Pontoon Based Facilities for Offshore Applications

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Abstracts. Pontoon based floating platforms are widely used in both inland and offshore waters. Their simple construction and large payload capacity provide reliable working surfaces at low cost. Due to its modular construction, a platform may be rapidly reconfigured, as mission changes, to maximize the benefit of investments. Known uses of this asset include drilling rigs, lighterage, and jack-up piers (Figure 1). Contemporary pontoons are mostly configured to meet ISO requirements for easy handling by the readily available equipment of the container shipping industry. Recent technology advances further allow on site assembly of a platform in rough waters. These new technologies substantially improve the cost effectiveness of pontoon facilities and greatly enhance their operation window for offshore applications. Just like any other offshore assets, dynamic stability is a prime concern for pontoon facilities. While these facilities inherit lots of merits from the box shaped floats, they also assume a highly weather dependent nature of large-water-plan buoyancy hulls. Use of this simple technology nevertheless requires thorough scrutiny and tradeoffs in areas relevant to installation and stability in open sea environments. This article addresses related technology advances as well as pertinent theories in support of technology development.

Installation. Figure 2 illustrates typical ISO pontoons. While their dimensions may vary, they are all configured in conformity to the ISO requirements for easy handling and shipping. Large platforms may be prefabricated to their ultimate sizes in safe heaven and subsequently towed to site. However, towing normally incurs high costs or requires extensive lead-time exceeding budget constraint for a small temporary task, due to the high risks en route.

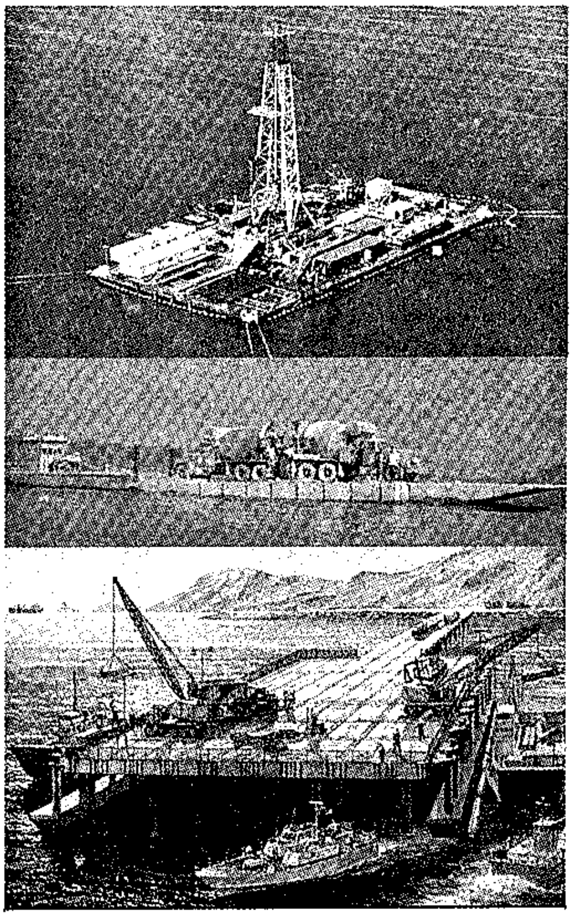

Figure 1. Pontoon based modular platforms

For platforms with no major super structure, a legitimate alternative is to ship them in small blocks suitable for transport by container ships and then assembling at site. Although most ISO pontoons allow assembling in calm water or low sea states, existing methods are rather labor intensive and hazardous in open seaways (Figure 3). Assembly of pontoons in rough water is influenced substantially by rapid, random motion induced by waves. At-sea assembly can be done

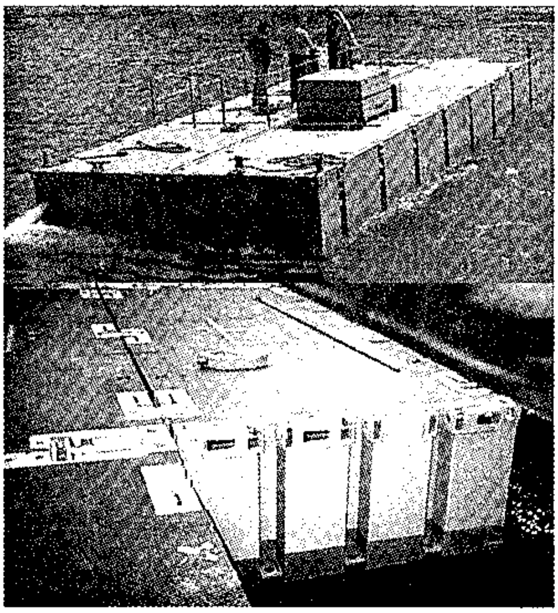

Figure 2. Samples of ISO pontoons.

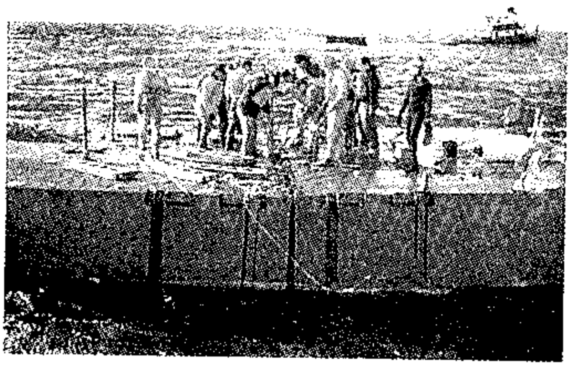

Figure 3 Existing open sea fabrication method

effectively by using a progressive connection approach (Figure 4a), in which connections between modules are completed in a sequence of automated drawing and aligning that eventually leads to a smooth engagement of connection hardware progressively. Experimental evidence suggests that a practical coupling device for at sea assembly requires an appropriate combination of flexibility, strength, and shock load absorbing capability to survive the coupling forces resulting from large relative motion between modules. Figures 4 b and c suggest a feasible hardware setup to achieve a rigid or a hinged connection respectively. Both connection systems consist of drawing lines, flexible alignment pins, and robust load taking members. Effectiveness of this connection system was fully confirmed in an at-sea demonstration of 1998 with a full-scale test bed (Figure 4d). Functional performance of all critically required mechanisms was confirmed for wave conditions far exceeding Sea State 3. Although the load-taking members may be more appealing, the drawing line and alignment pin combinations are actually doing most of the tricks leading to an acceptable open sea assembly. The greatest technical challenge to the design of coupling devices is the rapid, random motion between adjoining modules. Hydraulic model tests indicate that a particular coupling apparatus may either reduce or augment wave-induced relative motion, depending on the layout and dynamic characteristics of the rigging system. Improper rigging could result in unacceptable excursions between sections leading to collisions between pontoons or over tensioning of drawing lines. Both limit the success of engaging the coupling apparatus. The relative translational motions witnessed at the interface between two 12-m modules mating in sea state 3 conditions could exceed the amplitude of ambient waves (Figure 5a). The dynamic behavior of coupled pontoon sections is most sensitive to the wave period and the level of pre-tensioning within the drawing lines. Relative motions in five-second waves could be elevated by more than three times of those in eight-second waves (Figure 5b). This dynamic motion can be effectively suppressed by applying a separation force in the pontoon array to be connected as shown in Figure 5c. The conceptual alignment pin as recommended is simply a section of chain covered by an elastomeric sleeve. However, it performs the critical function of intermediate transitions effectively, that are required to tame the rapid relative motion at the connection interfaces, as experiments have shown. The combination of chain and sleeve is flexible enough to accommodate wild differential motions, yet sufficiently robust to withstand vigorous dynamic loads. Chains outperform rods or wire ropes as tendons because of strength and flexibility properties, and ability to absorb shock loads. The elastomeric sleeve prevents direct steel-to-steel abrasion and keeps the chain from tangling. The sleeve also allows for substantial bending, yet is effective in restraining the differential translations between pontoons at short free lengths due to a relatively large cross section. As a result, alignment pins are able to closely synchronize the random differential motions at the connection interface without suffering debilitating damage, and maintain the stabbing pins within close proximity to their respective receptacles long enough for connectors to engage. Assembly is easily and safely done by maintaining an adequate separation force within the pontoon array to

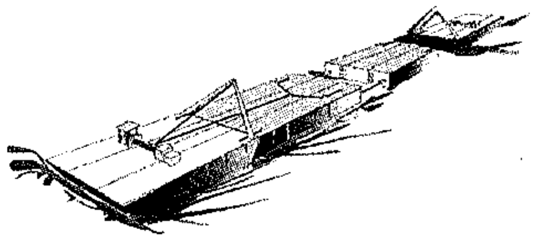

Figure 4a. Progressive connection concept

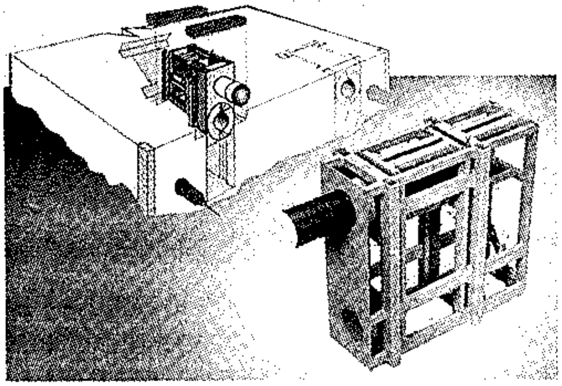

Figure 4b. Rigid connector

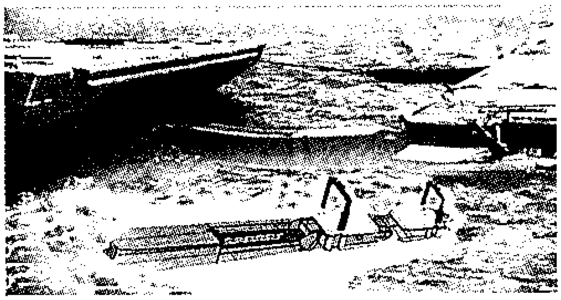

Figure 4c. Hinge Connector

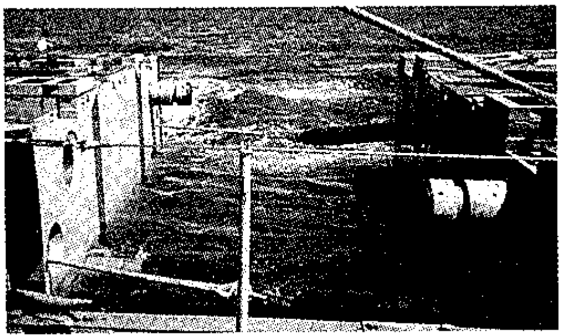

Figure 4d. Full scale at-sea demonstration.

offset surge forces generated by wave action. The separation forces required to alleviate possible snapping of the drawing lines increases as the wave period of prevailing sea decreases. Although connections may be completed at lower magnitudes of separation force, this option comes at the expense of added weight and increased manufacture cost as stronger, more durable components are needed. In addition, lower separation forces necessitate careful timing and, greater experience on the part of the operating crew.

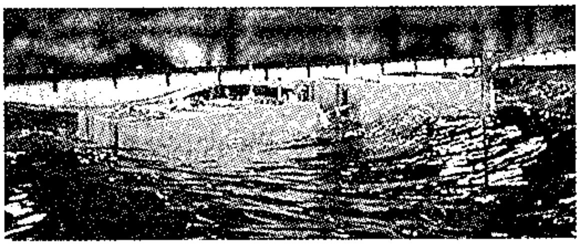

Figure 5a. Rapid random motion is a challenge.

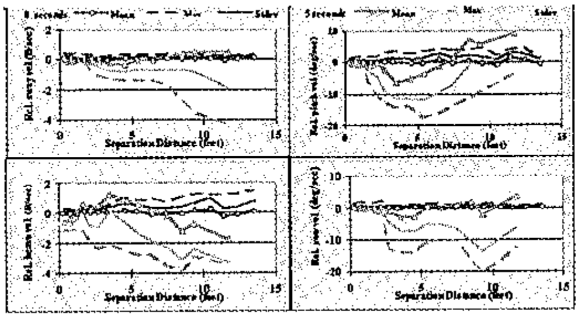

Figure 5b. Influence of wave periods on motions

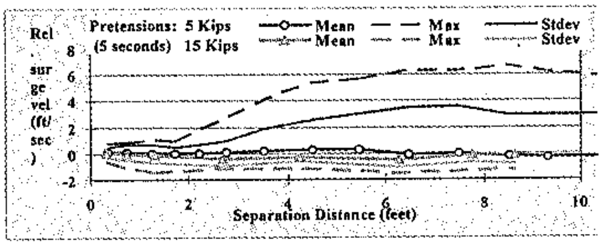

Figure 5c Influence of separation forces on the performance of connection system

Dynamic Stability. Attributing to its shallow, box-shaped construction, a pontoon platform presents several unique features relevant to its stability characteristics, which are not normally seen with conventional hulls. Of the most obvious are its geometric features of shallow depth, large water plane area, and broad flat keel with sharp edges. Besides, its wide open deck often invites heavy loads, which in turn lead to a low freeboard along with a high center of gravity. While large water plane renders a platform susceptible to wave excitations, heavy mass offers a counter measure for controlling dynamic motions. However, weights could work either in favor or against the stability. A platform may be tuned to follow the waves or to stay relatively steady to waves. The associated consequences are suffering high stresses in structures or heavily awashed decks (Figure 6). Tradeoffs are made in accordance to design preferences. The dynamic performance of an isolated platform in moderate seas may be well assessed in frequency domain with more cost-effective potential codes. However, for more complicated operations involving multiple hulls closely coupled, or a vessel undergoing extreme motions, time domain codes with proper compensation in viscous effects are more appropriate. Figures 7a and 7b illustrate open sea practices involving interface apparatus, which in the present examples are the open sea docking facility and the cargo offloading ramp. In both cases, the phase differentials of relative motion between vessels are known to be critical to the design of the interface apparatus. A recent numerical study indicates that recirculations at the sharp bilge keels of a rolling ship sustain even after the hull has reversed the direction of movement. The associated forces tend to hold back ship motion. Similar mechanism has been witnessed in a laboratory attempt to quantify drag forces of a rectangle cylinder, as shown in Figure 8. A strong recirculation was observed behind the vertical edges of a rectangular box under tow. The low pressure area as indicated by a clear depression at the recirculation suggests an additional drag to the moving box. The numerical study further indicated that the trend of phase lag becomes more clear at broader sections near mid-ship (Figure 9). This factor may be mild to most applications, however could drastically impact the extreme behaviors of a vessel such as capsizing. Discussion follows will focus on a towing tank observation of barge capsizing. Reasons causing a vessel to capsize are manifold. Although large waves are often blamed for the mishaps, improper load layout is

Figure 6 Pontoon platforms in seaways

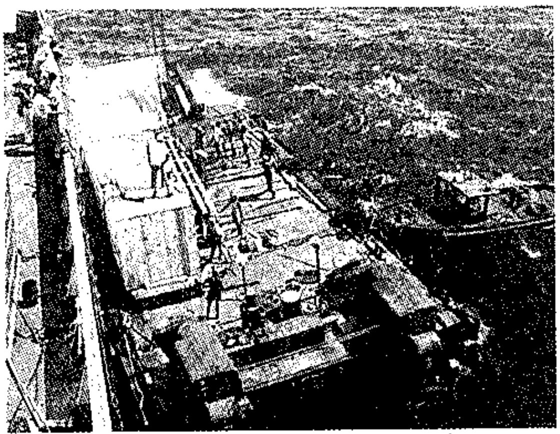

Figure 7a Open Sea Docking and Mooring

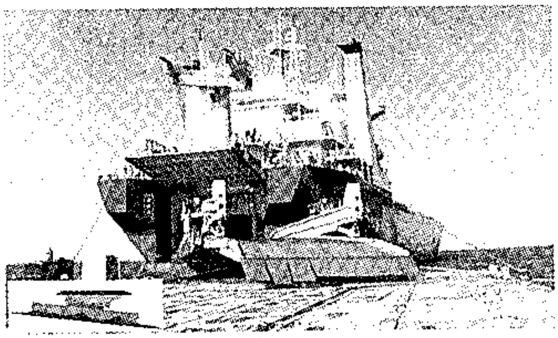

Figure 7b Cargo transfer ramp

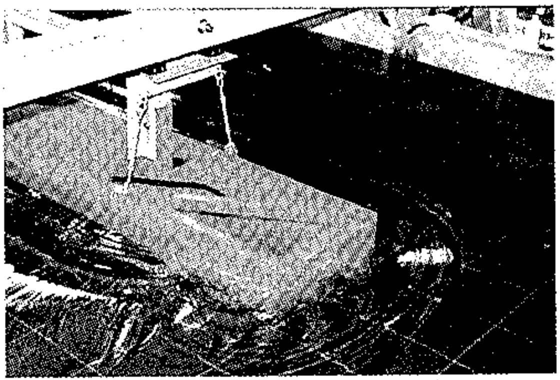

Figure 8. Recirculation at the sharp edges

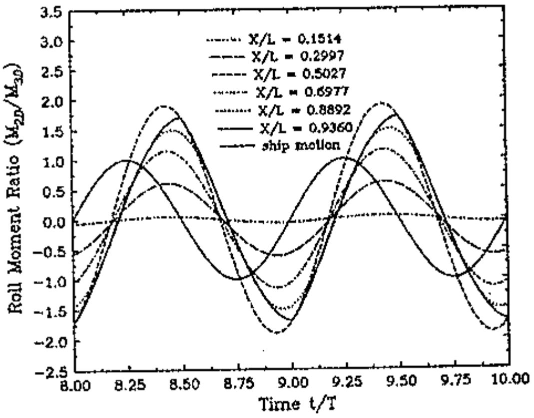

Figure 9. Phase shift introduced by recirculaitons

the primary cause responsible for capsizing an intact vessel according to the existing records. Field experiences concur that waves alone are unlikely to capsize a pontoon barge. This consent is well supported by the observation from a towing tank attempt to identify the ultimate threshold against capsizing of a pontoon barge. The barge under study is 120 ft long by 24 ft wide by 8 ft deep in full scale. This barge under heavy deck loads shows an amazing resilience in high waves. At a freeboard of 4 feet, it easily survives all challenges including twelve-foot waves at the resonance frequency of the barge, showing no sign of possible capsizing (Figure 10). It is interesting to note that the barge did not rock much more severely as the waves rose from Sea State 2 State 4 (top of Figure 11). Viscous damping alone does not seem sufficient to account for the outcome. The bottom chart of Figure 11summarizes the result from a numerical simulation based on potential theory, which adopted viscous corrections following Morison's approach. It took a drag coefficient way beyond the reasonable range to match the simulation results to the towing tank observations. Some mechanism must have been left out of the theory. There was only one occasion in the entire test program that the barge actually capsized (Figure 12). It occurred under a worst case combination of adverse load layouts and wave environments. At that moment, the barge was under an extreme load (twice of the design capacity) with an elevated center of gravity that essentially reduced the roll metacentric height to nearly zero. The freeboard at then was 2 feet. The test was successfully repeated with exactly the same parameters. Capsizing took place in Sea State 4. Ironically, the same barge did not capsize in 12-foot swells, possibly due to the additional buoyancy provided by the super structure holding ballast weights. Nevertheless, more details are required to discriminate the difference. A careful review of video records revealed several notable hints to lead the way for follow on studies. This barge was very heavy and dynamically soft. By that it means the barge was hard to move and, once moved, was slow in returning to equilibrium. As a result, it reacted promptly to larger waves and somewhat hesitated at smaller ones (Figure 13). In the mean time, the barge drifted side way substantially.

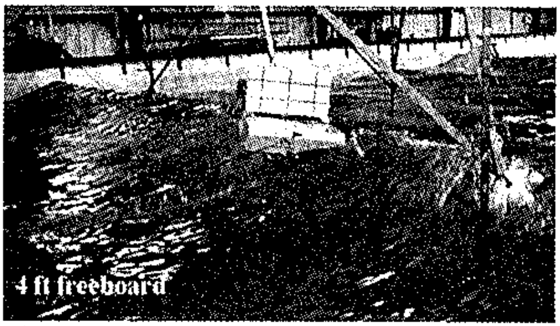

Figure 10. Barge at 4-ft freeboard

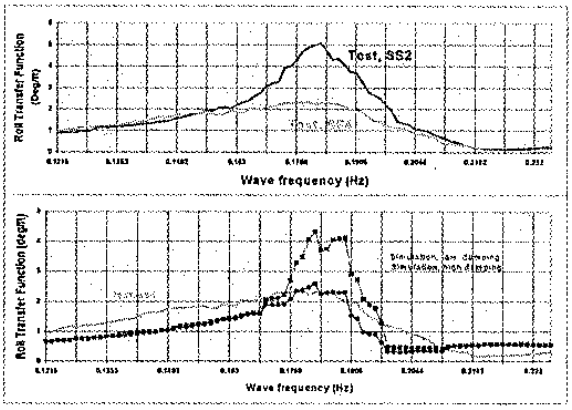

Figure 11. Dynamic responses of barge

Figure 12. Barge at 2-ft freeboard

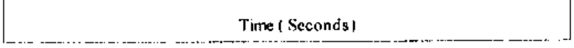

Figure 13. Motion history of a capsizing barge

Throughout the test run, the barge at two foot freeboard saw a large quantity of green water sweeping across the deck. However, as long as the green water was free to drain off the deck, there showed no threat of capsizing. This may be part of the reason that the barge did not capsize in swells of even greater severity. This implies the significance of phase angle of barge motion with respect to waves to barge stability. In both occurrences, the barge rolled heavily into the oncoming waves in an attitude that green water had no chance to escape before next large wave arrived. Random waves helped establish the right combination to trap the green water on deck and subsequently turn the barge up side down. Following the same line of thought, the phase shift introduced by the recirculation activities around sharp edges may have similar effects to the motion dynamics of a pontoon platform. There is little doubt that the mechanism leading to capsizing is far from being understood. Nevertheless this test identified a few subjects deserving further attention.

Summaries Pontoon platforms demonstrate prominent economical and logistic advantages for offshore applications. Recent technology advances in the areas of rapid deployment and on site assembly substantially enhance the economical advantage of the modular construction approach. Stability is still the primary concern prohibiting the use of their full capacity in seaways. At this moment, hydrodynamic characteristics of pontoon based ocean facilities are relatively unexplored. Ship experiences may not apply, due to the obvious differences in hull constructions and load configurations. Several technical deficiencies in analytical tools have been identified to lead the way toward future studies. Systematic studies to clarify uncertainties relevant to the performance of pontoon based floating platforms in rough waters are currently underway. Findings should greatly improve the confidence level of using pontoon technology for offshore activities.