Experimental Evaluation of Riser Dynamics and Comparison with Numerical Results

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Abstract: *In this work an experimental procedure for evaluating the dynamics of rigid (steel-catenary) and flexible risers is proposed. The small-scale analysis takes into account harmonic oscillations of the riser top and the effect of steady current. Tests were conducted at the IPT (The Institute for Technological Research of the State of São Paulo) towing tank. Riser tension was measured at the top for different combinations of amplitude and frequency of oscillation. Some very high values of amplitude were tested in order to make evident the dynamic compression phenomenon. Experimental results were compared to those obtained by numerical codes. A good agreement was obtained, in general, indicating that the numerical analysis is able to cope well with the dynamic compression phenomenon. Such validation is important for reassuring the reliability of numerical simulations of complex offshore systems, such as those performed at the University of São Paulo Numerical Offshore Tank.*

Keywords: *risers, dynamic compression, tension amplitude, experimental setup, towing-tank tests.*

1. Introduction

As offshore production moves to deeper waters, reliable assessment of riser dynamics becomes more and more critical in the evaluation of different design alternatives. Although a crucial issue in up-to-date offshore design, little experimental information exists in literature concerning dynamic compression of rigid and flexible risers. The main intent of this work is to provide some experimental results on the dynamic compression of two very different models, which will be used as a means of validation for the numerical codes of the recently implemented *Numerical Offshore Tank (NOT)* of the University of São Paulo, see Nishimoto *et al.* (2003). For that reason, models were not dimensioned with the objective to reproduce full-scale geometries, but care was taken in order to preserve the main dynamic characteristics of real risers. Also, very intense excitation was imposed to guarantee high levels of dynamic compression along the models, even at the top, where tension was measured. With the same spirit, high current velocities were tested, aiming to maximize its effects on the riser dynamics and, therefore, allow a more clear evaluation of the numerical assessment of such effects.

Experiments were conducted at the IPT towing tank facility by means of two small-scale models with very different rigidities, aiming to emulate a steel-catenary (SCR) and a flexible riser dynamic behavior. Harmonic circular motion was imposed at the top with various combinations of amplitude and frequency. Current effects were emulated by towing the model along the tank with different velocities and with two incidence conditions, both at the same plane of the catenary. Tension was measured at the top of each model by means of a load cell. Experimental setup and models are described in details in section 2.

A preliminary confrontation of experimental and numerical results was conducted using the commercial software *Orcaflex*, aiming to verify the general adherence of tension results and the numerical behavior under dynamic compression. The comparison here presented, however, is not extensive and a more complete analysis shall be made with the numerical codes implemented at the *NOT* and published in the future. Nevertheless, the preliminary results showed, in general, a very good agreement between numerical and experimental results, even in the most extreme cases of dynamic compression evaluated, when tri-dimensional dynamics of the flexible model was quite evident.

Section 3 summarizes the experimental results obtained. Comparison with numerical results is presented in section 4, and section 5 presents the main conclusions derived from the analysis.

2. The Experimental Setup

The experimental setup employed in the dynamic compression tests consisted of a mechanism capable of imposing circular motion to the top of the riser model, with constant angular velocity. Both, the amplitude and the frequency of oscillation could be varied continuously. Such mechanism was mounted on the carriage. The anchor point was mounted on a separate structure, which was coupled and driven by the carriage, so the whole line could be towed along the tank, in both directions, emulating uniform current profiles. The submergence of the anchor point was 3.0m and the vertical distance between the anchor and the top 3.36m. A schematic representation of the setup is presented in Fig. (1), below.

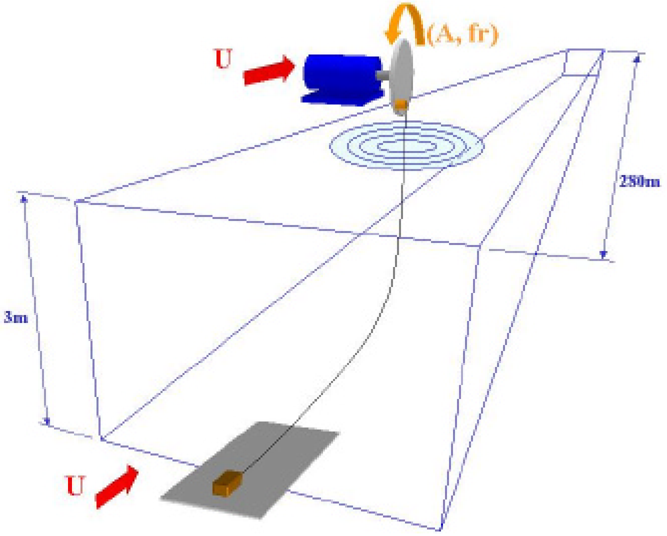


Figure 1. Schematic Representation of the Experimental Setup.

The top of the model was coupled to the oscillating mechanism by means of a standard load cell. Top tension measurements were taken for different combinations of amplitude (A, varying from 0.050m to 0.150m) and frequency (fr, varying from 0.75Hz to 1.50Hz) of oscillation. Carriage (current) velocity was varied from U=0m/s to U=±0.2m/s (+ indicates direction as in Fig. (1)).

The dynamics of a SCR was emulated by means of a small-scale model consisting of a circular steel rod. A much more flexible model was constructed with a concentric arrangement of a steel stripe and an external circular rubber coat. The axial and flexural rigidities of the flexible model were provided by the steel stripe, the rubber coat being applied mainly for hydrodynamic purposes. Also, the use of a stripe aimed to guarantee a much higher rigidity for out-of-plane oscillations. Schematic representations of the models are presented in Fig. (2) and the main characteristics of each model given in Tab. (1).

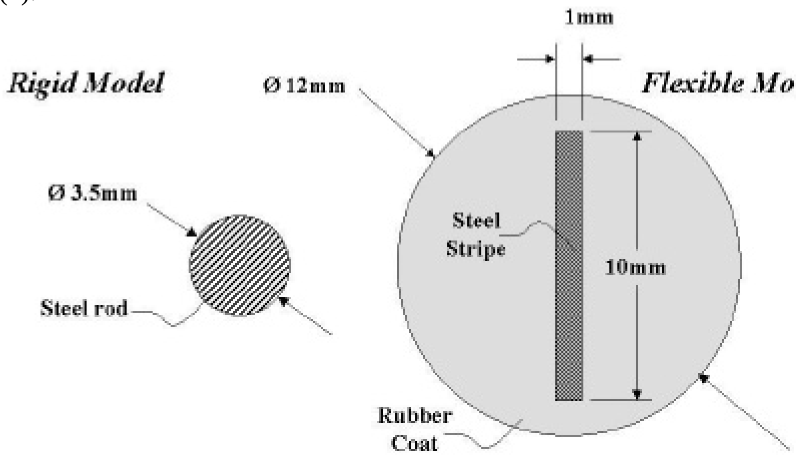


Figure 2. Schematic Representation of Rigid and Flexible Models.

Table 1. Main Characteristics of Rigid and Flexible Models.

Parameters	***Rigid Model***	***Flexible Model***
D_{ext} (mm)	3.50	12.0
L_T (m)	8.85	8.0
h (m)	3.0	3.0
R (m)	7.20	7.0
H (m)	3.36	3.36
EA_{eq} (kN)	2020.4	265.25

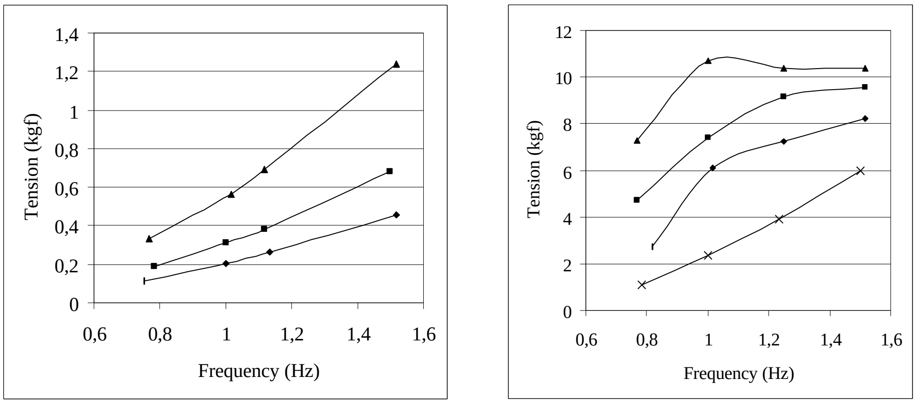
Where:

D_{ext}	External diameter.
L_T	Total length.
h	Water depth.
R	Horizontal distance anchor-top.
H	Vertical distance anchor-top.
EA_{eq}	Equivalent axial stiffness.

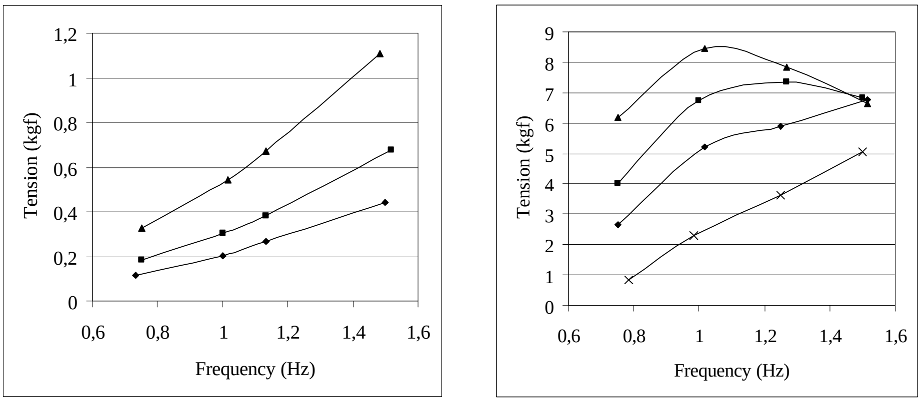
EJ_{eq} (kN.m^2)	1.5469E-3	2.6384E-4	EJ_{eq}	Equivalent flexural stiffness.
q (N/m)	0.736	2.193	q	Weight per unit of length.
θ_{TOP} (degree)	71	47.8	θ_{TOP}	Angle on the top (neutral position).
U (m/s)	0, ±0.20	0, ±0.20	V	Current velocity.
A (m)	0.075, 0.100, 0.150	0.050, 0.075, 0.100, 0.150	A	Amplitude of the motion (circular).
fr (Hz)	0.750, 1.000, 1.125, 1.500	0.750, 1.000, 1.250, 1.500	fr	Imposed frequency.

3. Top Tension Experimental Results

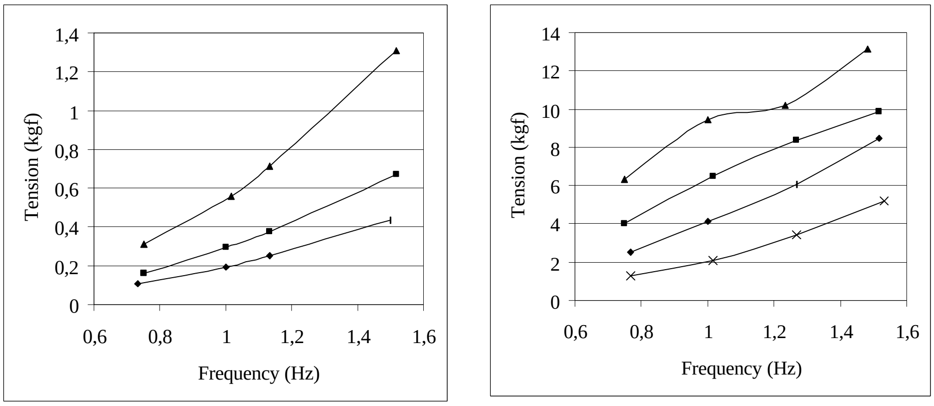
Figure (3) summarizes the mean values of maximum top tension measured on each model for different combinations of amplitude and frequency of the imposed circular motion and also for different current conditions.



(a) *U=0m/s* (d) *U=0m/s*



(b) *U=+0.2m/s* (e) *U=+0.2m/s*



(c) *U=-0.2m/s* (f) *U=-0.2m/s*

Figure 3. Experimental Top Tension Results on Rigid (a,b,c) and Flexible (d,e,f) Models: (▲) A=0.150m, (■) A=0.100m, (◆) A=0.075m and (x) A=0.050m.

In most experimental results presented in Fig. (3), dynamic compression occurred on the models (for more details on dynamic compression results, see section 4). Even though, the results for the SCR model (Fig. (3)a,b,c) showed that top tension increased monotonically with the frequency and amplitude of oscillation, as predicted by theoretical models (e.g., Aranha and Pinto (2001)). Results for the flexible model (Fig. (3)d,e,f), however, presented a somewhat distinct pattern. For the flexible model under severe dynamic compression, out-of-plane oscillations were clearly observed during the tests. The tri-dimensional oscillation of the model seems to be connected to the inflexion points that may be observed in the tension results, especially for the higher values of amplitude and frequency of imposed circular motion. Also, it might be observed that this pattern is influenced by current effects. Fig. (3)f presents the flexible model results with U=-0.2m/s, when static tension on the line was increased due to current effects and, therefore, monotonic increase of tension persists for higher values of A and fr, if compared to Fig. (3)d,e.

4. Discussion on Dynamic Compression and Comparison with Numerical Results

Dynamic compression is more accentuated near the touch-down point (TDP) of the riser, since, at this point, static tension is reduced by the effect of the suspended weight of the line. Although no tension measurements were taken near the TDP, the effects of dynamic compression became evident during the tests with the flexible model. Figure (4) shows a photograph of the TDP region of the flexible model during one of the tests. One could easily visualize a compression wave that was generated near the TDP and then propagated along the line, towards the top end.

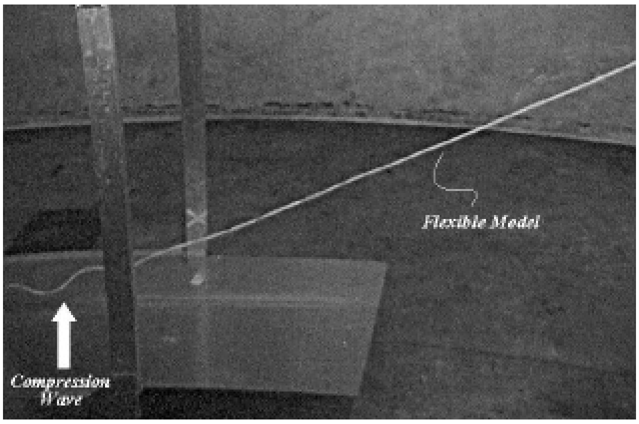


Figure 4. Dynamic Compression at TDP of the small-scale flexible model.

Figure (5) presents an excerpt of time-series of top tension measured on the flexible model for A=0.100m; fr=1.0Hz; U=0m/s. It may be readily seen that dynamic compression occurred even on the top of the model, what can be inferred by the saturation of the signal at a critical negative (compression) load.

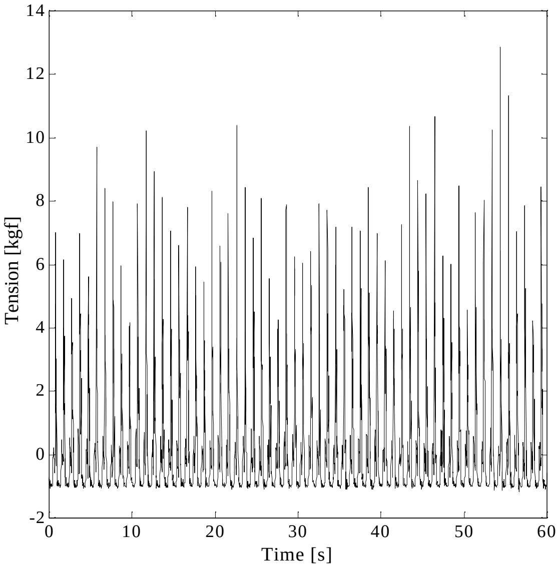


Figure 5. Excerpt of Time-Series of Tension Measured at the Top of the Flexible Model. A=0.100m; fr=1.0Hz; U=0m/s.

A direct comparison of the experimental signal of Fig. (5) with the tension time-series obtained numerically with the software *Orcaflex* is presented by Fig. (6), below.

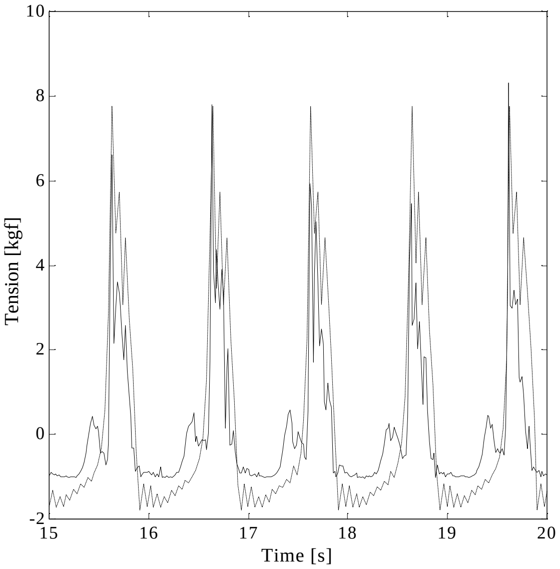


Figure 6. Comparison of Experimental and Numerical Time-Series. Flexible Model. A=0.100m; fr=1.0Hz; U=0m/s.

Although some discrepancy is observed concerning the critical compression load, maximum values of the tension are very well reproduced, as indicated in Fig. (6), above.

Another interesting feature of the time-series of the dynamically compressed flexible model deserves attention. In extreme cases of dynamic compression, numerical results sometimes present a spike or, in other words, a compression load below the critical value in the beginning of the compression cycle, for a short period of time (see, e.g, Aranha and Pinto (2001)). This behavior has sometimes been regarded as numerical imprecision related to a poor discretization of the structure. As shown by Aranha and Pinto (2001) such spikes in the numerical results depend strongly on the size of the elements in the finite elements mesh. Figure (7), below, presents an excerpt of the time-series of top tension measured on the flexible model, for the highest amplitude of top motion (A=0.150m) and for the highest frequency (fr=1.50Hz) of excitation. It can be seen that the spikes are present in the experimental results, reaching negative loads lower than the critical load and, therefore, represent a real structural effect associated with the dynamic compression phenomenon.

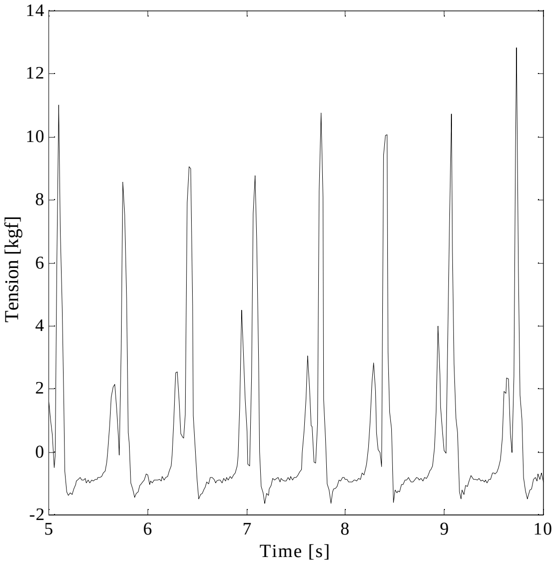
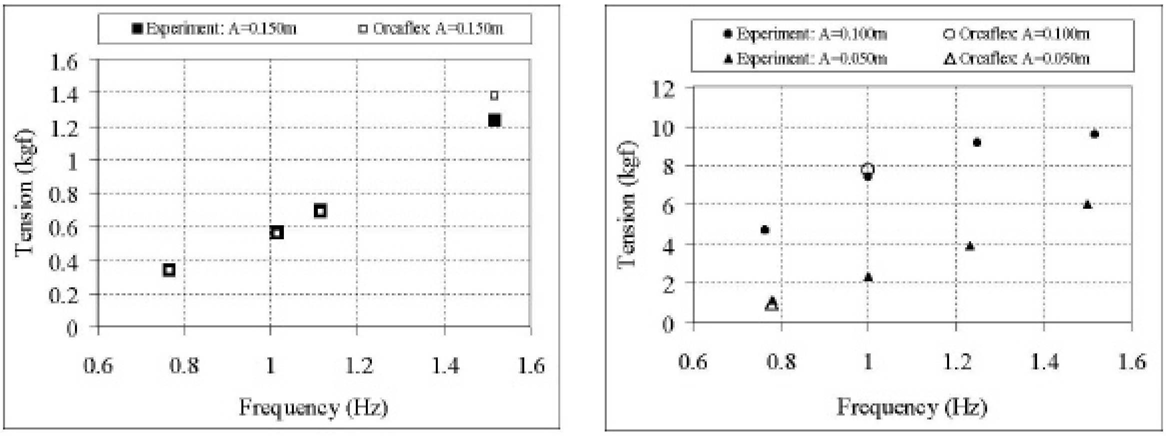


Figure 7. Excerpt of Top Tension Time-Series. Flexible Model. A=0.150m; fr=1.5Hz; U=0m/s.

Preliminary comparisons of the maximum tension loads for the rigid and flexible models were based on results generated with the software *Orcaflex*. Agreement of the numerical results with the experimental values presented in Fig. (3) may be evaluated in Fig. (8).



(a) *Rigid Model* (b) *Flexible Model*

Figure 8. Comparison Between Experimental and Numerical Results. (a) Rigid Model. (b) Flexible Model.

Although an extensive analysis has not been performed, results indicate that the numerical code is able to cope well with the dynamic compression of the models, even in extreme cases when dynamic compression occurred along the whole suspended length.

A more extensive evaluation is currently being performed; using the numerical codes implemented in the Numerical Offshore Tank of the University of São Paulo and shall be presented in a future paper.

5. Conclusions

Top tension results on rigid and flexible riser models were obtained by imposing harmonic circular motion at the suspended end. Current effects were taken into account by towing the models along the wave tank. Dynamic compression phenomenon effects became evident by the emulation of extreme top motion cases.

Results for the flexible model demonstrated that the dependency of tension on frequency and amplitude of the imposed excitation is strongly affected by out-of-plane oscillations of the model. Current effects also have an influence on such dependency.

Experimental results also indicated that, in extreme dynamic compression situations, compression loads lower than the critical values occur for short periods of time in the beginning of the compression cycle.

Comparison with numerical results obtained with *Orcaflex* demonstrated that the numerical code is able to cope well with dynamic compression effects, even in the extreme cases when the whole line was compressed.

6. Acknowledgements

This study has been conducted within the context of the projects TPN/CTPETRO’2000 and DICAS’3000, both supported by FINEP and Petrobrás. The authors also wish to thank Newton Y. Yamamoto and Dr. Melquisedec F. dos Santos, from the University of São Paulo, for their invaluable help.

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