Chapter 6: Conclusions and Recommendations

6.1 Conclusions

A three-dimensional nonlinear dynamic analysis of a moored cylinder to be used as a breakwater has been carried out in this thesis. Two models were used to represent the mooring lines. The first was the use of taut, linearly elastic, massless springs. The second model consisted of taut, massless, compressionless springs. FORTRAN programs were used to integrate the first-order differential equations of motion over time, and Microsoft Excel was used to plot and evaluate the data.

Several assumptions were necessary to carry out the nonlinear analysis. First, the breakwater was assumed to be in “dry” conditions, as if the cylinder was modeled in air with a net buoyant force pulling the cylinder upward. The cylinder was assumed to be rigid and solid. The wave forces acting on the cylinder were modeled as sinusoidal waves following a smooth build-up. Linear damping was used to model the fluid and mooring damping effects. The mooring lines were assumed to be rigidly attached to the seafloor.

Some general conclusions can be made regarding the effects of the stiffness on the configuration and free vibration of the breakwater. Except for very small mooring line stiffness, the stiffness does not affect the equilibrium height of the breakwater significantly. Also, the stiffness of the mooring lines barely affects the values of the dominant first and second natural frequencies. However, it greatly affects the less critical third, fourth, fifth, and sixth natural frequencies.

A couple of more conclusions regarding the free vibration of the breakwater can be made. For the special configuration case when the equilibrium length of the mooring lines equals the lines’ natural length, the first two natural frequencies are zero. Also, the free vibration for large motions is completely different and much more complicated than the linear free vibration behavior.

For the regular spring model, the nonlinear EOM's can prevent the displacement norms from monotonically increasing at high force amplitudes. Also for this model, chaotic motion was shown to slowly develop at high force amplitudes after first undergoing harmonic motion and then subharmonic motion for $\varepsilon = 0^o$ and 90^o.

Resonance response diagrams showed that the primary resonance occurred near the first or second natural frequency, depending on the direction in which the wave forces were applied. Also, for every wave direction considered, an irregular resonance occurred at a frequency close to, but not exactly at, half of the first and second natural frequencies. Small resonance also occurred at each of the higher natural frequencies, except the third frequency corresponding to yaw, if the direction of the wave affected motions in the DOFs associated with the corresponding natural mode of vibration.

Finally, as the coefficient of damping increases, the displacement norms monotonically decrease, except for very small values of damping, and slowly approach zero.

The compressionless spring model showed behavior at times completely different from that of the previous model. First, the added nonlinear characteristic of the compressionless springs generally causes much greater motions, more erratic behavior of the displacement norm curves, and extremely high and sudden tensions in the mooring lines (called snap loads). Results for moderate forcing conditions show that the mooring lines can go into a slack state for a very short period of time and not develop snap loads. Furthermore, often when snap loads begin to develop, they do not greatly affect all of the DOFs, and mostly affect rotations. Also for this mooring line model, chaos suddenly develops for increasing force amplitudes, unlike the steady progression from harmonic to subharmonic to chaotic motions seen in the regular spring model.

For the standard case values used, the resonant response diagram showed that for low frequency values, the breakwater reacts exactly like the regular spring model, meaning that the springs remain in tension throughout most of the forcing. Once snap loads fully develop, many local peaks appear near the resonant frequency. Resonance always occurs near the two lowest natural frequencies and at the irregular frequency, and rarely near any of the high natural frequencies.

For low damping coefficients, the displacement and tension norms react erratically, until a critical c value is reached, and thereafter the curves monotonically decrease and behave just as they did for the regular spring model.

6.2 Recommendations

Many areas related to cylindrical breakwaters should be researched to continue the development of the work in this thesis. Below are some topics that could be pursued.

Experimental research should be conducted on fully submerged, moored inflatable cylinders to be used as breakwaters. Inflatable breakwaters have many potential benefits that have been mentioned, but before they can be used in industry, more experimental tests need to be conducted to confirm the theoretical work that has been done. Many different waves could be tested on the breakwater, including random waves. Also, different materials can be tested to determine the advantages and vulnerabilities of potential materials for the inflatable breakwater and the mooring lines.

A more thorough analysis of the dynamics of cables should be conducted in relation to the development of snap loads on mooring cables attached to a cylindrical breakwater. Here the cables were modeled as straight, massless springs. Studies using continuous cable models should be carried out. The finite element method or finite difference method could be used to obtain numerical solutions for the motions and tensions. Fluid forces on the cables could be included. The results could be compared to those in this thesis.