DESIGN CONSIDERATIONS FOR OCEAN ENERGY RESOURCE SYSTEMS

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Abstract - The oceans occupy nearly three-quarters of the earth's surface and represent an enormous source of renewable energy. While many of the world's industrialized nations have conducted exploratory research and development, the total power currently available from ocean energy systems, with the exception of the French tidal power plant, is less than one hundred megawatts (MW). An increasing number of ocean energy conversion systems are approaching an acceptable stage of development for commercial utilization.

This paper considers the factors which are the most important in the design and development of ocean energy resource systems. Sources of renewable energy in the marine environment include tides, waves, currents, and thermal gradients. The challenge is to balance the energy resource potential with sources of environmental loading, which are applicable to a specific site, in the most logical and coherent manner possible, in order to make wise choices regarding site selection and system design.

INTRODUCTION

While the world's human population is approaching 6 billion and doubling approximately every 35 years, energy consumption is doubling nearly every 12 years. At the present time, the energy demand is largely being met by various forms of fossil fuels. Consequences of our overwhelming reliance on fossil fuels are becoming increasingly obvious.

Carbon dioxide released into the atmosphere from burning fossil fuels restricts radiation from earth to space raising the temperature on a global scale (the greenhouse effect). Dramatic climatic changes and inundation of precious, densely-populated coastal areas from the resultant rise in sea level could occur during the next century. There is tangible evidence that the rate of increase in the concentration of carbon dioxide in the atmosphere is accelerating. Measurements show an increase from 290 parts per million (ppm) in 1860 to 340 ppm presently, with projections to 370 ppm by the year 2000, and possibly 660 ppm within the next fifty years.

Environmental concerns are not the only reason for past and present endeavors to explore the use of alternative energy sources. Political instability in the Middle East has demonstrated the economic consequences of oil dependence. Efforts to fill the oil gap with increased utilization of coal and nuclear energy have resulted in acid rain and concerns about nuclear accidents and waste disposal. A global accounting of the amount of fossil fuels and estimated reserves, when compared with a projection of energy consumption, results in the realization that we will deplete the majority of these resources within a relatively short period of time. Present reserves of oil and natural gas will be consumed within a few decades, and coal within a few centuries. These periods are short from a historical perspective and should be within the planning horizon of nations, states, and other communities.

Renewable sources of energy are receiving increased consideration as an option to conventional fossil fuels in many cases. Solar energy has gained perhaps the greatest attention, and a wide variety of approaches to utilize the sun's power are now being explored. The major drawbacks to direct usage are intermittent availability and variation in energy intensity. Large storage facilities are necessary for uninterrupted and steady use of solar power. The ocean is the world's largest solar energy collector and storage system. On an average day, 60 million square kilometers of tropical seas absorb an amount of solar radiation equivalent in heat content to about 245 billion barrels of oil. If one-tenth of a percent of this stored solar energy is converted into electric power, it could supply the equivalent of 20 times the energy consumption of the entire United States.

Solar energy is stored either directly or indirectly in various forms within the ocean system. Specifically, solar power is stored directly in the form of thermal heat, and indirectly as wind, waves, and currents created by the temperature differences between tropical and polar waters. The availability of much of this energy is very site-specific and the conversion efficiencies of ocean energy systems are relatively low. While many of the various forms of energy conversion systems have experienced only small-scale utilization, the potential for a significant contribution to the world energy economy does exist and there is a continuing interest in the development of ocean energy systems. The more highly-developed ocean energy systems include wave and tidal energy systems.

The most visible form of ocean energy is contained within the surface waves. Waves are actually energy in transition being carried away from its origin. Ocean wave energy technology utilizes the kinetic energy of ocean waves to produce power. The primary sources of ocean energy are wind-generated seas and swell, tides generated from the lunar and solar gravitational fields, and thermal gradients between warm tropical waters and deep ocean water. Wind-generated waves are somewhat predictable, have high relative energy, and are somewhat consistent in many areas around the world. The tides are highly predictable and consistent, although commercial development is currently limited to sites where the tidal range is at least three meters (10 feet).

WAVE ENERGY CONVERSION SYSTEMS

Ocean wave energy conversion technologies utilize the kinetic energy of ocean waves to produce power. Wave energy is an environmentally benign and renewable energy resource. The general approaches to converting wave energy into electricity can be broadly categorized by means of deployment and means of energy extraction and conversion. Means of deployment include floating deep-water technologies and shallow-water, fixed-bottom technologies. Means of energy extraction and conversion include: mechanical cams, gears, and levers; hydraulic pumps; pneumatic turbines; oscillating water columns; and funneling devices.

The two components of energy within waves are potential energy and kinetic energy. Potential energy is associated with the form or elevation of the wave. Kinetic energy is associated with the movement or velocity of the water particles within the wave. The total energy of a wave is the sum of its potential and kinetic energy. For regular (sinusoidal) waves,

$$E = (\rho g H^2)/8$$

where E is the total energy per unit of water surface area, ρ is the mass density of ocean water (= 1030 kg/m^3), g is the gravitational acceleration (= 9.81 m/s^2), and H is the wave height from trough to crest. The relationship between the wave period (T), and the wave length (L), is:

$$L = gT^2/2\pi$$

The transfer of wave energy is known as wave power or energy flux. Small amplitude waves in deep water (water depth>L/2) will, according to linear theory, have a power per unit of wave crest width of:

$$P = E(c/2) = E(L/2T) = \rho g^2 H^2 T / 32\pi \approx H^2 T$$

where c is wave speed or phase velocity, H = wave height in meters, and T = wave period in seconds. For H = 2 meters and T = 10 seconds in deep water, the wave power is approximately 40 kilowatts per meter (kW/m) of crest width (Carmichael and Falnes, 1992).

The corresponding relation for random seas (irregular waves) is:

$$P \approx 0.5\, H_s^2\, T_z \;\; \text{(kW/m)},$$

where H_s = significant wave height (the average wave height of the largest 1/3 of the observed waves) and T_z = average time interval between successive crossings of the mean high water level as it moves upward. *This equation must be used to avoid* overestimating wave energy potential, since waves are generally irregular in the ocean (ECOR, 1989).

The approaches to converting wave energy into electricity can be broadly categorized by means of deployment and means of energy capture and conversion. The six general approaches to wave energy conversion are:

surge devices - utilizing the forward horizontal force of the waves,

oscillating water columns - conversion of wave induced fluctuations,

heaving floats - utilizing the vertical motion of relatively small buoys,

heaving and pitching floats - absorbs energy from heaving and pitching,

pitching devices - utilizing the pitching moment of rotary pumps,

heave and surge devices - utilizing heave and surge to pump water.

Wave energy research and development funding by various governments is estimated to be (White, 1991):

Great Britain - $20 million
Norway - $12 million
Japan - $10 million
Sweden - $5 million
Denmark - $3 million

The United Kingdom wave energy program was initiated in 1974. Recent projects include wave-powered desalination and pumping, investigation of the use of a Wells turbine in naturally-occurring rock gullies, construction of a 150 kW prototype wave power plant on the Scottish Island of Islay, production of wave-powered turbine generators for navigational buoys in Northern Ireland, and development and model testing of a small-scale wave energy converter at Loch Ness by Coventry Polytechnic. Systems developed and evaluated from 1974 to 1985, include a wide range of configurations of wave energy converters designed for relatively large outputs. Three of the more well-known are the Nodding (Salter) Duck, Sea Clam, and Bristol Cylinder.

Norway has conducted an extensive wave energy program since 1975. In the 1980s, these efforts culminated in the installation by Kvaerner Brug of a 500 kW wave power system, called the multiresonant oscillating water column (MOWC), at Toftestallen on the west coast of Norway. This system operated from November 1985 until the plant was swept off its foundation and destroyed during a severe, 100-year storm near the end of 1988. Preliminary agreements with the island countries of the Azores and Mauritius to build additional power stations are pending (Kerwin, 1990).

Another pilot system, the 350 kW tapered channel wave power plant (Tapchan), was installed at Toftestallen by Norwave and has been operational since 1986. Agreements with the governments of Indonesia and Tasmania to build commercial power plants at those locations by Norwave have been reached. Typically, a tapered channel is carved out of a rocky coastal area, using shaped charges, if necessary. The taper can handle a wide spectrum of wave lengths efficiently. As a wave passes through the tapered channel, its wave height is gradually increased as the channel narrows. The wave then spills over into a reservoir where it is stored and subsequently passes through a low-head Kaplan water turbine to generate electricity. The construction costs range from about $2,000/kW in Indonesia to $3,550/kW in Tasmania, and the systems are expected to produce power at rates of about 5 to 10 cents per kilowatt hour (Vadus 1991).

The Japanese government has a very active wave energy research and development program. Applications under investigation range from wave power generators for lighthouses and light buoys to wave pump systems, ship propulsion, and energy for road heating, heat recovery systems, and fish farming. Several technologies have been examined by both government and industry under the Japanese wave energy program. These include floating terminator-type wave devices, fixed coastal-type wave power extractors, and applications of oscillating water column turbines. The most well known project, supported by the International Energy Agency, was the Kaimei, a 500-ton barge-like platform containing about ten oscillating water columns. Wave action produces oscillations of the water column that produce pneumatic power, which is converted to electrical power via air turbo-generators.

The Port and Harbor Research Institute, Ministry of Transport is currently developing a wave energy absorption type caisson breakwater called a wave power extracting caisson. The performance of the breakwater is improved, in terms of stability against waves and reduction of reflected waves, by providing air chambers which serve as energy converters. The air chamber and machine room containing the turbine-generator system are located in the upper part of the caisson. The front wall of the air chamber is inclined at an angle of 45 degrees and is one-half meter thick. Large external pressure forces are expected to act on this wall from incoming waves, as well as large air pressure forces internally. During field work at Sakata Port in the Sea of Japan, the conversion ratio from wave to air power was 0.5, turbine efficiency was 0.39, and the generator efficiency was 0.92 (Miyazaki, 1991).

In Sweden, the use of an oscillating buoy as a wave energy converter has been extensively studied. Field tests of a 30 kW prototype hose-pump device were completed from 1983-84. Negotiations are currently underway for a 1 MW pilot plant to be installed off the Atlantic coast of Spain. India has announced plans to aggressively develop wave power over a six-year time period beginning in 1990. The Indian wave energy program includes plans to build a 5 MW offshore plant near Madras. Presently, a 150 kW demonstration plant using a Wells turbine-generator is under construction at a fishing harbor near the port of Trivandrum.

TIDAL POWER SYSTEMS

Coastal geography and bathymetry are important factors for the extraction of energy from the tides. Tides involve the rise and fall of the ocean, combining the gravitational pulls of the sun and moon with the rotation of the earth. The influence they have on the ocean can be amplified by natural configurations of coastline and sea bottom to provide differences between high and low tide of up to 16 meters (50 feet). Under such conditions, tidal energy conversion can occur utilizing relatively conventional hydroelectric turbines and related structures.

The primary factors influencing the height and timing of the tides include: the rotation of the earth on its axis (24 hours/rotation); the moon's orbit around the earth (29.53 days); the earth's orbit around the sun (365.24 days); the position of the moon with respect to the equator (declination); and the distance from the moon to the earth (apogee/perigee). Tidal energy extraction requires a strong ocean effect and a natural resonant inshore configuration to make it work economically. Just as hydroelectric power depends on natural differences in elevation of the terrain, tidal power depends on the natural configuration of inshore coastal features. There are relatively few coastal areas where conditions combine to produce the degree of resonance required. Natural and celestial circumstances appear to limit tidal energy development to within latitudes of 50 to 60 degrees (Warnock, 1987).

For a tidal cycle of 6.2 hours, the potential energy (E) can be estimated to be:

$$E(kW) = 226\ A(H^2)$$

where A is the surface area of the enclosed tidal basin in square kilometers and H is the tidal range in meters. The total annual power (P) is:

$$P(GWh) = 2.0\ A(H^2)$$

This relationship is derived by multiplying the energy (E) by 365 days/year and 24 hours/day (ECOR, 1989).

Conditions necessary for efficient and economic tidal energy conversion systems include: a tidal range of at least three meters (ten feet); an enclosed basin; solid submarine ground; and short transmission distance or means of energy storage. Countries with operational tidal energy systems are France, the former Soviet Union, Canada, and China. The La Rance tidal power station on the west coast of France, with an installed capacity of 240 MW, is the world's largest ocean energy conversion plant. Construction began in 1961 and was completed by 1968. The powerhouse is 332 meters long, housing twenty-four 10 MW bulb-turbine units. The plant has been operational since 1968 with 95 percent availability.

In 1968, the former Soviet Union put into operation a 400 kW pilot plant in Kislaya Bay. Called the Kislogubskaya pilot plant, it pioneered floating construction techniques. In 1985, the former Soviet Union announced plans to build a tidal plant on the White Sea coast with a generating capacity of 15,000 MW. This plant (Mezenskaya) is still in the preliminary stages of planning.

The Canadian tidal power project is the 20 MW plant at Annapolis Royal, Nova Scotia. This plant was built by the Nova Scotia Power Corporation. Located on the Annapolis River near its outlet at the Bay of Fundy, the plant contains a single "Straflo" hydropower turbine and has been operational since 1984. Presently, Canada is investigating the potential of such turbines for larger scale installations in the Bay of Fundy, and for low-head river developments.

In the People's Republic of China, tidal energy was first reported in 1959 with the installation of a 40 kW plant located in Shashan. A 165 kW tidal plant was later built in 1970 in the Shandong Province on the Jingang Creek. In May 1980, China's first two-way tidal plant, rated at 500 kW, began operating on the Jiangxia Creek near the Zhousan Islands. This plant was later expanded to 3.2 MW in 1986.

In the United Kingdom, a Salford transverse oscillator project with an installed capacity of 270 kW is under construction by Crouch and Hogg Consulting Engineers and Salford Civil Engineering, Ltd. This prototype barrage will be used to supply electricity to a hospital located in the Outer Hebrides, Scotland. Additionally, work is being conducted by the Severn Tidal Power group on a preliminary design for the Severn tidal power project, an ebb tide generating plant to be located on the Severn River estuary (Saris, 1989).

The United States has designed one tidal power plant for installation in the state of Maine. Called the Half Moon Cove Tidal Project, its installed capacity is planned to be 12 MW using two 6 MW units. Additional tidal power projects are planned for the Bay of Fundy in Canada, Cook Inlet in Alaska, Garolim Bay along the west coast of Korea, and Rann of Kutch in northwestern part of India (Warnock and Clark, 1992). The Korea Ocean Resource Development Institute (KORDI) recently announced the initiation of a major tidal power development project.

Tidal power generation is possible only when the available head (difference between basin and sea level) exceeds a certain threshold. This results in generation during less than 50% of the time. At the beginning and end of the power phase, when head is low, generation is less than capacity while during higher head, constant output is achieved by regulating turbine flow. Because the moon's position relative to the earth varies over a period of 24 hours and 50 minutes, tidal phase shifts every day. Hence generation occurs at different times on different days and will not always coincide with peak electrical demand.

CURRENT ENERGY SYSTEMS

The kinetic energy of river currents has been used from medieval times to produce power using simple water turbines. There are many old prints that show mechanical power produced from mills at bridges to pump river water to the adjacent communities. The proposed application of current turbines in the oceans is a comparatively recent development, and has been prompted by the observations of mariners and oceanographers of the swiftly-flowing current in some regions of the world. The Gulf Stream, or more specifically, the Florida Current, is of particular interest because of the high current velocity and its proximity to large centers of population on the Florida coast.

The performance of an ocean current turbine is similar to the performance of a wind turbine. The ocean or wind turbine transforms a proportion of the kinetic energy of the flow into mechanical power. A small ocean turbine was demonstrated in 1985 in the Florida Current. The unit was suspended from a research vessel at a depth of 50 meters and developed approximately 2 kW. The project was privately funded, and a proposal made to design and test 100 kW and 1 to 2 MW units of a similar design. More recently, a feasibility study was conducted concerning the utilization of currents in the Strait of Messina in Italy. The study included a basic design of the system, as well as a preliminary environment impact assessment (Berti and Garbuglia, 1993).

A 20 kW prototype turbine, designed by UEK Corporation, is also under development, for which testing is planned in New York City's tidal East River. Since 1979, Canadian researchers at Nova Energy Ltd. have been developing large Darrieus-type vertical axis turbines for hydropower applications and are presently completing testing of a 5 kW prototype. Australian current energy conversion units designed by Tyson Turbines Ltd. are small to medium size modular devices capable of producing an energy output of more than 670 kW depending on depth and stream velocity. These units are commercially available for a variety of applications and have been demonstrated in many countries including Australia, the Philippines, Mexico, the United States, and Canada (Saris, 1989).

From simple momentum analyses, it can be shown that the maximum power (P), that can be extracted from an ideal, non-ducted (open) turbine occurs when the turbine reduces the velocity of the stream to 1/3 of its initial value (Carmichael et al., 1986),

$$P\ (\text{kW}) = C_p\ (\rho v^3 A/2)$$

where C_p = power coefficient (=16/27 for an ideal turbine), ρ= fluid density (kg/m^3), v = fluid velocity (m/sec), and A = turbine disk area (m^2).

OCEAN THERMAL ENERGY CONVERSION

Solar energy is absorbed and stored as heat in the surface layer of the ocean. Ocean thermal energy conversion (OTEC) utilizes the temperature difference between warm surface water and cold water found at depths of 1000 meters (3280 feet) to convert thermal energy to mechanical energy for the generation of electricity. When the warm water and cold water temperature differ by at least 20°C, an OTEC system can produce net power. Tropical regions, bounded by 20 degrees north and south latitudes worldwide, have a temperature difference of 20°C or greater throughout the year.

Most of the development has focused on electrical power production; however, secondary products from OTEC systems, including transportation fuel from marine biomass, can improve their cost competitiveness. Research and development efforts have identified several applications for the cold, nutrient-rich and pathogen-free seawater in addition to the generation of electricity. Small-scale OTEC systems providing electrical power, fresh water, and nutrients for mariculture are ideal for expanding the economic potential of many island and coastal communities. The construction and operation of these systems would enable the technology to mature, strengthen commercial utility, and provide valuable experience for larger projects in the future (Takahashi and Trenka, 1992).

There are three basic types of OTEC cycles now under development. The closed-cycle system uses the warm surface seawater to evaporate a working fluid such as ammonia or Freon, which drives a turbine generator. After passing through the turbine, the vapor is condensed in a heat exchanger cooled by water drawn from the deep ocean. The working fluid is pumped back through the warm water heat exchanger, and the cycle is repeated continuously (National Oceanic and Atmospheric Administration, 1984).

The open-cycle system uses warm surface seawater as the working fluid. The warm water is pumped into a flash evaporator in which the pressure has been lowered by a vacuum pump to the point where the warm seawater boils at ambient temperature. The steam produced drives a low-pressure turbine to generate electricity. The steam is then condensed in a heat exchanger cooled by cold deep ocean water, producing desalinated water as a by-product (Solar Energy Research Institute, 1989).

The hybrid-cycle has not been tested, but in theory, this type of system combines the principles of the open- and closed-cycle systems, maximizing the use of the thermal resource by producing both electricity and desalinated water. First, electricity is generated in a closed-cycle stage. The temperature difference in the seawater effluent from the closed-cycle stage is sufficient to produce desalinated water by using a flash evaporator and a surface condenser in a second stage. Another possibility is the use of a second stage with an open-cycle system, which should double the output of desalinated water (Penny and Bharathan, 1987).

Early OTEC experiments focused on energy systems, but the deep ocean water, which is rich in nitrates, phosphates, and silicates, was soon identified as a resource with additional potential. Multiple-product OTEC systems not only generate electricity, but can be designed to produce desalinated water, air conditioning, refrigeration, mariculture and agriculture. This type of system is important for island communities that need energy, water and food to improve their economies and quality of life.

A 1987 survey investigated locations in the Pacific region as sites for deployment of OTEC systems. Of the thirty islands and Asian locations included in the survey, eight locations with especially high potential were identified: American Samoa, Western Samoa, Cook Islands, Tonga, Guam, Belau (Palau), Pohnpei, and the Commonwealth of the Northern Mariana Islands. A separate project also assessed Kiritimati (Christmas) Island in the Republic of Kiribati as another possible location for future OTEC development. A conceptual design of a 1 MW open-cycle OTEC plant was completed in 1989. This power output corresponds to the electricity demand of many small Pacific island communities.

One megawatt OTEC plants could presently be cost-competitive in remote, oil-dependent Pacific island countries. Fuel costs currently amount to more than half the total income from imports in these areas. The levelized cost of electricity from a 1 MW OTEC plant over a 30 year period is estimated at \$0.11 to \$0.19/kilowatt-hour. Since the cost of electricity ranges from \$0.16 to \$0.44/kilowatt-hour in isolated island communities, significant savings could be realized through the use of OTEC, in addition to the other benefits offered by this technology.

The desalinated water produced by open-cycle and hybrid-cycle OTEC systems is actually less saline than the water provided by most municipal water systems. Estimates indicate a 1 MW plant fitted with a second stage fresh water production unit could supply approximately 55 kilograms/second of fresh water (4,750 m^3/day), sufficient for a population of 20,000 people. Fresh water production from reverse osmosis and multi-stage flash desalination plants costs between \$1.30 and \$2.00/m^3 for a plant with a 4,000 m^3/day capacity. Using these figures, a 1 MW OTEC plant could produce almost \$3 million worth of desalinated water per year. In addition to potable, fresh water for domestic use, desalinated water from OTEC can be used for crop irrigation to increase agricultural production.

Compared with conventional air-conditioning equipment, cold seawater used to air-condition buildings can result in substantial savings. The cold seawater can be directly circulated through space heat exchangers or can alternatively cool a working fluid which is circulated through the heat exchangers. Research estimates that a 300 room hotel can be air-conditioned by the cold seawater from a 1 MW OTEC plant at less than 25% of the cost of electricity for operating a conventional air-conditioning system. The pay-back period for the capital investment of installing a cold seawater air-conditioning system is estimated to be four years or less. The cold water can also be used for the refrigeration of seafood and other products.

Many new strategies involving seafood and other products grown in seawater pumped from the ocean have been proposed and tested in Hawaii. OTEC-related mariculture ventures now represent more than 50 million U.S. dollars in capital investment. Several cold water pipes are in place, the largest which has a diameter of nearly one meter, pumping seawater from a depth of 700 meters. Current ventures include growing lobster, flat-fish, sea urchin, seaweed such as ogo and nori, and algae for chemical extracts.

A Japanese consortium built and tested a closed-cycle OTEC plant on the island of Nauru in 1981. From 1982 to the present, Japanese organizations have conducted OTEC simulations and experimental plant projects. The Kochi Artificial Upwelling Laboratory near the Murota Peninsula on Shikoku Island in Japan, features a 12.5 centimeter (5 inch) diameter cold water pipe, bringing water from 320 meter depths to the surface. Growth kinetics for marine plants and animals are being conducted. Although OTEC mariculture is still in the developmental stage, steady progress is being made. Further research and commercialization activities are needed to demonstrate its economic viability.

Researchers at the University of Hawaii have proposed the idea of using cold seawater in agriculture. An array of cold water pipes buried in the ground creates cool weather conditions not normally found in tropical environments. The system also produces drip irrigation by atmospheric condensation on the pipes. Using this method, the growth of strawberries and other spring crops and flowers throughout the year in the tropics has been demonstrated. Commercial developers have initiated cold-water agriculture enterprises in Hawaii.

DESIGN CONSIDERATIONS

The winds of the earth are primarily caused by unequal heating of the earth's surface by the sun.

During the day the air over the oceans and lakes remains relatively cool, since much of the sun's energy is consumed in evaporating water or is absorbed by the water itself. Over land, air is heated more during the day because less sunlight is absorbed and evaporation is less. The heated air expands, becomes lighter and rises. The cooler, heavier air over the ocean moves onshore to replace it. In this way, local sea breezes in coastal areas are created.

During the night, these local sea breezes reverse themselves, since land cools more rapidly than the water and so does the air above it. The cool air moves seaward to replace the warm air that rises from the surface of the ocean. Similar local breezes occur on mountainsides during the day as heated air rises along the warm slopes heated by the sun. During the night, the relatively cool and heavy air on the slopes flows downward into the valleys.

Circulating planetary winds are caused by the greater heating of the earth's surface near the equator than near the poles. This causes cold surface winds to blow from the poles to the equator to replace the hot air that rises in the tropics and moves in the upper atmosphere toward the poles. The rotation of the earth also influences these planetary winds.

The inertia in the cold air moving near the surface toward the equator tends to move it to the west, while the warm air moving in the upper atmosphere toward the poles tends to be turned to the east. This causes large counterclockwise circulation of the air around low pressure areas in the northern hemisphere and clockwise circulation in the southern hemisphere. Since the earth's axis of rotation is inclined at an angle of 23.5 degrees to the plane in which it moves around the sun, seasonal variations in the heat received from the sun result in seasonal changes in the strength and direction of the winds at any given location on the earth's surface.

The importance aspects of the wind in regards to structural design include wave generation, wind set-up, wind-induced currents, and direct forces on structures. Structural damage can occur due to strong winds. The destructiveness is proportional to the square of the wind speed. For example, a wind of 120 miles per hour has twice the force per unit area as a wind of 85 miles per hour. Wind tunnel experiments have shown that suction as well as pressure effects are important on buildings.

Roof overhangs and porch roofs are subject to external forces on both upper and lower faces and these often reinforce one another. In the wind tunnel experiments, the model buildings were leak-proof, but real buildings always allow some air to enter. Leakage through openings on the windward (upwind) side will increase the internal pressure and add to the suction effects on the roof, side and leeward (downwind) walls. Therefore, it is recommended to seal the windward walls as tightly as possible, but to leave an opening in the leeward wall to prevent internal pressure build-up.

Oscillations depending on the natural period of a structure may also lead to it's destruction. Structural damping reduces oscillation build-up, by dissipating energy build-up. Thus a strongly constructed building may resist static effects well but could allow dynamic oscillations to build dangerously (and vice versa).

Tornadoes have winds which may reach or exceed 200 miles per hour; however, direct measurements are not possible at the present. The pressure within the funnel is very low, possibly up to 100 millibars below the surrounding environment. The destruction is caused by external suction plus explosion, and roofs are taken to considerable heights. Waterspouts normally form over the ocean as funnel clouds and are usually less intense than tornadoes. Tornadoes have been known to start out as waterspouts over bodies of water and subsequently move onshore.

Generally speaking, two things occur when wind blows over a water surface. First, the friction between the moving air and the surface causes water to be dragged downwind, causing a wind-driven current. In addition, waves develop on the water surface. When waves are being generated they are called seas or wind waves. Associated with different wind velocities are various levels of wave heights and periods.

A violent cyclonic disturbance possesses the ability to strongly influence the water level through three separate mechanisms. First, water tends to mound up into the low pressure area within the disturbance. Second, the strong winds force water up abnormally high against the shoreline. An onshore wind component does this directly by applying a shear force on the water surface toward the land. Third, high wind-generated waves can travel further inland than normal and threaten natural and man-made coastal structures. The first two components together are known as storm tide or storm surge. The effect due to the wind itself is called wind set-up.

A severe tropical storm is called a hurricane or typhoon when the maximum sustained wind speeds reach 120 kilometers per hour (75 miles per hour/65 knots). Hurricane winds may reach sustained speeds of more than 240 kilometers per hour (150 miles per hour/130 knots). Hurricane season normally lasts from June to November. Hurricanes, unlike less severe tropical storms, generally are well organized and have a circular wind pattern with winds revolving around a center or eye (not necessarily the geometric center). The eye is an area of low atmospheric pressure and light winds. Atmospheric pressure and wind speed increase rapidly with distance outward from the eye to a zone of maximum wind speed which may be anywhere from 7 to 110 kilometers (4 to 70 statute miles) from the center. From the zone of maximum wind to the periphery of the hurricane, the pressure continues to increase; however, the wind speed decreases.

Many mathematical models have been proposed for use in studying hurricanes. Each is designed to simulate some aspect of the storm as accurately as possible without making excessively large errors in describing other aspects of the storm. Each model leads to a slightly different specification of the surface wind field. Available wind data are sufficient to show that some models duplicate certain aspects of the wind field better than certain other models, but there is not enough data for a determination of a best model for all purposes.

CONCLUSION

Natural processes associated with the world's oceans may someday become valuable sources of renewable energy. The ocean resource systems with the most potential include wave energy, tidal power, and OTEC. Design of these systems must be site specific and should include economic and social considerations, as well as environmental and technical.

Environmental considerations involve an assessment of local winds and wind-related phenomena such as wave generation, storm systems, and high water levels. The value of the resource at any site must be balanced with the cost required to design a system which can survive the harshest environmental conditions at that particular site.

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