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HYDRAULIC CAPACITY OF 2IN1 SEWERS

Flödeskapacitet hos 2i1-ledningar

by JONAS GERMAN, Tekniska kontoret, Skövde kommun, 541 83 Skövde
e-mail: jonas.german@skovde.se

Abstract

It is today possible to have an extra pipe installed in an existing sewer with traditional cured in place (CIPP) technology. Such an installation will affect the capacity of the sewer. The cross sectional area will decrease and the hydraulic radius will increase which decreases the capacity. The new liner will have a smother surface, which will increase the capacity of the sewer. The overall change of capacity of a sewer where a 2in1 liner has been installed was investigated. Traditionally the capacity of non-circular sections is calculated using the Colebrook-White equation with the diameter replaced with the hydraulic radius multiplied by 4. This approach can be questioned since this cross-section differs from other cross-sections normally calculated with this method, like egg-shaped or rectangular sections, through the introduction of an "obstacle" along the pipe. The validity of the Colebrook-White equation has been investigated using CFD-modelling. The results shows hat the traditional way of calculating the capacity of non-circular sections gives results on the conservative side and can be used for 2in1 pipes. In most cases the capacity of the sewer will decrease after installation of a 2in1 pipe, but this depend on several parameters and need to be investigated for each case.

Key words – 2in1 pipe, sewer, CFD, hydraulic capacity, non-circular section, Colebrook-White, Nikuradse

Sammanfattning

Det är idag möjligt att vid ledningsrenovering också installera en extra ledning för separering av delströmmar ur avsloppsvattnet eller för kabeldragning. En sådan installation kommer då att förändra ledningens kapacitet, tvärsnittsarean minskar och hydrauliska radien ökar vilket ger minskande kapacitet samtidigt som råheten minskar vilket ger en ökning av kapaciteten. Kapacitetsförändringen i ledningar där denna »2i1»-ledning installeras har här utretts. Det traditionella beräkningsförfarandet, d.v.s. att ersätta diametern i Colebrook-White's ekvation med hydrauliska radien multiplicerat med 4, skulle kunna ifrågasättas då den här typen av tvärsnitt skiljer sig från de tvärsnitt som vanligen beräknas med nämnda approximation, t.ex. äggformade eller rektangulära sektioner, genom att ett längsgående »hinder» introduceras i tvärsnittet. Giltigheten för Colebrook-White's ekvation och metoden för icke-cirkulära tvärsnitt har kontrollerats med CFD-beräkningar. Resultaten visar att det traditionella sättet att beräkna kapacitet i icke-cirkulära tvärsnitt ger resultat på säkra sidan för denna typ av tvärsnitt. I de flesta fall kommer sannolikt totala kapaciteten på det nya ledningssystemet att minska, men detta beror också på ursprunglig lednings skick och val av dimensioner på de nya ledningarna.

Introduction

Cured in place pipe (CIPP) relining is a commonly used technology to renovate sewers. A development of this technology has now made it possible to get an additional pipe in the sewer after the relining (Figure 1). This pipe can be used for different purposes, *e.g.* separating flows (blackwater and greywater, groundwater from garden drains and sewage, stormwater from sewage) or for cables. The installation of this "2in1" liner is done in a similar way and with the same equipment as traditional CIPP relining. Installation of a 2in1 system in a sewer creates one circular and one non-circular pipe and it will

Figure 1. *Picture on a 2in1 pipe after an above ground test.*

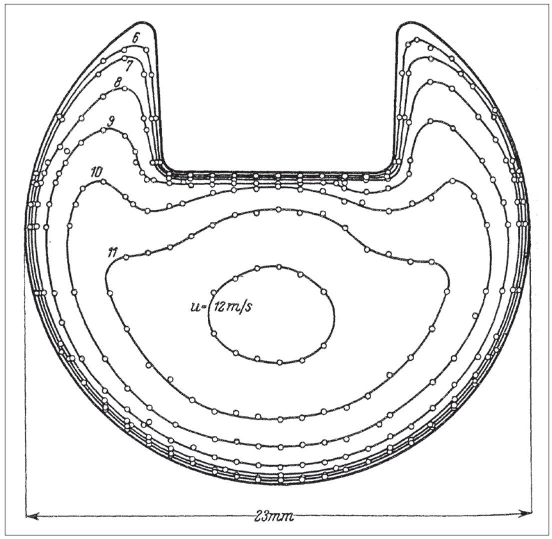

Figure 2. *Velocity distribution in the pipe investigated by Nikuradse (1930).*

affect the capacity of the sewer. This study is aimed to investigate the hydraulic capacity of a 2in1 pipe and the change of capacity of a sewer renovated with the 2in1 system.

Normally the pipe flow is calculated using the Colebrook-White equation (equation 1)

$$Q = -2A\sqrt{2 \cdot g \cdot d \cdot S}\log\left[\frac{2.51 \cdot \nu}{d\sqrt{2 \cdot g \cdot d \cdot S}} + \frac{k_s}{3.71 \cdot \mathrm{d}}\right] \quad (1)$$

where

Q = flow (m^3/s)
A = area (m^2)
d = diameter (m)
S = hydraulic gradient
k_s = equivalent roughness (m)
ν = kinematic viscosity (m^2/s)

For non-circular sections the concept of substituting the diameter (D) in Colebrook-White equation with 4R is commonly used. Here R is the hydraulic radius defined as A/P with A as the cross-sectional area of flow and P the wetted perimeter. Butler and Davies (2000) states that this is valid when the shape does not differ much from the circular. Nalluri and Featherstone (2001) explains that the boundary shear stress is not constant around the wetted perimeter for a non-circular section, but that experiments have shown that the error is small. Most of the experiments and knowledge is from egg-shaped, rectangular or horseshoe shaped sections, not from sections where an obstacle is introduced along the pipe. However, in one of the first investigation of flow in non-circular sections Nikuradse (1930) measured the flow resistance in a pipe with a section that resembles the 2 in 1 system (Figure 2). The experiment by Nikuradse was carried out on a small pipe made of brass and a conclusion drawn was that the flow resistance in the pipe could be calculated using the hydraulic radius for flows in the laminar and turbulent region. This study was done before Colebrook and White had presented their equation.

In order to establish dimensioning guidelines for 2in1 pipes the hydraulic capacity was calculated using the Colebrook-White equation with D=4R. However, questions can be raised if the installation of a new pipe in the old could introduce extra turbulence that increase the flow resistance more than predicted by this approach. Therefore it was decided also to investigate the flow capacity for one case using CFD-modelling. CFD-modelling of flows in closed conduits have been done on very few cases. Pollert *et al* (2005) used CFD modelling for studying the hydraulic capacity of deteriorating sewers. They used FLUENT as modelling tool and modelled the effect of different obstacles in the sewer such as displacements, bricks, intruding pipes, roots and more. Only local obstacles were studied. The results was used for developing a recalculation matrix to allow translation of failures found during CCTV inspections of sewers into parameters (equivalent sand roughness or Mannings roughness) that can be used in 1D hydraulic models, such as MOUSE or SWMM, to correct for obstacles.

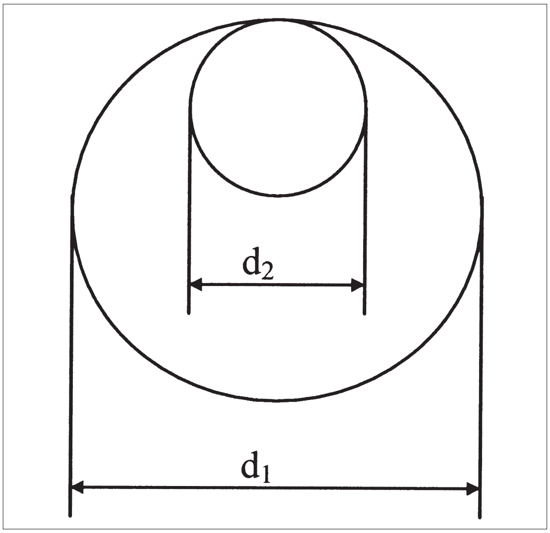

Figure 3. *Definitions of the diameters for the pipe.*

Method

For the CFD-modelling FLUENT 6 (FLUENT, 2005; FLUENT, 2007) was used as modelling tool. To assure that the results from the CFD-modelling correspond with results from the Colebrook-White equation, a test with a circular pipe was done before the 2in1 pipe was modelled. The model-setup was the same for both the 2in1 pipe and the circular pipe, except the geometry. In Figure 3 the designation of the diameters in the pipe is shown, d_1 is the inner diameter of the outer pipe and d_2 is the outer diameter of the inner pipe.

An inner diameter (d_1) of 225 mm was used for both the circular and the 2in1 pipe. The outer diameter of the inner pipe was set to 75 mm. An equivalent sand roughness, k_s of 0.2 mm was used for both pipes. Two different slopes (hydraulic gradients) were tested, 0.005 and 0.0005.

Three different grids were tested to assure grid-independent results. In Figure 4 the medium sized grid for the 2in1 pipe is shown. It should be noticed that in the calculations with the Colebrook-White equation a geometry where the inner pipe just touches the outer pipe at the crown was used. But in the CFD-modelling the area of the outer pipe is slightly smaller since the narrowest point between the pipes had to be cut off to enable the creation of a useable grid. This is also a more correct description of the geometry than the one used for calculations with the Colebrook-White equation (see Figure 1)

A standard k-ε model was used as turbulence model. Cyclic boundary conditions have been used to achieve uniform flow independent of the length of the pipe. Standard wall functions have been used to describe the wall friction. These are used to bridge the viscosity-affected region between the wall and the fully-turbulent region. The wall functions in FLUENT is calibrated to reproduce the data from Nikuradse's experiments (FLUENT, 2005).

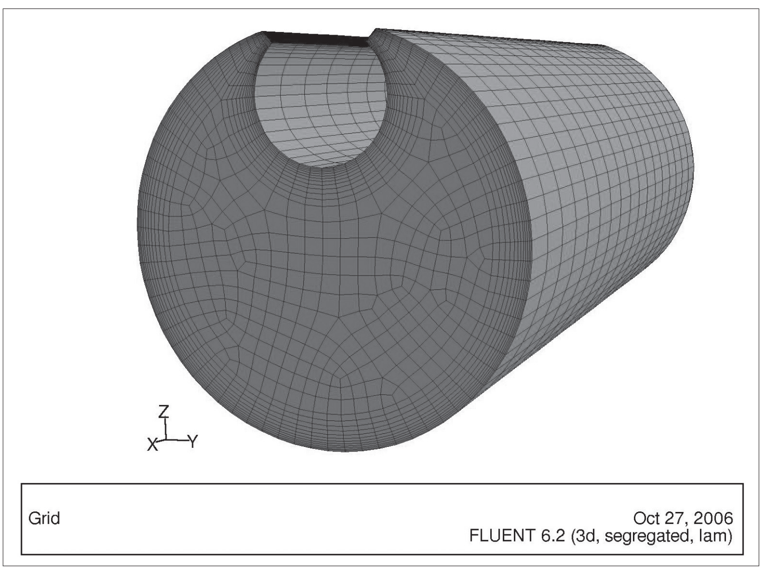

Figure 4. *Medium sized grid for the 2in1 pipe.*

Table 1. *Flow in the circular pipe, calculated with CFD, Colebrook-White (C-W) and with Nikuradse's original data on friction factor.*

Sand-roughness (mm)	Slope	Flow (l/s)		
		CFD	C-W	Nikuradse
0.2	0.005	44.3	41.4	45.3
0.2	0.0005	13.5	12.4	13.6
0	0.005	49.4	48.7	48.7
0	0.0005	13.7	13.5	13.5

Table 2. *Flow in the 2in1 pipe, calculated with CFD, Colebrook-White (C-W) and with Nikuradse's original data on friction factor.*

Sand-roughness (mm)	Slope	Flow (l/s)		
		CFD	C-W*	Nikuradse*
0.2	0.005	34.5	28.3	31.1
0.2	0.0005	10.3	8.4	9.1
0	0.005	37.8	33.1	33.1
0	0.0005	10.3	9.1	9.1

*Calculated with d=4R

Results and discussion

The results changed with less than 1 % from the coarsest to the finest grid size and therefore results here are only presented for the cases with medium grid. Results for the circular pipe is presented in Table 1. The results for Colebrook-White is calculated using an equivalent sand-roughness of 0.2 mm and 0 mm and the results in the "Nikuradse-column" is calculated with the friction factor (f) from Nikuradse's original experimental data with an sand-roughness of 0.2 mm (from Schlichting, 1979) and using equation 2. The data for the smooth pipe (k=0) have been calculated using von Kármán-Prandtl's equation (equation 3), which is the Colebrook-White equation with k_s=0.

$$Q = A\sqrt{\frac{2 \cdot g \cdot d \cdot S}{f}} \qquad (2)$$

$$Q = -2A\sqrt{2 \cdot g \cdot d \cdot S}\log\left[\frac{2.51 \cdot \nu}{d\sqrt{2 \cdot g \cdot d \cdot S}}\right] \qquad (3)$$

The difference between the Colebrook-White and the Nikuradse approach is explained by the use of *equivalent* sand-roughness in the Colebrook-White equation and a real sand-roughness in the experiments by Nikuradse. Fluent should reproduce Nikuradse's results since it is using Nikuradse's real sand-roughness as input data. The small deviation between CFD and calculations using Nikuradse's data can be explained by difficulties in reading the friction factor in the data from Nikuradse's experiments.

In Table 2 the same data for the 2in1 pipes are shown, using d=4R for the Colebrook-White and Nikuradse approaches. The difference between the flow calculated with CFD and the flow calculated with the Colebrook-White equation or the Nikuradse data have now increased compared to the case with circular pipe. CFD is predicting more than 20 % higher flows for the cases with k=0.2 mm than the other methods.

Partly filled pipe

A 2in1 pipe with the inner pipe at the crown will behave as a circular pipe until the water level reaches the inner pipe. In order to illustrate this, the flow capacity in the inner pipe in a 2in1 system has been calculated using Colebrook-White's equation with d=4*R and compared with a circular pipe with same inner diameter (Figure 5).

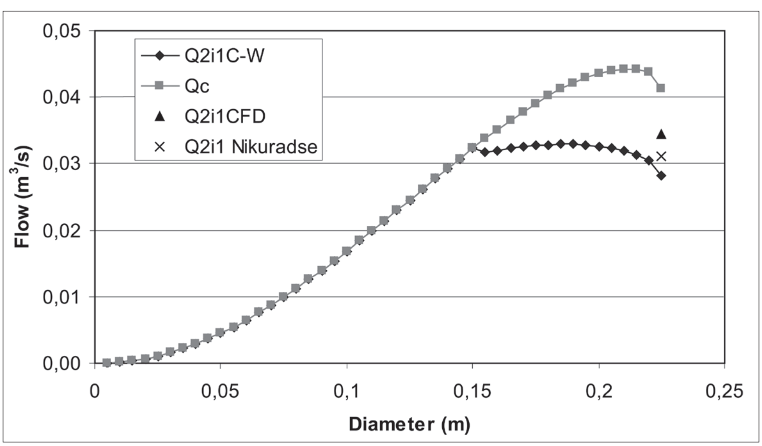

Figure 5. *Flow capacity in the inner pipe (Q2i1) of a 2in1 pipe and a circular pipe (Qc) depending on water level.*

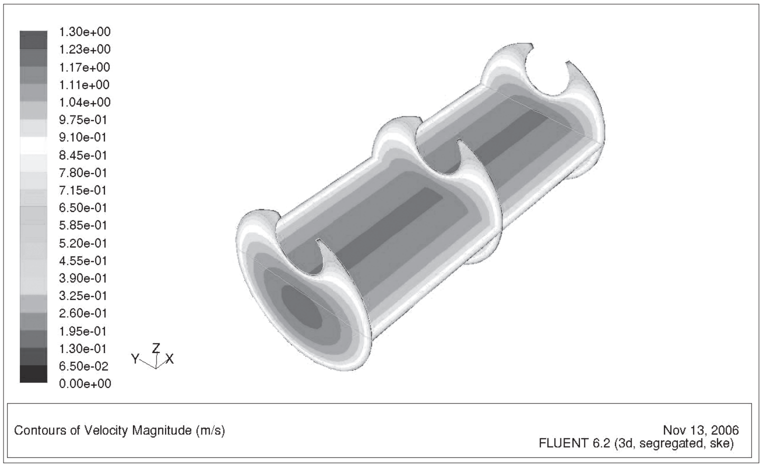

Figure 6. *Velocity contour plot of 2in1 pipe.*

The capacity of a 2in1 pipe will not increase noticeably when the water level has reached the outer pipe. The velocity distribution of a 2in1 pipe is illustrated in Figure 6, where it can be seen that there are low velocities in the upper part of the pipe.

Also a circular pipe will have its maximum capacity before it is full, but in contrast to the 2in1 system, just before it runs full. In Figure 5 the capacity for a full pipe, calculated with CFD and with Nikuradse's original data is shown as a comparison to Colebrook-White's equation.

Change of capacity in a pipe renovated with a 2in1 system

When a sewer is renovated with a 2in1 system several parameters that affect the capacity of the sewer is changed. Changes that decrease the capacity are decreases in diameter and area since a new internal wall is created inside the old pipe and increase of the wetted perimeter because of the new inner pipe. The new surface of the pipe will be smoother than the old (that often consists of deteriorated concrete), which will increase the capacity. The total change in capacity is difficult to estimate and will vary from case to case, since the wall thickness of the liner is decided depending of the condition on the old pipe and the roughness of the old pipe also depends on the condition. As an example the dependence of pipe diameter and slope has been calculated and is shown in Figure 7, in this case the wall thickness have been set to 6 mm in the outer pipe an 7.5 mm in the inner pipe, independent of diameter of the original pipe. The outer diameter of the inner pipe was assumed to be 1/3 of the diameter of the original pipe, equivalent sand roughness of the new pipe was assumed to be 0.2 mm and for the old pipe 2 mm. The capacity of the

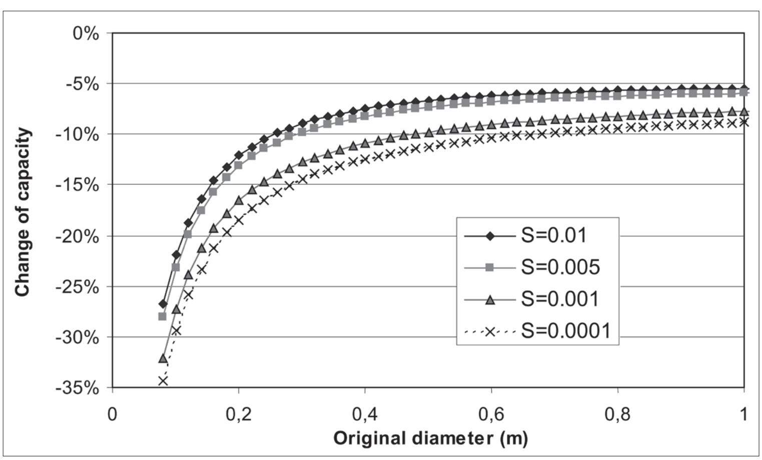

Figure 7. *The change of capacity in a sewer relined with the 2in1 system with a diameter of the inner pipe that is 1/3 of the diameter of the outer pipe. K_s for old pipe assumed to 2 mm and for the relined pipe to 0.2 mm, capacity for the new pipe has been calculated as $Q_{new} = Q_{outer} + Q_{inner}$.*

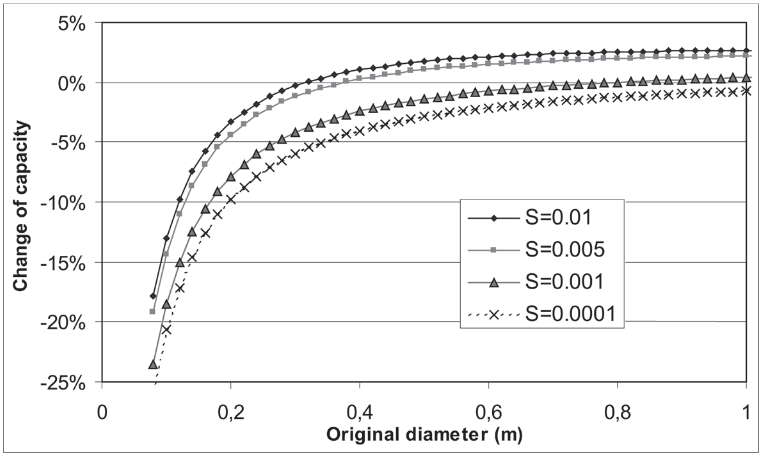

Figure 8. *The change of capacity in a sewer relined with the 2in1 system with a diameter of the inner pipe that is 1/4 of the diameter of the outer pipe. K_s for old pipe assumed to 2 mm and for the relined pipe to 0.2 mm, capacity for the new pipe has been calculated as $Q_{new} = Q_{outer} + Q_{inner}$.*

renovated sewer is calculated as the sum of the capacity in the inner and outer pipes.

In Figure 7 the change of capacity for a sewer renovated with a 2in1 system with an inner pipe diameter 1/3 of the outer is shown. The capacity decrease for all cases, but larger pipes with steeper slopes will have a lower decrease in capacity. The overall decrease of capacity will also be smaller if the ratio between the inner and outer pipes is smaller. This is illustrated in Figure 8, where the change of capacity for a system renovated with 2in1 pipes where the inner pipe diameter is 1/4 of the outer pipe diameter. In this case it is actually a small increase in overall capacity for larger pipes and steeper slopes.

Conclusion

- The CFD modelling gave grid independent results and the results for a circular pipe correspond well with the theoretical results calculated from Nikuradse's data. This assures that CFD produces reliable results with the given boundary conditions.
- The use of the Colebrook-White equation with the diameter, D, replaced with 4*R gives lower flows than the CFD modelling and can be used for calculating flows in 2in1 pipes with conservative results.
- Installation of 2in1 pipes will in most cases decrease the overall capacity of a sewer, but this must be investigated for each case to determine the importance of it.

Acknowledgement

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