Tuned floating platform for offshore power facilities

Thermal discharges to the environment are common to fossil- and nuclear-fueled central power stations. Air discharges, too, are common—significant quantities of particulates and gases from fossil-fueled systems, small quantities of radioactive gases from nuclear—and each type of system has an impact upon its environs. Each of these problems is mitigated by offshore siting of bulk power facilities. Offshore siting also offers such distinct advantages as thermal enhancement of the waters to increase recreational and commercial values, and, a very important consideration along our west coast, earthquake-isolation of the bulk power facility. Not a practiced art, offshore siting brings with it new design considerations such as collision-avoidance and sea-driven platform motion effects on huge rotating turbines.

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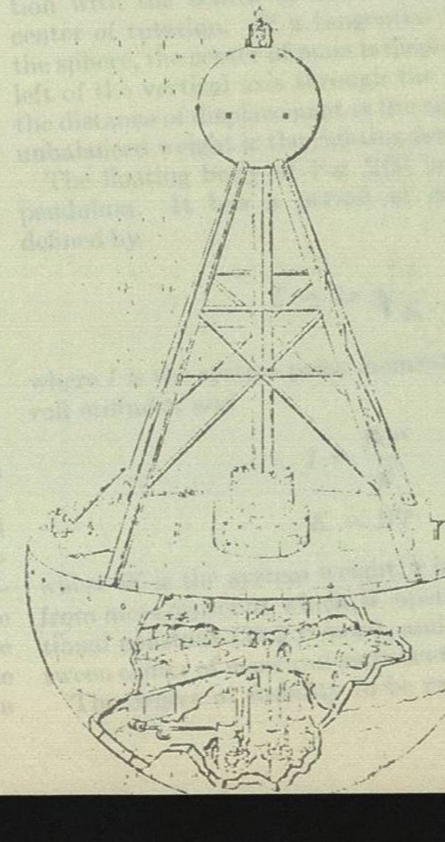
Among recommendations[1] for priority research made by the Energy Policy Staff of the Office of Science and Technology is study of advanced bulk-power-facility siting practices, specifically that $10,000,000 to $20,000,000 be expended in offshore siting studies and development. This should indicate that such siting is not routinely accomplished. Optional techniques include: (*a*) islands, existent and man-made; (*b*) bottom-mounted plants, floated to site and submerged or constructed in situ; and (*c*) floating platforms, tuned and un-tuned. Each has advocates and it is probable that each is a best solution in some certain specific circumstance.

The floating-platform technique is the subject of this article. It is shown in Fig. 1 with a 1000-MW(e) reactor power plant. Advantages include:

1 Construction of the hull and power-system platform is repeatedly accomplished by a skilled, stable shipyard workforce.

2 Dockside installation of the power system is also accomplished on a repeated basis by a trained, stable

Fig. 1 Tuned-spherical-platform offshore bulk power facility.



Based on a paper contributed by the ASME Energetics Division.

[1] *Electric Power and the Environment*, Energy Policy Staff, Office of Science and Technology, Executive Office of the President, Aug. 1970, p. 44.

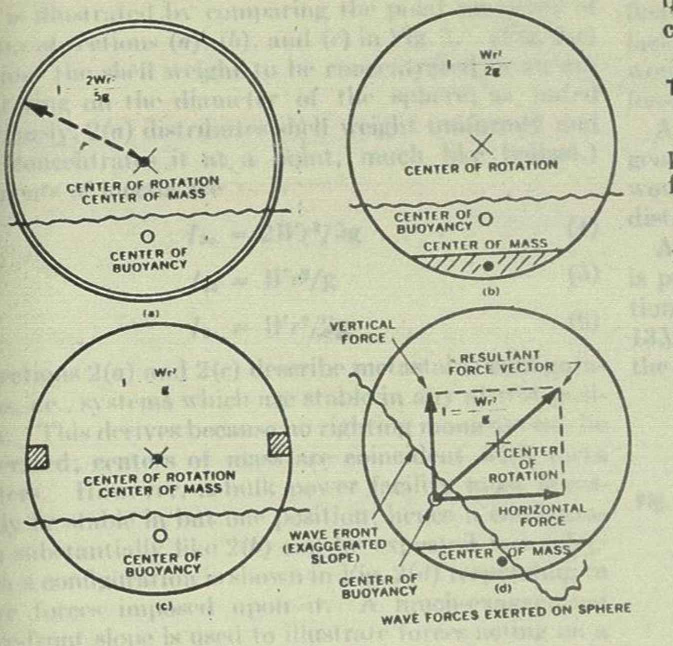


Fig. 2 Comparison of spherical buoys of different mass distributions.

workforce; this will increase the reliability of the operating system, a safety as well as an economic nuclear-power-plant consideration.

3 Mooring-site preparation is an economic operation vis-à-vis construction of island and subsurface offshore sites; a greater flexibility in site selection is also obtained.

4 The bulk power-plant facility is mobile, i.e., transportable; it can be towed to site, moved in response to changed requirements, returned to the shipyard to take advantage of technology improvements, etc.

Problems peculiar to the floating platform include:

1 Compliancy: The platform must be sufficiently stiff, i.e., noncompliant, that turbine-shaft misalignments (shafts can be as much as 200 ft long) do not cause turbine-generator failure.

2 Gyroscopic forces: Roll created by wave action must be made so minimal that side loads on the rotating turbine mass result only in negligible gyroscopic forces on turbine bearings and bearing mounts.

3 Mechanical loads: Platform motion in response to winds and waves must be minimal in order that loads on moorings and electric power transmission lines are not excessive.

The optimally noncompliant platform is a sphere. When used with a large secondary mass, the spherical platform can be "tuned" to have a natural roll frequency much lower than the exciting frequency of all conceivable waves; thus gyroscopic forces of consequence are eliminated and mechanical loads are minimized by constraining motion (heave) to be along the vertical axis (roll was removed by tuning). The spherical shape also assists in load reduction, since changes in draft due to acceleration and deceleration along the vertical axis are uniformly evidenced as buoyant-force changes equally applied around the circumference of the system.

Tuned Spherical Platform

To understand the principle of the tuned spherical platform, one must keep in mind these facts about a free-floating spherical body:

1 It has a center of mass whose location is determined by the system fabricator/designer.

2 It has a *fixed* center of rotation.

3 This center of rotation, the meta center, remains at the geometric center of the sphere *regardless* of how mass is distributed on or within the sphere.

4 All forces imposed on a free-floating spherical body operate inherently through, i.e., are vectored or directed through, the center of rotation.

Use can be made of the foregoing facts to design and fabricate an extremely stable, seaworthy platform for bulk power facilities. The sequence of sketches in Fig. 2 illustrates how.

Fig. 2(*a*) is simply a floating sphere with its weight uniformly distributed in its shell. Obviously, the centers of mass and rotation are coincident. In such a configuration the system is totally unstable with respect to roll. If a tangential force were applied to the sphere, it would begin spinning about the center of rotation; since the center of mass is at the center of rotation, no righting moment would exist and the spinning of the sphere would only be reacted and stopped by frictional forces at the sphere–air–water interfaces.

The foregoing implies that stability in roll is, in part, dependent on establishing a righting moment. Fig. 2(*b*) illustrates most simply how a righting moment is established. It assumes that the weight of the spherical shell is concentrated at a point on the circumference of the sphere. Two things happen: (1) The center of mass is displaced from the center of rotation to the surface of the sphere and (2) the sphere assumes a position with the center of mass immediately below the center of rotation. If a tangential force is applied to the sphere, the center of mass is displaced to the right or left of the vertical axis through the center of rotation; the distance of displacement is the righting arm and the unbalanced weight is the righting force.

The floating body of Fig. 2(*b*) acts as a compound pendulum. It has a period of oscillation which is defined by

$$T = 2\pi\sqrt{\frac{I}{K}} \qquad (1)$$

where I is the system polar moment of inertia, K is the roll stiffness, and

$$I = \frac{Wr^2}{g} \qquad (2)$$

$$K = Wl \qquad (3)$$

where W is the system weight, r is the effective radius from meta center at which W operates, g is the gravitational constant (32.2 ft/sec²), and l is the distance between center of mass and meta center.

The degree of stability to be exhibited by a floating platform is, in part, determined by its period of oscillation; that this is largely determined by mass distribution is illustrated by comparing the polar moments of inertia of sections (*a*), (*b*), and (*c*) in Fig. 2. (Fig. 2(*c*) assumes the shell weight to be concentrated in an annular ring on the diameter of the sphere; as noted previously, 2(*a*) distributes shell weight uniformly and 2(*b*) concentrates it at a point, much like ballast.) Moments of inertia are

$$I_{3a} = 2Wr^2/5g \tag{4}$$

$$I_{3b} = Wr^2/g \tag{5}$$

$$I_{3c} = Wr^2/2g \tag{6}$$

Sections 2(*a*) and 2(*c*) describe metastable configurations, i.e., systems which are stable in any at-rest position. This derives because no righting moments can be generated; centers of mass are coincident with meta centers. However, a bulk power facility must necessarily be stable in but one position; hence a configuration substantially like 2(*b*) can be expected to evolve. Such a configuration is shown in Fig. 2(*d*) responding to wave forces imposed upon it. A much-exaggerated wave-front slope is used to illustrate forces acting on a ballasted (tuned) sphere. Note that the spherical platform has not rolled in response to the wave front. The wave front has caused the center of system buoyancy to move, but the centers of system mass and rotation remain fixed; as a result, the system is translated vertically and horizontally but not rotationally. This in part is the case for the spherical platform. A nonspherical body, e.g., a boat or barge hull, would not react similarly to the passing wave front. The shift in center-of-buoyancy location would be accompanied by a shift in the meta center and hence in the meta-center-to-center-of-mass distance; roll would result.

In the intended application, a long period of spherical-platform oscillation is desired. This permits the platform to act as a "low-pass" filter of imposed wave forces. The platform, having a man-adjusted natural frequency longer than the forcing frequency of nature-adjusted waves, will, as a consequence, fail to be excited, i.e., rolled, by them. Platform stability will have been achieved through:

1 Selection of a platform shape having a fixed center of rotation.

2 Adjustment of the system center of mass such that desired roll stiffness (righting moment) exists.

3 Coincident adjustment of the system mass elements such that the system polar moment of inertia and roll stiffness define a system having a natural frequency not excited by seas to sea state 8.

Spherical-Platform Loadings

Roll is combatted in an offshore floating bulk-power-facility platform to ease platform compliancy constraints, to reduce gyroscopic forces on turbine-generator systems, and to minimize mechanical loads on moorings and power transmission lines.

Wave height and slope are the forcing functions on the platform. These are defined by Figs. 3 and 4. Significantly, a situation is described which indicates that a platform having a natural period of about 40 sec would be virtually unaffected by seas to sea state 8.

Reference-Design Tuned-Platform Nuclear Power Plant

A 1000-MW(e) tuned-spherical-platform offshore floating bulk nuclear power facility, as an example, lacks the additional complexity of system design that would be introduced by an ever-changing on-board fossil-fuel supply.

A boiling-water reactor system would be comprised generally as in Table 1. A pressurized-water reactor would have a similar total weight with component distribution as in Table 2.

A conceptual layout of the pressurized-water system is presented in Fig. 5; a mass-distribution approximation is shown in Fig. 6. Enclosed-system volume is 13M cu ft; a 300-ft-dia sphere weighing 66M lb houses the power system. Total bulk-power-facility weight is

Fig. 3. Maximum spectra of ocean waves.

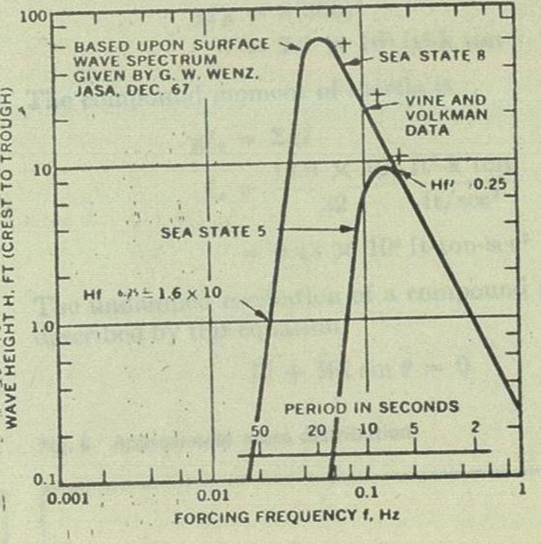


Fig. 4 Maximum slope angle of wave.

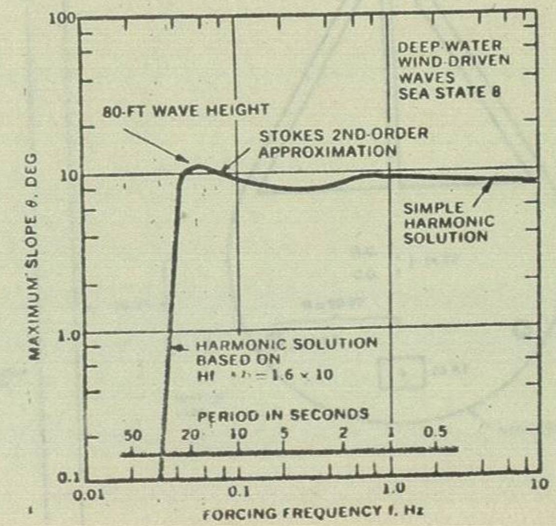


TABLE 1 Boiling-Water Reactor System

Subsystem	Weight (Millions of Pounds)
Reactor containment and pools	50
Nuclear steam-system equipment	3
Other reactor equipment	3
Turbine-generator equipment	23
Plant water	24
	103

TABLE 2 Pressurized-Water Reactor System

Subsystem	Weight (Millions of Pounds)
Reactor, pressure vessels, and pools	25
Nuclear steam-system equipment	25
Other primary-loop equipment	3
Secondary condenser and feed-water heater	3
Turbine-generator equipment	23
Plant water	24
	103

85,000 tons; such an equipped structure is well within shipyard construction capabilities and is, in fact, smaller than many ships.

Reference-Design Roll Response to Sea States

The system compound moment of inertia with respect to the meta center must be determined before roll response can be calculated. Several simplifying assumptions are made:

1 Reactor and steam-generator mass is concentrated at a point on the axis 90 ft from the meta center.

$$\begin{aligned} gI_R &= 25 \times (90)^2 \\ &= 2.03 \times 10^5 \text{ ft}^2\text{-k ton} \end{aligned} \qquad (7)$$

2 Turbine-generator-system and condenser mass is concentrated in an annular ring at a 90-ft radius from the centerline and 70 ft below the meta center.

$$\begin{aligned} gI_{TG} &= m_{TG}(90^2 + 70^2)/2 \\ &= 1.24 \times 10^5 \text{ ft}^2\text{-k ton} \end{aligned} \qquad (8)$$

3 The spherical-platform shell is continuous and ignores the struts to hold the water-ballast tuning tank.

$$\begin{aligned} gI_S &= 2M(150)^2/5 \\ &= 2.97 \times 10^5 \text{ ft}^2\text{-k ton} \end{aligned} \qquad (9)$$

4 The moment of inertia of the water-filled tuning ballast is

$$\begin{aligned} gI_B &= 8(300)^2 \\ &= 7.2 \times 10^5 \text{ ft}^2\text{-k ton} \end{aligned} \qquad (10)$$

The compound moment of inertia is

$$\begin{aligned} gI_c &= \Sigma gI \\ I_c &= \frac{13.9 \times 10^5}{32} \frac{\text{ft}^2\text{-k ton}}{\text{ft/sec}^2} \\ &= 0.43 \times 10^8 \text{ ft-ton-sec}^2 \end{aligned} \qquad (11)$$

The undamped oscillation of a compound pendulum is described by this equation:

$$I\ddot{\theta} + Wl \sin\theta = 0 \qquad (12)$$

Fig. 5 Conceptual layout of a 1000-MW(e) pressurized-water reactor.

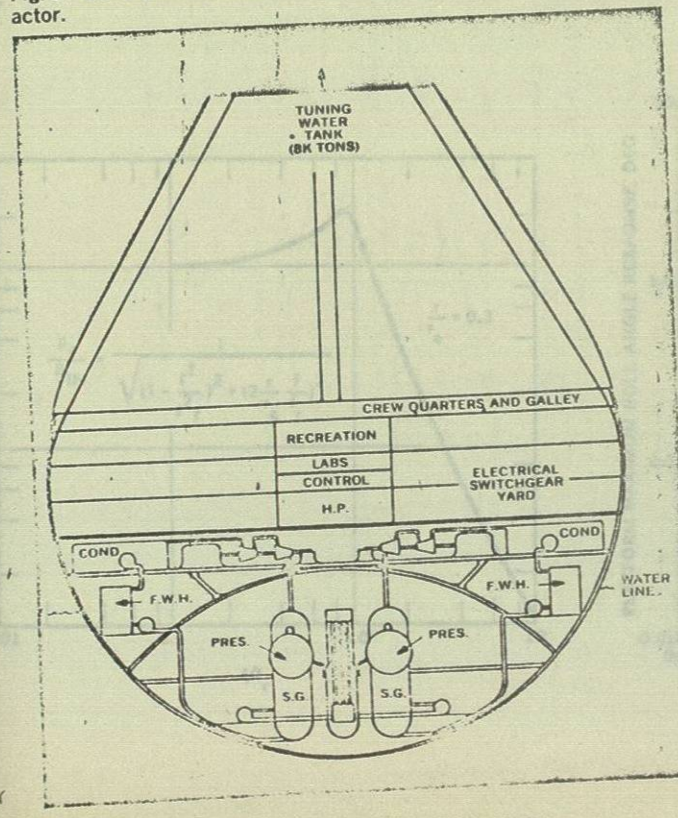


Fig. 6 Approximate mass distribution.