Parametric Analysis of Candidate Configurations for Early Seastead Platforms

Part 1: Platform Configurations and Cost Estimates

Part 2: Platform Performance in Ocean Environment

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Our Mission: To further the establishment and growth of permanent, autonomous ocean communities, enabling innovation with new political and social systems.

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INTRODUCTION

The primary mission of The Seasteading Institute is to promote the establishment and growth of permanent, autonomous ocean communities, enabling innovation with new political and social systems. By opening a new frontier, we intend to revolutionize humanity's capacity to improve quality of life worldwide by creating laboratories for experimentation in governance and encouraging the development of new legal, political and social structures.

Initially, it is anticipated that these fledgling communities will need to accommodate relatively small populations of around 100 to 200 people. In the longer term, however, successful seastead communities will likely attract larger populations, growing incrementally into the thousands and potentially (in the very long term) into full-fledged cities at sea.

From the outset, it is clear that the technology exists to accommodate people living at sea for extended periods of time; offshore platforms and cruise ships are two obvious examples. But the requirements for a seastead are quite different. Ocean platforms are designed to house workers in an industrial work-place environment, where accommodations are simple and facilities are (to varying degrees) communal. Cruise ships, on the other hand, strive to offer luxurious accommodations, but guests are generally on-board for only a short period of time; like staying in a luxury hotel ashore, there is no sense of ownership or community. Moreover, cruise ships are intended to transport guests from one place to another. Cruising, by definition, implies the requirement for mobility, while at the same time offering a wide variety of activities for guests to indulge in while journeying between ports of call.

Seasteading, by contrast, is intended to foster a sense of community and long-term residency unlike any other sea-based entity. Perhaps the closest counterpart is the *ResidenSea* ship, an enterprise that is more akin to a cruise ship catering to an ultra-wealthy clientele. Costs to purchase a unit aboard *ResidenSea* (recently posted at $600,000 for a 328-square-foot studio, or about $1,800 per square foot) are in the same lofty stratosphere as prime real estate in Midtown Manhattan, not to mention monthly maintenance fees that begin at $20,000 per month.

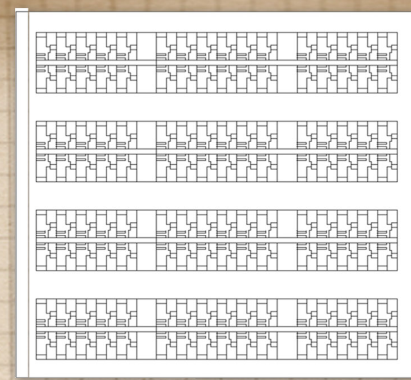
One of the challenges that will be critical for the success of the seasteading movement will be engineering a design solution that can be offered at a price per square foot that is comparable to upper-middle-class housing in the residential area of a typical mid-size American city. From pricing on Zillow.com, median prices for homes in the Los Angeles and New York metropolitan areas are in the range of $240 to $280 per square foot; before the bubble, those values were about $300 to $400 per square foot, respectively. Certainly, one would expect to pay a small premium for a home on the high seas; for sake of argument, we will assume seasteads should initially strive to meet a target price of not more than $500 per square foot of residential floor space. With economies of scale, reductions of 20% or more from that figure should be achievable; future technological advancements offer the possibility of additional cost savings, putting seasteading within the reach of a much broader segment of the population.

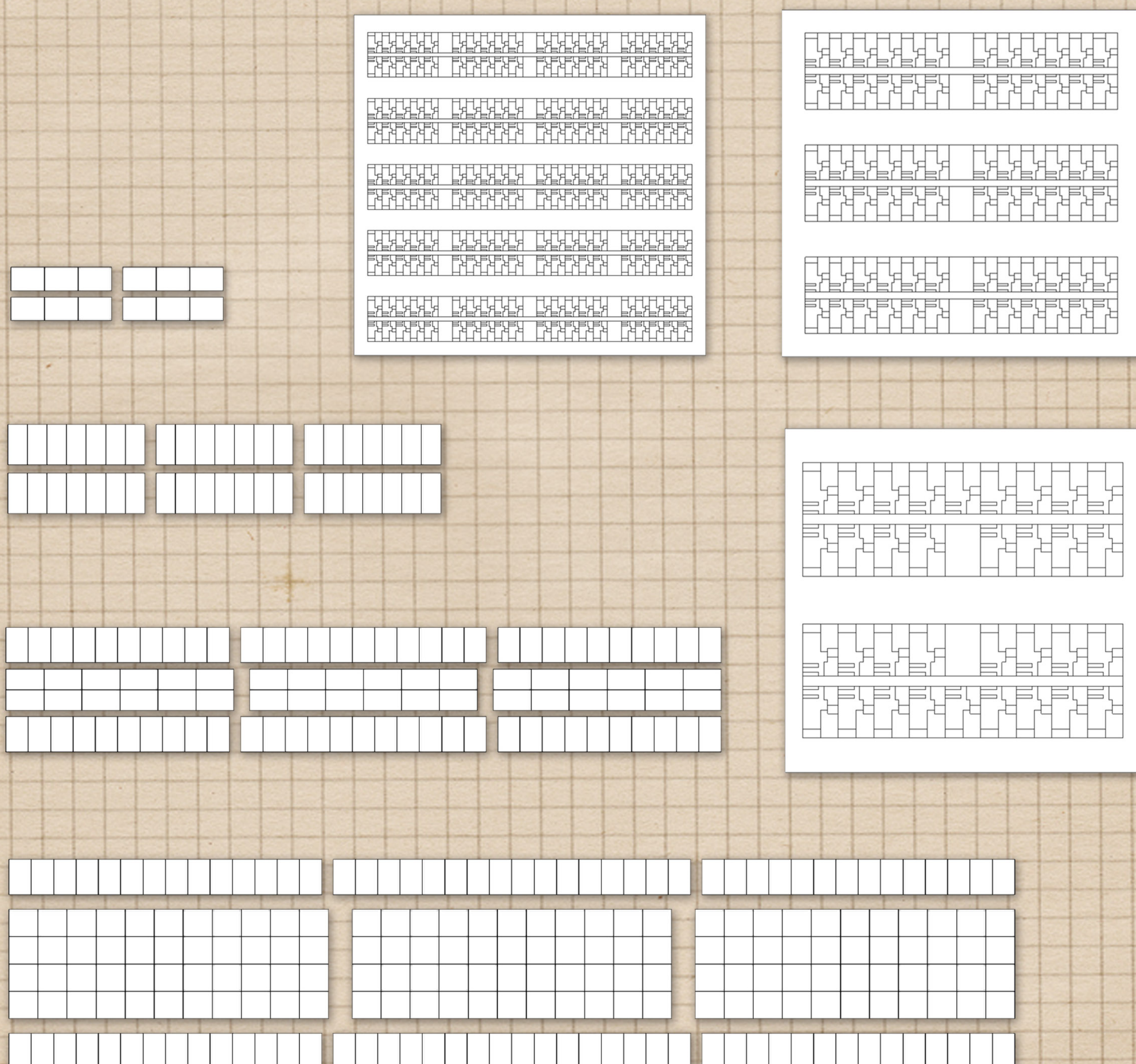
OBJECTIVE

The purpose of this engineering analysis is to systematically evaluate several different seastead configurations (in a range of sizes) and to quantify their cost, capacity, and performance with particular emphasis on early seastead communities (as opposed to large future cities at sea). The results provided in Part 1 of this analysis will indicate the economies of scale that should be achievable for larger seasteads. Comparisons of expected performance in different operating scenarios are provided in Part 2, as a basis for deciding what platform is most appropriate for a particular set of operating requirements.

Part 1:

Platform Configurations and Cost Estimates





SCOPE

This analysis considers three different hull configurations, namely,

- Semi-submersible, column stabilized platforms similar to offshore drilling rigs
- Ship-shaped hull, similar in proportion and appearance to a cruise ship
- Barge-shaped hull, deckhouse similar to a cruise ship but a wider, shallower hull

In terms of initial cost, semi-submersibles are thought to be the most expensive configuration, while barge-shapes are the cheapest; however, for long-term habitability on the open ocean, semi-submersibles are superior to ship-shaped hulls, while barge-shaped platforms would be suitable only in relatively sheltered waters.

Each of these three platform configurations is evaluated for four different sizes, which are rather arbitrarily referred to as follows:

- Very-small; capacity of about 100 people
- Small; capacity of about 300 people
- Medium; capacity of about 1,000 people
- Large; capacity of as many as 5,000 people

The lower end of the range represents the population assumed to be the minimum size of an initial "offshore" seastead community, while at the upper end of the size range the population approaches that of a large commercial cruise ship.

Cost estimates are based on parameters that are typical of new construction in a modern Asian shipyard, using a consistent set of assumptions, so that fair comparisons can be made between various configurations, and economies of scale are revealed in an objective manner. *These cost estimates are intended primarily as a basis for comparison between alternatives*; cost factors vary significantly depending upon the shipyard's location (USA, Europe, Asia, etc.) and may fluctuate with changes in global demand for ship construction at any given time.

It is noted that submersible configurations are not considered within the scope of this analysis. Although this concept has a number of enthusiasts within the seasteading community, the focus of the present engineering evaluation was limited to proven configurations that are widely used for offshore accommodations and are therefore deemed as the most likely candidates for early seastead communities.

It is further noted that "single-family" seasteads are not considered within the scope of this analysis. Proponents of single-family seasteads should not feel slighted by this omission, but rather should bear in mind that one of the primary objectives of this analysis is to quantify the expected economies of scale by evaluating a series of configurations and sizes that vary in a systematic, parametric fashion; that is to say, the variations within each configuration exhibit a consistent proportional similitude.

Somewhere in the transition between "Very Small" multi-family seasteads considered in this analysis and a hypothetical single-family seastead, the parameters (and hence the proportionalities) change. For example, the allocation between residential and public spaces will probably be very different, even if one assumes the need for "public" spaces on a single-family seastead.

To address the question of single-family seasteads, it would be much more instructive to look at the plethora of configurations that are viable candidates in that size range; common examples might include houseboats (with either pontoon or scow-shaped bottoms), trawlers, sailboats, or a variety of other innovative designs. This would more rightly be the subject of a separate engineering analysis.

For prospective seastead residents of modest to average means, an initial target price of $500 per square foot may seem daunting; that price translates into about $300,000 for a modestly sized residence of only 600 square feet. It is noted that, for the sake of consistency, the cost estimates in this study are based on new construction, purpose-built to accommodate the requirements of a hypothetical seasteading community. Such vessels would typically be designed for a service life of 20 to 25 years, but would likely remain functional for a substantially longer period of time, given proper maintenance, much like quality new cars are built with the expectation that they will continue to provide good transportation long after the warranty has passed.

One feasible strategy for reducing the cost of early seastead communities is by acquiring an older vessel (most likely a cruise ship) and renovating/refurbishing it to improve its suitability as a platform for permanent residence. Like shopping for a good used car, finding the right vessel will take a good deal of searching, and any assessment of costs would be highly dependent on the specific vessel under consideration; hence the “used cruise ship” concept has not been considered in this parametric analysis, but is nonetheless considered a viable option that may be explored as part of our ongoing engineering research.

SUMMARY OF CONFIGURATIONS CONSIDERED

General Approach and Assumptions

It is anticipated that most residents of early seastead communities will opt for relatively small living spaces, much as the early settlers of North America were content with modest cabins as their first homesteads. More to the point, small living spaces are the norm for present-day residents of places such as Hong Kong and Singapore. Nonetheless, it is recognized that the residential units of a seastead must offer much more habitability than is found in the typical staterooms of a large cruise ship or the cabins on an offshore oil platform.

To cite a representative example, the majority of staterooms aboard the Royal Caribbean International cruise ship *Freedom of the Seas* offer living areas ranging from 150 to 250 square feet (roughly 14 to 23 m^2); a bit smaller than an average-price standard hotel or motel room. Cabins on offshore oil rigs are even more spartan; typically just large enough for a pair of single berths, a dresser, desk, chair, shower and sink. Cruise ships and oil rigs can offer these modestly sized staterooms because it is assumed that their occupants will spend the majority of their waking hours elsewhere. Moreover, all meals will be prepared (and are usually consumed) in communal dining facilities.

Residents of a seastead, on the other hand, are expected to want to have a certain degree of autonomy in their lifestyle. It is anticipated that they may spend a significant portion of their waking hours in their staterooms; working, using computers, reading, watching TV, or engaged in other indoor leisure pursuits. Furthermore, it is assumed that each residential unit will have its own cooking facilities, including a refrigerator, sink, stove, cabinets and drawers. Additionally, since residents will be living aboard for much longer periods of time, they will require more closet space for clothing, and places to display the assorted items that make a space feel like home.

Accordingly, it is assumed that each residential unit will offer about 600 square feet (roughly 56 m^2) of living space; similar to the floor plan of a modest one-bedroom apartment with a galley kitchen, dining area/living room, computer alcove, walk-in closet and a bathroom with dual vanity and a full-size bathtub. An additional allowance of 10 percent is assumed for hallways, stairwells and elevators; thus the total number of residential units on each seastead configuration is based on about 650 square feet (roughly 60 m^2) per unit, or 325 square feet per person (double occupancy). This is about one-half the size of a modest 1,300-square-foot suburban home, which typically offers three bedrooms, two bathrooms, and comfortable accommodations for a family of four.

In addition, it is assumed that each seastead configuration will offer one or more decks that will serve as public areas for shops, offices, exercise facilities or other functions appropriate to the requirements of the seastead community. Depending on the configuration, these public areas may constitute as much as 30 to 40 percent of the total interior area. Furthermore, because they are considered to be potential revenue-producing spaces, they are included in the total area used as a basis for computing price-per-square-foot of capital and operating expenses.

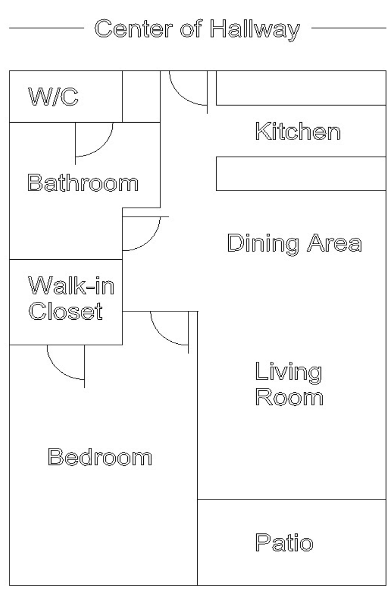
Baseline Accommodation Unit

Arrangement of the residential decks is based on a hypothetical 30'x20' accommodation unit that provides 600 square feet (60 m^2) of living space, as shown in the sketch below. Highlights of the layout include the following features:

- Entry foyer (3'x7') with large adjoining closet (2'x3')
- Galley-style kitchen (7'x9') with pass-through counter to dining area
  - Refrigerator-freezer (up to 21 ft^3) with icemaker
  - Four-burner electric stove with oven
  - Stainless steel sink
  - Built-in microwave oven
  - Nine feet of countertop space
  - Built-in cabinets over and under countertops
- Dining area (7'x12') with built-in seven-foot pantry/shelving unit
- Living room (10'x11') with built-in four-foot computer table
  - Six-foot convertible sleeper sofa with two end tables; 48" LCD HDTV opposite
  - Six-foot sliding glass door opening onto patio
- Open-air patio (5'x10')
- Master bedroom (10'x14') with queen/king bed (72"x84")
- Walk-in closet (5'x6')
- Bathroom (8'x11') with full-size tub, double sink, linen closet and separate W/C

This layout will comfortably accommodate a couple, with a convertible sofa for occasional overnight guests.

To provide roomier quarters, this layout lends itself to incremental expansion; using the same kitchen/dining/living room as the baseline unit, and adding additional 10' increments of width, a 30'x30' unit could offer two bedrooms and two bathrooms, while a 40'x30' layout might offer three bedrooms, two bathrooms, a small study and/or a second patio off the master bedroom.



Semi-Submersible Configurations

Unlike ships or barges, the semi-submersible lends itself quite naturally to a deck that is nearly square (similar dimension in length and beam) rather than relatively long and narrow. This offers both advantages and disadvantages.

The advantage is that a square-plan form is well suited to forming clusters of residences arranged side by side, with rows separated by wide "boulevards" that are intersected by somewhat narrower alleyways. Residences can thus be arranged in clusters of "micro-neighborhoods" that will tend to foster a feeling of community among residents.

The disadvantage is that if the deckhouse occupies more than 60 percent of the total deck area, it will make the superstructure look and feel like a tenement or cell block, with only a fraction of the units offering exposure to direct sunlight and fresh air. Conceptual arrangements shown in Figures 2a-d illustrate layouts that provide natural light and air to all units for four different sized semi-submersibles, as shown in Table 1, below. Ideally, not more than 50 to 60 percent of total deck space should be utilized for superstructure; however, it is noted that higher density accommodation layouts may constitute an acceptable path to reducing the cost per square foot for seastead communities.

As a baseline for this parametric study, it is assumed that 50 percent of total deck space is used for superstructure, i.e., for all interior public spaces and for residential units as described in the preceding section of this report. Results presented in the following chapter of this report show the cost implications that arise from this assumption, as well as the effects of higher (60, 75 and 85 percent) and lower (40 percent) deck space utilization.

Table 1 – Semi-Submersible Deck Configurations

Deck Size	Enclosed Area/Deck (sq. feet)	Percent of Area Used for Superstructure	Number of Accommodation Units* Per Deck	Total Number of Residents** Per Deck	No. of Res. Decks	Total No. of Res.
200' x 200'	23,760	59.4 %	34	68	2	136
300' x 300'	51,480	57.2 %	72	144	3	432
400' x 400'	95,040	59.4 %	128	256	4	1,024
500' x 500'	151,800	60.7 %	200	400	5	2,000

*refers to the 600-square-foot baseline accommodation unit described in the previous section
**assumes two residents per accommodation unit

Virtually all semi-submersibles have slender vertical columns located at or near the corners of the deck, perhaps with additional columns located along the sides or across the ends. These columns provide stability for the hull and support for the topside structure. The columns are sometimes circular in cross-section, for ease of fabrication and to reduce hydrodynamic drag; this is often the case in semi-submersible rigs of older design. The alternative is to use columns with a square or rectangular cross-section, because this offers superior static stability per unit of total water plane area; this is the configuration assumed in this analysis. The ramifications of this design aspect will be discussed in considerably more detail in Part 2 of this report.

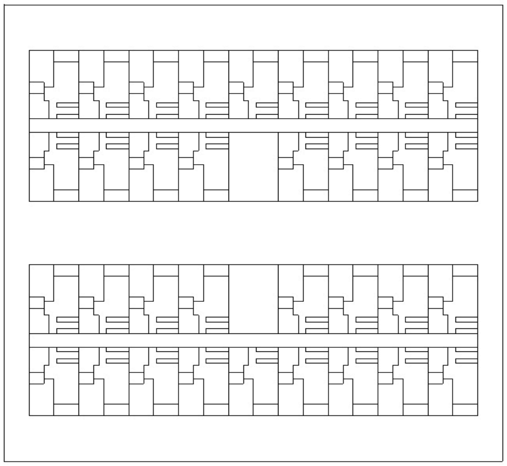


Figure 2a – Deck layout - 200’x200’

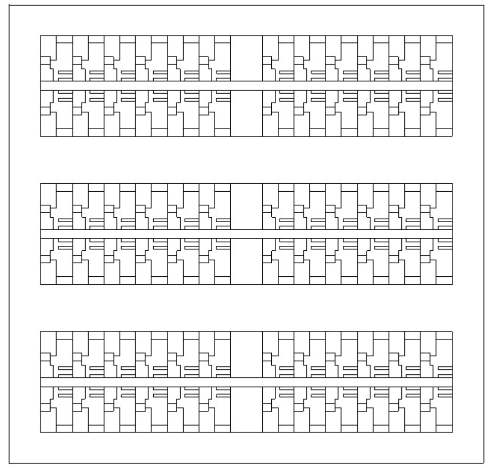


Figure 2b – Deck layout - 300’x300’

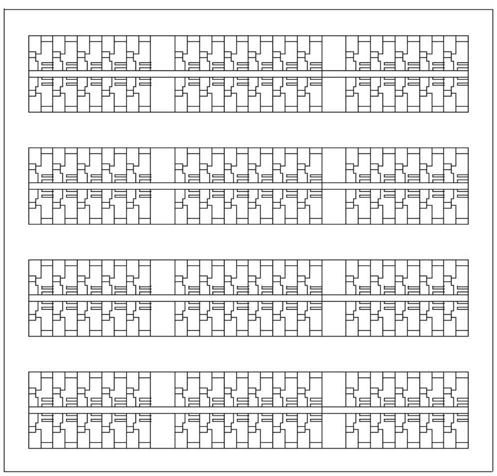


Figure 2c – Deck layout - 400’x400’

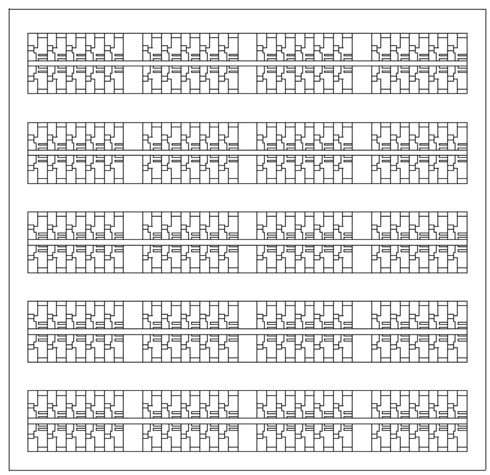


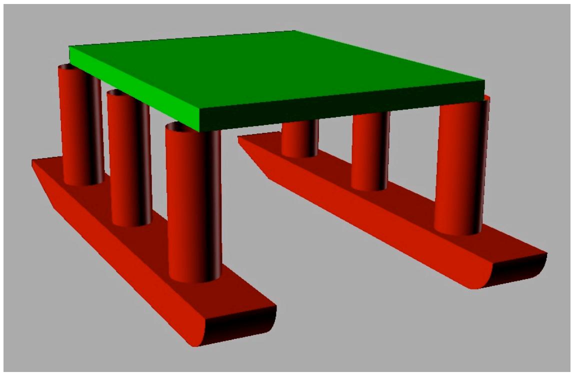
Figure 2d – Deck layout - 500’x500’

Figures 2a-d – Accommodation Layouts Using 60% of Deck Area for Semi-Submersibles

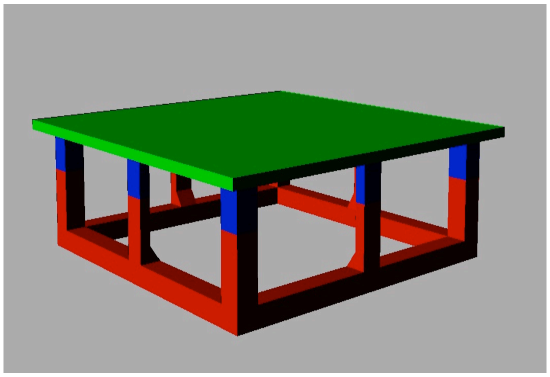
A majority of the buoyant force that keeps the hull afloat is provided by pontoons positioned beneath the columns. In some instances (as depicted, for example, in the ClubStead report, http://seasteading.org/mission/additionalreading/clubstead) these "pontoons" are individual "buoyancy pods" affixed to the base of each column. More typically, however, there are two pontoons that extend fore and aft along either side of the rig; in normal operation, the hull is ballasted so that the pontoons are deeply submerged. For transit, the hull is de-ballasted so that the columns are completely above the water; the long slender pontoons are only partially submerged, enabling the semi-submersible hull to reach transit speeds of 10 knots or better without excessive power demand.

For large semi-submersibles, significant hydrodynamic forces can occur that tend to "pry" the pontoons apart at the base of the columns, not unlike trying to break the wishbone of a turkey. To resist these forces, it is often necessary to use large diagonal "struts" to brace the columns; these are generally costly to fabricate, and the structural joints connecting the columns to the struts are a source of vulnerability in terms of potential long-term fatigue.

Rather than using a pair of pontoons for buoyancy (twin-pontoon), some configurations use a "ring pontoon" that runs fore and aft as well as side to side, binding the base of the columns like a giant steel belt and eliminating the need for diagonal struts. Not only is this configuration cheaper to build, it offers greater structural efficiency and better resistance to fatigue. The disadvantage is that the ring pontoon creates much higher drag; this has a strong impact on rig mobility considerations, and may also increase the power required for a dynamically positioned (DP) vessel to maintain a stationary position.



Twin-pontoon semi-submersible



Ring-pontoon semi-submersible

For a moored semi-submersible, it is assumed that mobility and transit speed are of secondary importance, suggesting that the ring pontoon configuration would generally be preferable. This is the configuration used as a baseline for this analysis; the cost differential associated with a more conventional twin-pontoon configuration is addressed in the summary of costs section of this report, as are the additional costs of a DP capability. Buoyancy pods (as depicted in the ClubStead report) combine negative aspects of both types of pontoon configuration; high drag, and thus limited mobility (like the ring pontoon) along with the need for diagonal struts (as with twin pontoons), therefore "pod" configurations are not considered in this analysis.

Ship-Shaped Configurations

Compared to semi-submersibles and barges, ships are long and slender; hull length is typically about seven times the maximum beam dimension. These proportions (combined with tapered bow and stern sections) produce very favorable resistance characteristics for ship-shaped hulls, allowing them to easily achieve transit speeds of 15 to 20 knots or more with reasonable power. However, the relatively narrow beam makes the hull vulnerable to rolling motions, especially in beam seas, when significant wave energy is imparted to the sides of the ship at frequencies that coincide with the resonant frequency of the ship in roll.

Various roll stabilization methods are employed in different types of ships; commercial cruise liners most commonly use some sort of active fin stabilization system. While these systems are very effective in moderate sea states when the ship is underway, fin stabilizers are of minimal efficacy when the ship is at anchor. For cruise ships, this is not a problem because anchorages are generally in harbors or other protected waters. But for a seastead platform in open waters, it is important that the ship avoid (or at least minimize) exposure to beam seas.

The need to minimize exposure to beam seas can impose severe constraints on the design of a ship-shaped seastead, and on the geographic locations in which the seastead can be expected to operate without exceeding allowable roll motion criteria. In areas where the waves are predominantly from a single direction, a ship could be moored in an orientation that faces into the prevailing seas, but such locations are rare. In areas where wave direction is more variable, the ship could use some form of turret mooring system (much more expensive than a simple spread mooring), where mooring cables connect to a single rotatable point on the ship. Alternatively, the ship could rely on dynamic positioning to maintain its desired location. Putting aside the capital cost implications of either a turret mooring or a dynamic positioning system, it is common in the open ocean for multiple wave systems to occur simultaneously, typically long swells in one direction, originating from a distant storm, along with shorter wind-driven waves in line with the prevailing wind. It is noted that the latter may change direction throughout the day, as local wind conditions develop. Thus, even for a vessel with dynamic positioning, it may be difficult or even impossible to avoid wave excitation on the beam.

A quantitative performance assessment of these considerations is presented in Part 2 of this report. The cost implications of mooring versus dynamic positioning are demonstrated in the cost estimate sections of Part 1.

The long, slender proportions of a ship-shaped hull dictate an accommodation arrangement that is different from the semi-submersible. Similar to the staterooms on a cruise ship, the residential units on a ship-shaped seastead will most likely be arranged along either side of a long corridor that runs lengthwise along the ship. Depending on the width of the ships, there may be more than one of these interior corridors, and the proportions of the baseline unit (shown previously in Figure 1) will change slightly to facilitate placement of a maximum number of units across the width of the deckhouse. Figure 3 illustrates possible deck layouts for each of the four ships; properties of each are summarized in Table 2.

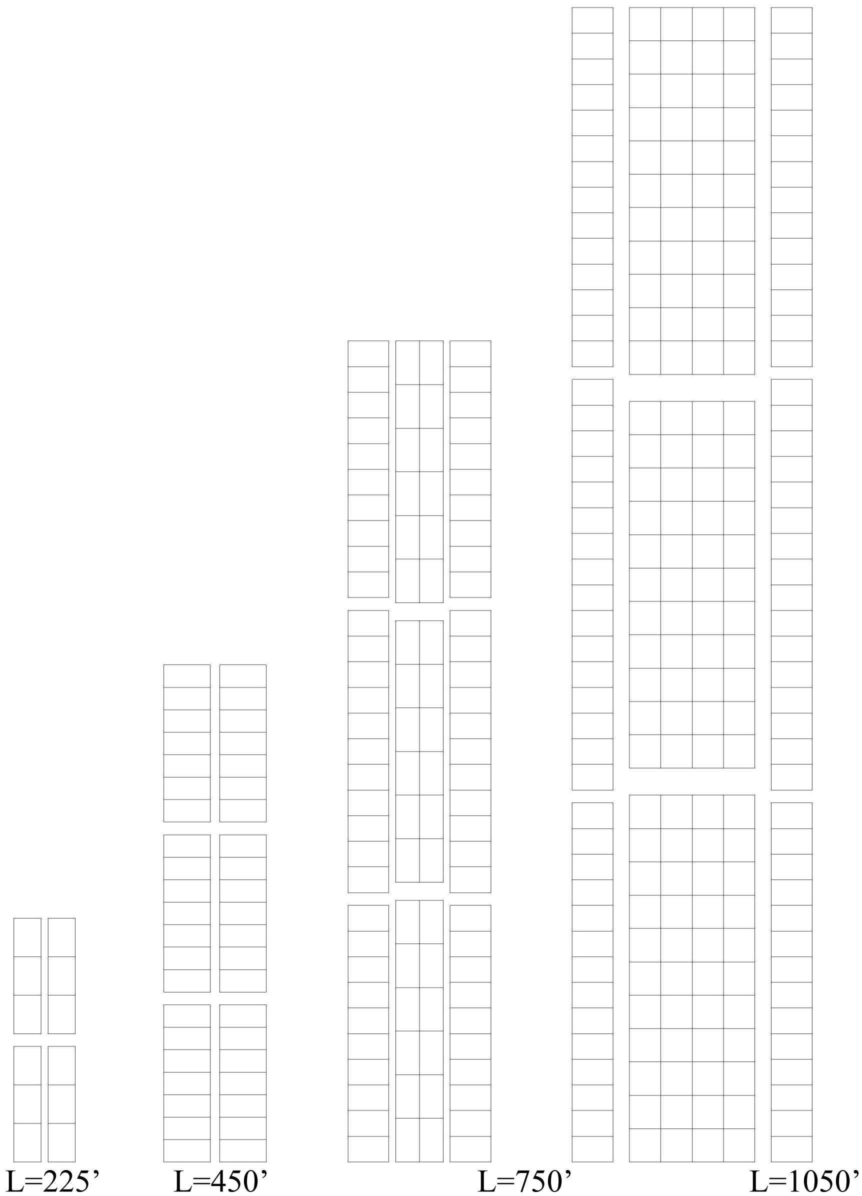


Figure 3 – Assumed Accommodation Unit Layout for Four Ship-Shaped Seasteads
Each unit is approximately 600 square feet

Table 2 – Deck Configurations for Ship-Shaped Seasteads

Ship Length (feet)	Ship Beam (feet)	Deckhouse Length* (feet)	No. of Inside Units	No. of Outside Units	Total Units/ Deck	Total No. of Res./ Deck	No. of Res. Decks	Total No. Res.
225	45	190	0	12	12	24	3	72
450	75	380	0	42	42	84	4	336
750	105	640	36	62	98	196	6	1,176
1,050	170	890	132	88	220	440	9	3,960

*Deckhouse length is assumed equal to 85% of ship length, as is typical for a cruise ship deck

Barge-Shaped Configurations

The distinction between barges and ships is largely based on proportions. Barges typically have a more rectangular form, with a blunt bow shape and hull approximately four times the length of the beam. Moreover, barges typically have proportionally shallower drafts (the distance from the water line to the keel) than ships. These characteristics arise from the fact that barges are usually required to carry heavy loads of cargo at relatively slow speeds. In addition, the shallow draft is intended to allow barges to ply shallower coastal or inland waters, and while it is noted that there are classes of ocean-going barges with proportions that are slightly more ship-like, there is still a relatively clear distinction between the two types of vessels. And while most barges are not self-powered, there are nonetheless many *self-propelled* barges; thus it is principally a matter of proportion and form rather than propulsion that distinguishes barges from ships.

Because of their characteristically blunt bow and full-bodied hull form, barges are typically able to achieve a transit speed of about six knots; faster than a semi-submersible with buoyancy pods or a ring-pontoon configuration, but slower than a twin-pontoon semi-submersible, and much slower than a ship-shaped hull. However, the most detrimental characteristic of a barge-shaped hull is its broad beam and shallow draft, which typically gives barges too much static stability, i.e., excessive "metacentric height". As a result, the natural period for roll motion of a barge is often in the range of 6 to 12 seconds, coinciding with the dominant period of the most commonly occurring ocean waves. This makes barges particularly vulnerable to excessive roll motion in all but the most benign sea conditions, as will be presented in Part 2 of this report.

It is noted that typical barge proportions (4:1) are squarely between those of a ship (7:1) and a semi-submersible (1:1); accordingly, the percentage of deck space allocated to superstructure is assumed to be 75 percent, approximately midway between the 85 percent assumed for ship-shapes and the maximum of 60 percent for semi-submersibles. It is further assumed that accommodation units will be arranged in rectangular modules running side to side across the ship, with each row of modules separated by a pedestrian walkway; similar to that shown in Figure 3 for the 450' ship, but oriented laterally rather than longitudinally. The fore and aft dimension of each accommodation block would be approximately 66' (two 20'x30' modules with a 6' hallway between); the 75 percent utilization factor would thus allow for a 22' open walkway between each row of modules. As a side benefit of this arrangement, all residences will have an exterior view and an open-air patio.

Table 3 – Deck Configurations for Barge-Shaped Seasteads

Barge Length (feet)	Barge Beam (feet)	Deckhouse Length* (feet)	Deckhouse Width (feet)	Deckhouse Area (ft^2)	Total Units/ Deck	Total No. of Res./ Deck	No. of Res. Decks	Total No. Res.
195	35	158	30	4,740	7	14	2	28
315	75	294	60	17,640	24	48	4	192
625	150	588	130	76,440	112	224	8	1,792
935	225	850	210	178,500	250	500	12	6,000

*Total deckhouse length is assumed equal to 75 percent of barge length.

SUMMARY OF COST ESTIMATES

General Approach and Assumptions; Capital Expense (CapEx)

All costs are estimated parametrically, based on the methodology described below. Using a consistent set of cost assumptions ensures that comparisons between alternatives will be valid. Cost factors cited below are based on construction in an Asian shipyard. Capital costs include allowance for installation, but do not include transit from the shipyard to the deployment site. All costs cited below are in US dollars.

Costs for hull steel and deckhouse are based on dollars per long-ton ($/LT) of steel weight, as is the customary basis for estimating all shipbuilding cost. Weight estimates, in turn, are based on well-developed formulas for estimating steel weight as a function of hull form and hull volume, i.e., the product of length, beam, depth and an appropriate "form coefficient".

The allowance for accommodation cost corresponds to about $150 per square foot, to include all interior finish, plumbing, electrical, heating, ventilation, air conditioning, etc. in each unit. While this figure may seem high in comparison to residential construction ashore, standards for offshore dwelling units are more stringent than their shore-based counterparts, especially with regard to specifications related to safety in general, and fire resistance in particular.

Parameters for other cost items are identified in the remainder of this section. Values are based on current quotes for propulsion, mechanical and electrical systems on the basis of cost per kW, or other broadly recognized basis.

To establish a level of confidence in these cost estimates, two completely independent studies were developed, one within The Seasteading Institute and the second by an independent contractor; the estimates generally agreed with each other within about 10 to 15 percent. To be conservative, the values reported herein are based on the higher of the estimates.

Hull Steel Cost

- Semi-submersibles: $10,000/LT because of complicated geometry
- Ship-shape: $9,000/LT for very small; $7,000/LT for small; $6,000/LT for large ship
- Barge-shape: $7,000/LT for very small; $6,000/LT for small; $5,000/LT for large barge

Deckhouse Cost

- Semi-submersibles: $7,000/LT irrespective of size; same for main deck structure
- Ship-shape: $7,000/LT for very small; $6,000/LT for small; $5,000/LT for large ship
- Barge-shape: $6,000/LT for very small; $6,000/LT for small; $5,000/LT for large barge

Accommodation Cost

- Allow $50,000 per passenger; $100,000 per 600 ft^2 residential unit; about $150/ft^2
  Includes all interior finish, plumbing, electrical and HVAC for accommodation spaces

Propulsion System Cost

- Main engines and DP thrusters: $550/kW

Mechanical System Cost

- Semi-submersible: 10x Propulsion system cost + $15,000 per foot of platform length
- Ship and Barge: 3x Propulsion system cost

Electrical System Cost
- Based on Total Generating Capacity: $1,300/kW

Engineering Cost
- Flat 7% of Hull, Deckhouse and Accommodation Cost

Program Management Cost
- Flat 3% of Hull, Deckhouse, Accommodation and Mooring Cost

Mooring Cost
- Semi-submersible: Baseline is $8,000,000 for 200'x200' rig in 1,000-foot depth
  Scale in proportion to $(\text{Length}/200)^{1.5}$ for larger rigs
- Ship-shape: Baseline is $3,000,000 for 225' ship in 1,000-foot depth
  Scale in proportion to $(\text{Length}/225)^{2/3}$ for larger ships
- Barge-shape: Baseline is $3,000,000 for 195' barge in 1,000-foot depth
  Scale in proportion to $(\text{Length}/195)^{2/3}$ for larger barges
- Variation with depth: (same for all vessel configurations)
  - At 1,000 feet, about 40% of cost is for mooring equipment
    This component will increase by 5% for each additional 1,000 feet
  - At 1,000 feet, about 60% of cost is for anchor line
    This component will increase linearly with depth beyond 1,000 feet
  - Example:
    - For 200'x200' semi-submersible, baseline = $8.0M for 1,000 foot depth
    - Equipment cost = 40% ($3.2M) for baseline 1,000 foot depth
      Equipment cost increases 5% (0.05x$3.2M) = $160,000 per 1,000 feet
    - Anchor line cost = 60% ($4.8M) for baseline 1,000 foot depth
      Anchor line cost increases linearly with depth = $4.8M per 1,000 feet
    - Thus for 200'x200' semi-submersible in 2,000 foot depth
      Cost is $8.0M + $4.8M + $0.160M = $12.96M
    - For 200'x200' semi-submersible in "D"-thousand foot depth
      Cost is $8.0M + [(D-1) x $4.8M] + [(D-1) x $0.160M]
  - For semis, ships and barges of any length:
    - First scale the "baseline cost" to length, as specified above
    - Then apply 60% and 40% factors to account for depth as per example

General Approach and Assumptions; Operating Expense (OpEx)

The following components of operating expense are included in this analysis:

- Crew Cost
    - Moored Semi-submersible; Minimum of one licensed officer plus two crew
    - DP Semi-submersible; Minimum of three licensed officers plus six crew
    - Ship, either moored or DP; Minimum of three licensed officers plus nine crew
    - Barge, self-propelled; Same as ship
    - Barge, non-self-propelled; Same as semi-submersible (Moored or DP)
- Maintenance
    - Hull inspection and survey for classification
    - Hull painting and protection
    - Deckhouse exterior painting and coating
    - Mechanical system maintenance and repair
- Insurance
    - Liability
    - Hull and Machinery
- Fuel Cost (excluding transit operations)
    - Electrical power generation (housekeeping loads)
    - Dynamic positioning power requirements

Crew salaries were obtained from a recently published survey of average monthly salaries paid by major operators in the cruise ship industry. Table 4 summarizes the manning and salaries assumed in this analysis:

Table 4 – Manning Assumptions and Crew Salaries
(in US dollars)

Annual Salary	Semi moored	Semi DP	Ship moored	Ship DP	Barge moored	Barge DP
Captain		84,000	84,000	84,000		84,000
1st Officer	48,000	48,000	48,000	48,000	48,000	48,000
2nd Officer		36,000	36,000	36,000		36,000
3rd Officer			24,000	24,000		
1st Engineer		72,000	72,000	72,000		72,000
2nd Engineer		48,000	48,000	48,000		48,000
3rd Engineer			36,000	36,000		
Bosun	24,000	24,000	24,000	24,000	24,000	24,000
Seaman	18,000	18,000	18,000	18,000	18,000	18,000
Seaman		18,000	18,000	18,000		18,000
Engineman		21,000	21,000	21,000		21,000
Engineman		21,000	21,000	21,000		21,000
Total	90,000	390,000	450,000	450,000	90,000	390,000

Estimates of maintenance costs are based on review of several published reports for a variety of ship types; not surprisingly, there is considerable variance in the published data. As a basis for this analysis, it was assumed that annual maintenance costs for the hull and deckhouse would be about 1 percent of the initial construction cost. This assumption is borne out by a detailed study of deep-draft ocean-going vessel operating costs conducted by the US Army Corps of Engineers for the period from 2004 to 2007. Recognizing the possibility that DP systems may require additional levels of maintenance, an additional margin of 0.25 percent was included for DP vessels.

Estimates of insurance cost were obtained from several published reports, and the figures for insurance were consistently equal to about 1% of initial construction cost.

Fuel cost is comprised of two major components; electrical power generation for housekeeping loads and dynamic positioning requirements. For housekeeping loads, the maximum generating capacity is based on 4.5-kW per person; to estimate fuel consumption, it is assumed that the average power load is approximately 50% of capacity, or an average consumption of 2.25-kW per person. This rate corresponds to slightly less than 20,000-kWh per year; this is higher than the national average of about 12,000-kWh per year, but not unreasonable considering that the seastead will have "housekeeping" requirements in addition to that required for the residential accommodations. Published data indicates that diesel generators consume about 72 gallons per hour per 1,000-kW of electricity produced; thus to produce 20,000-kWh per person per year will require approximately 20 x 72 = 1,440 gallons of diesel fuel per person per year. At current prices for marine diesel (assuming $5.00 per gallon, delivered) this would result in an annual fuel cost of about $7,200 per person.

For seasteads that utilize dynamic positioning systems, power must continually be applied to the thrusters to hold the vessel on location. Required power is highly dependent on average wind speed and current speed at the chosen location. For the purposes of this analysis, it is assumed that the seastead must withstand the combined effect of 1-knot current and 20-knot wind, on average. The corresponding drag forces on the hull and deckhouse are computed for each configuration, using appropriate drag coefficients, to obtain the total force that must be overcome by the thrusters. Using a nominal thruster efficiency (35-lb per horsepower), the average thruster power (converted to kW) is determined, from which the corresponding fuel consumption is obtained, as described in the preceding paragraph. For the wind and current conditions assumed, the fuel required for dynamic positioning is potentially greater than that required for housekeeping; in any event, it is concluded that fuel costs are likely to be a major component in the operating costs of a seastead.

COST SUMMARIES AND COMPARISONS

A top-level summary of costs for each configuration is given in Table 5 below. Detailed tables and graphs are provided in the remainder of this report for each configuration considered.

All configurations exhibit substantial economies of scale; for example, the cost per square foot for the baseline semi-submersible is $832 for the 200'x200' configuration, decreasing to $503 for the 500'x500' version.

The smallest semi-submersible considered (200'x200') has a construction cost of about $66M, with the capacity to accommodate 136 people. The cost of a 600-square-foot residential unit would be approximately $540,000.

By comparison, the smallest ship-shape (225' long) has a construction cost of only about $20M, with the capacity to accommodate 72 people. The cost of a 600-square-foot residential unit would be approximately $375,000.

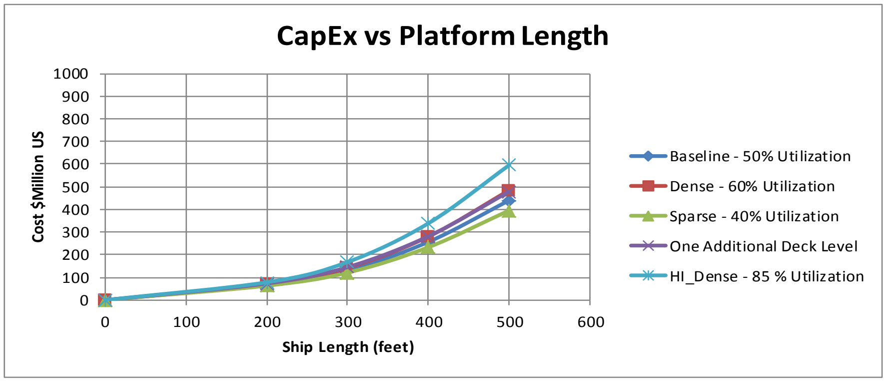
Table 5 – Summary of Estimated Construction Costs

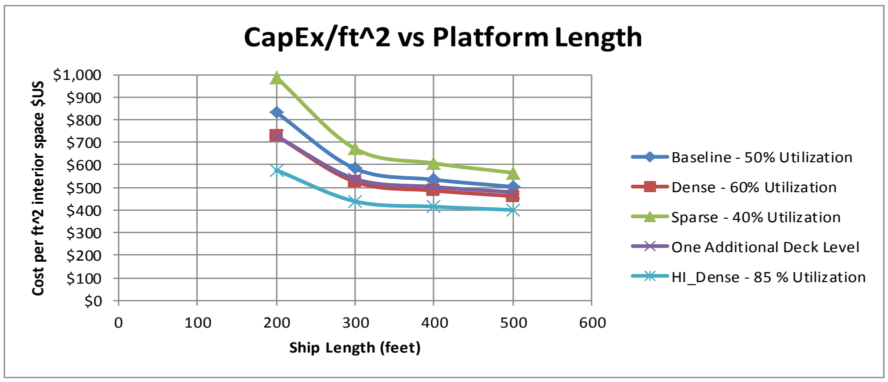
Configuration	Length (feet)	Beam (feet)	No. of People	Total Cost $US	Cost per Sq. Foot*	Cost per Res. Unit**
Baseline Semi-submersible	200	200	136	$66.6M	$832	$540K
	300	300	432	$131.3M	$584	$379K
	400	400	1,024	$256.6M	$535	$347K
	500	500	2,000	$440.0M	$503	$327K
Ship-shape	225	45	72	$19.9M	$578	$375K
	450	75	336	$82.7M	$481	$312K
	750	105	1,176	$236.0M	$438	$285K
	1,050	170	3,960	$702.0M	$386	$250K
Barge-shape	195	35	28	$10.6M	$691	$449K
	312	75	192	$47.5M	$450	$293K
	625	150	1792	$291.2M	$377	$245K
	935	225	6000	$903.6M	$358	$232K

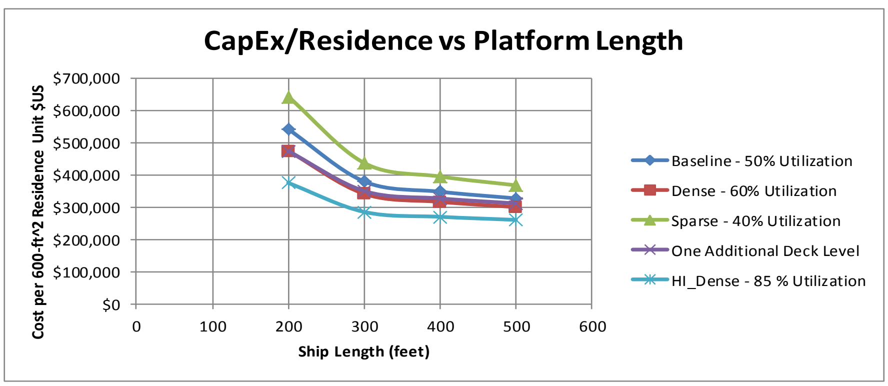
*assumes that the total cost is amortized over the total interior area, residential plus retail
**cost of each residential unit includes associated "common area," i.e., hallway, stairs, elevator

Graphs illustrating trends in CapEx and OpEx for a range of seastead sizes are provided in the following set of Figures, 4a-c and 5a-d. Detailed tabulations for each configuration are included as Tables 6a-e, 7, and 8.

Figure 4a - CapEx Comparison for all Semi-submersible seasteads







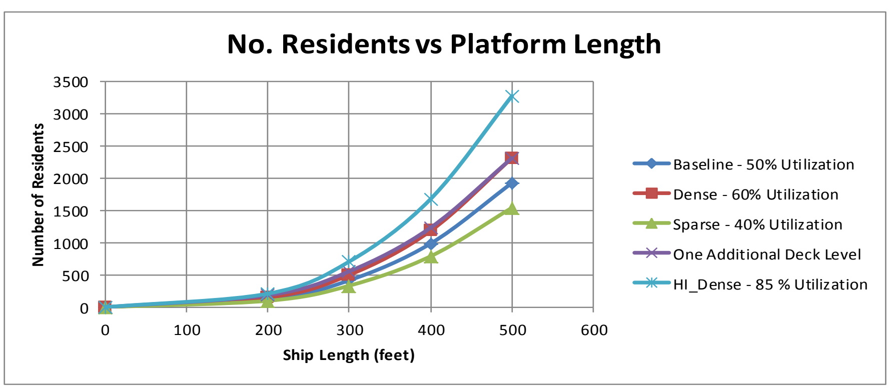
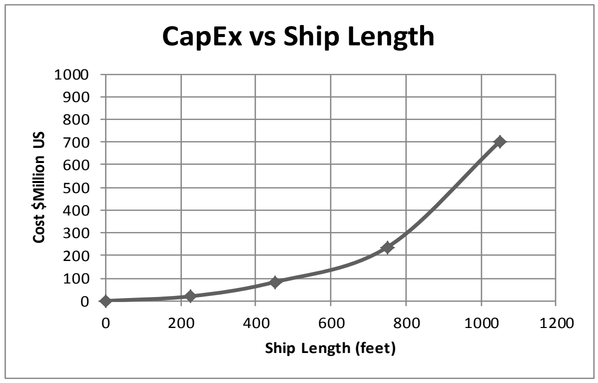
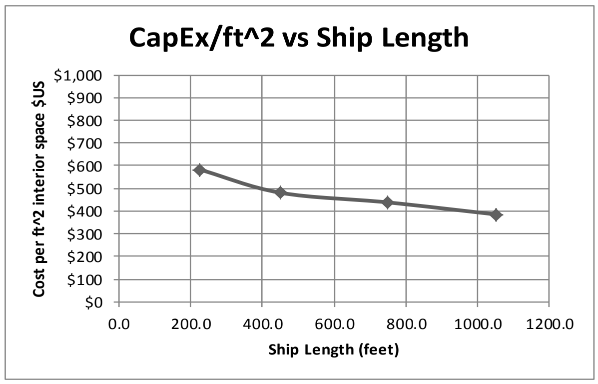
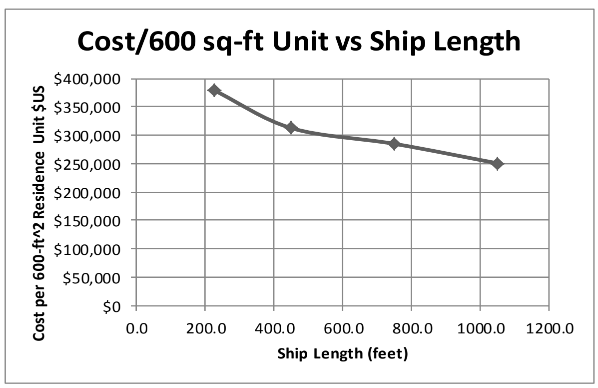


Figure 4b - CapEx Comparison for all Ship-shape seasteads







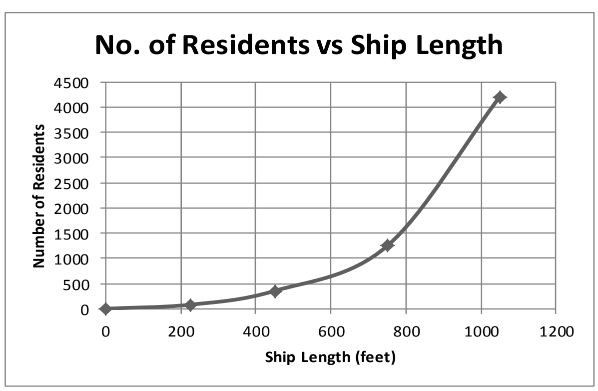
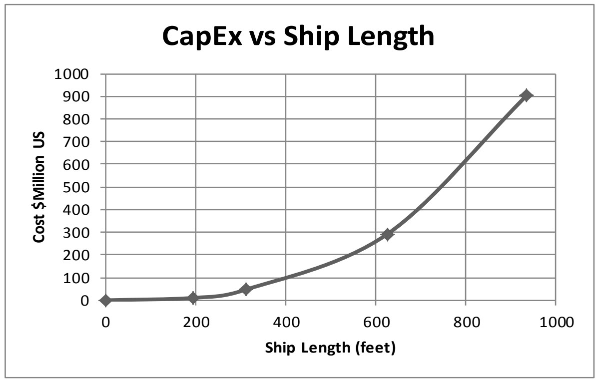
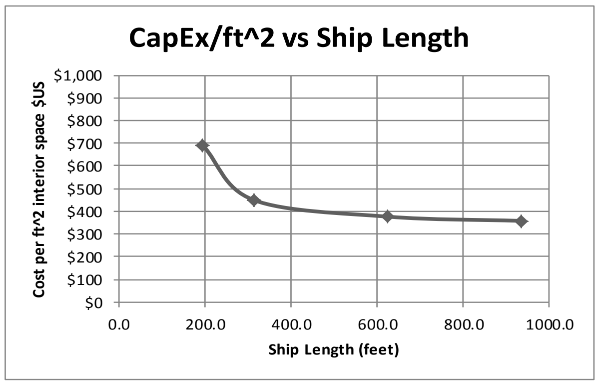
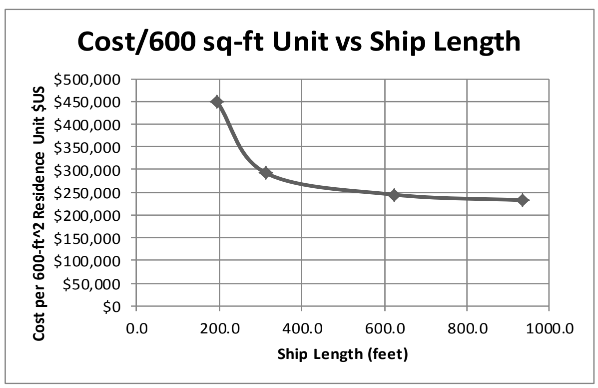


Figure 4c - CapEx Comparison for all Barge-shape seasteads







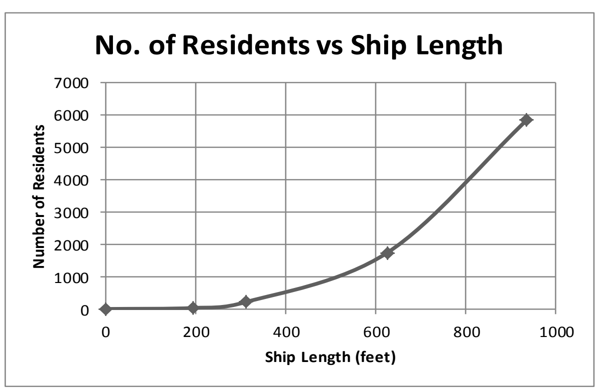
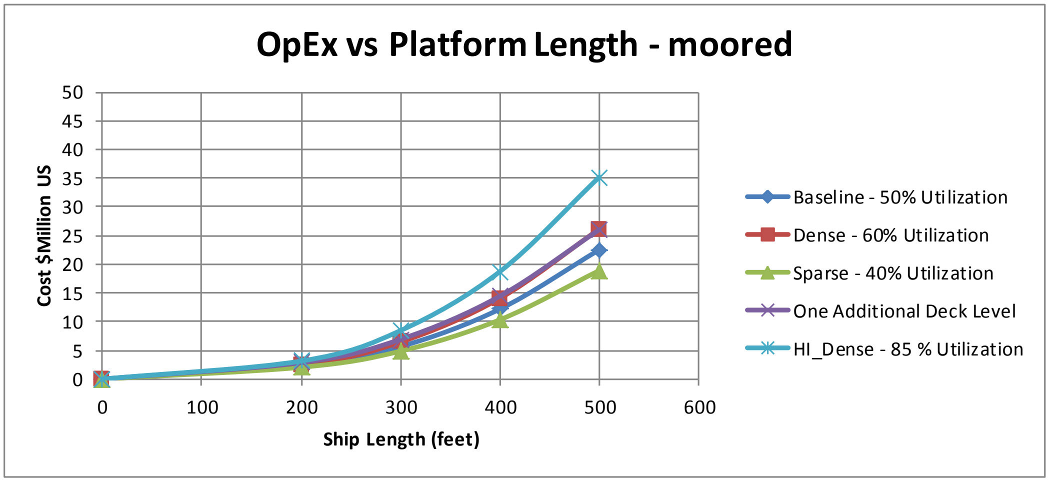
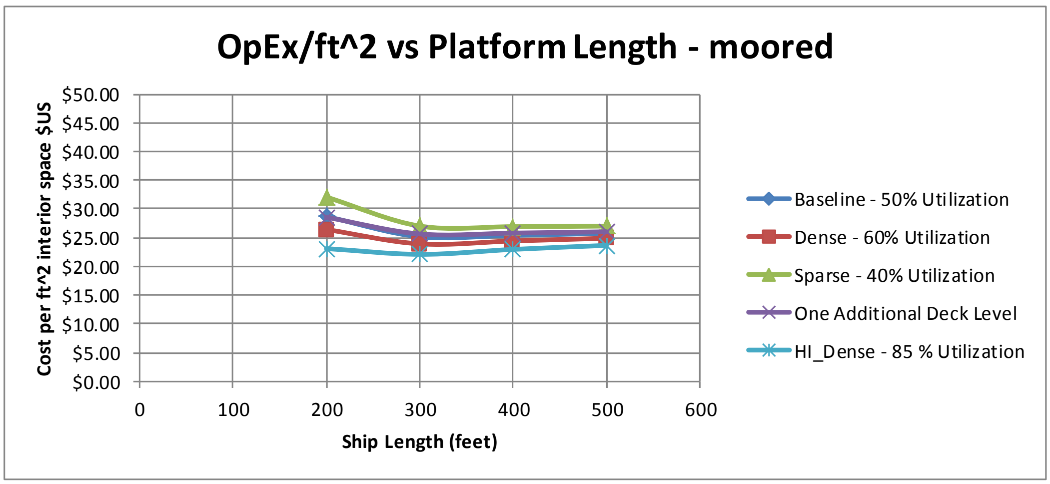


Figure 5a - OpEx Comparison for moored Semi-submersible seasteads





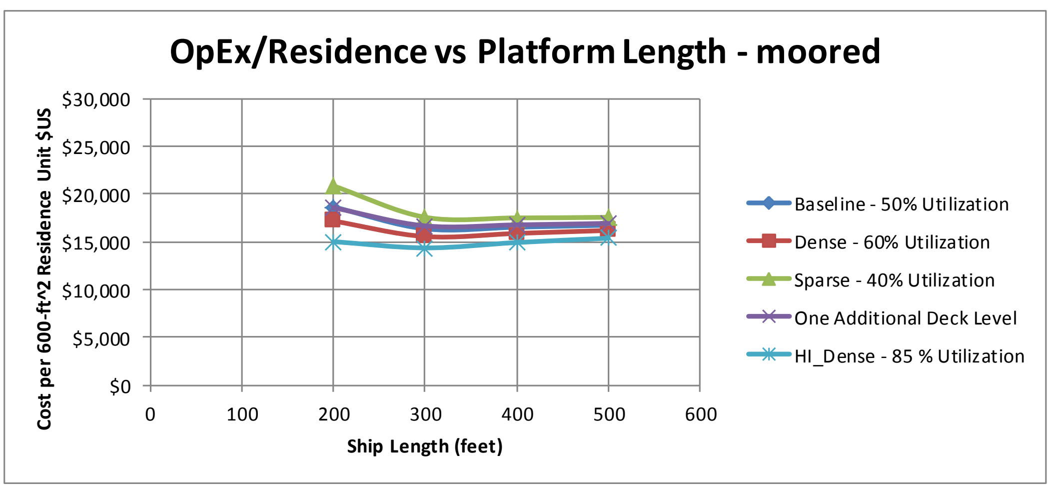
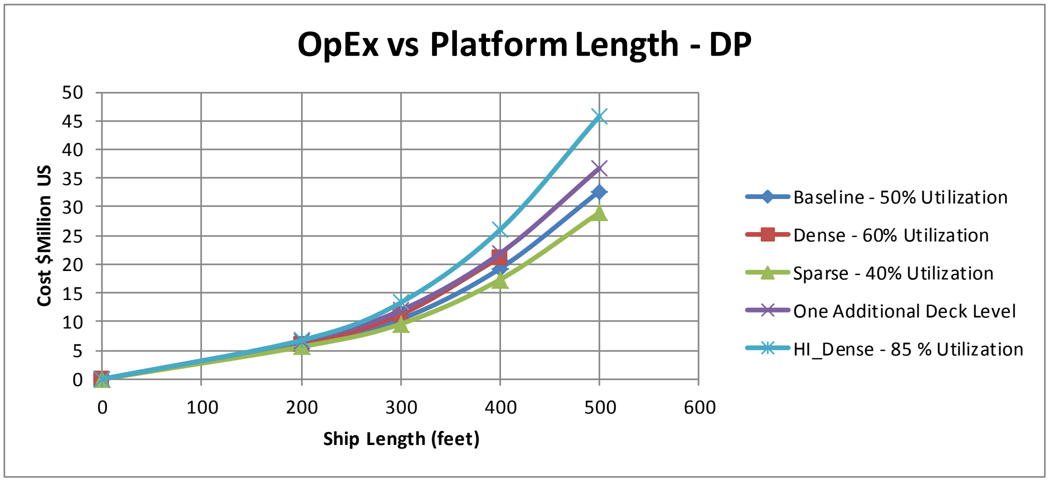
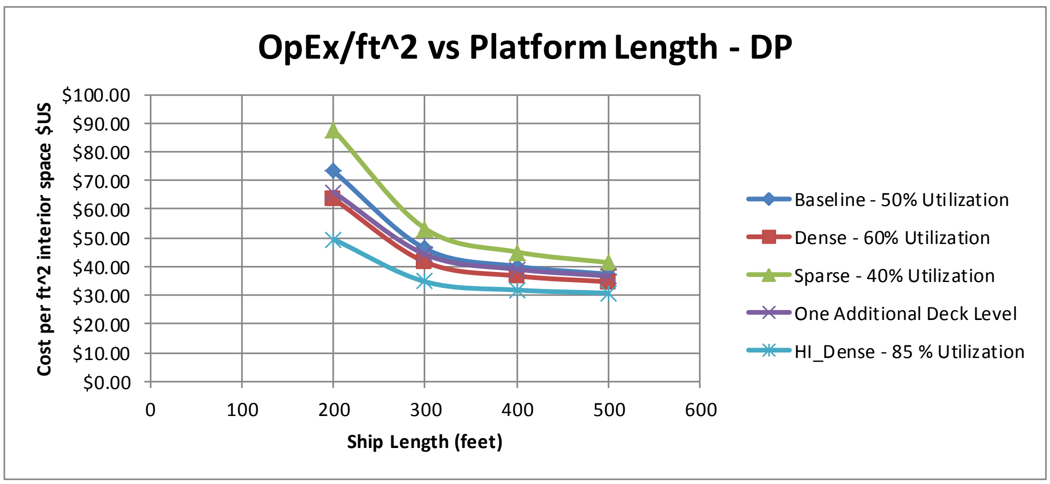


Figure 5b - OpEx Comparison for DP Semi-submersible seasteads





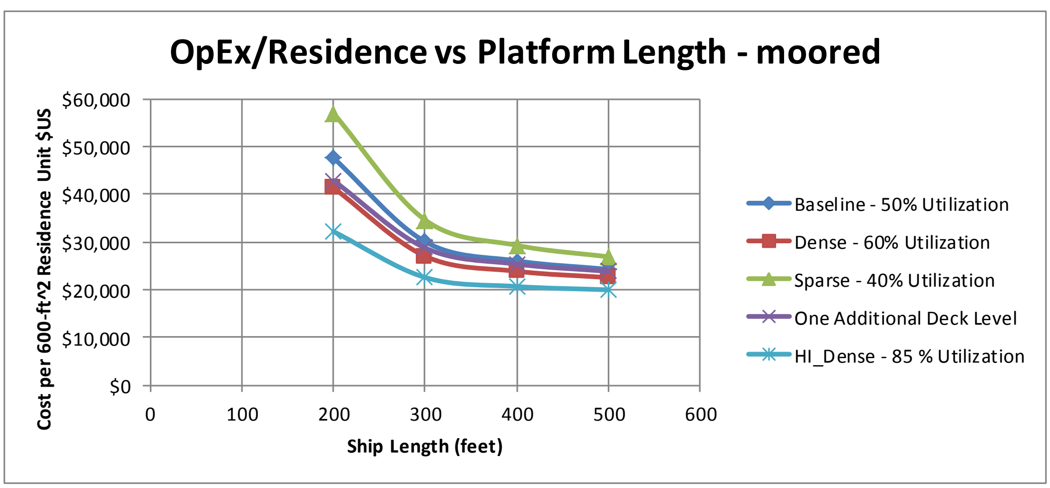
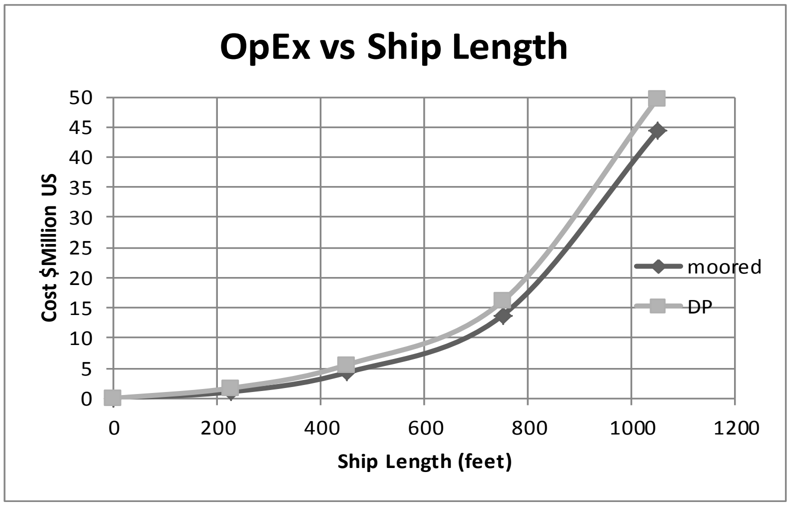
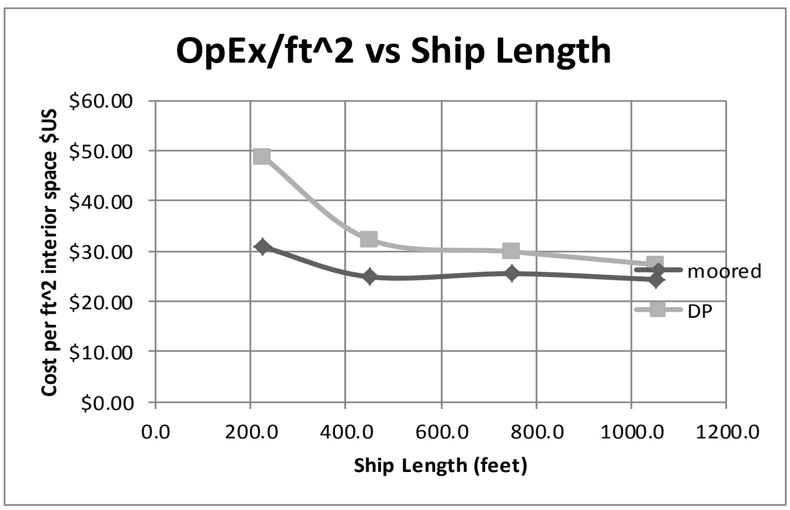


Figure 5c - OpEx Comparison for Ship-shape seasteads; moored and DP





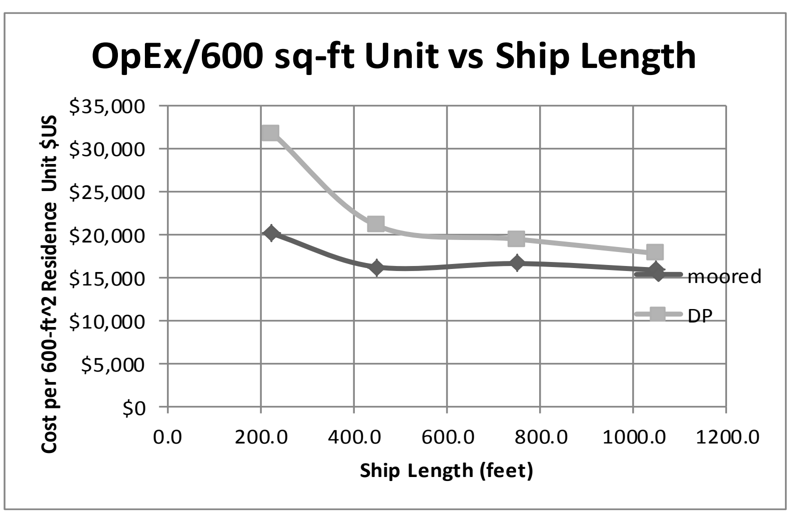
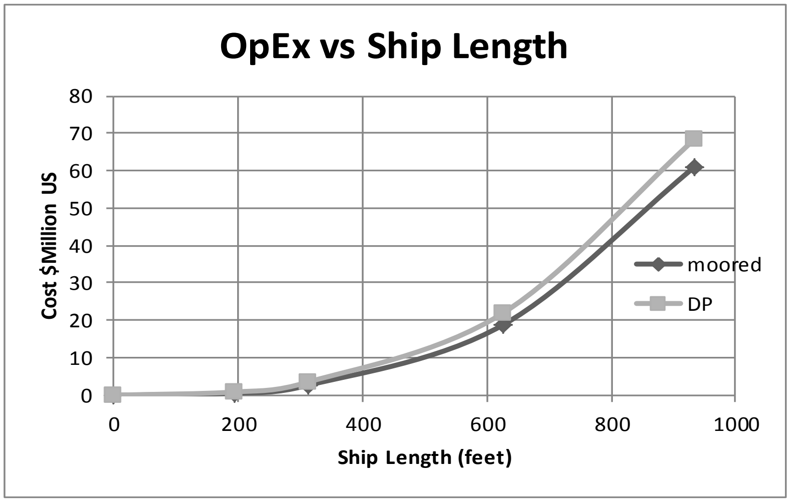
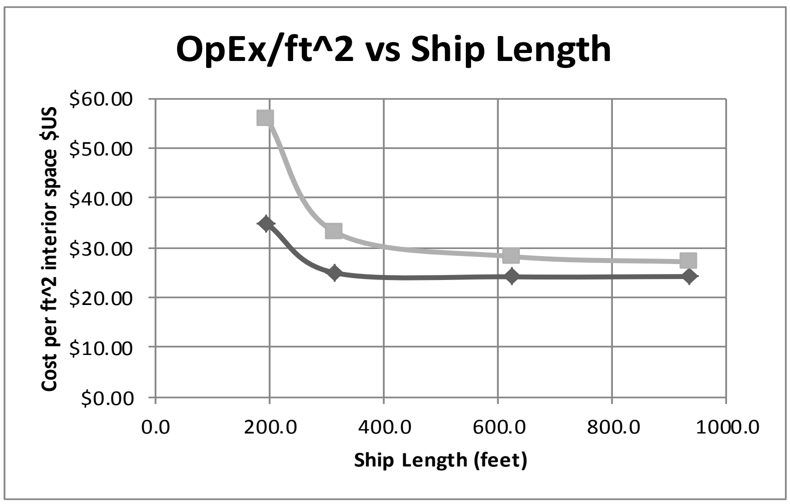
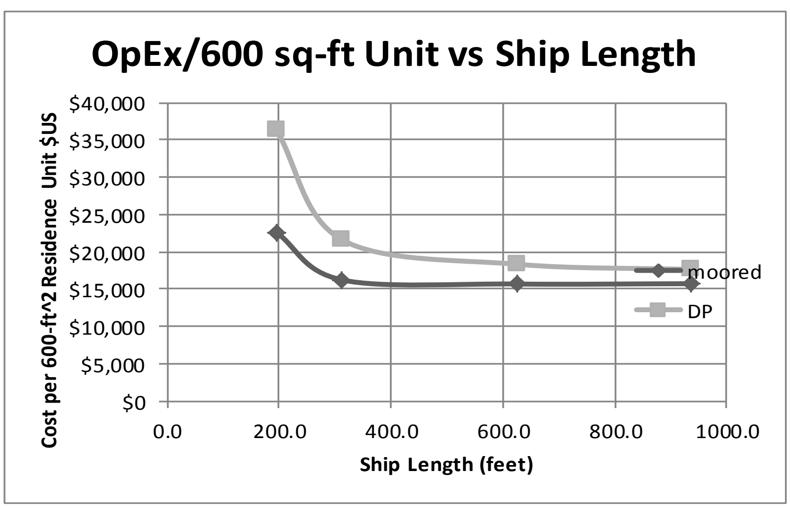


Figure 5d - OpEx Comparison for Barge-shape seasteads; moored and DP







Cost Estimate for Semi-submersible with Ring Pontoon

Table 6a - Baseline Configuration – 50% Utilization of Deck Area

		LBP (feet)		200		300		400		500
		Beam (feet)		200		300		400		500
		Draft (feet)		70		70		75		80
		Air Gap (feet)		40		40		40		40
		Depth (feet)		110		110		115		120
		Total Hull Volume (ft^3)		476,800		572,800		1,106,440		1,947,480
US$/LT	10,000	Hull Steel Cost		$22,857,143		$28,000,000		$54,049,429		$90,600,714
US$/LT	7,000	Deckhouse Cost		$11,812,500		$32,273,438		$67,500,000		$121,289,063
US$/LT	7,000	Main Deck Cost		$5,500,000		$12,375,000		$22,000,000		$34,375,000
US$/pax	50,000	Accommodation Cost		$9,230,769		$27,692,308		$61,538,462		$115,384,615
US$		Mooring System Cost		$8,000,000		$14,696,938		$22,627,417		$31,622,777
US$/kW	550	Propulsion System Cost		$0		$0		$0		$0
US$		Mechanical System Cost		$3,000,000		$4,500,000		$6,000,000		$7,500,000
US$/kW	350	Electrical System Cost		$726,923		$2,453,365		$5,815,385		$11,358,173
US$	7.0%	Engineering Cost		$2,811,875		$5,085,391		$10,048,460		$17,238,534
US$	3.0%	Program Mgmt Cost		$1,445,089		$2,620,361		$4,985,305		$8,336,627
US$/day	200,000	Installation Days / Cost	6	$1,200,000	8	$1,600,000	10	$2,000,000	12	$2,400,000
		Total Cost, less transport		$66,584,299		$131,296,801		$256,564,457		$440,105,503
		Interior Public Area (ft^2)		40,000		90,000		160,000		250,000
		Residential Area (ft^2)		40,000		135,000		320,000		625,000
		Total Interior Area (ft^2)		80,000		225,000		480,000		875,000
		Cost per square foot		$832		$584		$535		$503
		Cost per residence unit		$540,997		$379,302		$347,431		$326,936
		Percentage Public Area		50.0%		40.0%		33.3%		28.6%
		Percentage Residential		50.0%		60.0%		66.7%		71.4%
		Annual Crew Cost - moored		$90,000		$90,000		$90,000		$90,000
		Annual Crew Cost - DP		$450,000		$450,000		$450,000		$450,000
% CapEx	1.00%	Maintenance Cost - moored		$665,843		$1,312,968		$2,565,645		$4,401,055
% CapEx	1.25%	Maintenance Cost - DP		$832,304		$1,641,210		$3,207,056		$5,501,319
% CapEx	0.75%	Insurance Cost - Liability		$499,382		$984,726		$1,924,233		$3,300,791
% CapEx	0.25%	Insurance Cost - Hull/Mach		$166,461		$328,242		$641,411		$1,100,264
Avg Load	50%	Average Housekeeping kW		277		935		2,215		4,327
		Average DP Thrusters kW		963		1,288		1,914		2,762
gph/1000kW	72	Annual Fuel Burn - House		174,661		589,481		1,397,287		2,729,077
gph/1000kW	72	Annual Fuel Burn - DP		607,644		812,323		1,206,955		1,742,238
Fuel Price	$5.00	Annual Fuel Cost - moored		$873,305		$2,947,403		$6,986,437		$13,645,385
Fuel Price	$5.00	Annual Fuel Cost - DP		$3,911,524		$7,009,017		$13,021,212		$22,356,574
		Total Annual Cost - moored		$2,294,991		$5,663,339		$12,207,726		$22,537,495
		Total Annual Cost - DP		$5,859,671		$10,413,195		$19,243,912		$32,708,947
		OpEx per sq-foot - moored		$28.69		$25.17		$25.43		$25.76
		OpEx per sq-foot - DP		$73.25		$46.28		$40.09		$37.38
		OpEx per res. unit - moored		$18,647		$16,361		$16,531		$16,742
		OpEx per res. unit - DP		$47,610		$30,083		$26,059		$24,298

Cost Estimate for Semi-submersible with Ring Pontoon

Table 6b - Larger Deckhouse Footprint – 60% Utilization of Deck Area

		LBP (feet)		200		300		400		500
		Beam (feet)		200		300		400		500
		Draft (feet)		70		70		75		80
		Air Gap (feet)		40		40		40		40
		Depth (feet)		110		110		115		120
		Total Hull Volume (ft^3)		476,800		572,800		1,106,440		1,947,480
US$/LT	10,000	Hull Steel Cost		$22,857,143		$28,000,000		$54,049,429		$90,600,714
US$/LT	7,000	Deckhouse Cost		$14,175,000		$38,728,125		$81,000,000		$145,546,875
US$/LT	7,000	Main Deck Cost		$4,400,000		$9,900,000		$17,600,000		$27,500,000
US$/pax	50,000	Accommodation Cost		$11,076,923		$33,230,769		$73,846,154		$138,461,538
US$		Mooring System Cost		$8,000,000		$14,696,938		$22,627,417		$31,622,777
US$/kW	550	Propulsion System Cost		$0		$0		$0		$0
US$		Mechanical System Cost		$3,000,000		$4,500,000		$6,000,000		$7,500,000
US$/kW	350	Electrical System Cost		$872,308		$2,944,038		$6,978,462		$13,629,808
US$	7.0%	Engineering Cost		$2,900,250		$5,363,969		$10,685,460		$18,455,331
US$	3.0%	Program Mgmt Cost		$1,482,964		$2,739,752		$5,258,305		$8,858,111
US$/day	200,000	Installation Days / Cost	6	$1,200,000	8	$1,600,000	10	$2,000,000	12	$2,400,000
		Total Cost, less transport		$69,964,588		$141,703,592		$280,045,226		$484,575,154
		Interior Public Area (ft^2)		48,000		108,000		192,000		300,000
		Residential Area (ft^2)		48,000		162,000		384,000		750,000
		Total Interior Area (ft^2)		96,000		270,000		576,000		1,050,000
		Cost per square foot		$729		$525		$486		$462
		Cost per residence unit		$473,719		$341,138		$316,023		$299,975
		Percentage Public Area		50.0%		40.0%		33.3%		28.6%
		Percentage Residential		50.0%		60.0%		66.7%		71.4%
		Annual Crew Cost - moored		$90,000		$90,000		$90,000		$90,000
		Annual Crew Cost - DP		$450,000		$450,000		$450,000		$450,000
% CapEx	1.00%	Maintenance Cost - moored		$699,646		$1,417,036		$2,800,452		$4,845,752
% CapEx	1.25%	Maintenance Cost - DP		$874,557		$1,771,295		$3,500,565		$6,057,189
% CapEx	0.75%	Insurance Cost - Liability		$524,734		$1,062,777		$2,100,339		$3,634,314
% CapEx	0.25%	Insurance Cost - Hull/Mach		$174,911		$354,259		$700,113		$1,211,438
Avg Load	50%	Average Housekeeping kW		332		1,122		2,658		5,192
		Average DP Thrusters kW		963		1,288		1,914		2,762
gph/1000kW	72	Annual Fuel Burn - House		209,593		707,377		1,676,745		3,274,892
gph/1000kW	72	Annual Fuel Burn - DP		607,644		812,323		1,206,955		1,742,238
Fuel Price	$5.00	Annual Fuel Cost - moored		$1,047,966		$3,536,884		$8,383,724		$16,374,462
Fuel Price	$5.00	Annual Fuel Cost - DP		$4,086,185		$7,598,497		$14,418,499		$25,085,651
		Total Annual Cost - moored		$2,537,257		$6,460,956		$14,074,629		$26,155,965
		Total Annual Cost - DP		$6,110,388		$11,236,828		$21,169,517		$36,438,591
		OpEx per sq-foot - moored		$26.43		$23.93		$24.44		$24.91
		OpEx per sq-foot - DP		$63.65		$41.62		$36.75		$34.70
		OpEx per res. unit - moored		$17,179		$15,554		$15,883		$16,192
		OpEx per res. unit - DP		$41,372		$27,052		$23,889		$22,557

Cost Estimate for Semi-submersible with Ring Pontoon

Table 6c - Smaller Deckhouse Footprint – 40% Utilization of Deck Area

		LBP (feet)		200		300		400		500
		Beam (feet)		200		300		400		500
		Draft (feet)		70		70		75		80
		Air Gap (feet)		40		40		40		40
		Depth (feet)		110		110		115		120
		Total Hull Volume (ft^3)		476,800		572,800		1,106,440		1,947,480
US$/LT	10,000	Hull Steel Cost		$22,857,143		$28,000,000		$54,049,429		$90,600,714
US$/LT	7,000	Deckhouse Cost		$9,450,000		$25,818,750		$54,000,000		$97,031,250
US$/LT	7,000	Main Deck Cost		$6,600,000		$14,850,000		$26,400,000		$41,250,000
US$/pax	50,000	Accommodation Cost		$7,384,615		$22,153,846		$49,230,769		$92,307,692
US$		Mooring System Cost		$8,000,000		$14,696,938		$22,627,417		$31,622,777
US$/kW	550	Propulsion System Cost		$0		$0		$0		$0
US$		Mechanical System Cost		$3,000,000		$4,500,000		$6,000,000		$7,500,000
US$/kW	350	Electrical System Cost		$581,538		$1,962,692		$4,652,308		$9,086,538
US$	7.0%	Engineering Cost		$2,723,500		$4,806,813		$9,411,460		$16,021,738
US$	3.0%	Program Mgmt Cost		$1,407,214		$2,500,971		$4,712,305		$7,815,142
US$/day	200,000	Installation Days / Cost	6	$1,200,000	8	$1,600,000	10	$2,000,000	12	$2,400,000
		Total Cost, less transport		$63,204,011		$120,890,010		$233,083,688		$395,635,851
		Interior Public Area (ft^2)		32,000		72,000		128,000		200,000
		Residential Area (ft^2)		32,000		108,000		256,000		500,000
		Total Interior Area (ft^2)		64,000		180,000		384,000		700,000
		Cost per square foot		$988		$672		$607		$565
		Cost per residence unit		$641,916		$436,547		$394,543		$367,376
		Percentage Public Area		50.0%		40.0%		33.3%		28.6%
		Percentage Residential		50.0%		60.0%		66.7%		71.4%
		Annual Crew Cost - moored		$90,000		$90,000		$90,000		$90,000
		Annual Crew Cost - DP		$450,000		$450,000		$450,000		$450,000
% CapEx	1.00%	Maintenance Cost - moored		$632,040		$1,208,900		$2,330,837		$3,956,359
% CapEx	1.25%	Maintenance Cost - DP		$790,050		$1,511,125		$2,913,546		$4,945,448
% CapEx	0.75%	Insurance Cost - Liability		$474,030		$906,675		$1,748,128		$2,967,269
% CapEx	0.25%	Insurance Cost - Hull/Mach		$158,010		$302,225		$582,709		$989,090
Avg Load	50%	Average Housekeeping kW		222		748		1,772		3,462
		Average DP Thrusters kW		963		1,288		1,914		2,762
gph/1000kW	72	Annual Fuel Burn - House		139,729		471,584		1,117,830		2,183,262
gph/1000kW	72	Annual Fuel Burn - DP		607,644		812,323		1,206,955		1,742,238
Fuel Price	$5.00	Annual Fuel Cost - moored		$698,644		$2,357,922		$5,589,150		$10,916,308
Fuel Price	$5.00	Annual Fuel Cost - DP		$3,736,863		$6,419,536		$11,623,925		$19,627,497
		Total Annual Cost - moored		$2,052,724		$4,865,723		$10,340,823		$18,919,025
		Total Annual Cost - DP		$5,608,953		$9,589,561		$17,318,308		$28,979,303
		OpEx per sq-foot - moored		$32.07		$27.03		$26.93		$27.03
		OpEx per sq-foot - DP		$87.64		$53.28		$45.10		$41.40
		OpEx per res. unit - moored		$20,848		$17,571		$17,504		$17,568
		OpEx per res. unit - DP		$56,966		$34,629		$29,315		$26,909

Cost Estimate for Semi-submersible with Ring Pontoon

Table 6d - One Additional Deck Level – 50% Utilization of Area

			LBP (feet)		200		300		400		500
			Beam (feet)		200		300		400		500
			Draft (feet)		70		70		75		80
			Air Gap (feet)		40		40		40		40
			Depth (feet)		110		110		115		120
			Total Hull Volume (ft^3)		476,800		572,800		1,106,440		1,947,480
	US$/LT	10,000	Hull Steel Cost		$22,857,143		$28,000,000		$54,049,429		$90,600,714
	US$/LT	7,000	Deckhouse Cost		$14,343,750		$37,968,750		$77,625,000		$137,109,375
	US$/LT	7,000	Main Deck Cost		$5,500,000		$12,375,000		$22,000,000		$34,375,000
	US$/pax	50,000	Accommodation Cost		$12,307,692		$34,615,385		$73,846,154		$134,615,385
	US$		Mooring System Cost		$8,000,000		$14,696,938		$22,627,417		$31,622,777
	US$/kW	550	Propulsion System Cost		$0		$0		$0		$0
	US$		Mechanical System Cost		$3,000,000		$4,500,000		$6,000,000		$7,500,000
	US$/kW	350	Electrical System Cost		$1,090,385		$3,271,154		$7,269,231		$13,629,808
	US$	7.0%	Engineering Cost		$2,989,063		$5,484,063		$10,757,210		$18,345,956
	US$	3.0%	Program Mgmt Cost		$1,521,027		$2,791,221		$5,289,055		$8,811,236
	US$/day	200,000	Installation Days / Cost	6	$1,200,000	8	$1,600,000	10	$2,000,000	12	$2,400,000
			Total Cost, less transport		$72,809,059		$145,302,510		$281,463,496		$479,010,250
			Interior Public Area (ft^2)		40,000		90,000		160,000		250,000
			Residential Area (ft^2)		60,000		180,000		400,000		750,000
			Total Interior Area (ft^2)		100,000		270,000		560,000		1,000,000
			Cost per square foot		$728		$538		$503		$479
			Cost per residence unit		$473,259		$349,802		$326,699		$311,357
			Percentage Public Area		40.0%		33.3%		28.6%		25.0%
			Percentage Residential		60.0%		66.7%		71.4%		75.0%
			Annual Crew Cost - moored		$90,000		$90,000		$90,000		$90,000
			Annual Crew Cost - DP		$450,000		$450,000		$450,000		$450,000
	% CapEx	1.00%	Maintenance Cost - moored		$728,091		$1,453,025		$2,814,635		$4,790,103
	% CapEx	1.25%	Maintenance Cost - DP		$910,113		$1,816,281		$3,518,294		$5,987,628
	% CapEx	0.75%	Insurance Cost - Liability		$546,068		$1,089,769		$2,110,976		$3,592,577
	% CapEx	0.25%	Insurance Cost - Hull/Mach		$182,023		$363,256		$703,659		$1,197,526
	Avg Load	50%	Average Housekeeping kW		415		1,246		2,769		5,192
			Average DP Thrusters kW		1,014		1,365		2,016		2,890
	gph/1000kW	72	Annual Fuel Burn - House		261,991		785,974		1,746,609		3,274,892
	gph/1000kW	72	Annual Fuel Burn - DP		639,848		860,630		1,271,364		1,822,749
	Fuel Price	$5.00	Annual Fuel Cost - moored		$1,309,957		$3,929,871		$8,733,046		$16,374,462
	Fuel Price	$5.00	Annual Fuel Cost - DP		$4,509,199		$8,233,019		$15,089,867		$25,488,208
			Total Annual Cost - moored		$2,856,138		$6,925,921		$14,452,316		$26,044,667
			Total Annual Cost - DP		$6,597,403		$11,952,325		$21,872,796		$36,715,939
			OpEx per sq-foot - moored		$28.56		$25.65		$25.81		$26.04
			OpEx per sq-foot - DP		$65.97		$44.27		$39.06		$36.72
			OpEx per res. unit - moored		$18,565		$16,674		$16,775		$16,929
			OpEx per res. unit - DP		$42,883		$28,774		$25,388		$23,865

Cost Estimate for Semi-submersible with Ring Pontoon

Table 6e – Hi-Density Layout – 85% Utilization of Area

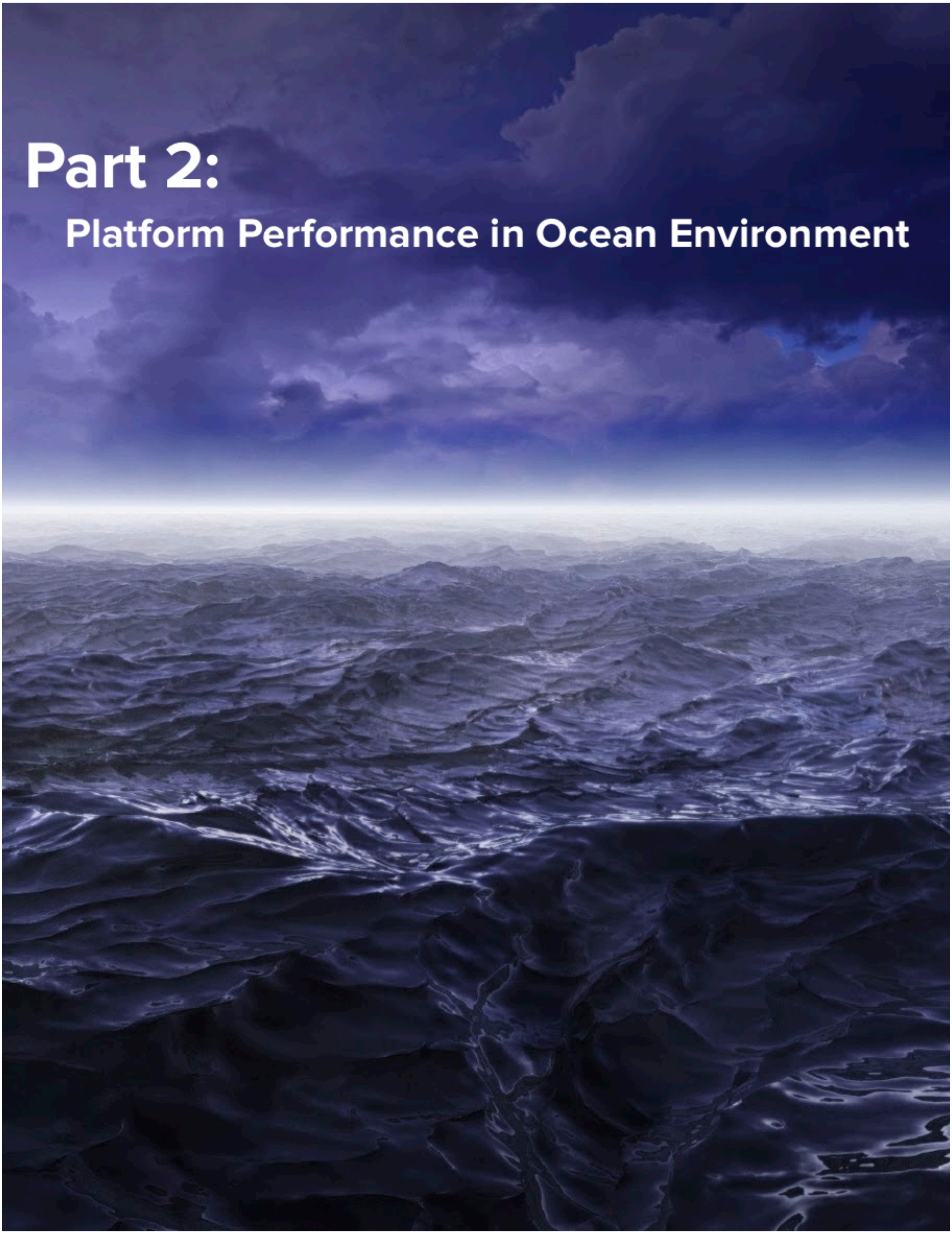
		LBP (feet)		200		300		400		500
		Beam (feet)		200		300		400		500
		Draft (feet)		70		70		75		80
		Air Gap (feet)		40		40		40		40
		Depth (feet)		110		110		115		120
		Total Hull Volume (ft^3)		476,800		572,800		1,106,440		1,947,480
US$/LT	10,000	Hull Steel Cost		$22,857,143		$28,000,000		$54,049,429		$90,600,714
US$/LT	7,000	Deckhouse Cost		$20,081,250		$54,864,844		$114,750,000		$206,191,406
US$/LT	7,000	Main Deck Cost		$1,650,000		$3,712,500		$6,600,000		$10,312,500
US$/pax	50,000	Accommodation Cost		$15,692,308		$47,076,923		$104,615,385		$196,153,846
US$		Mooring System Cost		$8,000,000		$14,696,938		$22,627,417		$31,622,777
US$/kW	550	Propulsion System Cost		$0		$0		$0		$0
US$		Mechanical System Cost		$3,000,000		$4,500,000		$6,000,000		$7,500,000
US$/kW	350	Electrical System Cost		$1,235,769		$4,170,721		$9,886,154		$19,308,894
US$	7.0%	Engineering Cost		$3,121,188		$6,060,414		$12,277,960		$21,497,323
US$	3.0%	Program Mgmt Cost		$1,577,652		$3,038,228		$5,940,805		$10,161,822
US$/day	200,000	Installation Days / Cost	6	$1,200,000	8	$1,600,000	10	$2,000,000	12	$2,400,000
		Total Cost, less transport		$78,415,309		$167,720,569		$338,747,149		$595,749,283
		Interior Public Area (ft^2)		68,000		153,000		272,000		425,000
		Residential Area (ft^2)		68,000		229,500		544,000		1,062,500
		Total Interior Area (ft^2)		136,000		382,500		816,000		1,487,500
		Cost per square foot		$577		$438		$415		$401
		Cost per residence unit		$374,779		$285,015		$269,835		$260,327
		Percentage Public Area		50.0%		40.0%		33.3%		28.6%
		Percentage Residential		50.0%		60.0%		66.7%		71.4%
		Annual Crew Cost - moored		$90,000		$90,000		$90,000		$90,000
		Annual Crew Cost - DP		$450,000		$450,000		$450,000		$450,000
% CapEx	1.00%	Maintenance Cost - moored		$784,153		$1,677,206		$3,387,471		$5,957,493
% CapEx	1.25%	Maintenance Cost - DP		$980,191		$2,096,507		$4,234,339		$7,446,866
% CapEx	0.75%	Insurance Cost - Liability		$588,115		$1,257,904		$2,540,604		$4,468,120
% CapEx	0.25%	Insurance Cost - Hull/Mach		$196,038		$419,301		$846,868		$1,489,373
Avg Load	50%	Average Housekeeping kW		471		1,589		3,766		7,356
		Average DP Thrusters kW		963		1,288		1,914		2,762
gph/1000kW	72	Annual Fuel Burn - House		296,924		1,002,117		2,375,389		4,639,431
gph/1000kW	72	Annual Fuel Burn - DP		607,644		812,323		1,206,955		1,742,238
Fuel Price	$5.00	Annual Fuel Cost - moored		$1,484,618		$5,010,585		$11,876,943		$23,197,154
Fuel Price	$5.00	Annual Fuel Cost - DP		$4,522,837		$9,072,199		$17,911,718		$31,908,343
		Total Annual Cost - moored		$3,142,924		$8,454,997		$18,741,886		$35,202,140
		Total Annual Cost - DP		$6,737,182		$13,295,912		$25,983,529		$45,762,702
		OpEx per sq-foot - moored		$23.11		$22.10		$22.97		$23.67
		OpEx per sq-foot - DP		$49.54		$34.76		$31.84		$30.76
		OpEx per res. unit - moored		$15,021		$14,368		$14,929		$15,382
		OpEx per res. unit - DP		$32,200		$22,594		$20,698		$19,997

Table 7 – Cost Summary for Ship-Shaped Seastead

Cost Estimate - BASS method									
LBP (feet)		225.0		450.0		750.0		1050.0	
Beam (feet)		45.0		75.0		105.6		170.0	
Depth (feet)		18.0		26.0		42.0		60.0	
Block Coefficient, Cb		0.65		0.65		0.65		0.65	
Draft (feet)		12.2		18.4		25.5		36.9	
Displacement (LT)		2,292		11,508		37,439		122,351	
Hull Steel Cost		$4,733,453	9,000	$19,483,934	7,000	$56,690,450	6,000	$162,630,918	6,000
Deckhouse Cost		$4,533,430	7,000	$20,188,556	6,000	$50,659,284	5,000	$171,262,922	5,000
Accommodation Cost		$3,972,115		$17,653,846		$62,141,538		$210,080,769	
Mooring System Cost		$3,022,103		$8,861,919		$19,457,703		$42,849,363	
Propulsion System Cost		$382,848		$2,623,469		$7,172,450		$10,963,565	
Mechanical System Cost		$1,148,544		$5,246,939		$14,344,900		$21,927,129	
Electrical System Cost		$475,462		$2,113,165		$7,438,342		$25,146,668	
Engineering Cost		$926,730		$4,012,844		$11,864,389		$38,078,223	
Program Mgmt Cost		$487,833		$1,985,648		$5,668,469		$17,604,719	
Installation Days / Cost	2	$400,000	3	$600,000	5	$600,000	7	$1,400,000	2
Total Cost, less transport		$20,082,518		$82,770,320		$236,037,526		$701,944,276	
Interior Public Area (ft^2)		8,606		57,375		134,640		455,175	
Residential Area (ft^2)		25,819		114,750		403,920		1,365,525	
Total Interior Area (ft^2)		34,425		172,125		538,560		1,820,700	
Cost per square foot		$583		$481		$438		$386	
Cost per residence unit		$379,191		$312,568		$284,879		$250,598	
Percentage Public Area		25.0%		33.3%		25.0%		25.0%	
Percentage Residential		75.0%		66.7%		75.0%		75.0%	
Annual Crew Cost - moored		$90,000		$90,000		$90,000		$90,000	
Annual Crew Cost - DP		$375,000		$450,000		$450,000		$450,000	
Maintenance Cost - moored		$200,825		$827,703		$2,360,375		$7,019,443	
Maintenance Cost - DP		$251,031		$1,034,629		$2,950,469		$8,774,303	
Insurance Cost - Liability		$150,619		$620,777		$1,770,281		$5,264,582	
Insurance Cost - Hull/Mach		$50,206		$206,926		$590,094		$1,754,861	
Average Housekeeping kW		181		805		2,834		9,580	
Average DP Thrusters kW		90		225		442		1,046	
Annual Fuel Burn - House		114,241		507,739		1,787,242		6,042,098	
Annual Fuel Burn - DP		56,505		142,015		278,728		659,742	
Annual Fuel Cost - moored		$571,207		$2,538,697		$8,936,212		$30,210,489	
Annual Fuel Cost - DP		$853,733		$3,248,773		$10,329,849		$33,509,201	
Total Annual Cost - moored		$1,062,857		$4,284,103		$13,746,962		$44,339,374	
Total Annual Cost - DP		$1,680,589		$5,561,105		$16,090,694		$49,752,947	
OpEx per sq-foot - moored		$30.87		$24.89		$25.53		$24.35	
OpEx per sq-foot - DP		$48.82		$32.31		$29.88		$27.33	
OpEx per res. unit - moored		$20,068		$16,178		$16,592		$15,829	
OpEx per res. unit - DP		$31,732		$21,001		$19,420		$17,762	

Table 8 – Cost Summary for Barge-Shaped Seastead

LBP (feet)		195.0		312.5		625.0		935.0	
Beam (feet)		35.0		75.0		150.0		225.0	
Depth (feet)		15.0		20.0		40.0		60.0	
Block Coefficient, Cb		0.92		0.92		0.92		0.92	
Draft (feet)		6.6		11.4		20.6		30.8	
Displacement (LT)		1,185		7,010		50,876		170,285	
Hull Steel Cost		$2,796,859	7,000	$11,264,635	6,000	$74,219,621	6,000	$222,621,815	6,000
Deckhouse Cost		$1,801,136	6,000	$12,370,439	6,000	$73,528,583	5,000	$237,465,396	5,000
Accommodation Cost		$1,575,000		$10,817,308		$86,538,462		$291,288,462	
Mooring System Cost		$3,000,000		$7,296,632		$19,657,047		$35,962,432	
Propulsion System Cost		$33,180		$53,173		$536,914		$959,988	
Mechanical System Cost		$99,540		$106,347		$1,073,829		$1,919,976	
Electrical System Cost		$193,489		$1,328,906		$10,631,250		$35,784,788	
Engineering Cost		$432,110		$2,411,667		$16,400,067		$52,596,297	
Program Mgmt Cost		$275,190		$1,252,470		$7,618,311		$23,620,143	
Installation Cost / Days	2	$400,000	3	$600,000	5	$1,000,000	7	$1,400,000	
Total Cost, less transport		$10,606,503		$47,501,578		$291,204,083		$903,619,296	
Interior Public Area (ft^2)		5,119		35,156		210,938		631,125	
Residential Area (ft^2)		10,238		70,313		562,500		1,893,375	
Total Interior Area (ft^2)		15,356		105,469		773,438		2,524,500	
Cost per square foot		$691		$450		$377		$358	
Cost per residence unit		$448,953		$292,750		$244,729		$232,661	
Percentage Public Area		33.3%		33.3%		27.3%		25.0%	
Percentage Residential		66.7%		66.7%		72.7%		75.0%	
Annual Crew Cost - moored		$90,000		$90,000		$90,000		$90,000	
Annual Crew Cost - DP		$225,000		$225,000		$225,000		$225,000	
Maintenance Cost - moored		$106,065		$475,016		$2,912,041		$9,036,193	
Maintenance Cost - DP		$132,581		$593,770		$3,640,051		$11,295,241	
Insurance Cost - Liability		$79,549		$356,262		$2,184,031		$6,777,145	
Insurance Cost - Hull/Mach		$26,516		$118,754		$728,010		$2,259,048	
Average Housekeeping kW		74		506		4,050		13,632	
Average DP Thrusters kW		52		196		724		1,590	
Annual Fuel Burn - House		46,490		319,302		2,554,416		8,598,164	
Annual Fuel Burn - DP		32,629		123,775		456,867		1,003,141	
Annual Fuel Cost - moored		$232,452		$1,596,510		$12,772,080		$42,990,821	
Annual Fuel Cost - DP		$395,598		$2,215,387		$15,056,413		$48,006,527	
Total Annual Cost - moored		$534,582		$2,636,542		$18,686,162		$61,153,207	
Total Annual Cost - DP		$859,245		$3,509,173		$21,833,505		$68,562,962	
OpEx per sq-foot - moored		$34.81		$25.00		$24.16		$24.22	
OpEx per sq-foot - DP		$55.95		$33.27		$28.23		$27.16	
OpEx per res. unit - moored		$22,628		$16,249		$15,704		$15,746	
OpEx per res. unit - DP		$36,370		$21,627		$18,349		$17,653	


Part 2:
Platform Performance in Ocean Environment

ENVIRONMENTAL CONDITIONS

Wave Height, Period and Direction

In a land-based community, buildings are constructed on relatively “fixed” foundations that (barring earthquakes, soil subsidence, or other exceptional conditions) do not move in any perceptible way. Seasteads, on the other hand, are intended to float upon the surface of the sea and will consequently move up, down, and sideways in accordance with the undulations of the ocean waves that act upon it. This is true even for submersible seastead configurations unless they are submerged to a sufficient depth below the surface of the sea.

While a certain amount of wave-induced motion is acceptable to most people (and may even be perceived as relaxing and enjoyable to some), excessive motions can cause discomfort and even illness or disability in many people. These factors are discussed in more detail in one of the following sections of this report, entitled *Limiting Motion Criteria*. In the present context, it is sufficient to note that wave conditions that produce motions below a certain threshold are deemed to be acceptable, and that wave conditions that produce more severe motions are problematic.

The exact make-up of any system of ocean waves is random, and as unique as a set of human fingerprints. Because ocean waves are an inherently random process, the only way they can be meaningfully characterized is by using some statistical measure. Even in a gentle, rolling seaway the “height” of every individual wave is different from the one that precedes it and the one that follows it. In stormy seas, the “height” of each individual wave is even more variable, making it all the more challenging to quantify.

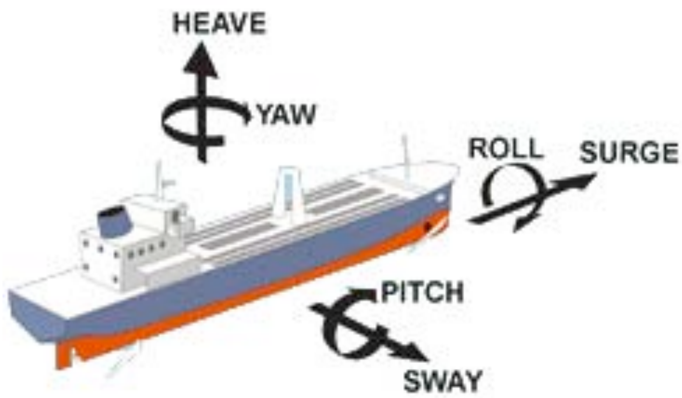
Nevertheless, we can characterize the properties of ocean waves by means of widely accepted statistical measures, as described below:

- Wave height – the vertical distance from the peak (or crest) of a wave to the trough of the same wave, if you were to observe the wave as it passes a fixed point of reference; because of the random nature of the sea, every individual wave has a unique height.
- Average wave height – if you recorded the height of every individual wave at a fixed reference point for a sufficient period of time (15 minutes, for example), the arithmetic average of the individual wave heights would be the “average” wave height. Although this is intuitive, and mathematically correct, the “average” value of wave height does not correlate well with the height that would be “perceived” by a trained observer, such as an experienced mariner.
- Significant wave height – instead of taking the average of all individual wave heights, it is customary to take the average of only the highest one-third waves in a sample of wave heights; this so-called “significant wave height” correlates very well with the perceptions of a trained observer, and is the most widely accepted statistical measure. Throughout the rest of this report, references to “wave height” will imply “significant wave height.”

Wave height is arguably the most important parameter influencing wave-induced motions, but other characteristics can also have a significant impact. The most problematic vessel motions are vertical and lateral displacements and accelerations that result from heave, pitch and roll, defined as follows:

- Heave – the vertical motion occurring at the vessel's center of gravity, usually combined with other components of vertical motion arising from pitch and roll
- Pitch – the angular motion that causes the bow and stern to rise and fall in synch with the wave action; vertical motion and acceleration increases in proportion to the distance forward or aft from amidships
- Roll – the rhythmic side-to-side angular motion of the vessel; large roll motions can cause discomfort, and can produce lateral accelerations that make people feel off balance

The diagram below illustrates the six-degree-of-freedom motions that a floating vessel may experience.



Motions of a Floating Vessel
(Illustration courtesy of Kongsberg Maritime)

Heave, pitch and roll are all oscillatory motions that have an associated natural period, similar to the regular interval of time between the swings of a pendulum in a grandfather clock or the swinging of a child on a playground swing. The so-called "natural period" is the time interval at which an object will oscillate (or swing) without the influence of an external force. Thus, if you pull a child backwards on a swing and then let go, the child will swing back and forth at a time interval (or period) that is solely related to the length of the swing; the pendulum in a clock will do the same. But the child quickly learns to "pump" in an effort to keep the swing moving. If the child does not pump at the proper intervals, the swing will come to a stop; but if the child can pump at just the right interval (at the "natural period" of the swing) then the swing can be made to go higher and higher.

In the example above, the time interval at which the child "pumps" the swing may be thought of as the "period" of the force that the child exerts on the swing. By analogy, the motion of a vessel in the ocean is caused by waves that produce forces on the hull, like the child pumping a swing. Ocean waves occur at various periods, depending on the sea state, and the vessel has its own set of natural periods (for heave, pitch and roll) depending on its geometry and loading.

When the period of the incoming waves coincides with the natural period of one or more of these motions, large displacements and accelerations can occur, like the child pumping a swing at just the right intervals to go higher and higher. Thus, wave period is an important factor in determining a vessel's response to ocean waves; in the most commonly occurring ocean waves, the dominant energy is usually between periods of 8 to 14 seconds. Vessels that have natural periods of heave, pitch or roll within that range of periods can expect to experience large wave-induced motions.

Typically, the natural periods for heave, pitch and roll motions are all longer than 20 seconds for a semi-submersible. Ocean waves rarely have significant energy in that low frequency band hence semis tend to have very small wave-induced motions. For barges and ship-shaped hulls, the heave and pitch natural periods are generally shorter than 6 to 8 seconds, or slightly shorter than the 8 to 14 second periods that are dominant in ocean waves; thus barge and ship-shapes tend to undulate up and down, following the surface of the waves. However, natural periods for roll motions of ships and barges are generally in the range of 8 to 18 seconds, coincident with the periods of maximum wave excitation. Thus, barges and ship-shaped hulls are highly susceptible to synchronous response, which can induce large roll amplitudes and high lateral accelerations.

Like wave height, wave period must also be characterized statistically, but a simplistic model will suffice in the present context. If you were to observe a series of waves passing a fixed point of reference, and record the interval of time between passages of each successive wave crest, the arithmetic average of these time intervals would correspond to the “average wave period,” or simply “wave period” for the purposes of this report.

Wave directionality is also an important factor for barges and ship-shaped hulls, especially if the orientation of a seastead results in waves striking the ship along the side (so-called “beam seas”), which can produce large roll motions. This suggests the desirability of dynamic positioning or some form of turret mooring for these vessels that will allow them to face into incoming waves, thereby minimizing exposure to beam sea conditions. For a semi-submersible hull, wave directionality is not as significant because of its relatively benign wave response characteristics.

Wave height and wave period statistics are commonly presented in the form of bi-variate probability distributions, as depicted in the following Tables 1a and 1b, representing an open ocean site in the North Atlantic and a near coastal site in the vicinity of Hawaii. These sites are illustrative of relatively severe and relatively benign deep-ocean conditions, respectively.

The values within each cell of the matrix represent the percent probability of occurrence for each combination of wave height (refer to the left side of the table) and wave period (refer to the top row of the table); thus, for example, wave heights between 3 and 4 meters having a period of about 12.4 seconds would be expected to occur about 3.7 percent of the time.

Annual Wave Statistics for North Atlantic - 58.3 N, 12.3 W N = 13,303 Samples

Significant Wave Ht. (meters)	Modal Wave Period (seconds)															Wave Height Probabilty	Cumulative Probability (%)
	3.2	4.8	6.3	7.5	8.8	9.7	10.5	12.4	13.8	15.0	16.4	18.0	20.0	22.5	25.7		
16 - 20													*0.001*			0.00	100.00
14 - 16												*0.05*	*0.05*	*0.001*		0.10	100.00
12 - 14											*0.05*	0.2	*0.05*	*0.001*		0.30	99.90
10 - 12										*0.05*	0.3	0.4	*0.05*	*0.001*		0.80	99.60
9 - 10									*0.05*	0.1	0.4	0.3	*0.05*	*0.001*	*0.001*	0.90	98.80
8 - 9									0.2	0.7	0.4	0.3	*0.05*	*0.001*	*0.001*	1.65	97.89
7 - 8								0.1	0.9	0.8	0.7	0.3	*0.05*	*0.015*	*0.001*	2.87	96.24
6 - 7								1.1	1.2	1.2	0.7	0.3	*0.05*	*0.015*	*0.001*	4.57	93.38
5 - 6							0.5	3.0	1.8	1.4	0.6	0.3	*0.05*	*0.015*	*0.001*	7.67	88.81
4 - 5						0.5	3.5	4.1	1.4	1.2	0.6	0.3	0.2	*0.020*		11.82	81.14
3 - 4					0.7	3.8	3.7	3.7	1.2	1.1	0.7	0.2	0.2	*0.020*		15.32	69.32
2 - 3				1.3	4.8	4.4	3.2	2.7	1.6	1.4	0.6	0.2	0.3			20.50	54.00
1 - 2		0.2	2.0	3.9	3.1	3.2	2.5	2.5	1.3	1.4	0.6	0.2	0.4			21.30	33.50
0 - 1	0.4	0.3	1.8	1.9	1.3	2.0	1.6	1.5	0.4	0.5	0.4		0.1			12.20	12.20
	0.40	0.50	3.80	7.10	9.90	13.90	15.00	18.70	10.05	9.85	6.05	3.05	1.61	0.09	0.01	<--- Wave Period Probability (%)	
Wavelength (meters)	16	36	62	88	121	147	172	240	297	351	420	506	624	790	1031		

Table 1a – Wave Height and Wave Period Probabilities in the North Atlantic Ocean

Annual Wave Statistics for Hawaii, NDBC 51004 N = 123,681 Samples

Significant Wave Ht. (meters)	Modal Wave Period (seconds)															Wave Height Probabilty	Cumulative Probability (%)
	3.2	4.8	6.3	7.5	8.8	9.7	10.5	12.4	13.8	15.0	16.4	18.0	20.0	22.5	25.7		
12.5 - 13.4																0.00	100.00
11.5 - 12.4																0.00	100.00
10.5 - 11.4										*0.001*						0.00	100.00
9.5 - 10.4									*0.001*							0.00	100.00
8.5 - 9.4								*0.001*	*0.001*							0.00	100.00
7.5 - 8.4								*0.001*	*0.001*			*0.001*				0.00	100.00
6.5 - 7.4							*0.001*	*0.001*	*0.001*		*0.001*		*0.001*	*0.001*	*0.001*	0.01	99.99
5.5 - 6.4						*0.040*	0.1	*0.040*	*0.040*	*0.040*	*0.003*	*0.001*	*0.001*	*0.001*	*0.001*	0.27	99.99
4.5 - 5.4						0.2	0.4	0.1	0.1	0.1	*0.004*	*0.002*	*0.001*	*0.001*	*0.001*	0.91	99.72
3.5 - 4.4					0.2	3.6	1.0	0.4	0.3	0.1	*0.003*	*0.001*	*0.001*			5.61	98.81
2.5 - 3.4				0.1	16.6	12.2	3.0	1.3	0.5	0.1	*0.001*	*0.001*				33.80	93.21
1.5 - 2.4				7.5	36.9	9.8	2.8	0.9	0.2	*0.001*						58.10	59.40
0.5 - 1.4			*0.001*	0.3	0.5	0.4	0.1	*0.001*								1.30	1.30
0 - 0.4																0.00	0.00
	0.00	0.00	0.00	7.90	54.20	26.24	7.40	2.74	1.14	0.34	0.01	0.01	0.00	0.00	0.00	<--- Wave Period Probability (%)	
Wavelength (meters)	16	36	62	88	121	147	172	240	297	351	420	506	624	790	1031		

Table 1b – Wave Height and Wave Period Probabilities off the Coast of Hawaii

A convenient way to visualize the relative wave severity at these two locations is a graph of the cumulative probability distributions (the right-hand column in Tables 1a and 1b), as shown below in Figure 1. The vertical scale indicates the probability that waves will be *less than* the height indicated along the horizontal axis. For example, in the North Atlantic, wave height will be less than 6 meters about 90 percent of the time; hence waves will be greater than 6 meters almost 10 percent of the time. By comparison, off the coast of Hawaii, the wave height will be less than 6 meters virtually 100 percent of the time; thus, almost never more than 6 meters.

The graph below depicting conditions off the coast of Hawaii approaches 100 percent at about 5 meters, thus we might deduce that to be nearly the maximum wave height at that location; however, Table 1b indicates that waves of 11 meters or more can occur, albeit in very rare instances. Similarly, the graph below appears to reach 100 percent at about 11 meters for the

North Atlantic, whereas Table 1a indicates that waves as high as 16 to 20 meters will occur on rare occasion. (Recall that these are significant wave heights; maximum individual waves are typically almost twice the significant wave height.)

Reading across the graph at the 90 percent level indicates the so-called 90th percentile wave height; that is, the wave height that will be exceeded 10 percent of the time. Off the coast of Hawaii, the 90th percentile wave height is a bit less than 3 meters, whereas in the North Atlantic the graph indicates the 90th percentile is nearly 6 meters, or about twice as high.

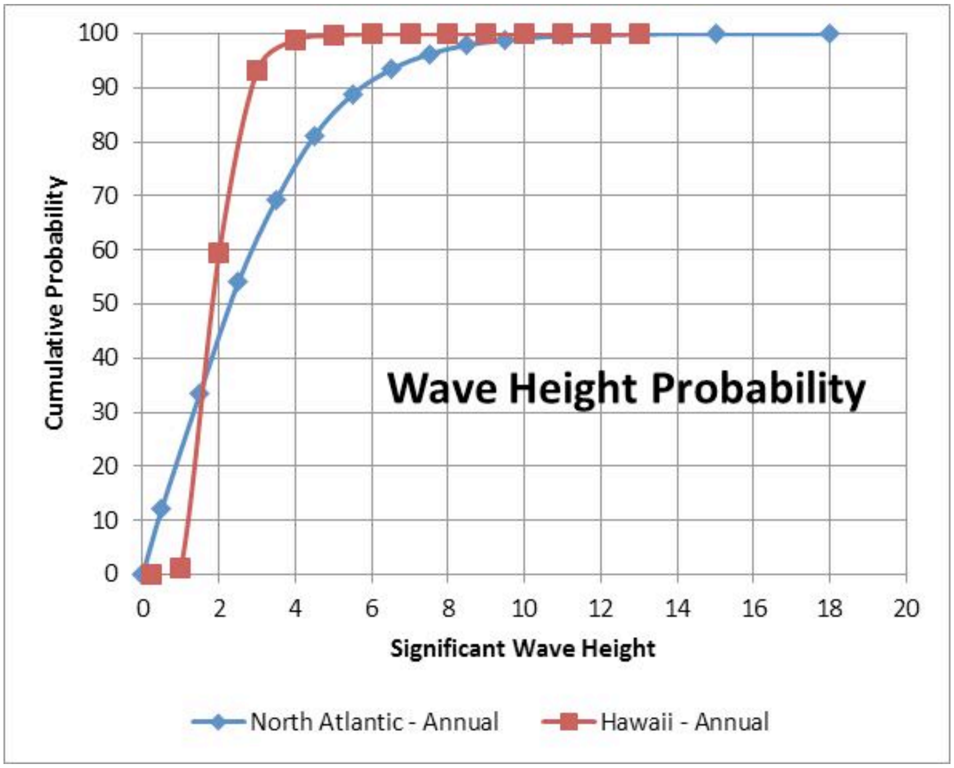


Figure 1 – Comparison of Wave Height Cumulative Probability in Two Locations (Note: Significant Wave Height is shown above in meters)

While the data shown in Figure 1 is useful for comparing the relative severity of two or more discrete locations, it is useful to consider the oceans of the world on a more holistic scale. Shown in Figure 2 is an image that The Seasteading Institute has prepared in conjunction with its ongoing location study, aimed at identifying the most promising locations for seasteads worldwide. Figure 2 illustrates the 90th percentile significant wave height around the world; note that colorations in the North Atlantic and the mid-Pacific are consistent with the values indicated in Figure 1, as discussed in the preceding paragraph.

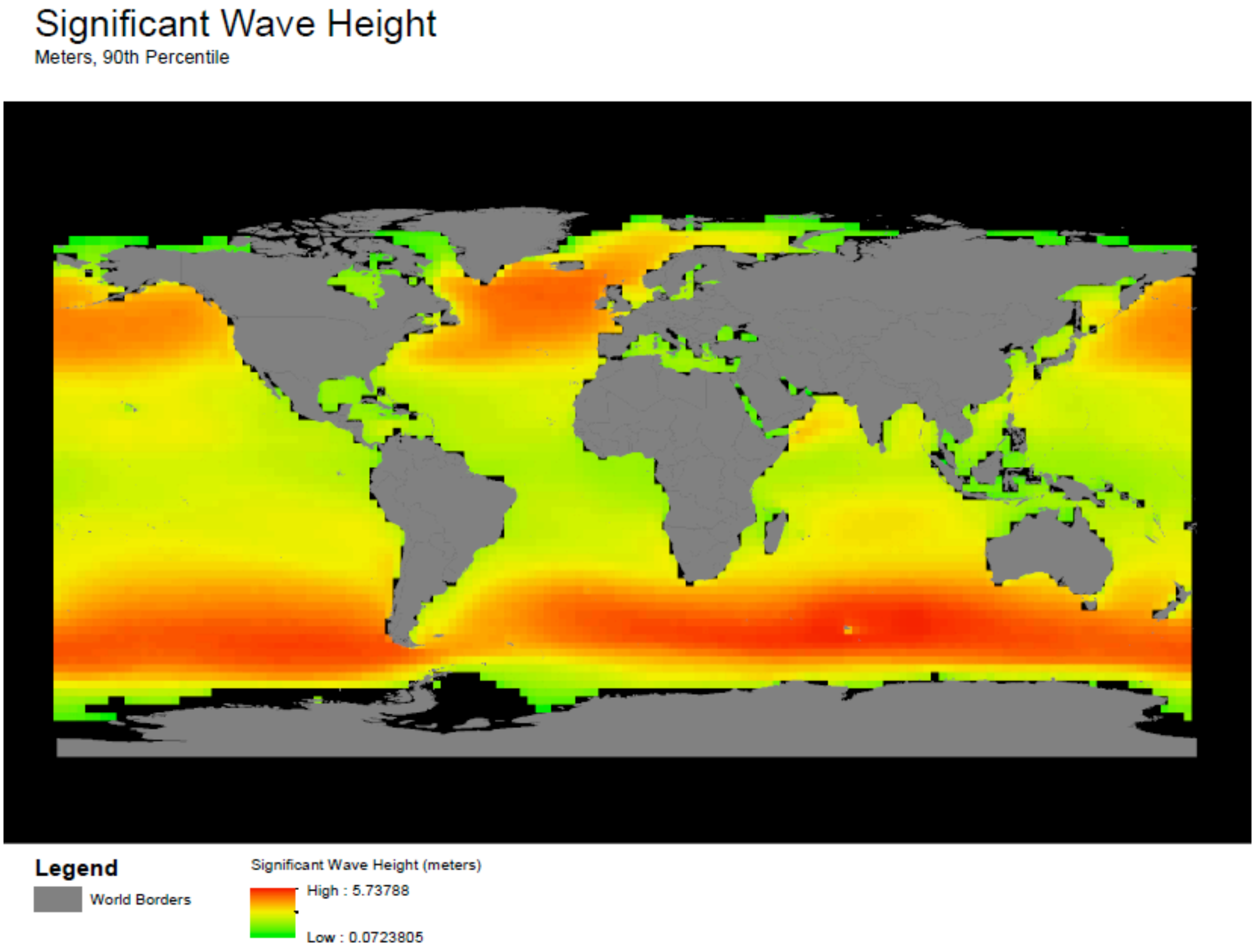


Figure 2 – Worldwide 90th Percentile Significant Wave Heights (meters)
Note: Blackened spaces along coast lines represent areas of missing data

Wind Speed and Current Speed

Whereas wave characteristics are important in the evaluation of vessel motions, it is wind speed and current speed that are of primary importance with regards to station-keeping, or maintaining a seastead in its desired location. Wind and current create drag forces on the hull and deckhouse of a seastead; it is these forces that must be overcome to keep the seastead in its desired location.

For a moored seastead, it is the maximum (roughly the 99th percentile) wind and current speeds that are of interest, because the corresponding forces will determine the required strength of the mooring system.

By contrast, a dynamically positioned seastead must continually consume energy to power the thrusters that keep it in position. The average thruster power (and hence the average rate of fuel consumption for dynamic positioning) is related to the average wind and current speeds; that is, to the 50^{th} percentile of each. However, similar to a moored seastead, the maximum wind and current is also important, because the thruster system must be capable of developing sufficient thrust to keep the seastead in position during severe storm conditions. (While some within the seastead community have suggested the idea of “lazy” positioning, i.e., letting the vessel meander from its nominal position, this analysis has taken the position that a seastead should always be able to control its location, so as not to present a potential hazard to other vessels in the vicinity.)

Depictions for wind speed and current speed (50^{th} and 99^{th} percentile) are shown in the following Figures 3a - 3b and 4a - 4b, respectively. Based on subjective evaluation of these figures, the selection of an average 20-knot (10-m/s) wind speed and a 1-knot (0.5-m/s) current speed used in this analysis is justified. Certainly the design of a seastead intended for a specific site should be based on the environmental characteristics (waves, wind, and current) that are appropriate to that location.

Water Depth

For a dynamically-positioned seastead, water depth is of no particular consequence from the standpoint of design and cost, because the vessel relies on thrusters rather than anchors to maintain position. However, for a moored seastead, water depth has important implications related to the cost of the mooring system. As noted in Part 1 of this report, at a nominal depth of 1,000 feet, the cost of anchor line represents about 60% of the total cost of a mooring system and anchor line cost increases linearly with increased water depth. Therefore, each additional 1,000-foot increment of water depth represents about a 60% increase in the capital cost of a mooring system.

Water depths throughout the world are depicted in Figure 5, which is an excerpt from the ongoing location study project (http://www.seasteading.org/wp-content/uploads/2012/03/Seasteading_Location_Study.pdf).

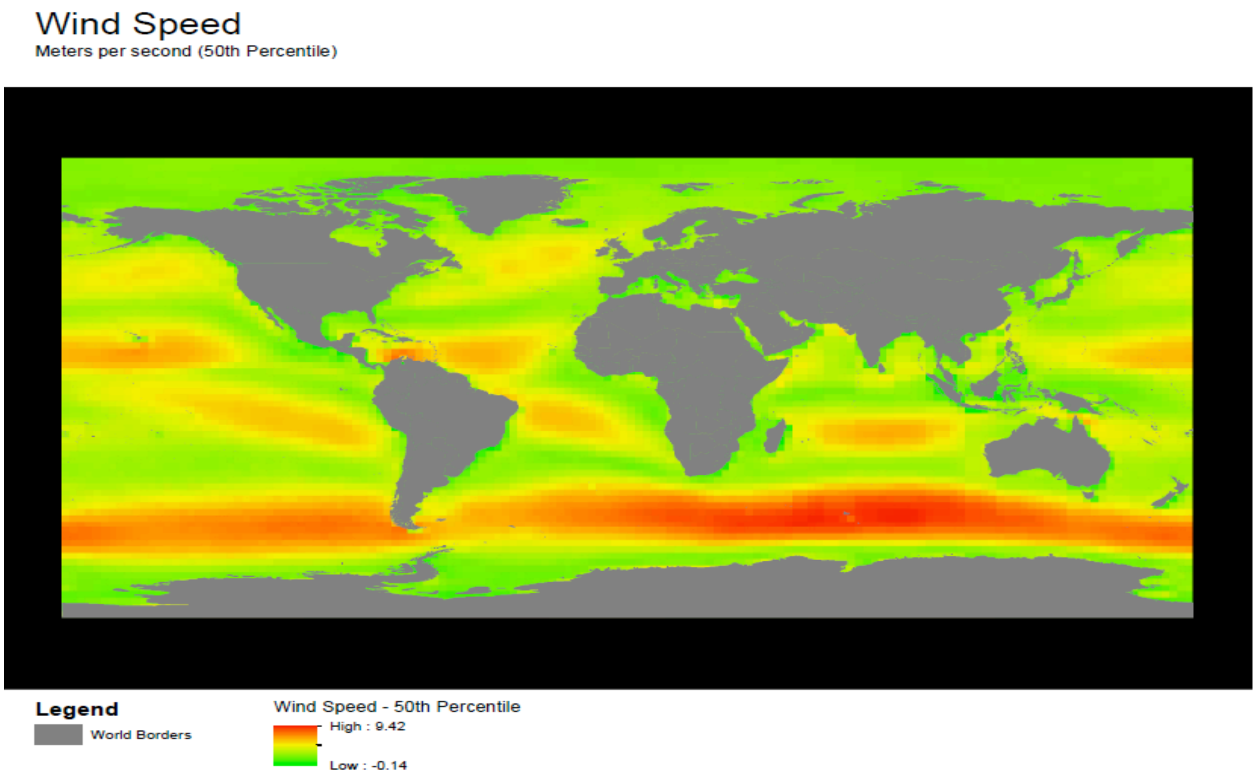


Figure 3a – Worldwide 50th Percentile of Wind Speed (meters per second)

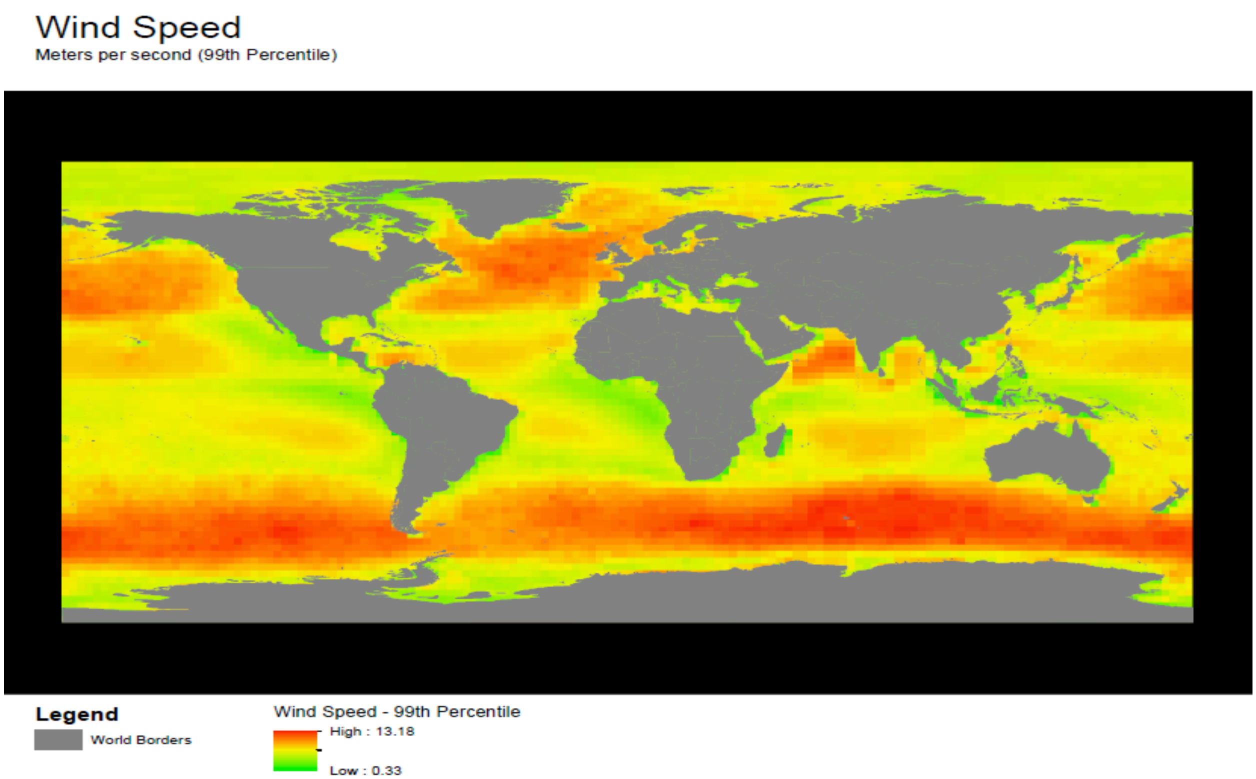


Figure 3b – Worldwide 99th Percentile of Wind Speed (meters per second)

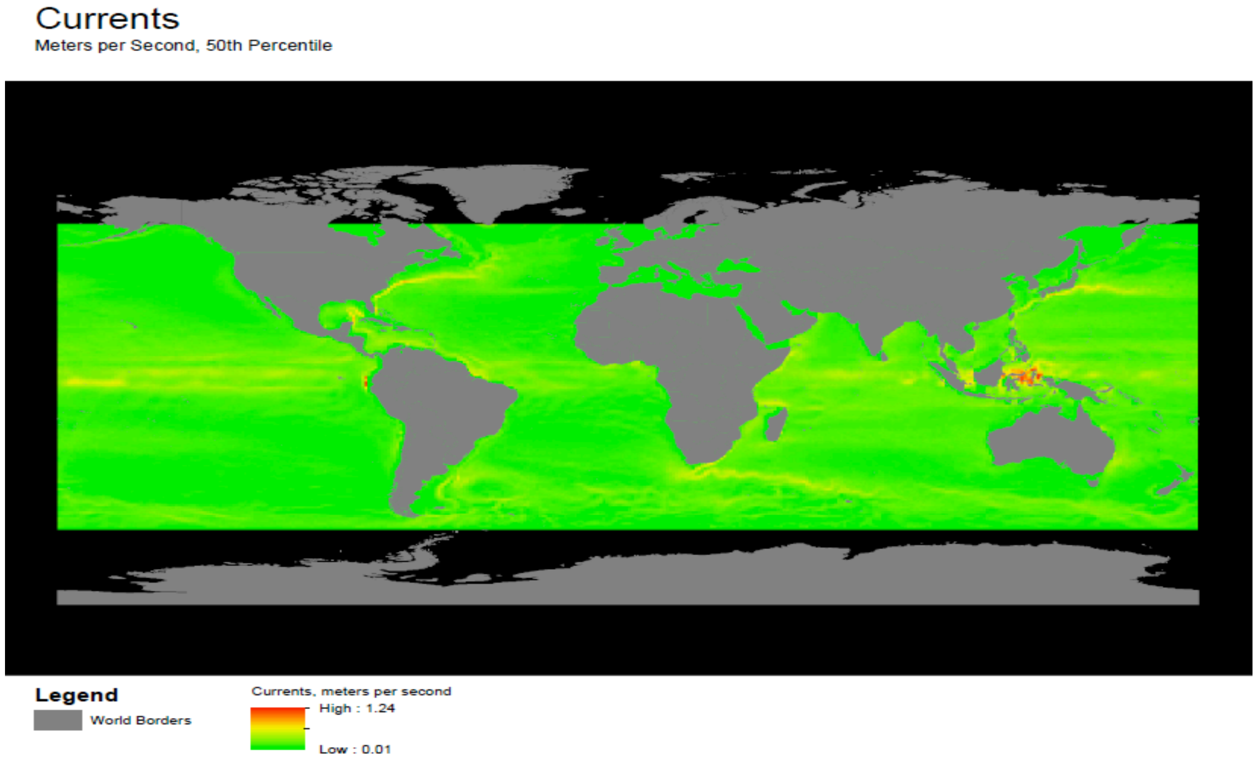


Figure 4a – Worldwide 50th Percentile of Current Speed (meters per second)

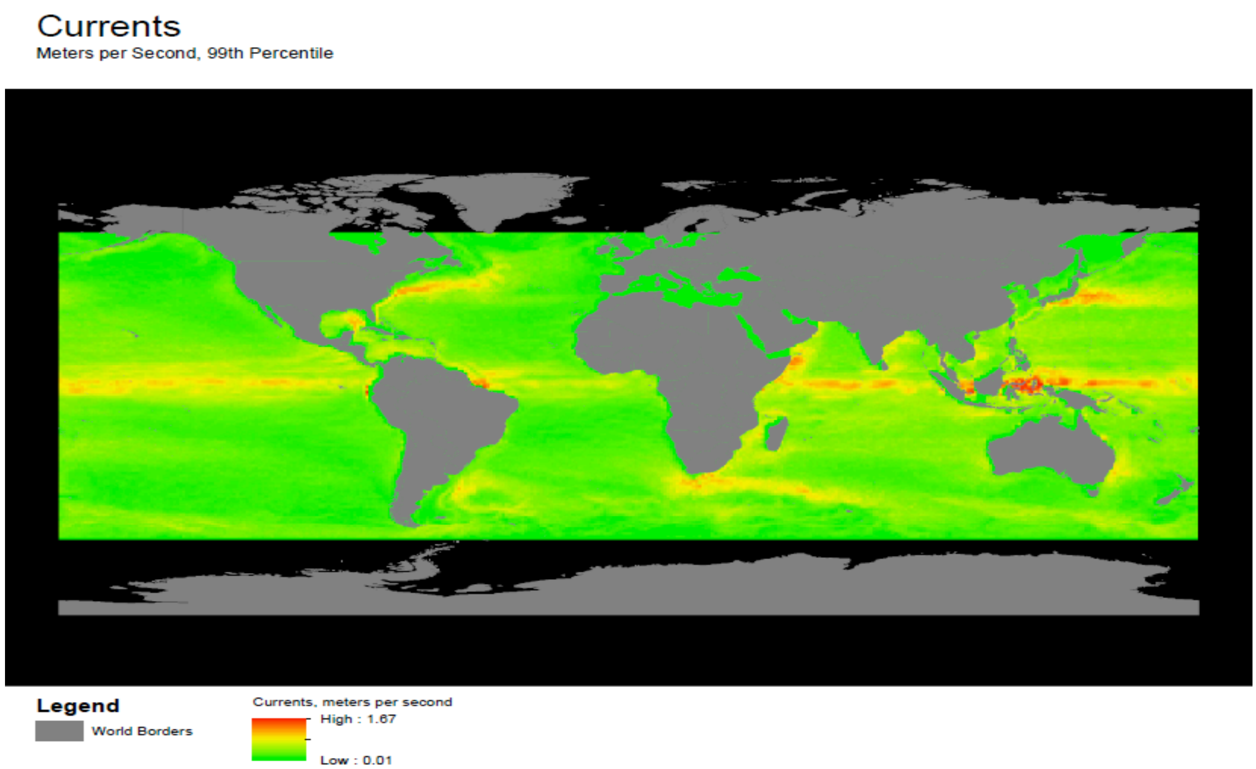


Figure 4b – Worldwide 99th Percentile of Current Speed (meters per second)

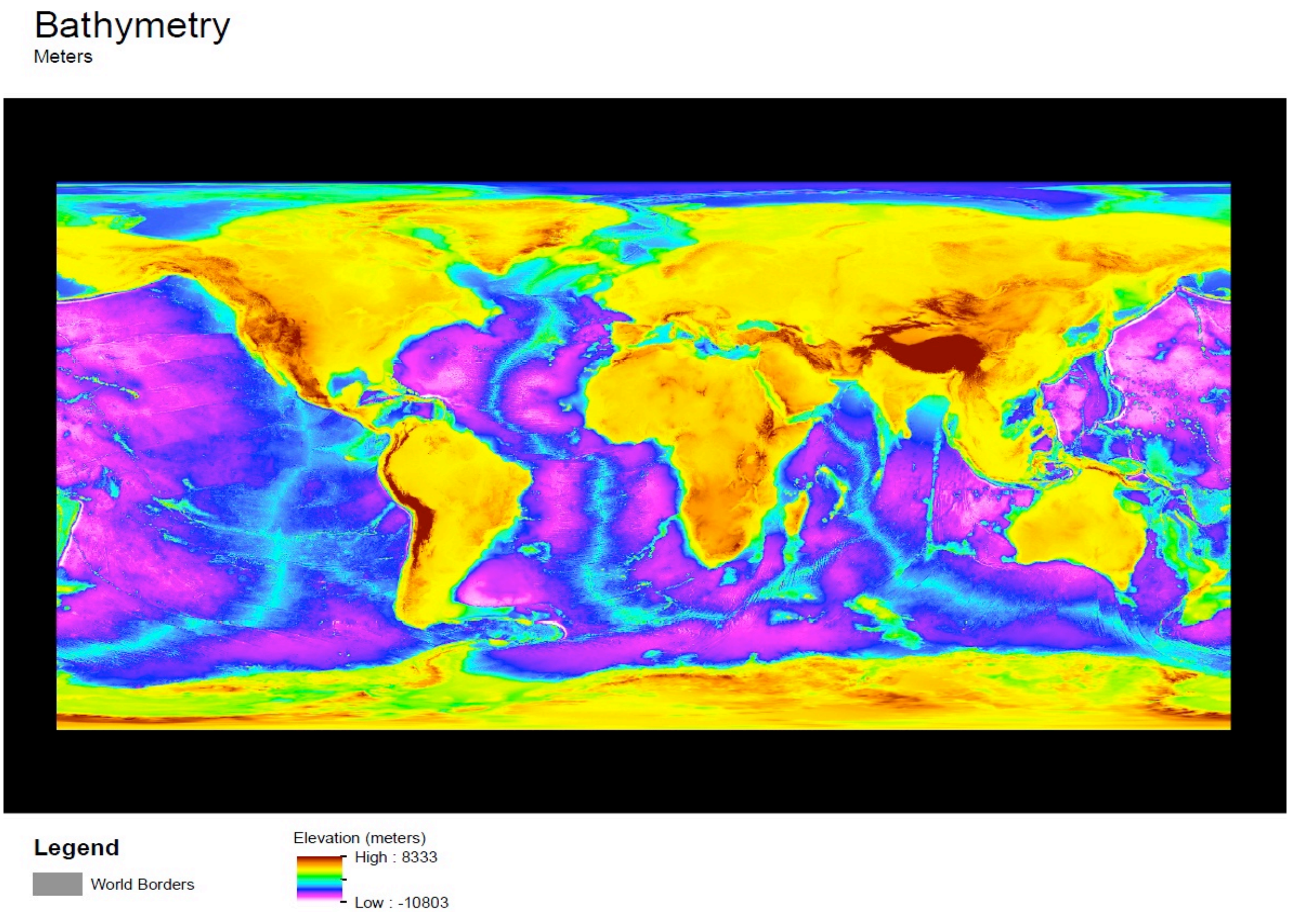


Figure 5 – Worldwide Water Depths (meters)

Note: Ocean depth appears as "negative elevation" above sea level

MOTION AMPLITUDES IN VARIOUS SEA CONDITIONS

General Approach

Graphs comparing significant motion amplitudes for roll, vertical acceleration and lateral acceleration are shown in Figures 6a, 6b, and 6c for the three ship lengths considered in this analysis: 1050’, 750’ and 450’ respectively. Likewise, graphs for the three barge configurations are shown in Figures 7a, 7b, and 7c for lengths of 935’, 625’ and 312’ respectively. A similar set of graphs for the three semi-submersible configurations (300’x300’, 400’x400’ and 500’x500’) is shown in Figure 8; note, however, that the ring semi-submersible is very nearly axisymmetric, therefore the motion responses are virtually the same for all headings.

The values shown in these graphs were computed with the aid of sophisticated hydrodynamic software that models the three-dimensional geometry of the vessel’s hull and the time-varying pressures within the waves as they pass by the hull. From the specified geometry and weight distribution for each configuration, the software computes how strongly the hull will respond to waves of varying frequency and direction; recall that (like a child on a swing) the amplitude of response will be greatest when the wave period coincides with one of the natural periods of the hull. The response characteristics of each vessel are then combined with a mathematical model of the energy in each of the seas conditions considered to obtain the values illustrated in each of the graphs. This requires a prodigious amount of computation, using software that has been verified by comparison with scale model tests for a wide variety of hull forms.

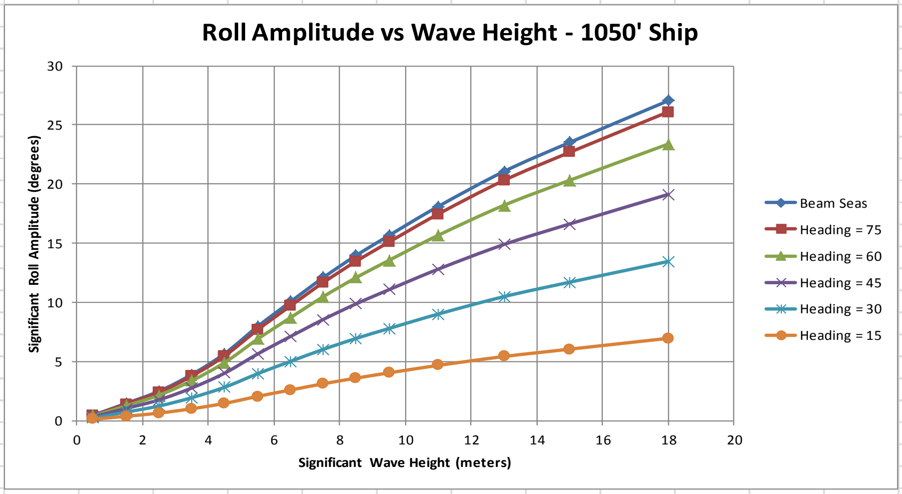
Each graph shows a series of curves, corresponding to different ship headings relative to the waves. Beam seas (waves approaching the ship directly from the side) are equivalent to a heading of 90 degrees, i.e., waves approaching from a direction perpendicular to the centerline of the ship. Other headings are likewise defined in terms of degrees from the centerline of the ship.

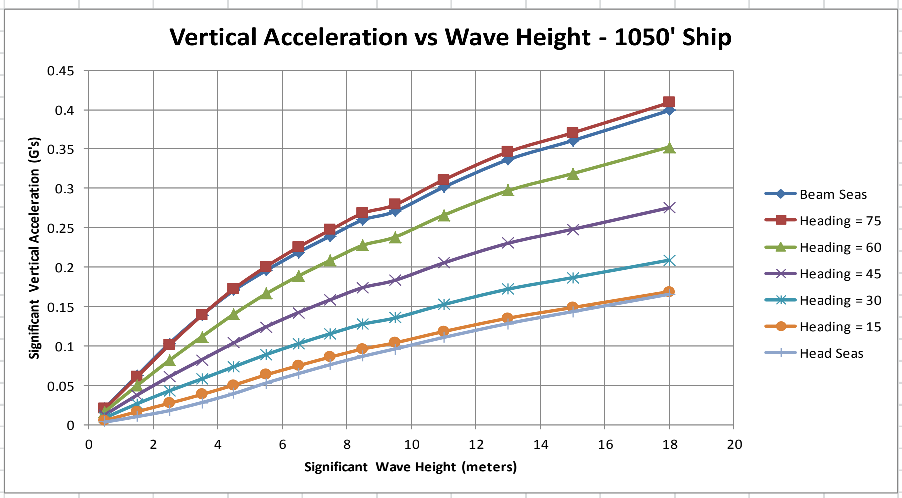
Referring to the topmost graph in Figure 6a, for example, the curve for *Beam Seas* indicates that the ship would roll about five degrees to either side of the vertical in a 4-meter wave height. However, at a wave heading of 45 degrees it would require a 5-meter wave height to produce the same roll angle. Moreover, if the wave heading were 30 degrees, it would take a wave height of 6 meters to produce the same 5-degree roll. Thus, it is apparent that as the ship becomes more aligned with the waves (closer to a “head sea” condition) the roll motion diminishes.

Graphs in the middle and bottom of Figure 6a illustrate similar trends with respect to vertical and lateral acceleration at the forward, outboard corner of the deckhouse. Each set of three graphs (one “set” for each seastead configuration) provides a transformation between the ship’s motion response at various headings and the wave heights required to produce those responses.

Ship-Shaped Configurations

Figure 6a – Motion Amplitudes Versus Wave Height for 1050' Ship-Shaped Seastead





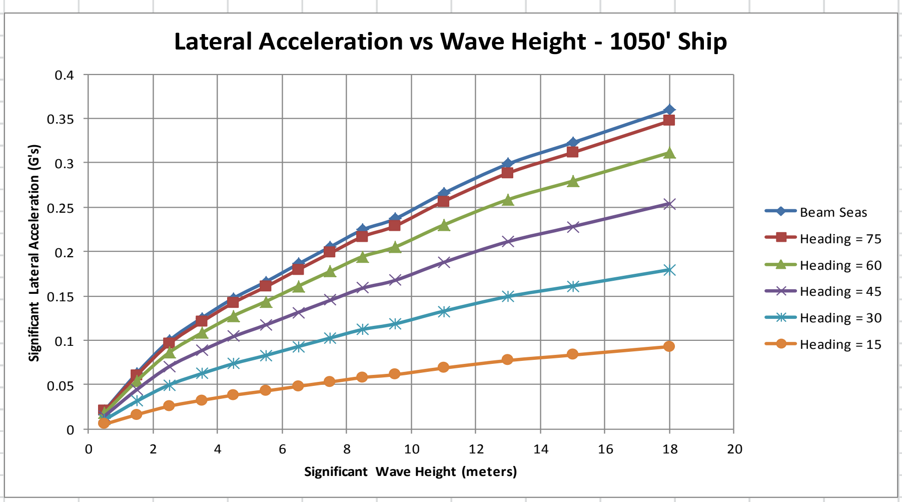


Figure 6b – Motion Amplitudes Versus Wave Height for 750' Ship-Shaped Seastead

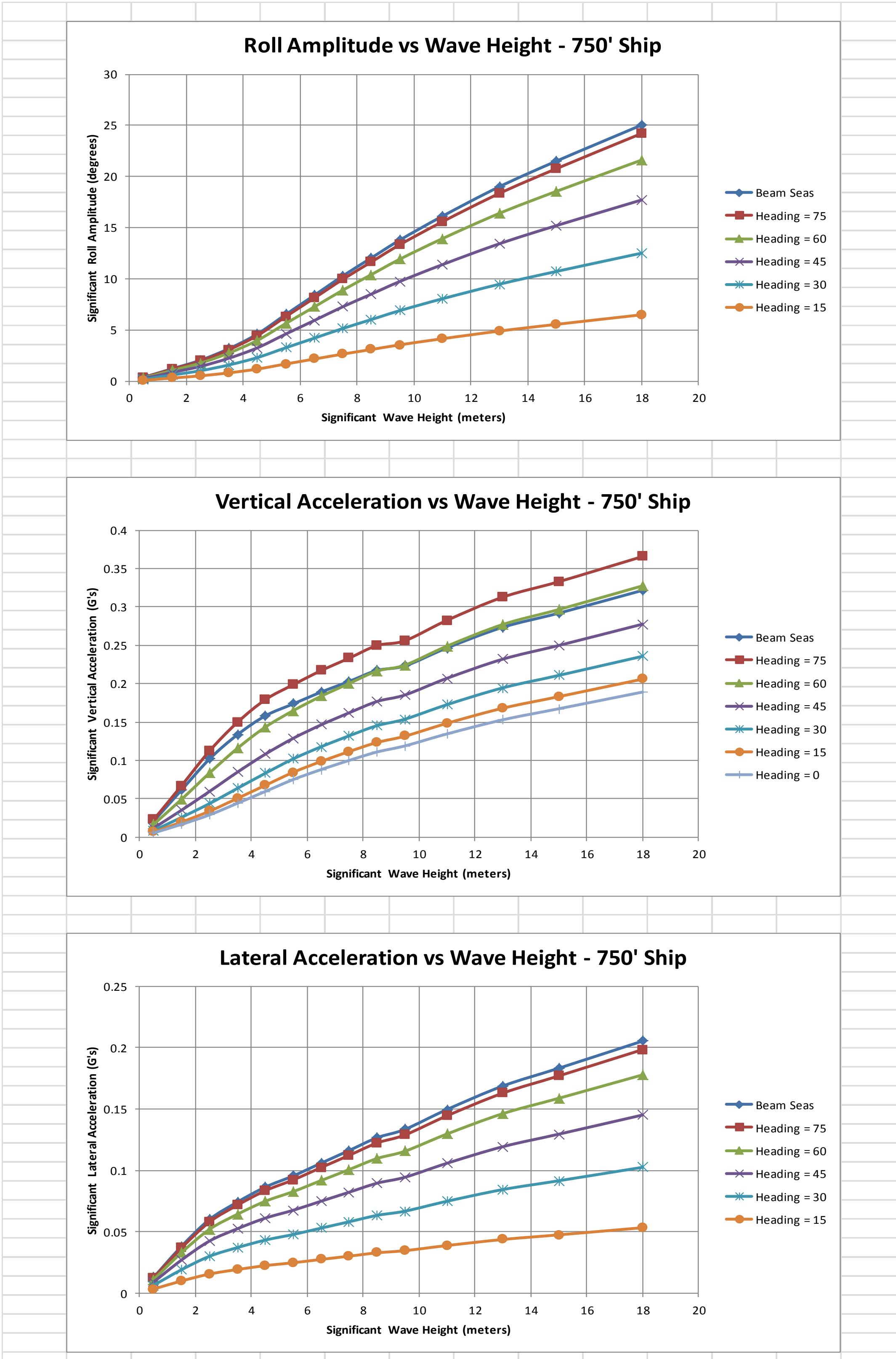
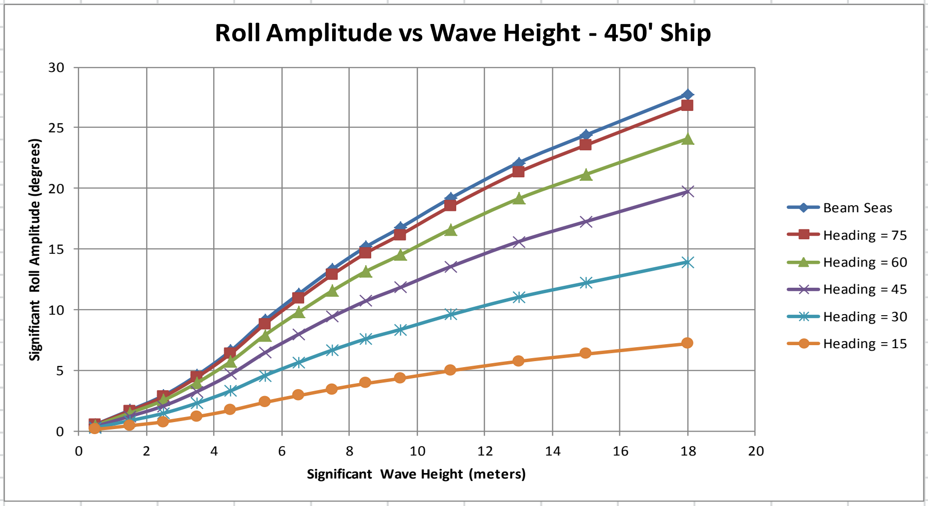
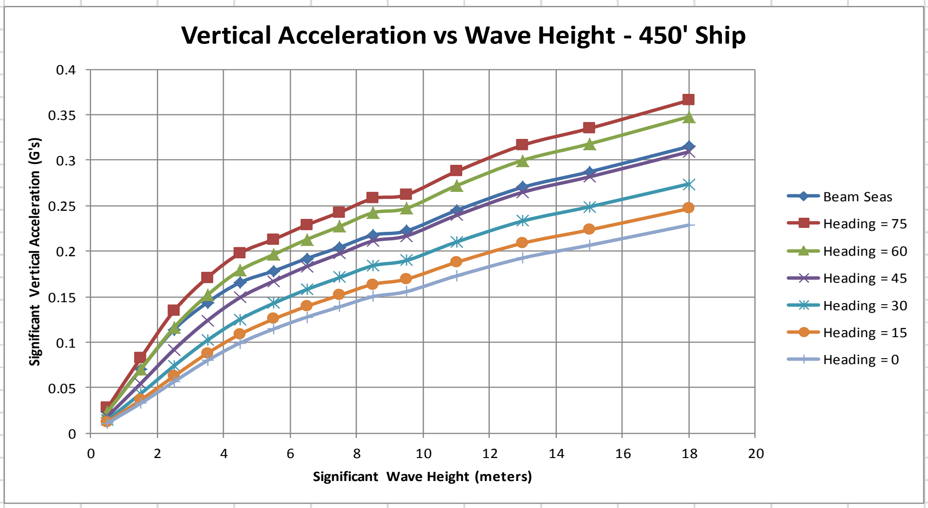
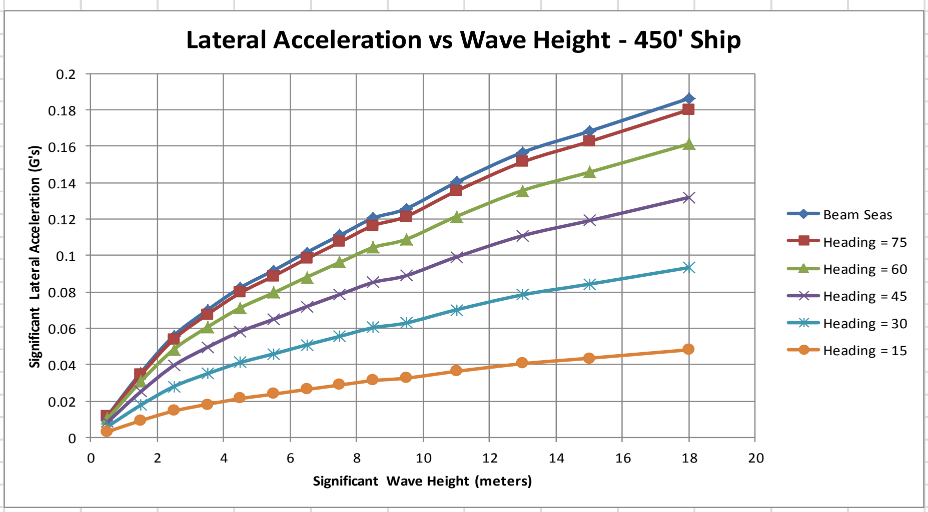


Figure 6c – Motion Amplitudes Versus Wave Height for 450' Ship-Shaped Seastead







Barge-Shaped Configurations

Figure 7a – Motion Amplitudes Versus Wave Height for 935' Barge-Shaped Seastead

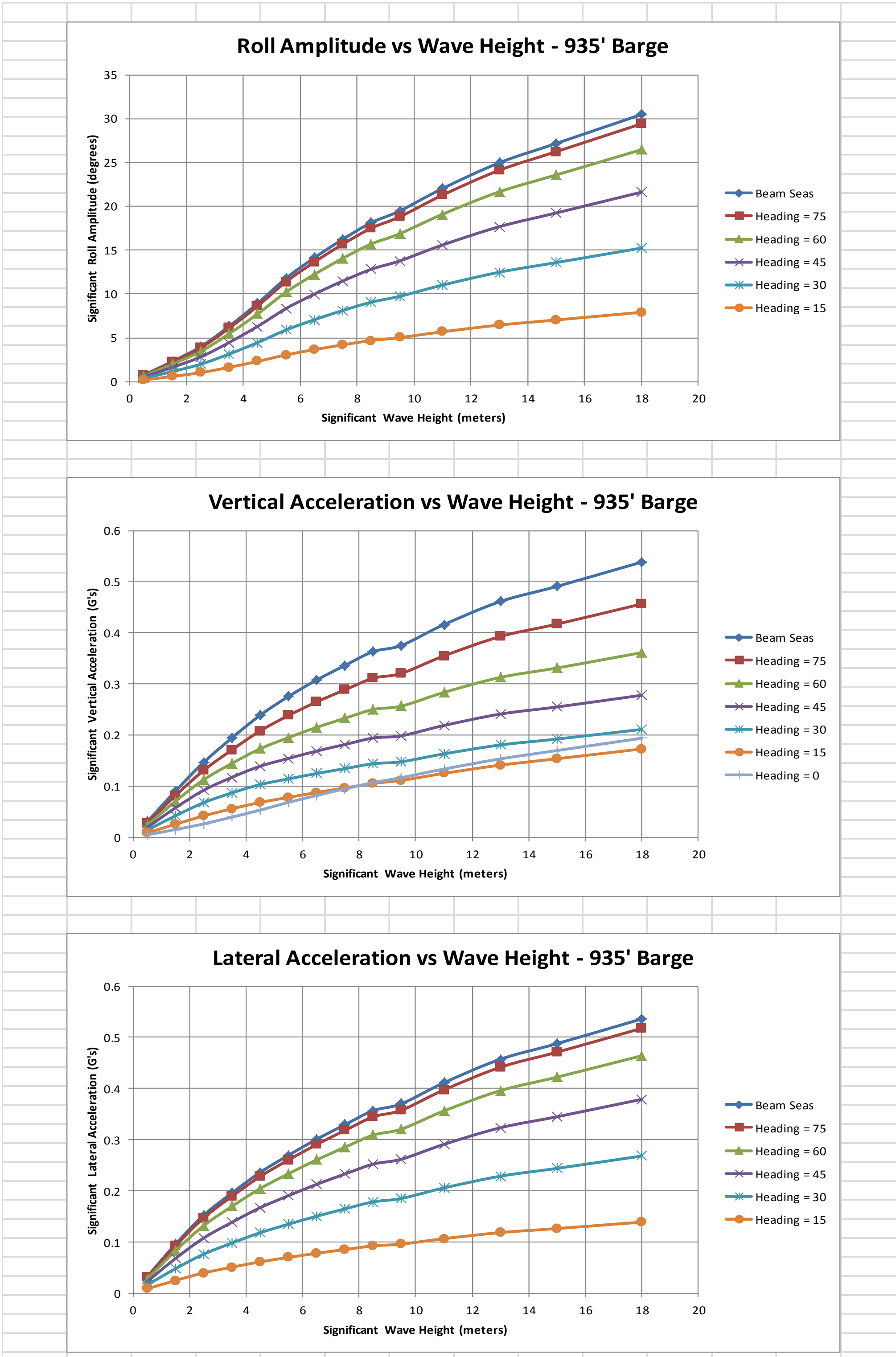
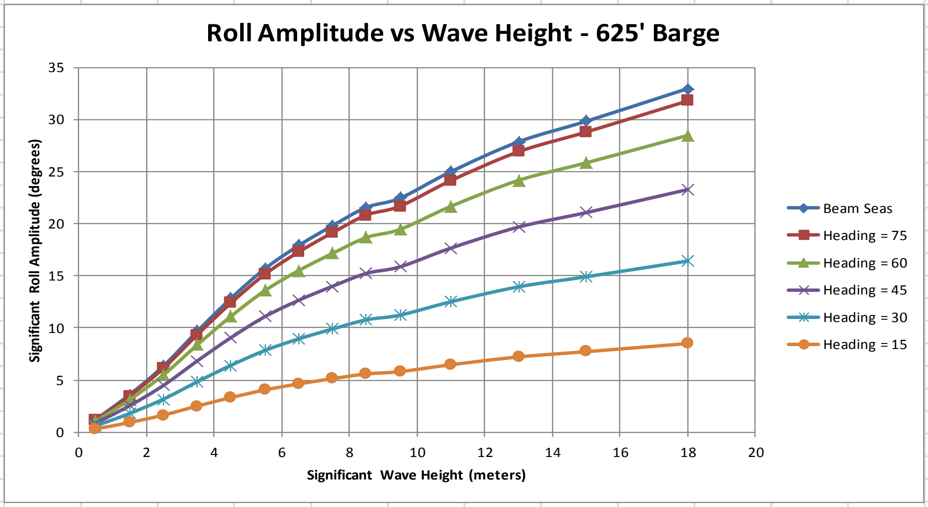
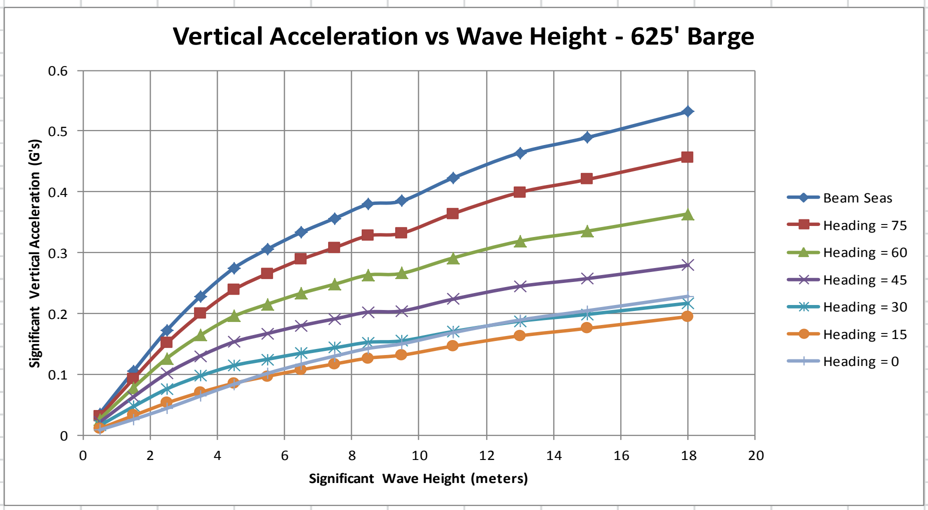


Figure 7b – Motion Amplitudes Versus Wave Height for 625' Barge-Shaped Seastead





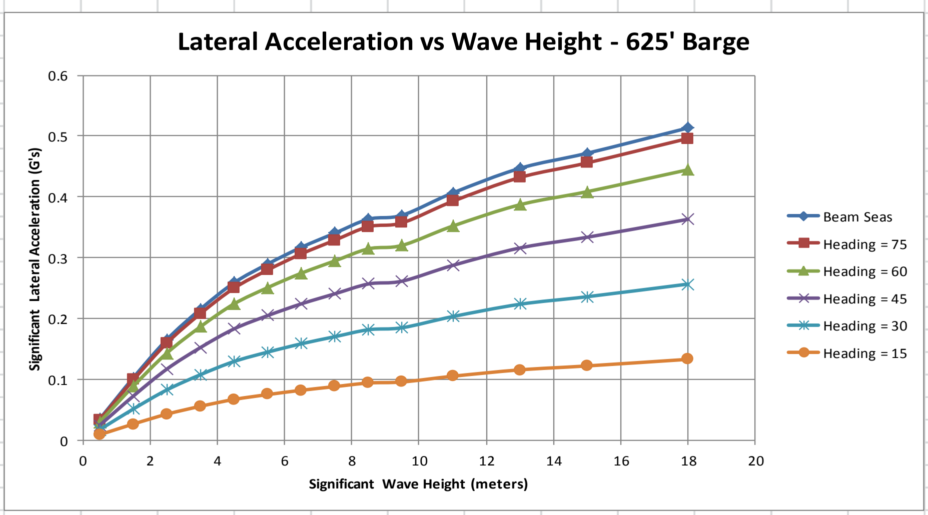
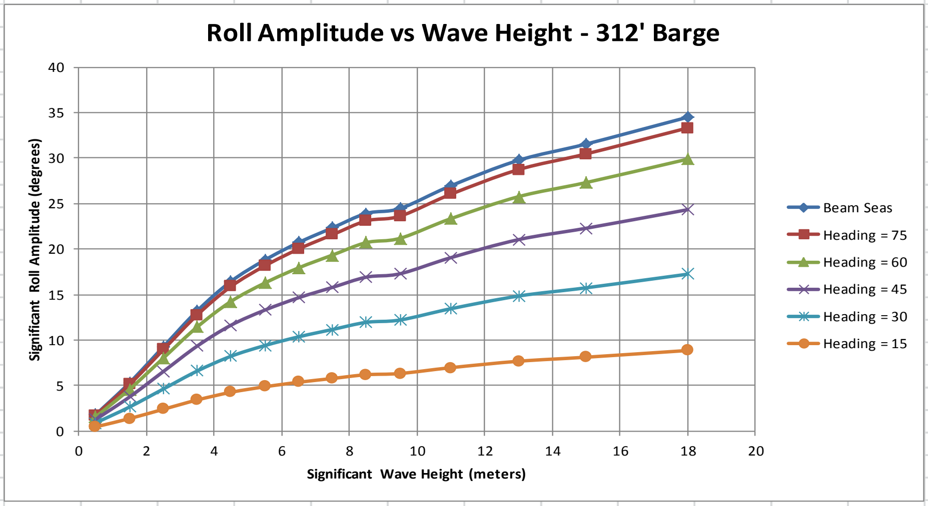
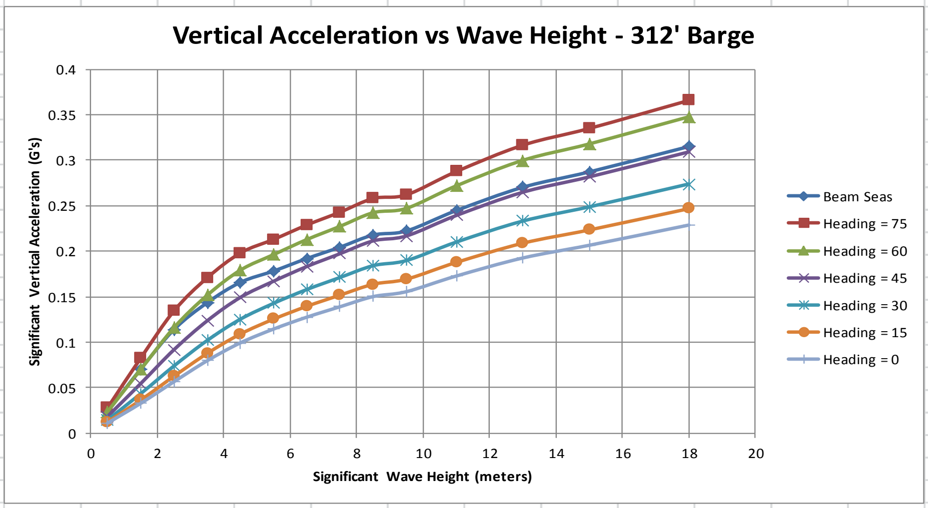
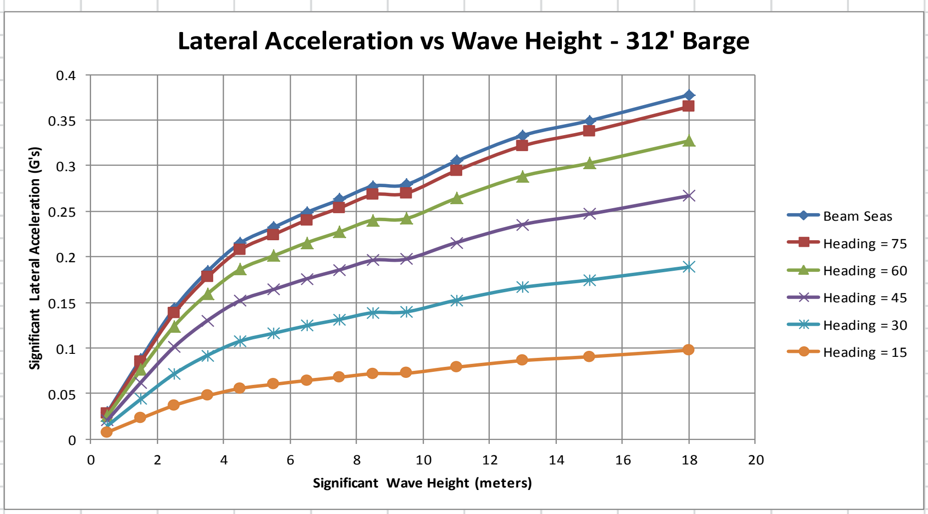


Figure 7c – Motion Amplitudes Versus Wave Height for 312' Barge-Shaped Seastead

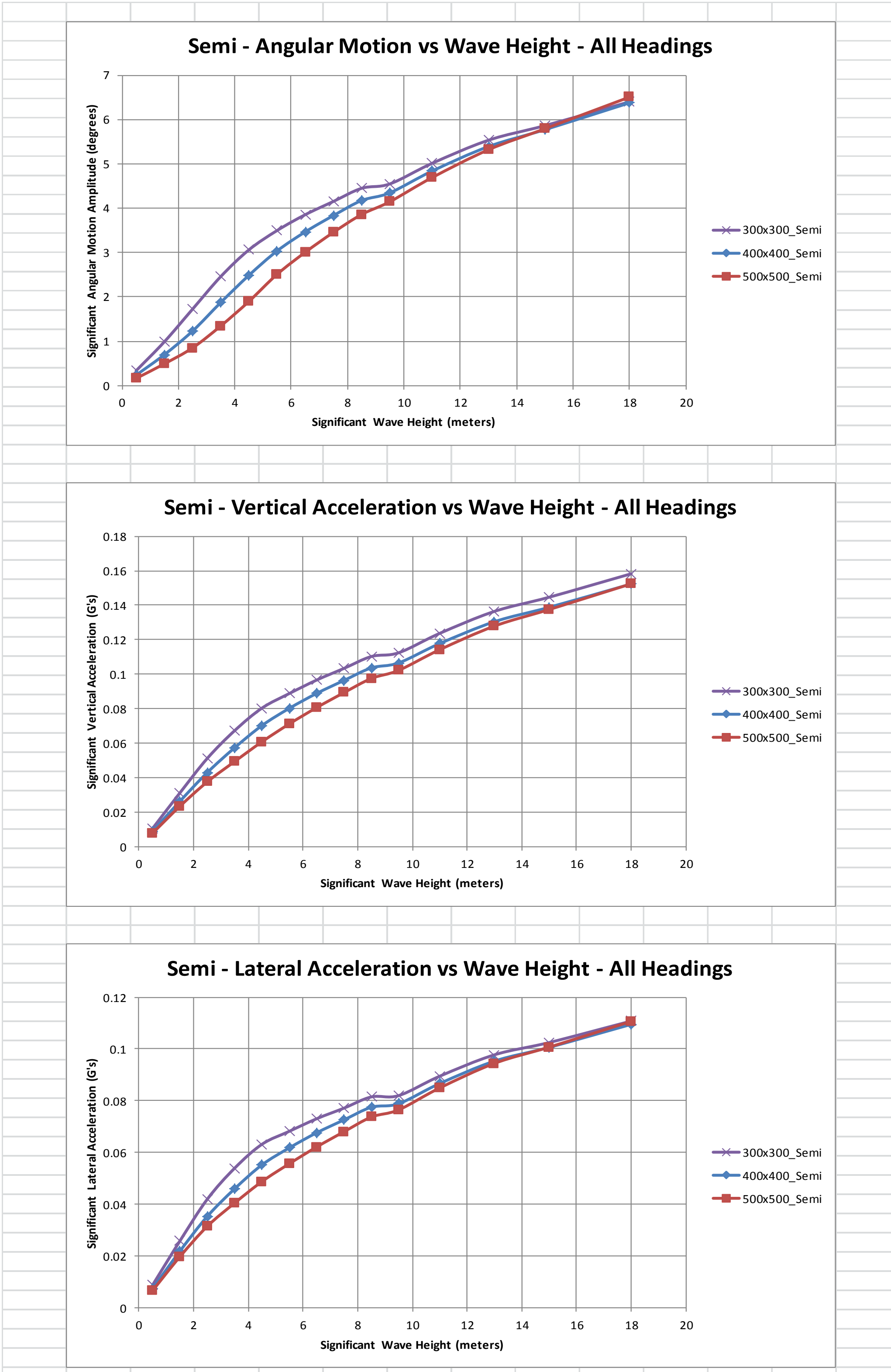






Semi-Submersible Configurations

Figure 8 – Motion Amplitudes Versus Wave Height for Semi-Submersible Seasteads



OPERATIONAL LIMITS AND PERFORMANCE ASSESSMENT

Limiting Motion Criteria

Establishing quantitative values for how much motion an individual can tolerate is problematic, to say the least. Recalling a visit to any amusement park will put the issue into context; some individuals not only tolerate but actually relish the whipsaw accelerations and non-stop spins of the wildest rides, while other folks may get a queasy feeling just from watching. In a report (http://www.seasteading.org/files/research/TSI/engineering/Feb2011_Report_p1.pdf) prepared by The Seasteading Institute last year, Eelco Hoogendoorn briefly discusses the issue, with reference to limits on roll amplitude, vertical acceleration, and lateral acceleration.

These motion responses are potentially disturbing in the following way:

- Roll amplitude – when a vessel rolls, the deck "tips" to some angle with respect to the horizontal. If roll amplitude is excessive, it can cause items to slide off of tables and it can cause people to lose their balance.
- Vertical acceleration – anyone who has ridden in an elevator that started or stopped too quickly has experienced the discomfort that large vertical accelerations can cause. More extreme is the sensation that one experiences when an airplane encounters turbulence and a sudden loss of altitude; large vertical accelerations can be very uncomfortable, even if they occur rarely. But when up-and-down vertical motion occurs continuously, even moderate accelerations can cause discomfort.
- Lateral acceleration – the forces that push you into the seatback of an airplane during takeoff or cause your torso to lurch forward upon landing are caused by large lateral accelerations. On a floating vessel or seastead, large lateral accelerations are usually associated with a short natural period (around 10 seconds or less) in roll; this is often referred to as a "snap roll", meaning the hull lurches from side to side very quickly.

Guidelines published by the International Towing Tank Conference (ITTC) based on ISO 2631 are used as the basis for the limiting motion criteria assumed in this analysis. These guidelines set forth tolerance limits for seasickness and fatigue due to long-term (several hours) exposure to oscillatory motions. They also specify levels of sudden acceleration that cause increased risk of injury due to loss of balance.

Based on the ITTC guidelines, the following motion limits have been adopted for this analysis:

Mode of Motion	Comfort Limit	Endurance Limit
Roll, degrees from vertical	4	8
Vertical acceleration, G's	0.1	0.2
Lateral acceleration, G's	0.075	0.15

Motions that exceed the "comfort" limit for an extended period of time are likely to produce seasickness or fatigue in the majority, whereas motions that exceed the endurance limit are more likely to cause loss of balance and possible injury.

For each of these limiting criteria, the corresponding limiting wave height is obtained for each seastead configuration, utilizing the graphs shown in the preceding section. Then, based on the wave statistics for a particular area, the probability of exceeding the limiting wave height is determined. The corresponding probability of *not* exceeding the limiting wave height then becomes the "operability" of the vessel for any particular wave heading scenario. The tables below illustrate the process, assuming each vessel is exposed to an equal probability of waves from all directions.

	Operability and Performance based on wave conditions in ***Hawaii - Annual***								
	450' ship	750' ship	1050' ship	312' barge	625' barge	935' barge	300' semi	400' semi	500' semi
Roll Amplitude - Comfort	98.8%	99.7%	98.6%	36.1%	71.1%	96.1%	99.8%	99.8%	99.9%
Vert. Accel - Comfort	99.8%	99.8%	99.8%	78.2%	70.5%	83.3%	99.8%	99.8%	99.9%
Lat. Accel. - Comfort	99.8%	99.8%	88.2%	50.3%	34.2%	42.0%	99.8%	99.8%	99.9%
Roll Amplitude - Endurance	99.8%	99.8%	99.8%	93.5%	98.8%	99.8%	100.0%	100.0%	100.0%
Vert. Accel - Endurance	100.0%	100.0%	100.0%	99.8%	99.7%	99.8%	100.0%	100.0%	100.0%
Lat. Accel. - Endurance	100.0%	100.0%	99.8%	98.6%	97.8%	98.8%	100.0%	100.0%	100.0%

	Operability and Performance based on wave conditions in ***North Atlantic - Annual***								
	450' ship	750' ship	1050' ship	312' barge	625' barge	935' barge	300' semi	400' semi	500' semi
Roll Amplitude - Comfort	76.3%	85.9%	81.1%	36.3%	49.6%	65.8%	95.5%	97.5%	98.6%
Vert. Accel - Comfort	88.4%	96.5%	91.4%	52.8%	49.3%	55.5%	95.5%	97.5%	98.6%
Lat. Accel. - Comfort	95.4%	93.9%	58.6%	41.3%	35.6%	38.4%	95.5%	97.5%	98.6%
Roll Amplitude - Endurance	93.9%	97.6%	95.8%	62.8%	76.3%	88.0%	99.9%	100.0%	100.0%
Vert. Accel - Endurance	99.9%	100.0%	99.9%	95.2%	87.0%	92.3%	99.9%	100.0%	100.0%
Lat. Accel. - Endurance	100.0%	100.0%	97.3%	80.4%	68.9%	75.0%	99.9%	100.0%	100.0%

Note: the tables above assume an equal probability of all wave headings

It is clear that the barge shapes are clearly unsuitable under any circumstances in the severe conditions of the North Atlantic, and fail to meet the "comfort" criteria even in the relatively benign waters off the coast of Hawaii. The ship-shaped configurations satisfy the "endurance" criteria in both areas, but fail to meet the "comfort" criteria in the North Atlantic. Not surprisingly, the semi-submersible configuration meets the criteria almost 100% of the time off the coast of Hawaii, and more than 95% of the time in the North Atlantic.

Dynamic Positioning Versus Mooring

Using the capital cost estimates for mooring systems given in Part 1 of this report, the mooring costs for various size semi-submersibles in a range of water depths is shown in the table below.

It is noted that these figures do not include the cost of anchor handling tugs, a service which would be required each time the seastead was moved.

Mooring Costs for Semi-Submersibles in a Range of Water Depth

Size		Baseline Cost for 1000 Depth	Total Capital Cost for Increased Water Depth 2000	3000	4000	5000	6000
200'x200'		$8,000,000	$12,960,000	$17,920,000	$22,880,000	$27,840,000	$32,800,000
equipment	40%	$3,200,000					
anchor line	60%	$4,800,000					
300'x300'		$14,696,938	$23,809,040	$32,921,142	$42,033,244	$51,145,346	$60,257,448
equipment	40%	$5,878,775					
anchor line	60%	$8,818,163					
400'x400'		$22,627,417	$36,656,416	$50,685,414	$64,714,413	$78,743,411	$92,772,410
equipment	40%	$9,050,967					
anchor line	60%	$13,576,450					
500'x500'		$31,622,777	$51,228,898	$70,835,020	$90,441,141	$110,047,263	$129,653,384
equipment	40%	$12,649,111					
anchor line	60%	$18,973,666					

Dynamic positioning systems provide both station-keeping and mobility; based only on station-keeping, and using the fuel consumption estimates given in Part 1 of this report, the total year-by-year cost for dynamic positioning of the same size semi-submersibles is shown in the table below.

Dynamic Positioning Costs for Semi-Submersibles

Size	DP Initial Cost	DP Annual Fuel Cost	Total Capital Cost plus Fuel Cost at the End of Each Year Year 1	Year 2	Year 3	Year 4	Year 5
200'x200'	$12,000,000	$3,900,000	$15,900,000	$19,800,000	$23,700,000	$27,600,000	$31,500,000
300'x300'	$14,000,000	$7,000,000	$21,000,000	$28,000,000	$35,000,000	$42,000,000	$49,000,000
400'x400'	$16,000,000	$13,000,000	$29,000,000	$42,000,000	$55,000,000	$68,000,000	$81,000,000
500'x500'	$18,000,000	$22,000,000	$40,000,000	$62,000,000	$84,000,000	$106,000,000	$128,000,000

Comparison of the two tables indicates that the total costs are about equal after five years, for water depths of up to 5,000 or 6,000 feet depending on the size of the semi-submersible. In depths shallower than 5,000 feet, mooring is the cheaper alternative unless the vessel is to be moved frequently.

Note that the annual fuel costs for dynamic positioning are based on an average 1-knot current and a 20-knot wind speed. Cost for fuel will vary roughly as the square of increases or decreases in wind and current speed. Similar trends would be expected for ship-shaped and barge-shaped seastead configurations.

CONCLUSIONS AND RECOMMENDATIONS

PART 1:

1. Based on results obtained in this analysis, there are significant economies of scale that can be achieved; most notably, CapEx costs per square foot for the "Very Small" seasteads considered are disproportionately higher than those for the larger sizes of semi-submersibles and barges, although not so much for ship-shaped seasteads. OpEx costs per square foot for "Very Small" seasteads are disproportionately higher for all configurations.

2. In terms of size, the "sweet-spot" is the so-called "Small" seastead, i.e., the 300'x300' semi, 450' ship or 312' barge; beyond those sizes, economies of scale (on a per square foot basis) begin to level off, while the absolute costs increase substantially. This size range would accommodate residences for about 200 to 400 people (based on a nominal 300 square foot per person); changing the per-person allocation of living space would increase of decrease the capacity in direct proportion, but would not significantly alter the cost per square foot.

3. The principal components of OpEx that can be controlled by design decisions relate to energy consumption and manning; particularly with regard to the choice between mooring and dynamic positioning (DP). Specifically, the use of a DP system will require a larger number of crewmembers and substantially greater fuel consumption. The greater mobility offered by a DP system should be weighed carefully against the increased cost compared to mooring; and it is further noted that mooring systems are quite suitable in water depths as great as 2,000 meters or more.

4. On the basis of this analysis, the following recommendations are offered:
   - Quantify the potential cost-benefits of alternative energy, such as wind, solar and wave-energy conversion
   - Identify other measures to reduce energy consumption requirements
   - Select a most-likely baseline configuration for an early seastead and develop a preliminary design in sufficient detail to get cost quotes from potential builders

PART 2:

1. Barge-shaped hulls appear to be suitable only for relatively benign or protected waters.

2. Semi-submersibles are the most tolerant hull configurations for severe wave conditions.

3. Ship-shaped seasteads appear to offer a desirable compromise between comfort and cost.

4. In water depths up to 6,000 feet, a fixed mooring system appears to offer cost advantages compared to dynamic positioning, unless the seastead is to be moved more frequently than once in five years.