STATIC AND DYNAMIC ANALYSIS OF SUBMARINE OUTFALL STRUCTURE

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Abstract. Submarine outfalls are composed of an oceanic disposal system, represented by a tube that transports domestic effluents to the sea. The discharge of sewage by underwater outfalls is shown as an efficient alternative for the final destination of sanitary effluents since it has a high capacity to disperse and purify organic materials in the marine environment. To design a submarine outfall as a method of disposal of effluents is necessary to evaluate several factors that can influence the behavior of the structure, such as the forces due to sea currents. Therewith, the study presents, through numerical modeling in SAP2000 software based on the finite element method, a comparison between static and dynamic model, in a submarine outfall. The hydrodynamic forces were applied by Morison's equation for two load case, multi-step static parameters were employed in the static model and the time history was putted in the dynamic model. The results were analyzed by means of the displacement of the structure by varying the height and period of the waves. The analysis presents significant differences in relation to the static and dynamic of structure comparison, mainly in the peak of the resonance.

Keywords: submarine outfalls, structure analysis, numerical modeling, dynamic analysis.

1 Introduction

According to Gonçalves and Souza [1], the outfall is a channel that transports the effluents from a Sewage Treatment Station to its end destination , the sea. This system is constituted by a terrestrial pipe destined to transport the effluents to the equilibrium chimney. By a submerged pipe destined to transport the effluents to the diffusing pipe that has the purpose of throwing the effluents into the sea. The distance of submerse pipes of coast depends in the oceans currents.

Dynamic analysis is a consolidated theme by several authors such as Lopes, Zuleta and Silva [2], De Paula, Inman and Savi [3] and Cellular, Monteiro and Savi [4]. Normally, research involving dynamic analysis is non-linear, such as developed by Cellular, Monteiro and Savi [4] who investigated an energy harvesting system using non-linear dynamics, analyzing the different energy harvesting behaviors. Lopes, Zuleta and Silva [2], in turn, performed static and dynamic non-linear analyzes of a self-elevating, cable-stayed platform and compared the results based on horizontal displacement. Therewith, it can be considered that the dynamic analysis of a structure is an extension of the static analysis in which the dynamic expression adds to the analysis a variation in time in addition to considering the effect of the resulting inertia actions, according to Meireles [5]. Thus, when a structure is subjected to this type of action from nature, it presents unusual responses that are difficult to be applied by static structural analysis, Silva [6].

Despite the great theories existing today about the dynamic behavior of structures, a comparative study between static and dynamic analysis is necessary to obtain results that attest to the relevance of using the two methods of analysis due to the actions of hydrodynamic forces in submerged structures, such the case of the submarine outfall. In 1999, the submarine outfall of Ipanema-RJ-Brasil collapsed. Its main submerged pipe ruptured, causing environmental damage. According to COPPETEC [7], the project of submarine outfall of Ipanema was developed for a static condition, not considering any type of dynamic action . Therefore, this work has as objective to compare the results in terms of displacements between static and dynamic analyzes in submarine outfall, considering the appropriate weight of the structure with the pipe and sewage and varying the height and period of the wave by the Morrison's equation.

2 Hydrodynamic Model

The dynamic model of the submarine outfall must consider some fundamental analyzes. Like the hydrodynamic forces on the structure, the material composition itself (stiffness), the weight of the structure, the viscous damping of the water and the stiffness of the soil in which the structure is anchored.

Based on dynamics systems of structures, the model consists of an oscillator of mass m that presents a displacement z the restitution force, linked to the stiffnes of the structure (k) both of the steel structure and the soil. For the force of linear damping, was used a damping factor (α) proportional to stiffness (Rayleigh hypothesis) and finally the hydrodynamic force, FT.

$$FT - [k]z - [\alpha]\dot{z} = m\ddot{z}. \tag{1}$$

The Morison formulation et al. [8], eq. 2 wil be used for hydrodynamic force.

$$FT = F_i + F_d = C_m \frac{w}{g} V \frac{dU}{dt} + C_d \frac{w}{2g} AU|U|. \tag{2}$$

Where,
FT = Hydrodynamic force per unit length acting normal to the object longitudinal axis.
F_i = Inertia force per unit length.
F_d = Drag force per unit length.
C_m = Inertia coefficient.
C_d = Drag coefficient.
w = Weight density of water.
g = gravitacional acceleration
A = Project area normal to object axis per unit length. Effective diameter of the object (D), including marine growth.
V = Displaced volume per unit length , $(\pi D^2)/4$.
U = Component of the water particle velocity acting normal to the axis of the object.
$|U|$= The absolute value of U.
$dU/dt =$ = Component of the water particle acceleration acting normal to the axis of the object.
The expressions for U and dU/dt shows in eq. (3) and (4), respectivy.

$$U = \frac{H}{2} . \omega . \frac{cosh[k(z+d)]}{sih(kd)} . cos\theta. \tag{3}$$

$$\frac{dU}{dt} = \frac{H}{2} . \omega^2 . \frac{cosh[k(z+d)]}{sih(kd)} . sin\theta. \tag{4}$$

Were, $\theta = kx - \omega t$ (fase angle), $k = \frac{2\pi}{T}$, $c = \frac{\omega}{k}$, t (time [s]), T (wave period [s]) and ω (angular wave frequency [1/s]).

For the static analysis, the morisson equation was also considered but without the variation in time. The loads were static at each point in the height and wave period.

3 Numerical simulations

The structure development in SAP2000 has undergone some adaptations in relation to the real characteristics of the submarine outfall of Ipanema. The first adaptation was to model only the largest section of reinforced and prestressed concrete (adopting a length of 50.0 m) which consists of tubes 2.80 m in diameter and 20 cm thick, plus half of each section (25 m). The emissary is at a depth of 24 m and rests on steel pillars 1.40 m in diameter and 1.6 cm thick. Another simplification was to determine that the tube is all at the same depth, disregarding the differences in pillar placement on the marine soil, contained in layers of sand that represent the material's stiffness, whose lateral reaction coefficient is 5000 kN / m³, varying linearly every meter of depth.

The three-dimensional model represents the prestressed concrete pipe in the horizontal part and just below, in the vertical, are the metal piles, containing submerged parts and embedded parts in soil, besides in addition to the springs represented at each meter of depth to simulate the horizontal reaction coefficients, as can be seen in Figure 1.

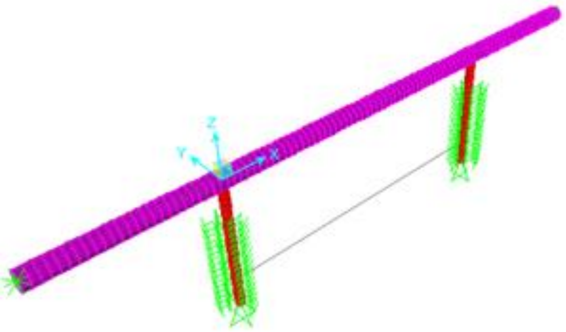


Figure 1: Three-dimensional model of submarine outfall in SAP 2000.

The dynamic problem considered in this work consist in determining the response of the structure composed by the pipe and piles to the marine forces. This problem considered the linear behavior of the piles, by adding the stiffness matrix of the materials and the geometric matrix of each of these structural components. The evaluation of these matrices is performed by the program for each time interval. The discretization was performed by 143 nodes and 142 frames. It was considered finite elements type "Frame".

The agitation conditions were characterized by the wave heights and taken from the database of the Brazilian Navy's Board of Hydrography and Navigation. With this, the characteristics are defined from descriptive terms, with a wave height of 0 m considered a calm sea, 0.5 to 1.5 m considered little agitated, 1.5 to 2.5 m considered agitated, 2.5 to 4 m considered rough sea and above 4 m considered thick.

Two analyzes were implemented in the SAP 2000 software under the effect of wave loads. The hydrodynamic forces were applied by Morison's equation for two load case, multi-step static parameters were employed in the static model and the time history was putted in the dynamic model. Also, it analyzed the behavior of the structure without a current and, subsequently, with a current of 0.5 m/s and direction of 90º, because it is the characteristic of the sea on the day that the first accident happened in the submarine outfall of Ipanema according to Gonçalves and Souza [1]. Furthermore, the wave height and wave period were varied according to the characteristics of the region.

For the variation of the height of the waves, we chose a variation of 1 to 4 m, as it is among the four main characteristics of the sea scale, being 1 m considered calm sea, 2 m little agitated, 3 m agitated and 4 m very agitated . Periods of 5 to 20 seconds were tested, and the one that best suited the real conditions was 10 seconds.

For the variation of the wave period, the wave height of 2.5 meters was chosen, as it is a characteristic of the sea between agitated and very agitated and the choice of the period of 7 and 9 seconds is due to be between the peak of structure resonance. The corresponding actions of the wave forces with height variation that obtained the biggest difference without applying the current and when applying the current were for a wave height equal to 2 and 4 m.

The input data in the SAP 2000 program for wave forces in the structure can be seen in Fig. 2, in this case for a wave height of 4 m.

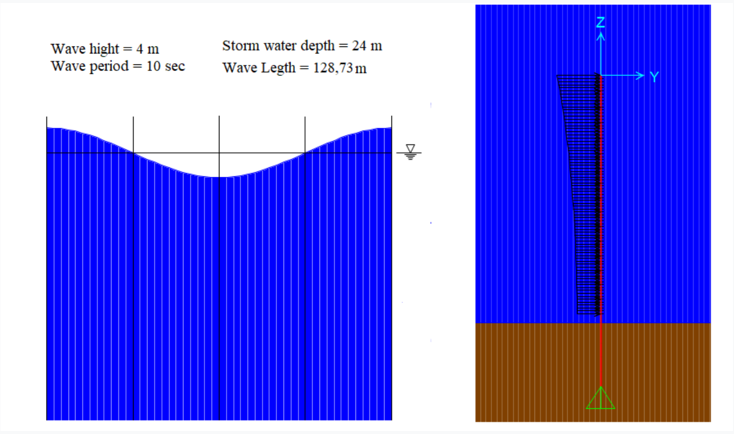
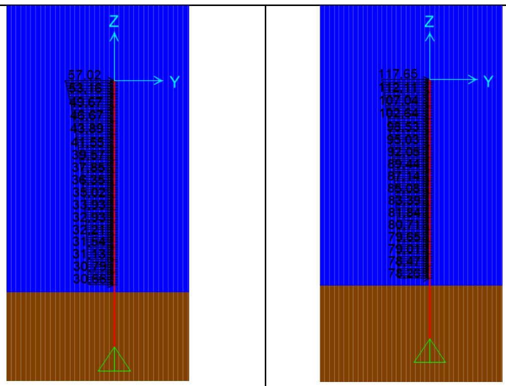


Figure 2: Input data for a wave height of 4 m.

For each wave loading case, the actions were analyzed at the first moment with the applied wave current and, at the second moment, without the applied wave current. The corresponding actions on the structure, for a wave height equal to 4 m, can be seen in Fig. 3.



Wave loading on the structure (no current)	Wave loading on the structure (with current)

Figure 3: Loading on structure [Kgf / m].

The Fig. 3 shows how the wave loading on the structure is generated. In this case, the maximum load for a wave with a height of 4 m, without the current is 57.02 Kgf / m and with the current is 117.65 Kgf / m.

3.1 Resulting period wave

The maximum wave velocity, for wave height variation and period variation, without current application and 0.5 m /s current application, are shown in Tab. 1.

Table 1. Wave velocity

	Wave height (m)	Wave period (s)	Wavelength (m)	Max wave velocity (no current) [m/s]	Max wave velocity (with current) [m/s]
L1	1.0	10	128.7	0.39	0.82
L2	2.0	10	128.7	0.79	1.23
L3	3.0	10	128.7	1.21	1.65
L4	4.0	10	128.7	1.65	2.09
L5	2.5	7	73.9	1.29	1.72
L6	2.5	9	110.8	1.06	1.49

The maximum velocity, without current is 1.65 m / s and with the current of 2.09 m / s whose wave height is 4 meters and a period of 10 seconds, as observed in Tab. 1. So, the higher the wave height, the greater the velocity. The Fig. 4 shows the spectrum where the maximum result of velocity without current (a) and with current (b) occurs.

(a) (b)

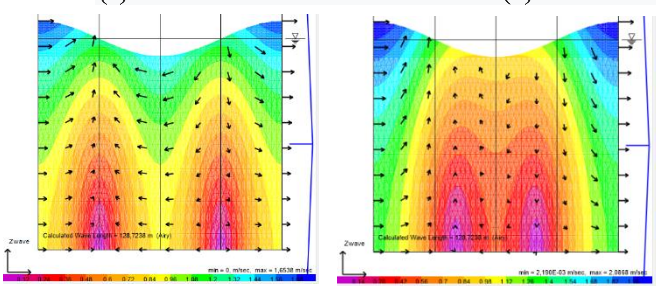
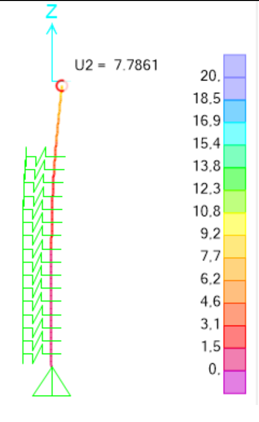


Figure 4: Representation of the result of the maximum velocity [m / s].

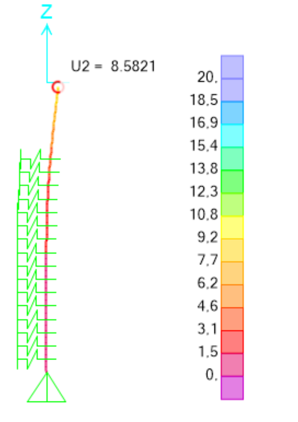
The spectrum illustrates where the result of the maximum velocity occurs, being close to the crest of the wave in both cases where the velocity of the wave is not dampened by water. Thus, the greater the depth, the lower the acting velocity. Even so, it is noted that with the current of 0.5 m / s applied, the velocity at the bottom of the sea is consequently higher. Vectors have the dual purpose of indicating the direction and magnitude of the velocity.

3.2 Displacement analysis

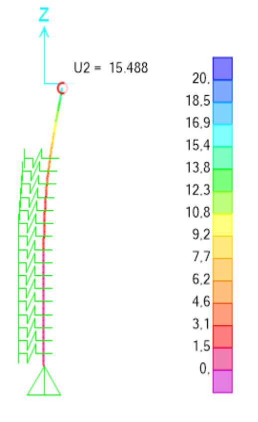
The study analyze the maximum displacements in the pile head, in the direction U2, whose values are shown in the Fig. 5. The Fig. 5 represent the maximum loading over the structure for height wave igual 4 meters e period of 10 seconds. The Fig. 5 (a) and the Fig. 5 (b) represents static analysis whitout and with current, respectively. The Fig. 5 (c) and the Fig. 5 (d) show the results the dynamic model without and with current, respectively.



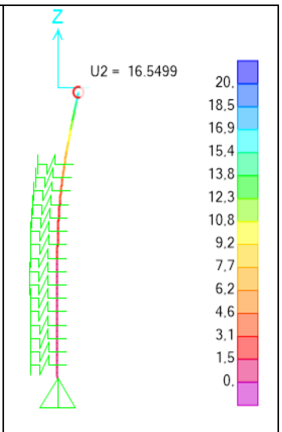
(a) Displacement static without current



(b) Displacement dynamic without current



(c) Displacement static with current.



(d) Displacement dynamic with current.

Figure 5: Displacement - Static and Dynamic [mm].

The maximum static displacement without current of 7.786 mm and a maximum dynamic displacement of 8.582 mm were obtained, respectively. With current application, the maximum displacement obtained in static analysis was of 15.488 mm and in dynamic analysis was of 16.549 mm.

The Fig. 6 and Fig. 7 present the variation between dynamic and static model in relation to the maximum displacement in pile head, varying the wave height without current and with current, respectively. The wave period fixed at 10 seconds.

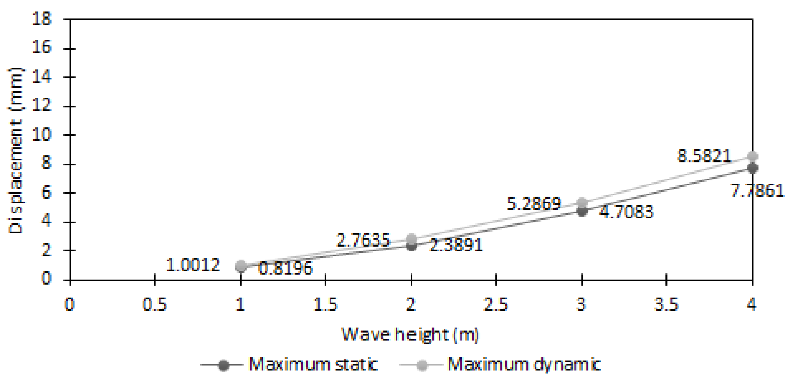


Figure 6: Maximum displacement in pile head in static and dynamic model varying wave height (without current).

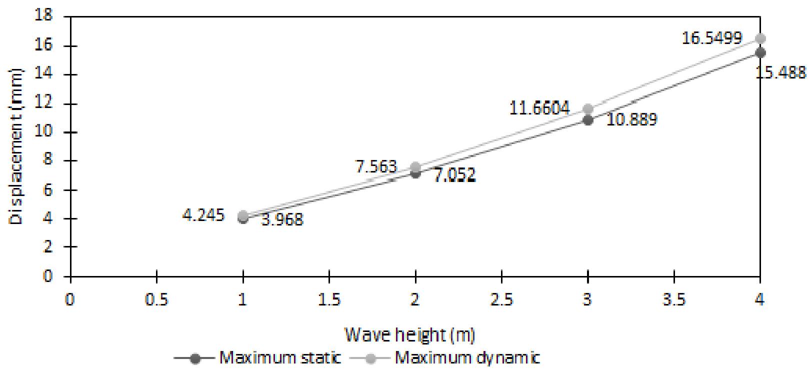


Figure 7: Maximum displacement in pile head in static and dynamic model varying wave (with current).

The Fig. 6 and Fig. 7 show as the wave height increases the values of the dynamic and static analysis are distanced in relation to the maximum displaciment. It happens because there is a higher loading over the structure and the displacement is greater when the current is inserted.

The Fig. 8 and Fig. 9 feature the maximum displacement at the pile head in relation to the variation of the wave period without current and with current, respectively. The displacement difference between the static and dynamic model with wave height igual four meters (4 m) is about 1 mm with current and less than 1 mm whitout current.

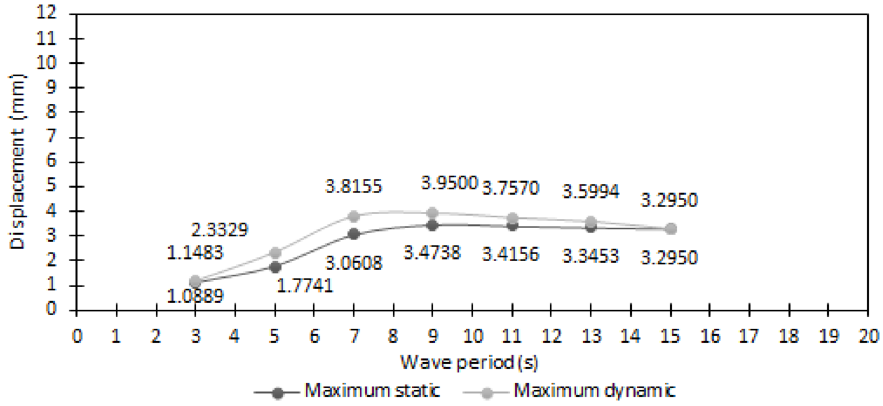


Figure 8: Static and dynamic comparison of the maximum arrow in relation to the wave period variation (without current).

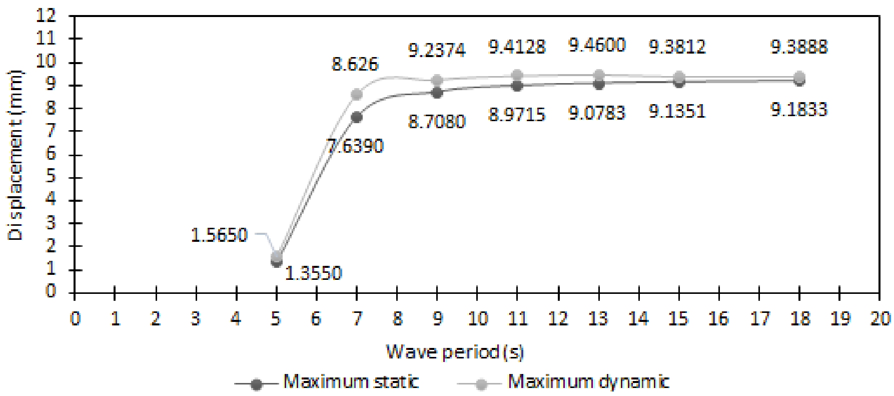


Figure 9: Static and dynamic comparison of the maximum arrow in relation to the wave period variation (with current).

The curves in Fig. 8 and Fig. 9 represent seven differents wave periods ranging from 3 to 18 seconds, in order to visualize the resonance peak of the structure that is between period 7 and 9. For periods of waves less than 3 and greater than 15, the results showed that the dynamic and the static analysis are practically the same. Furthermore, when there is the insertion of the continuous current of the velocity of 0.5 m / s, the dynamic and the static curves are even more nearby at peak resonance. This fact occurs due to the lower vibration of the structure in the dynamic analysis caused of the imposition of the current with an angle of ninety degrees over structure.

In the period of 7 seconds there is the greatest distance between the dynamic and static model without current. The displacement in dynamic model is 25% greater than static model, showing the importance of considering dynamic loading in structures of this type.

5 Conclusions

This article investigated static and dynamics efects in the a submarine outfall structure, varying loads. The wave height is chose for rough to very rough seas and the period variation contemplated the resonance peak. The current intruduced an increase in the load obtaining a greater displacement in structure. With the period variation, it observed that the most outlier values are close to the structure's resonance point . Furthermore, it was observed that with the application of the current the displacement of the structure was greater compared to the analysis without current. Results show that there is a considerable difference between the dynamic and the static model for larger height wave and period wave bigger. Therefore, the dynamic analysis model must be considered in the design phase in the structures that are submitted the marine environments.

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