Tractive tension on buildings residual water network

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Abstract: The present dissertation aims to clarify some hydraulic concepts, like, for example, the different types of hydraulic flow, the in what consists the carrying capacity of residual waters, the definition of tractive tension and the, physical and mathematical, source of its formula. It's also explained the different types of sediment present on the buildings sewage system, their characteristics, how it's made their transport and their sensitivity to various tractive tension values.

The present thesis also aims to gather the most information possible, about the performance demands on several countries relatively to the minimum velocity and tractive tension on the buildings drainage, domestic and storm, system. A bibliographic review about, national and international, regulations/standards was made, allowing a comparison between the several self-cleansing criteria's, and possible changes to the national standards, to achieve a more environmental and economic drainage system, with measures like, cutting material usage or costs. These changes will be applied to two fictional case studies, to analyze their impact, and see if they're better financial.

1. Introduction

The present laws of a buildings sewage system demand that the pipes are self-cleansing, but don't specify the criteria's.

A pipe is self-cleansing when there's conditions that can lift and transport solid sediments at any given moment. This normally is achieved by a certain velocity or tractive tension. On our current legislation there are demanded some minimum values for the sewage velocity and tractive tension, but for public pipes and not specific for buildings.

So, the information about the performance demands on buildings drainage systems in Portugal is very little. So, this thesis has the objective of making available, in a clear way, the different self-cleansing demands on various countries, relatively to the minimum water velocity and tractive tension, compare them and see if our legislation is conservative and where we can change it, so that it's possible to save some resources and costs.

The recent climate changes have led to longer periods of dry weather but more intense precipitation, so we can anticipate a rise of the hydraulic flow for the pipes on the storm systems. This will most likely lead to problems, as the rise in the pipes diameter will lead to sedimentation of particles on these pipes for the current types of rain. This topic will not be discussed on this thesis, but it's an important to be investigated on a future one.

2. Objetives

The present thesis has the following objectives:

- To evaluate the different self-cleansing criterions applied, in Portugal, to a buildings drainage system, and compare them to different developed countries around the world.

- To evaluate and propose potential changes to our current legislation.
- To evaluate the impacts made by theses changes, on the quantity of used materials and costs.
- To proposed secondary objectives related to the saving of material on a buildings drainage system, but not due to the criteria for checking the self-cleaning conditions.

3. Methodology

To see the impact of the proposed changes to our current legislation about the self-cleansing criteria's, there are going to be made 2 case studies, with two medium size housing buildings. For these case studies it will be done a budget analyses, so that's possible to observe the changes on the systems costs and material usage.

For these cases studies it will be applied the secondary changes, to see the impact of them on a buildings drainage system.

4. Water carrying capacity

4.1. Types of flow

There's three types of flow [1]:

- Permanent flow: the velocity of the water varies in space, but it's constant over time.
- Variable flow: the velocity of the water varies in space and time.
- Uniform flow: the water velocity is constant in its trajectory, being constant in module as well in direction.

4.2. Flow rate

The flow rate of a channel consists of the volume of fluid that travels across a surface in function of a given time unit. It can be calculated by the following equation [1]:

$$Q = V \times A\,, \qquad (1)$$

on what:
Q – Hydraulic flow (m^3/s);
V – Water velocity (m^2/s);
A – Liquid area (m^2).

4.3. Water flow on free surface

A flow is considered on free surface when a fluid runs on a channel, and its contour is partially in contact with a gas or atmosphere.

When the fluid moving is water, generally the hydraulic flow will be turbulent, so we can apply the Gauckler-Manning-Strickler equation to calculate the hydraulic flow [1]:

$$Q = K \times A \times R_h^{2/3} \times i^{1/2}\,, \qquad (2)$$

on what:
K – Roughness coefficient ($m^{1/3}/s$);
R_h – Hydraulic radius (m);
i – channel slope (m/m).

4.4. Tractive tension

When a fluid is in contact with a solid surface, it's created a surface tensions tangential to the solid surface.

The tractive tension consists of this surface tensions distributed by the surface area as is shown in the following equation:

$$\tau = \frac{R_x}{P \times L}\,, \qquad (3)$$

on what:

τ – Tractive tension (Pa);
P – Hydraulic perimeter (m);
L – Channel length (m);
R_x – Sum of tangential forces.

The hydraulic radius is given by the following equation for general use:

$$R_h = \frac{A}{P}\,, \qquad (4)$$

and for a half-full or full pipe:

$$R_h = \frac{D}{4}\,, \qquad (5)$$

where D(m) represents the inner diameter of the pipe.

The tractive tension equation can be obtained using the Euler theorem for a pipe flowing with a uniform flow on free surface. This theorem is explained next.

Figure 1 represents a uniform flow on a free surface.

In this type of hydraulic flow, waters energy loss is the same as the pipe slope for small slopes, as can be seen in the following equation:

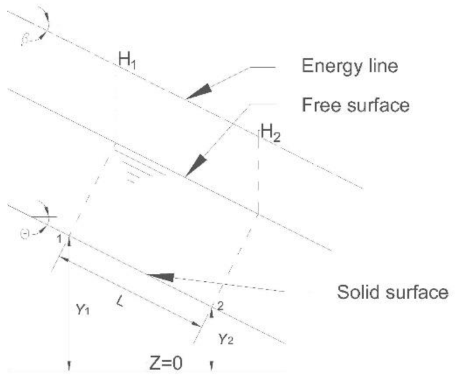

Figure 1 - Euler theorem

$$J = \sin\theta = i \ , \quad (6)$$

on what:
J – Energy loss (m).

Applying the Euler theorem to the volume of sections 1 and 2 of Figure 1, we obtain the following equations:

$$\vec{G} + \vec{\Pi} + \overrightarrow{M_1} - \overrightarrow{M_2} = 0 \ , \quad (7)$$

$$\vec{G} + \overrightarrow{\Pi_1} + \overrightarrow{\Pi_2} + \overrightarrow{\Pi_3} = 0 \ , \quad (8)$$

as:

$$\overrightarrow{M_1} = \overrightarrow{M_2} \ , \quad (9)$$

we get to:

$$\vec{\Pi} = \overrightarrow{\Pi_1} + \overrightarrow{\Pi_2} + \overrightarrow{\Pi_3} \ , \quad (9)$$

where $\overrightarrow{\Pi_1}$ and $\overrightarrow{\Pi_2}$ represent the pressure that the exterior fluid does on the interior one, on sections 1 and 2, and $\overrightarrow{\Pi_3}$ represents the total forces made by the pipe on the fluid. $\overrightarrow{M_1}$ and $\overrightarrow{M_2}$ compose the vectors for the fluids quantity movement and $\vec{G}$ the fluids weight vector.

If we replace $\overrightarrow{\Pi_3}$ with $\vec{R}$, the sum of the forces that the fluid exercises on the pipe walls we obtain the following equation:

$$G_x + \Pi_{1x} + \Pi_{2x} - R_x = 0 \ . \quad (10)$$

Given the next relations:

$$G_x = \gamma \times A \times L \times \sin\theta \ ; \quad \Pi_{1x} = p_1 \times A \ ;$$

$$L \times \sin\theta = y_1 - y_2 \ ; \quad \Pi_{2x} = -p_2 \times A \ .$$

Where y_1 and y_2 represent the section vertical coordinates, and p_1 and p_2 its piezometric pressures. With this we get the following equation:

$$R_x = \gamma \times A \times J \times R_h \ , \quad (11)$$

where:
γ – Volumetric weight (N/m^3)

And we finally can obtain the simplified equations for the tractive tension:

$$\tau = \frac{R_x}{P \times L} = \frac{\gamma \times A \times J \times L}{P \times L} \ , \quad (12)$$

$$\tau = \gamma \times i \times R_h \ . \quad (13)$$

4.5. Sediments on sewage pipes

There's two types of water on a buildings sewage system: domestic and storm. Theirs definition is explained next.

The domestic water consists on water coming from the domestic accessories, like for example: bathtubs, toilets, washing machines, etc. This type of water contains organic matter and pathogenic bacteria, and its discharge hydraulic flow is usually variable, being the highest in the morning and late afternoon.

The storm water, comes from the drainage of the roof and exteriors areas, like for example the balconies. Its discharge hydraulic flow is related to the respective area exposed to precipitation. The contaminants in this type of water, will be smaller, compared to the case of domestic water

For a drainage system to work properly, it's important to define minimum criteria for the water's carrying capacity, for example its flow velocity or tractive tension. This is important because it makes the drainage system self-cleansing, preventing clogs and needed maintenance in the system.

For the representation of the tractive tension was used the Equation 13, and the flow velocity the following equation [1]:

$$V = K \times R_h^{2/3} \times i^{1/2} \quad (14)$$

K – Roughness coeficient (m$^{1/3}$/s).

To understand better the necessary values for a pipes tractive tension, it's important to understand how the sediments move inside of the pipes and the minimum for them to initiate movement.

The transport of sediments on sewers can be:

1) Transport by dragging: the sediment is transported by rolling and sliding on the pipes lower surface;
2) Transport suspended: the sediment moves on the water's surface and can be in contact momentarily with the pipes bottom;
3) Transport by dragging and suspended, alternated: the sediments move alternately between small jumps and rolling.

A buildings sewage system usually contains various sediments with different sizes. In Table 1 can be found the sizes of the different sediments.

Table 1 - Types of sediments.

Type of sediment	Type of transport	Average sediment diameter (mm)			Relative density		
		Min.	.....	Max.	Min.	.....	Max.
Domestic sediments	Suspended (2)	0,01	0,04	0,06	1,01	1,40	1,60
Storm sediments	Suspended (2)	0,02	0,06	0,10	1,10	2,00	2,50
Grains of sand	Dragging/alternated (1 e 3)	0,30	0,75	1,00	2,30	2,60	2,70

So, to the minimum value for the tractive tension should be sufficient to transport the biggest sediment on the system by dragging. By that, the smaller sediment will also be transported, suspended or dragged.

Various studies state that for sediments without cohesion and non-erodible pipes, the beginning of sediment transport normally happens when the critical tractive tension is achieved. This is called the critical tractive tension.

The critical tractive tension can be calculated by the Shields diagram for non-cohesive and flat channels, that relates a dimensionless parameter with the Reynolds number, represented on the following equations [2]:

$$\tau_* = \frac{\tau_C}{(\gamma_S - \gamma) \times D_{50}} \ ; \qquad (15)$$

$$R_e^* = \frac{V_c^* \times D_{50}}{\upsilon} \ ; \qquad (16)$$

where:

τ_* – Dimensionless tractive tension;
τ_C – Critical tractive tension (Pa);
D_{50} – Average sediment diameter (m);
γ_S – Sediments volumetric weight (N/m3);
υ – Cinematic liquids viscosity (m2/s) (υ=1,00X10-6 m2/s for water at 20ºc);
V_c^* – Critical drag velocity, defined by $V_c^* = \sqrt{\tau_C/\rho}$;
ρ – Sediments volumetric mass (Kg/m^3).

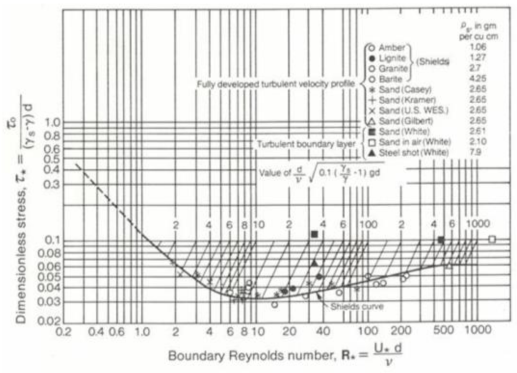

Figure 2 - Shields diagram.

To avoid iterations, Shield made a graduated axel defined by the following equation:

$$\frac{D_{50}}{\upsilon} \times \sqrt{0{,}1 \times (\frac{\gamma_S}{\gamma} - 1) \times g \times D_{50}} \ . \qquad (17)$$

Using Shields diagram were made some examples to demonstrate the influence of the sediments characteristics on their critical tractive tension. These results are on Table 2 next:

Table 2 - Sediments critical tractive tension.

Example	D_{50} (mm)	$\frac{\gamma_S}{\gamma}$	τ_C (N/m^2)
1	1,00	2,70	0,035
2	1,00	2,30	0,032
3	0,30	2,70	0,039
4	0,30	2,30	0,042

Although Shields method is accurate, it's not the best one for sewage sediments because it doesn't consider the cohesive properties of this types of sediments and it's used for horizontal channels. So, to ascertain the normal results of critical tractive tension for the conditions present on sewage pipes, were studied various studies. In these studies, there was mentioning of a tractive tension of 2,45Pa and 6,2Pa (Maguire rule). The first result is obtained by using a minimum slope of 1/D (D in mm) and Equation 13:

$$\tau = \gamma \times \frac{1}{D} \times R_h = 9800 \times \frac{1}{50} \times \frac{0{,}05}{4} = 2{,}45 \ Pa$$

$$(D = 50mm)$$

The second value, is obtained by using a minimum slope of 1/10D (D in inches):

$$\tau = \gamma \times \frac{1}{10D} \times R_h = 9800 \times \frac{1}{10 \times 1{,}96850} \times \frac{0{,}05}{4} = 6{,}2\ Pa$$

$$(D = 50mm)$$

These last results allow to deduce that the ones of Shields diagram are not adequate for sewage pipes, and that a tractive tension of 1 to 2Pa should be enough to accomplish a self-cleansing pipe.

5. Review of the different legislation.

About the different legislations, it was made a compilation with the minimum criteria for self-cleansing drainage systems, with the objective of comparing them with the Portuguese one's. On Table 3 and Table 4 are represented the various self-cleansing criteria's for the different legislations and the two types of water.

It's important to say, that some of these values are used for public drainage systems, not buildings, but it's ok its use in this case, because the particle size in both systems are the same. The major differences between the two, are the hydraulic flow, and tube diameter used.

Table 3 - Different self-cleansing criteria for domestic waters

	Velocity (m/s)		Tractive tension (Pa)
Country	*mínima*	*máxima*	*mínima*
Portugal	0,60	3,00	-
Spain	0,60	3,00	-
U.K.	0,60	3,00	6,20
Germany	0,70	2,50	2,50
U.S.A.	0,60	4,60	2,00
Canada	0,60	3,00	-
Mexico	0,60	2,50	-
Brasil	-	5,00	1,00
Chile	0,60	3,00	-
Australia	0,60	3,00	1,00

Table 4 - Different self-cleansing criteria for storm waters

	Velocity (m/s)		Tractive tension (Pa)
Country	*mínima*	*máxima*	*mínima*
Portugal	0,90	3,00	-
Spain	0,60	3,00	-
U.K.	0,75	6,00	6,20
Germany	0,70	2,50	2,50
U.S.A.	0,90	4,60	3,00
Canada	0,80	6,00	-
Mexico	0,60	3,00	-
Brasil	-	5,00	1,00
Chile	0,90	3,00	-
Australia	0,60	3,00	1,00

As can be shown in the previous tables, the Portuguese legislation in the domestic waters uses the minimum value, so it can't be made any changes. But in the case for storm waters, the Portuguese legislation is one of the highest, so it could be used a smaller minimum velocity.

6. Case studies.

To analyze the impact of the changes made to the self-cleansing criteria, were made two case studies. The buildings drainage systems were dimensioned according to these criteria's, and then it was made an economic analysis to both case studies.

Although is not mentioned on the Portuguese legislation, it's advised by Vitor Predroso [3], that a minimum tractive tension of 2,45Pa is used on the domestic sanitary system, so it was also considered as self-cleansing criteria to observe the differences.

The self-cleansing criteria's used were:

A. Domestic water:
   - Minimum tractive tension of 2,45Pa;
   - Use of secondary ventilation as possible;
   - Minimum water velocity of 0,6m/s;
   - Minimum water velocity of 0,6m/s and no minimum diameter to the collector pipes.

B. Storm water:
   - Minimum water velocity of 0,9m/s;
   - Minimum water velocity of 0,6m/s and a minimum diameter of 100mm on the collector pipes;

- Minimum water velocity of 0,6m/s and no minimum diameter to the collector pipes.

7. Case study 1.

This case study is a habitation building located in Lisbon, on the D. Estefânia street. It has 8 floors above ground, and 2 underneath.

In the storm drainage system, it was considered that the pluviometric region is a type A, and with a return period of 10 years. This is important so that is possible to estimate the hydraulic flow that converges to each pipe, allowing to proceed to the calculation of its diameter.

As for the domestic drainage system, the hydraulic flow used is based on the discharge flow of the sanitary devices confluent to the respective pipe. In case of multiple devices, it's used the following equation to determine the calculated hydraulic flow [3]:

$$Q_c = 7{,}3497 \times Q_a^{0{,}5352} \tag{18}$$

Q_c – Calculated hydraulic flow

Q_a – Accumulated hydraulic flow

So, with the hydraulic flow and the various self-cleansing criteria explained, it's possible to define the pipes diameter's, slopes and therefore it's costs. The Table 5 represents the various costs for the domestic system, and Table 6 for the storm system.

Table 5 - Domestic sanitary system cost

	τ_{min} =2,45Pa and D_{min}=100mm	V_{min}=0,6 m/s and D_{min}=100mm	V_{min}=0,6m/s and no D_{min}	V_{min}=0,6 m/s, D_{min}=100mm and secondary ventilation
Custo Total (€)	26500,92€	26507,51€	26486,66€	29727,59€

Table 6 - Storm sanitary system cost

	Vmin=0,9 m/s and Dmin=100mm	Vmin=0,6 m/s and Dmin=100mm	Vmin=0,6 m/s and no Dmin
Custo Total (€)	28520,01€	28774,20€	27311,25€

So as it can be seen, in the domestic system the use of a minimum self-cleansing velocity has approximately the same cost as using a tractive tension, being the biggest difference the smaller slopes needed on the first one. The use of a minimum velocity of 0,6m/s and no minimum diameter in the collector pipes has the advantage of reducing a little bit of the costs, but a very small quantity. In conclusion, if it's used a minimum velocity of 0,6m/s as the self-cleansing criteria, and removed the imposition of a diameter of at least 100mm in the collectors, it's possible to reduce the global cost, and the necessary slopes for the pipes, allowing more usable space on the ceiling/floor.

Regarding the storm sanitary system, as the table shows, there's a small increase in costs using a smaller velocity, but if we remove the collectors pipes minimum diameter of 100mm, it's possible to achieve a lower cost, and the need for smaller slopes, like in the domestic system.

8. Case study 2.

This case study is very similar to the first case study, it's a habitation building on Prof. Dias Amado street in Lisbon, made of 2 buried floors, and 7 above ground.

Table 7 - Domestic sanitary system cost

	τ_{min} =2,45Pa and D_{min}=100mm	V_{min}=0,6 m/s and D_{min}=100mm	V_{min}=0,6m/s and no D_{min}	V_{min}=0,6 m/s, D_{min}=100mm and secondary ventilation
Custo Total (€)	7032,67€	7032,67€	7019,32€	7765,71€

Table 8 - Storm sanitary system cost

	Vmin=0,9 m/s and Dmin=100mm	Vmin=0,6 m/s and Dmin=100mm	Vmin=0,6 m/s and no Dmin
Custo Total (€)	18704,57€	18810,02€	18207,45€

As the first case study, this one is located on a type A pluviometric region with a 10 year return period.

As for the domestic system, it's applied the same equations as the previous case study.

The Table 8 represents the various costs for the storm system, and Table 7 for the domestic system.

As can be observed by these two tables, the result is the same as the previous case study. In the domestic system, the use of a velocity and no minimum diameter for the collectors pipes, allows the use of smaller slopes and a very small saving in the total cost. As for the storm system, the use of a smaller velocity and no minimum collector pipe diameter, reduces the total cost of the system as well, and allows the use of smaller slopes on the pipes.

9. Conclusion

The present thesis had the objective of searching and provide the maximum of information about the self-cleansing requirements on a buildings sewer drainage network.

It was made a search of various norms and regulations, nationally and internationally, to identify the different self-cleansing criteria's and compare them with our laws. With this, it was possible to notice that our current laws on the storm system are very conservative, and so there were proposed some changes to enhance the efficiency of this type of drainage system. Also, there were consulted some studies to complete this thesis, like for example the origin of the tractive tension equation.

To demonstrate the effects of the proposed changes on the self-cleansing requirements for a buildings drainage system, there were made two case studies. On these case studies, the domestic part was dimensioned for a tractive tension of 2,45Pa, and a minimum flow velocity of 0,6m/s, and the storm part was dimensioned for a minimum flow velocity of 0,9m/s and of 0,6m/s. To assess the effects of this measures, there was made a budget analysis, that led to the conclusion that these types of changes were only successful on lowering the necessary slopes for the drainage pipes allowing space savings, but they were successful at lowering installation costs or material use. With these results, the current portuguese regulation could be a bit more flexible on the self-cleansing requirements, since there was assured a self-cleansing condition.

Beside the changes of the self-cleansing requirements, there was also made suggestions to secondary system requirements not related to its self-cleansing requirements. There was suggested that there were used always a ventilation column to the drop pipes, to try to lower their diameter, and there was suggested to use collector pipes with a diameter lower than the current minimum (100mm). These changes were applied to the two case studies and their budget analyses, and it was noticed that their effects were residual considering the total cost of a building drainage system.

So to conclude, none of the proposed changes made a noticeable effect on the cost on a buildings drainage system, but the portuguese could allow more flexible criteria's on the storm part of a drainage system, since it's achieved a self-cleansing condition.

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