XXXVI Ibero-Latin American Congress on Computational Methods in Engineering
CILAMCE
Rio de Janeiro, 22-25 Nov 2015

EXPERIMENT WITH A VERTICAL PIPE IN A WATER TANK

Ahmad Taha

ahmadtaha012@gmail.com

Caio Cesar de Oliveira Trigo

trigo@cepetro.unicamp.br

Celso Kazuyuki Morooka

morooka@dep.unicamp.br

Universidade Estadual de Campinas

Rua Mendeleiev, 200, São Paulo, Campinas, Brazil

Abstract. *The main aim of the present work is to study the dynamic response behavior of a vertical pipe in a still water tank. The vertical pipe has the bottom termination free and the top termination is forced to move by a motion device with a motor. Displacements along the pipe length are measured and vibration of the pipe is analyzed. Vertical pipes are commonly used for different offshore petroleum applications, such as petroleum wellbore drilling and sometimes to provide cold water from the ocean for cooling operations of the petroleum process plant in floating platforms and ships. Imposed motions at the top of the vertical pipe intend to represent motions coming from the surface vessel due to waves, sea current and wind. Results obtained from the experiment allowed better understanding of the pipe behavior and to investigate numerical simulation procedures by the use of a commercial software (Orcaflex©). In the present work, a physical model with small pipe diameter has been developed for the laboratory experiment, and optical measurement system for pipe displacements in a still water tank with imposed motions on the pipe top termination was developed. Experiment is described in details and comparative analysis among numerical simulations and experiment is carried out. The proposed numerical simulation approaches as well as experimental measurement procedures have shown very promising results to evaluate the behavior of a vertical pipe in water.*

Keywords: *Offshore structure – hydrodynamic, Water tank experiment, Rigid Riser*

1 INTRODUCTION

Slender tubular elements is present in submerged systems such as drilling and production risers, support buoy for risers, subsea manifolds, and other marine structures. They are used in systems to develop and to produce offshore oil and gas fields. Drilling riser is used for construction of a wellbore through petroleum well drilling operations. Subsea production pipeline and risers interconnects a wellhead located on the seabed with a floating platform on the sea surface, and they are responsible to flow oil and gas lifted from the subsea petroleum well, and sometimes, they are used for water injection into the reservoir. Slender vertical pipes are also used to get cold water from the ocean (Franciss, 1999) for chilling process plant equipment onboard of floating production platforms and ships.

Riser systems can be of various types (Chakrabarti, 1987). The Steel Catenary Riser (SCR), a rigid riser in catenary configuration, resists some movement, but it can present problems if this movement is excessive. Top Tensioned Riser (TTR), a rigid riser in vertical configuration, is used for wellbore drilling or for production in fixed and heave free floating platforms such as Tension Leg Platform (TLP). Flexible risers are pipes made by several layers of different materials, and they can be set to produce oil and gas in several configurations such as in Lazy S, Lazy Wave, Steep S, and others.

Ocean waves cause movements of the floating platform and underwater systems. These movements typically occur in six degrees of freedom (three translations and three rotations). Because of these movements and the direct loading of waves and currents onto a subsea equipment, evaluation of the static and dynamic behavior of a submerged system should be conducted very carefully, in order to avoid disruptions, damages which can lead to operational problems. Sometimes, it may result on fluid spill from the petroleum well with undesirable environmental impacts, as well as financial losses.

Furthermore, the occurrence of the VIV (Vortex induced vibration) in slender structures is important to be observed. This phenomenon occurs due to sea current passing through the pipe and the detachment of vortices around the pipe which provoke cyclical loads and vibrations of the pipe, and it can result on material fatigue.

In this scenario, computational tools for numerical simulation can greatly help in predicting the behavior of a riser against these external loads. Note that with such a well-adjusted tool it will be possible to determine the feasibility of using rigid risers in different situations, even before its application in the field and allowing anticipate malfunctions or accidents that may cause loss of life, material as well as possible damage into the environment.

This paper presents a silicone made vertical pipe model, stuck in the upper part to a forcing mechanism, and free at the bottom end. Experiments have been conducted with this pipe model immersed in a still water tank, and also in air. Numerical simulations have been conducted, and comparisons with experiment have been done to improve understanding of the dynamic behavior of a vertical pipe under hydrodynamic effects.

2 NUMERICAL SIMULATION

2.1 The Numerical Model

Simulations have been done by using Orcaflex© software that allow to model the pipe according to the lumped mass method (Orcaflex, 2014). The Figure 1 in below shows a scheme of the pipe model for simulation in the software, and one element of the model is highlighted in the scheme.

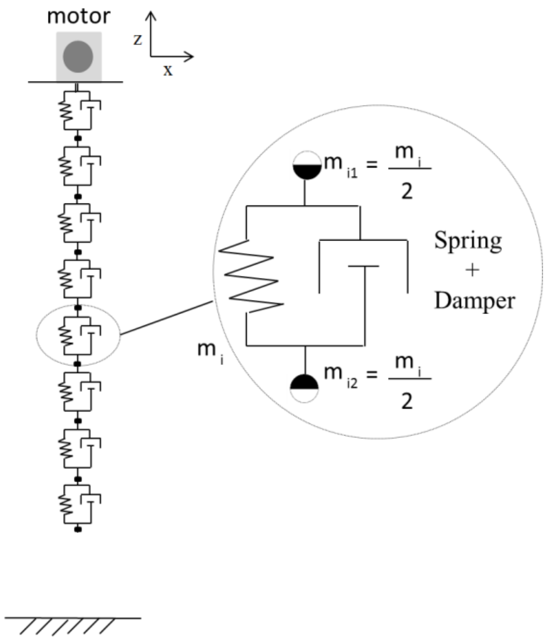


Figure 1. Pipe element within Lumped Mass Method

By the lumped mass method, the total mass of each element is equally divided and the half mass is concentrated into the each element extremities (nodes), respectively. The connection between two adjacent elements is made by springs and shock absorbers, whose function is to restrict transverse movements and rotations in the shared node.

In first step of the simulation, tension is calculated and oriented in space for the each mass element of the pipe. Then, the curvature is calculated, and the bending moment of each node which depends on the effective tension and the curvature are obtained. In following, shear strength and torsion are computed on each element. And finally, as the last step of calculation the equations of motion is assembled into the matrix form.

The implicit method was used for solution, despite the possibility to solve it explicitly. The implicit integration used is α-Generalized described by Chung & Hulbert (1993). Then, the equation of motion is solved at the end of each step.

Because the position and velocity are unknown in the end of the step, an iterative solution method is required. Consequently, each step implicit solution consumes significantly more computational time that an explicit step. However, the implicit method is more stable, and therefore is faster.

2.2 Dynamic analysis

Numerical analysis of the dynamic behavior of a pipe starts with the knowledge of the natural frequencies of the system by the static analysis. In the present simulations, natural frequencies are obtained from the modeling of a discrete system, and not from the continuous actual system. Usually, discrete systems are a good approximation, and get better when the number of discretized elements increases.

Results of the static analysis are used to find natural vibration modes. Undamped mass is attached to a spring in N degrees of freedom, forming the overall system.

The equation of motions for a mass spring system, with mass M and stiffness K, is solved by a harmonic proposal.

The eigenvalue problem with N solutions is solved. Each solution corresponds to a natural mode of the pipe vibration. Orcaflex© solves the eigenvalue problem by an iterative algorithm (Lanczos, 1950), which is fast and requires low computer memory space. For other cases, when n does not fit restrictions, the routine solves the problem by a direct method based on diagonalization of tridiagonal matrix.

3 THE EXPERIMENT

3.1 Laboratory Setup

Experiment has been conducted in the water tank in calm water. Figure 2 shows the sketch of the water tank and pipe used in the experiment. The tank is made in a steel structured frame with glass windows resistant to water pressure.

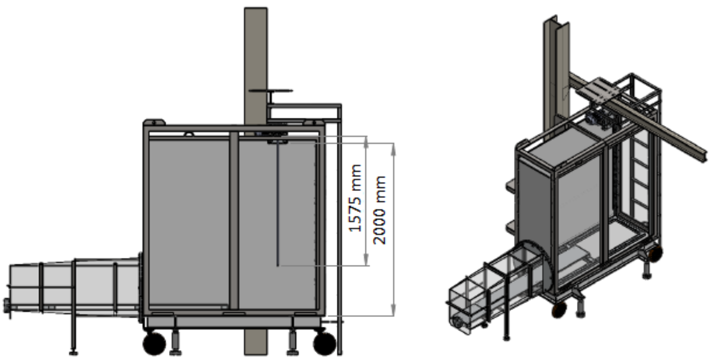
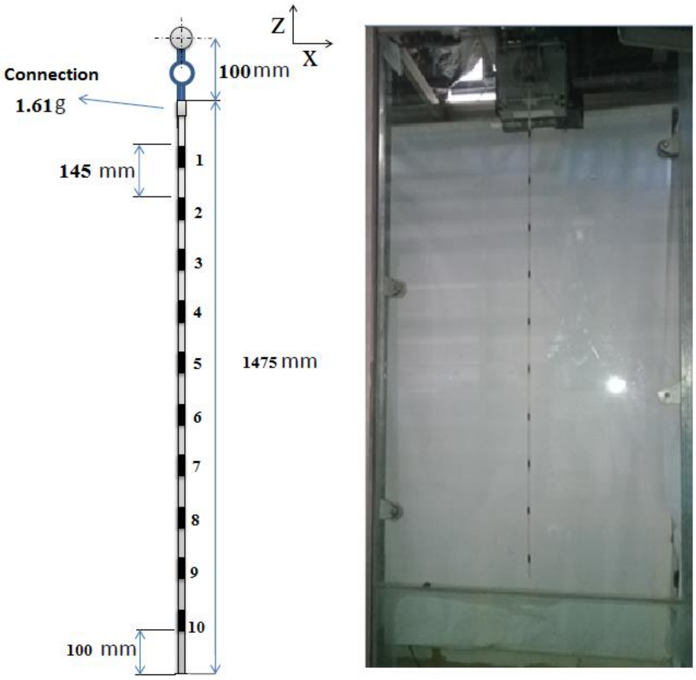


Figure 2. Experimental apparatus used: water tank and the end free pipe suspended.

Furthermore, preparation of the silicone pipe model was necessary for the camera to capture movements of the points of interest along the pipe length. Ten points were highlighted with a black tape along the pipe, equally spaced of 145 mm. As the pipe model is transparent, one can know the instantaneous position of each point after appropriate image processing. The Figure 3 in below shows a sketch of the pipe with highlighted points and a picture of its set up in the water tank. Each black point in the pipe received a number of 1 to 10, counting from the top to the bottom end. Two cameras for position measurements were fixed outside the water tank.



(a) (b)

Figure 3. (a) Scheme of the pipe and system coordinates. (b) A picture of the pipe with points of interest positioned inside the water tank.

The pipe is connected to a support of the moving mechanism at the top. In the present case, only x direction movement (one degree of freedom connection) is taken. The motor in the experimental set up is located 5 cm beyond the pipe connection, outside in air from the water surface. Two front cameras were placed at 1 meter away from the front glass of the tank to capture the whole pipe model movement.

The motion imposed into the pipe model was sinusoidal and in the horizontal direction (x direction) with the amplitude of 1 cm. Periods were chosen close to natural periods of vibration because in these cases larger movement amplitudes were expected.

The experiment was first made with the pipe in the air (water tank empty), and natural frequencies were measured. Then, experiment was repeated with water in the tank. In both tests, displacements for each point along the pipe model have been measured.

3.2 Pipe Model Characteristics

The pipe model used in the experiment has characteristics as in the Table 1.

To adjust the weight per length of the pipe, small weights were equally distributed along the pipe length with total mass of 7.48g. Each weight was placed within the pipe, in order to the fluid dynamic drag was not affected.

Table 1. Pipe model characteristics in the experiment

Length	1.575 m
Inner diameter	6.00E-03 m
Outer diameter	8.00E-03 m
linear mass (dry)	2.45E-02 kg/m
Density	1114.09 kg/m³
Modulus of elasticity	2.30 Mpa
Material	Silicone

4 RESULTS AND DISCUSSION

4.1 Natural Frequencies

Table 2 shows vibration frequencies for the lower natural modes of the pipe in air, obtained from both, experiment and numerical simulations. Frequencies from the experiment were obtained by using decrement logarithm approach. Higher the modes are larger differences are observed between experiment and numerical results. Observed deviations can be uncertainties coming from nominal material properties used for numerical simulations.

Table 2. Pipe natural frequencies [Hz] in air.

MODE	Numerical	Experimental	% Error
1	0.477	0.496	4.1%
2	1.108	1.167	5.4%
3	1.820	2.007	10.3%

4.2 Time domain responses

Figures 4 to 6 show time series of the pipe response (x horizontal direction) for three different locations along its length. Forced sinusoidal oscillation in x direction with period of 8.1 second has been considered. Numerical simulation is compared with the experiment for the points 2, 5 and 8 as previously shown in the Figure 3. The amplitudes of displacement have been normalized by the external diameter of the pipe (0.008m). Larger differences are observed for positions near to the bottom end.

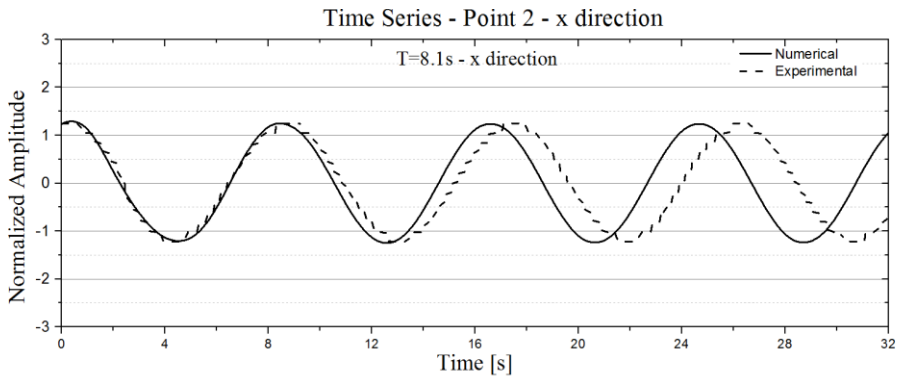


Figure 4. Time series of the response in x direction of the Point 2 with horizontal top oscillation.

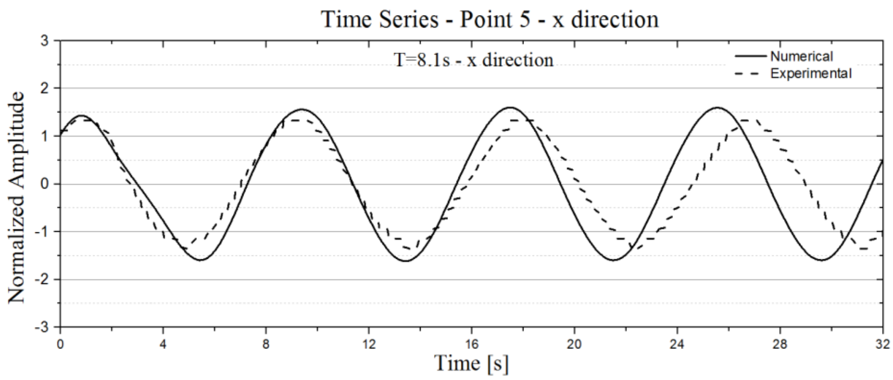


Figure 5. Time series of the response in x direction of the Point 5 with horizontal top oscillation.

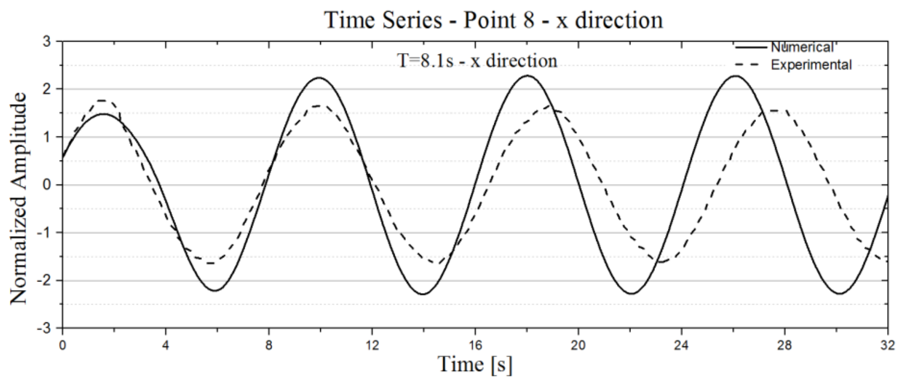


Figure 6. Time series of the response in x direction of the Point 8 with horizontal top oscillation.

In Figures 7 to 9, time series of the response in x direction with top excitation period of 3.5 seconds are shown. Numerical simulation results are compared with experimental ones. Similar tendency observed for the forced oscillation at the top with 8.1 seconds are also observed for these results. It was concluded for the experiment, material homogeneity of the model and its manufacturing process is very important to have stretch vertical pipe. Deviations on geometry of the pipe, especially along its length can induce fake displacements of the model when forced to vibrate.

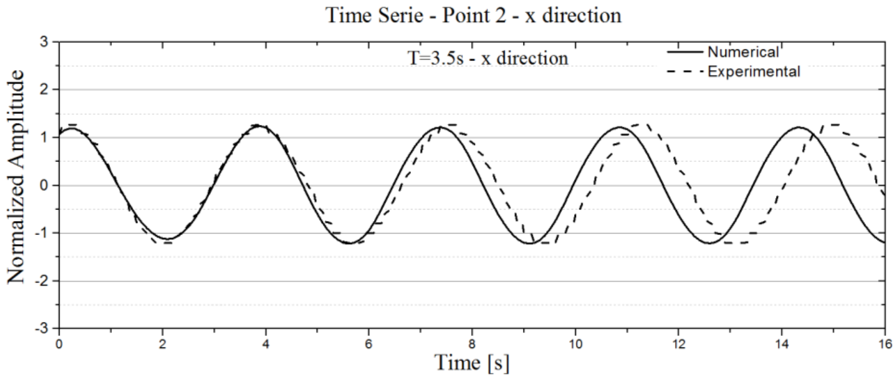


Figure 7. Time series of the response in x direction of the Point 2 with horizontal top oscillation.

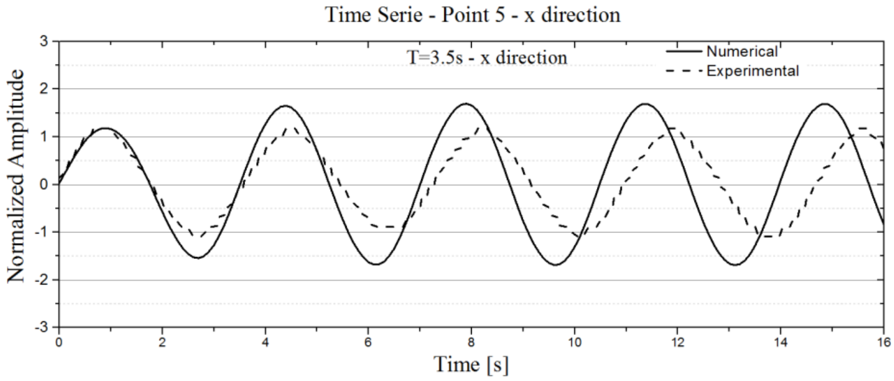


Figure 8. Time series of the response in x direction of the Point 5 with horizontal top oscillation.

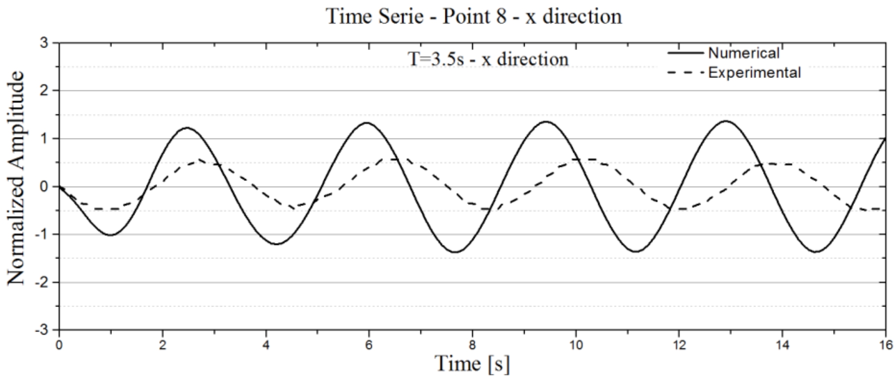


Figure 9. Time series of the response in x direction of the Point 8 with horizontal top oscillation.

4.3 Maximum and Minimum Amplitude Envelop for the Displacement

Figures 10 to 12 show the maximum amplitude envelop of lateral (x horizontal direction) for the pipe. Envelop of maximum and minimum amplitude of displacements from numerical simulations compared with experiment is shown for three different periods of forced oscillation. In general, numerical simulations follow the experimental result.

For the transverse direction to the top forced oscillation direction, significant displacements were observed from the experiment. However, almost no response was obtained from the numerical simulations. Further investigation will be conducted in future for vibrations of the pipe in the transverse direction, perpendicular to the forced oscillation direction.

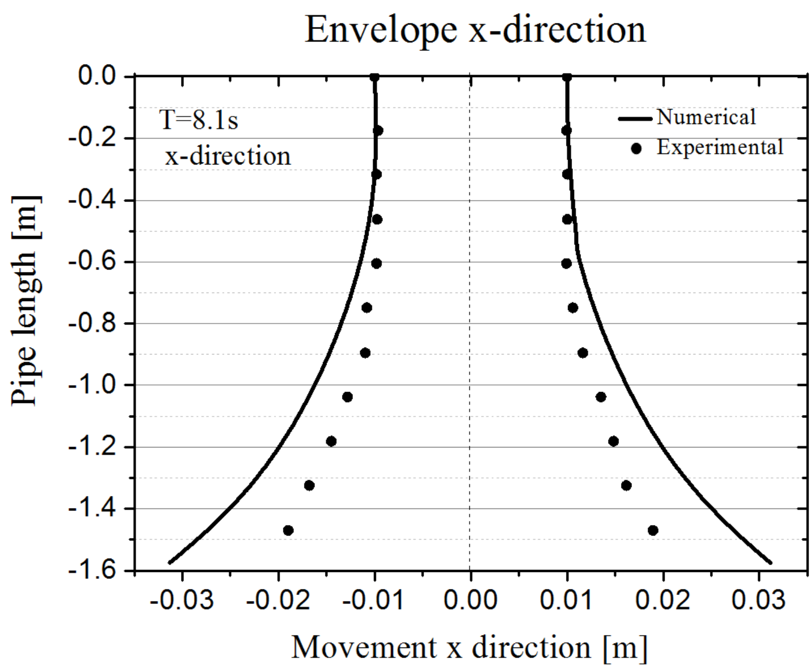


Figure 10. Envelope of minimum and maximum amplitude of displacements with pipe top oscillation (T=8.1s).

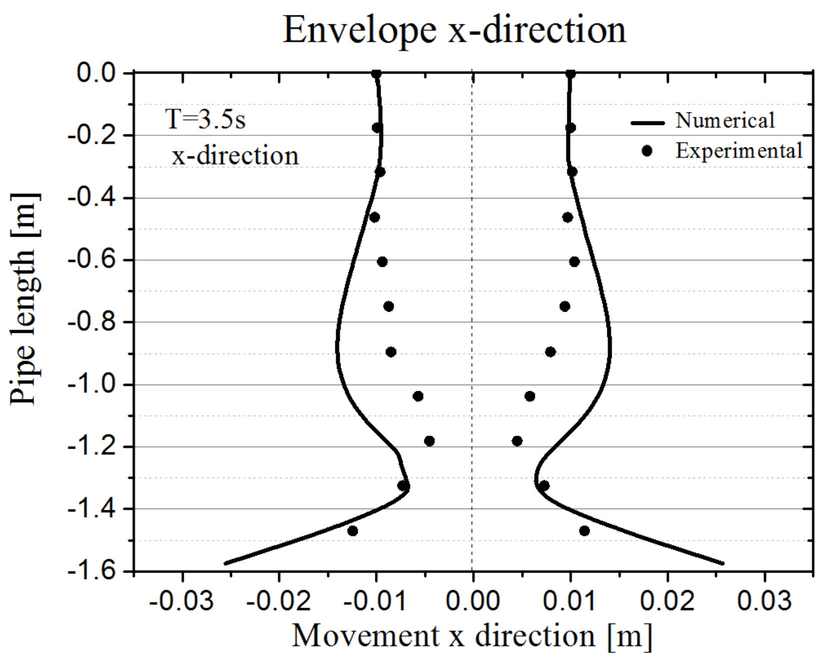


Figure 11. Envelope of minimum and maximum amplitude of displacements with pipe top oscillation (T=3.5s).

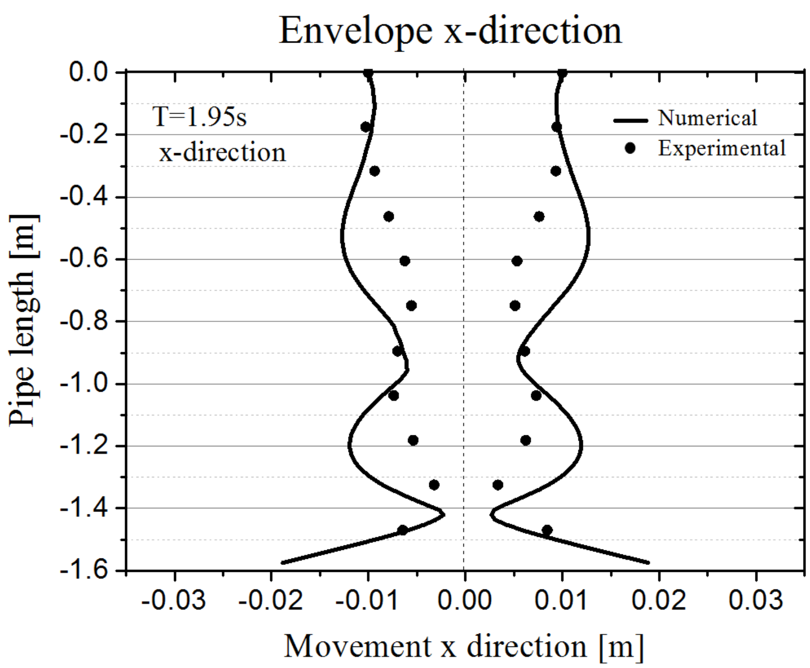


Figure 12. Envelope of minimum and maximum amplitude of displacements with pipe top oscillation (T=1.95s).

5 CONCLUSION

Experiment with a vertical pipe in a water tank including top forced oscillation device have been designed. Optical measurement fundamentals and image capturing system have been developed, and displacements along the pipe model were successfully obtained.

Difficulties on the experimental procedure and to manufacture pipe model as well as to set up experimental set up could be obtained. In future works, deviations between design and actual experiment will be deeply investigated and improvement added, particularly regarding the manufacture of the pipe model.

From the present work it is concluded that numerical simulation model is succeeded, and these results followed in a good manner experimental ones. Envelop of maximum and minimum amplitude of displacements successfully from numerical simulations followed very well the experimental results, as well as reproduced the shape of the amplitude responses.

ACKNOWLEDGEMENTS

We would like to acknowledge the Unicamp, CNPq and “Frade Japão Petróleo Limitada” (FJPL – a joint venture established by INPEX Corporation and Sojitz Corporation) for the support of the present academic research.

REFERENCES

Chakrabarti, S. K., 1987. *Hydrodynamics of Offshore Structures,* WIT Press.

Chung, J., Hulbert, G. M., 1993. *A time integration algorithm for structural dynamics with improved numerical dissipation: the generalized-α method*, J. Appl. Mech. 60: 371-375.

Franciss, R., 1999. *Vortex induced vibration in slender structures of offshore vessels*, PhD thesis, Universidade Federal do Rio de Janeiro/Rio de Janeiro.

Lanczos, C., 1950. *An iteration method for the solution of the eigenvalue problem of linear differential and integral operators*, J. Res. Nat. Bur. Standards 45: 255-282.

Orcina, 2014. *Orcaflex documentation*, available in: http://www.orcina.com/SoftwareProducts/OrcaFlex/Documentation/OrcFxAPIHelp.