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A COMPUTATIONAL MODEL FOR PRELIMINARY STUDIES OF OCEAN OUTFALLS

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SUMMARY.

Sewage disposal into the sea by means of submarine outfalls is a common practice in coastal cities. In this paper a computational model for the preliminary design of those outfalls is presented. Firstly, the model enables the definition of the general characteristics of the diffusor and the evaluation of the length of the outfall which is necessary in order to achieve the required quality standards. That length depends on the treatment provided on land. Cost functions both for outfalls and treatment plants are also included in the model, allowing the economic comparison of several alternatives. Model application is illustrated by means of an example.

NOTATION.

Small letters.

- b projection of the diffusor perpendicularly to the current
- c experimental coefficient
- do port diameter
- g acceleration due to gravity
- q flow per unit length
- t time
- ua current velocity
- uo jet velocity
- x distance from the diffusor
- y depth
- z abcissa of the jet centerline

Capital letters.

A	parameter which depends on Teta, Eq (4)
D	outfall diameter
Eo	coefficient of turbulent diffusion
F	parameter defined by Eq (3)
Fo	densimetric Froude number, Eq (11)
L	initial width of the sewage field
S	total dilution
S1	near-field dilution
S2	far-field dilution
S3	time-decay "dilution"

Other symbols.

Beta	parameter defined by Eq (7)
Roa	seawater density
Roo	sewage density
Teta	angle between current and diffusor

,	decimal comma
+	addition
-	subtraction
/	division
^	power
E	exponent of 10

1. INTRODUCTION.

Ocean outfalls for sewage disposal consist on submarine pipelines which promote the transport of the effluents to some distance from the shore, where they are discharged, usually by means of a multiport diffusor. With this method it is aimed to reduce pollutants concentration by means of dispersion and mixing with the seawater, as well as time-decay for non-conservative ones.

Quality standards depend on the use of the receiving waters, but fecal coliforms are the indicator which usually determines the length of the outfall in bathing areas. In most European countries, treatment prior to discharge is usually rudimentary; however, recent legislation from EEC might modify this situation in the future.

Preliminary studies of ocean outfalls usually include the analysis of several alternatives, concerning, for example, its localization, orientation, diffusor characteristics and treatment degree. Also different scenaries concerning to flow fluctuations, direction and intensity of the currents, time-decay rates, etc., should usually be taken into account. This is a time-consuming process that might be fastened by the use of a computational model.

2. MODEL DESCRIPTION.

2.1. General.

In outfall design, if a certain starting point and orientation are defined, it is possible to obtain the bathymetric profile and, consequently, to relate the depth of the discharge to the length of the outfall. At the beginning, a certain length is fixed, which corresponds to a certain depth. The general characteristics of the diffusor, namely its length and diameter, as well as the number, spacing and diameter of the ports are then defined as a function of the depth and of the flow to be discharged.

The efficiency of the outfall in terms of obtained dilutions is studied afterwards. For non-conservative pollutants, such as coliforms, dilution is considered as the product of three factors: (i) "near-field" dilution; (ii) "far-field" dilution and (iii) time-decay.

Next, a certain increment of the length is considered and a new dilution is evaluated. A function "dilution-versus-length" is obtained in this way, and then, by interpolation, it is possible to find the length which will be necessary in order to assure the desired dilution.

Sensitivity studies should be done, namely for currents and time-decay rates. It is also usual to consider different hypothesis of treatment, which correspond to as many alternative solutions for the outfall. The developed model allows an estimation of each solution costs.

2.2. Diffusor characteristics.

Firstly the user defines the bathymetric profile. Then he fixes an initial length for the outfall (for instance, 1000 meters), the corresponding depth being calculated from that profile. With the evaluated depth and once given the flow to be discharged, the model gives information about the general characteristics of the diffusor, which are established according to the following basis:

i) The length of the diffusor will be such that the flow per unit length will be 10 (l/s)/m;

ii) The upstream diameter is considered between 75% and 80% of the outfall diameter;

iii) The ports are supposed to discharge alternately from one and the other side of the diffusor and their spacing is made equal to 20% of the depth;

iv) With the diffusor length and the port spacing it is possible to evaluate the total number of ports; its diameter is then obtained by considering a velocity discharge of 3 m/s. The results might have to be adjusted in order to satisfy the condition that the total area of the ports should not exceed the cross section area of the diffusor.

2.3. Dilution evaluation.

i) In the near-field, momentum, buoyancy and currents promote mixing between the emitted jets and seawater. Dilution (S1) is evaluated by

$$S1 = c.(y.ua)/q \qquad (1)$$

where (y)=depth, (ua)=current velocity, (q)=flow per unit length and (c) is a coefficient given by Roberts (1979) experiments. Neves (1989) suggested the following expressions, which fit those experimental results quite fairly:

$$c = 0,27.F^{(-1/3)}.(1+A.F^{2})^{(1/6)} \qquad (2)$$

where (F) is a parameter which depends on the current velocity and kinematic buoyancy flux,

$$F = ua^{3}/(((Roa-Roo)/Roo).g.q) \qquad (3)$$

and (A) is another parameter, related to the angle between the current and the diffusor (Teta, in degrees),

$$A = 0,050+2,593.Teta^{3,366} \qquad (4)$$

In these expressions, (Roa)=seawater density, (Roo)=wastewater density and (g)=acceleration due to gravity.

ii) In the far-field, dilution (S2) is evaluated by Brooks (1960) model, which takes in consideration turbulent diffusion and advection. Assuming the "4/3 law",

$$S2 = (\mathrm{erf}(1{,}5/((L/b)^{2}-1))^{(1/2)})^{(-1)} \quad (5)$$

in which (erf)=error function and

$$L/b = (1+(2/3).Beta.(x/b))^{(3/2)} \quad (6)$$

$$Beta = 12.Eo/(ua.b) \quad (7)$$

$$Eo = 0{,}01.b^{(4/3)} \quad (8)$$

with (Eo) in cm2/s and (b) in cm.

In these expressions (L)=initial width of the sewage field, (x)=distance from the diffusor, (Eo)=coefficient of turbulent diffusion and (b)=projection of the diffusor on a direction perpendicular to the current. The least value of (b) is assumed to be, Neves (1989),

$$b = 2.z+0{,}4.y \quad (9)$$

where (z) is the abcissa of the jets centerline at the surface, given by

$$z/D = 2{,}113.Fo^{0{,}419}.(y/D)^{0{,}241} \quad (10)$$

(Fo) is the densimetric Froude number, represented by

$$Fo = (uo^{2})/(((Roa-Roo)/Roa).g.do) \quad (11)$$

where (do)=port diameter, (uo)=jet velocity.

Equations (9) and (10) are based on Abraham (1963) experiments, assumming that (ua <<< uo).

iii) Fecal coliforms time-decay (S3) is evaluated by

$$S3 = 10^{(t/T90)} \quad (12)$$

$$t = x/a \quad (13)$$

where (T90)=time for 90% coliforms reduction.

Reported (T90) values vary between 1 hour and 6 hours.

Theoretically, the total dilution would be given by

$$S = S1.S2.S3 \quad (14)$$

This is a minimum value, which we believe too conservative because of the simplifications introduced in its genesis. In practice it is common the use of a majoration factor of $2^{(1/2)}$.

2.4. Cost functions.

According to Russel (1976) the cost per meter of ordinary ocean outfalls can be estimated as

$$p1 = K1.1{,}92^{D} \quad (15)$$

where (D) is the diameter, in meters, and (K1) is a coefficient which depends on the specific conditions of each case. Actually, in Portugal, its value is around (166000) if (p1) is expressed in Portuguese Escudos (1 USD = 140 Portuguese Escudos).

Concerning to treatment plants, construction costs are estimated as, Pereira (1986),

$$P2 = K2.Pop^{0{,}82}.Cap^{0{,}09}.EBOD5^{0{,}81}.ESS^{0{,}09} \quad (16)$$

Where (Pop)=population, (Cap)=sewage production per capita (m3/day), (EBOD5)=reduction of 5 days biochemical oxygen demand, (ESS)=reduction of suspended solids. (K2) is a coefficient which, actually, in Portugal, has a value around (55000) if (P2) is expressed in Portuguese Escudos.

It is intended to include in the model operation and maintenance costs, after collection and analysis of the scarce existing data. It is known, however, that they favour solutions with longer outfalls and simpler land treatment.

3. MODEL APPLICATION.

i) The following example has been studied, in order to illustrate how the described model can be used:

Flow to be discharged 1,5 m3/s
Fecal coliforms in raw sewage .... 5E7/100 ml
Fecal coliforms allowed in the beach .... 100/100 ml
Current velocity .... 0,1 m/s
Current direction .... parallel to the diffusor
T90 (3 hypothesis) .... 2: 2,5 and 3 hours

Also given are the bathymetric profile and some complementary data.

ii) Results.

Diffusor length is evaluated in 150 meters. The main characteristics of the diffusor, as well as the near-field dilution are presented in Table 1 as a function of the outfall length (an initial length of 1000 meters was considered and thereafter increments of 250 meters).

TABLE 1 - Characteristics of the diffusor.
Q = 1,5 m3/s ; Length of the diffusor = 150 m.

Length (m)	Depth (m)	No. of ports	Diam (m)	Veloc (m/s)	Fo	b (m)	Disch (l/s)	S1
1000	16.7	46	0.12	3.00	280	24	32.6	63
1250	18.8	42	0.12	3.00	267	26	35.7	71
1500	20.4	38	0.13	3.00	254	27	39.5	77
1750	21.4	36	0.13	3.00	247	28	41.7	81
2000	22.4	34	0.14	3.00	240	29	44.1	85
2250	23.4	34	0.14	3.00	240	29	44.1	88
2500	24.4	32	0.14	3.00	233	30	46.9	92
2750	25.4	30	0.15	3.00	226	31	50.0	96
3000	26.4	30	0.15	3.00	226	31	50.0	100

Figure 1 illustrates the total dilution as a function of the outfall length and of (T90).

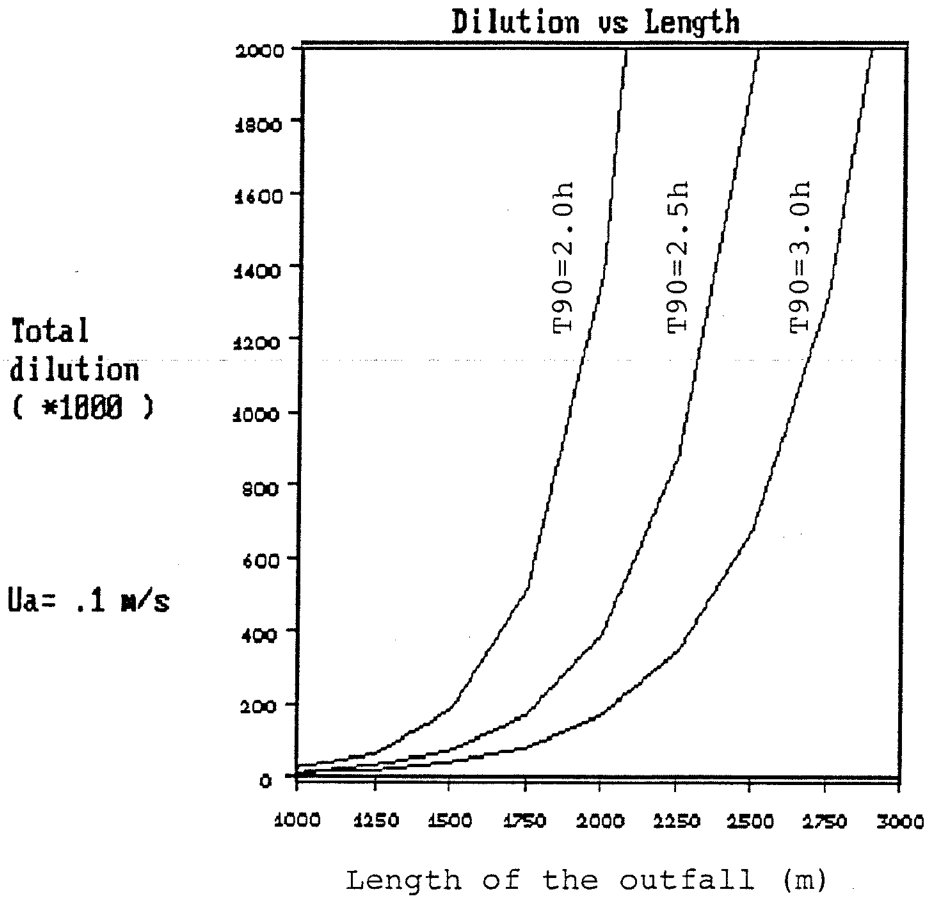

Figure 1 - Dilution vs. Length of the diffusor.

TABLE 2 - Cost analysis (millions of Portuguese Escudos)

	Preliminary Treatm.		Primary Treatment		Secondary Treatm.	
	Length	Cost	Length	Cost	Length	Cost
T90 = 2h	1702	a) 415 b) 572 c) 987	1378	1712 463 2174	1028	2562 345 2907
T90 =2.5h	2032	415 682 1098	1641	1712 551 2262	1203	2562 404 2966
T90 = 3h	2334	415 784 1199	1884	1712 633 2344	1352	2562 454 3016

(Obs: a) treatment plant; b) outfall; c) total cost)

Table 2 shows the length that would be necessary for each treatment hypothesis, as well as the outfall and treatment plant costs. The longest outfall associated to preliminary treatment would be the most economic solution for all values of (T90) that have been considered. In practice other situations should be analised, including different current, flow to be discharged and diffusor characteristics.

4. CONCLUSION.

A computational model for preliminary studies of ocean outfalls has been presented.

The model provides a fast and easy-to-use tool for the analysis of multiple alternative solutions and for sensitivity study of several parameters.

The model presented is not the final step of the design by itself, but it helps, in an early stage of the project, to select the solutions that will be studied in detail.

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