NWRI CONTRIBUTION 87-13

Marsalek (84)

This paper has been submitted to the Fourth International Conference on Urban Storm Drainage. This report is to provide information prior to publication and the contents are subject to change.

HEAD LOSSES AT JUNCTIONS OF TWO OPPOSED LATERAL SEWERS

by

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January 1987

PERSPECTIVE-GESTION

Cette étude donne des renseignements très utiles pour la conception de réseaux d'égouts.

Il est prévu que les réseaux d'égouts débordent à une fréquence déterminée. Toutefois, si les informations techniques servant à l'étude et à la construction sont insuffisantes, les systèmes d'égouts risquent de déborder plus souvent que prévu ou de s'avérer plus coûteux qu'il ne le faut.

Les données sur les pertes d'énergie contenues dans ce document permettront au concepteur d'optimiser les coûts du système d'égouts et la fréquence des débordements.

Le chef intérimaire,

Division de l'hydraulique

MANAGEMENT PERSPECTIVE

This paper provides information which is very useful for sewer network design.

Sewer networks are designed to flood at a designated frequency. However, if design information is insufficient, the system may flood more frequently or may cost more than necessary.

The data on energy losses provided by this paper will help the designer to optimize the sewer system for costs and frequency of flooding.

A/Chief
Hydraulics Division

RÉSUMÉ

Les pertes et les changements de pression ont été étudiés aux points de raccordement de deux tuyaux latéraux opposés munis de diverses banquettes. On a constaté que ces pertes et changements de pression dépendaient des débits latéraux respectifs de la configuration des raccordements. Les données d'observation sur les pertes de charge et les coefficients de changement de pression observés peuvent être utilisés telles quelles pour l'étude et la construction de raccordements d'égouts.

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SUMMARY: Head losses and pressure changes were studied at junctions of two opposed lateral sewers with various benchings. Such losses and pressure changes were found to depend on the relative lateral flows and junction geometry. Observed head loss and pressure change coefficients can be used directly in design of sewer junctions.

INTRODUCTION

Experience with operation of sewer systems indicates that many problems with sewer surcharging and the resulting basement flooding or sewage overflows are often caused by excessive head losses at sewer junction manholes. Thus, the design of junction manholes should focus on energy and pressure head considerations and, as a general rule, it is recommended to conserve flow energy by keeping the head losses at junctions as low as practical.

Recent design methods for sewer networks often allow sewer surcharging and the head losses at sewer junctions may then become much more important than in the conventional design of sewer systems as open-channel networks. It should be recognized that limited surcharging of sewers is not necessarily harmful, as long as the hydraulic grade line does not exceed the critical elevation above which flood damages or overflows occur. A proper design of surcharged systems is therefore based on computerized pressure flow routing through the sewer network and concurrent computations of hydraulic grade line elevations. The sophistication and accuracy of such calculations is defeated by neglect or improper consideration of junction head losses.

To provide information on junction head losses, a number of experimental studies have been undertaken in recent years. Such studies dealt with straight-flow-through junctions (Archer et al., 1978; Hare, 1983; Howarth and Saul, 1984; Lindvall, 1984; Marsalek, 1984), manholes with a bend (Archer et al., 1978; Hare, 1983; Marsalek, 1985), and junctions of a main and a lateral (deGroot and Boyd, 1983; Hare, 1983; Lindvall, 1984; Marsalek, 1985). The paper that follows expands the existing experimental data base for data on head losses and pressure changes at junctions of two opposed laterals and focuses on the effects of junction benchings on such phenomena.

GENERAL CONSIDERATIONS

General problems of flow through channel junctions were discussed by Chow (1959) who concluded that the flow through junctions was a complicated hydraulic phenomenon which could not be solved analytically and that the best solutions would be found by experimental model studies. This conclusion was confirmed by a literature survey which showed that, in recent studies, the most common approach to investigations of junction hydraulics was indeed experimental investigation in physical models of junctions.

In experimental studies of hydraulic phenomena, it is useful to start by dimensional analysis of the problem on hand. Such analysis is presented below for junctions of two opposed laterals using the notation given in Fig. 1 and defining $K = 2g\Delta E/V_o^2$ and $K_p = 2g\Delta P/V_o^2$, where ΔE is the energy head loss due to the junction (later referred to simply as the head loss), ΔP is the pressure change, K is the energy head loss coefficient, K_p is the pressure change coefficient, V_o is the mean velocity in the outfall pipe, and g is the acceleration due to gravity.

For a steady pressurized flow through a particular junction of two opposed laterals, the head loss coefficient K may be expressed as a function of eleven independent variables in the following form:

$$K = f(\rho, \mu, Q_o, Q_\ell, S, a, b, B, D_{\ell_1}, D_{\ell_2}, D_o) \quad (1)$$

where f is a function, ρ is the fluid density, μ is the fluid viscosity, Q_o is the outfall pipe discharge, Q_{ℓ_1} is the left lateral pipe discharge (the right lateral pipe discharge $Q_{\ell_2} = Q_o - Q_{\ell_1}$), S is the water depth at the junction, a is the junction length, b is the junction width, B is the junction benching, and D_{ℓ_1}, D_{ℓ_2}, and D_o are the diameters of the left lateral, right lateral, and outfall pipes, respectively.

Dimensional analysis then yields the following final expression for K:

$$K = f\left(\frac{V_o}{\sqrt{gD_o}}, \frac{V_o D_o}{\nu}, \frac{Q_{\ell_1}}{Q_o}, \frac{S}{D_o}, \frac{a}{D_o}, \frac{b}{D_o}, B, \frac{D_{\ell_1}}{D_o}, \frac{D_{\ell_2}}{D_o}\right) \quad (2)$$

In Eq. (2), the first four variables are hydraulic variables and the remaining five terms describe the junction geometry. As discussed below, Eq. (2) may be further simplified using the results of earlier experimental research.

The first hydraulic variable is the Froude number written for the outfall pipe. As shown by Sangster et al. (1958), head loss coefficients do not depend on the Froude number and this term may be omitted.

The second hydraulic variable is the Reynolds number (Re). Earlier studies indicate (Black and Pigott, 1983; Marsalek, 1985) that head loss coefficients do not depend on Re for Re's greater than some limiting value which may be taken as 3×10^4. Thus, as long as the Reynolds numbers in model experiments are maintained above such a value, Re may be omitted from further considerations.

The next hydraulic variable is the junction submergence S/D_o. Although this variable seems to affect head losses at some simple junctions, such as straight-flow-through junctions (Lindvall, 1984), mainly by formation of secondary flows, it seems rather unimportant in the case of junctions with higher losses and turbulence, particularly if S/D_o is maintained above a certain limiting value (deGroot and Boyd, 1983; Sangster et al., 1958). In the experiments described here, S/D_o did not affect head losses at values as low as 1.5. Thus, by maintaining S/D_o in experiments above 1.5, it was possible to omit S/D_o from further considerations.

The last hydraulic variable is the relative flow through the left lateral $Q_r = Q_{\ell_1}/Q_o$ (see Fig. 1). This is an important variable which strongly influences head losses. Note that the relative flow in the other lateral can be expressed as $(1 - Q_r)$.

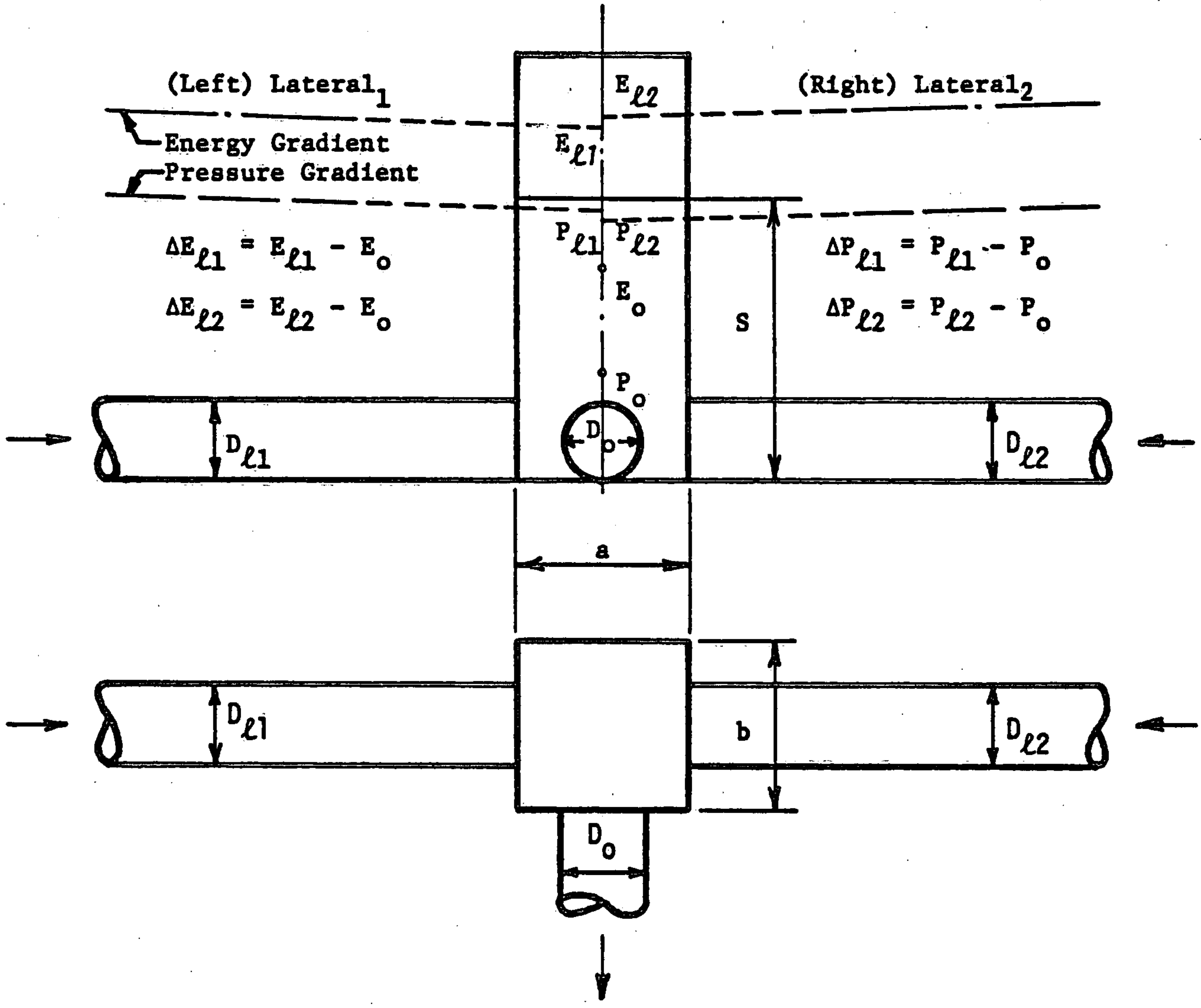

Fig. 1. Notation Sketch

The last five terms are simply geometric parameters of the junction. The first two, a/D_o and b/D_o, describe the relative size and shape of the manhole base. Common manholes have square, rectangular and circular bases. In the last case, terms a/D_o and b/D_o can be replaced by a single term, D_{mh}/D_o, where D_{mh} is the manhole diameter.

Dimensionless parameter B is used here to describe the arrangement of flow channels inside the junction, which is further referred to as the benching. The use of this parameter is much more convenient than the introduction of several geometric parameters fully describing various benchings. Four types of benchings were studied and these are further described below as designs B1-B4 (see also Fig. 2).

The first design, B_1, is the case where no benching is used inside the junction. Design B2 represents two semicircular channels, which follow a 90° segment of a circle in the plan and gradually merge. This type of benching provides some guidance for both lateral flows and their gradual merging at the junction. Design B3 represents an improved variation of B2 which was obtained by replacing the semicircular channels by U-channels extending to the pipe crowns. Such an arrangement should provide even more flow guidance and hence lower head losses.

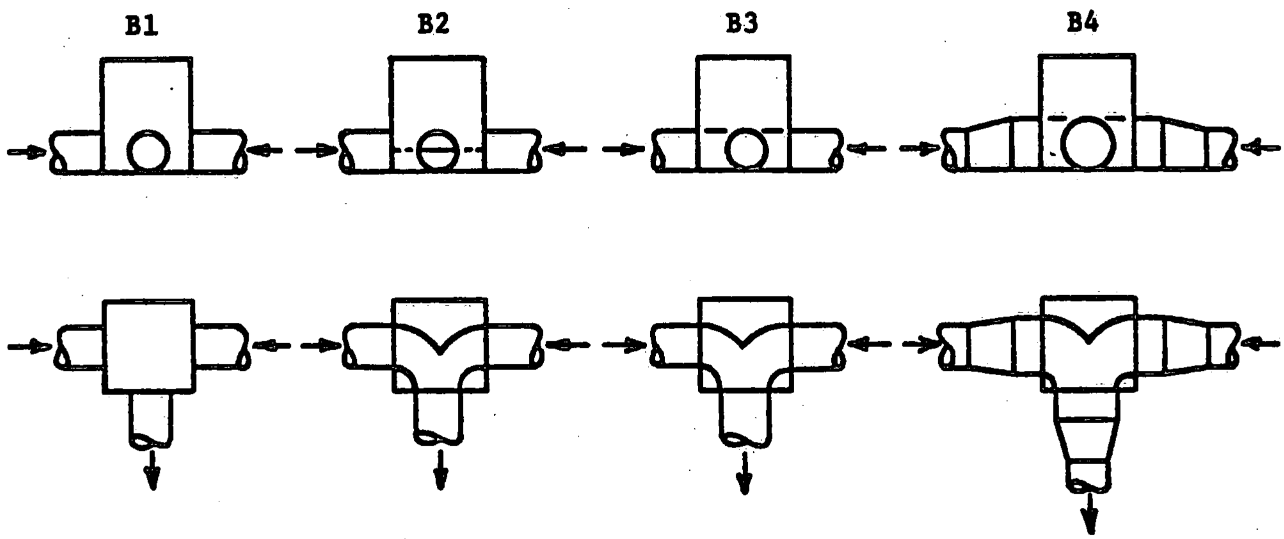

Fig. 2. Benching Designs Tested

Finally, design B4 was proposed to further reduce head losses at the junction. It is essentially design B3 with expanded channel dimensions at the junction. The transition between the sewer pipes and the expanded junction channels is obtained by means of standard eccentric pipe expanders and reducers.

Finally, the last two terms describe the relative lateral sizes. Sangster et al. (1958) showed that the smallest head losses were obtained in the case where both laterals were of comparable sizes. This case was therefore studied here and for other cases, it is recommended to use the data given by Sangster et al. (1958).

After considering all the above simplifications, a simplified equation for K may be written as

$$K = f(Q_{\ell_1}/Q_o, a/D_o, b/D_o, B) \tag{3}$$

It should be noted that a similar expression would be obtained for K_p and that both coefficients, K and K_p, are related as shown elsewhere (Marsalek, 1985).

EXPERIMENTAL PROGRAM

Observations of head losses at junctions of two opposed laterals were done in an experimental apparatus described in detail elsewhere (Marsalek, 1985). Basically, the apparatus consisted of two lateral sections, each about 12 m long, and the outlet section 7 m long. Pipes of two diameters, 75 and 152 mm, were used in the experiments. At the upstream end of both laterals, water supply head tanks with flow measurement devices were located. The downstream end of the outfall pipe was equipped with a variable surcharge tank draining into a measuring weir box. After setting a desired junction geometry, flows through the pipes were alowed to stabilize and piezometric readings were taken along all the three pipes. From these readings, increased by the appropriate velocity heads, energy grade elevations were determined for all three pipes. Finally, the pressure and energy readings were approximated by fitted straight lines and the respective differences between such grade lines at the junction were taken as head losses or pressure changes at the junction. After dividing such values by the outfall velocity head, the head loss and pressure change coefficients were obtained for both laterals. Such coefficients were then plotted against the relative lateral flow and further smoothed by numerical fitting procedures. Note that because of the symmetry of the installation, the respective coefficients for the left and right laterals are related by the following expression:

$$K_{\ell_1}(Q_r) = K_{\ell_2}(1 - Q_r) \qquad (4)$$

EXPERIMENTAL RESULTS

Altogether, 14 experimental runs were conducted using the relative lateral inflow, benching, and the manhole base shape and relative size as major experimental variables. Experimental results were evaluated with regard to power losses and coefficients K and K_p calculated from observations for both laterals. For evaluation of power losses, a power loss coefficient C_p was introduced and defined as the total power loss at the junction divided by the power of the flow entering the junction. Further simplifications were achieved by averaging C_p over the full range of Q_r's and by grouping results for various manhole sizes and base shapes together. Such mean aggregated C_p's are listed for various benchings in Table 1.

Table 1. Power Loss Coefficients for Junctions of Two Opposed Laterals With Various Junction Benchings

	C_p (the mean power loss as a fraction of the incoming flow power)			
Benching	B1	B2	B3	B4
	0.56	0.54	0.48	0.40

It is obvious that although the mean power loss is somewhat reduced by improved benching design, such reductions are relatively minor for design B2, and only designs B3 and B4 bring about a more significant improvement.

As stated earlier, coefficients K and K_p were also determined from experiments. For design purposes, the experimental values were rounded off and presented in Table 2.

CONCLUSIONS

Head losses at junctions of two opposed laterals are affected by both the junction geometry and the relative discharge $Q_r = Q_{\ell_1}/Q_o$. In most cases, such losses increase with an increasing deviation of Q_r from the value of 0.5. Among the geometric parameters of opposed laterals junctions, with comparable pipe sizes and operating under pressure, the benching has the most pronounced effect on head losses. For the full range of Q_r's, the mean head loss coefficients for designs B2, B3 and B4 represented, respectively, 86%, 66% and 50% of the loss found for B1. For the pressure change coefficient, the

Table 2. Head Loss and Pressure Change Coefficients for Junctions of Two Opposed Laterals

$\frac{Q_{\ell_1}}{Q_o}$	$\frac{Q_{\ell_2}}{Q_o}$	K_{ℓ_1}*, K_{ℓ_2}* B1	B2	B3	B4	$K_{p\ell_1}$*, $K_{p\ell_2}$* B1	B2	B3	B4
0.0	1.0	1.6	1.1	0.7	0.7	2.6	2.1	1.7	1.7
0.2	0.8	1.1	0.8	0.6	0.5	2.1	1.8	1.5	1.5
0.4	0.6	0.9	0.7	0.6	0.5	1.8	1.6	1.4	1.3
0.6	0.4	1.0	0.9	0.7	0.5	1.6	1.5	1.4	1.2
0.8	0.2	1.3	1.3	1.0	0.7	1.7	1.6	1.4	1.1
1.0	0.0	1.9	1.9	1.5	1.0	1.9	1.9	1.5	1.0

* The values of K_ℓ's and $K_{p\ell}$'s should be read for the corresponding values of Q_ℓ/Q_o's.

analogous percentages were 91%, 78%, and 68%, respectively. To minimize head losses at junctions of two opposed laterals, it is recommended to design such junctions with identical diameters of both laterals, comparable discharges through both laterals, and hydraulically efficient benchings, such as designs B3 and B4.

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