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HEAD LOSS AT TWO-WAY CIRCULAR MANHOLES IN DRAINAGE SYSTEMS UNDER SURCHARGE CONDTIONS

The loss coefficients at sewer manholes are an important part of input data that affected the computing of hydraulic and energy line elevations in sewer systems. The paper presents the results of investigations focused on determination of the loss coefficient K_S for straight-through and angled manholes, depending on varied relative depth during surcharge. When the depth $h_s/d_0 > 3$ the values of K_S are almost constant for all types of constructions. The results obtained are slightly different from those calculated from the equation recommended in literature – the differences were specially distinct for the angled manholes, reaching even 60% when $h_s/d_0 < 2$. The head losses at the manholes with perforated cover plate above full benching can be significantly reduced, over 50% in comparison to commonly used manholes.

1. INTRODUCTION

The design methods based on open-channel conditions must be carefully planned and should include evaluation of the potential for excessive and inadvertent flooding created when a storm event more disastrous than the design storm pressurizes the drainage system. Storm drainage systems can often alternate between pressure and open channel flow conditions from one section to another. In properly designed sewer networks made of modern materials (HDPE, GRP), the surcharge conditions do not pose an operational problem until the grade line is under ground level. In older systems with lime-mortar joints they may cause an increase in exfiltration and advancing of structural damage; however, such conditions hardly ever occur.

Hydrodynamic models of sewer network are often designed for extremely rainfalls that cause pressure conditions, so accurate calculations of the hydraulic and energy line elevations are of prime importance owing to the credibility of the simulation results (figure 1).

The head or energy losses in the flow in a pipe are made up of:

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- friction losses caused by forces between liquid and a solid boundary distributed along the length of the pipe; main factors affected the friction losses are: mean velocity, pipe roughness and viscosity of the fluid;
- local losses occurring at points where the flow is disrupted by manholes and valves; in certain circumstances these can be equal to or greater than the friction losses.

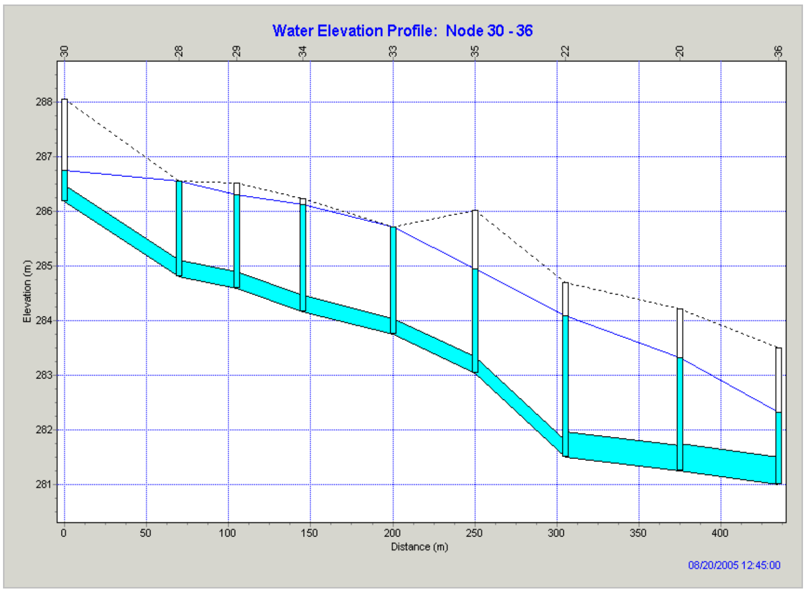

Fig. 1. Profile of sewer system with hydraulic grade line (simulation results from SWMM5)

There are several methods that have been developed to quantify pipe friction, but the Darcy–Weisbach equation can be said to be fundamentally the most sound constitutive relationship for pipe flow (Manning equation is also widely used). It is the friction factor λ (dependent on the Reynolds number and relative roughness) that brings about major problem in calculations. This problem is usually solved by iterative (i.e., Colebrook–White) or approximate equations.

Determination of energy losses at manholes is more complicated, as a result of wide range of different constructions applied in sewer systems – from the simplest one (two-way without the change of flow direction) to so complex constructions as three-inlet pipes connected at different angles and of different diameters (plunging effects). The head loss on moving from one pipe to another through a manhole or inlet is commonly proportional to the velocity head at the outlet pipe. Using K_S to express this constant of proportionality, the energy loss is approximated as follows:

$$\Delta H_S = K_S \frac{v_0^2}{2g}, \tag{1}$$

where:

K_S – adjusted loss coefficient [-],

v_0 – mean velocity in outlet pipe [m/s].

The loss coefficient K_S is dependent on several different factors and can be approximated by the following equation when the inflow pipe invert is below the water level in the manhole [5]:

$$K_S = \left(0.1\left(\frac{d_S}{d_0}\right)\cdot(1-\sin\alpha)+1.4\left(\frac{d_S}{d_0}\right)^{0.15}\cdot\sin\alpha \right)\cdot C_D\cdot C_H\cdot C_Q\cdot C_P\cdot C_K\,, \tag{2}$$

where:

d_S – the manhole diameter,

d_0 – the outlet pipe diameter;

α – the angle between inflow and outflow pipes;

C_i – correction factors.

The correction factor for the pipe diameter C_D should be taken into account only in the case where the predicted water depth is at least 3 times as great as the outlet pipe diameter. If $d_W = d_0$ the correction factor $C_D = 1$ regardless of the depth at manhole. The correction factor for flow depth C_H is significant only in the case of free surface or low-pressures flow at $h_S/\mathrm{d}_0 \in \langle 1.0; 3.0\rangle$. To determine the applicability of this factor, the water depth in an access hole is approximated by the level of the hydraulic grade line at the upstream end of the outlet pipe. The correction factor for the flow depth C_H is calculated by the following equation:

$$C_H = 0.5\left(\frac{h_S}{d_0}\right)^{0.6}, \tag{3}$$

where h_S is the water depth in a manhole or at the inlet above outlet pipe.

Correction factor for relative flow C_Q is a function of the angle of incoming flow as well as the percentage of flow coming in through the pipe of interest compared with this factor for other incoming pipes. The correction factor is applied only when there are 2 or more pipes entering the structure at approximately the same elevation; otherwise the value of C_Q equals unity (i.e., two-way manhole). The correction factor for plunging flow (C_P) is calculated when one or more of the pipes incoming to a structure have invert elevations higher than the elevation of the free water surface in the structure; then a stormwater plunges into the manhole. The resulting turbulence and energy dissipation within the manhole affect the head loss in other incoming pipes where flow is not plunging. If there is no plunging effect at manhole, then $C_P = 1$. The correction factor for benching C_K explains how the conduit is placed with respect to the manhole (flat floor, half bench, full bench).

2. LOSS COEFFICIENTS FOR TWO-WAY MANHOLE

In urban sewer systems, the majority of manholes are the two-way constructions, with straight or angled flow. Due to some differences in the loss coefficient values reported in professional literature [1]–[5], the laboratory experiments have been undertaken in order to determine the values of K_S (scheme of laboratory model, see figure 2). The manhole model was made of PMMA pipe with diameter $d_S = 290$ mm and it gives approximate scale of 1:3. Inlet and outlet pipes, made also of PMMA, were connected with manhole at the same height and have the same internal diameter $d = 70$ mm. Water was pumped to upstream reservoir, then the inflow to a model was valve-controlled to facilitate the measurements by a magnetic inductive flow-meter under steady and unsteady flow conditions. Piezometer openings on the inverts of the pipes at the distances of 400 and 800 mm and in the centre of the manhole were available for pressure head measurements. The submergence (relative depth h_S/d_0) could be varied by a adjustable weir in the outlet basin. At the known value of Q it was possible to calculate the mean velocity and loss coefficient K_S from equation (1).

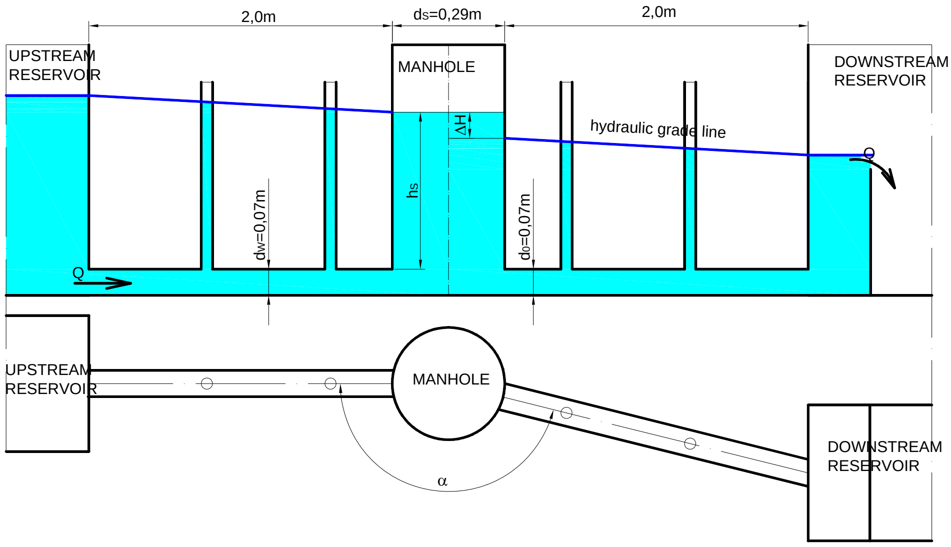

Fig. 2. Layout of the experimental system

2.1. HEAD LOSS IN STRAIGHT-FLOW MANHOLES

Straight-through flow manholes are the most common and the simplest construction in drainage systems. Laboratory experiments carried out within the range of relative depth $h_S/d_0 \in \langle 1; 5 \rangle$ show (figure 3):

- linear increase in K_S value when a relative depth at manhole is $h_S/d_0 \in \langle 1; 3\rangle$,
- almost constant value of loss coefficient $K_S = 0.45$ for $h_S/d_0 \in \langle 3; 5\rangle$.

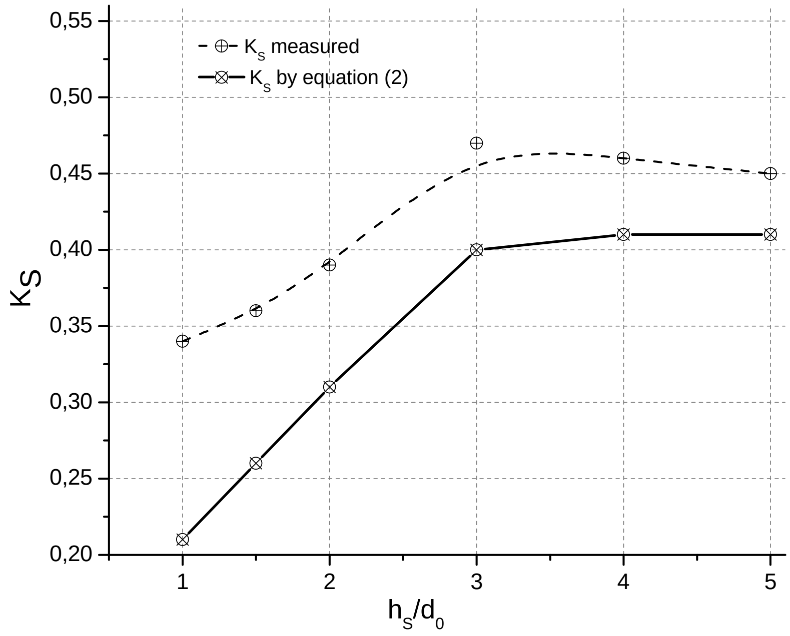

Fig. 3. Comparison of experimental and calculated values of K_S for straight-through flow manhole

The results obtained are similar to these calculated from equation (2) – an absolute difference range from 0.04 to 0.12. The relative differences vary from 50% (when $h_S/d_0 \approx 1$) to 10% (when a relative depth $h_S/d_0 \in \langle 3; 5\rangle$). For the straight-through flow manholes, the following equation can be derived:

$$K_S = 0.11\left(\frac{d_S}{d_0}\right)C_H\ , \tag{4}$$

where C_H is calculated only when $h_S/d_0 \in \langle 1; 3\rangle$ and is equal to:

$$C_H = 0.75\left(\frac{h_S}{d_0}\right)^{0.25}\ , \tag{5}$$

where all symbols as above.

2.2. ENERGY LOSS COEFFICIENT AT ANGLED MANHOLES

Energy losses at manholes that change the flow direction increase proportionally to the angle between inflow and outflow channels. In engineering practice, the angle α is in the range from 180° (straight-through flow manhole) to 90° (minimum allowable angle for manholes in sewage systems). The measurements carried out for three different angles: 90°, 112.5° and 135° confirm the above dependence and simultaneously show slight influence of a relative depth on K_S value (figure 4). The coefficient K_S increases insignificantly (about 8%) at $h_S/d_0 = 2$, hence it is generally justified to assume its constant value at a specific angle:

$$K_S = 0.45 + \sin\alpha \,. \tag{6}$$

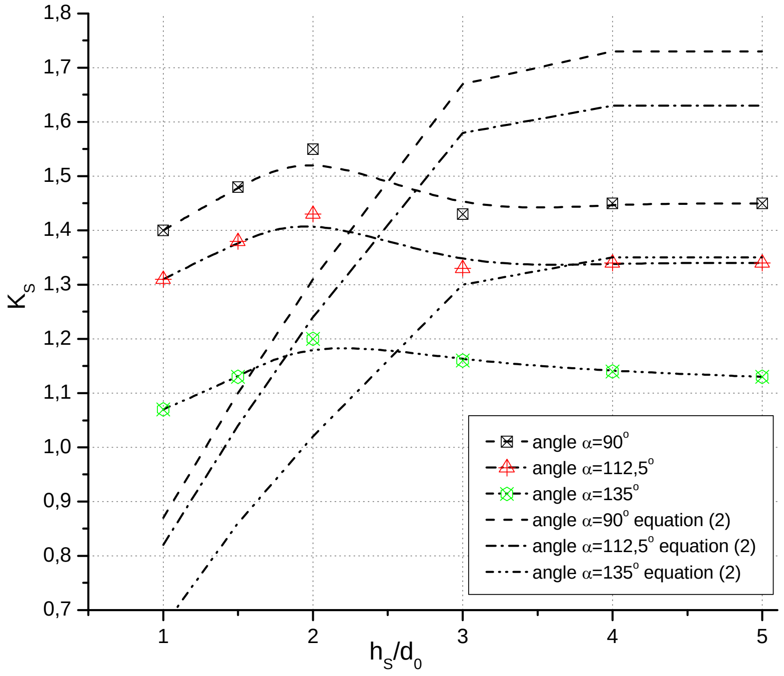

Fig. 4. Energy loss coefficient for angle manhole – the comparison of measured and calculated values at relative depth $h_S/d_0 \in \langle 1; 5\rangle$

The comparison of the measured and calculated values shows an significant differences; when relative depth $h_S/d_0 = 1$ they can reach even 60%. When $h_S/d_0 > 3$ the values of K_s were almost constant and higher than the calculated ones, on average of 0.2–0.3, which gives the relative differences of about 20%.

2.3. THE CORRECTION FACTOR FOR BENCHING

In order to estimate an influence of the bottom shape on the loss energy, a series of measurements was carried out for the following shapes of manhole bottom (figure 5): flat bottom, half benching $b_K = 0.5\ d_0$), full benching ($b_K = d_0$), full benching with perforated (50%) cover plate. For each benching type a number of test were conducted in straight-through manhole.

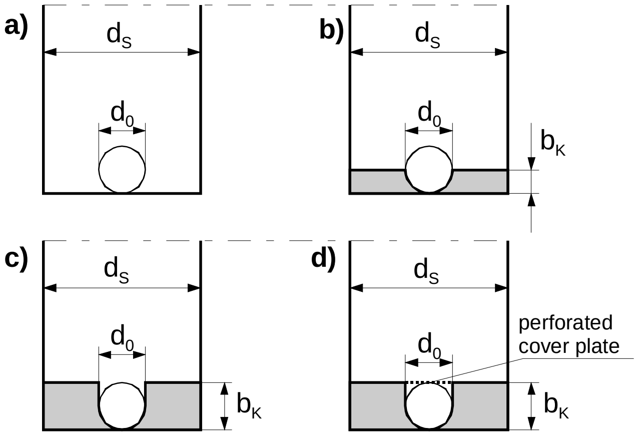

Fig. 5. Sewer manhole benching types: a) flat bottom, b) half benching, c) full benching, d) full benching with perforated cover plate

The correction factor C_K can be defined as follows:

$$C_K = \frac{K_{SK}}{K_{SF}}, \tag{7}$$

where:

K_{SF} – loss coefficient for the manhole with flat bottom,

K_{SK} – loss coefficient for the manhole with benching.

The results obtained show a significant influence of benching type on energy losses at a manhole (figure 6). The half benching commonly used in engineering practice in Poland poorly affected the reduction of the energy losses – only 5–7% reduction in comparison to the flat bottom. Incomparably more effective is the full benching, giving the reduction in a range of 22–28%, depending on a relative depth at manhole.

Additional flat cover mounted over the bench creates flow conditions resembling these in the filled closed conduits. Therefore the energy losses are significantly smaller than for flat and half benching bottom of the manhole – they can achieve even 60–70%. Flat covers can be easily disassembled if necessary, so they do not constrain the basic maintenance activities.

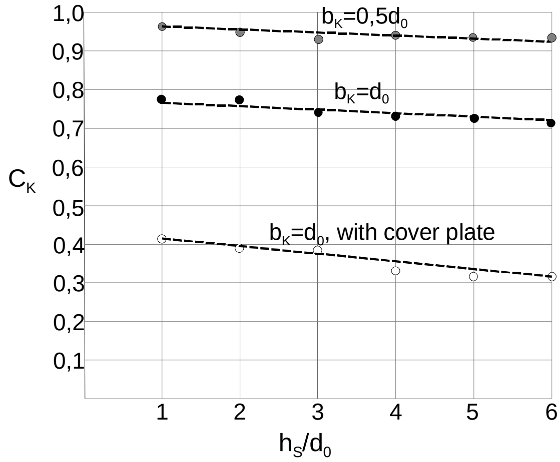

Fig. 6. Correction factor C_K versus relative depth

3. CONCLUSIONS

The operation of drainage systems under surcharge conditions allows maximum usage of the flow and detention capacities. Accurate and reliable description of loss coefficients at manholes is of great importance for the accuracy of hydrodynamic simulations. Although the energy losses at a single manhole are relatively small (a few centimetres), a total value of local losses is significant due to a huge number of such structures, located every 50–60 meters on each conduit. The laboratory-scale tests on the hydraulic model of two-way manholes indicate that:

- The most important factor that affects energy losses at manholes is the outlet velocity and depth at manhole related to the diameter of outlet channel, especially when $h_S/d_0 \in \langle 1; 3 \rangle$.
- The loss coefficient at straight-through manholes for the depth $h_S/d_0 \in \langle 1; 3 \rangle$ increases linearly, while for $h_S/d_0 > 3$ has almost constant value $K_S = 0.45$.
- The values of the loss coefficient for angled two-way manholes differ from the values calculated from equations recommended in literature. These differences are greater than 50%, especially when relative depth is smaller than 3, so these constructions should be investigated on a full technical scale.
- The energy losses can be reduced by even by 60% when a perforated cover plate is installed.

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WYZNACZANIE STRAT ENERGII STRUMIENIA ŚCIEKÓW W STUDZIENKACH KANALIZACYJNYCH

Wyznaczenie współczynników strat energii dla różnego rodzaju konstrukcji studzienek kanalizacyjnych przy zmiennych wartościach napełnień ma znaczący wpływ na dokładność modelowania przebiegu linii piezometrycznych na poszczególnych odcinkach sieci. W artykule przedstawiono wyniki badań przeprowadzonych dla najprostszych konstrukcji – studzienek przelotowych oraz kierunkowych wyposażonych w jeden wlot i jeden wylot. Wyniki badań wskazują na wyraźną zmienność współczynnika strat energii K_S w zakresie względnych napełnień $h_S/d_0 \in \langle 1; 3\rangle$. Przy większych napełnieniach można przyjmować, że współczynnik start energii ma wartość stałą dla wszystkich rodzajów badanych konstrukcji. W porównaniu z istniejącymi wzorami empirycznymi uzyskane wyniki znacząco różniły się w przypadku studzienek kierunkowych, gdzie różnice względne wynosiły nawet 60% dla $h_S/d_0 < 2$. Wielkość strat energii w studzienkach można ograniczyć nawet o ok. 50%, stosując podwyższone kinety z perforowanymi pokrywami.