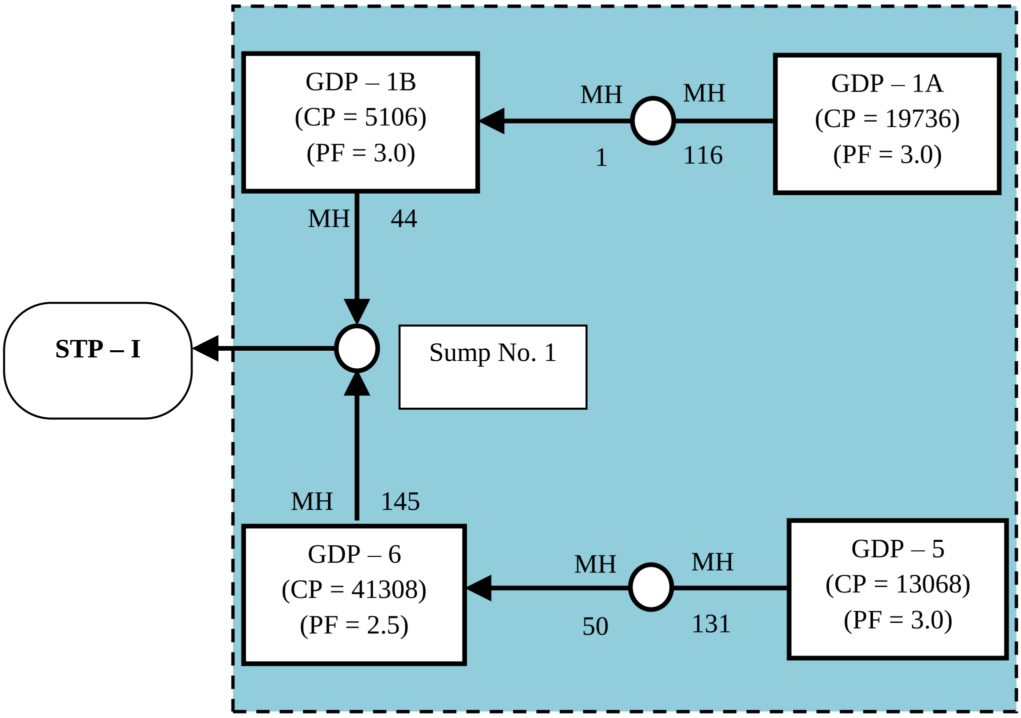

Figure 5. Flow diagram for Zone I

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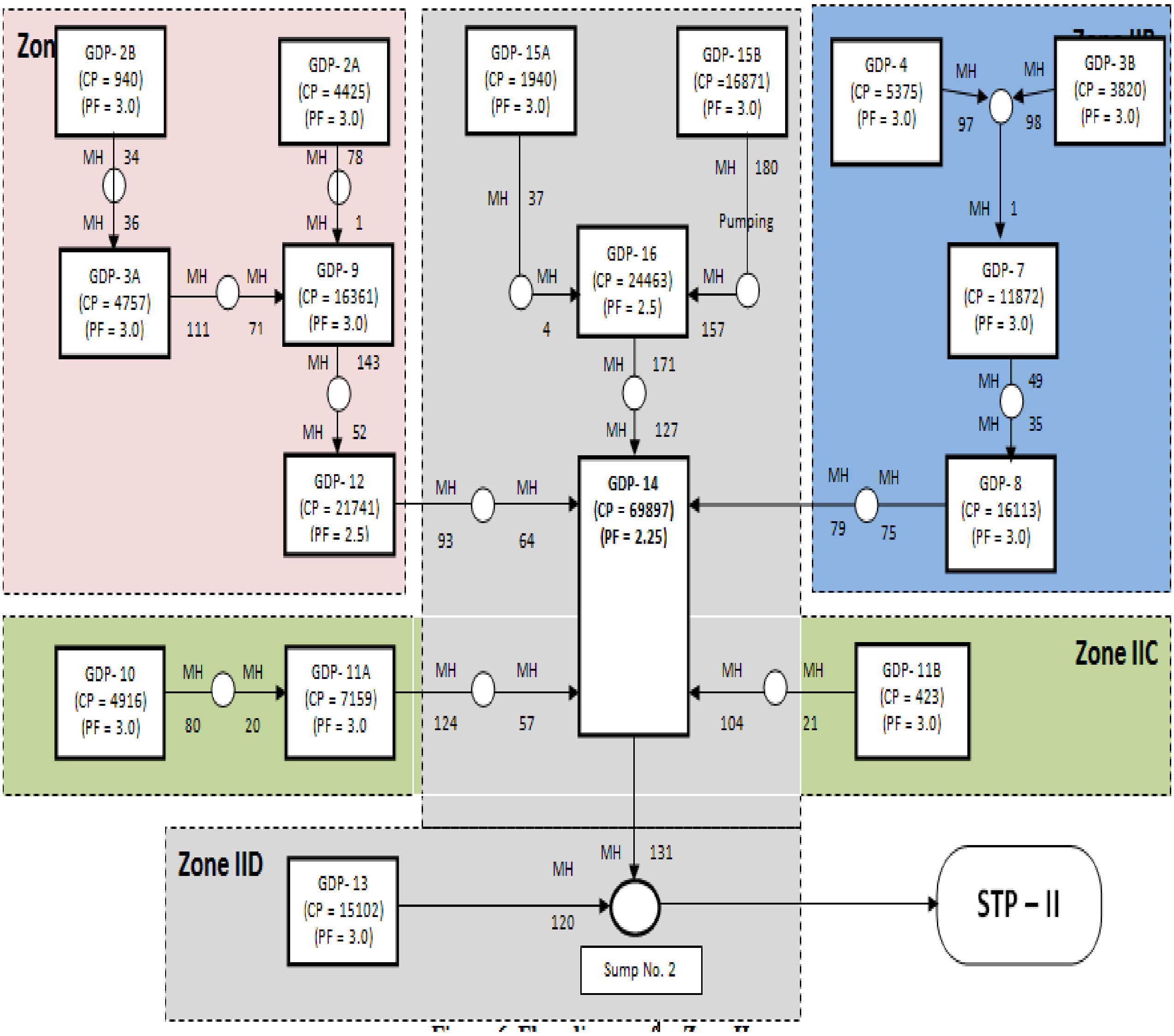

Figure 6. Flow diagram for Zone II

Contributing Flows at Manhole and PF

In SEWER 3.0 software flows contributing at manholes are required to be given as primary data along with PF. To estimate flows at each manhole, population is projected ward wise by classifying them in to three different categories as low, medium, and high density wards. Population growth factor is taken same as that observed for the city for the wards with medium density. For the wards with lower density, highest growth factor is adopted and vice versa. Care is taken so that ward wise projected population matches with the projected population for the entire city. Sewer network in any subzone is found to cover some wards fully and some of them partly. Total population in each sub zone are obtained by considering the sum of : (i) full population of wards lying completely in that sub-zone; and (ii) population in proportion to area of partly-lying ward in that subzone. This population is assumed to be distributed uniformly along the total pipe length. The population contributing flow along any link are considered to be contributing at upstream manhole on that link for the design purpose. To decide about the nodal PF, a trial run of SEWER 3.0 is carried out with PF 1.0 and average flow contribution at each manhole. Link flows are noted and total contributing population at each outgoing sewer of manhole are determined. Based on contributing population, PF is decided at the manholes using Table.1. In a subzone, if total contributing population is less than 20000, then PF at each node can be directly considered as 3.0.

Design of Sewer Networks

Each part of the sewer network is designed using SEWER 3.0, starting from downstream part. Outgoing sewer at 1st manhole of connected subzone, where one or more previously designed zones contributes, is provided diameter at least equal to that of last diameter in previous zone. Also this outgoing line is started considering the invert level of links in previous zones. SEWER 3.0 provides design based on given policy. It may be possible that feasible solution is not given by SEWER 3.0 in a single run. Thus, software may provide infeasible design and report constraints violations. Most of the time, problem lies in the initial stretch of sewer network, where average flows are less. In an attempt to satisfy minimum velocity without violating constraints of maximum depth. Software selects largest possible size and when fails, reports velocity less than minimum. In such cases, diameters are required to be fixed along with gradient as suggested by CPHEEO. SEWER 3.0 allows fixing diameter but gradient cannot be fixed. So the option is to reduce velocity requirement such that software adopts some desirable gradient. Therefore, several runs are required to eliminate all constraint violations reported by software and obtain a feasible design. To further optimise the design, depth of all incoming lines at a junction manhole can be checked. Suitable changes can be made in one of the line considering overall reduction in cost, if possible. Abstract of pipes in different subzones are given Table 3, and cost details are given in Table 4. Herein, comparison of design could not be made as SEWER does not allow to adopt PF link wise.

V SUMMARY AND CONCLUSIONS

The problem of sudden change in PFs as observed due to CPHEEO recommendation of slab wise consideration of PF, and inability of software SEWER Vr. 3.0 in considering PFs link wise has been solved by assigning peak factors node (manhole) wise to the flow contributed at the manhole. This results in gradual reduction in PF. Effective peak factor curve is generated and it is observed that peak factors as considered using the proposed methodology is slightly on higher side as compared to PFs given by Babbitt or Harmon formula, and the difference between the two reduces as the contributing flow increases. It is proposed to consider higher PFs than 3.0 for population less than 10,000. Peak factor of 4, 5 and 6 have been suggested for contributing population in the range of 1000-10000, 1000-300, and below 300, respectively. The proposed methodology is applied to design sewer network of Gadchiroli Town. The comparison of two designs could not be made as software SEWER does not allow to adopt PF link wise.

Table 3. Subzone-wise details of pipes

Subzone/ STP	Pipe Wise Abstract (Rmt.)								Total
	150	200	250	300	350	400	450	500	
1A-STP-1	7190	747	166	706					8809
1B-STP-1	1307	65		36	242	877	2260		4787
2A-STP-2	5305	103							5408
2B-STP-2	1699								1699
3A-STP-2	5384	623	194						6201
3B-STP-2	5015	198							5213
4-STP-2	4147	338							4485
5-STP-1	6533	303	230						7066
6-STP-1	5717	592	379	65	383	468		1441	9045
7-STP-2	2322				452				2774
8-STP-2	3978	136			617				4731
9-STP-2	7185	419			187	485			8276
10-STP-2	5512	1414							7026
11A-STP-2	5127	183	86						5396
11B-STP-2	1079								1079
12-STP-2	4906	243					833		5982
13-STP-2	5593	628	742	600					7563
14-STP-2	7879			711	681	840	695	500	11306
15A-STP-2	4178	530							4708
15B-STP-2	7225	478	1782						9485
16-STP-2	9969	991	585		623				12168
Total	**107350**	**7991**	**4164**	**2118**	**3185**	**2670**	**3788**	**1941**	**133207**

Table 4. Summary Cost Table for Project Pipe and Excavation

Pipe Dia (mm)	Pipe Cost (1000 Rs.)	Total Pipe Cost (1000 Rs.)	Excavation Cost (1000 Rs.)	Total Sewer Cost (1000 Rs.)
150	31556	54703	8257	62960
200	2989			
250	1406			
300	1346			
350	2280			
400	3824			
450	7042			
500	4261			

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