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EXPERIMENTAL SET UP TO STUDY THE OSCILLATION INDUCED BY TWO-PHASE FLOW IN SMALL SCALE MODELS OF PRODUCTION RISERS FOR OFFSHORE PETROLEUM FIELDS

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Abstract. *Nowadays, the major oil and gas production in Brazil comes from offshore fields under very deep waters. In this scenario, the riser is a component of paramount importance in the production system. The riser is a suspended pipeline through which oil and gas flow from the production system at the bottom of the sea to the floating production unit at the surface of the sea. Risers are subject to different types of loadings, both internal and external, which have an impact on the integrity of these suspended pipelines. The objective of the present work is to develop an experimental apparatus to study the effect of internal two-phase flow on the oscillatory movement of these risers. The apparatus consists of a small scale water tank, where a flexible pipe is submerged while water and air are pumped through it, simulating oil and gas with various combinations of flow rates. The pipe movement caused by the internal flow is captured by video cameras, and the frames' pictures are processed by an image treatment computer program to gather position data as a function of time. Therefore the displacement amplitude and frequency are obtained. Tests can be run with the piper under water or in the air, for comparison to discriminate the effect of the surrounding media, which will be useful for the developer of computer models aimed at the simulation of the risers.*

Keywords: *petroleum production, offshore risers, multiphase flow, slug flow.*

1. INTRODUCTION

The constant search for oil and gas reserves under deep water regions has become a fact, especially in Brazil, with the discovery of oil in pre-salt zones. For those offshore fields, risers are extremely important equipments of production, also presenting large costs. These risers are slender pipelines, through which the petroleum fluids flow from the submarine pipelines connected to the wellhead, at the bottom of the sea, up to a floating production unit at the sea level. These risers are subjected daily to several cyclical loads, hence, subjected to constant vibrations. The evaluation of the forces acting on the risers is essential to the questions regarding the structural integrity and stability of these risers.

The internal two-phase flow of oil and gas also excites the risers, but there is a lack of information on this subject. In order to overcome this gap, the present study is proposed. With this goal in sight, an experimental apparatus of small scale was set up, to simulate the flow conditions on a suspended pipe. The oscillatory movements due to the internal flow are observed by cameras and the pipe displacement is obtained by treatment by an image processing program, thus, providing the amplitude and frequency of the movement.

As a result, substantial displacement oscillations have been observed for the slug flow regime. It is proposed that this outcome is due to the variation of weight of the two-phase mixture and to the changing of momentum direction caused by the curvature of the trajectory, since the riser assumes a catenary shape when suspended.

2. LITERATURE REVIEW

Basically, production risers may be rigid, flexible or hybrid. Flexible risers are tubes constructed in multilayer, which confer good stiffness to different loadings, as well as good compliance to platform movements. They are more expensive than the rigid ones. The multilayer risers show the restriction of not operating on aggressive environment, such as high temperature and high acidity. Rigid risers are basically steel pipes. The hybrid has both characteristics of rigid and flexible, some of these with sophisticated materials such as titanium. (Bai, 2001)

According to Carter & Ronalds (1998), the use of rigid risers in deep waters is a feasible alternative, inasmuch as in these conditions the heave-depth ratio is less pronounced, not requiring large complacence; besides, rigid risers are safer against aggressive conditions and cheaper than the other types of risers.

The riser selection, according to DNV (2003) should consider water depth, flow assurance, surface and subsurface facilities and lift methods. According to Bai (2001) there are several risers geometries: free hanging catenary, lazy wave, steep wave, lazy-S, among others, such as show in Figure 1.

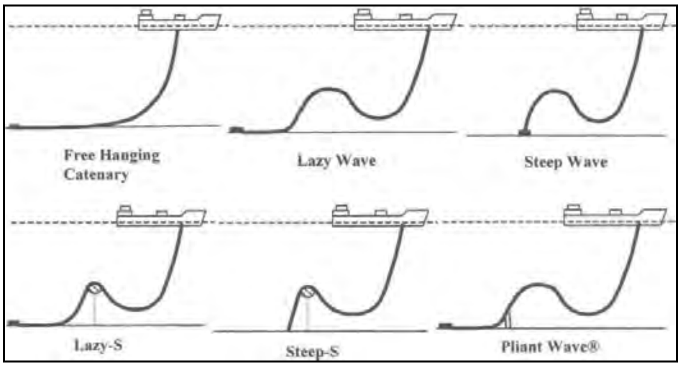

Figure 1. Riser configurations – extracted from Bai & Bai (2005).

The free hanging catenary is the simpler type of risers, widely used in deep waters; it doesn't need heave compensators. An important point on this configuration is the TDP, touchdown point, where the riser touches the soil of the seabed. The riser moves as a function of the forces exerted on it; its body can be lifted or lowered, modifying the TDP and creating a TDP zone. Due to the fact that all movements are directly transferred to TDP, this point is notably the most stressed, therefore, more likely to fail. Figure 2 shows a scheme of a rigid riser and the TDP.

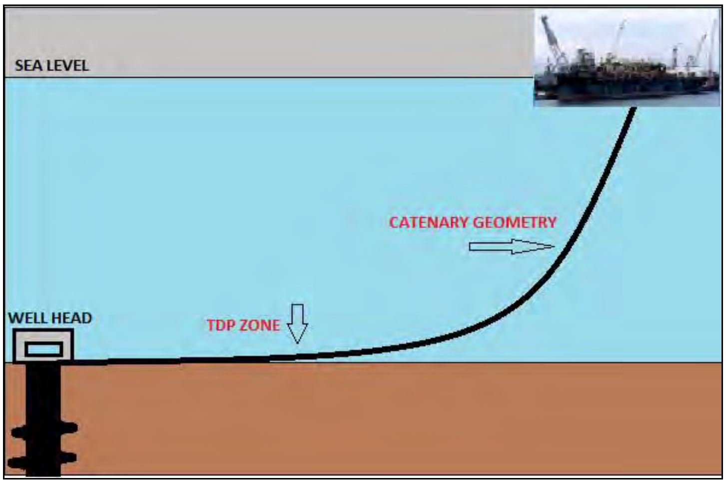

Figure 2. Rigid catenary riser configuration.

According to API (1998), these risers are subjected to various loads – due to sea currents, wave movement, top displacement and the internal flow. During production, water, oil and gas flow from the well, so multiphase flow of several flow regimes may occur. The flow regime inside the pipe depends on the flow rates of the phases and on the geometry of the pipe. A classical flow regime in production risers is the slug pattern. According to Shoham (2005) and Brill & Beggs (1991), the slug is characterized by intermittence as depicted in Figure 3.

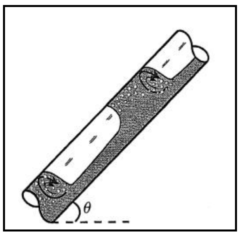

Figure 3. Slug in inclined pipe.

Due to different angles of inclination, different flow regimes are possible. For horizontal stretches, the Beggs & Brill (1973) modeling, a priori designed for inclined pipes, may be applied. The characterization of flow regimes obtained from Beggs & Brill is shown on the Figure 4.

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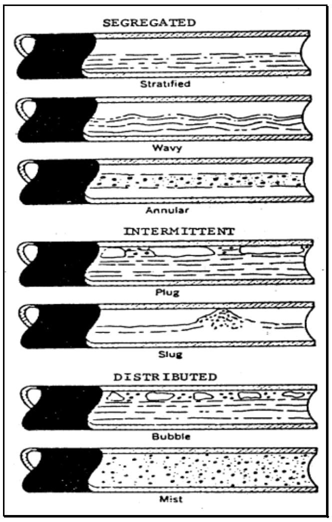

Figure 4. Phase arrangement by Beggs & Brill (1973)

Taitel et al (1980) proposed physical models for the transition of each flow regime in vertical tubes. On these models, the flow patterns considered, for the transition, are bubble, slug, churn and anular. The phase arrangement by Taitel et al (1980) is shown on the Figure 5.a. The authors determined the phase regions, based on surface phase velocities, as shown on the Figure 5.b.

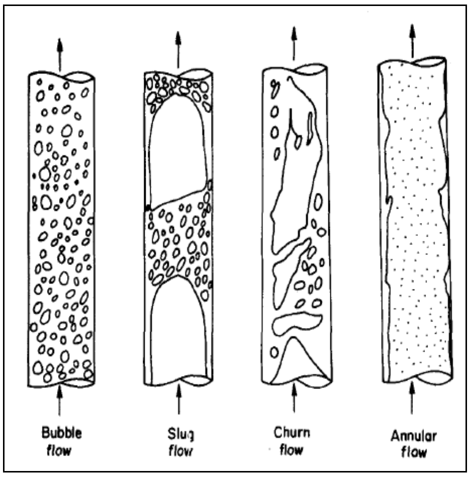

Figure 5.a. Phase arrangement by Taitel et al (1980)

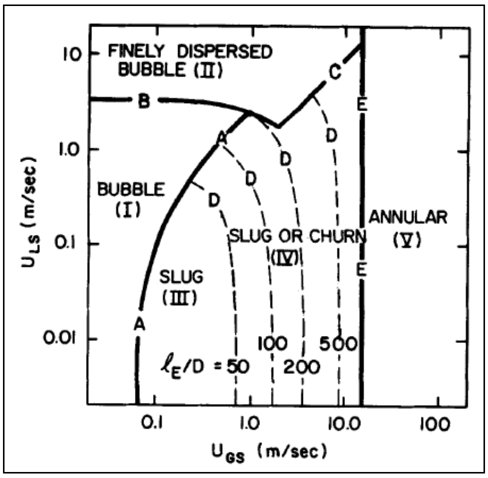

Figure 5.b. Phase regions by Taitel et al (1980)

Barnea et al (1985) checked the model applicability of Taitel et al (1980) in two pipes of different diameters. The results obtained shown good agreement with the theory proposed by Taitel et al (1980).

Using a numerical procedure, Patel & Seyed (1989) studied the effect of the pressure gradient and flow regime on the dynamic and static behavior of flexible risers. They considered the effect of hydrostatic pressure and the momentum effect, both influenced by the pipe curvature. One of their conclusions was that the flow may induce the pipe into tension variation, introducing cyclic effects, contributing to the fatigue.

Bordalo et al (2008) studied the oscillatory effect caused by the internal flow in suspended catenary pipes in air. Considerable magnitude of displacement oscillations took place on slug and churn patterns, very little on bubble and annular patterns, and none for pure liquid and pure gas flows. According to the authors, this was due to the great intermittency of the slug and churn regimes.

Valdívia (2008) computed the oscillatory effect caused by the internal flow in small scale catenary risers in air. Large amplitudes took place on slug and churn regimes. The author verified that it happened on regions near the natural frequency of the pipe configuration.

The objective of this work is to follow up on the work of Bordalo (2008) and Valdivia (2008), but now considering the effect of the internal flow in pipes **submerged in water**.

3. EXPERIMENTAL PROCEDURE

The experimental apparatus consists of a water tank, with glass panels, flexible test pipes, air compressor and water pump, valve and flow meters for water and air, fluids mixer, camera system, image treatment and data processing software.

The test tank simulates the submarine surroundings without currents or waves. The tank's glass walls allow visualization of the movement of the flexible pipe. In order to observe the oscillation in air and water, experiments were done in air and water. Considering the slug flow regime, the two phases (air and water) were adjusted by flow meters, before injecting them into a fluid mixer.

The water tank and its dimensions are shown in Figure 6 and Table 1, respectively.

Figure 6. Water tank

Table 1. Water tank dimensions

Height (m)	2,30
Length (m)	2,10
Width (m)	0,60

A section of the test pipe used is shown in Figure 7 and its characteristics are in Table 2.

Figure 7: Silicone test pipe

Table 2. Pipe characteristics

Material	silicone
Catenary length (m)	2,8
Vertical projection (m)	2,3
Horizontal projection (m)	2,0
Outer diameter (mm)	25,0
Inner diameter (mm)	19,0

The centrifugal pump requires 1,5 CV and its maximum flow rate is 15 m^3/h, while the air compressor requires 50 CV and has a maximum operational pressure of 960 kPa. The water flow meter system consists on two different devices, one for high and another for low flow rate. Its characteristics are shown on Table 3, together with the characteristics of the air flow meter.

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Table 3. Main characteristics of flow meters

Flow rate of water flow meter (high flow) (m^3/h)	0,048 – 0,480
Flow rate of water flow meter (low flow) (m^3/h)	0,216 – 2,160
Flow rate of gas flow meter (m^3/h)	0,060 – 4,020

The fluid mixer is show in Figure 8.

Figure 08. Fluids mixer

A target was set up on the pipe outer surface (Figure 9), which was filmed, and its movement was recorded and latter treated by an image processing software. Its displacements were evaluated by the location of the geometric center on the Y direction, CGY, and by location of the geometric center on the X direction, as shown in Figure 9.

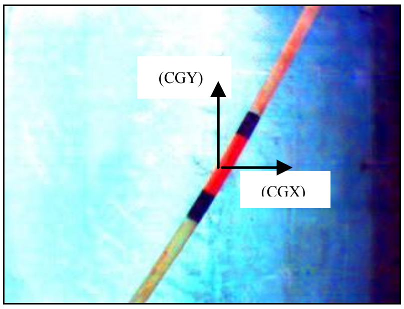

Figure 9. Pipe with a target (red strip).

Cameras positioned in front of the pipe captured its movement. The generated frames were stored, and after treatment provided values of displacement, frequency and amplitude of oscillations. The program used to acquire and treat the frames was LABVIEW. Figure 10.a shows the camera, while Figure 10.b shows the capture and treatment data system.

Figure 10.a. A camera

Figure 10.b. Acquisition data system

The main characteristics of camera are shown on Table 4.

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Table 4: Main characteristics of the camera

Resolution	640 x 480 (VGA) 352 x 288 (CIF)
Acquisition rate	10 – 15 frames/s (VGA) 20 – 30 frames/s (CIF)
Image type	RGB 24

The frames are, initially, treated by a Labview device, Vision. In order to treat the frames, they are eroded, dilated and removed of small objects. The signals treatment uses FFT (Fast Fourier Transform), on LabView, which converts time data into frequency data, which gives an overview of the energy distribution over the frequency range of interest.

4. RESULTS AND DISCUSSIONS

The main parameters governing the process are the geometry (pipe diameter and length, plus the catenary shape), the fluid's properties, and the liquid and gas flow rates. In the experiment, the fluids are water and air, and the geometry is kept fixed. Therefore, the controlled variables are just the flow rates. The dependent variables are the displacement frequency and amplitude of the pipe body, which are obtained by the video processing system, which provides the coordinates of the pipe against time.

During the development of the apparatus only one video target was employed; but once the learning stage is over, more targets will be set up along the pipe body.

The following are the very first exploratory results of the workings of the experimental apparatus. The results from experiments developed with the pipe in air and water are shown on the Figures 11, 12, 13 and 14. The comparisons must be qualitative only, since the flow meters were still not ready and calibrated. The set up for water was kept constant by a fixed setting of the feed valve, while only two air flow states (low and high) were provided by fixed settings of the air choke valve.

The displacements are standardized by pipe diameter. Figures 11 and 12 show that larger displacements occurred with the increase of the air flow rate, with the pipe in air. When increasing the air flow rate, the mixture velocity also increased, thus, increasing the momentum; this leads to higher forces, therefore increasing the oscillatory displacement. This is consistent with the previous work of Bordalo (2008) and Valdivia (2008), which was also performed in air, but in a somewhat larger scale (six times larger).

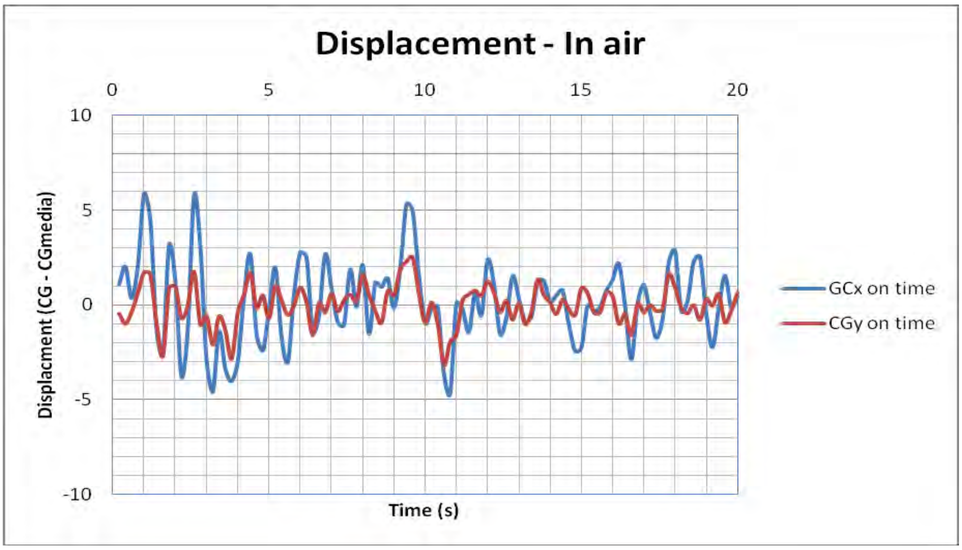

Figure 11. Experiments with pipe in air – low air rate

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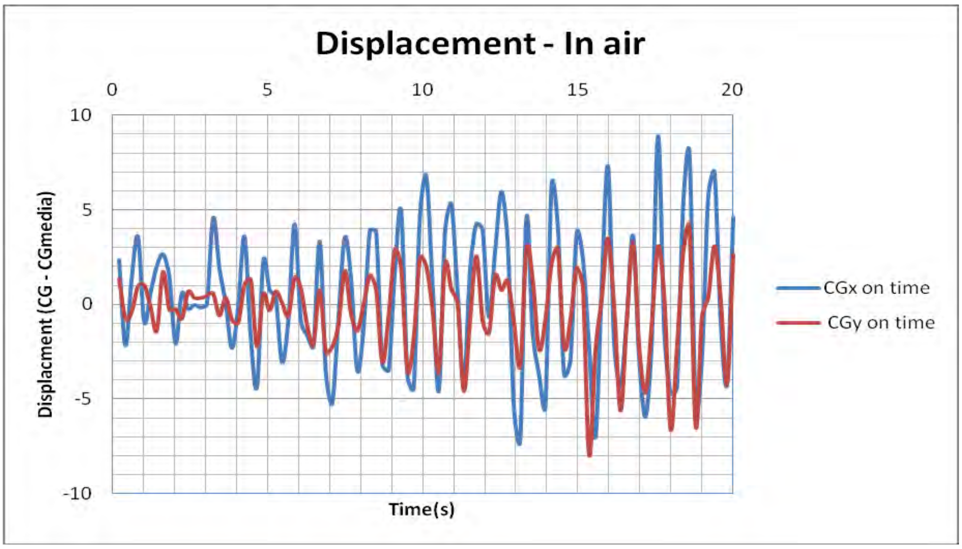

Figure 12. Experiments with pipe in air – high air rate

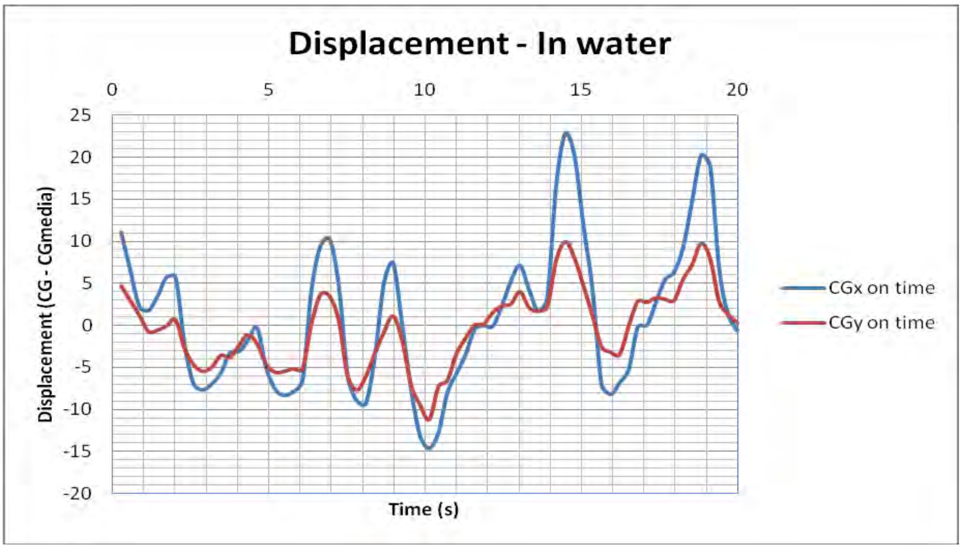

Figure 13. Experiments with pipe in water – low air rate

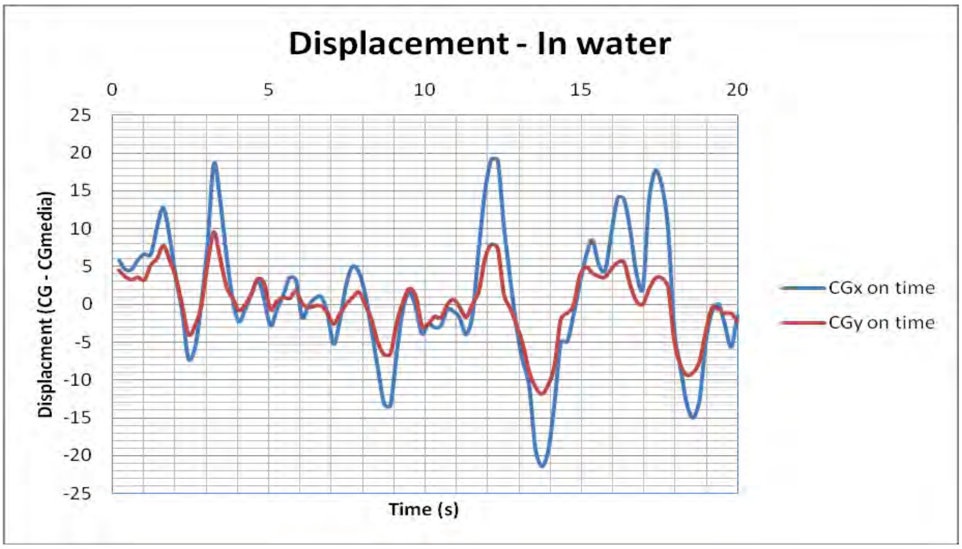

Figure 14. Experiments with pipe in water – high air rate

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The observed effect of the immersion in water was lower frequencies, as shown in Figure 13 and Figure 14, probably due to the added inertial mass of the surrounding media. Although lower displacements may be expected due to the higher dissipation of energy in water, as compared to air (Figure 11 and Figure 12), the present experiment was compromised by high buoyancy forces which interfered with the movement caused by the internal flow. This effect will be compensated in the next experiments with the employment of pipes with much less floating or with negative floating.

The frequency spectrum, for oscillations in air is shown on Figures 15 and 16, where peak frequency was observed close to 1,2 Hz; from Figures 17 and 18, the peak frequency under water is near 0,2-0,4 Hz.

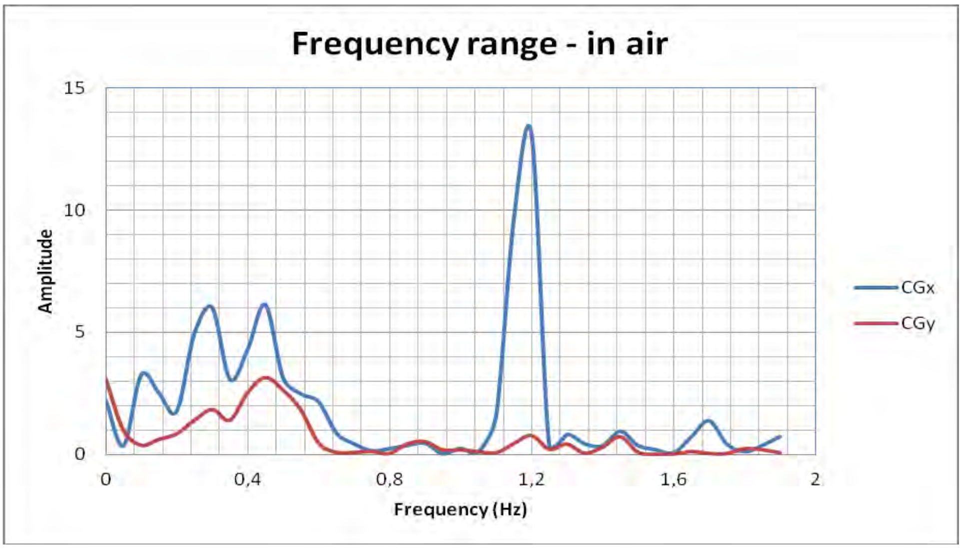

Figure 15. FFT Experiment with pipe in air – low air rate

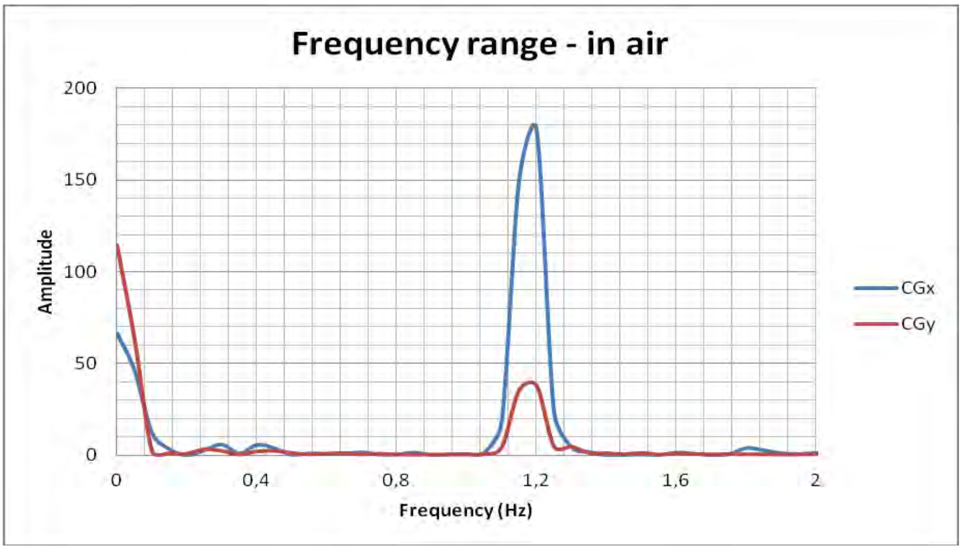

Figure 16. FFT Experiment with pipe in air – high air rate

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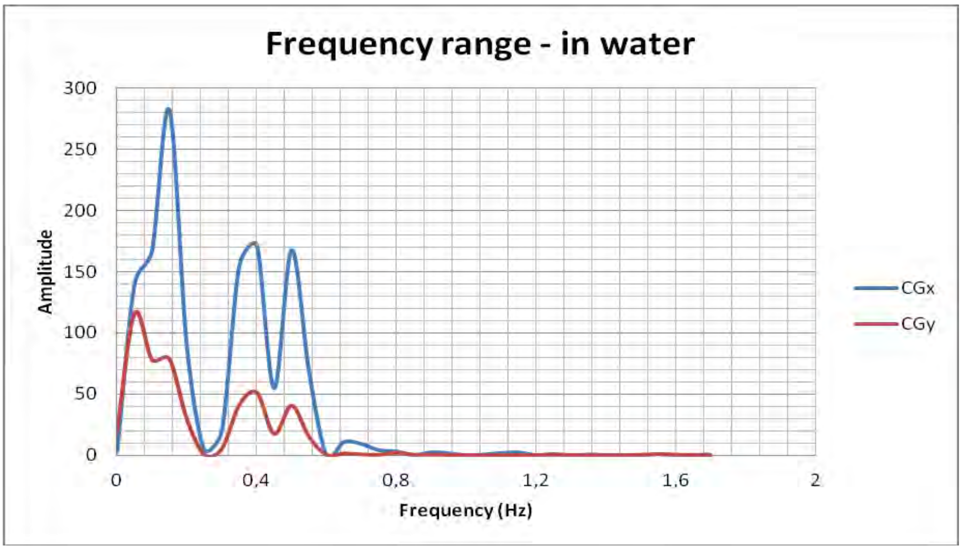

Figure 17. FFT Experiment with pipe in water – low air rate

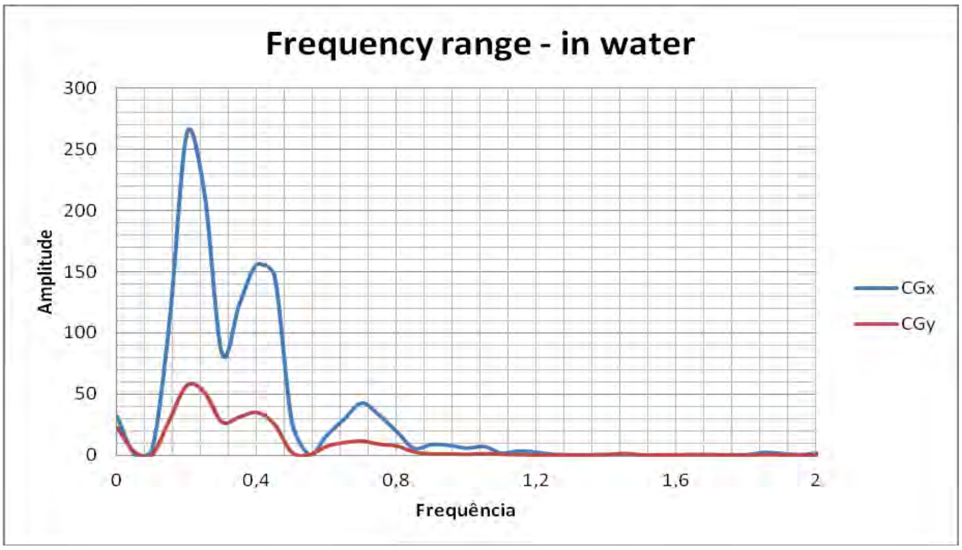

Figure 18. FFT Experiment with pipe in water – high air rate

5. CONCLUSIONS

Exploratory experiments were started in order to visualize the effect of the internal flow on the oscillatory movements of petroleum risers. In order to accomplish this task, an experimental apparatus was developed, using a water tank and an image acquisition and processing for video recordings. The pattern studied was the slug flow regime. At this time, the very first results were aimed at developing the non-intrusive method of measuring the pipe displacement with video cameras, and flow measurement devices were still not available. In this situation, it was observed, **qualitatively**, that the increase of air flow induces an increase on the displacement amplitude, which was observed clearly in air, but was obfuscated by buoyancy of the pipe in water. When the pipe was submerged in water, lower oscillation frequencies were observed, probably due to the added mass effect.

For the next steps of this experimental work, a broad range of combinations of flow rates of water and air will be examined with the aid of flow measuring devices. Also, we will attempt to cancel out the buoyancy effect by changing the test pipe. In the meantime, a numerical model is under study to simulate the response of the riser to the intermittent internal flow of liquid and gas.

6. ACKNOWLEDGEMENTS

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