

# BM-6 DYNAMIC DEPLOYMENT SIMULATION USING SEADYN

BY  
W. E. BAXLEY  
SOUTH FLORIDA TESTING FACILITY

## 1.0 INTRODUCTION

The Naval Surface Warfare Center Carderock Division's South Florida Testing Facility (SFTF) ocean engineering group conducted computer simulations of the BM6 Shock Test Model in the summer of 1993. The subject system consisted of a surface support ship, strong back, two support cables, and a large cylindrical model. SFTF modeled the system's dynamic response while suspended from the OCP SEACON. Analysis was conducted using SEADYN, a FORTRAN-based finite-element code for cable system simulations. This report details the procedure and results of the analysis.

## 2.0 INITIAL ANALYSIS

The factors evaluated by SFTF involved the environmental effects on the model while it was suspended under the SEACON. It was known that the launch and recovery maneuver worked dock-side, and deployments had been successful in inland lakes.

The ocean environment, however, is very dynamic, and unique in the types of loads placed on deployed systems. The effects of currents, wave action, and ship motion all play significant parts in the integrity of the system. It is these parameters that SFTF is most concerned about.

The proposed configuration deploys the model from the stern of the SEACON, with the longitudinal axis perpendicular to the axis of the ship. The model is suspended beneath the ship on two cables at a depth of 300 feet, as shown in Figure 1.

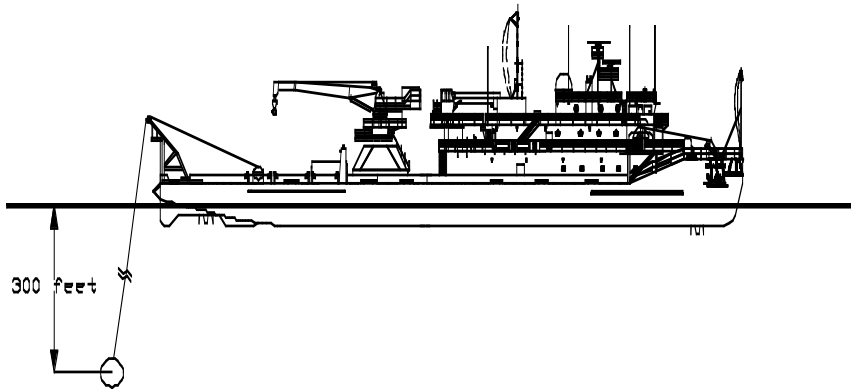


Figure 1

The behavior of the model is the main concern during handling system design, due to potentially large cable forces and model motions. The forcing functions in the system appear to be current and ship motion, with the model following some induced behavior. The analysis of the deployed model system involved graphical representations of the predicted behavior, scale model testing, and computer simulation.

## 3.0 ENVIRONMENT AT PROPOSED DEPLOYMENT SITE

Our analysis investigates the dynamic loading induced by the ocean environment. The main factors involve the currents, winds, and sea states encountered off the coast of southern Florida. The water currents in the area range from 0.25 to 4 kts, depending on location and time of year. Winds can range from calm to 30 kts, and seas from flat

to 8-10 ft waves. Due to this wide range, a set of operating conditions had to be determined. These limits are based on ship geometry and previous experience with similar systems.

A judgment was made on the maximum working sea state for the deployment. A limit was set of 2-3 ft seas, based on ship parameters and observed motions during typical deployment days. This wave size coincides to approximately 4 degrees of roll, for an amplitude of 0.976 ft and total vertical excursion of 1.952 ft at the stern, which was modeled as 2.0 ft.

Wind speed significantly affects the handling of the SEACON, so the maximum operational wind speed of 25 kts was used for the allowable wind speed. This factor would most likely be secondary to any decision making, since sea state is typically unacceptable at such wind speeds.

The maximum current was recommended to 0.5 kts, although further analysis indicated it may need to be modified. The design current was assumed to be uniform with depth, since this would provide a "worst-case" condition, as opposed to a stratified or linearly declining profile.

#### **4.0 LOADING CONDITIONS**

The primary loads imparted on the system were currents and ship motion. The current loads on the system result from drag on the model and supporting cables, causing trailback and increased line tensions. These effects are primarily static, with relatively constant loadings. There are dynamically induced forces, however, that contribute to the overall instability.

The proposed deployment method suspends the system with the longitudinal axis perpendicular to the current flow. This causes some problems, namely dynamic yaw and cable twisting. The open ended shape of the model also contributes to overall instability, acting as cups to catch the water flow.

Initially the body is stable, but any variation in flow direction or magnitude induces unbalanced drag loads. This applies an external moment to the system, with the model turning about its central axis. The restoring moment results from the two twisted support cables, and tends to swing the model back through equilibrium, similar to a torsional pendulum. This twisting motion grows larger in magnitude, until some resonant frequency is achieved.

This motion is detrimental in several cases, namely surface support loadings and model position and orientation during the test. The motions of the model are transmitted up the cables, which side-load the A-frames and introduce dynamic loads. Depending on the magnitude of these forces, the maximum working loads of both the cables and support structures may be exceeded. The model position for testing is also significantly affected, since the swinging and twisting does not allow for the proper charge-bubble geometry.

#### **4.1 SHIP-MOTION LOADINGS**

The ship motion due to waves introduces dynamic forces, through roll and heave. Pitch is not as severe on the SEACON, due to the large length to beam ratio. The modes investigated for handling are the cable slacking and tensioning due to the vertical movement, and the swinging from side to side of the model. The roll was used as the primary forcing function, since the other motions are small in comparison.

#### **5.0 CURRENT-INDUCED YAW MOTIONS**

The configuration can be looked at as a hollow cylinder with its axis perpendicular to the flow, suspended on two thin support cables. The restoring forces in the system come from the twisting cables, and a counter force from hydrodynamic drag. The current-induced yaw was one of the major questions investigated, due to the complexity and potential severity of the motions. The orientation of the model with respect to the current flow presented a challenge in modeling, since not much empirical data or research has been done.

The first thoughts on the yawing motions involved the flow around the model, and the unbalanced forces acting on it. With the model perpendicular to the flow, the water flows over and under the cylinder, as well as "into" the ends.

This water flow causes a force offset from the center axis, imparting a moment to the system. The moment is countered by the cables resisting the model rotation. In order to understand the magnitude of these forces, it is necessary to develop equations to calculate the drag and cable forces as a function of twist angle.

The equation for water drag affecting the stability used the standard drag equation

$$F_D = 0.5 C_D \rho v^2 A_p$$

The area ( $A_p$ ) for the equation was found by calculating the normal projection of the exposed inside surface at angle  $\theta$ , by the equation

$$AREA_p(\theta) = \text{Height} \times \text{Width} \times \tan(\theta) \cos(\theta)$$

The drag coefficient ( $C_D$ ), 1.3 for a flat plate, was only a very rough cut at the correct coefficient. The  $C_D$  would change as a function of the yaw angle, which was beyond the scope of this analysis.

The cable twisting function was derived using the initial length of the cables and the forced elongation due to twisting as the restoring force. This equation is

$$F_{TWIST}(\theta) = e \times E_M \times A_{CS} + F_{INITIAL}$$

The restoring moment is then

$$M_{REST} = F_T(\phi) \times (a) \times \text{RADIUS}$$

where  $[\phi]$  is angle made from the surface attachment point with the horizontal displacement of the cable end, given by

$$a = \text{ATN}((2R \sin(\phi)) / L_0)$$

All of these equations were then entered into a computer program to calculate the restoring moment as a function of  $\theta$ , the model yaw angle.

## 6.0 SCALE MODEL TESTING

A dimensionally-similar model was tested in air to visualize the expected behavior of the model in a current. A piece of PVC pipe was used as the model, and was suspended from the work rack on one of SFTF's trucks. The truck was then driven at a fixed speed, and the motion video taped.

The mode shapes were just what had been predicted, although to a different scale due to weight, air viscosity, and other parameters. The general behavior, however, was almost identical to what was expected. The dynamic yawing due to unbalanced fluid flow, and the restoring moments of the support ropes all verified the initial predictions.

The Reynolds number for the pipe was calculated at the speed of oscillation, 18 miles per hour, and was found to be  $6.267 \times 10^4$ . This was used to find the corresponding velocity in water, which was 0.06 knots. This speed was for the Reynolds-number dependent behavior only, but gave an approximate order of magnitude as to what may be expected in the full-scale deployment. The same model was dragged through a test tank at SFTF, and the model began oscillating at the correct speed of 2.5 ft/sec, calculated from the above Reynolds number.

Based on the results of the air model, it was decided to proceed with the dynamic modeling, and continue working out the equations for the shape-induced yaw motions.

## 7.0 SEADYN DYNAMIC MODELING

The dynamic response of the model was simulated using a state-of-the-art computer program, SEADYN, from the Naval Facilities Engineering Service Center in Port Hueneme, California. The program is a finite-element FORTRAN program which allows user-defined cable system to be modeled dynamically. The output is organized into coordinates, velocities, and tensions for each element and node in the model. The program usually only runs on a mainframe computer, but a PC version was used at SFTF. This program was obtained from Allied Techsystems in Seattle, Washington, and allowed test cases to be executed at SFTF on a personal computer.

### 7.1 SYSTEM MODEL

The system was modeled as a U-shaped cable hanging in the water column, with each section represented as a cable element with properties similar to the system component. The cables, for instance, were modeled as 10 elements per side, with the EA (modulus and cross-sectional area) and submerged weight equivalent to the actual cables. The model was identified as a single cable element with the same diameter, unit weight, and strength properties. The model element was specified to support compression, so the nodal separation distance would remain constant.

Once the system was modeled, a dead, live, and dynamic simulation was performed for various sea-states and current conditions. The dead portion simply calculated the elongation of the cables in the water column, while the live simulation applied a uniform current to the system. For the models, no current, 0.5, and 1.0 knots cases were used, as they were the ideal conditions for deployment.

The static results in SEADYN showed that current would move the model aft of the ship approximately 11.3 ft in the maximum 1.0 knot condition. This does not, however, include any dynamic or geometrically induced motions of the model.

### 7.2 DYNAMIC CONDITION

The dynamic analysis proved to be the most interesting, with the motions of the ship used as forcing functions to the cable ends. In order to simulate the roll of the SEACON on a typical day, the period was both calculated and measured at sea, and produced a roll period of 5.5 seconds. The vertical motion resulting from roll was found by simply taking the center of the ship as the roll axis, measuring the distance to the support point, inputting the roll angle of interest, and calculating the corresponding distances via a right triangle. The roll angle for the maximum day, 2 to 3 foot seas, was found by measurement to be 4 degrees. The vertical cable end excursion was 1.952 ft, and was modeled as 2.0 ft in the simulation. The characteristics of the SEACON are:

Length	260 ft
Beam	48 ft
Draft	14 ft
Roll Period	5.5 sec
Pitch Period	5.5 sec

The time function for the model used a sine function with a ramp-up time for introducing the motion to the system. Typically, one would use a long ramp-up to prevent shock loading the system, although during deployment, time is usually a luxury, not a certainty. The ramp-up for the simulation was 120 seconds, assuming that was the time period required to place the model into the water and for the forces to begin affecting it. The model was run for 900 seconds, taking data every 6 seconds. The main area of interest was the behavior of the model itself, identified by nodes 11 and 12 in the simulation.

The models were run at SFTF Fort Lauderdale on a 486/33 MHz personal computer, using the converted SEADYN code. Average run times for the 900 second models was 24 hours.

## 8.0 SIMULATION RESULTS

The computer runs took approximately two weeks to complete, and each generated a large output file of nodal positions and other information. Each test case was decomposed into desired information using a custom BASIC extraction program. The main areas of interest were the behavior of the model and the surface cable tensions.

Analysis involved producing graphs of the nodal position versus time, thereby illustrating model behavior throughout the deployment. The motions in the horizontal (XY) plane were investigated in terms of nodal excursion from the free-hanging position. Depth changes were studied based on nodal depth change and relative depth difference between model ends. Line tensions for the test cases were analyzed, to determine if dynamic forces would overload the cables.

## **8.1 ZERO-CURRENT CONDITIONS**

The first test case deployed the system in zero-current, with only the roll motion of the ship as the dynamic forcing function. The model motion in the X direction reached excursions from the initial position up to 9 feet over the time interval. Y-motions peaked at the introduction of ship motion, but settled out to nearly zero after approximately 400 seconds. The Z-motion, or depth change, was predominant, with relative depth differences between ends peaking at 26 feet, averaging at about 10 feet.

## **8.2 PERPENDICULAR ORIENTATION**

The second test case had the system positioned with the model's longitudinal axis perpendicular to the current flow, representing the proposed method of deployment. Two current velocities were used, 0.5 and 1.0 knots, to provide some basis for comparison. Each model-representing node was considered individually, but both had the same basic behavior, separated by a minor phase difference.

Excursions in the X-direction, across the current, reached 3 feet at 0.5 knots, and 1 foot at 1.0 knots. The Y-motion, in-line with current flow, included an initial displacement due to system trailback. Initial steady-state trailback was about 3 feet for 0.5 knots and 11.3 feet for 1.0 knot, and increased to 7 feet and 17 feet, respectively. This increase was due to the dynamic vertical oscillations of the system, and the varying projections to the flow. Once the dynamic trailback was reached, however, the system tended to maintain at that position. Both currents caused a slight oscillation of about 2 feet about the trailback point. Depth changes peaked at 20 feet for 0.5 knots, and 10 feet for 1.0 knots, averaging at 8 feet and 4 feet, while relative depth differences ranged from 15 feet to 5 feet, receptively.

Cable tensions in the perpendicular orientation produced extreme load peaks, with values approaching the cable breaking strength. The breaking strength of 1.5 inch diameter steel core wire rope is 182 thousand pounds. The largest peak at 0.5 knots was 178 thousand, and the 1.0 knot loading reached 93 thousand pounds. The average peaking was 110 thousand for 0.5 knots, and 40 thousand for 1.0 knot. These peaks indicate the large dynamic loadings caused by model motion and separation distance between model and support structure.

## **8.3 PARALLEL ORIENTATION**

The parallel orientation, similar to a tow body, was modeled to investigate the benefits and drawbacks of possibly changing the deployment scheme. Since the SEACON can hold any desired heading, regardless of current direction, this would not require much modification.

In this orientation, the program indicated that all motions in the Y-direction, now across the current, would be eliminated. This would most likely be false, unless some sort of system is used to prevent "wagging", similar to that of an understabilized tow fish. It was not expected that SEADYN would model this, however, so the zero-motion was accepted.

Motion in the X-direction, the direction of flow, had an initial and dynamic trailback displacement, although not as large as the perpendicular position. Total trailback was 4 feet for 0.5 knot, with 2.5 feet oscillations, and 8 feet for 1.0 knots, with 0.5 foot variation. Z-motions were approximately the same as the perpendicular deployment, with relative depth differences of 16 feet for 0.5 knots and 6 feet for 1.0 knots.

Loads for this configuration showed similar peaks, although not as severe. The maximum 0.5 knot load was 115 thousand pounds, averaging at about 70 thousand. The 1.0 knot current model peaked at 93 thousand, averaging at 50 thousand pounds.

These loadings are smaller than the perpendicular orientation, but still far above the acceptable safe working load of 34 thousand pounds (safety factor of 5). The reduced peaks at higher currents also indicate a dampening affect provided by the flowing water. This behavior, along with reduced motion at higher currents, could be an answer to controlling the model deployment.

## **9.0 RECOMMENDATIONS**

Based upon the SEADYN data and analysis, the ideal configuration for ship deployment would be with the longitudinal axis parallel to the flow, in current of at least 1.0 knot. The lower current conditions do not dampen the system as well as the higher flows. The attitude to the flow is also important, since one mode of motion is eliminated (or reduced) with the parallel orientation.

One drawback to this deployment, however, is the effect of flowing water on the shape of the charge bubble. This is another problem completely, but one that must be addressed. The high-current, tow fish-like orientation appears to be the most stable of the ship-deployed schemes.